NONRESIDENT
TRAINING
COURSE

April 1995

Engineering Aid 3

NAVEDTRA 14069

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Although the words “he,” “him,” and “his” are used sparingly in this course to enhance communication, they are not intended to be gender driven or to affront or discriminate against anyone.

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04 Jun 96

ERRATA # 2

Specific Instructions and Errata for
Training Manual

ENGINEERING AID BASIC

1. This errata supersedes all previous errata.

2. No attempt has been made to issue corrections for errors in typing, punctuation, and so forth, that do not affect technical accuracy or readability.

3. Make the following changes:

Page	Column	Change
2-3	1	Replace "Naval Publications and Forms Center" with "Aviation Support Office"
3-11		Replace figure 3-14 with figure 3-14 A & B
3-19	2	Replace "DOD-STD-1OOC" with "MIL-STD-1OOE"
5-7		Replace figure 5-12 with figures 5-11 and 5-12
7-17	1	Replace figure 7-22 with figures 7-21 and 7-22
14-19		Replace caption in figure 14-20 with "Sample field notes from cross-section leveling at first three stations shown in figure 14-17."
14-28	2	Replace 1200/3.7 with 3.7/1200
14-28	2	Replace 800/-5.0 with -5.0/800

DRAWING FORMATS

Drawing format is the systematic space arrangement of required information within the drafting sheet. This information is used to identify, process, and file drawings methodically. Standard sizes and formats for military drawings are arranged according to DoD-STD-100C, *Engineering Drawing Practices,* and MIL-HDBK- 1006/1, *Policy and Procedures for Project Drawing and Specification Preparation.* With the exception of specific local command requirements, DoD-STD-1OOC and MIL-HDBK-1006/1 are your guidelines for preparing SEABEE drawings.

Most of the documents applicable to these standards have recently been revised and updated in order to gain like information and to share uniformity of form and language within the Naval Construction Force and between DoD organizations. Other influencing factors are the current widespread use of reduced-size copies of both conventional and computer-generated drawings and exchange of microfilm.

SHEET SIZES

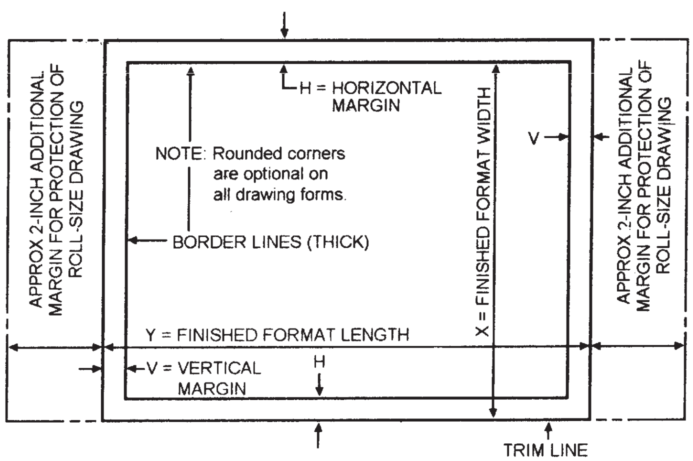
Standard drawing sheet sizes are used to facilitate readability, reproduction, handling, and uniform filing. Blueprints produced from standard size drawing sheets are easily assembled in sets for project stick files and can readily be folded for mailing and neatly filed in project letter size or legal size folders. (Filing drawings and folding blueprints will be covered later in this training manual.)

Finished format sizes for drawings shown in figure 3-14, view A, are according to ANSI Y14.1

FLAT SIZES					ROLL SIZES					
SIZE DESIGNATION LETTER	X (WIDTH)	Y (LENGTH)	MARGIN H (HORIZ)	MARGIN V (VERT)	SIZE DESIGNATION LETTER	X (WIDTH)	Y (LENGTH) MIN	Y (LENGTH) MAX	MARGIN H (HORIZ)	MARGIN V (VERT)
A(HORIZ)	8.5	11.0	0.38	0.25	G	11.0	22.5	90.0	0.38	0.50
A(VERT)	11.0	8.5	0.25	0.38	H	28.0	44.0	145.0	0.50	0.50
B	11.0	17.0	0.38	0.62	J	34.0	55.0	176.0	0.50	0.50
C	17.0	22.0	0.75	0.50	K	40.0	55.0	143.0	0.50	0.50
D	22.0	34.0	0.50	1.00						
E	34.0	44.0	1.00	0.50						
F	28.0	40.0	0.50	0.50						

NOTES: 1. ADDITIONAL PROTECTION MARGINS FOR ROLL SIZE DRAWINGS ARE NOT INCLUDED IN ABOVE DIMENSIONS.
2. ALL DIMENSIONS ARE IN INCHES.

A



B

84NP0082

45.857

Figure 3-14.—Guide for preparing horizontal and vertical margins, sizes, and finished drawing format.

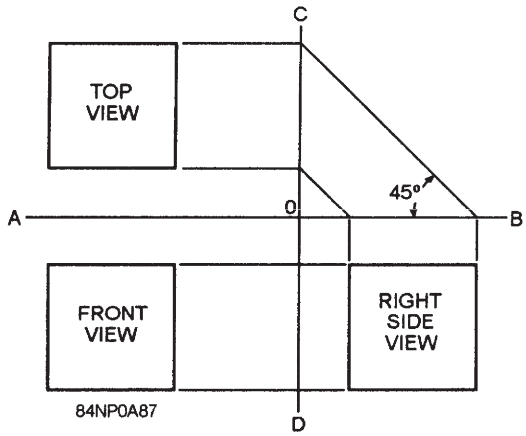


Figure 5-11.—Alternative method of extending to top view projection lines.

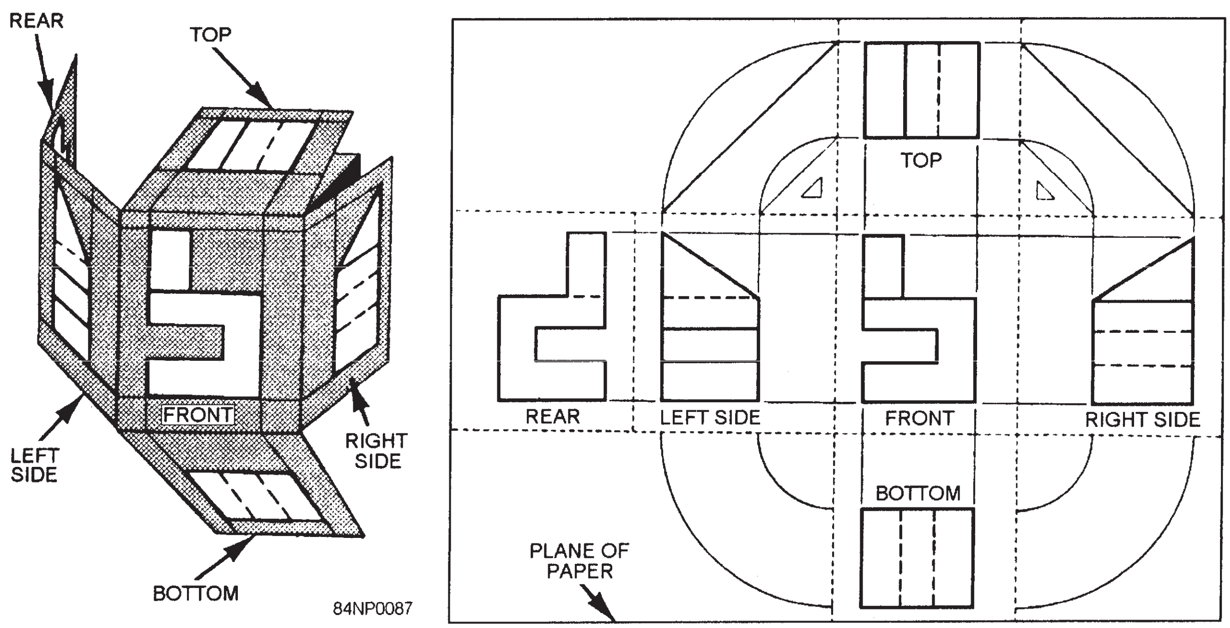


Figure 5-12.—American standard arrangement of views in a six-view third-angle multi-view projection.

view always lies in the plane of the drafting surface and does not require any rotation. Notice that the front, right side, left side, and rear views line up in direct horizontal projection.

Use the minimum number of views necessary to show an item. The three principal views are the top, front, and right-side. The TOP VIEW (also called a PLAN in architectural drawings) is projected to and drawn on an image plane above the front view of the object. The FRONT VIEW (ELEVATION) should show the most characteristic shape of the object or its most natural appearance when observed in its permanent or fixed position. The RIGHT-SIDE VIEW (ELEVATION) is located at a right angle to the front and top views, making all the views mutually perpendicular.

SPACING OF VIEWS.— Views should be spaced on the paper in such a manner as

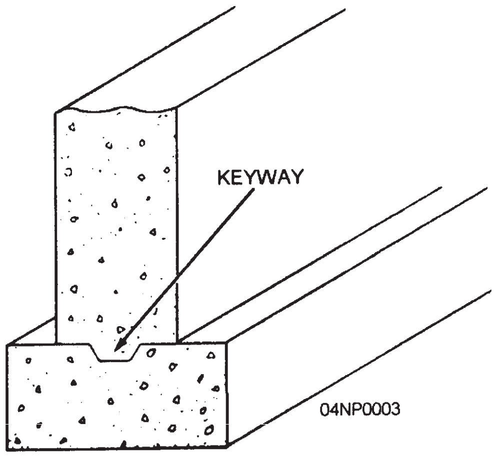


Figure7-21.—Construction joint between wall and footing with a keyway.

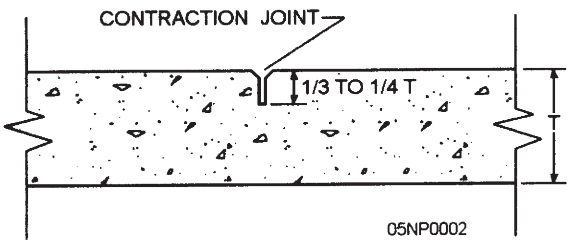


Figure 7-22.—Use of a contraction joint.

incident to shrinkage of the concrete. Atypical dummy contraction joint (fig. 7-22) is usually formed by cutting a depth of one third to one fourth the thickness of the section. Some contracting joints are made with no filler or with a thin coat of paraffin or asphalt and/or other materials to break the bond. Depending on the extent of local temperature, joints in reinforced concrete slabs may be placed at 15- to 25-ft intervals in each direction.

Expansion Joints

Wherever expansion might cause a concrete slab to buckle because of temperature change, expansion joints (also called isolation joints) are required. An expansion joint is used with a pre-molded cork or mastic filler to separate sections from each other, thus allowing room for expansion if elongation or closing of the joint is anticipated. Figures 7-23, 7-24, and 7-25 show

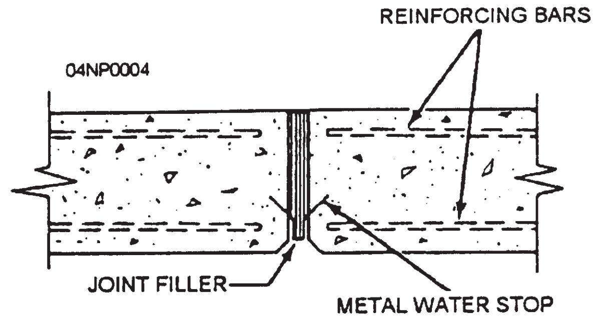


Figure 7-23.—Expansion joint for a wall.

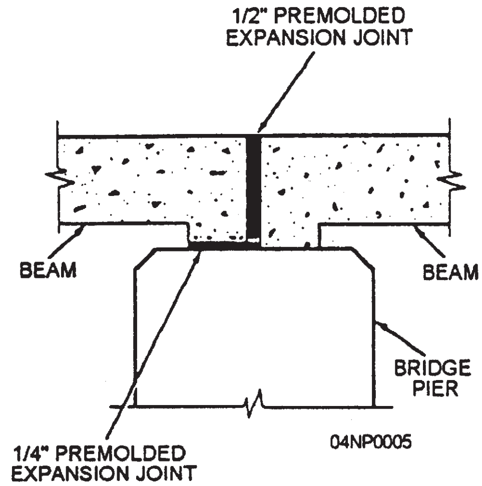


Figure 7-24.—Expansion joint for a bridge.

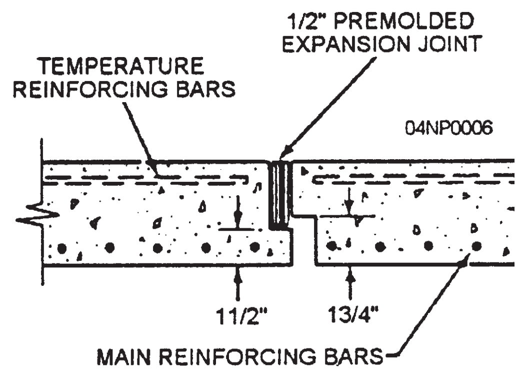


Figure 7-25.—Expansion joint for a floor slab.

expansion joints for a variety of locations. Expansion joints may be installed every 20 ft.

CONCRETE FORMS

Most structural concrete is made by placing (also called CASTING) plastic concrete into

PREFACE

By enrolling in this self-study course, you have demonstrated a desire to improve yourself and the Navy. Remember, however, this self-study course is only one part of the total Navy training program. Practical experience, schools, selected reading, and your desire to succeed are also necessary to successfully round out a fully meaningful training program.

THE COURSE: This self-study course is organized into subject matter areas, each containing learning objectives to help you determine what you should learn along with text and illustrations to help you understand the information. The subject matter reflects day-to-day requirements and experiences of personnel in the rating or skill area. It also reflects guidance provided by Enlisted Community Managers (ECMs) and other senior personnel, technical references, instructions, etc., and either the occupational or naval standards, which are listed in the Manual of Navy Enlisted Manpower Personnel Classifications *and Occupational Standards*, NAVPERS 18068.

THE QUESTIONS: The questions that appear in this course are designed to help you understand the material in the text.

VALUE: In completing this course, you will improve your military and professional knowledge. Importantly, it can also help you study for the Navy-wide advancement in rate examination. If you are studying and discover a reference in the text to another publication for further information, look it up.

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1995 Revision
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Sailor's Creed

"I am a United States Sailor.

I will support and defend the Constitution of the United States of America and I will obey the orders of those appointed over me.

I represent the fighting spirit of the Navy and those who have gone before me to defend freedom and democracy around the world.

I proudly serve my country's Navy combat team with honor, courage and commitment.

I am committed to excellence and the fair treatment of all."

CONTENTS

CREDITS

The illustration indicated below is included in this edition of *Engineering Aid Basic* through the courtesy of the designated company. Permission to use this illustration is gratefully acknowledged.

SOURCE	FIGURE
ELE International, Inc.	15-28

INSTRUCTIONS FOR TAKING THE COURSE

ASSIGNMENTS

The text pages that you are to study are listed at the beginning of each assignment. Study these pages carefully before attempting to answer the questions. Pay close attention to tables and illustrations and read the learning objectives. The learning objectives state what you should be able to do after studying the material. Answering the questions correctly helps you accomplish the objectives.

SELECTING YOUR ANSWERS

Read each question carefully, then select the BEST answer. You may refer freely to the text. The answers must be the result of your own work and decisions. You are prohibited from referring to or copying the answers of others and from giving answers to anyone else taking the course.

SUBMITTING YOUR ASSIGNMENTS

To have your assignments graded, you must be enrolled in the course with the Nonresident Training Course Administration Branch at the Naval Education and Training Professional Development and Technology Center (NETPDTC). Following enrollment, there are two ways of having your assignments graded: (1) use the Internet to submit your assignments as you complete them, or (2) send all the assignments at one time by mail to NETPDTC.

Grading on the Internet: Advantages to Internet grading are:

- you may submit your answers as soon as you complete an assignment, and
- you get your results faster; usually by the next working day (approximately 24 hours).

In addition to receiving grade results for each assignment, you will receive course completion confirmation once you have completed all the assignments. To submit your assignment answers via the Internet, go to:

https://courses.cnet.navy.mil

COMPLETION TIME

Courses must be completed within 12 months from the date of enrollment. This includes time required to resubmit failed assignments.

PASS/FAIL ASSIGNMENT PROCEDURES

If your overall course score is 3.2 or higher, you will pass the course and will not be required to resubmit assignments. Once your assignments have been graded you will receive course completion confirmation.

If you receive less than a 3.2 on any assignment and your overall course score is below 3.2, you will be given the opportunity to resubmit failed assignments. **You may resubmit failed assignments only once.** Internet students will receive notification when they have failed an assignment--they may then resubmit failed assignments on the web site. Internet students may view and print results for failed assignments from the web site. Students who submit by mail will receive a failing result letter and a new answer sheet for resubmission of each failed assignment.

COMPLETION CONFIRMATION

After successfully completing this course, you will receive a letter of completion.

STUDENT FEEDBACK QUESTIONS

We value your suggestions, questions, and criticisms on our courses. If you would like to communicate with us regarding this course, we encourage you, if possible, to use e-mail. If you write or fax, please use a copy of the Student Comment form that follows this page.

NAVAL RESERVE RETIREMENT CREDIT

If you are a member of the Naval Reserve, you will receive retirement points if you are authorized to receive them under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 20 points. These points will be credited in units as follows:

Unit 1 - 12 points upon satisfactory completion of Assignments 1 through 8

Unit 2 - 8 points upon satisfactory completion of Assignments 9 through 13

(Refer to *Administrative Procedures for Naval Reservists on Inactive Duty,* BUPERSINST 1001.39, for more information about retirement points.)

COURSE OBJECTIVES

In completing this nonresident training course, you will demonstrate a knowledge of the subject matter by correctly answering questions on the following subjects: Mathematics and Units of Measurement; Drafting Equipment; Drafting: Fundamentals and Techniques; Drafting: Geometric Construction; Drafting: Projections and Sketching; Reproduction Process; Wood and Light Frame Structures; Concrete and Masonry; Mechanical Systems and Plan; Electrical Systems and Plan; Construction Drawings; Elements of Surveying and Surveying Equipment; Direct Linear Measurements and Field Survey Safety; Horizontal Control; Direct Leveling and Basic Engineering Surveys; Materials Testing: Soil and Concrete; and Administration.

Student Comments

Course Title: *Engineering Aid 3*

NAVEDTRA: 14069 **Date:** ______________

We need some information about you:

Rate/Rank and Name: ______________ SSN: ______________ Command/Unit ______________

Street Address: ______________ City: ______________ State/FPO: ______________ Zip ______________

Your comments, suggestions, etc.:

Privacy Act Statement: Under authority of Title 5, USC 301, information regarding your military status is requested in processing your comments and in preparing a reply. This informationwill not be divulged without written authorization to anyone other than those within DOD for official use in determining performance.

NETPDTC 1550/41 (Rev 4-00)

CHAPTER 1

MATHEMATICS AND UNITS OF MEASUREMENT

Mathematics is the Engineering Aid's basic tool. The use of mathematics is found in every rating in the Navy, from the simple arithmetic of counting for inventory purposes to the complicated equations encountered in computer and engineering designs. In the Occupational Field 13 ratings, the Engineering Aid is looked upon as superior in knowledge when it comes to the subject of mathematics, which generally is a correct assumption; however, to be worthy of this calling, you have the responsibility to learn more about this subject. Mathematics is a broad science that cannot be covered fully in formal service school training, so it is up to you to devote some of your own time to the study of this subject.

The EA must have the ability to compute easily, quickly, systematically, and accurately. This requires a knowledge of the fundamental properties of numbers and the ability to estimate the accuracy of computations based on field measurements or collected field data. To compute rapidly, you need constant practice and should be able to use any available device to speed up and simplify computations. In solving a mathematical problem, you should take a different approach than you would if it were simply a puzzle you were solving for fun. Guesswork has no place in its consideration, and the statement of the problem itself should be devoid of anything that might obscure its true meaning. Mathematics is not a course in memory but one in reasoning. Mathematical problems should be read and so carefully analyzed that all conditions are well fixed in mind. Avoid all unnecessary work and shorten the solution wherever possible. Always apply some proof or check to your work. Accuracy is of the greatest importance; a wrong answer is valueless.

This chapter covers various principles of mathematics. The instructions given will aid the EA in making mathematical computations in the field and the office. This chapter also covers units of measurement and the conversion from one system to the other; that is, from the English to the metric system.

FUNDAMENTALS OF MATHEMATICS

MATHEMATICS is, by broad definition, the science that deals with the relationships between quantities and operations and with methods by which these relationships can be applied to determine unknown quantities from given or measured data. The fundamentals of mathematics remain the same, no matter to what field they are applied. Various authors have attempted to classify mathematics according to its use. It has been subdivided into a number of major branches. Those with which you will be principally concerned are arithmetic, algebra, geometry, and trigonometry.

ARITHMETIC is the art of computation by the use of positive real numbers. Starting with the review of arithmetic, you will, by diligent effort, build up to a study of algebra.

ALGEBRA is the branch of mathematics that deals with the relations and properties of numbers by means of letters, signs of operation, and other symbols. Algebra includes solution of equations, polynomials, verbal problems, graphs, and so on.

GEOMETRY is the branch of mathematics that investigates the relations, properties, and measurement of solids, surfaces, lines, and angles; it also deals with the theory of space and of figures in space.

TRIGONOMETRY is the branch of mathematics that deals with certain constant relationships that exist in triangles and with methods by which they are applied to compute unknown values from known values.

STUDY GUIDES

Mathematics is an exact science, and there are many books on the subject. These numerous books are the result of the mathematicians' efforts to solve mathematical problems with ease. Methods of arriving at solutions may differ, but the end results or answers are always the same. These different approaches to mathematical problems make the study of mathematics more interesting, either by individual study or as a group.

You can supplement your study of mathematics with the following training manuals:

1. *Mathematics, Vol. 1,* NAVEDTRA 10069-D1
2. *Mathematics, Vol. 2-A,* NAVEDTRA 10062
3. *Mathematics, Vol. 2-B,* NAVEDTRA 10063
4. *Mathematics, Vol. 3,* NAVEDTRA 10073-A1

TYPES OF NUMBERS

Positive and negative numbers belong to the class called REAL NUMBERS. Real numbers and imaginary numbers make up the number system in algebra. However, in this training manual, we will deal only with real numbers unless otherwise indicated.

A real number may be rational or irrational. The word *rational* comes from the word *ratio.* A number is rational if it can be expressed as the quotient, or ratio, of two whole numbers. Rational numbers include fractions like 2/7, whole numbers (integers), and radicals if the radical is removable. Any whole number is rational because it could be expressed as a quotient with 1 as its denominator. For instance, 8 equals 8/1, which is the quotient of two integers. A number like $\sqrt{16}$ is rational since it can be expressed as the quotient of the two integers in the form 4/1. An irrational number is a real number that cannot be expressed as the ratio of two integers. The numbers

$$\sqrt{3},\quad 5\sqrt{2},\quad \sqrt{7+5},\quad \frac{3}{8}\sqrt{20},\quad \frac{3}{\sqrt{5}}$$

and 3.1416 (π) are examples of irrational numbers.

An integer may be prime or composite. A number that has factors other than itself and 1 is a composite number. For example, the number 15 is composite. It has the factors 5 and 3. A number that has no factors except itself and 1 is a prime number. Since it is advantageous to separate a composite number into prime factors, it is helpful to be able to recognize a few prime numbers. The following are examples of prime numbers: 1, 2, 3, 5, 7, 11, 13, 17, 19, and 23.

A composite number may be a multiple of two or more numbers other than itself and 1, and it may contain two or more factors other than itself and 1. Multiples and factors of numbers are as follows: Any number that is exactly divisible by a given number is a multiple of the given number. For example, 24 is a multiple of 2, 3, 4, 6, 8, and 12 since it is divisible by each of these numbers. Saying that 24 is a multiple of 3, for instance, is equivalent to saying that 3 multiplied by some whole number will give 24. Any number is a multiple of itself and also of 1.

FRACTIONS, DECIMALS, AND PERCENTAGES

The most general definition of a fraction states that "a fraction is an indicated division. " Any division may be indicated by placing the dividend over the divisor with a line between them. By the above definition, any number, even a so-called "whole" number, may be written as a common fraction. The number 20, for example, may be written as 20/1. This or any other fraction that amounts to more than 1 is an IMPROPER fraction. For example, 8/3 is an improper fraction, The accepted practice is to reduce an improper fraction to a mixed fraction (a whole number plus a proper fraction). Perform the indicated division and write the fractional part of the quotient in its lowest term. In this case, 8/3 would be 2 2/3. A fraction that amounts to less than 1 is a PROPER fraction, such as the fraction 1/4.

To refresh your memory, we are including the following rules in the solution of fractions:

1. If you multiply or divide both the numerator and denominator of a fraction by the same number, the value does not change. The resulting fraction is called an EQUIVALENT fraction.

2. You can add or subtract fractions only if the denominators are alike.

3. To multiply fractions, simply find the products of the numerators and the products of the denominators. The resulting fractional product must be reduced to the lowest term possible.

4. To divide a fraction by a fraction, invert the divisor and proceed as in multiplication.

5. The method of CANCELING can be used to advantage before multiplying fractions (using the principle of rule No. 1) to avoid operations with larger numbers.

A decimal fraction is a fraction whose denominator is 10 or some power of 10, such as 100, 1,000, and so on. For example,

$$\frac{7}{10}, \frac{23}{100}, \text{ and } \frac{87}{1,000}$$

are decimal fractions. Accordingly, they could be written as 0.7, 0.23 and 0.087 respectively. Decimal fractions have certain characteristics that make them easier to use in computations than other fractions. Chapter 5 of NAVEDTRA 10069-D1 deals entirely with decimal fractions. A thorough understanding of decimals will be useful to the Engineering Aid in making various engineering computations. Figure 1-1 shows decimal equivalents of fractions commonly used by Builders, Steelworkers, Utilitiesmen, and other trades.

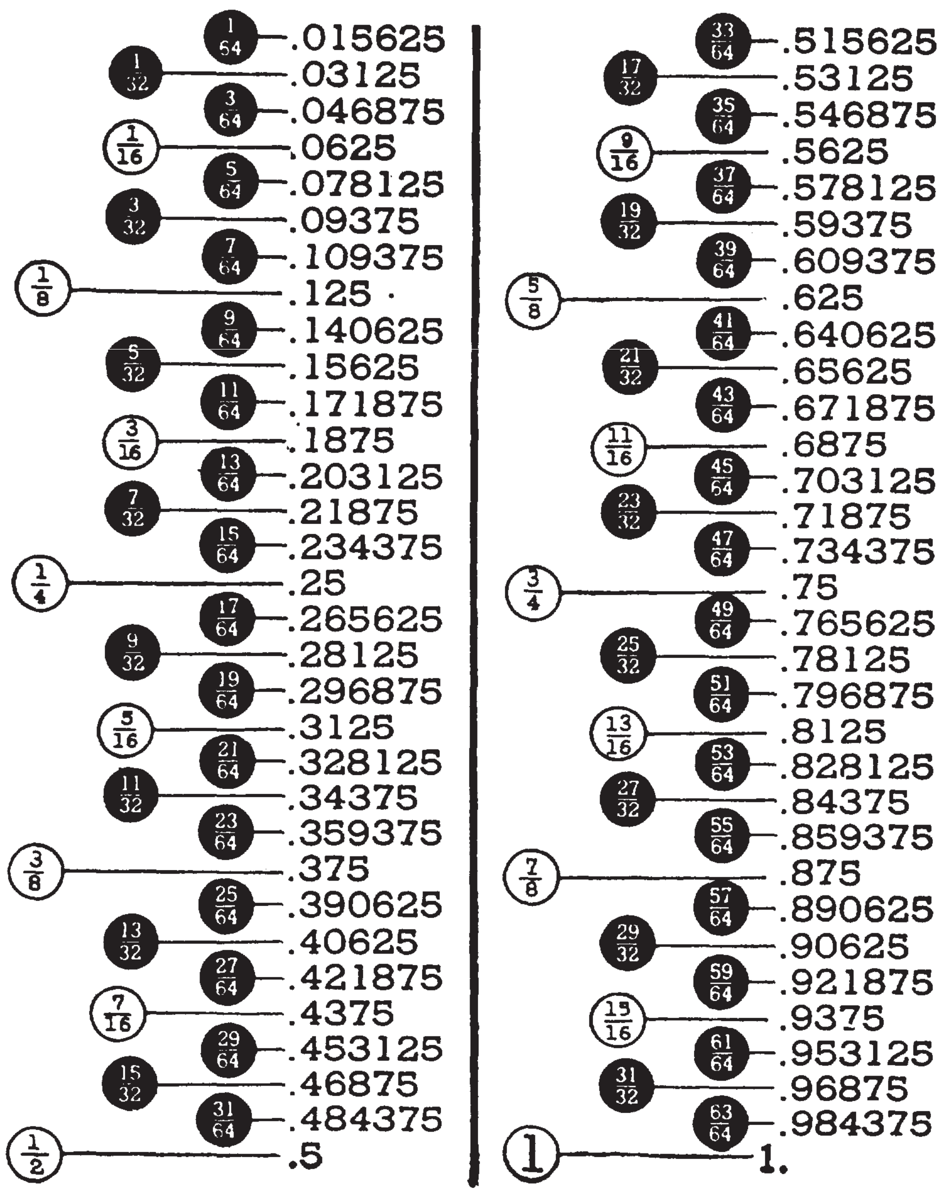

Figure 1-1. Decimal equivalents.

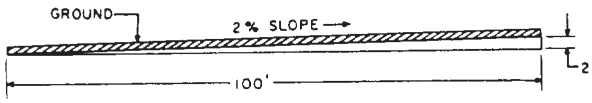

Figure 1-2.-2-percent grade.

In connection with the study of decimal fractions, businessmen as early as the fifteenth century made use of certain decimal fractions so much that they gave them the special designation PERCENT. The word *percent is* derived from Latin. It was originally *per centum,* which means "by the hundredths." In banking, interest rates are always expressed in percent; statisticians use percent; in fact, people in almost all walks of life use percent to indicate increases or decreases in production, population, cost of living, and so on. The Engineering Aid uses percent to express change in grade (slope), as shown in figure 1-2. Percent is also used in earthwork computations, progress reports, and other graphical representations. Study chapter 6 of NAVEDTRA 1-0069-D1 for a clear understanding of percentage.

POWERS, ROOTS, EXPONENTS, AND RADICALS

Any number is a higher power of a given root. To raise a number to a power means to multiply, using the number as a factor as many times as the power indicates. A particular power is indicated by a small numeral called the EXPONENT; for example, the small 2 on 3^2 is an exponent indicating the power.

Examples:

$$3^2 = 3 \times 3 = 9$$

$$3^3 = 3 \times 3 \times 3 = 27$$

$$6^2 = 6 \times 6 = 36$$

$$6^3 = 6 \times 6 \times 6 = 216$$

Many formulas require the power or roots of a number. When an exponent occurs, it must always be written unless its value is 1.

A particular ROOT is indicated by the radical sign ($\sqrt{\ }$), together with a small number called the INDEX of the root. The number under the radical sign is called the RADICAND. When the radical sign is used alone, it is generally understood to mean a square root, and $\sqrt[3]{\ }$, $\sqrt[5]{\ }$, and $\sqrt[7]{\ }$, indicate cube, fifth, and seventh roots, respectively. The square root of a number may be either + or – . The square root of 36 may be written thus: $\sqrt{36} = \pm 6$, since 36 could have been the product of (+ 6)(+ 6) or (– 6)(– 6). However, in practice, it is more convenient to disregard the double sign (±). This example is what we call the root of a perfect square. Sometimes it is easier to extract part of a root only after separation of the factors of the number, such as: $\sqrt{27} = \sqrt{9 \times 3} = 3\sqrt{3}$. As you can see, we were able to extract only the square root of 9, and 3 remains in the radical because it is an irrational factor. This simplification of the radical makes the solution easier because you will be dealing with perfect squares and smaller numbers.

Examples:

$$\sqrt{25} = \sqrt{5 \times 5} = 5$$

$$\sqrt{24} = \sqrt{4 \times 6} = 2\sqrt{6} = 2 \times 2.236 = 4.472$$

$$\sqrt[3]{40} = \sqrt[3]{8 \times 5} = 2\sqrt[3]{5} = 2 \times 1.710 = 3.420$$

Radicals are multiplied or divided directly.

Examples:

$$\sqrt{3} \times \sqrt{6} = \sqrt{18} = \sqrt{9 \times 2} = 3\sqrt{2}$$

$$\frac{\sqrt{12}}{\sqrt{3}} = \frac{\sqrt{4} \times \sqrt{3}}{\sqrt{3}} = \sqrt{4} = \pm 2$$

Like fractions, radicals can be added or subtracted only if they are similar.

Examples:

$$2\sqrt{5} + \sqrt{5} = 3\sqrt{5}$$

$$\sqrt{2 \times 4} + \sqrt{2 \times 9} = \sqrt{2}(\sqrt{4}) + \sqrt{2}(\sqrt{9})$$

$$= 2\sqrt{2} + 3\sqrt{2}$$

$$= 5\sqrt{2}$$

When you encounter a fraction under the radical, you have to RATIONALIZE the denominator before performing the indicated operation. If you multiply the numerator and denominator by the same number, you can extract the denominator, as indicated by the following example:

$$\sqrt{\frac{2}{5}} = \frac{\sqrt{2}}{\sqrt{5}} \times \frac{\sqrt{5}}{\sqrt{5}} = \frac{\sqrt{10}}{\sqrt{25}} = \frac{1}{5}\sqrt{10}$$

The same is true in the division of radicals; for example,

$$\sqrt{\frac{3}{6}} = \frac{\sqrt{3}}{\sqrt{6}} \div \frac{\sqrt{3}}{\sqrt{3}} = \frac{1}{\sqrt{2}}$$

Any radical expression has a decimal equivalent, which may be exact if the radicand is a rational number. If the radicand is not rational, the root may be expressed as a decimal approximation, but it can never be exact. A procedure similar to long division may be used for calculating square root. Cube root and higher roots may be calculated by methods based on logarithms and higher mathematics. Tables of powers and roots have been calculated for use in those scientific fields in which it is frequently necessary to work with roots. Such tables may be found in appendix I of *Mathematics, Vol. 1,* NAVEDTRA 10069-D 1, and in *Surveying Tables and Graphs,* Army TM 5-236. This method is, however, slowly being phased out and being replaced by the use of hand-held scientific calculators.

Arithmetic Extraction of Square Roots

If you do not have an electronic calculator, you may extract square roots arithmetically as follows:

Suppose you want to extract the square root of 2,034.01. First, divide the number into two-digit groups, working away from the decimal point. Thus set off, the number appears as follows:

$$\sqrt{20\ 34.01}$$

Next, find the largest number whose square can be contained in the first group, This is the number 4, whose square is 16. The 4 is the first digit of your answer. Place the 4 above the 20, and place its square (16) under the first group, thus:

```
     4
   √20 34.01
    16
```

Now perform the indicated subtraction and bring down the next group to the right, thus:

```
     4
   √20 34.01
    16
     434
```

Next, double the portion of the answer already found (4, which doubled is 8), and set the result down as the first digit of a new divisor, thus:

```
     4
   √20 34.01
    16
  8 /434
```

The second digit of the new divisor is obtained by a trial-and-error method. Divide the single digit 8 into the first two digits of the remainder 434 (that is, into 43) until you obtain the largest number that you can (1) add as another digit to the divisor and (2) use as a multiplier which, when multiplied by the increased divisor, will produce the largest result containable in the remainder 434. In this case, the first number you try is 43 + 8, or 5. Write this 5 after the 8 and you get 85. Multiply 85 by 5 and you get 425, which is containable in 434.

The second digit of your answer is therefore 5. Place the 5 above 34. Your computation will now look like this:

```
     4  5
   √20 34.01
    16
  85/434
     425
```

Proceed as before to perform the indicated subtraction and bring down the next group, thus:

```
     4  5
   √20 34.01
    16
  85/434
     425
       901
```

Again double the portion of the answer already found, and set the result (45 x 2, or 90) down as the first two digits of a new divisor thus:

```
     4  5
   √20 34.01
    16
  85/434
     425
  90/  901
```

Proceed as before to determine the largest number that can be added as a digit to the divisor 90 and used as a multiplier which, when multiplied by the increased divisor, will produce a result containable in the remainder, 901. This number is obviously 1. The increased divisor is 901, and this figure, multiplied by the 1, gives a result exactly equal to the remainder 901.

The figure 1 is therefore the third and final digit in the answer, The square root of 2,034.01 is therefore 45.1

Your completed computation appears thus:

```
     4  5. 1
   √20 34.01
    16
  85/434
     425
  901/ 901
       901
```

Fractional and Negative Exponents

In some formulas, like the velocity (V) of liquids in pipes, which you will encounter later in *Engineering Aid 1 &* C, it is more convenient to use FRACTIONAL EXPONENTS instead of radicals.

Examples:

$$\sqrt{3} = 3^{\frac{1}{2}}$$

$$\sqrt[3]{3} = 3^{\frac{1}{3}}$$

$$\sqrt[3]{3^2} = 3^{\frac{2}{3}}$$

It is readily observed that the index of the root in the above examples is the denominator of the fractional exponent. When an exponent occurs in the radicand, this exponent becomes the numerator of the fractional exponent. Roots of numbers not found in tables may be easily computed by proper treatment of the radical used.

Examples:

$$\sqrt{\frac{7}{16}} = \frac{\sqrt{7}}{\sqrt{16}} = \frac{1}{4}\sqrt{7} = \frac{2.646}{4} = 0.06615$$

$$\sqrt{8\frac{3}{4}} = \sqrt{\frac{35}{4}} = \frac{\sqrt{35}}{\sqrt{4}} = \frac{1}{2}\sqrt{35} = \frac{5.916}{2} = 2.958$$

In some work, NEGATIVE exponents are used instead of the reciprocals of numbers.

Examples:

$$3^{-1} = \frac{1}{3} \qquad 10^{-1} = \frac{1}{10}$$

$$3^{-2} = \frac{1}{3^2} = \frac{1}{9} \qquad 10^{-2} = \frac{1}{100}$$

$$\frac{1}{5^{-1}} = 5 \qquad 10^{-3} = \frac{1}{1,000}$$

Very small or very large numbers used in science are expressed in the form 5.832×10^{-4} or 8.143×10^{6} to simplify computation. To write out any of these numbers in full, just move the decimal point to either left or right, the number of places equal to the exponent, supplying a sufficient number of zeros depending upon the sign of the exponent, as shown below:

$5.832 \times 10^{-4} = 0.0005832$ (decimal moved four places to the left)

$8.143 \times 10^{6} = 8,143,000$ (decimal moved six places to the right)

RECIPROCALS

The reciprocal of a number is 1 divided by the number. The reciprocal of 2, for example, is 1/2, and the reciprocal of 2/3 is 1 divided by 2/3, which amounts to 1 x 3/2, or 3/2. The reciprocal of a whole number, then, equals 1 over the number, while the reciprocal of a fraction equals the fraction inverted.

In problems containing the power of 10, generally, it is more convenient to use reciprocals rather than write out lengthy decimals or whole numbers.

Example:

$$\frac{1}{250,000 \times 300 \times 0.02} = \frac{1}{2.5 \times 10^5 \times 3 \times 10^2 \times 2 \times 10^{-2}}$$

$$= \frac{10^{-5}}{2.5 \times 3 \times 2} = \frac{10^{-5}}{15} = \frac{1 \times 10^{-5}}{15}$$

$$= .0667 \times 10^{-5} = 6.67 \times 10^{-2} \times 10^{-5}$$

$$= 6.67 \times 10^{-7}$$

$$= 0.000000667$$

Reciprocal is also used in problems involving trigonometric functions of angles, as you will see later in this chapter, in the solutions of problems containing identities.

RATIO AND PROPORTION

Almost every computation you will make as an EA that involves determining an unknown value from given or measured values will involve the solution of a proportional equation. A thorough understanding of ratio and proportion will greatly help you in the solution of both surveying and drafting problems.

The results of observation or measurement often must be compared to some standard value in order to have any meaning. For example, if the magnifying power of your telescope is 20 diameters and you see a telescope in the market that says 50 diameter magnifying power, then one can see that the latter has a greater magnifying power. How much more powerful? To find out, we will divide the second by the first number, which is

$$\frac{50}{20} = \frac{5}{2}.$$

The magnifying power of the second telescope is 2 1/2 times as powerful as the first. When the relationship between two numbers is shown this way, the numbers are compared as a RATIO. In mathematics, a ratio is a comparison of two quantities. Comparison by means of a ratio is limited to quantities of the same kind, For example, in order to express the ratio between 12 ft and 3 yd, both quantities must be written in terms of the same unit. Thus, the proper form of this ratio is 4 yd:3 yd, not 12 ft:3 yd. When the parts of the ratio are expressed in terms of the same unit, the units cancel each other and the ratio consists simply of two numbers. In this example, the final form of the ratio is 4:3.

Since a ratio is also a fraction, all the rules that govern fractions may be used in working with ratios. Thus, the terms may be reduced, increased, simplified, and so forth, according to the rules for fractions.

Closely allied with the study of ratio is the subject of proportion. A PROPORTION is nothing more than an equation in which the members are ratios. In other words, when two ratios are set equal to each other, a proportion is formed. The proportion may be written in three different ways, as in the following examples:

$$15:20::3:4:$$

$$15:20 = 3:4$$

$$\frac{15}{20} = \frac{3}{4}$$

The last two forms are the most common. All of these forms are read, “15 is to 20 as 3 is to 4.” In other words, 15 has the same ratio to 20 as 3 has to 4.

The whole of chapter 13, NAVEDTRA 10069-D1, is devoted to an explanation of ratio and proportion, the solution of proportional equations, and the closely related subject of variation. In addition to gaining this knowledge, you should develop the ability to recognize a computational situation as one that is available to solution by proportional equation. A very large area of surveying computations—the area that involves triangle solutions—uses the proportional equation as the principal key to the determination of unknown values on the basis of known values. Practically any problem involving the conversion of measurement expressed in one unit to the equivalent in a different unit is solvable by proportional equation. Similarly, if you know the quantity of a certain material required to produce a certain number of units of product, you can determine by proportional equation the quantity required to produce any given number of units.

In short, it is difficult to imagine any mathematical computation involving the determination of unknown values on the basis of known values that is not available to solution by proportional equation.

Your knowledge of equations need not extend beyond that required to solve linear equations; that is, equations in which the unknown appears with no exponent higher than 1. The equation

$$4x + 7 = \frac{15}{6},$$

for example, is a linear equation, because the unknown (technically known as the “variable’ ‘), x, appears to only the first power. The equation $X^2 + 2x = -1$, however, is a quadratic, not a linear, equation because the variable appears to the second power.

The whole of chapter 11 of NAVEDTRA 10069-D1 is devoted to an explanation of linear equations in one variable. The whole of chapter 12 is devoted to an explanation of linear equations in two variables.

ARITHMETIC

The common arithmetical operations are addition, subtraction, multiplication, and division. Arithmetical operations with positive whole numbers are explained in chapter 2 of NAVEDTRA 10069-D1, and arithmetical operations with signed numbers, in chapter 3. Arithmetical operations with common fractions are explained in chapter 4, and arithmetical operations with decimal fractions, in chapter 5.

ALGEBRAIC NOTATION AND ALGEBRAIC OPERATIONS

Algebraic notation—meaning generally the substitution of symbols (usually letters) for numerical values-is explained in chapter 9 of NAVEDTRA 10069-D1. Algebraic fundamentals, such as the meanings of terms; systems of groupings; and the addition, subtraction, multiplication, and division of algebraic monomials and polynomials are explained in the same chapter. The factoring of algebraic expressions is explained in chapter 10.

GEOMETRY

Since geometry is the branch of mathematics that investigates the relations, properties, and measurement of solids, surfaces, lines, and angles, it follows that just about everything a surveyor does involves geometry in some way or other. Whenever you establish a point, chain a linear distance, measure a vertical distance, turn an angle, or determine an area or a volume, you are working with geometry.

To begin with, you must know how to recognize the common types of geometrical plane and solid figures and how to compute the areas of the plane figures and the volumes of the solids.

SURFACES AND FIGURES

There is a surface on this sheet of paper. A geometrical surface has length and breadth. It has no thickness. A surface may be either a plane surface or a curved surface. When this page is held perfectly level at every point, the surface is then a plane surface. When the page is rolled to resemble a tube, the plane surface becomes a curved surface.

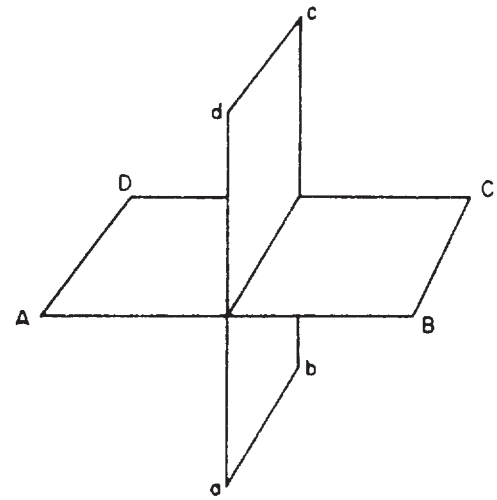

Figure 1-3.-Intersecting planes.

A plane is a real or imaginary surface in which a straight line between any two points lies wholly on that surface. Figure 1-3 shows two intersecting planes. Plane ABCD is shown to be a horizontal plane; plane abed is a vertical plane perpendicular to ABCD.

A plane surface is a surface on which every point lies in the same plane.

Plane figures are plane surfaces bounded by either straight lines or curved lines.

POLYGONS

A plane figure that is bounded by straight-line sides is called a polygon. The smallest possible number of sides for a polygon is three, and a three-sided polygon is called a triangle.

Some terms and definitions relating to polygons are as follows:

Sides	The boundary lines of a polygon
Perimeter	The sum of the sides

Triangle	A polygon bounded by three sides
Quadrilateral	A polygon bounded by four sides
Hexagon	A polygon bounded by six sides
Heptagon	A polygon bounded by seven sides
Octagon	A polygon bounded by eight sides
Equilateral	A polygon with sides of equal length
Regular	An equilateral polygon
Irregular	A nonequilateral polygon
Parallelogram	A quadrilateral with both pairs of opposite sides parallel
Rectangle	A parallelogram in which adjacent sides join at right angles
Square	An equilateral rectangle
Oblong	A nonequilateral rectangle
Trapezoid	A quadrilateral with only one pair of opposite sides parallel, the other pair being not parallel
Trapezium	A quadrilateral with no sides parallel
Rhombus	An equilateral parallelogram in which adjacent sides join at oblique (other than right) angles
Rhomboid	A nonequilateral parallelogram in which adjacent sides join at oblique angles

A triangle, quadrilateral, pentagon, hexagon, heptagon, and octagon are shown in figure 1-4. A trapezoid, trapezium, rhombus, and rhomboid are shown in figure 1-5.

DETERMINING AREAS

The area of any surface is the number of units of area measure the surface contains. A unit of area measure is a square unit. The main thing to remember when computing for areas is that the dimensions used must be of the same unit of measure—if in inches, all units must be in inches and if in feet, all must be in feet.

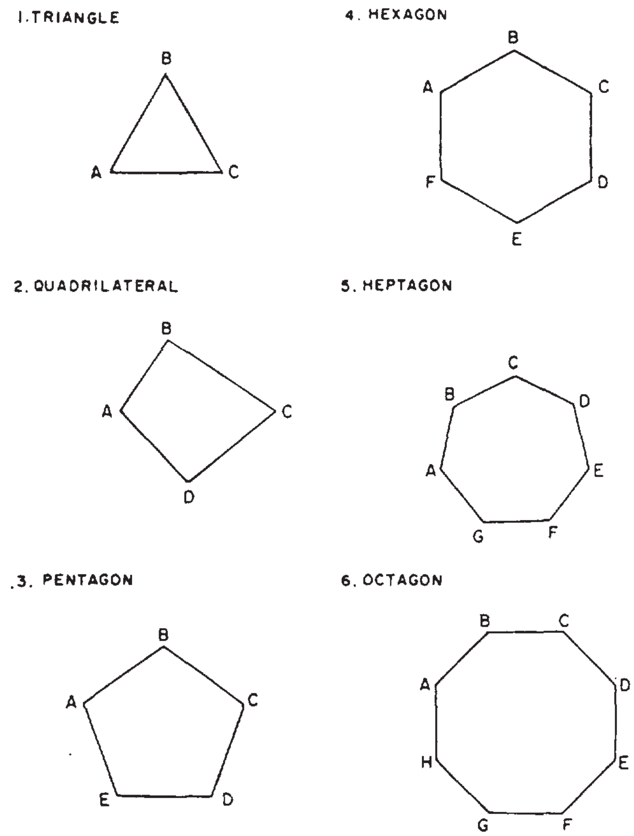

Figure 1-4.-Geometric figures of a triangle, quadrilateral, pentagon, hexagon, heptagon, and octagon.

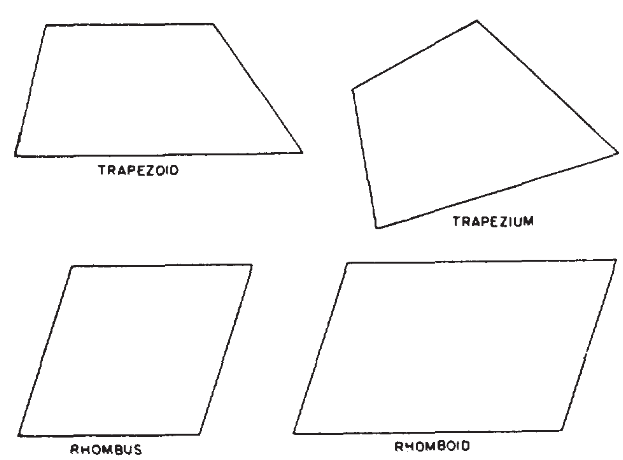

Figure 1-5.-Geometric figures of a trapezoid, trapezium, rhombus, and rhomboid.

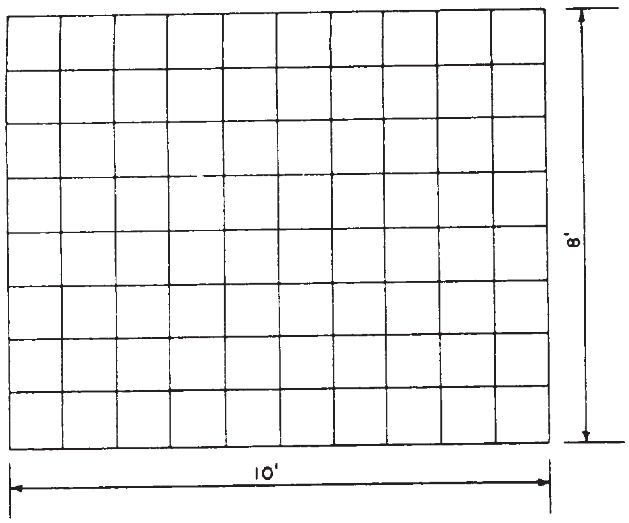

Figure 1-6.-Area of a rectangle.

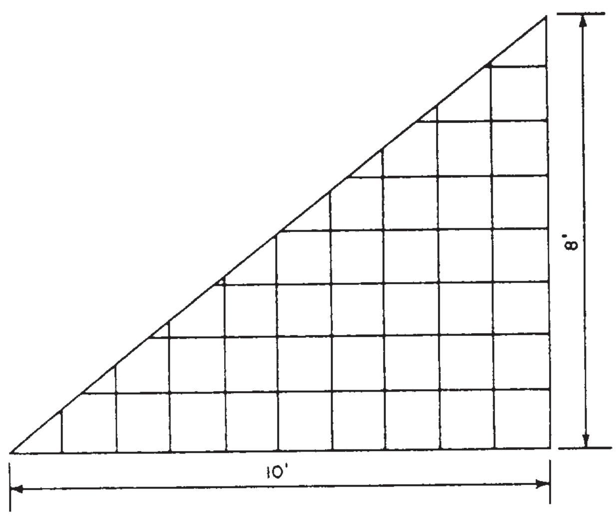

Figure 1-7.-Area of a triangle.

Area of a Rectangle

Figure 1-6 shows a rectangle measuring 10 ft by 8 ft, divided up into units of area measure, each consisting of 1 sq ft. If you were to count the units, one after the other, you would count a total of 80 units. However, you can see that there are 8 rows of 10 units, or 10 rows of 8 units. Therefore, the quickest way to count the units is simply to multiply 10 by 8, or 8 by 10.

You could call the 8-ft dimension the width and the 10-ft dimension the length, in which case you would say that the formula for determining the area of a rectangle is the width times the length, or A = wl. Or, you could call the 10-ft dimension the base and the 8-ft dimension the altitude (meaning height), in which case your formula for area of a rectangle would be A = bh.

Area of a Triangle

Figure 1-7 shows a triangle consisting of one-half of the rectangle shown in figure 1-6. It is obvious that the area of this triangle must equal one-half of the area of the corresponding rectangle, and the fact that it does can be demonstrated by geometrical proof. Therefore, since the formula for the area of the rectangle is A = bh, it follows that the formula for the triangle is A = 1/2bh.

The triangle shown in figure 1-7, because it is half of a corresponding rectangle, contains a right angle, and is therefore called a right triangle. In a right triangle the dimension h corresponds to the length of one of the sides. The triangle shown in figure 1-8, however, is a scalene triangle, so-called because no two sides are equal. Classification of triangles will be discussed later in this chapter.

Now, a perpendicular CD drawn from the apex of the triangle (from angle C) divides the triangle into two right triangles, ΔADC and ΔBDC. The area of the whole triangle equals the sum of the areas of ΔADC and ΔBDC. The area of ΔADC equals 1/2 (AD)(DC), and the area of ΔBDC equals 1/2(DB)(DC). Therefore, the area of the whole triangle equals

$$\frac{AD}{2}(DC) + \frac{DB}{2}(DC), \text{ or } DC\left(\frac{AD + DB}{2}\right).$$

But since AD + DB = AB, it follows that the area of the whole triangle equals

$$DC\left(\frac{AB}{2}\right).$$

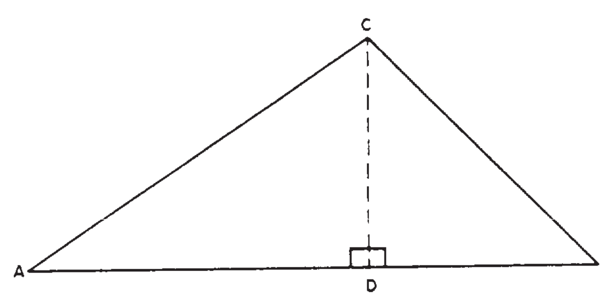

Figure 1-8.-Triangle.

The length of AB is called the base (b), and the length of DC, the altitude (h); therefore, your formula for determining the area of an oblique triangle is again A = 1/2bh.

You must remember that in a right triangle h corresponds to the length of one of the sides, while in an oblique triangle it does not. Therefore, for a right triangle with the length of the sides given, you can determine the area by the formula A = 1/2bh. For an oblique triangle with the length of the sides given, you cannot use this formula unless you can determine the value of h, Later in this chapter you will learn trigonometric methods of determining areas of various forms of triangles on the basis of the length of the sides alone.

Area of a Rhombus or Rhomboid

Figure 1-9 shows a rhomboid, ABCD. If you drop a perpendicular, CF, from ∠ C to AD, and project another from ∠A to BC, you will create two right triangles, ΔAEB and ΔCFD, and the rectangle AECF. It can be shown geometrically that the right triangles are similar and equal.

You can see that the area of the rectangle AECF equals the product of AF x FC. The area of the triangle CFD equals 1 /2(FD)(FC). Because the triangle AEB is equal and similar to CFD, the area of that triangle also equals 1/2(FD)(FC). Therefore, the total area of both triangles equals (FD)(FC). The total area of the rhomboid equals the area of the rectangle AECF + the total area of both triangles.

The total area of the rhomboid equals (AF)(FC) + (FD)(FC), or (AF + FD)(FC). But AF + FD equals AD, the base. FC equals the altitude. Therefore, the formula for the area of a rhomboid is A = bh. Here again you must remember that h in a rectangle corresponds to the length of one of the sides, but h in a rhombus or rhomboid does not.

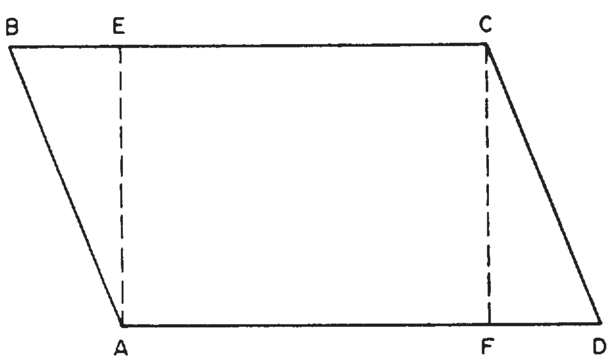

Figure 1-9.-Rhomboid.

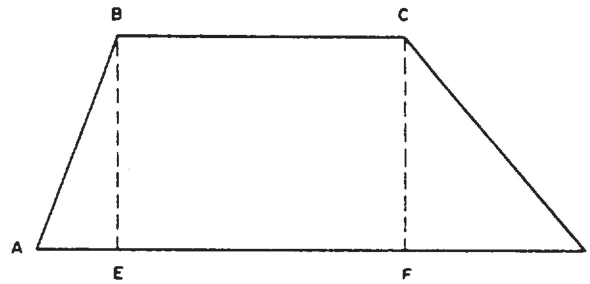

Figure 1-10.-Trapezoid.

Area of a Trapezoid

Figure 1-10 shows a trapezoid, ABCD. If you drop perpendiculars BE and CF from points B and C, respectively, you create the right triangles AEB and DFC and the rectangle EBCF between them. The area of the trapezoid obviously equals the sum of the areas of these figures.

The area of ΔAEB equals 1/2(AE)(FC), the area of ΔDFC equals 1/2(FD)(FC), and the area of EBCF equals (EF)(FC). Therefore, the area of the trapezoid ABCD equals 1/2(AE)(FC) + (EF)(FC) + 1/2(FD)(FC), or

$$\frac{(AE + FD + 2EF)(FC)}{2}.$$

However, 2EF = EF + BC. Therefore, the area of the trapezoid equals

$$\frac{(AE + FD + EF + BC)(FC)}{2}.$$

But AE + FD + EF = AD. Therefore, the area of the trapezoid equals

$$\frac{(AD + BC)(FC)}{2}.$$

AD and BC are the bases of the trapezoid and are usually designated as b_1 and b_2, respectively. FC is the altitude and is generally designated as h. Therefore, the formula for the area of a trapezoid is

$$A = 1/2\,(b_1 + b_2)h.$$

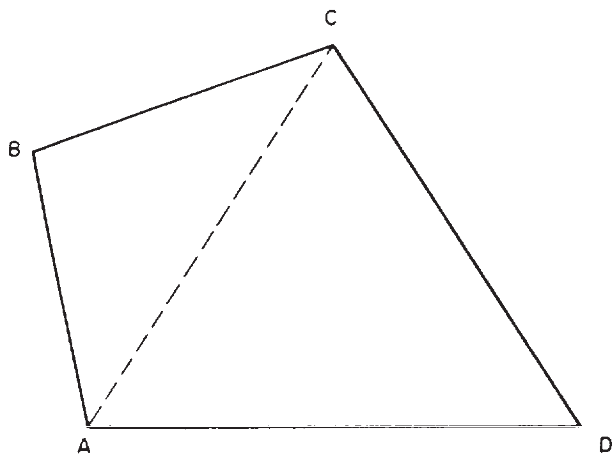

Figure 1-11.-Trapezium.

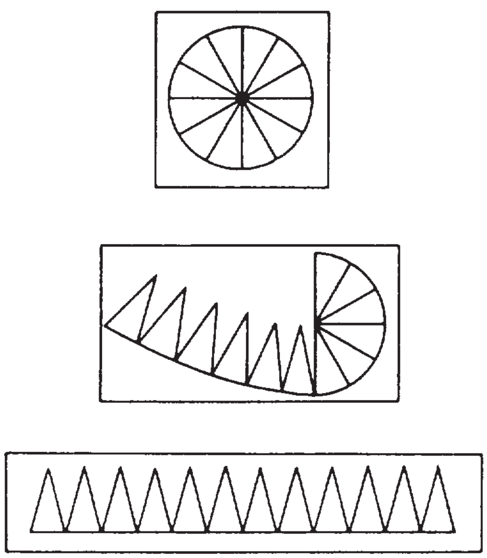

Figure 1-12.-Area of a circle.

Stated in words, the area of a trapezoid is equal to one-half the sum of its bases times its altitude.

Area by Reducing to Triangles

Figure 1-11 shows you how you can determine the area of a trapezium, or of any polygon, by reducing to triangles. The dotted line connecting A and C divides the figure into the triangles ABC and ACD. The area of the trapezium obviously equals the sum of the areas of these triangles.

Area of a Circle

Figure 1-12 shows how you could cut a disk into 12 equal sectors. Each of these sectors would constitute a triangle, except for the slight curvature of the side that was originally a segment of the circumference of the disk. If this side is considered the base, then the altitude for each triangle equals the radius (r) of the original disk. The area of each triangle, then, equals

$$\frac{br}{2},$$

and the area of the original disk equals the sum of the areas of all the triangles. The sum of the areas of all the triangles, however, equals the sum of all the b's, multiplied by r and divided by 2.

But the sum of all the b's equals the circumference (c) of the original disk. Therefore, the formula for the area of a circle can be expressed as

$$A = \frac{cr}{2}.$$

However, the circumference of a circle equals the product of the diameter times π (Greek letter, pronounced "pi"). π is equal to 3.14159. . . The diameter equals twice the radius; therefore, the circumference equals $2\pi r$. Substituting $2\pi r$ for c in the formula

$$A = \frac{cr}{2}, \text{ we have } A = \frac{(2\pi r)(r)}{2}, \text{ or } \frac{2\pi r^2}{2}, \text{ or } \pi r^2.$$

This is the most commonly used formula for the area of a circle. If we find the area of the circle in terms of circumference.

$$A = \frac{c^2}{4\pi}.$$

Area of a Segment and a Sector

A segment is a part of a circle bounded by a chord and its arc, as shown in figure 1-13. The formula for its area is

$$A = \frac{r^2}{2}\left(\frac{\pi n}{180} - \sin n\right)$$

where r = the radius and n = the central angle in degrees.

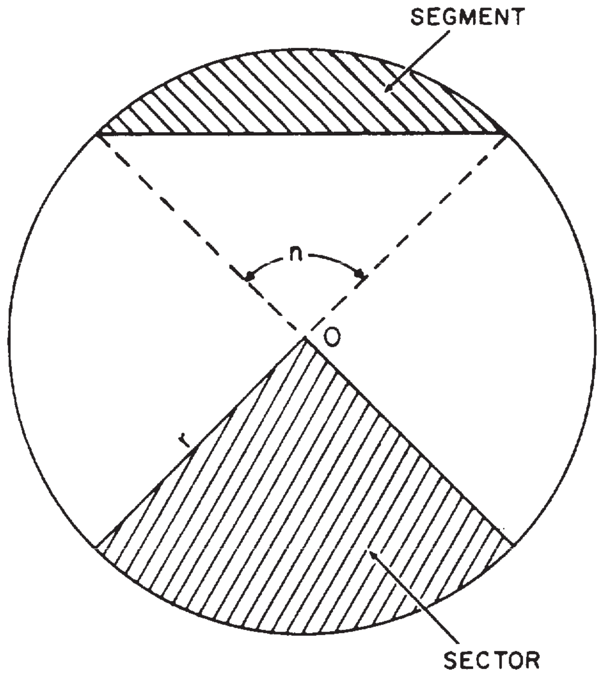

Figure 1-13.-Segment and sector of a circle,

A sector is a part of a circle bounded by two radii and their intercepted arc. The formula for its area is

$$A = \frac{\pi r^2 n}{360}$$

where r and n have the same designation as above.

Area of Regular Polygons

Figure 1-14 is a regular polygon. In any regular polygon, the area is equal to one-half the perimeter of the polygon times the radius of the inscribed circle. This is expressed in formula form as follows:

$$A = \frac{\text{perimeter} \times r}{2}$$

You can verify the above formula by dividing the polygon into equal triangles with the sides as their bases and with r as their altitudes; if you multiply the areas of the individual triangles by the number of sides in the polygon, you will arrive at the above formula.

Area of an Ellipse

The derivation of an ellipse from a conic section and methods of drawing ellipses are

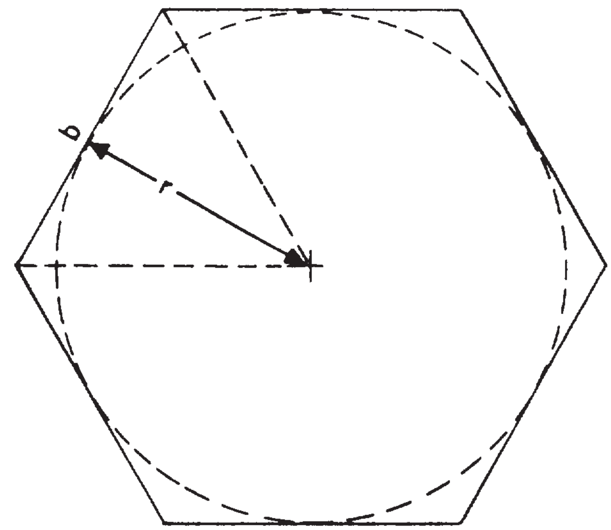

Figure 1-14.-Regular polygon.

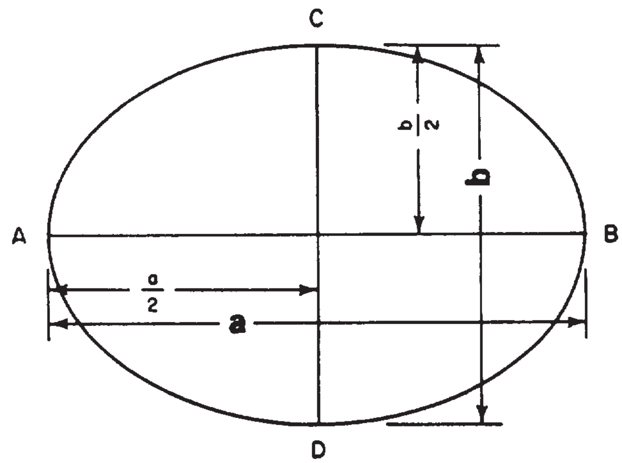

Figure 1-15.-Ellipse.

explained in chapter 3. An ellipse is shown in figure 1-15, The longer axis, AB, is called the major axis, and the shorter axis, CD, the minor axis. Call the length of the major axis a and that of the minor axis b. The area equals the product of half the major axis times half the minor axis times π. In formula form, it is stated as

$$A = \pi\left(\frac{a}{2} \times \frac{b}{2}\right)$$

$$= \pi\left(\frac{ab}{4}\right)$$

$$= 0.7854ab$$

Irregular Areas

Irregular areas are those areas that do not fall within a definite standard shape. As you already have learned, there are formulas for computing the area of a circle, a rectangle, a triangle, and so on. However, we do not have a standard formula for computing the area of an irregular shaped plane, unless we use higher mathematics (calculus), and integrate incremental areas using lower and upper limits that define the boundaries.

As an EA, however, most areas you will be concerned with are those you will meet in plane surveying. In most surveys, the computed area is the horizontal projection of the area rather than the actual surface of the land. The fieldwork in finding areas consists of a series of angular and linear measurements, defining the outline of whatever the shape is of the area concerned, and forming a closed traverse. The following office computation methods, which you will learn as you advance in rate, are:

1. Plotting the closed traverse to scale and measuring the enclosed area directly with a polar planimeter (used only where approximate results are required, or for checking purposes).

2. Subdividing the area into a series of triangles, and taking the summation of all the areas of these triangles.

3. Computing the area using the coordinates of the individual points of the traverse (called coordinate method).

4. Computing the area by means of the balanced latitude and departure, and calculated DOUBLE MERIDIAN DISTANCES of each course (called the DMD method).

5. Computing the area by counting squares; this method is nothing but just superimposing small squares plotted on a transparent paper having the same scale as the plotted traverse (or of known graphical ratio) and counting the number of squares within the traverse. The smaller the squares, the closer to the approximate area you will get.

6. Computing an irregular area bounded by a curve and perpendicular lines, as shown in figure 1-16. Here, you can use the TRAPEZOIDAL RULE. The figure is considered as being made up of a series of trapezoids, all of them having the same base and having common distances between offsets. The formula in computing the total area is as follows:

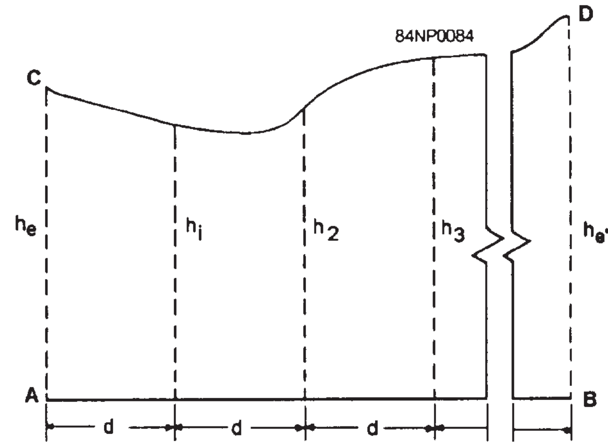

Figure 1-16.-Irregular area by trapezoidal rule.

$$A = \left(\frac{h_e}{2} + \sum h + h_{e'} \right) d$$

Where h_e and h_e = the end offsets of the series of trapezoids

$\sum h$ = the sum of the intermediate offsets ($h_1 + h_2 + h_3 + ...$)

and d = the common distance between the offsets

For the present time, try to find the areas of irregular figures by subdividing the area to series of triangles and by the method of counting the squares.

There are also areas of spherical surfaces and areas of portions of a sphere. For other figures not covered in this training manual, consult any text on plane and solid geometry.

DETERMINING VOLUMES

From the preceding section you learned the formulas for computing the areas of various plane figures. These plane areas are important in the computation of VOLUMES, as you will see later in this section.

When plane figures are combined to form a three-dimensional object, the resulting figure is

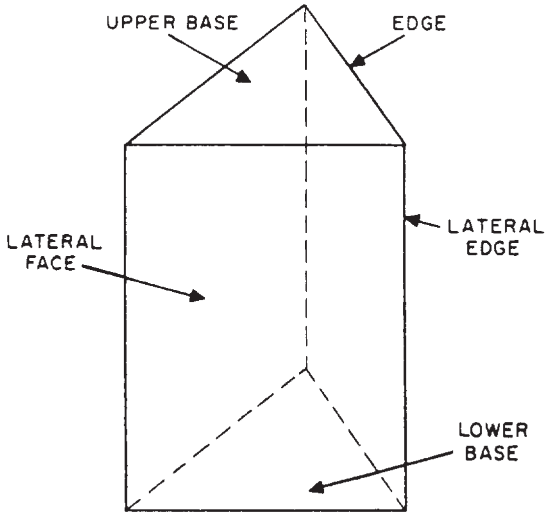

Figure 1-17.-Parts of a prism (triangular).

a solid. For example, three rectangles and two triangles may be combined as shown in figure 1-17. The flat surfaces of the solid figure are its FACES, the top and bottom faces are the BASES, and the faces forming the sides are the LATERAL FACES or SURFACES.

Some solid figures do not have any flat faces, and some have a combination of curved surfaces and flat surfaces. Examples of solids with curved surfaces include cylinders, cones, and spheres. Those solids having no flat faces include a great majority of natural objects, such as rocks, living matter, and many other objects that have irregular surfaces.

A solid figure whose bases or ends are similar, equal, and parallel polygons, and whose faces are parallelograms, is known geometrically as a PRISM. The name of a prism depends upon its base polygons. If the bases are triangles, as in figure 1-17, the figure is a TRIANGULAR PRISM. A RECTANGULAR PRISM has bases that are rectangles, as shown in figure 1-18. If the bases of a prism are perpendicular to the planes forming its lateral faces, the prism is a RIGHT prism.

A PARALLELEPIPED is a prism with parallelograms for bases. Since the bases are parallel to each other, this means that they cut the lateral faces to form parallelograms. If a parallelepipeds is a right prism and if its bases are rectangles, it is a rectangular solid. A CUBE is a rectangular solid in which all of the six rectangular faces are squares.

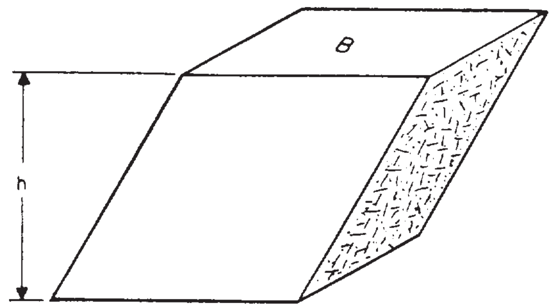

Figure 1-18.-Rectangular prism, showing its height when not a right prism.

In determining the volume of most solids, you should use the following general formula:

$$V = B h$$

Where V = the volume

B = the area of the base or end area

h = the height of the solid (the perpendicular height from its base)

Volume of a Prism

For the volume of any prism, then, you simply determine the end area or the base area by the appropriate method and multiply the end area by the length or the base area by the height.

Volume of a Cylinder

From the standpoint of volume calculation, the only difference between a cylinder and a prism lies in the fact that the end or base of a cylinder is a circle rather than a polygon. Therefore, the volume of a cylinder is equal to its end area times its length. But you determine its end area from the formula πr^2, which is the formula used for computing the area of a circular plane. Therefore, the volume of a cylinder is $\pi r^2 L$.

Volume of a Cone or Pyramid

The best way to approach the problem of determining the volume of a cone or pyramid is on the basis of the fundamental fact that the volume of a cone equals one-third of the volume of the corresponding cylinder, while the volume of a pyramid equals one-third of the volume of the corresponding prism. For any of these solids, volume equals base area times height divided by 3. Therefore, the formula for computing the volume of a cone is

$$V = \frac{1}{3}\pi r^2 h,$$

and that for a pyramid is

$$V = \frac{1}{3}Bh.$$

A pyramid may have either a rectangular or a triangular base.

Volume of Other Geometric Figures

There will be no attempt to illustrate the derivation of formulas presented in this section. The formulas for the computations of volumes and surface areas of the following geometric figures are presented here only for additional information.

A frustum is that portion of a cone or pyramid that remains after the upper part is cut off by a plane parallel to the base.

1. SPHERE

   Volume of a sphere $= \frac{4}{3}\pi r^3$

   Surface area $= 4\pi r^2$

   Where r = the radius of the sphere

2. FRUSTUM OF A CONE

   Volume of frustum = volume of large cone − volume of small cone

   $= \frac{1}{3}\pi h(r_1^2 + r_1 r_2 + r_2'^2)$ cubic units

   Lateral area $= \pi(r_1 + r_2)s$ square units

   Where h = the altitude of the frustum

   r_1 = the radius of the base

   r_2 = the radius of the top

   s = the slant height

3. FRUSTUM OF A PYRAMID

   Volume of a frustum = volume of large pyramid − volume of small pyramid

   $= \frac{1}{3}h\,(B_1 + \sqrt{B_1 B_2} + B_2)$

   Where h = the altitude of frustum

   B_1 = the area of lower base

   B_2 = the area of upper base

TRIGONOMETRY

Our discussion will focus primarily on the study of plane trigonometry. It is intended only as a review of the relationships among the sides and angles of plane triangles and their ratios, called the TRIGONOMETRIC FUNCTIONS. The information presented here is based on *Mathematics, Vol. 1,* NAVEDTRA 10069-D1, chapter 19, and *Mathematics, Vol. 2-A,* NAVEDTRA 10062, chapters 3, 4, and 6.

Spherical trigonometry will be covered as you advance in rate. It is a prerequisite to the study of navigation, geodesy, and astronomy. Hence, the subject of spherical trigonometry will be introduced in the Engineering Aid class C1 school curriculum.

MEASURING ANGLES

When two straight lines intersect, an angle is formed, You can also generate an angle by rotating a line having a set direction, Figure 1-19 depicts the generation of an angle. The terminal line OB is generated from the initial point OA and forms $\angle$ AOB, which we will call θ (Greek letter, pronounced "theta"). Angle θ is generally expressed in degrees. The following paragraphs will discuss the degree and the radian systems that are generally used by Engineering Aids.

The DEGREE SYSTEM is the most common system used in angular measurement. Angular measurement by REVOLUTION is perhaps the unit you are most familiar with.

In the degree system, a complete revolution is divided into 360 equal parts called degrees (360°). Each degree is divided into 60 minutes (60´), and each minute into 60 seconds (60"). For convenience in trigonometric computations, the 360° is divided into four parts of 90° each. The

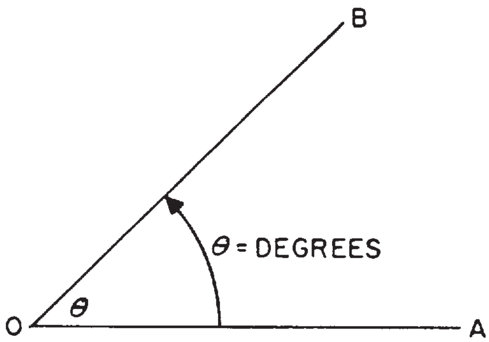

Figure 1-19.-Generation of an angle, resulting angle measured in degrees.

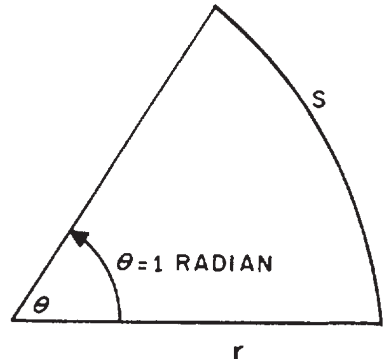

Figure 1-20.-Radian measure.

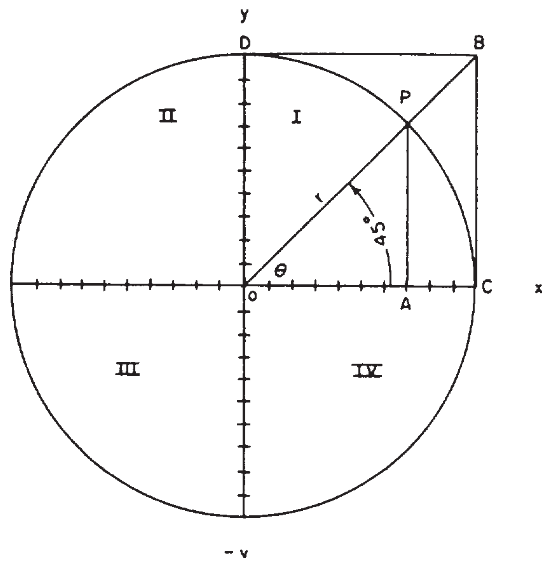

Figure 1-21.-Circle of unit radius with quadrants shown.

90° sectors, called QUADRANTS, are numbered counterclockwise starting at the upper right-hand sector.

When the unit radius r (the line generating the angle) has traveled less than 90° from its starting point in a counterclockwise direction (or, as conventionally referred to as, in a positive direction), the angle is in the FIRST quadrant (I). When the unit radius lies between 90° and 180°, the angle is in the SECOND quadrant (II). Angles between 180° and 270° are said to lie in the THIRD quadrant (III), and angles greater than 270° and less than 360° are in the FOURTH quadrant (IV).

When the line generating the angle passes through more than 360°, the quadrant in which the angle lies is found by subtracting from the angle the largest multiple of 360 that the angle contains and determining the quadrant in which the remainder falls.

The RADIAN SYSTEM of measuring angles is even more fundamental than the degree system. It has certain advantages over the degree system, for it relates the length of arc generated to the size of the angle and the radius. The radian measure is shown in figure 1-20. If the length of the arc (s) described by the extremity of the line segment generating the angle is equal to the length of the line (r), then it is said that the angle described is exactly equal to one radian in size; that is, for one radian, s = r.

The circumference of a circle is related to the radius by the formula, $C = 2\pi r$. This says that the circumference is 2π times the length of the radius. From the relationship of arc length, radius, and radians in the preceding paragraph, this could be extended to say that a circle contains 2π radians, and the circumference encompasses 3600 of rotation. It follows that

$$2\pi \text{ radians} = 360^\circ$$

$$\pi \text{ radians} = 180^\circ$$

By dividing both sides of the above equation by π, we find that

$$\text{radian} = \frac{180^\circ}{\pi} = 57.2959^\circ, \text{ or } 57.3^\circ \text{ (approximately)}$$

As in any other formula, you can always convert radians to degrees or vice versa by using the above relationship.

FUNCTIONS OF ANGLES

The functions of angles can best be illustrated by means of a "circle of unit radius" like the one shown in figure 1-21. A so-called "Cartesian axis" is inscribed within the circle. Coordinates measured from 0 along the x axis to thc right are positive; coordinates measured from 0 along the x axis to the left are negative. Coordinates measured along the y axis from 0 upward are positive; coordinates measured along the y axis from 0 downward are negative.

Angles are generated by the motion of a point P counterclockwise along the circumference of the circle. The initial leg of any angle is the positive leg of the x axis. The other leg is the radius r, at the end of which the point P is located; this radius always has a value of 1. The unit radius (r = OC) is subdivided into 10 equal parts, so the value of each of the 10 subdivisions shown is 0.1.

For any angle, the point P has three coordinates: the x coordinate, the y coordinate, and the r coordinate (which always has a value of 1 in this case). The functions of any angle are, collectively, various ratios that prevail between these coordinates.

The ratio between y and r (that is, y/r) is called the **sine** of an angle. In figure 1-21, AP seems to measure about 0.7 of y; therefore, the sine θ, which is equal to 45° in this case, would seem to be 0.7/1, or about 0.7. Actually, the sine of 45° is 0.70711. Graphically, the sine is indicated in figure 1-21 by the line AP, which measures 0.7 to the scale of the drawing.

The ratio between x and r (that is, x/r) is called the **cosine** of the angle. You can see that for 45°, x and y are equal, and the fact that they are can be proven geometrically. Therefore, the cosine of 45° is the same as the sine of 45°, or 0.70711. Graphically, the length of line OA represents the cosine of angle θ when the radius (r) is equal to 1.

The ratio between y and x (that is, y/x) is known as the **tangent** of an angle. Since y and x for an angle of 45° are equal, it follows that the tangent of an angle of 45° equals 1. The tangent is also indicated graphically by the line BC, drawn tangent to the circle at C and intersecting the extended r at B and DB, which is also drawn tangent at D. As you examine figure 1-21, you can deduce that BC is equal to OC. OC is equal to the unit radius, r.

The three functions shown in figure 1-21 are called the "direct" functions. For each direct function there is a corresponding "reciprocal" function–meaning a function that results when you divide 1 by the direct function. You know that the reciprocal of any fraction is simply the fraction inverted. Therefore, for the direct function sine, which is y/r, the reciprocal function (called the **cosecant)** is divided by y/r, which is r/y.

Since y at sine 45° equals about 0.7, the cosecant for 45° is r/y, which is equal to 1/0.7, or about 1.4. The cosecant is indicated graphically by the line OB in figure 1-21. If you measure this line, you will find that it measures just about 1.4 units to the scale of the drawing.

For the direct function cosine, which is x/r, the reciprocal function (called the **secant)** is r/x. Since x for cosine 45° also measures about 0.7, it follows that the secant for 45°, r/x, is the same as the cosecant, or also about 1.4. The secant is indicated graphically in figure 1-21 by the line OB also.

For the direct function tangent, which is y/x the reciprocal function (called the **cotangent)** is x/y. Since x and y at tangent 45° are equal, it follows that the value for cotangent 45° is the same as that for the tangent, or 1. The cotangent is shown graphically in figure 1-21 by the line DB, drawn tangent to the circle at D.

FUNCTIONS AND COFUNCTIONS

The functions cosine, cosecant, and cotangent are cofunctions of the functions sine, secant, and tangent, respectively. A cofunction of an angle A has the same value as the corresponding function of (90° – A); that is, the same value as the corresponding function of the complement of the angle. The sine of 30°, for example, is 0.50000. The cosine of 60° (the complement of 30°) is likewise 0.50000. The tangent of 30° is 0.57735. The cotangent of 60° (the complement of 30°) is likewise 0.57735.

Commonly used functions and cofunctions are as follows:

$$\sin A = \cos (90° - A)$$

$$\sec A = \csc (90° - A)$$

$$\tan A = \cot (90° - A)$$

FUNCTIONS OF OBTUSE ANGLES

In figure 1-22, the point P has generated an obtuse (larger than 90°) angle of 135°. This angle is the supplement of 45° (two angles are supplementary when they total 180°). We have left a dotted image of the reference angle A, which is equal to the supplementary angle of 135°. You

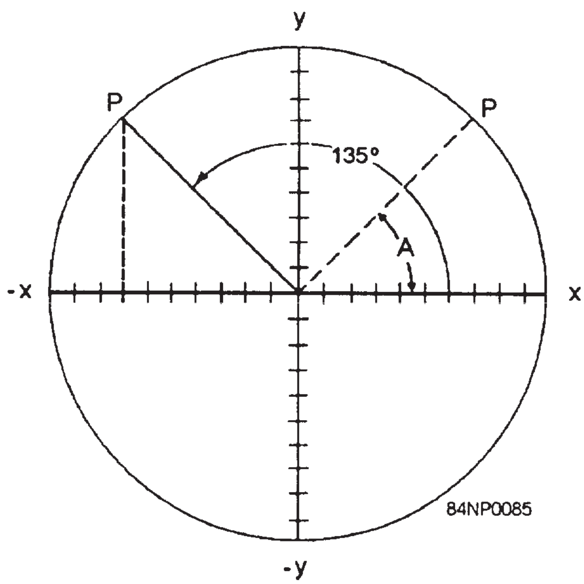

Figure 1-22.-Function of an obtuse angle.

can see that the values of x, y, and r are the same for 135° as they are for 45°, except that the value of x is negative. From this it follows that the functions of any obtuse angle are the same as the functions of its supplement, except that any function in which x appears has the opposite sign.

The sine of an angle is y/r. Since x does not appear in this function, it follows that sin A = sin (180° – A).

The cosine of an angle is fir. Since x appears in this function, it follows that cos A = - cos (180° – A).

The tangent of an angle is y/x. Since x appears in this function, it follows that tan A = – tan (180°- A).

The importance of knowing this lies in the fact that many tables of trigonometric functions list the functions only for angles to a maximum of 90°. Many oblique triangles, however, contain angles larger than 90°. To determine a function of an angle larger than 90° from a table that stops at 90°, you lookup the function of the supplement of the angle. If the function is a sine, you use it as is. If it is a cosine or tangent, you give it a negative sign.

The relationships of the function of obtuse angles are as follows:

$$\sin A = \sin (180° - A)$$

$$\cos A = -\cos (180° - A)$$

$$\tan A = -\tan (180° - A)$$

$$\cot A = -\cot (180° - A)$$

$$\sec A = -\sec (180° - A)$$

$$\csc A = \csc (180° - A)$$

The above relationships apply only when angle A is greater than 90° and less than 180°.

FUNCTIONS OF ANGLES IN A RIGHT TRIANGLE

For an acute angle in a right triangle, the length of the side opposite the angle corresponds to y and the length of the side adjacent to the angle corresponds to x, while the length of the hypotenuse corresponds to r. Therefore, the functions of an acute angle in a right triangle can be stated as follows:

$$\text{Sine} = \frac{\text{side opposition}}{\text{hypotenuse}} \qquad \text{Cosecant} = \frac{\text{hypotenuse}}{\text{side opposite}}$$

$$\text{Cosine} = \frac{\text{side adjacent}}{\text{hypotenuse}} \qquad \text{Secant} = \frac{\text{hypotenuse}}{\text{side adjacent}}$$

$$\text{Tangent} = \frac{\text{side opposite}}{\text{side adjacent}} \qquad \text{Cotangent} = \frac{\text{side adjacent}}{\text{side opposite}}$$

If you consider a 90° angle with respect to the “circle of unit radius” diagram, you will realize that for a 90° angle, x = 0, y = 1, and r (as always) equals 1. Since sine = y/r, it follows that the sine of 90° = 1. Since cosine = X/r, it follows that the cosine of 90° = 0/1, or 0. Since tangent= y/x, it follows that tan 90° = 1/0, or infinity (00). From one standpoint, division by 0 is a mathematical inpossibility, since it is impossible to state how many zeros there are in anything. From this standpoint, tan 90° is simply impossible. From another standpoint it can be said that there arc an “infinite” number of zeros in 1. From that standpoint, tan 90° can be said to be infinity.

In real life, the sides of a right triangle y, x, and r, or side opposite, side adjacent, and hypotenuse, are given other names according to the circumferences. In connection with a pitched roof rafter, for instance, y or side opposite is “total rise,” x or side adjacent is “total run,” and r or hypotenuse is “rafter length.” In connection with a ground slope, y or side opposite is “vertical rise,” x or side adjacent is “horizontal distance,” and r or hypotenuse is “slope distance.”

METHODS OF SOLVING TRIANGLES

To "solve" a triangle means to determine one or more unknown values (such as the length of a side or the size of an angle) from given known values. Here are some of the methods used.

Pythagorean Theorem

When you know the lengths of two sides of a right triangle, or its hypotenuse and one side, you can determine the length of the remaining side, or the length of the hypotenuse, by applying the Pythagorean theorem. The Pythagorean theorem states that the square of the length of the hypotenuse of any right triangle equals the sum of the squares of the lengths of the other two sides.

Figure 1-23 shows a right triangle with acute angles A and B and right angle C. Sides opposite A and B are designated as a and b; the hypotenuse (opposite C) is designated as c. Side a measures 3.00 ft, side b measures 4.00 ft, and the hypotenuse measures 5.00 ft. Any triangle with sides and hypotenuse in the ratio of 3:4:5 is a right triangle.

If $C^2 = a^2 + b^2$, it follows that $c = \sqrt{a^2 + b^2}$. The formulas for solving for either side, given the other side and the hypotenuse; or for the hypotenuse, given the two sides, are

$$a = \sqrt{c^2 - b^2}$$
$$b = \sqrt{c^2 - a^2}$$
$$c = \sqrt{a^2 + b^2}$$

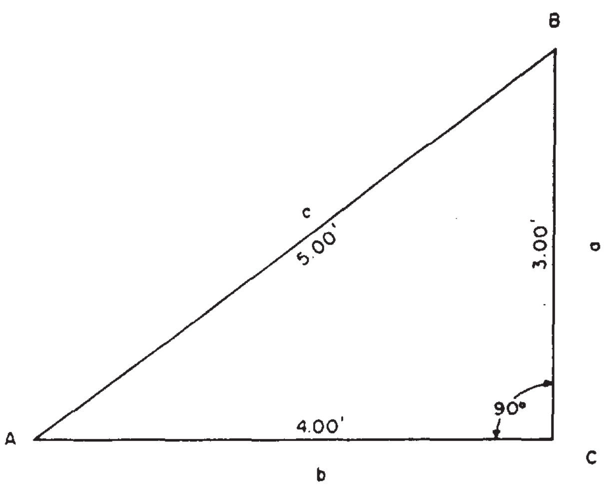

Figure 1-23.-A right triangle.

In figure 1-23, $a^2 = 9$, $b^2 = 16$, and $c^2 = 25$. Therefore, a = the square root of (25 − 16), or 3; b = the square root of (25 − 9), or 4; and c = the square root of (9 + 16), or 5.

Acute Angle of Right Triangle by Tangent

One of the angles in a right triangle always measures 900. Because the sum of the three angles in any triangle is always 180°, it follows that each of the other two angles in a right triangle must be an acute (less than 90°) angle. Also, if you know the size of one of the acute angles, you can determine the size of the other from the formulas A = (90° − B) and B = (90° − A).

In any right triangle in which you know the lengths of the sides, you can determine the size of either of the acute angles by applying the tangent of the angle. Take angle A in figure 1-23, for example. You know that

$$\tan A = \frac{a}{b}, \text{ or } \frac{3.00}{4.00}, \text{ or } 0.75.$$

Reference to a table of natural tangents shows that an angle with tangent 0.75 measures to the nearest minute, 36°52'.

Side of Right Triangle by Tangent

If you know the length of one of the sides of a right triangle and the size of one of the acute angles, you can determine the length of the other side by applying the tangent. Suppose that for the triangle shown in figure 1-23 you know that angle A measures 36°52' and that side b measures 4.00 ft. You want to determine the length of side a. Since

$$\tan A = \frac{a}{b},$$

it follows that a = b (tan A). From a table o natural tangents you find that tar 36°52′ = 0.74991. Therefore,

$$a = 4.00(0.74991), \text{ or } 3.00 \text{ ft}.$$

Side of Right Triangle by Cotangent

Suppose that for the triangle shown in figure 1-23, you know that angle B measures 53°08′ and that side a measures 3.00 ft. You want to determine the length of side b. You could do this as previously described by applying

$$\tan B = \frac{b}{a}.$$

However, the fact that side b is larger than side a means that tan B is larger than 1 (you recall that any angle larger than 45° has a tangent larger than 1).

You know that the cotangent is the reciprocal function of the tangent. Therefore, if

$$\tan B = \frac{b}{a}, \cot B = \frac{a}{b},$$

it follows that

$$b = \frac{a}{\cot B}.$$

A table of natural functions tells you that cot 53°08' = 0.74991. Therefore,

$$b = \frac{3}{0.74991}, \text{ or } 4.00.$$

Acute Angle of Right Triangle by Sine or Cosine

If you know the length of the hypotenuse and length of a side of a right triangle, you can determine the size of one of the acute angles by applying the sine or the cosine of the angle. Suppose that for the triangle shown in figure 1-23, you know that the hypotenuse, c, is 5.00 ft long and that the length of side a is 3.00 ft long. You want to determine the size of angle A. Side a is opposite angle A; therefore,

$$\sin A = \frac{a}{c}, \text{ or } \frac{3}{5}, \text{ or } 0.6.$$

A table of natural functions tells you that an angle with sine 0.6 measures (to the nearest minute) 36°52'.

Suppose that, instead of knowing the length of a, you know the length of b (4.00 ft). Side b is the side adjacent to angle A. You know that

$$\cos A = \frac{b}{c}, \text{ or } \frac{4}{5}, \text{ or } 0.8.$$

A table of natural functions tells you that an angle with cosine 0.8 measures 36°52'.

If you know the size of one of the acute angles in a right triangle and the length of the side opposite, you can determine the length of the hypotenuse from the sine of the angle. Suppose that for the triangle shown in figure 1-23, you know that angle A = 36°52' and side a = 3.00 ft.

$$\text{Sin } A = \frac{a}{c}; \text{ therefore, } c = \frac{a}{\sin A}, \text{ or } \frac{3}{0.6}, \text{ or } 5.00 \text{ ft.}$$

If you know the size of one of the acute angles in a right triangle and the length of the side adjacent, you can determine the length of the hypotenuse from the cosine of the angle. Suppose that for the triangle in figure 1-23, you know that angle A = 36°52' and side b = 4.00 ft.

$$\text{Cos } A = \frac{b}{c}; \text{ therefore, } c = \frac{b}{\cos A}.$$

Tables show that cos 36°52' = 0.80003. Therefore,

$$c = \frac{4.00}{0.80003}, \text{ or } 5.00 \text{ ft.}$$

Solution by Law of Sines

For any triangle (right or oblique), when you know the lengths of two sides and the size of the angle opposite one of them, or the sizes of two angles and the length of the side opposite one of them, you can solve the triangle by applying the law of sines. The law of sines (which is explained and proved in NAVPERS 10071-B, chapter 5) states that the lengths of the sides of any triangle are proportional to the sines of their opposite angles. It is expressed in formula form as follows:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

In the triangle shown in figure 1-24, $\angle A$ = 41°24', a = 8.00 ft, and b = 12.00 ft. If

$$\frac{b}{\sin B} = \frac{a}{\sin A},$$

it follows that

$$\sin B = \frac{b \sin A}{a}.$$

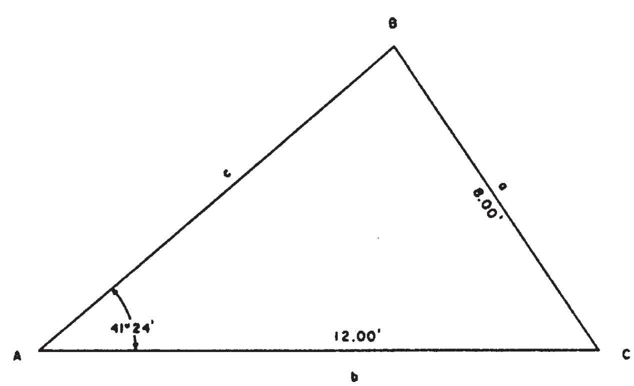

Figure 1-24.—Oblique triangle (law of sines).

The sine of 41°24′ is 0.66131; therefore,

$$\sin B = \frac{12(0.66131)}{8}, \text{ or } 0.99196.$$

Tables show that the angle with sine 0.99196 measures 82°44′. Therefore, $\angle B$ = 82°44′. $\angle C$ = 180° − (A + B), or 180° − (41°24′ + 82°44′), or 180° − 124°08, or 55°52′.

If $\frac{c}{\sin C} = \frac{a}{\sin A}$, then $c = \frac{a \sin C}{\sin A}$. The sine of 55°52′ is 0.82773. Therefore,

$$c = \frac{8(0.82773)}{9.66131}, \text{ or } 10.01 \text{ ft.}$$

Solution by Laws of Cosines

Suppose you know two sides of a triangle and the angle between the two sides. You cannot solve this triangle by the law of sines, since you do not know the length of the side opposite the known angle or the size of an angle opposite one of the known sides. In a case of this kind you must begin by solving for the third side by applying the law of cosines. The law of cosines is explained and proved in chapter 5 of NAVPERS 10071-B. If you are solving for a side on the basis of two known sides and the known included angle, the law of cosines states that in any triangle the square of one side is equal to the sum of the squares of the other two sides minus twice the product of these two sides multiplied by the cosine of the angle between them. This statement may be expressed in formula form as follows:

$$a^2 = b^2 + c^2 - 2bc \cos A$$

$$b^2 = a^2 + c^2 - 2ac \cos B$$

$$c^2 = a^2 + b^2 - 2ab \cos C$$

For the triangle shown in figure 1-25, you know that side c measures 10.01 ft; side b, 12.00 ft; and angle A (included between them), 41°24'. The cosine of 41°24' is 0.75011. The solution for side a is as follows:

$$a = \sqrt{b^2 + c^2 - 2bc \cos A}$$

$$a = \sqrt{144 + 100.20 - 2(12)(10.01)(0.75011)}$$

$$a = \sqrt{244.20 - 180.20}$$

$$a = \sqrt{64}$$

$$a = 8.00 \text{ ft}$$

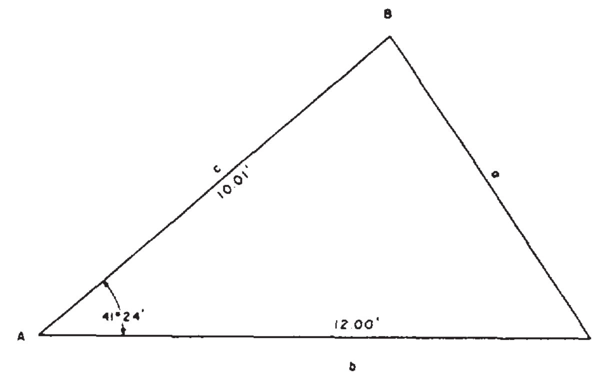

Figure 1-25.-Oblique triangle (law of cosines).

Knowing the length of this side, you can now solve for the remaining values by applying the law of sines.

If you know all three sides of a triangle, but none of the angles, you can determine the size of any angle by the law of cosines, using the following formulas:

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

$$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$$

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$$

For the triangle shown in figure 1-26, you know all three sides but none of the angles. The solution for angle A is as follows:

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

$$\cos A = \frac{144 + 100.20 - 64}{2(12)(10.01)}$$

$$\cos A = \frac{180.20}{240.24}$$

$$\cos A = 0.75008$$

The angle with cosine 0.75008 measures (to the nearest minute) 41°24.

Solution by Law of Tangents

The law of tangents is expressed in words as follows: In any triangle the difference between two sides is to their sum as the tangent of half the difference of the opposite angles is to the tangent of half their sum.

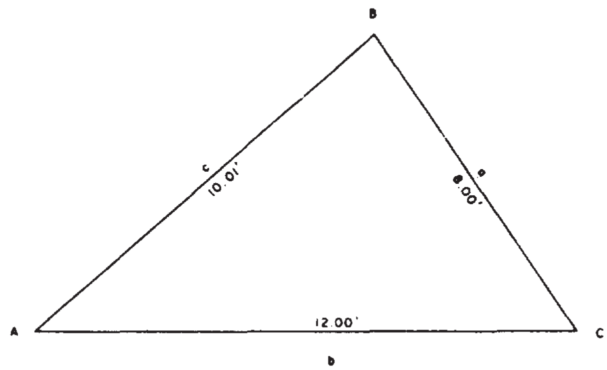

Figure 1-26.-Any triangle, three sides given.

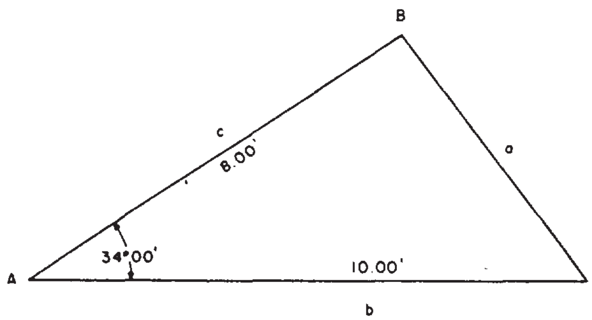

Figure 1-27.-Oblique triangle (law of tangents).

For any pair of sides—as side a and side b—the law may be expressed as follows:

$$\frac{a - b}{a + b} = \frac{\tan 1/2\,(A - B)}{\tan 1/2\,(A + B)}$$

For the triangle shown in figure 1-27, you know the lengths of two sides and the size of the angle between them. You can determine the sizes of the other two angles by applying the law of tangents as follows.

First note that you can determine the value of angles (B + C), because (B + C) obviously equals 180° – A, or 180° – 34°, or 146°. Now, if you know the sum of two values and the difference between the same two, you can determine each of the values as follows:

$$\begin{aligned} x + y &= 5 \\ x - y &= 1 \\ \text{(add) } 2x &= 6 \\ x &= 3 \\ y &= 5 - x \\ y &= 2 \end{aligned}$$

Now, you know the sum of (B + C). Therefore, if you could determine the difference, or (B – C), you could determine the sizes of B and C You can determine 12(B — C) from the law of tangents, written as follows:

$$\tan \frac{1}{2}(B - C) = \frac{(b - c)\tan \frac{1}{2}(B + C)}{b + c}$$

One-half of (B + C) means one-half of 146°, or 73°. The tangent of 730 is 3.27085. The solution for 12(B – C) is therefore as follows:

$$\tan \frac{1}{2}(B - C) = \frac{(10 - 8)(3.27085)}{10 + 8}$$

$$\tan \frac{1}{2}(B - C) = \frac{6.54170}{18} = 0.36342$$

(from table of natural tangents) 1/2 (B - C) = 19°58' (B – C) = 2(19058') = 39°56'

Knowing both the sum (B + C) and the difference (B – C), you can now determine the sizes of B and C as follows:

$$\begin{aligned} B + C &= 146°00' \\ B - C &= 39°56' \\ 2B &= 185°56' \\ B &= 92°58' \\ C &= (146° - 92°58') = 53°02' \end{aligned}$$

The Ambiguous Case

When the given data for a triangle consists of two sides and the angle opposite one of them, it may be the case that there are two triangles that conform to the data. A situation in which there can be two triangles is called the ambiguous case. Figure 1-28 shows two possible triangles that

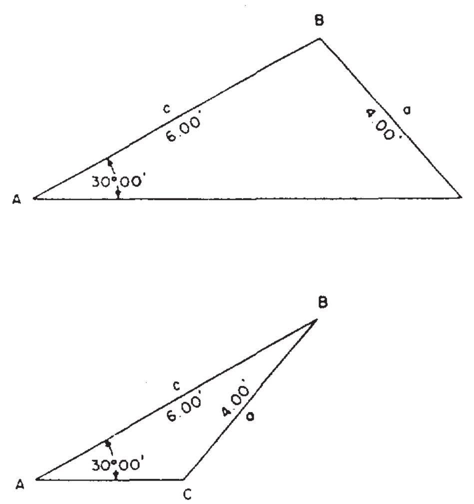

Figure 1-28.-Two ambiguous case triangles (solution of one will satisfy the other).

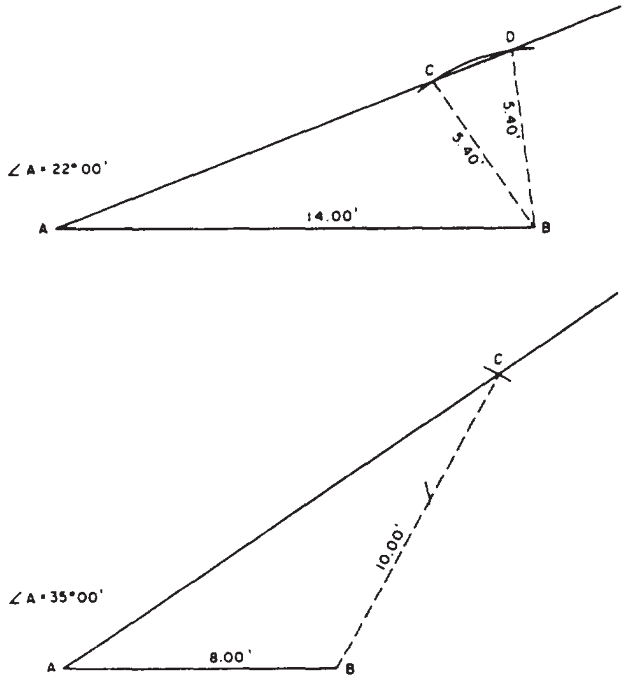

Figure 1-29.-Comparison of an ambiguous case triangle to a standard triangle.

might satisfy this situation. Both triangles shown are with given angle A = 30°00′, given side a = 4.00 ft, and given side c = 6.00 ft.

The best way to determine whether or not the given data for a triangle involves an ambiguous case is to lay out a figure to scale on the basis of the data, as shown in figure 1-29. Suppose, for example, that the data describes a triangle with angle A = 22°00'; side opposite, 5.40 ft; and other side, 14.00 ft. Lay off a line, AB, 14.00 ft long (to scale, of course), as shown in the upper triangle of figure 1-29. Use a protractor to lay off a line from A at 22°00'. Set a compass to the graphical distance of 5.40 ft (length of side opposite A) and with B as a center, strike an arc. You observe that this arc intersects the line from A at two places. Therefore, the triangle ACB and the triangle ADB both satisfy the data, and you have an ambiguous case.

Suppose now that the data describes a triangle with angle A = 35°00′; side opposite, 10.00 ft; and other side, 8.00 ft. Lay off the line AB 8.00 ft long as shown in the lower triangle of figure 1-29, and lay off a line from A at 35°00', Set a compass to 10.00 ft (length of side opposite A) and with B as a center, strike an arc. This arc will intersect the line from A at only one point. Therefore, only one triangle satisfies the data.

Determination of Angle from Three Known Sides

There are several formulas for determining the size of an angle in a triangle from three known sides. The most convenient involves the versed sine of the angle, which means (1 -cos) of the angle. The formula goes as follows:

$$1 - \cos A = \frac{2(s - b)(s - c)}{bc}$$

$$1 - \cos B = \frac{2(s - a)(s - c)}{ac}$$

$$1 - \cos C = \frac{2(s - a)(s - b)}{ab}$$

The value s means one-half the sum of sides a, b, and c, or

$$s = \frac{a + b + c}{2}.$$

For the triangle shown in figure 1-30, you would determine the size of angle A as follows:

$$s = \frac{10.00 + 12.00 + 15.00}{2} = \frac{37.00}{2} = 18.50$$

$$1 - \cos A = \frac{2(18.50 - 15)(18.50 - 10)}{(15)(10)}$$

$$= \frac{2(3.50)(8.50)}{150}$$

$$1 - \cos A = \frac{59.50}{150} = 0.39667$$

$$\cos A = 1 - 0.39667 = 0.60333$$

The angle with cosine 0.60333 measures (to the nearest minute) 52°53′.

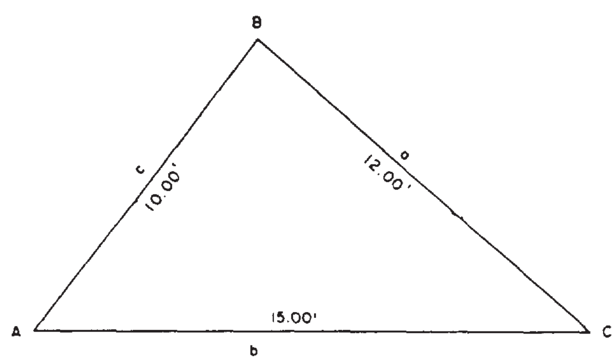

Figure 1-30.—Oblique triangle with three sides given and solved by versed sine formula.

Trigonometric Determination of Area

If you know all three sides of a triangle, you can determine the area by applying the following formula:

$$\text{area} = \sqrt{s(s-a)(s-b)(s-c)}$$

Where s = 1/2 perimeter of a triangle

For the triangle shown in figure 1-30, the area computation is

$$\text{area} = \sqrt{18.50(18.50-12.00)(18.50-15.00)(18.50-10.00}$$

$$\text{area} = \sqrt{18.50(6.50)(3.50)(8.50)}$$

$$\text{area} = \sqrt{3577.44}$$

area = 59.81 sq ft

When you know two sides of a triangle and the angle included between them, you can determine the area by applying, appropriately, one of the following formulas:

area = 1/2bc sin A

area = 1/2ac sin B

area = 1/2ab sin C

In figure 1-31, two sides, b = 13.00 ft and c = 9.00 ft, and the included angle, A = 40°00´, are given. The sine of 40°00´ is 0.64279. The area computation is as follows:

area = 1/2 bc sin A

area = 1/2(13.00)(9.00)(0.64279)

area = 58.50(0.64279)

area = 37.60 sq ft

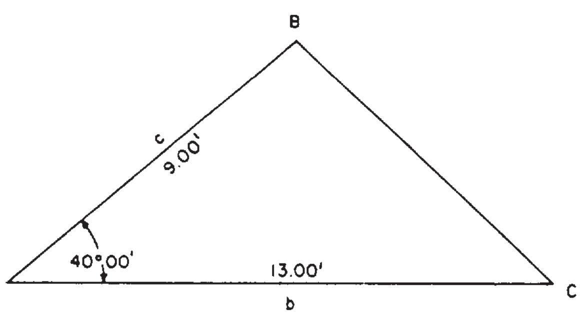

Figure 1-31.-Area of a triangle with two sides and one angle given.

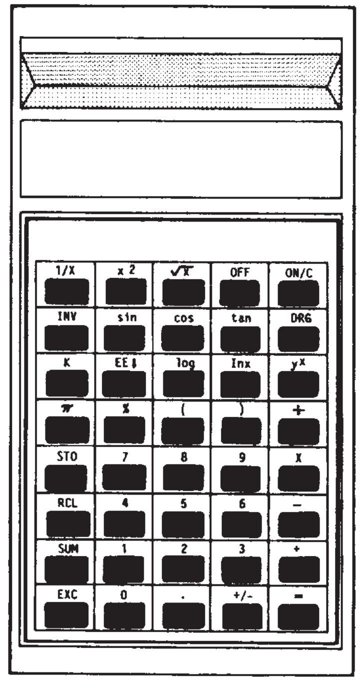

Figure 1-32.-Scientific pocket calculator.

SCIENTIFIC POCKET CALCULATOR

Figure 1-32 illustrates a typical pocket calculator that replaces the slide rule, logarithm tables, and office adding machine. This tool, packed with the latest in state-of-the-art solid-state technology, is a great asset for our trade. With it we can handle many problems quickly and accurately without having to hassle with lengthy, tedious computations. This tool should serve us faithfully for a long time if we treat it with respect and care.

Today's hand-held calculators have become an everyday part of our lives. Rugged and inexpensive, they're a practical answer to the real need we all have for quick, accurate calculations.

THE KEYBOARD

Your calculator has many features to make calculations easy and accurate. To allow you to use all of these features without crowding the keyboard, the designer has caused some of the keys to have more than one function. If you look closely at the keyboard, you'll notice that the keys in the column on the left side have two function symbols. These keys are called dual-function keys because they perform two functions. If you want to perform one of the first functions, simply press the key. To perform one of the second functions, you'll need to press the [2nd] key and then press the key for the function you wish to perform.

INSTRUCTION MANUAL

Every calculator on the market should have an instruction manual enclosed with it. Check out all the features and functions summarized in the instruction manual to become familiar with what your calculator will (and will not) do for you.

HINTS ON COMPUTING

It is a general rule that when you are expressing dimensions, you express all dimensions with the same precision. Suppose, for example, you have a triangle with sides 15.75, 19.30, and 11.20 ft long. It would be incorrect to express these as 15.75, 19.3, and 11.2 ft, even though the numerical values of 19.3 and 11.2 are the same as those of 19.30 and 11.20.

It is another general rule that it is useless to work computations to a precision that is higher than that of the values applied in the computations. Suppose, for example, you are solving a right triangle for the length of side a, using the Pythagorean theorem. Side b is given as 16.5 ft, and side c, as 20.5 ft. By the theorem you know that side a equals the square root of $(20.5^2 - 16.5^2)$, or the square root of 148.0. You could carry the square root of 148.0 to a large number of decimal places. However, any number beyond two decimal places to the right would be useless, and the second number would be determined only for the purpose of rounding off the first.

The square root of 148.0, to two decimal places, is 12.16. As the 0.16 represents more than one-half of the difference between 0.10 and 0.20, you round off at 0.2, and call the length of side a 12.2 ft. If the hundredth digit had represented less than one-half of the difference between 0.10 and 0.20, you would have rounded off at the lower tenth digit, and called the length of side a 12.1 ft.

Suppose that the hundredth digit had represented one-half of the difference betwveen 0.10 and 0.20, as in 12.15. Some computers in a case of this kind always round off at the lower figure, as, 12.1. Others round off at the higher figure, as 12.2. Better balanced results are usually obtained by rounding off at the nearest even figure. By this rule, 12.25 would round off at 12.2, but 12.35 would round off at 12.4.

UNITS OF MEASUREMENT

Engineering science would not be so precise as it is today if it did not make use of systems of measurement. In fieldwork, drafting, office computation, scheduling, and quality control, it is important to be able to measure accurately the magnitudes of the various variables necessary for engineering computations, such as directions, distances, materials, work, passage of time, and many other things.

The art of measuring is fundamental in all fields of engineering and even in our daily lives. We are familiar, for instance, with "gallons," which determines the amount of gasoline we put in our car and with "miles," which tells us the distance we have to drive to and from work. It is also interesting to note that the development of most of these standard units of measure parallels the development of civilization itself, for there has always been a need for measurement. In the early days, people used night and day and the cycle of the four seasons as their measure of time. The units of linear measure were initially adopted as comparison to the dimensions of various parts of a man's body. For example, a "digit" was at that time the width of a man's middle finger, and a "palm" was the breadth of an open hand. The same applies to most other units of linear measure that we know today—like the "foot," the "pace," and the "fathom." The only difference between today's units of measure and those of olden days is that those of today are standardized. It is with the standard types of measurements that we are concerned in this training manual.

At present, two units of measurement are used throughout the world. They are the English system and the metric system, Many nations use the metric system.

The metric system is the most practical method of measurement, for it is based on the decimal system, in which units differ in size by multiples of tens, like the U.S. monetary system in which 10 mills equal 1 cent; 100 mills or 10 cents equal 1 dime; and 1,000 mills, 100 cents, or 10 dimes equal one dollar. When we perform computations with multiples of 10, it is convenient to use an exponential method of expression as you may recall from your study of mathematics.

Table 1-1.-Linear Conversion Factors

	Inches	Feet	Yards	Statute miles	Centimeters	Meters	Kilometers
Inch	1	.083333	.0277		2.540005	.0254	
Foot	12	1	.333		30.48006	0.304801	
Yard	36	3	1	.000568	91.44018	.914402	.000914
Statute mile	63,360	5280	1760	1		1609.347	1.609347
International nautical mile		6076.10	2025.36	1.150777			
United States nautical mile		6080.20	2026.73	1.151553			
Centimeter	.3937				1	.01	
Meter	39.37	3.280833	1.093611		100	1	.001
Kilometer				0.62137		1000	1
Decimeter	3.937	.328				.1	
Decameter	393.7	32.8				10	
Hectometer		328'-1"					.1
Myriameter				6.213712			10

A unit of measurement is simply an arbitrary length, area, or volume, generally adopted and agreed upon as a standard unit of measurement. The basic standard for linear measurement, for example, is the meter, and the actual length of a meter is, in the last analysis, equal to the length of a bar of metal called the International Meter Bar, one replica of which is kept in the National Bureau of Standards, Washington, D.C.

As an EA, you will not necessarily be working with all the units described in this chapter, and therefore need not attempt to memorize them all. Many are included simply to show that units are arbitrary and that there are many different kinds of units in use.

UNITS OF LINEAR MEASUREMENT

Linear measure is used to express distances and to indicate the differences in their elevations. The standard units of linear measure are the foot and the meter. In surveying operations, both of these standard units are frequently divided into tenths, hundredths, and thousandths for measurements. When longer distances are involved, the foot is expanded into a statute or to a nautical mile and the meter into a kilometer. Table 1-1 shows the conversion factors for the common linear measurements.

English Units

In the English system, the most commonly used basic unit of linear measurement is the foot, a unit that amounts to slightly more than three-tenths of the international meter. In what is called ENGINEER'S measurement, the foot is subdivided decimally; that is, into tenths, hundredths, or thousandths of a foot. In what is called CARPENTER'S measurement, or English units, the foot is subdivided into twelfths called inches, and the inch is further subdivided into even-denominator fractional parts, as 1/2 in., 1/4 in., 1/8 in., and so on.

Fractions or multiples of the basic 1-ft unit are used to form larger units of linear measure as follows:

1 link	=	0.66 ft
1 yard	=	3.00 ft
1 rod, pole, or perch	=	16.50 ft
1 Gunter's chain	=	66.00 ft
1 engineer's chain	=	100.00 ft
1 statute mile U.S.	=	5,280.00 ft
1 nautical mile (international)	=	6,076.10 ft

A unit of linear measurement, called a VARA of Spanish and Portuguese origin, was formerly used to measure land boundaries in those areas of the United States that were at one time under Spanish control. In those areas old deeds and other land instruments still contain property descriptions in varas, which vary from state to state and country to country from 32 to 43 in.

Metric Units

In many of the non-English-speaking countries of the world, the most commonly used basic unit of linear measure is the meter. The length of a meter was originally designed to equal (and does equal very nearly) one ten-millionth part of the distance, measured along a meridian, between the earth's equator and one of the poles. A meter equals slightly more than 1.09 yd.

The big advantage of the metric system is the fact that it is a decimal system throughout; that is, the fact that the basic unit can be both subdivided into smaller units decimally and converted to larger units decimally by simply moving the decimal point in the appropriate direction. Names of units smaller than the meter are indicated by the Latin prefixes deci- (one-tenth), centi- (one-hundredth), mini- (one-thousandth), and micro- (one-millionth), as follows:

1 decimeter = 0.1 meter (1×10^{-1})

1 centimeter = 0.01 meter (1×10^{-2})

1 millimeter = 0.001 meter (1×10^{-3})

1 micrometer = 0.000001 meter (1×10^{-6})

Names of units larger than the meter are indicated by the Greek prefixes deca- (ten), hecto- (one hundred), kilo- (one thousand), myria- (ten thousand), and mega- (one million), as follows:

1 decameter = 10.00 meters (1×10)

1 hectometer = 100.00 meters (1×10^{2})

1 kilometer = 1,000.00 meters (1×10^{3})

1 myriameter = 10,000.00 meters (1×10^{4})

1 megameter = 1,000,000.00 meters (1×10^{6})

UNITS OF AREA MEASUREMENT

In the English and metric system, area is most frequently designated in units that consist of squares of linear units, as square inches, feet, yards, or miles; or square centimeters, meters, or kilometers. In the English system, the land-area measurements most commonly used are the square foot and the acre. Formerly the square rod (1 rod = 16.5 ft) and the square Gunter's chain (1 Gunters's chain = 66 ft) were used. One of the area measurements, with its equivalents, is as follows:

1 acre = 10 sq Gunter's chains

= 160 sq rods

= 43,560 sq ft

An equilateral rectangular (square) acre measures 208.71 ft on a side. There are 640 acres in a square mile.

Other area equivalents that may be of value to you are as follows:

1 square inch (sq in.) = 6.4516 + square centimeters (sq cm)

1 square foot (sq ft) = 144 sq in.

= 0.0929 + square meter (sq m)

1 square yard (sq yd) = 9 sq ft

= 0.8361 − sq m

1 square meter (sq m) = 10.7639 sq ft

= 1.1960 + sq yd

Actually, more attention should be given to linear equivalents. If you know the linear conversion factor from one unit to the other, you can always compute for any equivalent area or even volume. Just remember, area is expressed in square units and volume is expressed in cubic units.

Example: Find the area of a rectangle 2 ft by 3 ft in square inches.

Area = 2 ft x 3 ft = (2 x12)(3 x 12) = 864 sq in.

UNIT OF VOLUME MEASUREMENT

From your study of mathematics, you learned that volume is the measure of the amount of space that matter occupies. It is expressed in certain cubic units, depending upon the linear measurements or dimensions of the object.

As an EA, you will find that your interest in unit volume of measurements will be from the standpoint of earthwork, construction materials, material testing, rainfall runoff, and capacities of structures, such as, for example, a reservoir. The accuracy of your computations will depend upon your knowledge of the correct conversion factors and the units used. Remember that your dimensions must always be expressed in one kind of unit of measure; for instance, if you are using the meter, all dimensions must be in meters. The basic units of volume that you might be using are as follows:

1 cubic inch (cu in.) = 16.3872 cubic centimeters (cc)

1 cubic foot (cu ft) = 1,728 cu in. = 0.0283 cubic mete (cu m)

1 cubic yard (cu yd) = 27 cu ft = 0.7646 cubic meter

1 cubic meter (cu m) = 1,000,000 cc = 35.3145 cu ft

= 1.3079 cu yd

1 U.S. gallon = 231 cu in.

1 cu ft = 7.4805 gal

1 acre ft = 43,560 cu ft

= 1,233.49 cu m

UNITS OF WEIGHT

The units of weight most frequently used in the United States for weighing all commodities except precious stones, precious metals, and drugs are the units of the so-called AVOIRDUPOIS system. Avoirdupois units of weight are as follows:

437 1/2 grains (gr) = 1 ounce (oz)

16 ounces (oz) = 1 pound (lb)

100 pounds (lb) = 1 hundred-weight (c

1,000 pounds (lb) = 1 kip (K)

2,000 pounds (or 20 cwt) = 1 short ton (T)

2,200 pounds (lb) = 1 long ton

Precious stones and precious metals are usually weighed in the United States by the system of TROY weight, in which there are 12, rather than 16, oz in the pound. Drugs are weighed by APOTHECARIES' weight, in which there are also 12 oz in the pound.

The basic unit of the metric system of weight is the GRAM, which contains 15.432 grains. The GRAIN was originally supposed to be equal to the weight of a single grain of wheat, The gram of 15.432 grains is also used in the avoirdupois, troy, and apothecaries' system of weights.

Multiples and subdivisions of the basic unit of metric weight (the gram) are named according to the usual metric system of nomenclature, as follows:

0.000001 g = 1 microgram

0.001 g = 1 milligram

0.01 g = 1 centigram

0.10 g = 1 decigram

10.00 g = 1 decagram

100.00 g = 1 hectogram

1,000.00 g = 1 kilogram

A METRIC TON equals 1,000 kilograms, which equals 1.1 short tons.

The Engineering Aid is interested in the weight of his instruments and the pull to be applied to the ends of the tape to give correct linear measurements. The common units of weight in surveying are the OUNCE, the POUND, the GRAM, and the KILOGRAM. The following tabulation gives the relationship between these units:

1 ounce (oz) = 28.3495 grams (g)

1 pound (lb) = 453.5924 g = 0.4536 kg

1 kilogram (kg) = 2.2045 lb = 35.27 oz

UNITS OF ANGULAR MEASUREMENT

ANGULAR or CIRCULAR MEASURE is used for designating the value of horizontal and vertical angles. For general use in the measurement of angles, the circumference of the circle is divided into some even number of equal parts. The unit of angular measure is the angle at the center of the circle subtended by one of the small subdivisions of the circumference. The various units of angular measure are known as UNITS OF ARCS. In practice these units of arcs may be further expressed in decimal or fractional parts.

The Engineering Aid may encounter three systems of angular measure in the use of surveying instruments. They are the sexagesimal, the centisimal or metric, and the mil system.

Sexagesimal or North American System

In the sexagesimal or North American system, the circle is divided into 360 equal parts known as DEGREES of arc, each degree into 60 equal parts known as MINUTES of arc, and each minute into 60 equal parts known as SECONDS of arc. As an example, angles in this system are written as 263047’16”.48 which is read as “two hundred sixty-three degrees, forty-seven minutes, and sixteen point four eight seconds of arc.” In the United States, this is the most commonly used system of angular measurement.

Centisimal or Metric System

In the centisimal or metric system, the full circle is divided into four quadrants, and each quadrant is divided into 100 equal parts known as GRADS or GRADES. Each grad is further divided into decimal parts. As an example, angles in this system are written as $376^g.7289$, or $376^g72'89''$ which is read as “three hundred seventy-six point seven two eight nine grads,” or as “three hundred seventy-six grads, seventy-two centisimal minutes, and eighty-nine centisimal seconds.”

Mil System

In the mil system, the circle is divided into 6,400 equal parts known as MILS. The mil is divided into decimal parts. As an example, angles in this system are written as 1728.49 roils, which is read as “one thousand seven hundred twenty-eight point four nine mils.” This system is used principally by the artillery people. The significance of this unit of angular measure is the fact that 1 mil is the angle that will subtend 1 yd at a range of 1,000 yd.

The relationship among values in the three systems of angular measure are as follows:

1 circle = 360 degrees = 400 grads = 6,400 mils

1 degree = 1.1111 grads = 17.7778 mils

1 minute = 0.2963 mils

1 grad = 0.9 degree = $0°54'00''$ = 16 mils

1 mil = 0.0562 degree = $0°03'22''.5$ or 3.3750 minutes

= 0.0625 grad

MORE UNITS OF MEASUREMENT

Aside from the units of measurement discussed above, the EA must also deal with other units of measurement, such as TIME, TEMPERATURE, PRESSURE, and so forth. He must use exact time in computing problems in astronomy and some laboratory works. He must be able to apply temperature corrections to his tape readings. He must also evaluate the effect of atmospheric pressure at different elevations and get involved in some other types of measure that will be discussed in the following paragraphs.

Time Measurement

For practical purposes in everyday affairs and in surveying, the measurement of time intervals is of great concern. The time used in everyday life is known as STANDARD TIME and is based on the mean apparent revolution of the sun around the earth because of the earth’s rotation on its axis. Standard time is used in surveying to regulate the normal day’s operations. But, when it is necessary to observe the sun or the stars to determine the azimuth of a line or the position of a point on the earth’s surface, the surveyor uses three other kinds of time. They are APPARENT (true) SOLAR TIME, CIVIL (mean solar) TIME, and SIDEREAL (star) TIME. You will learn more about these different times when you study the chapter on “Geodesy and Field Astronomy” in *Engineering Aid 1 & C*.

In all four kinds of time, the basic units of measure are the YEAR, DAY, HOUR, MINUTE, and SECOND of time. The duration of any one of these units is not the same for all kinds of time. For example, the sidereal day is approximately 4 min shorter than a standard- or civil-time day.

In the practice of surveying, it is customary to say, or write, the time of day as the number of hours, minutes, and seconds since midnight. Then the recorded time would appear, for example, as $16^h37^m52^s.71$ which is read as “sixteen hours, thirty-seven minutes, and fifty-two point seven one seconds of time.”

Units of time measure are sometimes used to designate the sizes of angles. The longitude of a point on the earth’s surface is often expressed in this manner. The relationship between the units of time measure and the units of angular measure in the sexagesimal system are as follows:

1 hour = 15 degrees ($1^h = 15°$)

1 minute of time = 15 minutes of arc ($1^m = 15'$)

1 second of time = 15 seconds of arc ($1^s = 15''$)

1 degree = 4 minutes of time ($1° = 4^m$)

1 minute of arc = 4 seconds of time ($1' = 4^s$)

1 second of arc = 0.0667 second of time ($1'' = 0.0667^s$

Temperature Measurement

In certain types of measurement, when the existing temperature differs from a standard temperature, the measured values will be in error and must be corrected, In each of the several temperature-measurement scales, the unit of measure is called a DEGREE, which varies for the different temperature scales, When the scale extends below zero, values below zero are identified by a minus sign. Temperatures are written, for example, as 23°F or – 5°C, the letter designating the particular temperature scale. To avoid confusion when writing or talking about temperature, we should always be sure to indicate the type of scale used, Two of the most commonly used temperature scales are the CENTIGRADE scale and the FAHRENHEIT scale.

On the Centigrade scale (also known internationally as "Celsius Scale" after Anders Celsius, a Swedish astronomer who first devised it), zero is the freezing point of water, and plus 100 is its boiling point.

On the Fahrenheit scale, the temperature of the freezing point of water is plus 32°, and its boiling point is plus 212°.

Now let us compare these scales. A Fahrenheit degree represents five-ninths of the change in heat intensity indicated by a degree on the Centigrade scale. Temperatures on either of the two scales can be converted to the other by the following formulas:

Degrees C = 5/9 (degrees F – 32°,

Degrees F = (9/5 degrees C) + 32°

Note that, when converting Fahrenheit to Centigrade, you should first subtract the 32°, then multiply by 5/9. When converting Centigrade to Fahrenheit, you should first multiply by 9/5, then add the 32°.

Pressure Measurement

Measurements of atmospheric pressure are used in surveying to determine approximate differences in elevation between points on the earth's surface and to determine the best approximate correction for the effect of atmospheric refraction. The units of measure for atmospheric pressure and their relationships are as follows:

1 atmosphere = 29.9212 inches of mercury

= 760 millimeters of mercury

= 14.6960 pounds per square inch

= 1,03323 kilograms per square centimeter

= 33.899 feet of water

= 1.01325 bars, or 1013.25 millibars

Dry Measure

Dry measure is a system of measure of volume used in the United States for dry commodities, such as grains, fruits, and certain vegetables. The basic unit in dry measure is the BUSHEL. The standard U.S. bushel contains about 77.6 lb of water. Since there are about 62.4 lb of water in a cu ft, it follows that a U.S. bushel has a volume of

$$\frac{77.6}{62.442}, \text{ or about } 1\ 1/4 \text{ cu ft.}$$

Units of dry measure are as follows:

1 bushel = 4 pecks

1 peck = 8 quarts

1 quart = 2 pints

Board Measure

Board measure is a method of measuring lumber in which the basic unit is a BOARD FOOT (bf). A board foot is an abstract volume 1 ft long by 1 ft wide by 1 inch thick. The chief practical use of board measure is in cost calculations; lumber is sold by the board foot just as sugar is sold by the pound.

There are several formulas for calculating the number of board feet in any given length of lumber of given section dimensions. Because lumber dimensions are most frequently given by length in feet and width and thickness in inches, the following formula is probably the most practical:

$$\text{bf} = \frac{\text{thickness in in.} \times \text{width in in.} \times \text{length in ft}}{12}$$

Board measure is calculated on the basis of the nominal, not the actual, section dimensions. The actual section dimensions of (for example) 2 by 4 stock, which is surfaced on all four surfaces (S4S), are about 1 5/8 in. thick by 3 5/8 in. wide. Nevertheless, the computation for the number of (for example) 300 linear ft of 2 by 4 stock would be as follows:

$$\frac{\overset{1}{\cancel{2}} \times \overset{2}{\cancel{4}} \times \overset{100}{\cancel{300}}}{\cancel{12}\ \rightarrow \cancel{6} \rightarrow \cancel{3} \rightarrow 1} = 200 \text{ bf}$$

Liquid Measure

In the United States the basic unit of liquid measure is the GALLON, which has a volume of 231 cu in. or 0.13 cu ft. The gallon is subdivided into smaller units as follows:

1 gallon = 4 quarts

1 quart = 2 pints

1 pint = 4 gills

Units larger than the gallon in liquid measure are as follows:

1 barrel = 31.5 gallons

1 hogshead = 63 gallons or 2 barrels

For petroleum products the standard barrel contains 42 gallons.

In the metric system the basic unit of liquid measure is the LITER, equal in volume to a cubic decimeter, or about 61 cu in. There are 3.785 liters in a U.S. gallon.

Following the usual metric system of nomenclature, subdivisions and multiples of the liter are as follows:

0.000001 liter = 1 microliter

0.001 liter = 1 milliliter

0.01 liter = 1 centiliter

0.10 liter = 1 deciliter

10.00 liter = 1 decaliter

100.00 liter = 1 hectoliter

1,000.00 liter = 1 kiloliter

Electrical Measure

In an electrical circuit there is a flow of electrons, roughly similar to the flow of water in a water pipe. The flow is occasioned by the production, at a generating station, battery, or other source, of an ELECTROMOTIVE FORCE (E), roughly similar to the "head" of water in a water system. The size of the electromotive force is measured in units called VOLTS.

The rate of flow of the electrons through the circuit is called the CURRENT (I). Current is measured in units called AMPERES.

The usual conductor for transporting a flow of electrons through a circuit is wire. Generally speaking, the smaller the diameter of the wire, the more will be the RESISTANCE (R) to the flow, and the larger the diameter, the less the resistance. Resistance is measured in units called OHMS.

The definitions of the units volt, ampere, and ohm are as follows:

1 volt	Electromotive force required to send a current of 1 ampere through a system in which the resistance measures 1 ohm.
1 ampere	Rate of flow of electrons in a system in which the electromotive force is 1 volt and the resistance, 1 ohm.
1 ohm	Resistance offered by a system in which the electromotive force is 1 volt and the current, 1 ampere.

The ohm is named for Georg Simon Ohm, a German scientist and early electrical pioneer, who discovered that there is a constant relationship between the electromotive force (E), the current (I), and the resistance (R) in any electrical circuit. This relationship is expressed in "Ohm's law" as follows:

$$I = \frac{E}{R}$$

From the basic law it follows that

$$E = IR$$

$$R = \frac{E}{I}$$

From Ohm's law you can (1) determine any one of the three values when you know the other two and (2) determine what happens in the circuit when a value is varied.

Suppose, for example, that the resistance (R) is increased, while the electromotive force (E) remains the same. It is obvious that the current (I) must drop proportionately. To avoid a drop in the current, it would be necessary to increase the electromotive force proportionately.

When an electrical circuit is open (that is, when there is a break in the circuit, such as an open switch), there is no flow of electrons through the circuit. When the circuit is closed, however, the current will begin to flow. With a constant electromotive force (E), the rate at which the current (1) flows will depend on the size of the resistance (R). The size of the resistance will increase with the number of electrical devices (such as lights, motors, and the like) that are placed on the circuit, and the amount of POWER each of these consumes.

Power may be defined as "electrical work per unit of time." James Watt, another early pioneer in the electrical field, discovered that there is a constant relationship between the electromotive force (E), the current (I), and the power consumption (P) in a circuit. This relationship is expressed in the formula P = IE, from which it follows that

$$I = \frac{P}{E}, \text{ and } E = \frac{P}{I}.$$

Power is measured in units called WATTS, a watt being defined as the work done in 1 second when 1 ampere flows under an electromotive force of 1 volt.

Suppose, now, that you have a 110-volt circuit in your home. The constant E of this circuit, then, is 110 volts. In the circuit there is probably a 15-ampere fuse. A fuse is a device that will open the circuit by "burning out" if the current in the circuit exceeds 15 amperes. The reason for the existence of the fuse is the fact that the wiring in the circuit is designed to stand safely a maximum current of 15 amperes. A current in excess of this amount would cause the wiring to become red hot, eventually to "burn out," and perhaps to start an electrical fire.

Suppose you light a 60-watt bulb on this circuit. Your E is 110 volts. By the formula

$$I = \frac{P}{E},$$

you know that the current in the circuit with the 60-watt bulb on is

$$\frac{60}{110},$$

or about 0.54 amperes, which is well within the margin of safety of 15 amperes. Dividing 15 amperes by 0.54 amperes you find that this fuse will protect a 27-lamp circuit.

But suppose now that you place on the same one-lamp circuit an electric toaster taking about 1,500 watts (electrical devices are usually marked with the number of watts they consume) and an electrical clothes dryer taking about 1,200 watts. The total P is now 60 + 1,500 + 1,200, or 2,760 watts. The current will now be

$$\frac{2{,}760}{110}$$

or 25 amperes. Theoretically, before it reaches this point, the 15-ampere fuse will burn out and open the circuit.

Mechanical Power Measure

Mechanical power (such as that supplied by a bulldozer) is measured in units called FOOT-POUNDS PER SECOND (ft-lb/sec) or FOOT-POUND PER MINUTE (ft-lb/min). A foot-pound is the amount of energy required to raise 1 lb a distance of 1 ft against the force of gravity.

One HORSEPOWER equals 33,000 ft-lb/sec or 550 ft-lb/min. One horsepower equals about 746 watts.

CONVERSION OF UNITS

To convert a measure expressed in terms of one unit to the equivalent in terms of a different unit is, when you know the ratio between the units, a simple proportional equation problem. Suppose, for example, that you want to convert a linear distance in engineer's measure (feet and decimals of feet) to the equivalent in carpenter's measure (feet and twelfths of feet) to the nearest one-eighth in. Suppose that the original distance is 12.65 ft. This means "12 ft and 65 hundredths of a foot." You want to determine first, then, how many twelfths of a foot there are in 65 hundredths of a foot. The original ratio is 12/100. The proportional equation solution is as follows:

$$\frac{x}{65} = \frac{12}{100}$$

$$x = \frac{12 \times 65}{100} = \frac{780}{100} = 7.8$$

Therefore, there are 7.8 in. (twelfths of a foot) in 0.65 ft. The next step is to determine how many eighths of an in. there are in 0.8 in.; that is, in eight-tenths of an in. The initial ratio is 8/10, and the proportional equation solution is as follows:

$$\frac{x}{8} = \frac{8}{10}$$

$$x = \frac{8 \times 8}{10} = \frac{64}{10} = 6.4$$

Therefore, there are (rounded off) 6/8 in,, or 3/4 in., in 0.8 in. In 12.65 ft, then, there are 12 ft 7 3/4 in. to the nearest 1/8 in.

Actually, the proportional method used above can be simplified by using the following solution:

Convert 12.65 ft to the nearest 1/8 in. in carpenter's measure.

12.65 ft = 12 ft + (0.65 x 12 = 7.8 in,)

= 12 ft 7.8 in.

= 12 ft 7.0 in. + (0.8 x 8 = 6.4 eighths)

= 12 ft 7.0 in. + 6/8 in. or 3/4 in. to the nearest eighth in.

= 12 ft 7 3/4 in.

In converting from engineer's to carpenter's linear measure, or vice versa, surveyors working with values to only the nearest 0.01 ft frequently use the following conversions to decimal equivalents of inches from 1 through 11 and decimal equivalents of the common carpenter's-measure subdivisions of the inch.

1 in. = 0.08 ft

2 in. = 0.17 ft

3 in. = 0.25 ft

4 in. = 0.33 ft

5 in. = 0.42 ft

6 in. = 0.50 ft

7 in. = 0.58 ft

8 in. = 0.67 ft

9 in. = 0.75 ft

10 in. = 0.83 ft

11 in, = 0.92 ft

$\frac{1}{8}$ in. = 0.01 ft

$\frac{1}{4}$ in. = 0.02 ft

$\frac{1}{2}$ in. = 0.04 ft

$\frac{3}{4}$ in. = 0.06 ft

Using these values, you can convert decimals of a foot to inches carpenter's measure, or inches carpenter's measure to decimals of a foot, very easily. To convert (for example) 0.37 ft to inches carpenter's measure, you have the following:

0.33 ft = 4 in.

0.04 ft = $\frac{1}{2}$ in.

0.37 ft = $4\frac{1}{2}$ in.

To convert (for example) 7 3/8 in. carpenter's measure to engineer's measure, you have the following:

$$7 \text{ in.} = \qquad 0.58 \text{ ft}$$

$$\frac{3}{8} \text{ in.} = (3 \times 0.01) = \underline{0.03} \text{ ft}$$

$$7\frac{3}{8} \text{ in.} = \qquad 0.61 \text{ ft}$$

For a great many types of conversions there are tables in which you can find the desired values by inspection. Various publications contain tables for making the following conversions:

Meters to feet

Feet to meters

Degrees Centigrade to degrees Fahrenheit

Degrees Fahrenheit to degrees Centigrade

Inches and sixteenths to decimals of a foot

Sixteenths of an inch to decimals of a foot

Minutes to decimals of a degree

Degrees to roils and roils to degrees

Grads to degrees, minutes, and seconds

A conversion factor is a number that, if multiplied by a value expressed in terms of one unit, will produce the equivalent value expressed in terms of a different unit. The factor for converting linear feet to miles, for instance, is 0.00019. If you multiply 5,280 ft by 0.00019, you get 1.0032 miles, which is close enough to a mile to satisfy most practical purposes.

When you know the ratio between two different units, you can easily work out your conversion factor. For example, you know that the ratio of degrees to roils is

$$\frac{9}{160}.$$

The conversiom factor for converting degrees to roils is the number of roils in 1 degree, which is

$$\frac{160}{9}, \text{ or } 17.8.$$

The conversion factor converting roils to degrees is the number of degrees in a roil, which is

$$\frac{9}{160}, \text{ or } 0.0562.$$

Some of the common conversion factors are as follows :

Linear feet x 0.00019 = miles

Linear yards x 0.0006 = miles

Square inches x 0.007 = square feet

Square feet x 0.111 = square yards

Square yards x 0.0002067 = acres

Acres x 4840.0 = square yards

Cubic inches x 0.00058 = cubic feet

Cubic feet x 0.03704 = cubic yards

CHAPTER 2

DRAFTING EQUIPMENT

Drawing is often called the universal language. Drafting is the particular phase of drawing that engineers and designers use to convey and record ideas or information necessary for the construction of structures and machines. There are definite rules of usage to ensure that the same meaning is conveyed at all times and to enable those who learn the rules to interpret what is presented in a drawing. In contrast to pictorial drawings, such as paintings of landscapes and living things, engineering drawings use a graphical language to describe every integral part of an object. As an Engineering Aid, you will specialize in engineering drawings, whereas the Illustrator Draftsman will specialize in pictorial drawings.

In studying this chapter, you will learn that drafting is classified into types, such as technical, illustrative, mechanical, freehand, and engineering drafting. Then you will go on to learn about charts, graphs, drafting guidelines, and a variety of instruments and materials, all of which are designed to help you perform your drafting duties. This chapter also contains many pointers that will help you operate, adjust, and maintain your drafting instruments.

TYPES OF DRAFTING

Generally, drafting is classified according to its purpose or the means by which it is accomplished.

TECHNICAL AND ILLUSTRATIVE DRAFTING

A distinction is often made between technical drafting and illustrative drafting. TECHNICAL DRAFTING presents technical information in a graphic form; for example, a drawing that shows the type and proper placement of structural members in a building. ILLUSTRATIVE DRAFTING presents a pictorial image only; an example is a perspective drawing of a proposed structure. The term *illustrative drafting* is not commonly used in construction drafting.

MECHANICAL AND FREEHAND DRAFTING

MECHANICAL DRAFTING, as distinguished from freehand drafting, is any drawing in which the pencil or pen is guided by mechanical devices, such as compasses, straightedges, and french curves. In FREEHAND DRAFTING the pencil or penis guided solely by the hand of the draftsman. Sketches are the result of freehand drafting. With the exception of lettering, most technical drafting is mechanical drafting in this sense of the term.

In a different sense, the term *mechanical* applies to certain types of industrial or engineering drawings, regardless of whether the drawings are done mechanically or freehand. Some authorities confine the term, used in this sense, to the drawing of machinery details and parts. Others confine it to the drawing of plumbing, heating, air conditioning, and ventilating systems in structures. In the SEABEEs, mechanical drawing means the arrangements of machinery, utility systems, heating, air conditioning, and ventilating systems.

ENGINEERING DRAFTING

As an Engineering Aid, you will be primarily concerned with the following broad types of engineering drafting:

1. Topographic drafting, or drafting done in connection with topographic and civil engineering surveys. It may include drawings not directly related to topographic maps, such as plotted profiles and cross sections.
2. Construction drafting, or drafting of architectural, structural, electrical, and mechanical drawings related to structures.

3. Administrative drafting, or drafting done in support of the administrative and operational functions of your unit, such as technical and display charts, safety and embarkation signs, project completions, and unit readiness graphics.

In performing drafting duties, you will be working from sketches, field notes, or direct instructions from your drafting supervisor.

Engineering Charts and Graphs

Graphic presentation of engineering data means using CHARTS and GRAPHS, rather than numerical tables or word descriptions, to present statistical engineering information. Properly constructed, each form of chart or graph offers a sharp, clear, visual statement about a particular aspect or series of related facts. The visual statement either emphasizes the numerical value of the facts or shows the way these facts are related, A chart or graph that emphasizes numerical value is called **quantitative;** one that emphasizes relationships is called **qualitative.** The trend of an activity over a period of time, such as the mishaps summary report of a deployed unit rendered over a 6-mo deployment period, is more easily remembered from the shape of a curve describing the trend than from numerical statistics. Successful graphic presentation of engineering data requires as much drafting ability as the graphic representation of engineering objects. Lines must be sharp, opaque, well contrasted, and of uniform weight. Letters and figures are normally executed with the standard lettering set according to accepted conventions.

Charts and graphs are classified as **technical** or **display** charts.

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

DISPLAY CHARTS are organized primarily to convey data to nontechnical audiences. The message presents a general picture of a situation, usually comparative. There are many varieties of display charts, including bar charts, status charts, and training aids. In a SEABEE battalion, display charts are frequently used in operations and training departments. When so used, they must conform to minimum standards prescribed by the command.

Any construction job involves quantities of people, materials, and equipment. Efficient operation and completion of the job result from planning, organization, and supervision. Graphic presentation of data is important. Statistics based on the results of past jobs with similar working conditions provide a basis for predicting the amount of time that a proposed job will take. These statistics offer the best possibilities for study when presented graphically, usually in the form of a curve. The prediction of expected achievement usually is presented as a bar chart and is called a time-and-work schedule, When the scheduled work progress is compared with the actual progress (work in place), the chart is called a progress chart.

Drafting Guidelines

As stated earlier, there are definite guidelines in drafting. These guidelines provide uniform interpretation of all engineering drawings. Any drawing prepared by or for the Navy must be prepared following the latest military standard (MIL-STD), Department of Defense Standard (DOD-STD), and applicable NAVFACENGCOM design manuals. For subjects not covered by these references, you might refer to civilian publications, such as the *Architectural Graphic Standards.* Or, you may devise your own symbols, provided that any nonstandard features in your drawing are supported with adequate explanation by notes or by legend.

Many drawings continue in use for years. Therefore, you will have occasion to work with drawings that contain obsolete symbols. Look for a legend on the drawings; it should help you in reading symbols with which you are not familiar. If there is no legend, study the drawing carefully and you should be able to interpret the meaning of unfamiliar symbols and abbreviations.

DoD drawing standards, which are constantly being updated, are published by the Assistant Secretary of Defense (Supply and Logistics), Office of Standardization. Any Navy activity can obtain copies of these standards by writing to the following: Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, PA 19120. All requests should state the title and identifying number and should be submitted on DD Form 1425. To ensure that you have the latest edition of a standard, check the *Department of Defense Index of Specifications and Standards,* which is issued 31 July of each year. Also check the supplements to the Index.

Current editions of the following military standards should be available to the EA:

MIL-HDBK-1006/1	*Policy and Procedures for Project Drawings and Specifications Preparation*
MIL-STD-12D	*Abbreviations for Use on Drawings and in Technical Type Publications*
MIL-STD-14A	*Architectural Symbols*
MIL-STD-17B	*Mechanical Symbols*
MIL-STD-18	*Structural Symbols*
DOD-STD-100C	*Engineering Drawing Practices*

In addition, the following civilian industry standards should be on hand in the drafting room:

ANSI Y14.1	*Drawing Sheet Size and Format*
ANSI Y14.2	*Line Conventions and Lettering*
ANSI Y14.3	*Multi and Sectional View Drawings*
ANSI Y14.5-82	*Dimensioning and Tolerancing for Engineering Drawings*
AWS A3.0-85	*Welding Terms and Definitions Standards*
ASTM E380	*Standard for Metric Use*

DRAFTING EQUIPMENT

To be a proficient draftsman, you must be familiar with the tools of your trade and the proper techniques of using them. Great care must be given to the proper choice of drafting equipment and accessories. To have a few good pieces of equipment is much better than to have a large stock of undependable and shoddy equipment.

NAVAL MOBILE CONSTRUCTION BATTALION'S STANDARD DRAFTSMAN KIT

As a means of ensuring that every Naval Mobile Construction Battalion's (NMCB's) drafting section is properly outfitted with adequate drafting equipment and accessories, standard draftsman kits are provided in each NMCB's allowance. The drafting equipment and supplies contained in the draftsman kit #0011 are listed in the NMCB's TABLE OF ALLOWANCE (Assembly 80011). For this reason, no attempt will be made here to list all equipment and supplies currently carried in the standard draftsman kit. One complete NMCB's draftsman kit is designed to be used by three draftsmen. Normally, two complete draftsman kits will be carried in a battalion allowance, available for checkout to the drafting section supervisor or engineering chief. It is the responsibility of each crew leader to make sure that the kits assigned to him are complete. The kits are continuously reviewed and updated according to current battalion requirements.

Most of the consumable items contained in the kit, such as pencils, pencil leads, lead holders, masking tape, and ink, are stocked in the battalion supply department for kit replenishment. Additional drafting equipment and supplies, such as pointers and dust brushes, are also stocked in most battalion drafting rooms to supplement the drafting kits.

To avoid losing any equipment and supplies not included in the draftsman kit, personnel should not pack them with the kit when the kit is turned in to the supply department at the end of a deployment or homeport period.

The following sections will acquaint you with general drafting equipment and supplies, with emphasis being placed on items used by SEABEE draftsmen.

DRAFTING MEDIA

Materials used to draw on are referred to as DRAFTING MEDIA. Generally there are three types: paper, cloth, and film. For all practical purposes, you, as a SEABEE draftsman, will use tracing paper, profile paper, plan/profile paper, and cross-section paper. Although it is not found in the draftsman kit, illustration board is used for preparing signs and charts. Tracing cloth and film are rarely used by SEABEE draftsmen, and hence will not be described here.

TRACING PAPER (also called TRACING VELLUM) is a high-grade white (or slightly tinted) transparent paper that takes pencil well, and from which pencil lines can be easily erased. Also, reproductions can be made directly from pencil drawings on tracing paper; however, for better results in reproduction, a pencil drawing on tracing paper is usually inked over.

PROFILE, PLAN/PROFILE, and CROSS-SECTION PAPER are referred to as GRIDDED MEDIA. Each type of gridded media is designed for a specific purpose. Most gridded media used by EAs are suitable for reproduction.

PROFILE PAPER is normally available in two grid patterns: 4 by 20 lines (4 lines vertical and 20 lines horizontal) per inch and 4 by 30 lines per inch with the vertical lines accented every 10th line. Horizontal lines on the 4 by 20 are accented medium-weight every 5th line and heavyweight every 50th line. Horizontal lines on the 4 by 30 have heavyweight accent lines every 25th line. Profile paper is generally used for road design profiles.

PLAN/PROFILE PAPER has rulings and grid accents similar to those of 4 by 20 and 4 by 30 profile paper, except that the grid patterns occupy only the lower half of the paper. The upper half is plain paper, used to draw the plan view in relation to the profile or to add explanatory notes to the profile. Plan/profile paper is also used for road design.

CROSS-SECTION PAPER, sometimes referred to as graph paper, is available in a variety of grid patterns. Generally, graph paper used by the EA has a grid scale of 10 by 10 lines per square inch. It is used for drawing road cross sections, rough design sketching, preparing schedules, plotting graphs, and many other uses.

Most drafting media are available in three styles: plain sheets or rolls, preprinted sheets with borders and title blocks, and sheets with non-reproducible grids. For further information on the many varieties of drafting media available, refer to suppliers' catalogs, such as those published by Keuffel & Esser Co. and Eugene Dietzgen Co.

ILLUSTRATION BOARD is a drawing paper with a high rag content mounted on cardboard backing. The type normally found in a SEABEE drafting section has a smooth white drawing surface that takes ink readily. Normally, the board is 30 in. by 40 in. and comes in 50-sheet packages. Illustration board is used by the EA for making signs and for large unmounted charts and for mounting maps, photos, and drawings that require a strong backing. A thinner board, called BRISTOL BOARD, is also used for making small signs and charts. The thickness of bristol board is about the same thickness as an ordinary index card. Unlike illustration board, bristol board has two white smooth sides that take ink very well. Bristol board is less expensive than illustration board and is easily cut, to size with a paper trimmer. It is available in many sizes; the most popular size is 20 in. by 30 in. in 50- or 100-sheet packages.

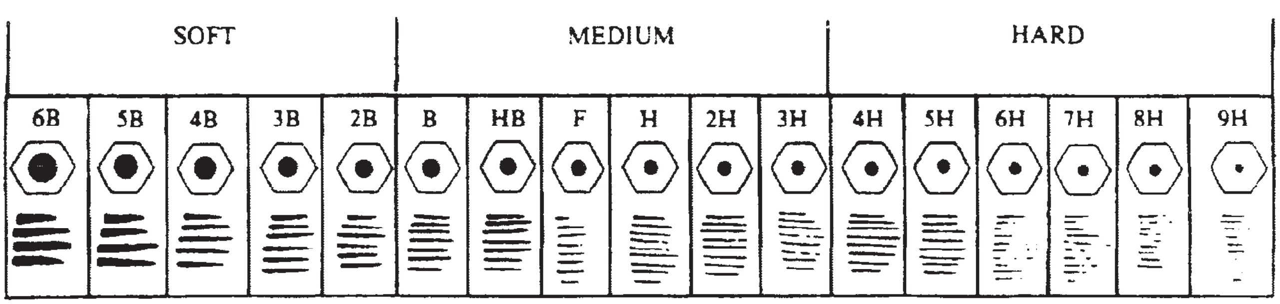

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Figure 2-1.—Grades of drafting pencils.

DRAFTING PENCILS

Two types of pencils are used in drafting: wooden and mechanical. The latter is actually a lead holder and may be used with leads of different hardness or softness.

Drafting pencils are graded according to the relative hardness of their graphite lead. A pencil that is considered soft is designated by the letter *B*. On the other hand, a hard pencil is designated by the letter *H*. Figure 2-1 shows 17 common grades of drafting pencils from 6B (the softest and the one that produces the thickest line) to 9H (the hardest and one that produces a thin, gray line).

You will notice that the diameters of the lead vary. This feature adds strength to the softer grades. As a result, softer grades are thicker and produce broader lines, while harder grades are smaller and produce thinner lines. Unfortunately, manufacturers of pencils have not established uniformity in grades. Hence, a 3H may vary in hardness from company to company. With experience and preference, you may select the trade name and grade of pencil that suits your needs. Selection of drafting pencils will be covered in chapter 3.

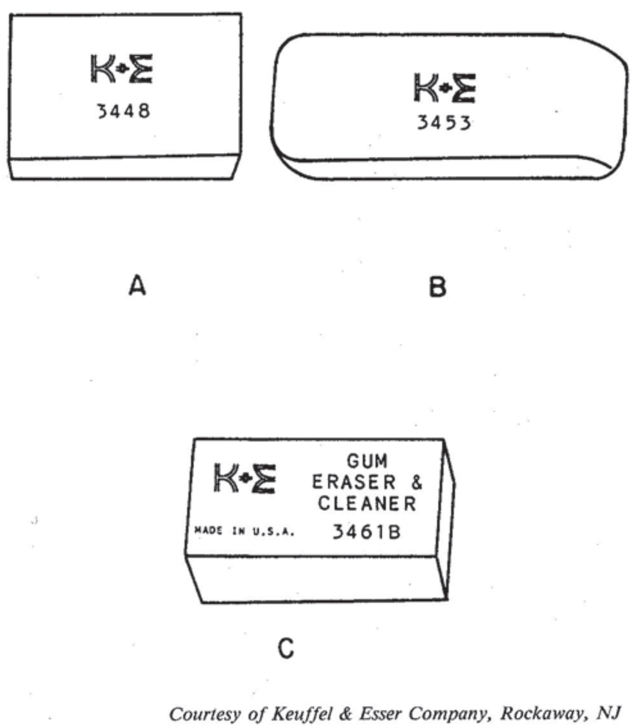

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Figure 2-2.-Types of erasers.

ERASERS AND ERASING ACCESSORIES

You must be very careful in selecting an eraser that will remove pencil or ink lines without damaging the surface of the drawing sheet.

A vinyl eraser (fig. 2-2, view A) is ideal for erasing lines drawn on tracing cloth and films. An ordinary double-beveled pencil eraser generally comes in red or in pink color (sometimes called a PINK PEARL). A harder eraser (sometimes called a RUBY RED) (fig. 2-2, view B) is designed for erasing lines in ink. The ART GUM eraser (fig. 2-2, view C), made of soft pliable gum, will not mar or scratch. It is ideally suited for removing pencil or finger marks and smudges.

You can also use a kneaded eraser—the type used by artists. It is a rubber dough, kneadable in your hand, and has the advantage of leaving very little refuse on the drawing sheet.

The so-called STEEL ERASER, shown in figure 2-3, is, of course, actually a scraper. It is used principally for scraping off erroneous ink lines, especially from tracing cloth. The figure shows a short-bladed steel eraser; long-bladed steel erasers are also available. A steel eraser is not generally recommended for use by beginners because it has a tendency to damage the surface of the drawing sheet.

Figure 2-4 shows an ELECTRIC ERASER. The control switch is directly under the fingertip;

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Figure 2-3.-Steel eraser.

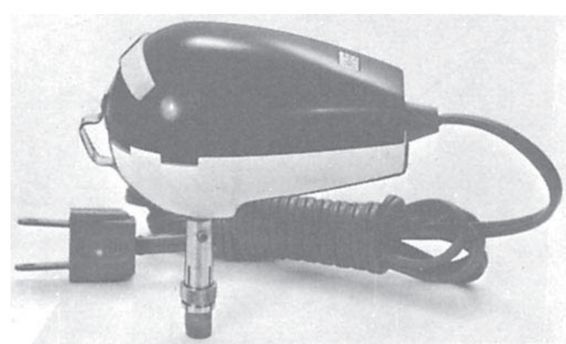

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Figure 2-4.-Electric eraser.

the body of the machine fits comfortably in the palm of the hand, and the rotating eraser can be directed as accurately as a pencil point. Refills for either ink or pencil erasing are available.

CAUTION: Do not hold the electric eraser steady in one spot, or you may easily wear a hole or damage the surface of the material being erased.

When there are many lines close together and only one needs to be removed or changed, the desired lines may be protected by an erasing shield, as shown in figure 2-5.

Finely pulverized gum eraser particles are available in squeeze bottles or in DRY CLEAN PADS for keeping a drawing clean while you work on it. If a drawing or tracing is sprinkled occasionally with gum eraser particles, triangles, T squares, scales, french curves, and the like, not only tend to stay clean themselves, but also tend to clean the drawing or tracing as they are moved over the surface.

Before a drawing is inked, it is usually prepared by sprinkling on POUNCE (a very fine bone dust) and then rubbing in the pounce with a felt pad on the container. Pounce helps to prevent a freshly inked line from spreading. A draftsman's DUST BRUSH should be used for brushing dust and erasure particles off a drawing.

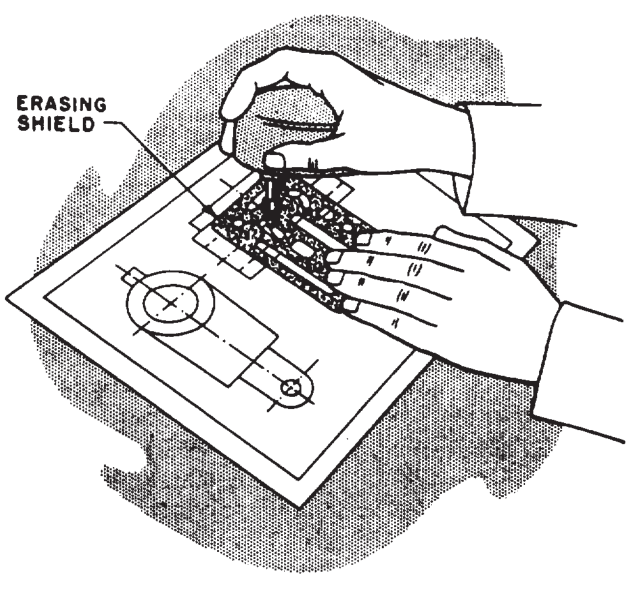

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Figure 2-5.-Use of an erasing shield.

DRAFTING TABLES WITH BOARDS

Most EA shops are furnished with standard drafting tables with drafting boards, as shown in figure 2-6. The majority of this furniture is easily adjustable to the users' needs. The height of the table should be such that if you desire to work in a standing position, you can do so without stooping or holding your arms in a raised position. Hinged attachments for the drafting board are provided to adjust the incline so that your line of sight will be approximately perpendicular to the drafting surface. Your drafting stool should be high enough in relation to the table for you to see the whole drafting board but not so high that you are uncomfortably seated.

The drafting boards contained in the draftsman kit are constructed of joined strips of softwood, usually clear white pine or basswood. They are equipped with hinged attachments for securing the board to a table or fabricated base. If suitable bases are not available, table bases may be constructed at the unit carpenter shop.

You should consider only the left-hand vertical edge as a working edge for the T square if you are right-handed (the right-hand edge if you are left-handed). The T square should never be used with the head set against the upper or lower edge of the board, as the drafting board may not be perfectly square.

The drafting board should be covered. A variety of good drafting board cover material is available. Available cover materials are cellulose acetate-coated paper, vinyl, and mylar film. The vinyl drafting board covers have the added advantage of being able to close up small holes or cuts, such as those made by drafting compasses or dividers. In general, these covers protect the drafting board surface by preventing the drafting pencil from following the wood grain, by reducing lighting glare, and by providing an excellent drafting surface.

Since you will be constantly using your eyes, it is important that your working area be well lighted. Natural light is best, if available and ample, although in the majority of cases acceptable natural light will be the exception rather than the rule. Drafting rooms are usually lighted with overhead fluorescent fixtures. Ordinarily, these fixtures are inadequate in quality and intensity of light. Adjustable lamps will improve the lighting conditions. The most popular type of adjustable lamp is the floating-arm fluorescent fixture that clamps onto the drafting

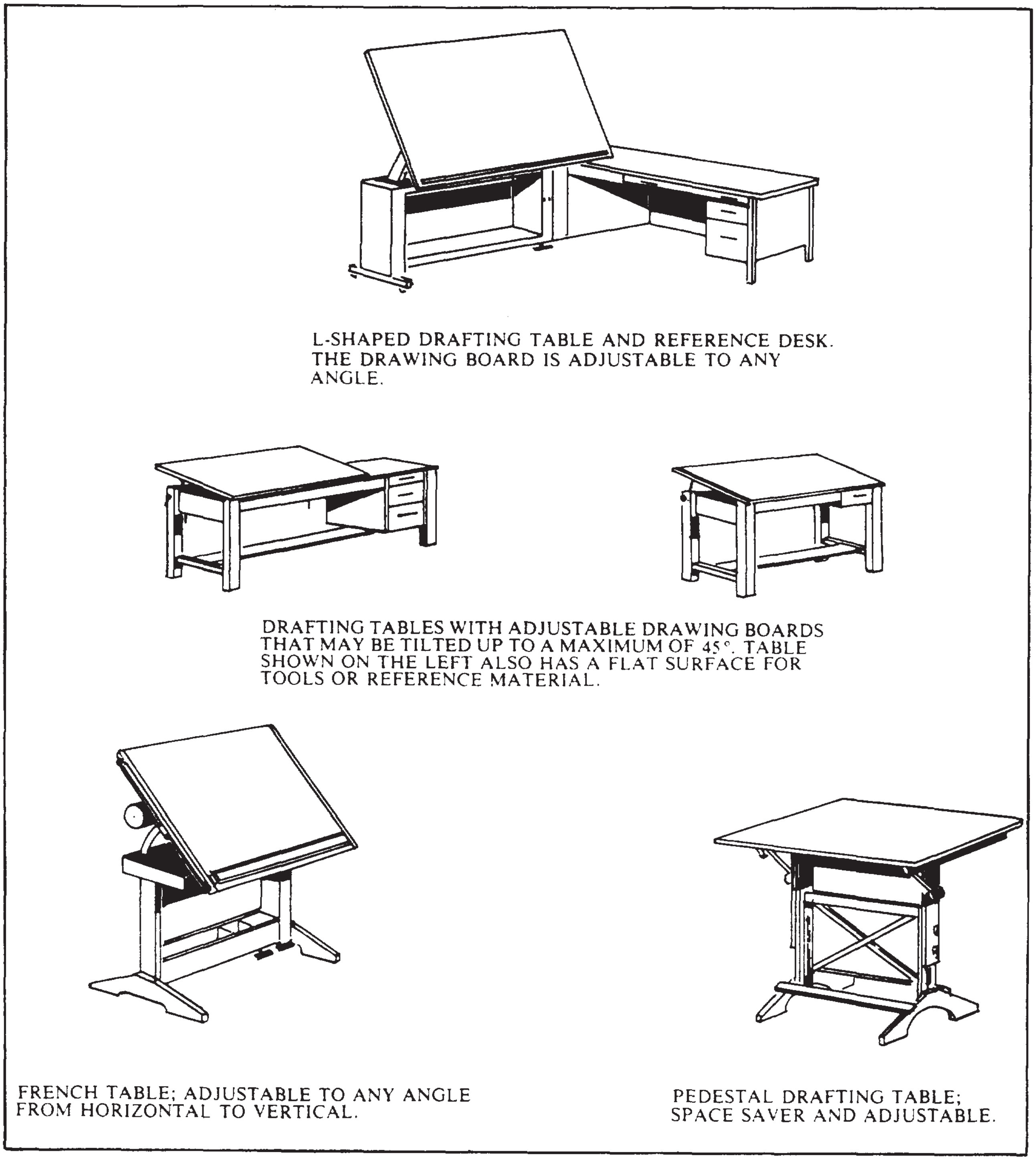

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Figure 2-6.-Drafting tables with boards.

table. Arrange your lighting to come from the front-left, if you are right-handed; from the front-right, if you are left-handed. This minimizes shadows cast by drawing instruments and your hands.

Never place your drafting board so that you will be subject to the glare of direct sunlight. North windows are best for admitting daylight in the Northern Hemisphere. Conservation of vision is of the utmost importance. You must make every possible effort to eliminate eyestrain.

T SQUARES

The T square gets its name from its shape. It consists of a long, straight strip, called the blade, which is mounted at right angles on a short strip, called the head. The head is mounted under the blade so that it will fit against the edge of the drawing board while the blade rests on the surface. T squares vary in size, ranging from 15 in. to 72 in. in length, with the 36-in. length being the most common.

The T square shown in figure 2-7 is typical of the ones used by an EA. The head is made of hardwood and the blade, usually of maple with a natural or mahogany finish. The edges of the blade are normally transparent plastic strips glued into grooves on both edges of the blade, as shown in the cross section in figure 2-7. This allows the edge of the T square to ride above the drawing as the blade is moved up or down the board. This arrangement is a great advantage when you are drawing with ink. Since the tip of the ruling pen does not come in contact with the blade, but is below it, ink cannot be drawn under the blade to blot the drawing.

The T square is used for drawing horizontal lines only. Always draw lines along the upper edge of the blade. The T square also serves as a base for the triangle when vertical and inclined lines are drawn. Some T squares are designed with adjustable heads to allow angular adjustments of the blade.

Handle your T square carefully. If dropped, it may be knocked out of true and become useless. Additionally, to prevent warping, hang the T square by the hole in the end of the blade or lay it on a flat surface so that the blade rests flat.

Before beginning a new job, you should test the top edge of your T square for warp or nicks by drawing a sharp line along the top of the blade.

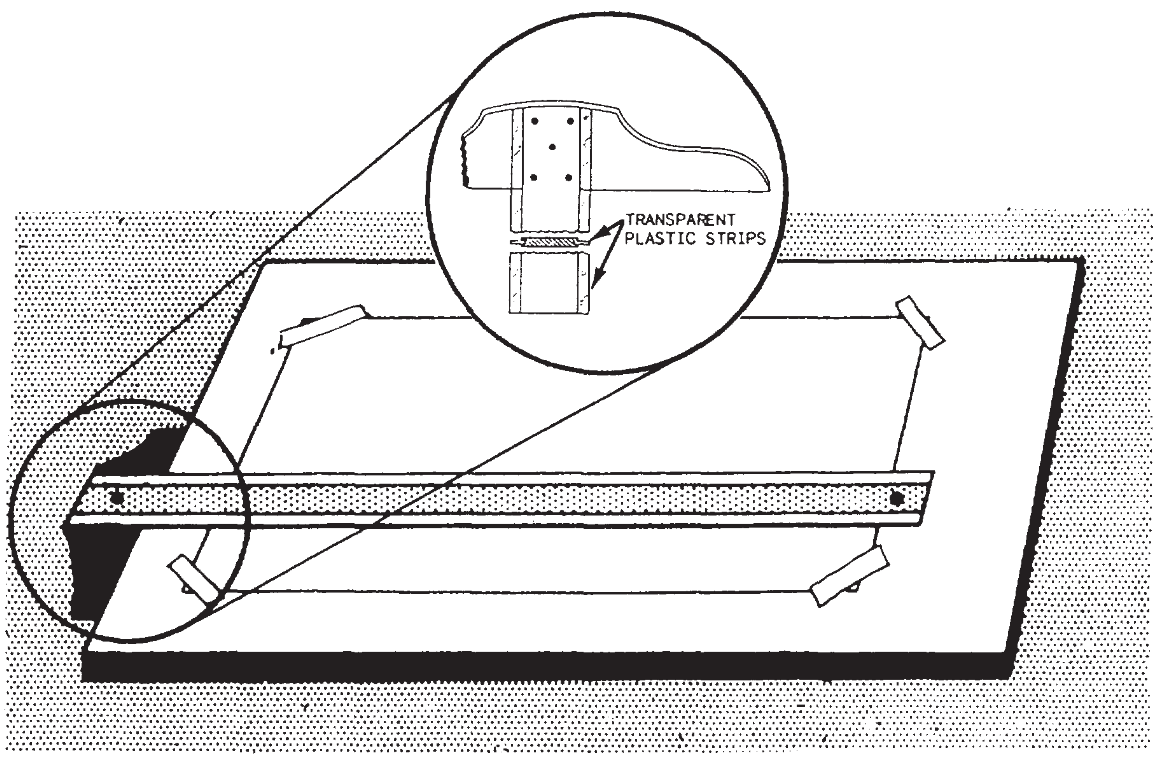

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Figure 2-7.-Drafting board with T square and drafting paper in place.

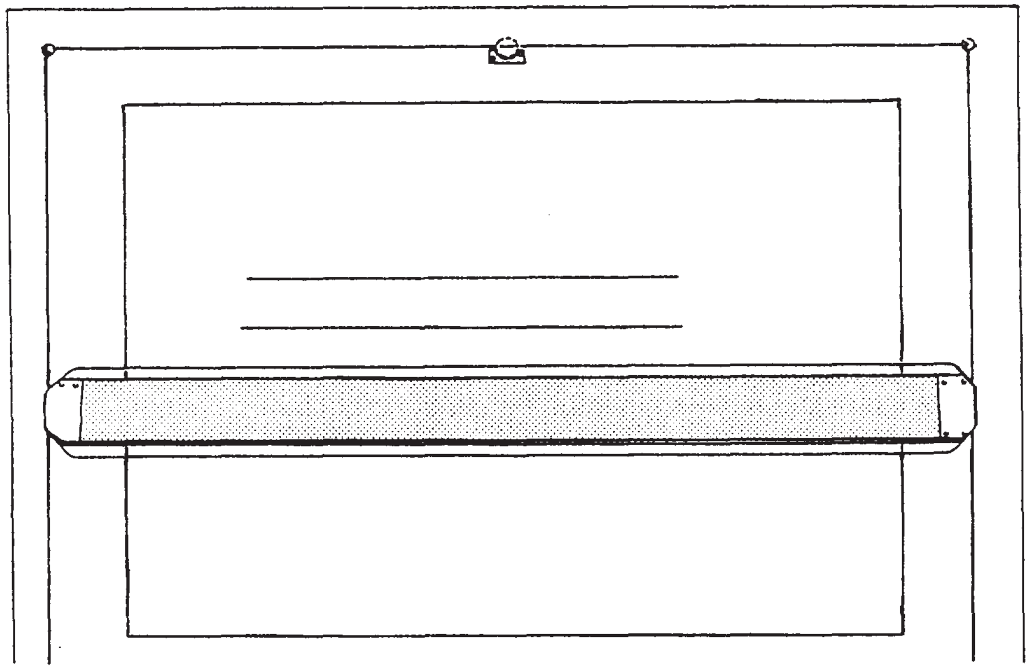

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Figure 2-8.-Parallel straightedge.

Turn the T square over and redraw the line with the same edge. If the blade is warped, the lines will not coincide.

If the blade swings when the head is held firmly against the edge of the drawing board, the blade may be loose where it is joined to the head, or the edge of the T square head may be warped. You can usually tighten a loose blade by adjusting the screws that connect it to the head, but if it is out of square, warped, or in bad condition, you should select a new T square.

PARALLEL STRAIGHTEDGE

Many draftsmen prefer to use a PARALLEL STRAIGHTEDGE (fig. 2-8) rather than a T square. The primary purpose of the parallel straightedge is the same as the T square.

The parallel straightedge is a laminated maple blade with transparent plastic edges similar to those on the T square. The parallel straightedge uses a system of cords and pulleys so that it is supported at both ends by a cord tacked to the drawing board. You can move the straightedge up or down the board with pressure at any point along its length and maintain parallel motion automatically. It comes complete with cord, tacks, cord tension adjuster, and mounting instructions. Some straightedges, like the one shown in figure 2-8, are equipped with a cord lock on one end of the blade. The straightedge is locked into place by turning the cord lock clockwise. This permits use of the straightedge on an inclined board. It also prevents accidental movement when you are inking or using mechanical lettering devices. The advantages of the parallel straightedge become particularly significant when you are working on large drawings. While the T square works well for small work, it becomes unwieldy and inaccurate when you are working on the far right-hand side of large drawings.

STEEL STRAIGHTEDGE

When drawing long, straight lines, you should use a STEEL STRAIGHTEDGE (fig. 2-9) because its heavy weight helps keep the straightedge exactly in position. The steel

Courtesy of Keuffel & Esser Company, Rockaway, NJ

45.677X

Figure 2-9.-Steel straightedge.

straightedge is also excellent for trimming blueprints and cutting heavy illustration board.

Steel straightedges are usually made of stainless steel and are available in lengths of 15 in. to 72 in. The one included in the draftsman kit is 42 in. long. Some have a beveled edge, like the one shown in figure 2-9.

TRIANGLES

TRIANGLES are used in combination with the T square or straightedge to draw vertical and inclined lines. They are usually made of transparent plastic, which allows you to see your work underneath the triangles.

Triangles are referred to by the size of their acute angles. Figure 2-10 shows two basic drafting triangles: the 45° (each acute angle measures 45°, and the 30°/60° (one acute angle measures 30°; the other, 60°). The size of a 45° triangle is designated by the length of the sides that form the right angle (the sides are equal). The size of a 30°/60° triangle is designated by the length of the longest side that forms the right angle. Sizes of both types of triangles range from 4 in. through 18 in. in 2-in. increments.

Like all other drafting equipment, triangles must be kept in good condition. If plastic triangles are dropped, their tips may be damaged. Also, triangles may warp so that they do not lie flat on the drawing surface, or the edge may deviate from true straightness. To prevent warping or chipping, you should always lay them flat or hang them up when they are not in use. Since there is seldom enough drawer space available to permit laying triangles flat, it is best to develop the habit of hanging them up. If the tips are bent, use a sharp knife to cut off the damaged part. If the triangle is warped, you may be able to bend it back by hand. If this does not straighten it, leave the triangle lying on a flat surface with weights on it or hold the triangle to the opposite curvature with weights. If the triangle becomes permanently warped so that the drawing edges are curved or the angles are no longer true, throw it away and get another.

To test the straightness of a triangle, place it against the T square and draw a vertical line, as shown in figure 2-11. Then reverse the triangle and draw another line along the same edge. If the triangle is straight, the two lines will coincide; if they don't coincide, the error is half the resulting space.

PROTRACTORS

PROTRACTORS are used for measuring and laying off angles other than those that may be drawn with the triangle or a combination of triangles. Most of the work you will do involving the use of the protractor will involve plotting information obtained from field surveys.

Like the triangle, most protractors are made of transparent plastic. They are available in 6-, 8-, and 10-in. sizes and are either circular or semicircular in shape, as shown in figure 2-12.

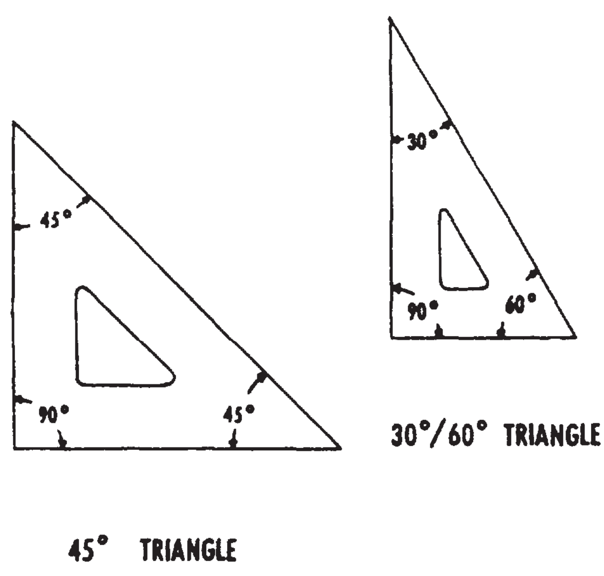

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Figure 2-10.-45° and 30°/60° drafting triangles.

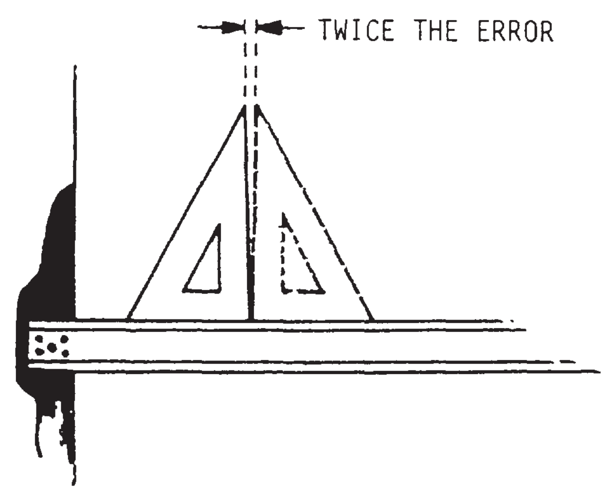

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Figure 2-11.-Testing a triangle for straightness.

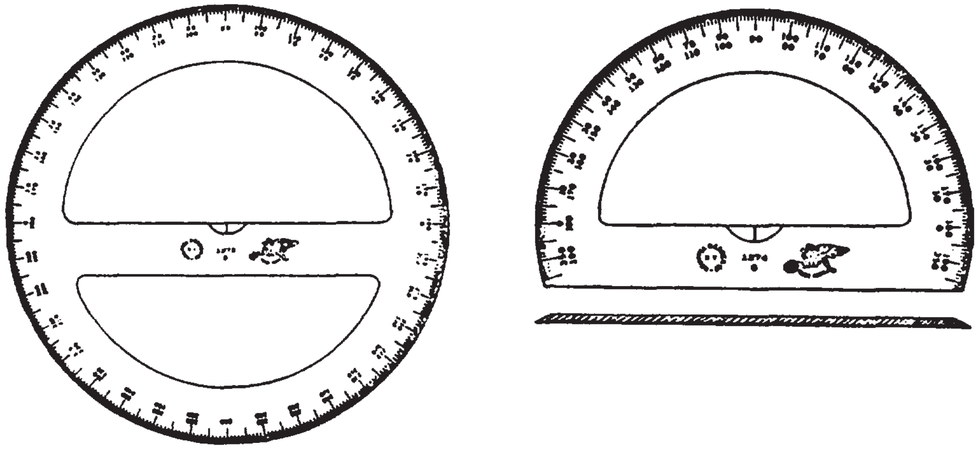

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Figure 2-12.-Types of protractors.

Protractors used by the EA are usually graduated in increments of 1/2°. By careful estimation, angles of 1/4° may be obtained. Protractor numbering arrangement varies. Semicircular protractors are generally labeled from 0° to 180° in both directions. Circular protractors may be labeled from 0° to 360° (both clockwise and counterclockwise), or they may be labeled from 0° to 90° in four quadrants.

Protractors should be stowed and cared for in the same manner as triangles.

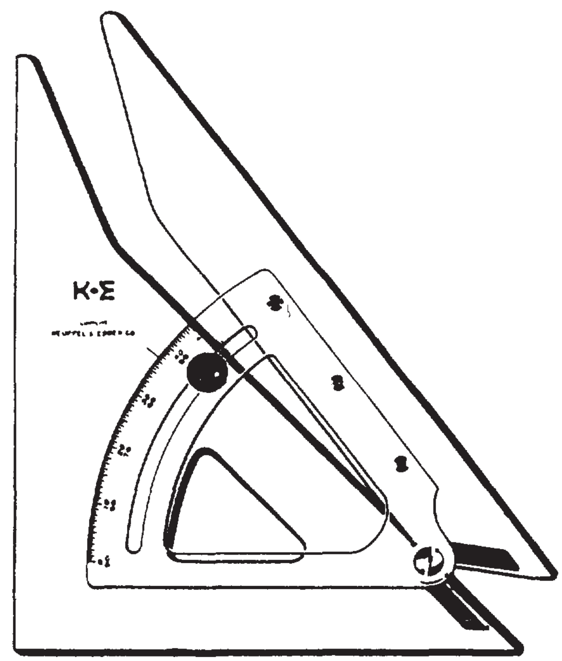
ADJUSTABLE TRIANGLES

The ADJUSTABLE TRIANGLE, shown in figure 2-13, combines the functions of the triangle and the protractor. When it is used as a right triangle, the hypotenuse can be set and locked at any desired angle to one of the bases. The transparent protractor portion is equivalent to a protractor graduated in 1/2° increments. The upper row of numbers indicates angles from 0° to 45° to the longer base; the lower row indicates angles from 45° to 90° to the shorter base. By holding either base against a T square or straightedge, you can measure or draw any angle between 0° and 90°.

The adjustable triangle is especially helpful in drawing building roof pitches. It also allows you to transfer parallel inclined lines by sliding the base along the T square or straightedge.

FRENCH CURVES

Irregular curves (called FRENCH CURVES) are used for drawing smooth curved lines that are not arcs or circles, such as ellipses, parabolas, and spirals. Transparent plastic french curves come in a variety of shapes and sizes.



Courtesy of Keuffel & Esser Company, Rockaway, NJ

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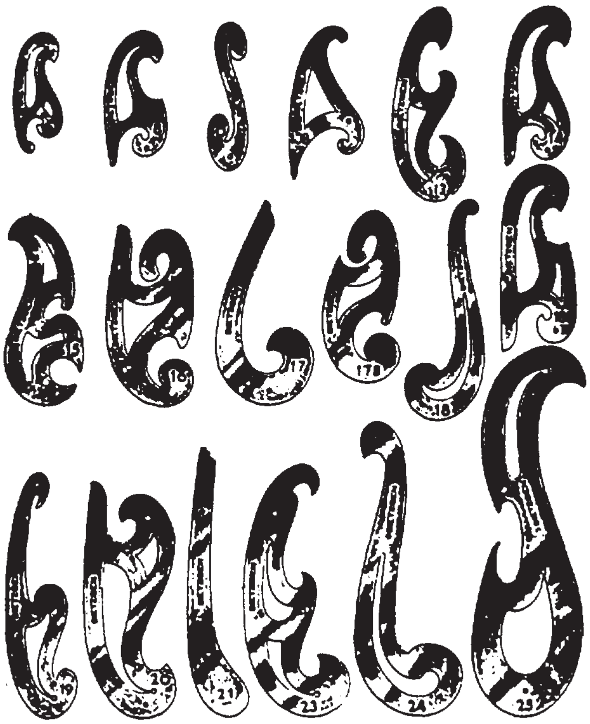
Figure 2-13.-Adjustable triangle.



Courtesy of Dietzgen Corporation

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Figure 2-14.-French curves.

Figure 2-14 shows an assortment of french curves. In such an assortment you can find edge segments that can be fitted to any curved line that you need to draw.

French curves should be cared for and stowed in the same manner as triangles.

DRAWING INSTRUMENT SETS

So far we have discussed only those instruments and materials that you will need for drawing straight lines (with the exception of french curves). Many drawings that you will prepare will require circles and circular arcs. For this purpose, instruments contained in a drawing instrument set are used. Many types of drawing instrument sets are available; however, it is sometimes difficult to judge the quality of drafting instruments by appearance alone. Often their characteristics become evident only after they are used.

The drawing instrument set shown in figure 2-15 is typical of those sets found in the standard draftsman kit. The following sections describe these instruments. Some special-purpose instruments not found in the set will also be described. They may be purchased separately or found in other instrument sets.

Compasses

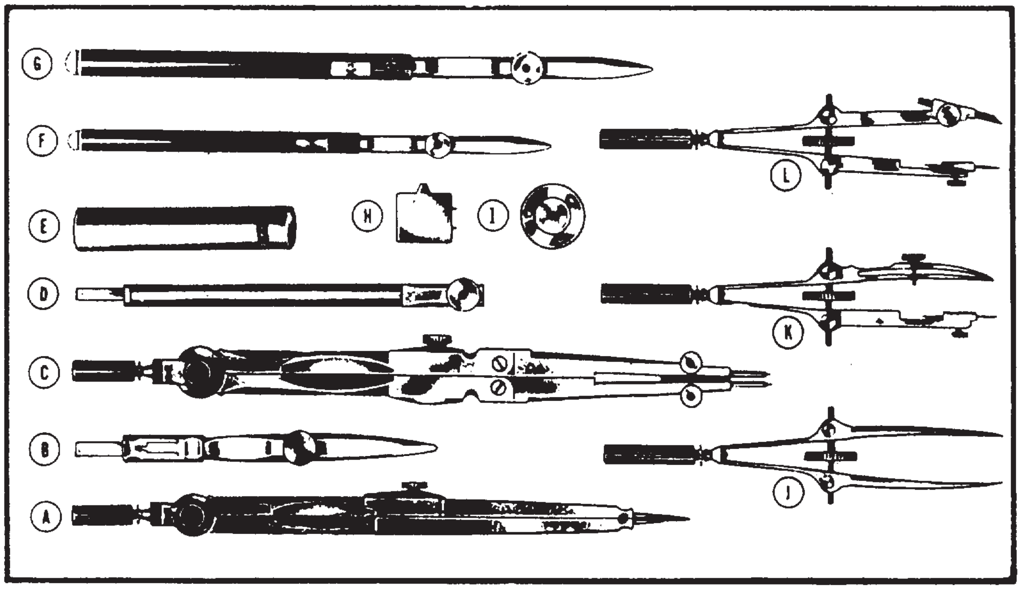
Circles and circular curves of relatively short radius are drawn with COMPASSES. The large **pivot joint compass** (fig. 2-15C) is satisfactory for drawing circles of 1 in. to about 12 in. in diameter without an extension bar. The pivot joint provides enough friction to hold the legs of the compass in a set position. One of the legs is equipped with a setscrew for mounting either a pen (fig. 2- 15B) or a pencil attachment on the compass. There is also an extension bar (fig. 2-15D), which can be inserted to increase the radius of the circle drawn.

The other type of compass found in the drawing instrument set is the **bow compass** (fig. 2-15K and 2- 15L). Many experienced draftsmen prefer the bow compass over the pivot joint compass. The bow compass is much sturdier and is capable of taking the heavy pressure necessary to produce opaque pencil lines without losing the radius setting.

There are two types of bow compasses. The location of the adjustment screw determines the type. The bow pen (fig. 2-15K) and bow pencil (fig. 2-15L) are the **center adjustment type,** whereas the bow instruments shown in figure 2-16 are the **side adjustment type.** Each type comes in two sizes: large and small. Large bow compasses are usually of the center adjustment type, although the side adjustment type is available. The large bow compasses are usually about 6 in. long; the small, approximately 4 in. long. Extension bars are available for large bow compasses. Bow compasses are available as separate instruments, as shown in figures 2-15 and 2-16, or as combination instruments with pen and pencil attachments.

Most compasses have interchangeable needlepoints. The conical or plain needlepoint is used when the compass is used as dividers. The shoulder-end needlepoint is used with pen or pencil attachments.

When many circles are drawn using the same center, the compass needle may tend to bore an oversized hole in the drawing. To prevent these holes, use a device called a **horn center** or **center disk** (fig. 2-151). This disk is placed over the center point. The point of the compass needle is then placed into the hole in its center.



INSTRUMENT SET CONTENTS

- (A) HAIRSPRING DIVIDERS, 6"
- (B) COMPASS PEN ATTACHMENT
- (C) FRICTION HEAD PIVOT JOINT COMPASS, 6 1/2"
- (D) COMPASS EXTENSION BAR
- (E) CONTAINER W/PENCIL LEADS
- (F) RULING PEN, 4 1/2"
- (G) RULING PEN, 5 1/2"
- (H) KEY-SCREWDRIVER COMBINATION
- (I) HORN CENTER, 1/2" DIAMETER
- (J) CENTRAL THUMBSCREW BOW DIVIDERS, 3 3/4"
- (K) CENTRAL THUMBSCREW BOW PEN, 3 3/4"
- (L) CENTRAL THUMBSCREW BOW PENCIL, 3 3/4"

Courtesy of Keuffel & Esser Company, Rockaway, NJ

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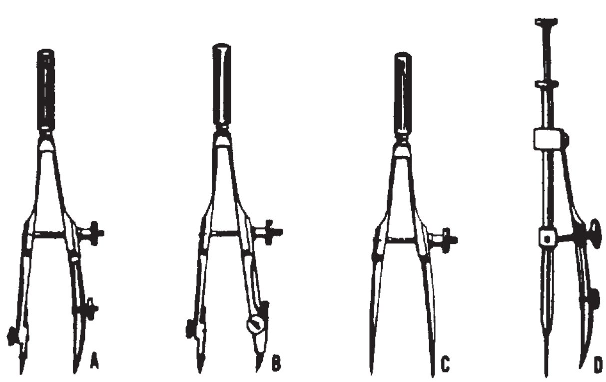
Figure 2-15.-Typical drawing instrument set.



Courtesy of Keuffel & Esser Company, Rockaway, NJ

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Figure 2-16.-Bow instruments: (A) Bow pen; (B) Bow pencil; (C) Bow dividers; (D) Drop bow pen.

Dividers

DIVIDERS are similar to compasses, except that both legs are provided with needlepoints. The instrument set (fig. 2-15) contains two different types and sizes of dividers: **large 6-in. hairspring dividers** (fig. 2-15A) and **small center adjustment bow dividers** (fig. 2- 15J). The large pivot joint compass (fig. 2-15C) may also be used as dividers. As with compasses, dividers are available in large and small sizes, and in pivot joint, center adjustment bow, and side adjustment bow types. Figure 2-16C shows small side adjustment bow dividers. Pivot joint dividers are used for measurements of approximately 1 in. or more. For measurements of less than 1 in., bow dividers should be used. Dividers are used to transfer measurements, to step off a series of equal distances, and to divide lines into a number of equal parts.

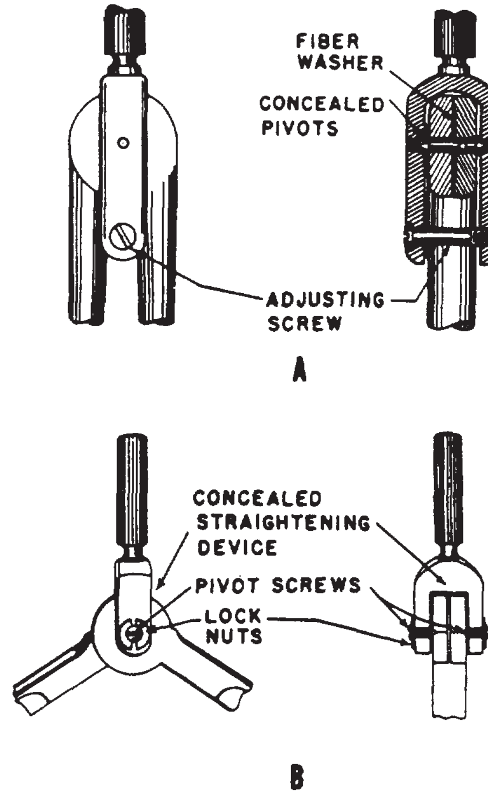
Drop Bow Pen

The DROP BOW PEN (fig. 2-16D) is not one of the standard instruments. However, for some jobs it is essential. It is used to ink small circles with diameters of less than a quarter of an inch. As the name indicates, the pen assembly is free to move up and down and to rotate around the main shaft. When using this instrument, hold the pen in the raised position, adjust the setscrew to give the desired radius, and then gently lower the pen to the paper surface and draw the circle by rotating the pen around the shaft.

Maintenance of Compasses and Dividers

Figure 2-17 shows the three shapes in which compasses and dividers are made: round, flat, and bevel. Figure 2-18 shows two types of pivot joints commonly found on compasses and dividers. When you select compasses and dividers, test them for alignment by bending the joints and bringing the points together. New instruments are factory adjusted for correct friction setting. They rarely require adjustment. A small jeweler's screwdriver or the screwdriver found in some instrument sets (fig. 2-15H) is used for adjusting most pivot joint instruments. Instruments that require a special tool should be adjusted by skilled instrument repairmen.

Pivot joint compasses and dividers should be adjusted so that they may be set without undue friction. They should not be so rigid that their manipulation is difficult, nor so loose that they will not retain their setting.



Courtesy of Keuffel & Esser Company, Rockaway, NJ

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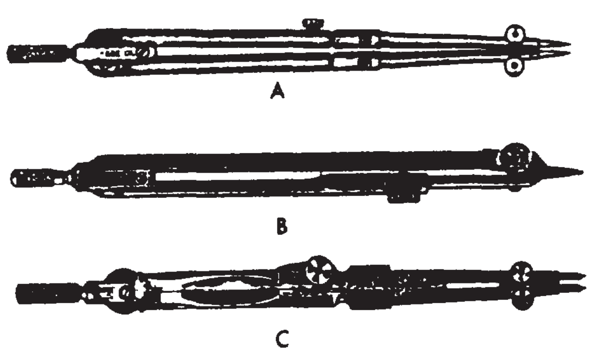
Figure 2-18.-Sections of pivot joints.



Courtesy of Keuffel & Esser Company, Rockaway, NJ

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Figure 2-17.-Shapes of compasses and dividers: (A) Round; (B) Flat; (C) Bevel.

Divider points should be straight and free from burrs. When the dividers are not in use, the points may be protected by sticking them into a small piece of soft rubber eraser or cork. When points become dull or minutely uneven in length, make them even by holding the dividers vertically, placing the legs together, and grinding them lightly back and forth against a whetstone. (See fig. 2-19, view A.) Then hold the dividers horizontally and sharpen each point by whetting the outside of it back and forth on the stone, while rolling it from side to side with your fingers (fig. 2-19, view B). The inside of the leg should remain flat and should not be ground on the stone. The outside of the point should not be ground so that a flat surface results. In shaping the point, be careful to avoid shortening the leg.

Needles on compasses and dividers should be kept sharpened to a fine taper. When they are pushed into the drawing, they should leave a small, round hole in the paper no larger than a

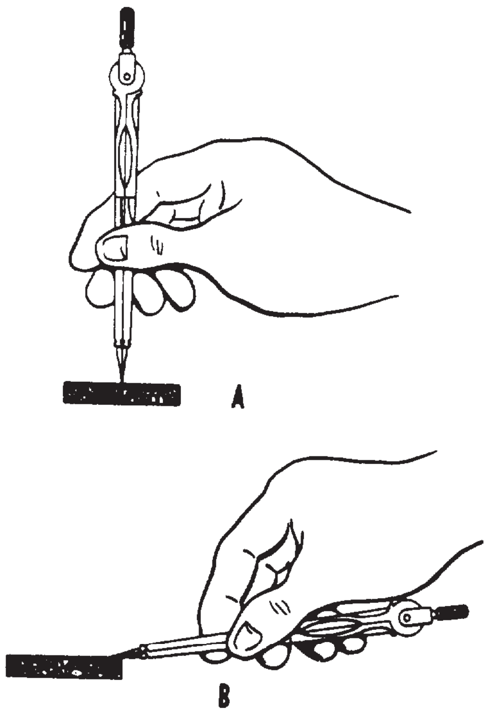

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Figure 2-19.-Divider maintenance: (A) Evening the legs of dividers; (B) Sharpening divider needlepoints.

pinhole. Since the same center is often used for both the compasses and dividers, it is best that needles on both be the same size. If the compass needle is noticeably larger, grind it until it is the correct size.

To make a compass needle smaller, wet one side of the whetstone and place the needle with its shoulder against this edge. Then grind it against the whetstone, twirling it between your thumb and forefinger (fig. 2-20). Test it for size by inserting it in a hole made by another needle of the correct size. When it is pushed as far as the shoulder, it should not enlarge the hole.

The screw threads on bow instruments are delicate. Because of this, you should take care never to force the adjusting nut. Threads must be kept free from rust or dirt.

If possible, it is best to keep drawing instruments in a case, since the case protects them from damage from falls or unnecessary pressures. Then, too, the lining of the case is usually treated with a chemical that helps prevent the instruments from tarnishing or corroding.

To protect instruments from rusting when they are not in use, clean them frequently with a soft cloth and apply a light film of oil to their surface

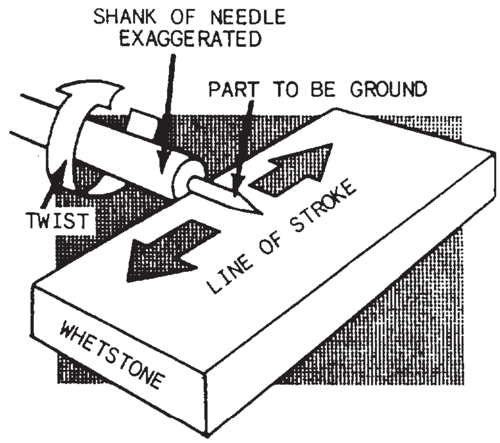

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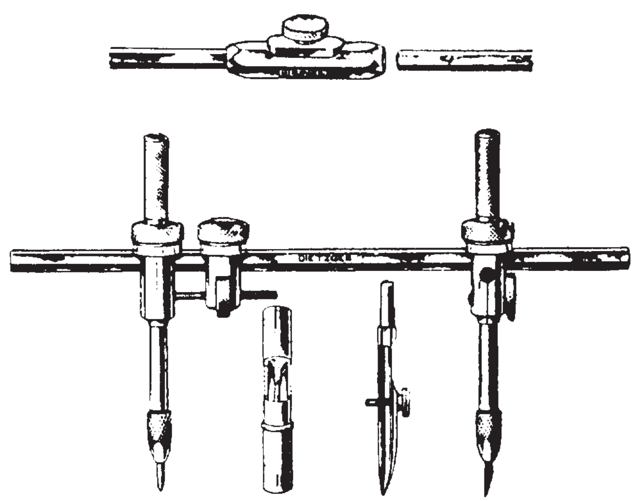
Figure 2-20.-Shaping a compass needle.

with a rag. Joints on compasses and dividers should not be oiled. When the surface finish of instruments becomes worn or scarred, it is subject to corrosion; therefore, a knife edge or an abrasive should never be used to clean drafting instruments.

Beam Compass

The BEAM COMPASS (fig. 2-21) is used for drawing circles with radii larger than can be set on a pivot joint or bow compass. Both the needle-point attachment and the pen or pencil attachment on a beam compass are slide-mounted on a metal



Courtesy of Dietzgen Corporation

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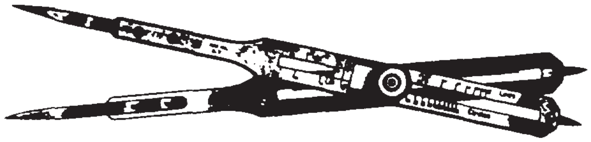
Figure 2-21.-Beam compass.



Courtesy of Keuffel & Esser Company, Rockaway, NJ

45.132X
Figure 2-22.-Proportional dividers.

bar called a beam. The slide-mounted attachments can be locked in any desired position on the beam. Thus, a beam compass can be used to draw circles of any radius up to the length of the beam. With one or more beam extensions, the length of the radius of a beam compass ranges from about 18 in. to 70 in.

PROPORTIONAL DIVIDERS

PROPORTIONAL DIVIDERS (fig. 2-22) are used for transferring measurements from one scale to another. This capability is necessary when drawings are to be made to a larger or smaller scale. They can also be used to divide lines or circles into equal parts.

Proportional dividers consist of two legs of equal length, pointed at each end, and held together by a movable pivot. By varying the position of the pivot, you can adjust the lengths of the legs on opposite sides of the pivot so that the ratio between them is equal to the ratio between two scales. Therefore, a distance spanned by the points of one set of legs has the same relation to the distance spanned by the points of the other set as one scale has to the other.

On the proportional dividers, a thumb nut moves the pivot in a rack-and-gear arrangement. When the desired setting is reached, a thumb-nut clamp on the opposite side of the instrument locks the pivot in place. A scale and vernier are provided on one leg to facilitate accurate setting. On less expensive models, the movable pivot is not on a rack and gear, and there is no vernier. The dividers may be set by reference to the table of settings that is furnished with each pair; they will accommodate varying ranges of scales from 1:1 to 1:10. However, it is better not to depend entirely on the table of settings. You can check the adjustment by drawing lines representing the desired proportionate lengths, and then applying the points of the instrument to them in turn until, by trial and error, the correct adjustment is reached.

To divide a line into equal parts, set the divider to a ratio of 1 to the number of parts desired on the scale marked Lines. For instance, to divide a line into three parts, set the scale at 3. Measure off the length with points of the longer end. The span of the points at the opposite ends will be equal to one-third the measured length. To use proportional dividers to transfer measurements from feet to meters, draw a line 1 unit long and another line 3.28 units long and set the dividers by trial and error accordingly.

Some proportional dividers have an extra scale for use in getting circular proportions. The scale marked Circle indicates the setting for dividing the circumference into equal parts.

The points of the dividers are of hardened steel, and if they are handled carefully, these points will retain their sharpness during long use. If they are damaged, they may be sharpened and the table of settings will still be usable, but the scale on the instrument will no longer be accurate.

SCALES

In one sense, the term scale means the succession of graduations on any graduated standard of linear measurement, such as the graduations on a steel tape or a thermometer. In another sense, when we refer to the "scale of a drawing," the term means the ratio between the dimensions of the graphic representation of an object and the corresponding dimensions of the object itself.

Suppose, for example, that the top of a rectangular box measures 6 in. by 12 in. If you draw a 6-in. by 12-in. rectangle on the paper, the dimensions of the drawing would be the same as those of the object. The drawing would, therefore, be a full-scale drawing. This scale could be expressed fractionally as 1/1, or it could be given as 1 in. = 1 in.

Suppose that instead of making a full-scale drawing, you decided to make a half-scale drawing. You should then draw a 3-in. by 6-in. rectangle on the paper. This scale could be expressed fractionally as 1/2, or it could be given as 1 in. = 2 in., or as 6 in. = 1 ft.

In this case, you made a drawing on a smaller scale than the scale of the original object, the scale of an original object being always 1/1, or unity. The relative size of a scale is indicated by the fractional representation of the scale. A scale whose fractional representation equals less than unity is a less-than-full scale. One whose fractional representation is greater than unity (such as a scale of 200/1) is a larger-than-full scale. A scale of 1/10,000 is, of course, smaller than a scale of 1/100.

A scale expressed as an equation can always be expressed as a fraction. For example, the scale of 1 in. = 100 ft, expressed fractionally, comes to 1 over (100 x 12), or 1/1,200.

It is obvious that any object that is larger than the drawing paper on which it is to be represented must be "scaled down" (that is, reduced to less-than-full scale) for graphic representation. Conversely, it is often desirable to represent a very small object on a scale larger than full scale for the purpose of clarity and to show small details. Because the drawings prepared by an EA frequently require scaling down, the following discussion refers mostly to that procedure. However, scaling up rather than down simply means selecting a larger-than-full scale rather than a smaller-than-full scale for your drawing.

You could, if necessary, determine the dimensions of your drawing by arithmetical calculation; for example, on a half-scale drawing, you divide each of the actual dimensions of the object by 2. However, this might be a time-consuming process if you were drawing a map of a certain area to a scale of 1 in. = 1,000 mi, or 1/6,335,000 ft.

Consequently, you will usually scale a drawing up or down by the use of one or another of a variety of scales. This sense of the term scales refers to a graduated, rulerlike instrument on which scale dimensions for a drawing can be determined by inspection.

Scales vary in types of material, shapes, style of division, and scale graduations. Good quality scales are made of high-grade boxwood or plastic, while inexpensive scales are sometimes made of yellow hardwood. The boxwood scales have white plastic scale faces that are permanently bonded to the boxwood. The graduation lines on the boxwood scales are cut by a highly accurate machine. Plastic scales, while less expensive than boxwood scales, have clear graduations and are reasonably accurate.

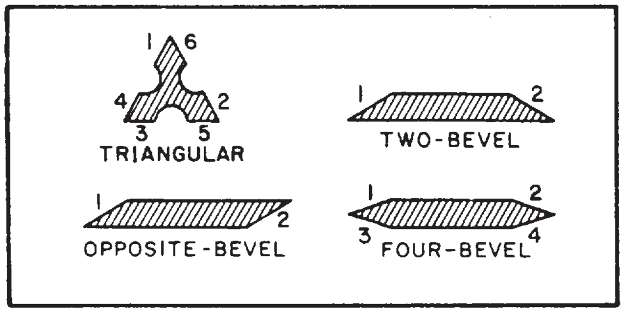


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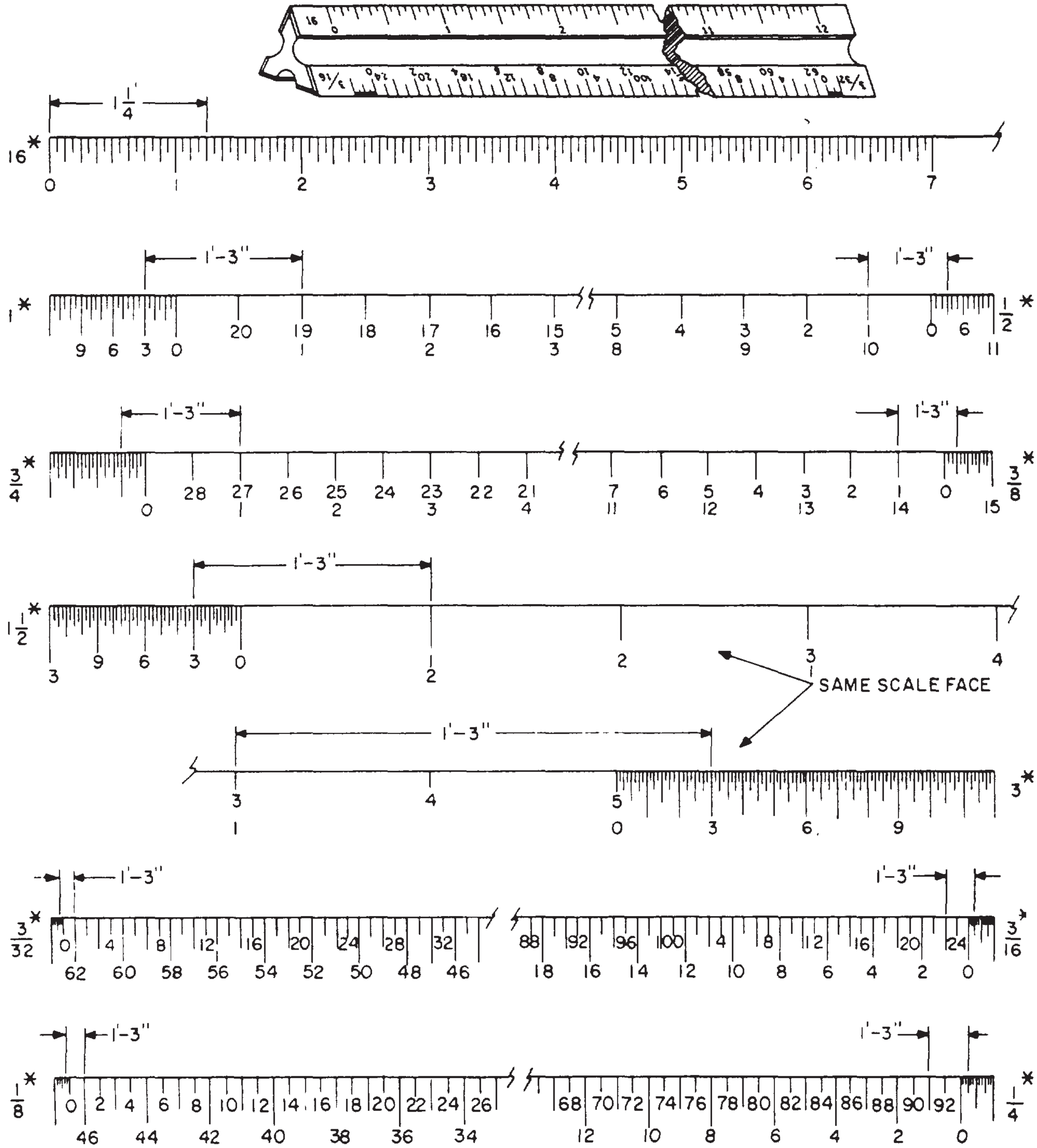
Figure 2-23.-Types of scales in cross section.

Scales are generally available in four different shapes, as shown in figure 2-23. The numbers in the figure indicate the location of the scale face. The triangular scale provides six scale faces on one rule. The two-bevel flat scale provides two scale faces on one side of the rule only. The opposite-bevel flat scale provides two scale faces, one on each side of the rule. And the four-bevel flat scale provides four scale faces, two on each side of the rule. The most common types of scales are the architect's, the engineer's, the mechanical engineer's, and the metric. All of these scales are found in the EA's draftsman kit with the exception of the mechanical engineer's scale, which is primarily used by machine draftsmen.

To gain a better understanding of the architect's and engineer's scale, which will be described in the following sections, it may be helpful to have the actual scales at hand as you study.

Architect's Scale

ARCHITECT'S SCALES are usually triangular in shape and are used wherever dimensions are measured in feet and inches. Major divisions on the scale represent feet which, in turn, are subdivided into 12ths or 16ths, depending on the individual scale.



NOTE:
16 SCALE IS SUBDIVIDED INTO SIXTEENTHS.
ALL OTHERS ARE SUBDIVIDED INTO TWELFTHS.
* SCALE DESIGNATION NUMBERS.

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Figure 2-24.-Architect's scale.

Figure 2-24 shows the triangular architect's scale. Also shown are segments of each of the eleven scales found on this particular type of scale. Notice that all scales except the 16th scale are actually two scales that read from either left to right or right to left. When reading a scale numbered from left to right, notice that the numerals are located closer to the outside edge. On scales that are numbered from right to left, notice that the numerals are located closer to the inside edge.

Architect's scales are "open" divided (only the main divisions are marked throughout the length) with the only subdivided interval being an extra interval below the 0-ft mark. These extra intervals are divided into 12ths. To make a scale measurement in feet and inches, lay off the number of feet on the main scale and add the inches on the subdivided extra interval. However, notice that the 16th scale is fully divided with its divisions being divided into 16ths.

Now let's measure off a distance of 1 ft 3 in. to see how each scale is read and how the scales compare to one another. (Refer to fig. 2-24.) Since the graduations on the 16th scale are subdivided into 16ths, we will have to figure out that 3 in. actually is 3/12 or 1/4 of a foot. Changing this to 16ths, we now see we must measure off 4/16ths to equal the 3-in. measurement. Note carefully the value of the graduations on the extra interval, which varies with different scales. On the 3 in. = 1 ft scale, for example, the space between adjacent graduations represents one-eighth in. On the 3/32 in. = 1 ft scale, however, each space between adjacent graduations represents 2 in.

The scale 3/32 in. = 1 ft, expressed fractionally, comes to 3/32 = 12, or 1/128. This is the smallest scale provided on an architect's scale. The scales on the architect's scale, with their fractional equivalents, are as follows:

3 in. = 1 ft . . . . 1/4 scale

1 1/2 in. = 1 ft . . . . 1/8 scale

1 in. = 1 ft . . . . 1/12 scale

3/4 in. = 1 ft . . . . 1/16 scale

1/2 in. = 1 ft . . . . 1/24 scale

3/8 in. = 1 ft . . . . 1/32 scale

1/4 in. = 1 ft . . . . 1/48 scale

1/16 in. = 1 ft . . . . 1/64 scale

1/8 in. = 1 ft . . . . 1/96 scale

3/32 in. = 1 ft . . . . 1/128 scale

Engineer's Scale

The chain, or civil engineer's, scale, commonly referred to as the ENGINEER'S SCALE, is usually a triangular scale, containing six fully divided scales that are subdivided decimally, each major interval on a scale being subdivided into 10ths. Figure 2-25 shows the engineer's scale and

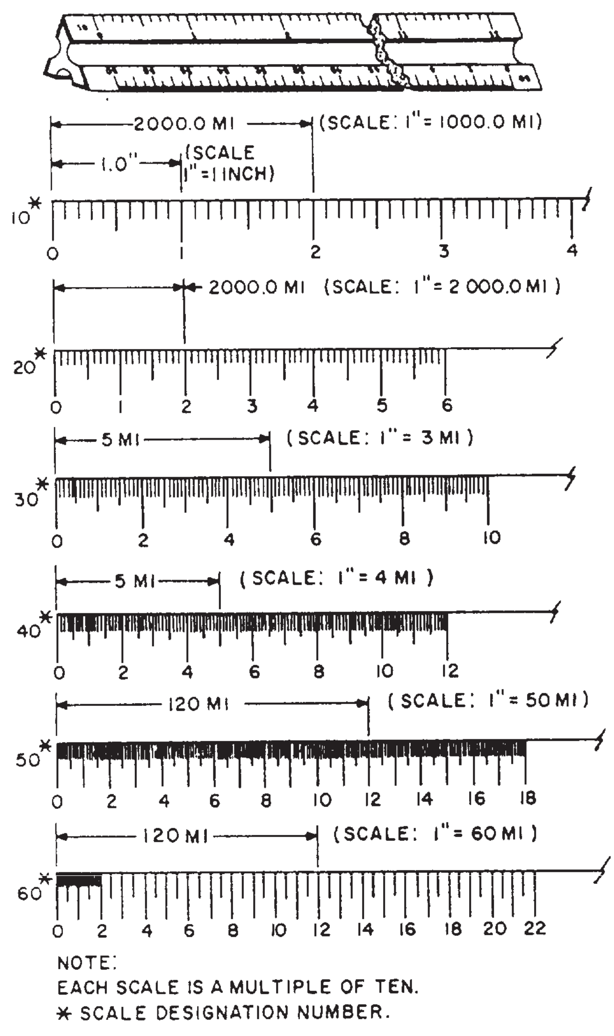

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Figure 2-25.-Engineer's scale.

segments of each of the six scales. Each of the six scales is designated by a number representing the number of graduations that particular scale has to the linear inch. On the 10 scale, for example, there are 10 graduations to the inch; on the 50 scale there are 50. You can see that the 50 scale has 50 graduations in the same space occupied by 10 on the 10 scale. This space is 1 linear inch.

To determine the actual number of graduations represented by a numeral on the engineer's scale, multiply the numeral by 10. On the 50 scale, for instance, the numeral 2 indicates 2 x 10, or 20 graduations from the 0. On the 10 scale, the numeral 11 indicates 11 x 10, or 110 graduations from the 0. Note that the 10 scale is numbered every major graduation, while the 50 scale is numbered every other graduation. Other scales on the engineer's scale are the 20, 30, 40, and 60.

Because it is decimally divided, the engineer's scale can be used to scale dimensions down to any scale in which the first figure in the ratio is 1 in. and the other is 10, or a multiple of 10.

Suppose, for example, that you wanted to scale a dimension of 150 mi down to a scale of 1 in. = 60 mi. You would use the 60 scale, allowing the interval between adjacent graduations to represent 1 mi. To measure off 150 mi to scale on the 60 scale, you would measure off 2.5 in., which falls on the 15th major graduation.

Suppose now that you want to scale a dimension of 6,500 ft down to a scale of 1 in. = 1,000 ft. The second figure in the ratio is a multiple of 10 times a multiple of 10. You would therefore use the 10 scale, allowing the interval between adjacent graduations on the scale to represent 100 ft, in which case the interval between adjacent numerals on the scale would indicate 1,000 ft. To measure off 6,500 ft, you would simply lay off from 0 to 6.5 on the scale.

To use the engineer's scale for scaling to scales that are expressed fractionally, you must be able to determine the fractional equivalent of each of the scales. For any scale, this equivalent is simply 1 over the total number of graduations on the scale, or 1 over the product of the scale number times 12, which comes to the same thing. Applying this rule, the fractional expressions of each of the scales is as follows:

10 scale = 1/120

20 scale = 1/240

30 scale = 1/360

40 scale = 1/480

50 scale = 1/600

60 scale = 1/720

Suppose you wanted to scale 50 ft down to a scale of 1/120. The 10 scale gives you this scale; you would therefore use the 10 scale, allowing the space between graduations to represent 1 ft, and measuring off 5 (for 50 ft). The line on your paper would be 5 in. long, representing a line on the object itself that is 120 in. x 5 in., or 600 in., or 50 ft long.

Similarly, if you wanted to scale 50 ft down to a scale of 1/600, you would use the 50 scale and measure off 5 for 50 ft. In this case, the line on your paper would be 1 in. long, representing a line on the object itself that is 1 x 600, or 600 in., or 50 ft long.

When it is not required that the drawing be made to a specified scale—that is, when the dimensions of lines on the drawing are not required to bear a specified ratio to the dimensions of lines on the object itself—the most convenient scale on the engineer's scale is used. Suppose, for example, that you want to draw the outline of a 360-ft by 800-ft rectangular field on an 8-in, by 10 1/2-in. sheet of paper with no specific scale prescribed. All you want to do is reduce the representation of the object to one that will fit the dimensions of the paper. You could use the 10 scale, allowing the interval between adjacent graduations to represent 10 ft. In this case, the numerals on the scale, instead of representing 10, 20, and so on, will represent 100, 200, and so on. To measure off 360 ft to scale, you should measure from 0 to the 6th graduation beyond the numeral 3. For 800 ft you should measure from 0 to the numeral 8.

Because you allowed the interval between adjacent graduations to represent 10 ft, and because the 10 scale has 10 graduations to the in., the scale of your drawing would be 1 in. = 100 ft, or 1/1,200.

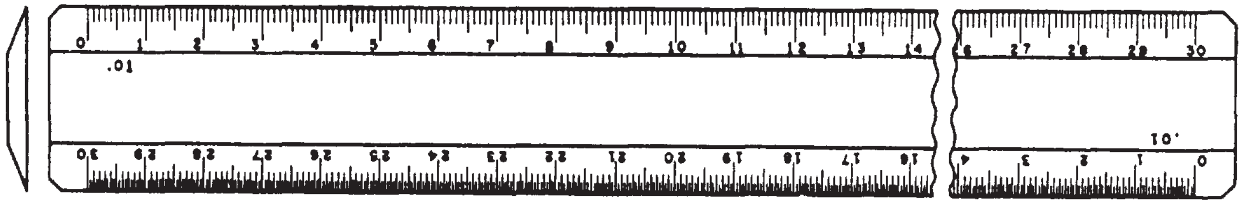

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Figure 2-26.-Flat metric scale.

Metric Scale

The METRIC SCALE is used in the place of the architect's and the engineer's scale when measurements and dimensions are in meters and centimeters. Metric scales are available in flat and triangular shapes. The flat 30-cm metric scale is shown in figure 2-26. The top scale is calibrated in millimeters and the bottom scale in half millimeters. The triangular metric scale has six fully divided scales, which are 1:20, 1:33 1/3, 1:40, 1:50, 1:80, and 1:100.

When you are using scales on a drawing, do not confuse the engineer's scale with the metric scale. They are very similar in appearance. Whenever conversions are made between the metric and English system, remember that 2.54 cm equals 1 in.

Triangular Scale Clip

For use with a triangular scale, a scale clip or scale guard, such as the one shown in figure 2-27, is very helpful. The clip makes it easy for you to identify what scale you are using. Large spring-type paper clips will serve the same purpose when scale clips are not available.

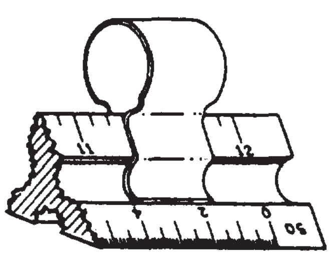

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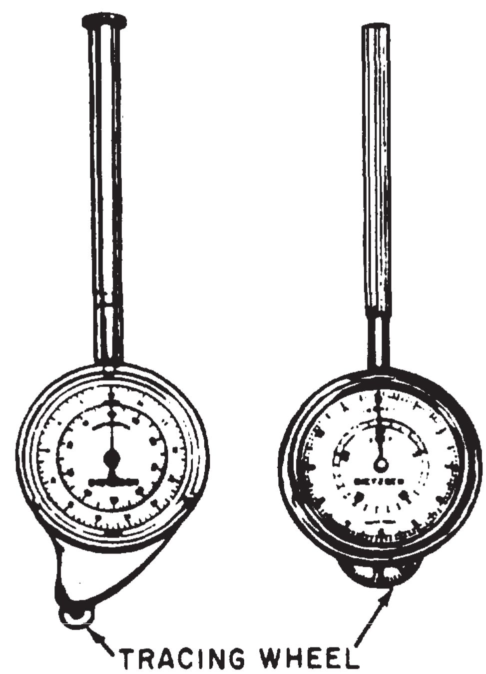
Figure 2-27.-Use of triangular scale clip.

MAP MEASURES AND SCALE INDICATORS

MAP MEASURES are precision instruments for measuring the lengths of roads, pipelines, and other irregular outlines on maps and drawings. Distances are measured by first setting the instrument to zero, then tracing the line to be measured with the small, projecting tracing wheel, like that on the map measures shown in figure 2-28.

In using map measures, do not depend entirely on the indicated numerical scale. Always check it against the graphical scale on the map or drawing. Verify if, for example, 1 in. traversed



Courtesy of Dietzgen Corporation

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Figure 2-28.-Types of map measures.

on the graphical scale really registers 1 in. on the dial; if not, make the proper correction to the distance measured. Actually, a map measure is just another odometer. Odometers are used to measure actual distances, while the map measures are used to measure scaled distances.

There are many ways of indicating the scale on a drawing. Among these are the fractional method, the equation method, and the graphic method.

In the fractional method, the scale is indicated as a fraction or a ratio. A full-size scale is indicated as 1/1; enlarged scale, as 10/1, 4/1, 2/1, etc.; and reduced scale, as 1/2, 1/4, 1/10, etc. Notice that the drawing unit is always given as the numerator of the fraction and the object unit as the denominator. On maps, the reduced scale fraction may be very large (for example, 1/50,000), as compared with the typical scales on machine drawings. On maps, the scale is frequently expressed as a ratio, such as 1:50,000.

In the equation method, a certain number of inches on the drawing is set equal to a certain length on the object. Symbols are used for feet (') and inches ("). On architectural drawings, a certain number of inches on the drawing is set to equal to 1 foot on the object. A full-size scale is entered as 12" = 1' – 0"; an enlarged scale, as 24" = 1'–0"; and a reduced scale, as 1/8" = 1' – 0". On civil engineering drawings, 1 in. on the drawing is set to equal to a certain measurement on the object: 1" = 5', 1" = 100', 1" = 1 mi.

In the graphic method, an actual measuring scale is shown on the drawing. Typical graphic scales are shown in figure 2-29. Note that in each case, the primary scale lies to the **right** of the 0; a subdivided primary scale unit lies to the **left** of the 0.

DRAFTING TEMPLATES

DRAFTING TEMPLATES are timesaving devices that are used for drawing various shapes and standard symbols. They are especially useful when shapes and symbols must appear on the drawing a number of times. Templates are usually made of transparent green or clear plastic. They are available in a wide variety of shapes, including circles, ellipses, hexagons, triangles, rectangles, and arcs. Special templates are available for symbols used on architectural drawings, mechanical drawings, and maps. Templates for almost every purpose are available from the well-known drafting supply companies. Figure 2-30 shows only a few of the more common types of drafting templates. One set of commonly used drafting templates is included in the EA's draftsman kit.

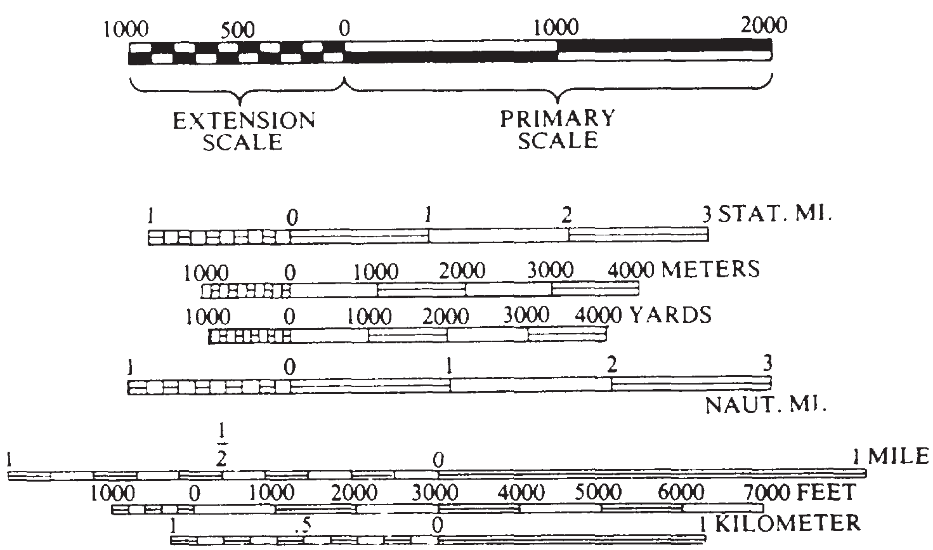

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Figure 2-29.-Typical graphic scales.

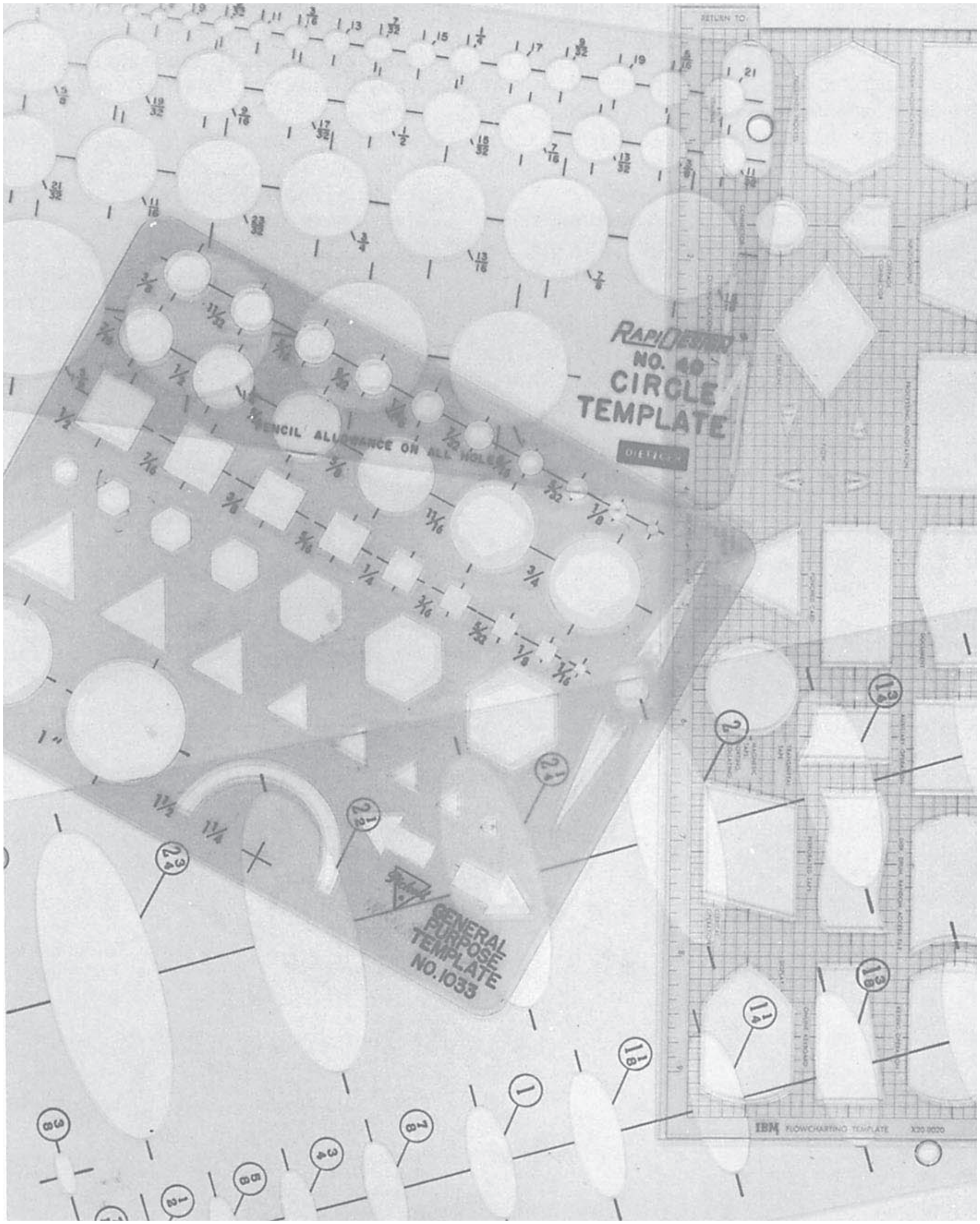

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Figure 2-30.—Drafting templates.

FREEHAND LETTERING PENS

Frequently, you will prepare inked drawings, maps, or charts that require freehand lines and lettering. There are many types of freehand pens available. But here we will be concerned only with those pens used by the EA. Included in the draftsman kit is a reservoir pen set, which may be used either with a penholder, as a freehand pen, or fitted into a mechanical lettering device for template lettering.

The technical fountain pen (sometimes called a Rapidograph pen or reservoir pen) may be used for ruling straight lines of uniform width with the aid of a T square, triangle, or other straightedge. It may also be used for freehand lettering and drawing and with various drawing and lettering templates. One of the best features of the technical fountain pen is its ink reservoir. The reservoir, depending on the style of pen, is either built into the barrel of the pen or is a translucent plastic ink cartridge attached to the body of the pen. The large ink capacity of the reservoir saves time because you do not have to constantly replenish the ink supply. Therefore, many EAs prefer the technical fountain pen to the ruling pen.

A typical technical fountain pen is shown in figure 2-31. Variations in pen style and line size are offered from various manufacturers. Some pens are labeled by the metric system according to the line weight they make. Other pens are labeled with a code that indicates line width measured in inches. For instance, a No. 2 pen draws a line .026 in. in width. Most technical fountain pens are color-coded for easy

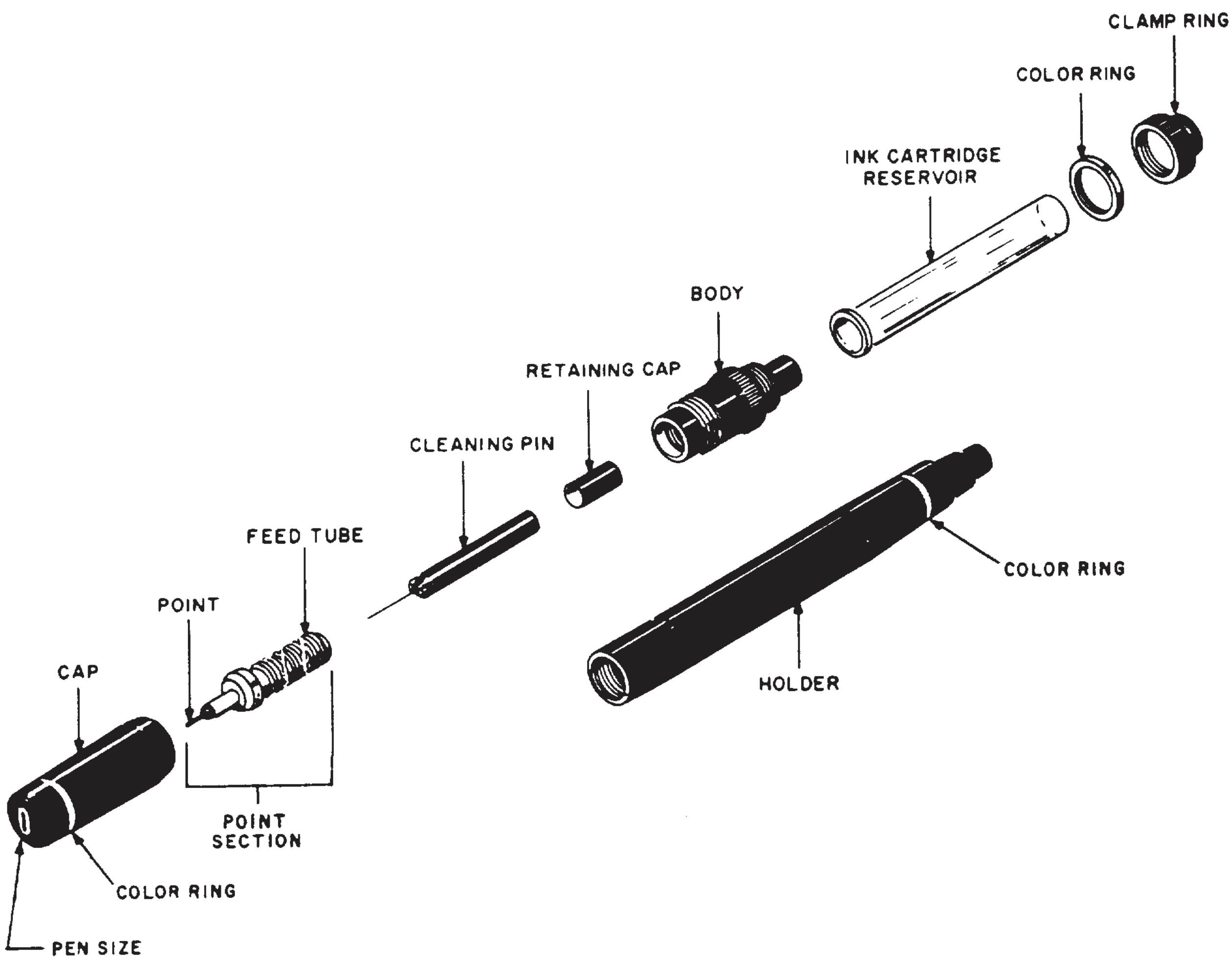

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Figure 2-31.-Technical fountain pen.

identification of pen size. These pens are available either as individual fountain pen units, resembling a typical fountain pen, or as a set, having a common handle and interchangeable pen units. The pen shown in figure 2-31 is a part of a set of technical fountain pens.

Some reservoir pens for lettering are made so the point section will fit in a Leroy scriber. (The Leroy letter set will be discussed in chapter 3.) These pens may also be used for any work that a regular technical fountain pen is used for.

Processes of Using the Technical Fountain Pen

As shown in figure 2-32, you must hold the technical fountain pen so that it is perpendicular to the drawing surface at all times. If you don't hold the pen in the correct manner, the point will bevel or wear unevenly and eventually form an elliptical point. With the point in this condition, the pen will produce lines of inconsistent widths.

To fill the reservoir of a fountain pen, use the knob located on the barrel opposite the point. When you turn the knob counterclockwise, a plunger is forced down into the barrel forcing out any ink remaining in the reservoir. Place the point end of the pen into the ink and turn the knob clockwise to pull the plunger up. As the plunger is pulled up, ink is drawn through the point, filling the reservoir.

To fill the ink cartridge type of pen shown in figure 2-31, remove the cartridge from the body and insert the ink bottle dropper all the way into the reservoir cartridge. Place the dropper in contact with the bottom of the reservoir cartridge to prevent the ink from forming air bubbles. Fill the cartridge to approximately three-eighths of an inch from the top, then replace the cartridge and clamp ring.

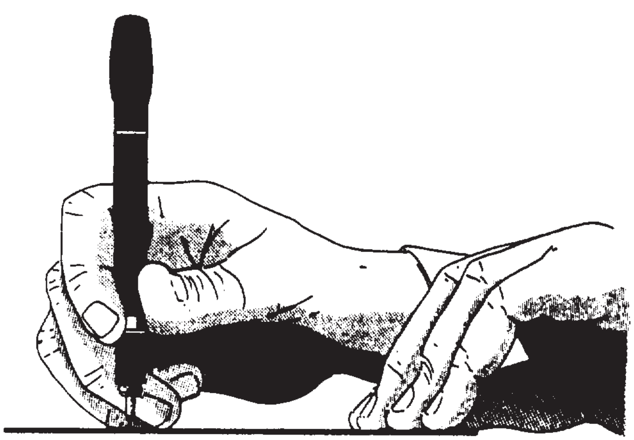

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Figure 2-32.-Drawing with a technical fountain pen.

Care and Cleaning of the Technical Fountain Pen

The feed tube of the pen point is threaded (fig. 2-3 1). Along this threaded portion is an inclined channel that allows air to enter the ink reservoir. This channel must be free of dried ink or foreign particles to ensure correct ink flow. When cleaning the pen, scrub the threads and channel with a brush, such as a toothbrush, wetted with a cleaning solution of soap and water. A cleaning pin (a tiny weighted needle) is made so that it fits into the feed tube and point (fig, 2-31). This cleaning pin assures a clear passage of ink from the reservoir to the point. Usually, a light shake of the pen will set the cleaning pin in motion, removing any particles that settle in the tube when not in use. (Do not shake the pen over your drawing board.)

If the pen is not used frequently, the ink will dry, clogging the point and feed tube. When the pen becomes clogged, soak the pen in pen cleaner or ammonia water until it will unscrew with little or no resistance. A better practice is to clean the pen before you put it away if you know in advance that you will not be using it for several days.

The cleaning pin must be handled with care, especially the smaller sizes. A bent or damaged cleaning pin will never fit properly into the feed tube and point.

DRAWING INK

A draftsman's drawing ink is commonly called INDIA INK. Drawing ink consists of a pigment (usually powdered carbon) suspended in an ammonia-water solution. Ink that has thickened by age or evaporation maybe thinned slightly by adding a few drops of solution of four parts aqua ammonia to one part distilled water. After the ink dries on paper, it is waterproof. Drawing ink is available in many different colors, but for construction and engineering drawings, black ink is preferred for reproduction and clarity. Small

3/4- or 1-oz bottles of black, red, and green ink are found in the standard draftsman kit. Larger bottles are available for refilling the small bottles. The stopper for a small ink bottle is equipped with either a squeeze dropper or a curved pipette for filling pens.

When you are working with ink, always keep the stopper on the ink bottle when you are not filling the pen, and keep the bottle far away from your drawing. Nothing is more frustrating for a draftsman than to spill a bottle of ink on a finished drawing. Special bottle holders are available to minimize this hazard. If you do not have a bottle holder, it would be to your advantage to devise your own.

OTHER TOOLS

Many tools other than the ones already presented in this chapter are currently used to help create technical drawings. A variety of drafting machines (not in the draftsman kit) are available at several shore-based support activities. Dependent upon the requirements of that particular activity, an EA assigned to staff or independent duty may also be exposed to a more advanced and sophisticated computer-assisted drafting method.

The standard drafting machine combines the functions of a parallel ruler, protractor, scales, and triangles. Various drafting operations requiring straight and parallel lines may be performed advantageously with a drafting machine.

The majority of drafting machines are constructed so that the protractor head may be moved over the surface of a drafting table without change in orientation by means of a parallel-motion linkage consisting of two sets of double bars. Figure 2-33 shows a rigid metal connecting link or arms, commonly called pin-joint linkage.

Another type of drafting machine has two steel bands enclosed in tubes working against one another (fig. 2-34) (although this type may also

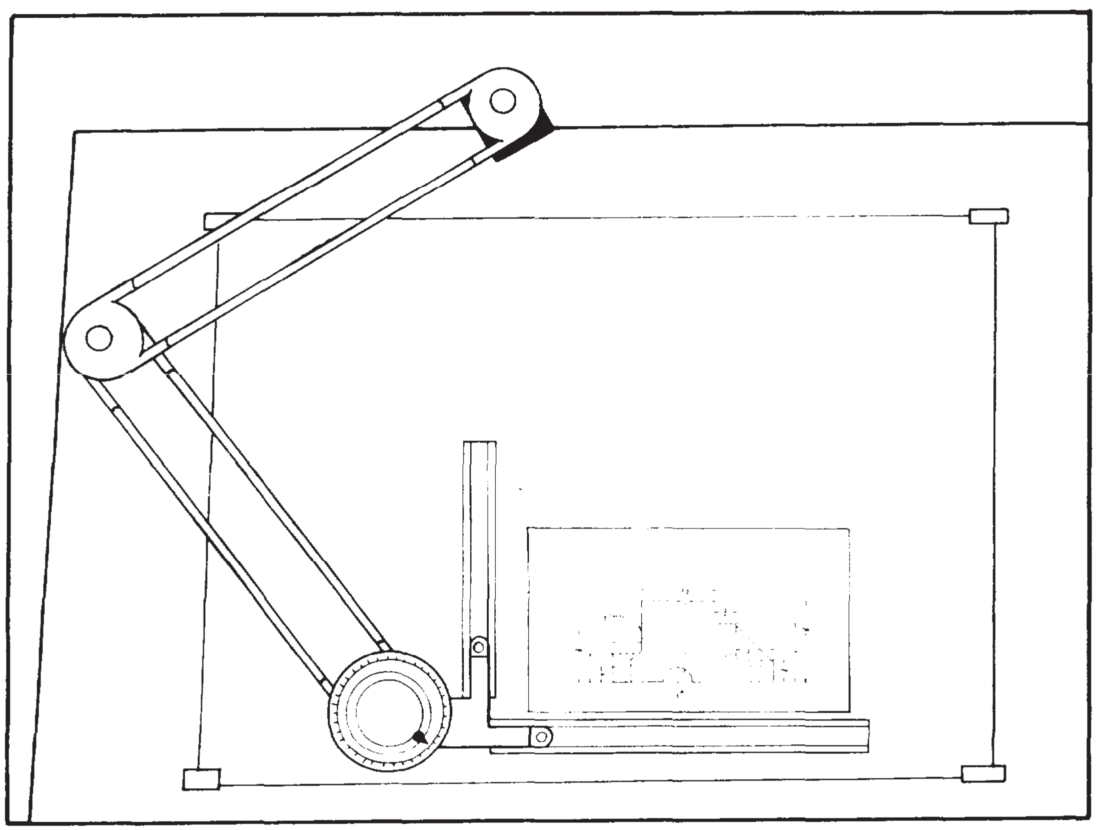

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Figure 2-33.-Drafting machine with rigid arms.

have the bands without the tubes). If these bands become loose through wear or expansion, the tension can be increased on them. This type of drafting machine is superior to that with pin-point linkage because there is less lost motion.

To learn more about other tools and their uses, refer to chapter 1 of the field manual FM 5-553, General Drafting, published by the Headquarters, Department of the Army, and other civilian publications.

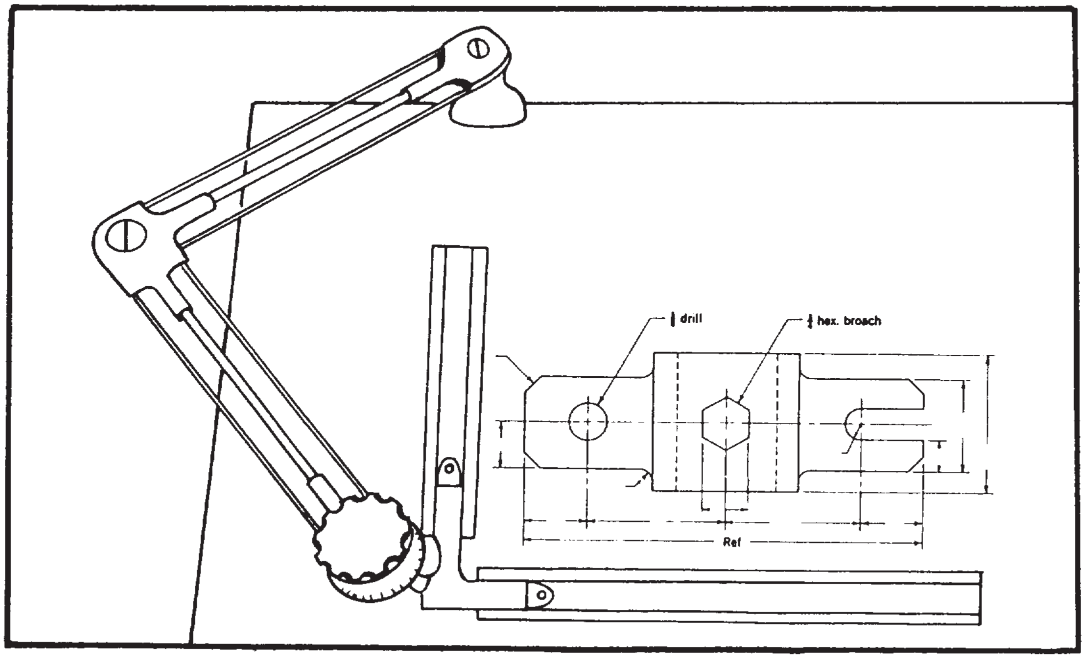

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Figure 2-34.-Drafting machine with enclosed steel bands.

CHAPTER 3

DRAFTING: FUNDAMENTALS AND TECHNIQUES; REPRODUCTION PROCESS

In this chapter you will learn the fundamental and basic techniques associated with the use of drafting equipment and accessories commonly used by the EA in preparing drawings and charts. The techniques are applied using standard drawing format, line conventions, and lettering described in detail in two of the publications you will use most often: DoD-STD-100C, *Engineering Drawing Practices,* and MIL-HDBK-1006/1, *Policy and Procedures for Project Drawing and Specification Preparation.* It is your responsibility to keep up to date on these publications and other applicable reference materials to ensure that your drawings are prepared according to the latest revisions.

This chapter also covers the procedures related to the safe use and maintenance of the typical reproduction equipment and discusses the different methods of reproducing drawings and the types of drawing paper used.

This training manual will not cover specific reproduction responsibilities since each command may have different reproduction equipment depending on its mission and the size of its engineering department. When you are assigned this responsibility, you will be given additional on-the-job training.

WORK PREPARATION

Before you begin to work, you should devote some time and thought to organizing your working area. Drafting furniture should be arranged so you can work comfortable y without fatigue or eyestrain. Be sure to check the lighting before you set up your drafting table. You can devise a system of stowing your equipment and supplies so that they are handy and in order.

WORK AREA

Your immediate work area should be large enough to allow sufficient freedom of movement, but not so large that you waste time reaching for equipment, supplies, and reference publications. An ideal working area allows each draftsman approximately 90 sq ft of space, although you may actually have more or less depending on the total area of the drafting room and the number of draftsmen who will work there.

If you are easily distracted, do not butt your drafting table up against and facing another draftsman's table.

Ensure that you have adequate lighting. The best light for drafting is natural light coming over the left shoulder and from the front left to avoid shadows cast by your hands, T square or parallel ruling straightedge, and triangles. Avoid a glaring light as it will cause eyestrain. Use the drafting lamp that was described in chapter 2. Your drafting table height should be from 36 to 40 in. above floor level. Your drafting chair or stool should be high enough that you can see the whole drawing board, but not so high that you have to lean over uncomfortably to draw. As mentioned in chapter 2, the board may be inclined or left flat according to your preference. A slope of 1 to 8 works well for the inclined position. By shifting your body or head slightly, you should be able to look directly at any point on an average-sized drawing sheet; that is, your line of sight should be approximately perpendicular to the drawing surface.

Before you begin to draw, arrange your equipment in an orderly manner. Place each article so that you can reach it easily, and keep it in place when you are not using it. A systematic arrangement is timesaving and efficient. You decrease the likelihood of accidentally dropping your tools or pushing them off the table if you keep them in order. You will find it very convenient to have a small worktable adjacent to your drafting board. Placing your drafting tools and reference publications on the worktable leaves you with an uncluttered drawing board surface. When you use the drafting board in the inclined position, a separate worktable becomes a necessity.

YOUR EQUIPMENT AND MATERIALS

Selection of drafting equipment and materials will depend largely upon each of your drafting assignments. Let your good judgment and common sense guide you in their selection. After some experience, you will automatically select proper equipment and materials as they are required. Until you become proficient, don't hesitate to seek the advice of your drafting supervisor or an experienced draftsman. Assignments to staff and support billets within the Naval Construction Force (NCF) will expose you to modern drafting equipment and materials, such as the adjustable drafting board with a drafting machine attached.

Drafting Board

As a SEABEE draftsman, you will probably not be able to select your drafting board. Unless the board is new, it will probably be marred and full of small pinholes. To obtain a smooth drawing surface, you should cover the board with a vinyl material or heavy manila paper. Laminated vinyl covering minimizes pencil scoring, is non-glaring, and is easily kept clean by wiping with a damp cloth. Heavy manila paper will serve the same purpose, but must be replaced when it becomes soiled or marked with use.

Drafting Paper

Most of the drawings that you will prepare will be drawn on tracing paper, which was described in chapter 2. You will use tracing paper to copy or trace drawings either in pencil or in ink. You will also prepare most of your original pencil drawings on tracing paper. This type of paper is especially suited for reproduction of blueprints. However, it tears easily and becomes soiled after repeated handling.

When making a drawing directly on tracing paper, you should place a smooth sheet of white paper below it (detail paper works well). The whiteness of this sheet (called a platen sheet) gives better line visibility, and its hard surface makes it possible to draw good pencil lines without grooving the tracing paper.

Do not usc gritty erasers on tracing paper, especially when ink is to be applied. If erasures must be made, use a green or red ruby eraser, which is only slightly abrasive. Abrasive erasers wear away the surface. Erase carefully so you don't tear the drawing. A light back-and-forth motion works best. If the surface of the drawing becomes scratched by erasing, it can be partially smoothed by burnishing the damaged area with a hard, smooth object or your thumbnail. Avoid using the electric eraser on tracing paper, as it will quickly "burn" a hole through the paper. To clean up smudges and dust, use a soft art gum eraser or sprinkle pounce on the drawing and rub lightly with your hand or a triangle.

Water, perspiration, or graphite from your pencil will ruin drawing paper. In order to keep moist hands or arms from marring the drawing, use a clean sheet of paper as a mask to protect the drawing surface next to the work area. Between drawing sessions you should protect unfinished drawings by covering them.

Tracing paper must not be folded. The crease marks will damage the lines on the drawing and cause blurred prints when the drawing is reproduced. For that matter, no drawing should ever be folded. Drawings and tracings should be either stored flat or rolled and placed in cylindrical containers. Prints or drawings larger than 8 1/2 in. by 11 in. may be folded so that they can be filed in standard filing cabinets.

Besides tracing paper, you will select other types of paper for special uses. You will be mainly concerned with the gridded papers described in chapter 2. The quality of the gridded paper that you will use is similar to that of tracing paper and should be used in the same manner.

As you gain experience, you will learn which type of paper to use for each drafting assignment. Of course, you will be limited by the types of paper available and the guidelines given to you by your drafting supervisor.

Drafting Pencils

For the average drafting assignment, three or four pencils are usually sufficient. A hard pencil, 4H or 5H, should be used to lay out the drawing in light construction and projection lines. A medium pencil, H or F, is then used to darken the required lines and to make arrowheads and lettering. The grade of drawing paper you use will also determine which pencil you choose for making a drawing. A soft, rough-textured paper usually requires a softer pencil for layout work, since a hard pencil would leave indentations in the paper and thus spoil the appearance of the drawing.

One way to find out if you are using the proper pencils on a drawing is to make a blueprint (reproduction) of the drawing. If the reproduced lines do not appear, or appear too light, use a softer pencil. If, on the other hand, lines appear too dark in relation to other lines, use a harder pencil. You may be able to vary the weight of lines by the amount of pressure exerted on the pencil, but this should not be attempted without experience. Bearing down on a hard pencil to produce darker lines may cause grooves in the paper.

Another way to find out if you are using the proper pencil is to hold your drawing up to a light and view it from the back side. Pencil adjustment is the same as in the previous method. Of course, both methods apply only when transparent drawing paper is used.

To sharpen a pencil, cut the wood away from the unlettered end (fig. 3-1, view A) with a draftsman's pencil sharpener or a penknife. The lettered end should be left intact so that the grade of pencil can always be identified. The cut should be started about 1 1/2 in. from the end, leaving a half inch of lead exposed. To produce a conical or needlepoint (fig. 3-1, view B), which is best for general use, rotate the pencil between the fingers at the same time as the exposed lead is rubbed back and forth across the full length of the sandpaper pad (fig. 3-1, view C). Many draftsmen prefer to use a mechanical lead pointer instead of the sandpaper pad. The mechanical pointer quickly produces a uniform conical or needlepoint. However, the sandpaper pad must still be used to produce other types of points. The resulting needlepoint should be dulled slightly by drawing it lightly across a piece of scrap paper several times. Avoid sharpening pencils near your drawing. Graphite particles will cause smudges that are difficult to erase. A cloth or tissue should be used to wipe away graphite particles that cling to the pencil after it is sharpened. A wedge point (fig. 3-1, view D) will aid an experienced draftsman in the extensive drawing of straight lines. This point is produced by sharpening a pencil to the conical point just described, then flattening both sides on the sandpaper pad. For an elliptical point, hold the pencil firmly with thumb and fingers and cut the lead on the sandpaper pad by a back-and-forth motion, keeping the pencil at an angle of about 25 degrees to the pad. Continue until a flat ellipse is formed, as shown in figure 3-1, view E. A good draftsman never uses a dull pencil.

Some draftsmen prefer to use mechanical drafting pencils instead of wooden pencils. The lead of a mechanical pencil is sharpened in the same manner as the lead of a wooden pencil. However, the length of the mechanical pencil is not depleted as the lead is sharpened. This is an advantage over wooden pencils that become difficult to use when they are less than 3 in. in length. When leads for the mechanical pencil are exchanged, ensure that the changeable lead grade designator on the mechanical pencil corresponds to that of the lead used.

BASIC DRAFTING TECHNIQUES

You should practice handling and using drafting instruments before attempting complex drawing problems. Developing correct drawing habits will enable you to make continuous improvement in the quality of your drawings. The

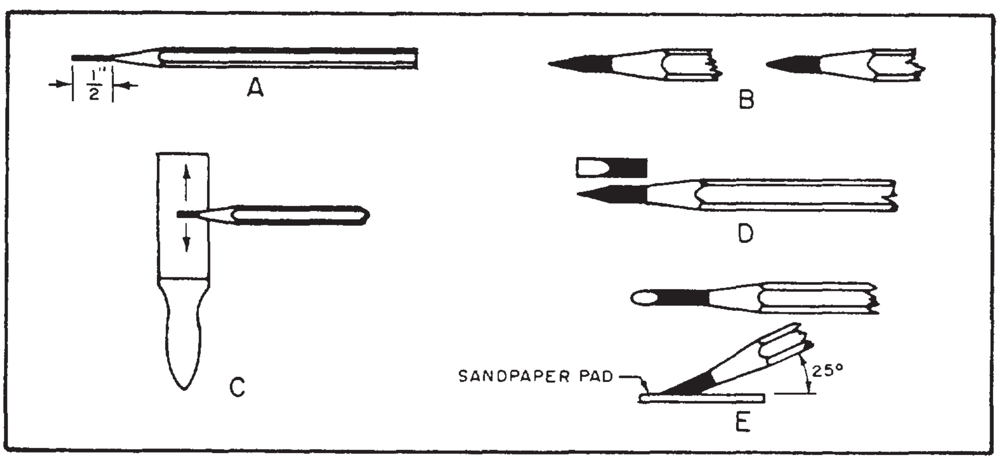

Figure 3-1.-Sharpening pencil points.

main purpose of making your first drawings is to learn to use instruments. Each drawing will offer an opportunity for practice. Later on, good form in the use of instruments will become a natural habit.

Accurate pencil drawings are of first importance since all inked drawings and tracings are made from finished pencil drawings. It is a mistake to believe that a poor pencil drawing can be corrected when you make the ink tracing. Any drawing important enough to be inked or traced in ink must be accurate, legible, and neat. Because most military and commercial blueprints are made from pencil drawings, ambitious trainees will work to acquire skill in pencil drawing as they perfect their technique. Good technique and skillful pencil drawing are basic to proficiency in drafting.

The following sections will guide you in attaching your drawing paper to the board and in drawing basic lines with the T square, triangles, and pencil.

ATTACHMENT OF PAPER TO THE BOARD

Now that you have become relatively familiar with your equipment and materials, it is time to get started by attaching your drafting paper to the board. The sheet should be placed close to the left edge of the drafting board. Working in this area makes the T square easier to handle and reduces the likelihood of error because of T square "swing." The drafting sheet should be far enough from the bottom of the board (about 3 in.) to ensure firm support for the head of the T square when you are drawing at the lower part of the sheet. A drawing sheet properly attached to the board on which a T square is used is shown in figure 3-2. After aligning the drawing sheet, smooth out any wrinkles and fasten the four corners with short strips of drafting tape. If you are attaching large sheets, you should place additional strips of tape at the top and bottom edges of the sheet. Drafting tape has a lighter coating of adhesive than does masking tape. Consequently, it will hold the drawing firmly, yet can be removed without tearing or marring the drawing. If you use masking tape or transparent tape, leave a large margin in the event you tear the paper when removing the tape. When placed diagonally across the corners of the sheet, as shown in figure 3-2, the drafting tape offers little obstruction to movement of the T square and triangles. Avoid the use of thumbtacks; they will eventually ruin the drafting board.

If you are using a parallel straightedge or drafting machine instead of a T square, the procedure just described is the same with one exception. Instead of placing the paper close to the left edge of the board, you should place it approximately at the midpoint of the length of the parallel straightedge or in the center of the drawing board surface when you are using a drafting machine.

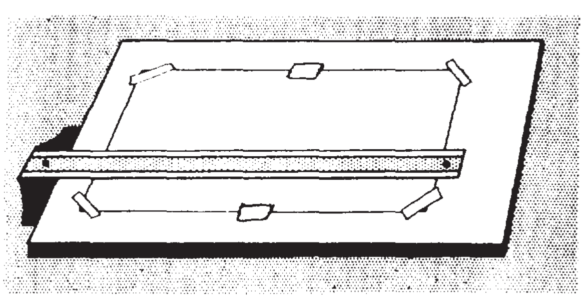

Figure 3-2.-Attaching drafting paper to the board.

HORIZONTAL LINES

The draftsman's horizontal line is constructed by drawing from left to right along the working

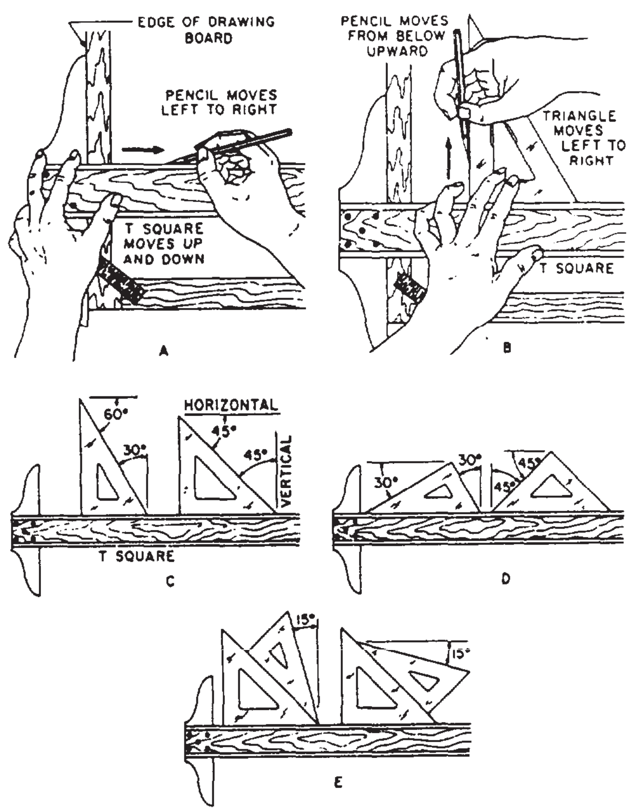

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Figure 3-3.-Construction of basic lines.

edge of a T square, as shown in figure 3-3, view A. This working edge, when true, is perpendicular to the working edge of the drafting board. When you draw horizontal lines, keep the working edge of the T square head in firm contact with the working edge of the drafting board. The pencil should be inclined to the right at an angle of about 60 degrees, with the point close to the junction of the working edge and the paper. Hold the pencil lightly and, if it was sharpened with a conical point, rotate it slowly while drawing the line to achieve a uniform line width and preserve the shape of the point. Normally, when a series of horizontal lines is being drawn, the sequence of drawing is from the top down.

VERTICAL LINES

Vertical lines are produced parallel to the working edge of the drafting board by using triangles in combination with a T square. One leg of a triangle is placed against the working edge of the blade and the other faces the working edge of the board to prevent the draftsman from casting a shadow over his work. Lines are drawn from the bottom up, as shown in figure 3-3, view B. The pencil is inclined toward the top of the working sheet at an angle of approximately 60 degrees, with the point as close as possible to the junction of the triangle and the drafting paper. Sequence in drawing a series of vertical lines is from left to right. At no time should the lower edge of the T square blade be used as a base for triangles.

INCLINED LINES

The direction or angle of inclination of an inclined line on a drafting sheet is measured by reference to the base line from which it is drawn. Inclined lines at standard angles are constructed with the T square as a base for triangles used either singly, as shown in views C and D of figure 3-3, or in combination, as shown in view E of figure 3-3.

Used in combination with the T square as a base, the triangles serve as guides for producing lines at intervals of 15 degrees, as shown in figure 3-4. Used singly, the 45-degree triangle will divide a circle into 8 equal parts; the 30°/60° triangle will divide a circle into 12 equal parts. For drawing lines at angles other than those described above, you should use a protractor.

PROTRACTION OF ANGLES

To measure an angle, place the center mark of the protractor at the vertex of the angle, with the 0-degree line along one side. Then note the degree mark that falls on the side. To lay off an angle, position the protractor as above and use a needlepoint or a sharp-pointed pencil to mark the desired values. Then project lines from the vertex to these marks.

Using only the three points on the protractor, as described above, may result in considerable inaccuracy, particularly if the lines of an angle are to be extended for some distance beyond the protractor. A refinement of the procedure is indicated in figure 3-5. Suppose angle BOA is to

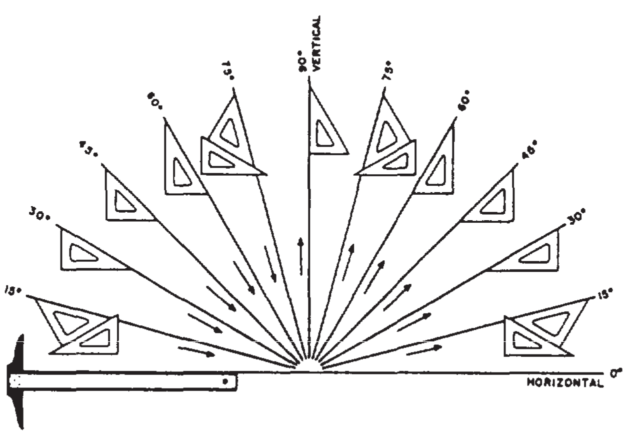

Figure 3-4.-Using T square (or parallel straightedge) and triangles to draw lines at different angles to the horizontal. Arrows indicate the direction in which the lines should be drawn.

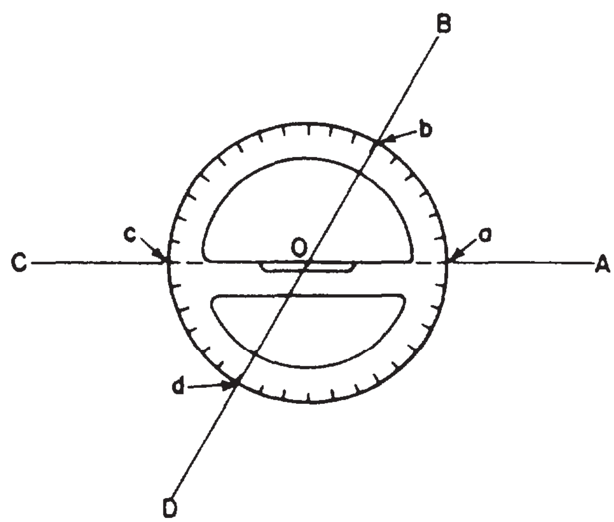

Figure 3-5.-Protracting an angle.

be measured. Extend line AO on to C; extend line BO on to D. When you set the center of the protractor at O, make sure that both points c and a are on line AC. Take your reading at point d as well as at point b when you measure the angle. If you are laying off the angle BOA, protract and mark point d as well as point b; this gives you three points (d, O, and b) for establishing line DB. If you are using a semicircular protractor, you can't, of course, locate point d; but your accuracy will be improved by lining up c, O, and a before you measure or lay off the single angle BOA.

PARALLEL AND PERPENDICULAR LINES

To draw a line parallel to a given line (fig. 3-6, view A), adjust the hypotenuse of a triangle in combination with a straightedge (T square or triangle) to the given line; then, holding the straightedge firmly in position, slip the triangle to the desired position and draw the parallel line along the hypotenuse.

To construct a line perpendicular to an existing line, use the triangle and straightedge in combination, with the hypotenuse of the triangle resting against the upper edge of the straightedge (fig. 3-6, view B). Adjust one leg of the triangle to a given line. Then slide the triangle along the supporting straightedge to the desired position and draw the line along the leg, perpendicular to the leg that was adjusted to the given line. In the same manner, angles with multiples of 15 degrees may be drawn, using the triangle combinations shown in figure 3-4.

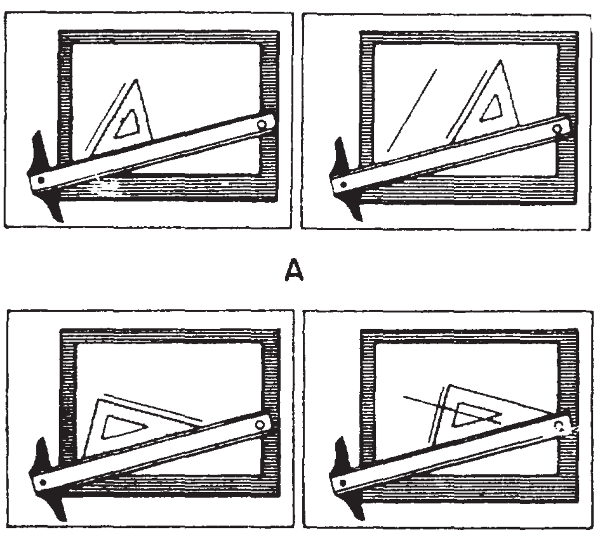

Figure 3-6.-Drawing parallel and perpendicular lines.

CURVED LINES

Many drawings that you will prepare require the construct ion of various curved lines. Basically there are two types of curved lines: circles and segments of circles, called arcs, which are drawn with a compass; and noncircular curves, which are usually drawn with french curves. In this chapter we will discuss only techniques for using the compass and the french curve. Application of compass techniques in geometric construction will be covered in chapter 4.

Use of the Compass

When you are drawing circles and arcs, it is important that the lines produced with the compass are the same weight as corresponding pencil lines. Since you cannot exert as much pressure on the compass as you can with pencils, you should use a compass lead that is

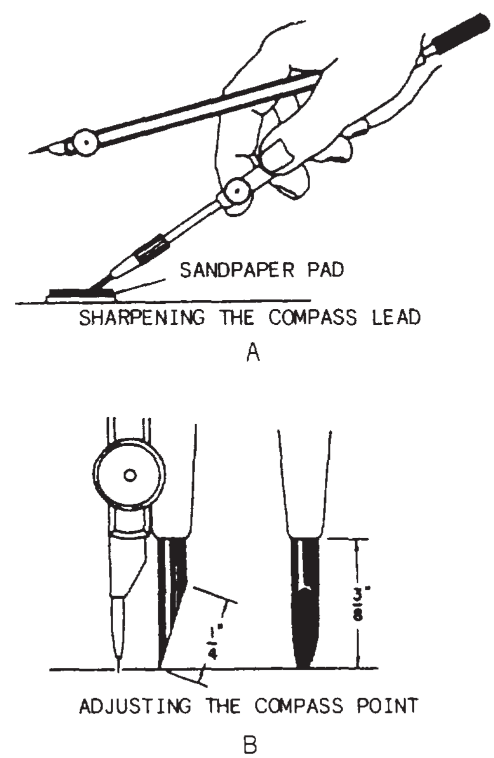

Figure 3-7.-Sharpening the compass lead and adjusting the point.

about one grade softer than the pencil used for corresponding line work. For dim construction lines, use 4H to 6H leads. Avoid using leads that are too short.

The compass lead should be sharpened with a single elliptical face, as shown in figure 3-7, view A. A sandpaper pad works best for sharpening compass leads. The elliptical face of the lead is normally placed in the compass so that it faces outward from the other compass leg. Adjust the shoulder-end needlepoint so that the point extends slightly farther than the lead (fig. 3-7, view B). With the needlepoint pressed lightly in the paper, the compass should be centered vertically when the legs are brought together.

Bow compasses and pivot joint compasses are used in the same manner. To draw a circle with a compass, lightly press the needlepoint into the drawing paper and rotate the marking leg around it. Always rotate the compass clockwise. As you rotate, lean the compass slightly forward. With a little practice, you will find that you can easily draw smooth circles using only the thumb and forefinger of one hand. It is important that you use an even pressure as you rotate the compass. You may find it necessary to rotate the compass several times to produce a circle with a uniform dense black line.

When you wish to set the compass to draw a circle of a given diameter, use a piece of scratch paper and follow the steps listed below, referring to figure 3-8.

1. Draw a horizontal line with a straightedge.
2. With the straightedge as a base, use a triangle and draw a vertical line intersecting the horizontal line (fig. 3-8, view A).
3. Measure the radius of the circle with a scale, as shown in figure 3-8, view B, and draw a second vertical line from this point.
4. Set the needlepoint at the intersection of the first vertical line and the horizontal line (fig. 3-8, view C). This is the center of the circle.
5. Set the marking leg to fall on the intersection of the second vertical line and the horizontal line (fig. 3-8, view D).
6. Draw a half circle with the compass fig. 3-8, view E).
7. Check your work by measuring the diameter established by this half circle with a scale (fig. 3-8, view F).

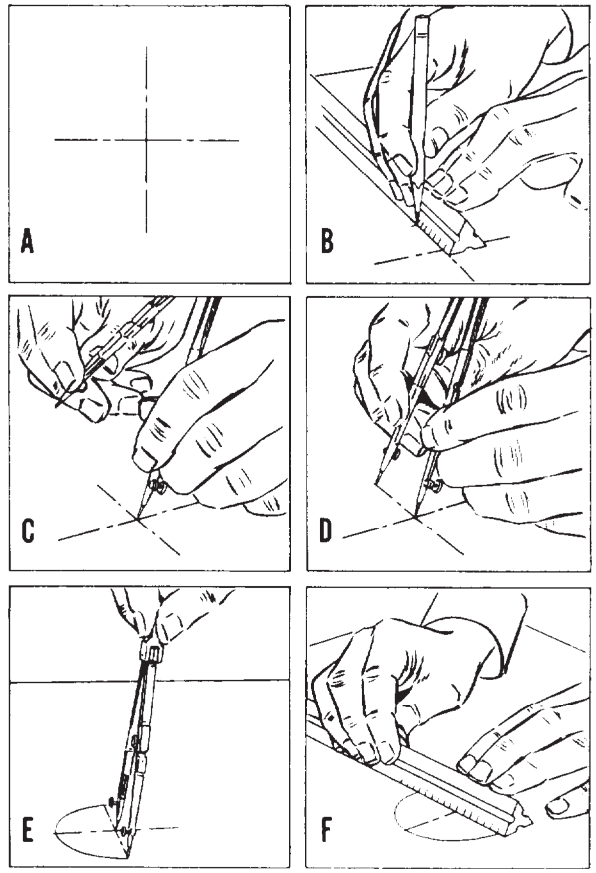

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Figure 3-8.-Drawing a circle of a given radius.

Once You have set the compass to the exact radius of the circle, handle it very carefully so that you don't disturb the setting. Set the needlepoint at the center of the circle and carefully rotate the compass to draw a line describing the circumference of the circle. Do not apply too much pressure on the needlepoint or it will bore a hole in the paper and you will lose the accurate center mark. To keep the diameter of the hole to a minimum, you may set the needlepoint of the compass on a small strip of paper or thin cardboard over the drafting sheet at the center of the circle.

When you are using the pencil leg to draw circles smaller than 1 in. in radius, keep the adjustable pencil and needle legs straight. For larger circles, both legs should be adjusted so that they are perpendicular to the paper. On the other hand, when you are using the compass with the pen leg, you MUST adjust it at the hinge joint to keep it perpendicular to the paper for all size

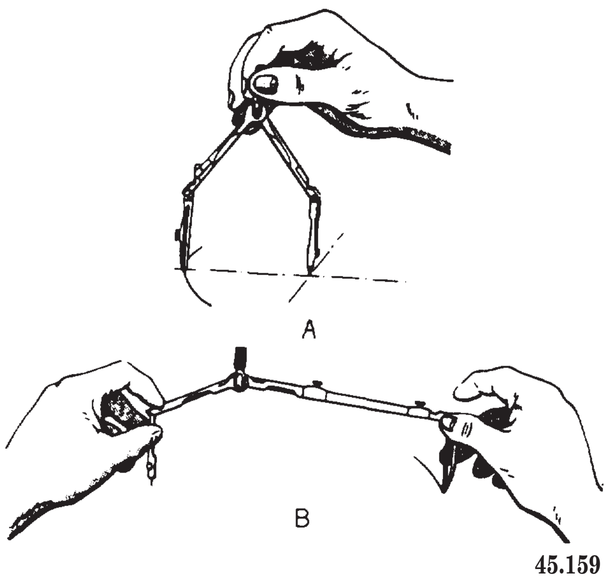

Figure 3-9.-Drawing a circle in ink.

circles. (See fig. 3-9, view A.) If the pen is not perpendicular to the paper, ink will not flow properly. To draw large circles, insert the extension bar in the pen or pencil leg, as shown in figure 3-9, view B. When the extension bar is used to draw large circles, the process of using the compass with only one hand becomes awkward. You should use both hands, as shown in figure 3-9, view B.

Use of the French Curve

The french curve is used to draw a smooth line through predetermined points. After the points are plotted, a light pencil line should be sketched to connect the points in a smooth flowing line. To draw the finished line over the freehand line, match the various parts of the french curve to various segments of the freehand curve. Avoid abrupt changes in curvature by placing the short radius of the french curve toward the short radius portion of the line to be drawn. Change your position around the drawing board when necessary so that you can work on the side of the french curve that is away from you. You should avoid working on the "under" side of the french curve. Place the french curve so that it intersects at least two points of the line. When drawing the line along the edge of the french curve, stop short of the last point intersected. Then move the french curve along to intersect two or three more points and make sure that the edge of the curve connects smoothly with the line already drawn. When using the irregular curve, you can draw a perfectly smooth curved line by plotting enough points (the

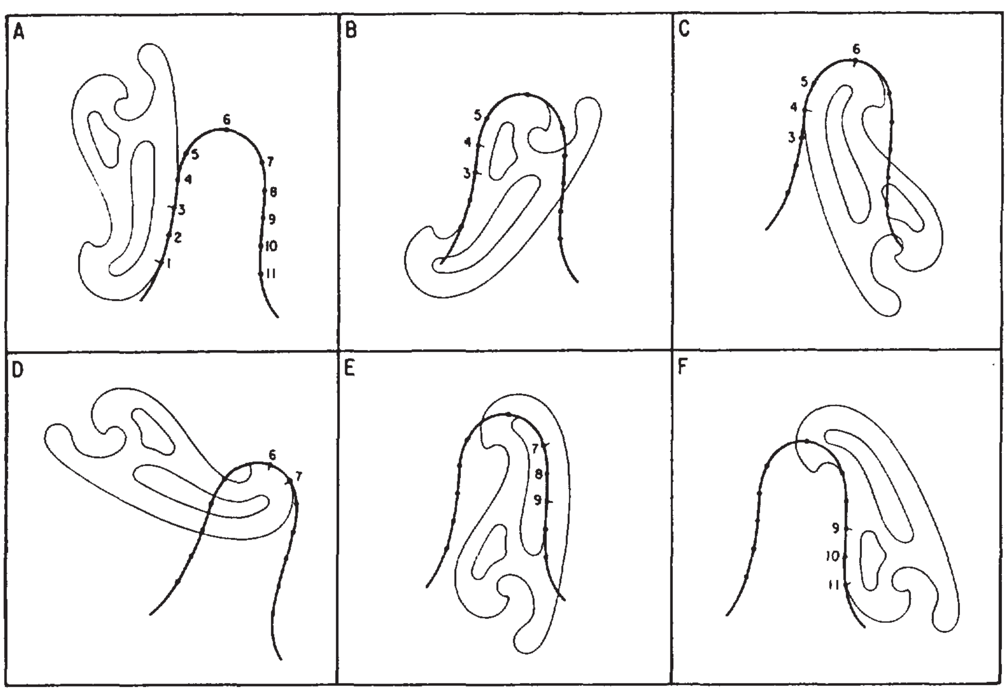

Figure 3-10.-Use of the french curve.

sharper the curve, the more points you need) and by drawing in shorts steps.

Figure 3-10 shows how a smooth line is drawn through a series of plotted points. The french curve in view A matches points 1, 2, 3, and 4. Draw a line from 1 to 3 only (not to 4).

At B, the curve matches points 3 to beyond 4. Draw a line from 3 to 4 only (not to 5).

At C, it matches points 4, 5, and 6. Draw a line from 4 to just short of 6.

At D, it matches a point short of 6 to beyond 7. Draw a line from 6 to 7.

At E, it matches a point short of 7 to beyond 9. Draw a line from 7 to 9.

At F, it matches a point short of 9 to beyond 11. Draw a line from 9 to 11.

You will probably notice how the french curve is turned over and reversed to find portions that fit the points on the line with increasing or decreasing changes in curvature.

When you are drawing a curved line that extends into a straight line, the curve should be drawn first, and the straight line joined to it.

USE OF DRAFTING TEMPLATES

Drafting templates should be used only when accuracy can be sacrificed for speed. Circles or arcs, for example, can be drawn more quickly with a template than with a compass. Templates must be used properly to be effective.

To draw a circle with the circle template (fig. 3-11), lay out center lines on the drawing where the circle is to be drawn. Then place the correct circle opening over the center line so that the quadrant lines on the template coincide with the center lines on the paper. Draw the circle, using a sharp, conical point on the pencil. Allowance must always be made for the width of the pencil line in placing the template opening in the right position on the drawing.

To draw an arc, lay out tangent lines on the drawing. Then place the correct size circle of the template on the paper so that the template quadrant lines coincide with the tangent lines, and draw the arc.

When using a template, you must hold it down firmly to keep it from slipping out of position. Figures or circles from the template must be drawn with the correct line weight on the first setting as it is difficult to reset the template in the exact position.

USE OF THE DIVIDERS

As we stated in chapter 2, dividers are used to transfer measurements, to step off a series of equal distances, and to divide lines into a number of equal parts. Dividers are manipulated with one hand. In setting dividers (fig. 3-12, view A), hold

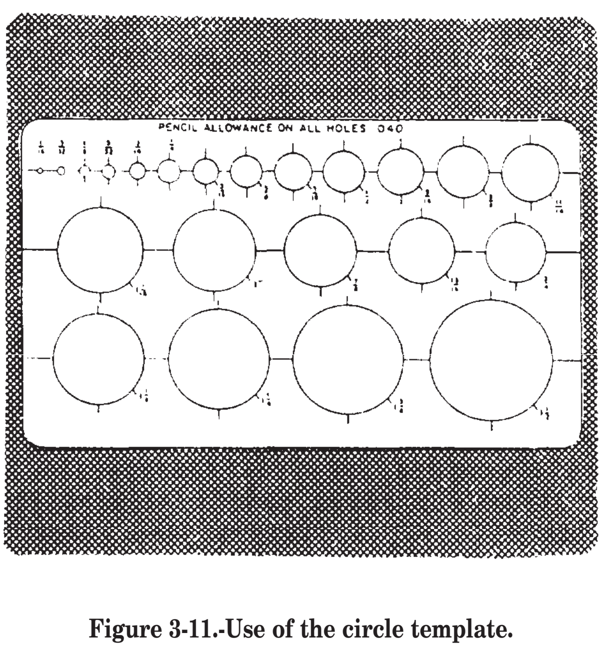

Figure 3-11.-Use of the circle template.

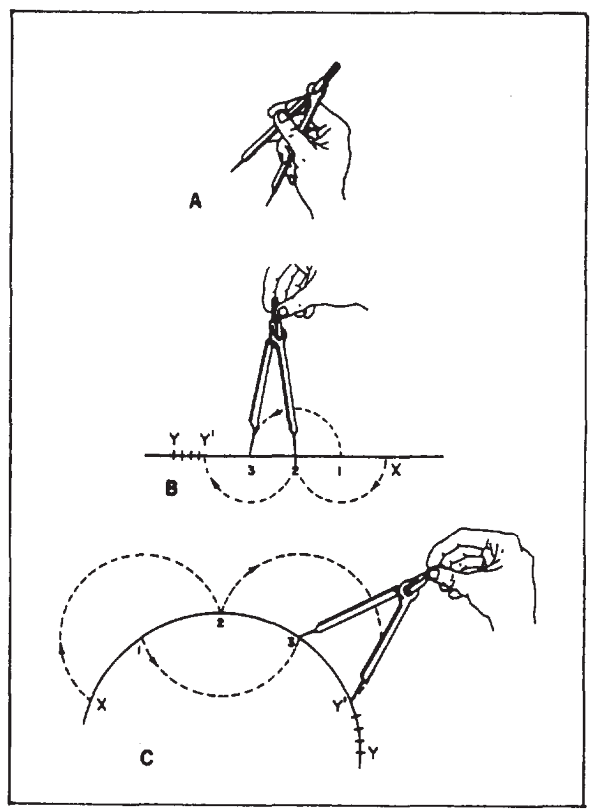

Figure 3-12.-Use of the dividers.

one leg between the thumb and the first and second fingers, and hold the other leg between the third and fourth fingers. Place the second and third fingers on the inside of the legs; the dividers are opened by spreading these fingers apart. Dividers are closed by squeezing the thumb and first finger toward the fourth finger while gradually slipping out the other two fingers.

To transfer measurements on a drawing, set the dividers to the correct distance, then transfer the measurements to the drawing by pricking the drawing surface very lightly with the points of the dividers.

To measure off a series of equal distances on the line, set the dividers to the given distance. Then step off this distance as many times as desired by swinging the dividers from one leg to the other along the line, first swinging clockwise 180 degrees, then counterclockwise 180 degrees, and so on.

In dividing either a straight line (fig. 3-12, view B) or a curved line (fig. 3-12, view C) into a given number of equal parts (for example, four) by trial, open the dividers to a rough approximation of the first division (in this case, one quarter of the line length) and step off the distance lightly, holding the dividers by the handle and pivoting the instrument on alternate sides of the line at each step. If the dividers fall short of the end of the line after the fourth step, hold the back leg in place and advance the forward leg, by guess, one quarter of the remaining distance. Repeat the procedure until the last step falls at the end of the line. Be careful during this process not to punch holes in the paper, but just barely mark the surface for future reference. To identify prick marks made with small dividers for future reference, circle the marks lightly with a pencil.

USE OF THE DRAFTING SCALE

Accuracy in drawing depends to a great extent upon correct use of the scale in marking off distances. You should place the edge of the scale parallel to the line being measured (fig. 3-13). To eliminate shadows cast by your body or hands, point the desired scale face away from you for horizontal measurements and toward your left for vertical measurements. With a sharp pencil, mark off short dashes at right angles to the scale at the correct distances, aligning the mark carefully with the scale graduation. Have your eye approximately over the point being measured,

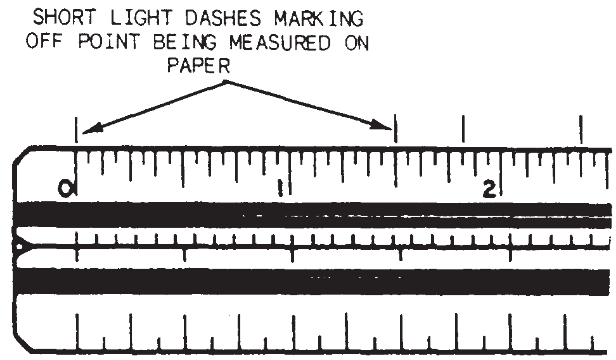

Figure 3-13.-Use of the drafting scale.

and make light marks to denote the point of measurement.

When setting the compass to a given radius or when setting divider points, never place the sharp points of these instruments on the scale. Lay out the desired radius or distance on a straight pencil line by using the scale in the manner described above. Then adjust the compass or dividers to the indicated length by using the measured line. A scale surface marred by pinpricks is difficult to read and is unsuitable for accurate work.

In making successive measurements along the same line, make as many measurements as possible without moving the scale. If a number of distances are to be laid out end to end, hold the scale in one position and add each successive measurement to the preceding one. If the scale is moved to a new position each time, slight errors in measurement may accumulate. For example, four successive measurements of 1 5/8 in. each should give an overall length of 6 1/2 in., not 6 9/16 in. Therefore, make as many measurements as you can without changing the reference point. This will avoid cumulative errors in the use of the scale.

Note that your pencil touches the scale only for the purpose of marking a point on the paper. Never use a scale as a straightedge for drawing lines. A typical office ruler has a metal edge; it is a scale and straightedge combined. But a draftsman's measuring scale is for measuring only; it is not a ruler. A scale properly used will last for decades, but a scale used as a straightedge will soon have the graduations worn away.

DRAWING FORMATS

Drawing format is the systematic space arrangement of required information within the drafting sheet. This information is used to identify, process, and file drawings methodicaly. Standard sizes and formats for military drawings are arranged according to DoD-STD-100C, *Engineering Drawing Practices,* and MIL-HDBK-1006/1, *Policy and Procedures for Project Drawing and Specification Preparation.* With the exception of specific local command requirements, DoD-STD-100C and MIL-HDBK-1006/1 are your guidelines for preparing SEABEE drawings.

Most of the documents applicable to these standards have recently been revised and updated in order to gain like information and to share uniformity of form and language within the Naval Construction Force and between DoD organizations. Other influencing factors are the current widespread use of reduced-size copies of both conventional and computer-generated drawings and exchange of microfilm.

SHEET SIZES

Standard drawing sheet sizes are used to facilitate readability, reproduction, handling, and uniform filing. Blueprints produced from standard size drawing sheets are easily assembled in sets for project stick files and can readily be folded for mailing and neatly filed in project letter size or legal size folders. (Filing drawings and folding blueprints will be covered later in this training manual.)

Finished format sizes for drawings shown in figure 3-14, view A, are according to ANSI Y14.1

FLAT SIZES

SIZE DESIGNATION LETTER	X (WIDTH)	Y (LENGTH)	MARGIN H (HORIZ)	MARGIN V (VERT)
A(HORIZ)	8.5	11.0	0.38	0.25
A(VERT)	11.0	8.5	0.25	0.38
B	11.0	17.0	0.38	0.62
C	17.0	22.0	0.75	0.50
D	22.0	34.0	0.50	1.00
E	34.0	44.0	1.00	0.50
F	28.0	40.0	0.50	0.50

ROLL SIZES

SIZE DESIGNATION LETTER	X (WIDTH)	Y (LENGTH) MIN	Y (LENGTH) MAX	MARGIN H (HORIZ)	MARGIN V (VERT)
G	11.0	22.5	90.0	0.38	0.50
H	28.0	44.0	145.0	0.50	0.50
J	34.0	55.0	176.0	0.50	0.50
K	40.0	55.0	143.0	0.50	0.50

NOTES: 1. ADDITIONAL PROTECTION MARGINS FOR ROLL SIZE DRAWINGS ARE NOT INCLUDED IN ABOVE DIMENSIONS.
2. ALL DIMENSIONS ARE IN INCHES.

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Figure 3-14.-Guide for preparing horizontal and vertical margins, sizes, and finished drawing format.

(1980), approved and adopted for use under DoD-STD-100C. Flat size refers to drawings that, because of their relatively small size, should be stored or filed flat. Roll size refers to drawings that, because of their lengths, are filed in rolls. Finished format sizes for a drawing refer to the dimensions between trim lines (X and Y in figure 3-14, view A). The TRIM LINE is the outside line of either the vertical or horizontal margin. The inside lines of the margins are called BORDERLINES. Width (X) is always PARALLEL to the working edge of the drawing board; length (Y) is always PERPENDICULAR to the working edge of the drawing board.

Notice, in figure 3-14, view B, that 2 in. should be added to the left margin and to the right margin for protection of roll-size drawings. The edge of a drawing prepared on tracing paper will tear easily after it is rolled and unrolled several times.

SHEET LAYOUT

Sheets of drafting or tracing paper are cut slightly larger than their required finished sizes and are fastened to the drafting board as previously described. Using a hard (4H to 6H) pencil and a T square (or parallel straightedge), draw a horizontal trim line near the lower edge of the paper. Then draw a vertical trim line near the left edge of the paper with a T square (or parallel straightedge), pencil, and triangle, as previously described. Dimensions establishing the finished length of the sheet (distance between vertical trim lines) and the location of the vertical borderlines are marked off on the horizontal trim lines. A full-size scale should be used when you are laying off a series of measurements along a line. Dimensions establishing the finished width of the sheet (distance between horizontal trim

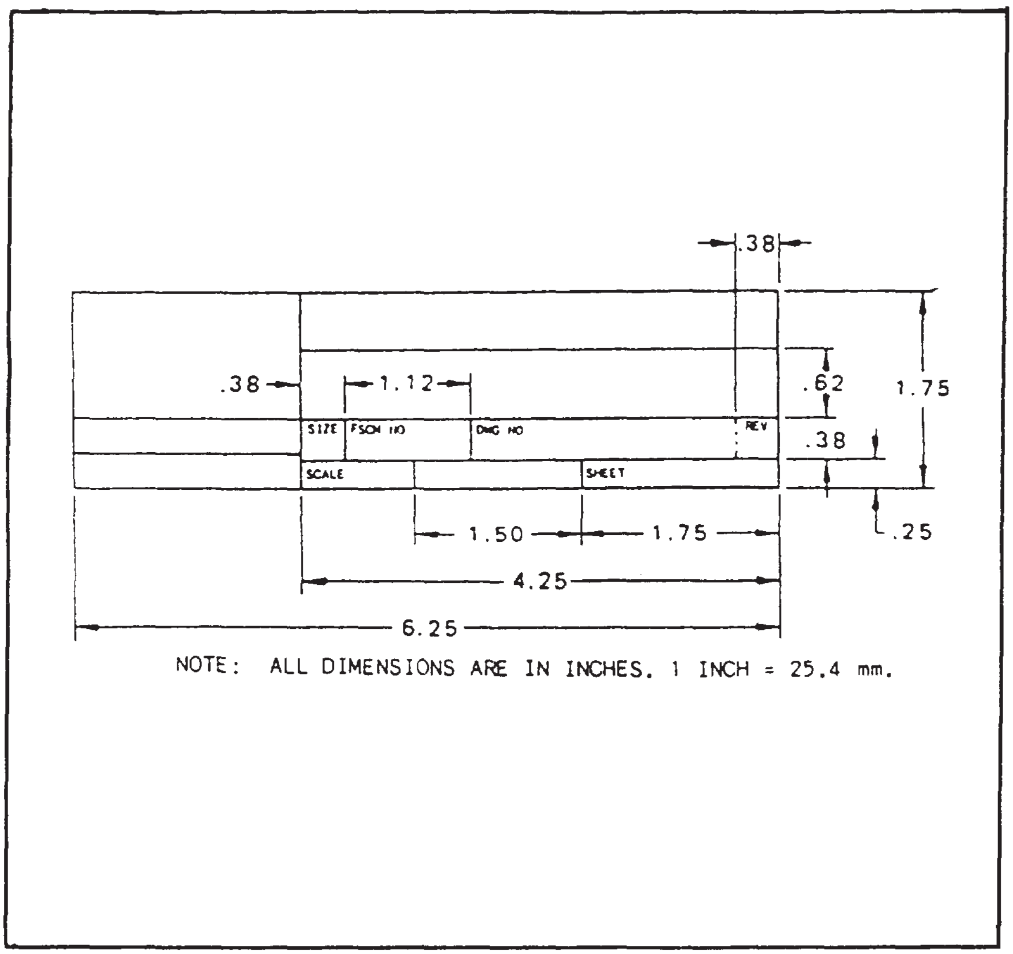


Figure 3-15.-Preparing title block for A-, B-, C-, and G-size drawings.

lines) and the location of the horizontal borderlines are marked off on the vertical trim lines. Dimensions may be scaled along the borderlines.

After the drawing is completed, borderlines are given the required weight. After the completed drawing has been removed from the board, it is cut to its finished size along the trim line. If blueprints are to be made on paper that is not precut to the standard drawing size, you may find it necessary to leave an extra margin outside the trim lines. By leaving an extra margin, you can darken the trim lines. The darkened trim lines, when reproduced, will provide a visible line for trimming the blueprints to size. The extra margin will also help protect the drawing when it is repeatedly handled or attached to the drawing board later for revisions.

BASIC FORMAT

The following discussion deals with the basic drafting format. By basic format, we mean the title block, revision block, list of materials, and other information that must be placed on applicable size drafting sheets. Although you may find slight variations on local-command-prepared drawings, the basic format specified in MIL-HDBK-1006/1 is required on all NAVFACENGCOM drawings.

Title Block

The primary purpose of a drawing title block is to identify a drawing. Title blocks must be uniform in size and easy to read. They may be mechanically lettered, neatly lettered freehand, or preprinted commercially on standard size drafting sheets.

Generally, the title block is placed in the lower right-hand corner of the drawing sheet, regardless of the size of the drawing (except for vertical title block). There are three sizes of title blocks: a block used for A-, B-, C-, and G-size drawings (fig. 3-15), a slightly larger block for D-, E-, F-, H-, J-, and K-size drawings (fig. 3-16), and a

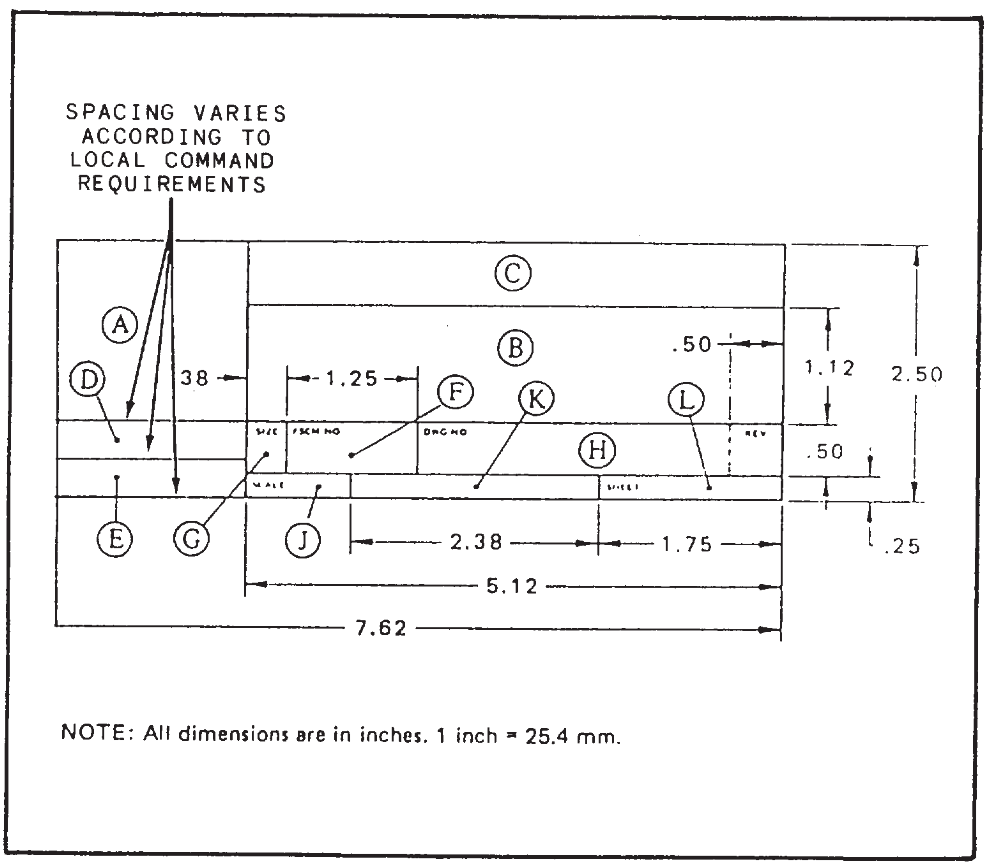


Figure 3-16.-Preparing title block for D-, E-, F-, H-, J-, and K-size drawings.

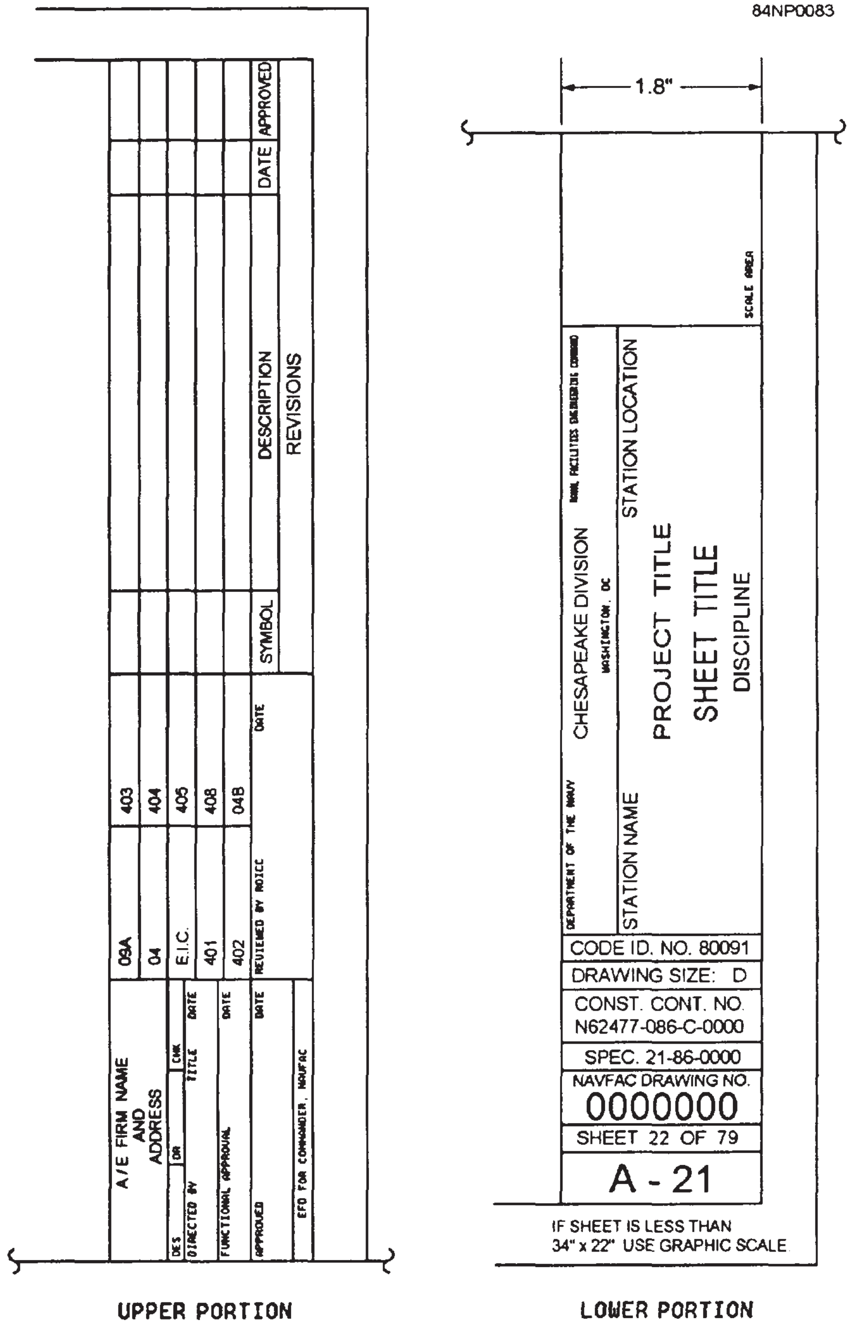


Figure 3-17.-Example of vertical title block prepared by NAVFACENGCOM.

vertical title block (fig. 3-17). The vertical title block format must be used for all 22-in. by 34-in. (D-size) drawings and is optional for 28-in. by 40-in. (F-size) drawings.

In a multiple-sheet drawing, either the basic title block or a "continuation sheet title block" format (fig. 3-18) may be used for second and subsequent sheets provided all sheets are of the same size. Certain information common to all drawings in the basic title block is optional in the continuation sheet title block.

The letter designations shown in figure 3-16 are used to locate the following title block information:

(A) Record of preparation. This information will vary with each command or activity, but will normally include the dates and the surnames of the persons concerned with the preparation of the drawing. The applicable work request number or locally assigned drawing number may also be placed in the upper prtion of this space. This block is optional for continuation sheets.

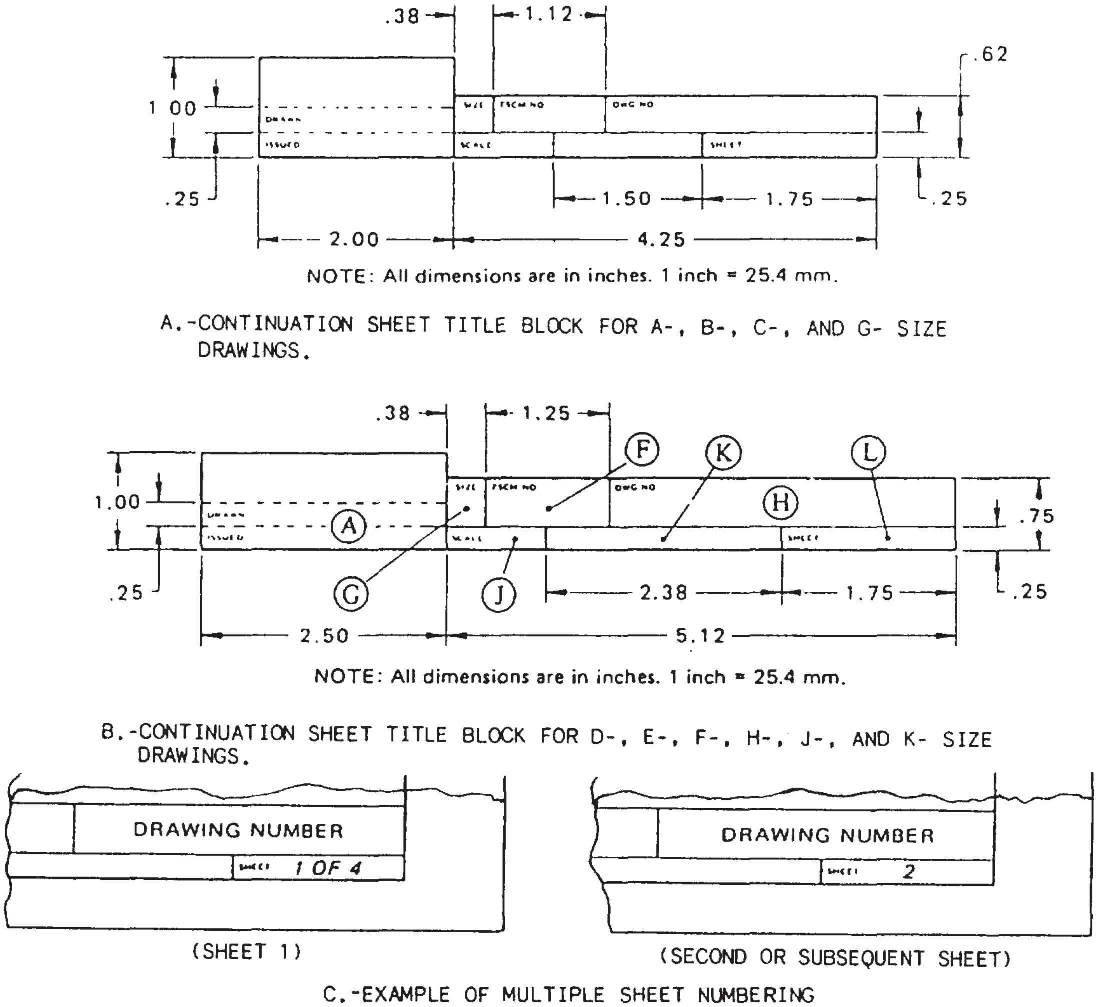


Figure 3-18.-Use of continuation sheet title block and multiple sheet numbering.

(B) Drawing title. In the space provided for the drawing title, the general project and the specific features shown on the drawing should be included.

Example 1:

RESTROOM FACILITIES SEABEE PARK ARCHITECTURAL PLANS, ELEVATIONS, SECTIONS, DETAILS

Example 2:

DEFINITIVE DRAWING BERTHING PIER

The general project (RESTROOM FACILITIES, SEABEE PARK, in example 1) once entered in the title block of sheet 1, is not to be repeated on each sheet of a set of multiple-project drawings. Example 2 is the title taken from the title block of a drawing contained in NAVFAC P-272, *Definitive Designs for Naval Shore Facilities.* In this example the general project or common title, DEFINITIVE DRAWING, appears as the top line title on all drawings in NAVFAC P-272. This block is optional for continuation sheets.

(C) Preparing activity. This space is reserved for the name and location of the activity preparing the drawing. In addition, the words DEPARTMENT OF THE NAVY are placed in this space. This block is optional for continuation sheets.

The information placed in spaces (D) and (E) (fig 3-16) varies with each command and the

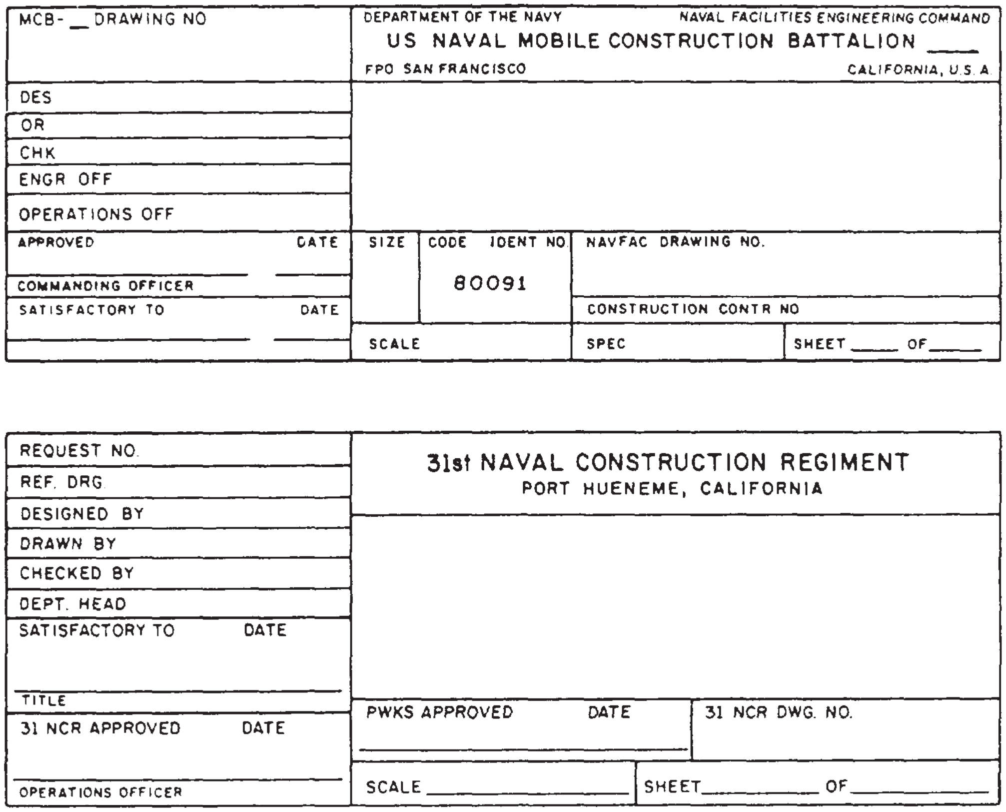


Figure 3-19.-Examples of title blocks used on drawings prepared by Naval Construction Battalion and Naval Construction Regiment.

purpose of the drawing (fig. 3-19). One space is usually reserved for the signature of (APPROVED BY) your commanding officer or officer in charge, and the other space is for the signature of the commander of the activity or command requiring the drawing (SATISFACTORY TO). As shown in the examples in figure 3-19, these two spaces may be used interchangeably. This is acceptable as long as consistency is maintained. It is also acceptable to use only space (E) when a SATISFACTORY TO space is not required for the drawing, as shown on the NAVFAC title blocks in figures 3-20 and 3-21. In this case the (E) space is extended upward or the (A) space may be extended downward if additional space is required. These blocks, if not required, may be absorbed into block (A) far continuation sheets or used for other purposes.

(F) Code identification number. The federal supply code for manufacturers (FSCM) is a five-digit number used to identify the government design activity; that is, the activity having responsibility for the design of an item. For most of your drawings, NAVFAC has the ultimate design responsibility. Therefore, the identification number "80091" is to appear in the title block of all NAVFACENGCOM drawings. You may choose to use either "FSCM" or "Code 10" (the terms are interchangeable) in the title block.

(G) Drawing size. This space is reserved for the letter designating the drawing format size.

(H) Drawing number. If the drawing is prepared for or by NAVFACENGCOM, a NAVFAC drawing number will be assigned. Assignment of NAVFAC drawing numbers is covered in MIL-HDBK 1006/1, *Policy and Procedures for Project Drawing and Specification Preparation.* If the drawing does not require a NAVFAC drawing number, this space will be left blank, and a local command drawing number will be placed in space (A). Occasionally, local title blocks require the drawing number to be placed in space (H). (Refer to fig. 3-19.)

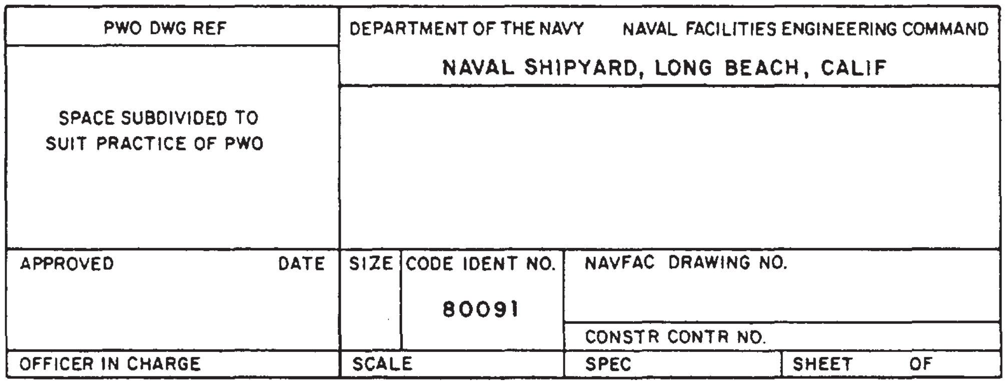


Figure 3-20.-Example of a title block prepared by an activity not requiring NAVFACENGCOM approval.

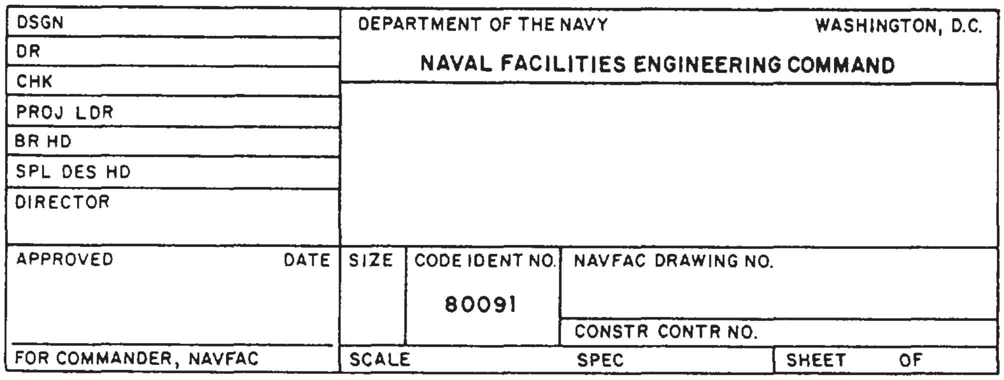


Figure 3-21.-Example of a title block used on drawings prepared by NAVFACENGCOM.

(J) Scale. This space is reserved for the scale to which the drawing is prepared. When more than one scale is used on the drawing, the words AS SHOWN or AS NOTED are entered after the word SCALE in the space (J). If the drawing was not to scale, the word NONE is entered.

(K) Specification number. On drawings that are prepared for or by NAVFACENGCOM, this space is reserved for the project specification or contract number. If the drawing does not pertain to a particular project specification or contract, this space will normally be left blank.

(L) Sheet number. On a single construction drawing, SHEET 1 of 1 will be entered in this space. For numbering of second and subsequent sheets in a multiple-sheet drawing (fig. 3-18, view C), similar drawing numbers appear in both basic and continuation sheet title blocks; however, the total sheet number is entered on sheet 1 while the specific sheet number is entered on each subsequent sheet.

Satisfactory To Block

In addition to spaces (D) and (E) on the title block, which are provided for approval signatures, a second SATISFACTORY TO block may be required when an outside activity requests a drawing. The extra SATISFACTORY TO block is identical to the SATISFACTORY TO space in the title block but is located adjacent to title block space (E).

Revision Block

A REVISION block contains a list of all revisions made to the drawing. On construction drawings, the revision block is placed in the upper right-hand corner. Basically, all revision blocks provide the same information; only the

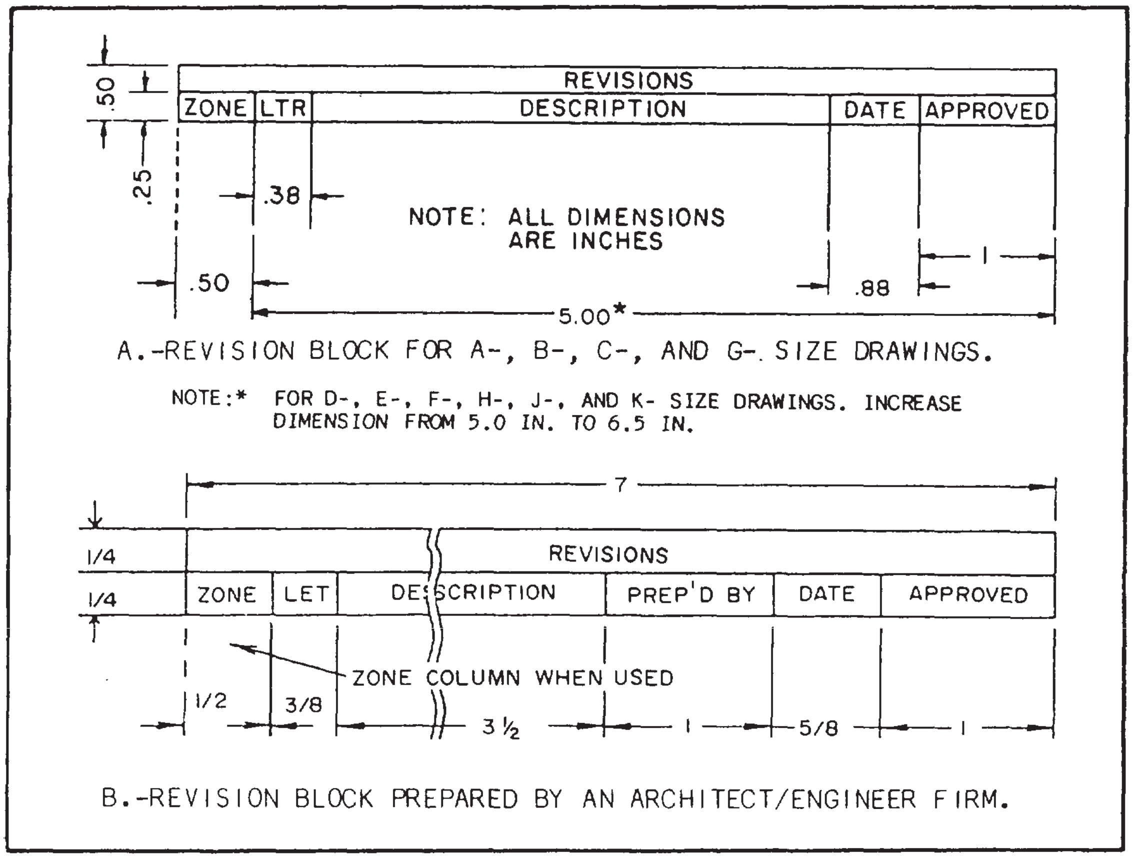


Figure 3-22.-Format used in preparing revision blocks.

sizes of the blocks differ (fig. 3-22). Revision information is entered chronologically starting at the top of the revision block.

Revision letters are used to identify a change or revision to a drawing. Uppercase letters are used in alphabetical sequence, omitting the letters *I, O, Q, S, X,* and *Z.* The first revision to a drawing is assigned the *A.* On a drawing, all changes that are incorporated at one time are identified by the same revision letter. The changes may be numbered sequentially to permit ready identification of a specific change. In this case, the appropriate serial number will appear as a suffix to the revision letter (for example, A1, A2, A3, etc.). Whenever possible the revision letter will be placed near the actual change on the drawing. It should be placed so it is not confused with other symbols on the drawing. Usually, the revision letter is placed inside of a circle or triangle (Ⓐ or △A). If a circle or triangle is used on the drawing, it should also be used in the revision block.

A brief description of each change is made in the description column, adjacent to its revision letter, in the revision block. The approval signature and date of revision are also entered in the appropriate columns. For all drawings prepared by Architect/Engineer (A/E) firms, the revision block should include a separate PREPARED BY column (fig. 3-22, view B).

The zone column on the standard revision block is normally omitted on construction drawings but may be used in reviewing maps. Zones are indicated by alphabetical or numerical entries and are evenly spaced in the margin for locating an object on the drawing or map. Use of zoning is described in DoD-STD-100C.

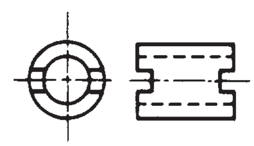
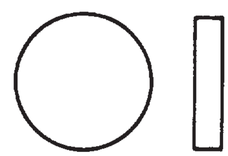
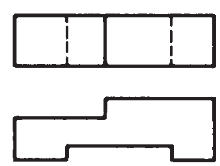
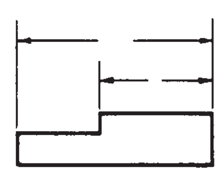
Like title blocks, revision blocks may vary with each command, and you will be required to follow command guidelines. The procedure for making revisions to drawings is covered in DoD-STD-100C.

Bill of Materials

When a BILL OF MATERIALS block is used on a construction drawing, it is placed directly above the title block against the right-hand margin. A bill of materials is a tabulated list of material requirements for a given project. The size of the BILL OF MATERIALS block will depend on the size of the drawing and the number of material items listed. On most construction projects, it is impossible to list all items in a single BILL OF MATERIALS block; therefore, it is omitted from the drawings, and a separate list of materials is prepared by an estimator.

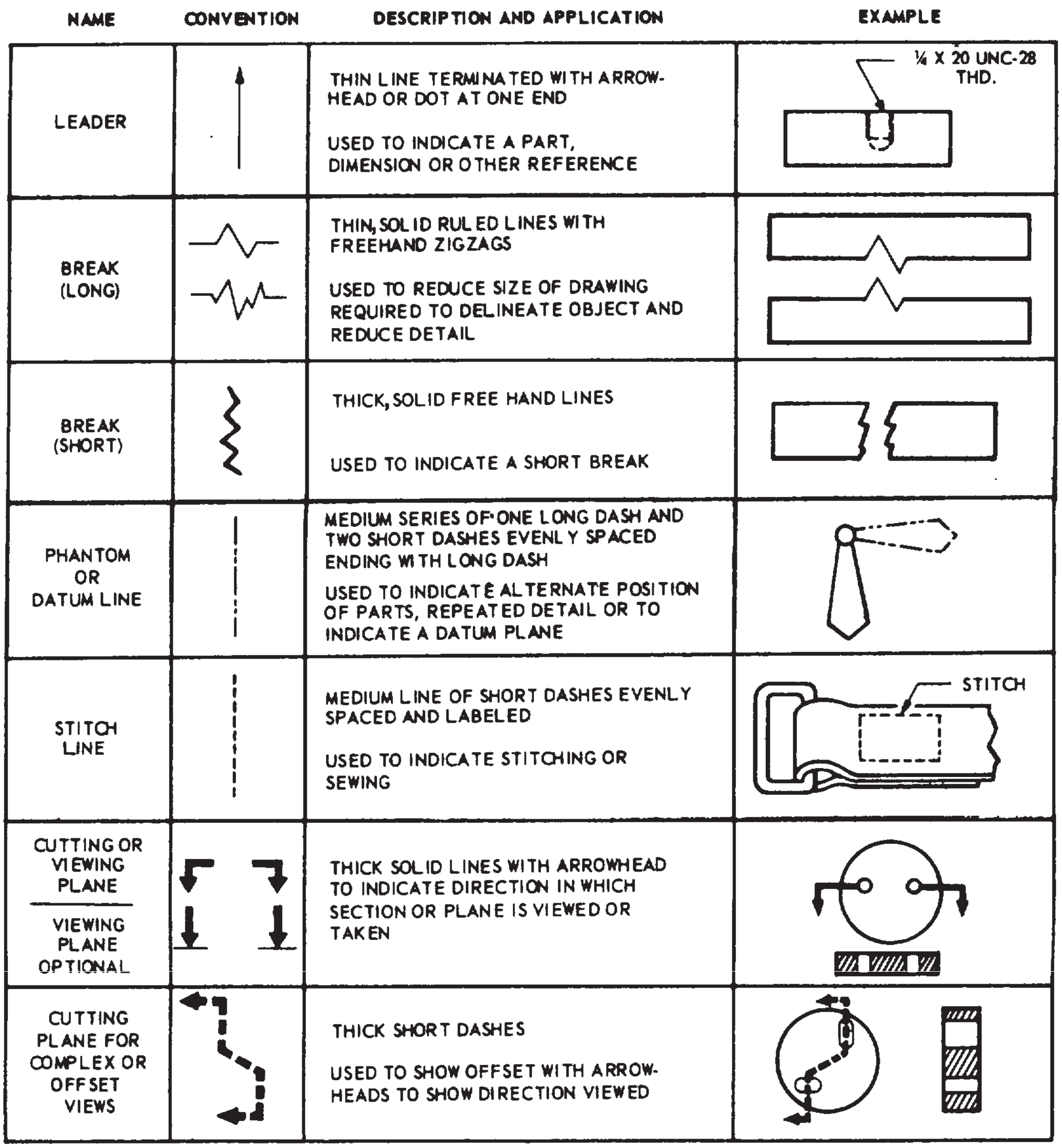
LINE CONVENTIONS

When you are preparing drawings, you will use different types of lines to convey information. Line characteristics, such as widths, breaks in the line, and zigzags, all have definite meanings. Figure 3-23, taken from DoD-STD-100C, shows the different types of lines that should be used on your drawings.

LINE STANDARDS			
NAME	CONVENTION	DESCRIPTION AND APPLICATION	EXAMPLE
CENTER LINES		THIN LINES MADE UP OF LONG AND SHORT DASHES ALTERNATELY SPACED AND CONSISTENT IN LENGTH USED TO INDICATE SYMMETRY ABOUT AN AXIS AND LOCATION OF CENTERS	
VISIBLE LINES		HEAVY UNBROKEN LINES USED TO INDICATE VISIBLE EDGES OF AN OBJECT	
HIDDEN LINES		MEDIUM LINES WITH SHORT EVENLY SPACED DASHES USED TO INDICATE CONCEALED EDGES	
EXTENSION LINES		THIN UNBROKEN LINES USED TO INDICATE EXTENT OF DIMENSIONS	
DIMENSION LINES		THIN LINES TERMIMATED WITH ARROW HEADS AT EACH END USED TO INDICATE DISTANCE MEASURED	

142.46.1

Figure 3-23.-Use of line characteristics and conventions.



142.46.2

Figure 3-23.-Use of line characteristics and conventions–Continued.

The widths of the various lines on a drawing are very important in interpreting the drawing. DoD-STD-100C specifies that three widths of line should be used: thin, medium, and thick. As a general rule, on ink drawings, these three line widths are proportioned 1:2:4, respectively. However, the actual width of each type of line should be governed by the size and the type of drawing.

The width of lines in format features (that is, title blocks and revision blocks) should be a minimum of 0.015 in. (thin lines) and 0.030 in. (thick lines). To provide contrasting divisions between elements of the format, thick lines are required for borderlines, outline of principal blocks, and main divisions of blocks, whereas thin lines are required for minor divisions of title and revision blocks and bill of materials. Use of medium line width for letters and numbers is recommended.

The width of lines drawn with a pencil cannot be controlled as well as the width of lines drawn with pen and ink. However, pencil lines should be opaque and of uniform width throughout their length. Cutting plane and viewing plane lines should be the thickest lines on the drawing. Lines used for outlines and other visible lines should be differentiated from hidden, extension, dimension, or center lines.

CONSTRUCTION LINES

Usually the first lines that you will use on a drawing are construction lines. These are the same lines that you used to lay out your drafting sheet. They will also be used to lay out the rest of your drawing. Line weight for construction lines is not important since they will not appear on your finished drawing. They should be heavy enough to see, but light enough to erase easily. A 4H to 6H pencil with a sharp, conical point should be used. With the exception of light lettering guidelines, all construction lines must be erased or darkened before a drawing is reproduced.

CENTER LINES

Center lines are used to indicate the center of a circle, arc, or any symmetrical object. (See fig. 3-24.) Center lines are composed of long and short dashes, alternately and evenly spaced, with a long dash at each end. They should extend at least one-fourth in. outside the object. At intersecting points, center lines should be drawn as short dashes.

A very short center line may be drawn as a single dash if there is no possibility of confusing it with other lines. Center lines may also be used to indicate the travel of a moving center, as shown in figure 3-24.

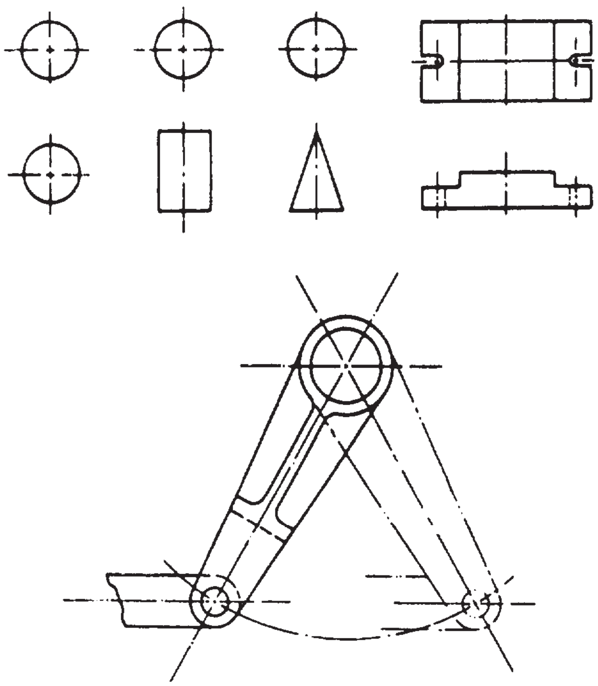


Figure 3-24.-Use of center lines.

VISIBLE LINES

The visible edge lines of the view are drawn as solid, thick lines. These include not only the outlines of the view, but lines defining edges that are visible within the view. (See fig. 3-25.)

HIDDEN LINES

Hidden edge lines are drawn with short dashes and are used to show hidden features of an object. A hidden line should begin with a dash in contact with the line from which it starts, except when it is the continuation of an unbroken line. (See fig. 3-26.)

To prevent confusion in the interpretation of hidden edge lines, you must apply certain standard techniques in drawing these lines. A hidden edge line that is supposed to join a visible or another hidden line must actually contact the line, as shown in the upper views of figure 3-27;

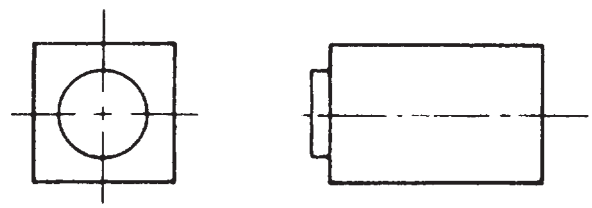


Figure 3-25.-Use of visible edge lines.

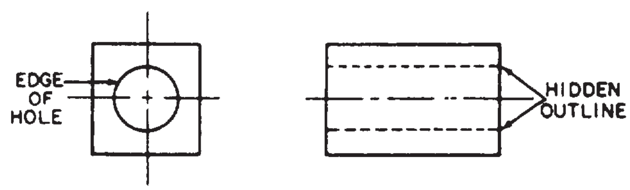


Figure 3-26.-Use of hidden edge lines.

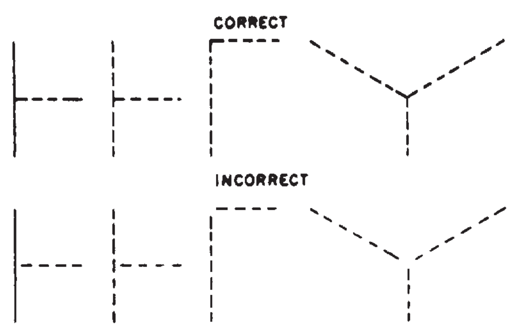


Figure 3-27.-Correct and incorrect procedures for drawing adjoining bidden lines.

the incorrect procedure is shown in the lower views.

Figure 3-28 shows an intersection between a hidden edge line and a visible edge line. Obviously, on the object itself the hidden edge line must be below the visible edge line. You indicate this face by drawing the hidden edge line as shown in the upper view of figure 3-28. If you drew it as indicated in the lower view, the hidden edge line would appear to be above, rather than beneath, the visible edge line.

Figure 3-29 shows an intersection between two hidden edge lines, one of which is beneath the other on the object itself. You indicate this fact by drawing the lines as indicated in the upper view of figure 3-29. If you drew them as indicated in the lower view, the wrong line would appear to be uppermost.

EXTENSION LINES

Extension lines are used to extend dimensions beyond the outline of a view so that they can be read easily. These thin, unbroken lines are started about one sixteenth of an inch from the outline of the object and extend about one eighth of an inch beyond the outermost dimension line. They are drawn parallel to each other and perpendicular to the distance to be shown. (See fig. 3-30.) In unusual cases, extension lines may be drawn at other angles if their meaning is clear.

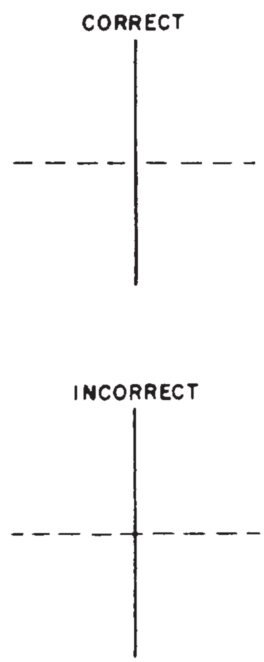


Figure 3-28.-Correct and incorrect procedures for drawing a hidden edge line that intersects a visible edge line.

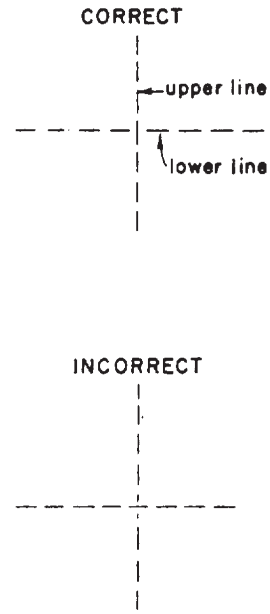


Figure 3-29.-Correct and incorrect procedures for drawing intersecting hidden edge lines that are on different levels.

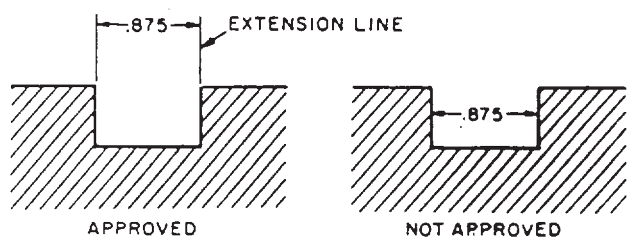


Figure 3-30.-Use of extension lines.

As far as practical, avoid drawing extension lines directly to the outline of an object. When it is necessary for extension lines to cross each other, they should be broken, as shown in figure 3-31.

DIMENSION LINES

A dimension line, terminating at either end in a long, pointed arrowhead, is inserted between each pair of extension lines. It is a thin line, and, except in architectural and structural drafting, it is usually broken to provide a space for the dimension numerals. Occasionally, when the

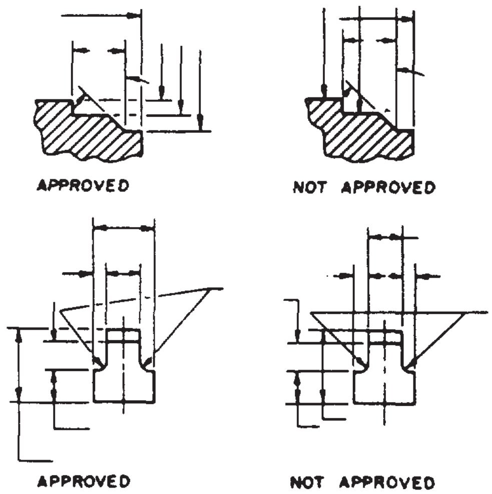


Figure 3-31.-Breaking extension lines and leaders at points of intersection.

radius of an arc is to be indicated, there is an arrow at only the end of the line that touches the arc. The other end, without an arrow, terminates at the point used as the center in drawing the arc.

The arrowhead on a dimension or leader line is an important detail of a drawing. If these arrowheads are sloppily drawn and vary in size, the drawing will not look finished and professional. The size of the arrowhead used on a drawing may vary with the size of the drawing, but all arrowheads on a single drawing should be the same size, except occasionally when space is very restricted.

The arrowheads used on Navy drawings are usually solid, or filled in, and are between one eighth and one fourth of an inch long, with the length about three times the spread. (See fig. 3-32.)

With a little practice, you can learn to make good arrowheads freehand, Referring to figure 3-32, first define the length of the arrowhead with a short stroke as shown at A. Then draw the sides of the arrowhead as indicated at B and C. Finally, fill in the area enclosed by the lines, as shown at D.

LEADERS

Leaders are used to connect numbers, references, or notes to the appropriate surfaces

Figure 3-32.-Method of drawing an arrowhead.

or lines on the drawing. From any suitable portion of the reference, note, or number, a short line is drawn parallel to the lettering. From this line the remainder of the leader is drawn at an angle (dog leg) to an arrowhead or dot. In this way, the leader will not be confused with other lines of the drawing. If the reference is to a line, the leader is always terminated at this line with an arrowhead, as shown in figure 3-33. However, a reference to a surface terminates with a dot within the outline of that surface.

BREAK LINES

The size of the graphic representation of an object is often reduced (usually for the purpose of economizing on paper space) by the use of a device called a break. Suppose, for example, you want to make a drawing of a rectangle 1 ft wide by 100 ft long to the scale of 1/12, or 1 in. = 1 ft. If you drew in the full length of the rectangle, you would need a sheet of paper 100 in. long. By using a break, you can reduce the length of the figure to a feasible length, as shown in figure 3-34.

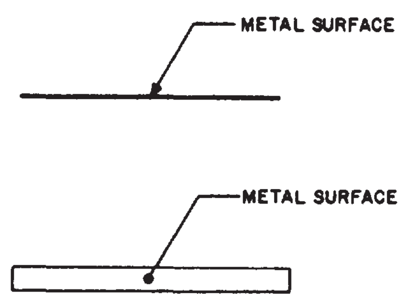


Figure 3-33.-Use of a leader.

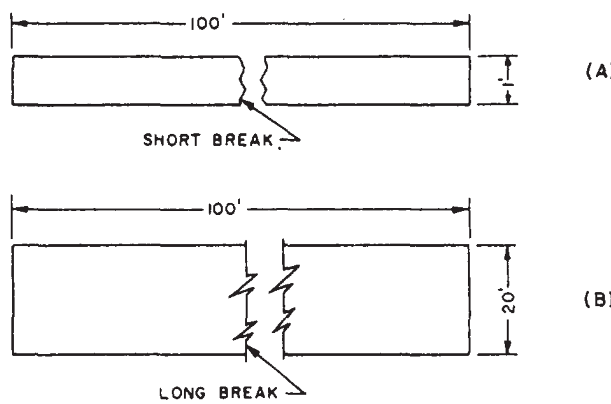


Figure 3-34.-Use of proper line conventions for (A) short break, and (B) long break.

On the original object, the ratio of width to length is 1:100. You can see that on the drawing the ratio is much larger (roughly about 1:8). However, the break tells you that a considerable amount of the central part of the figure is presumed to be removed.

The thick, wavy lines shown in view (A), figure 3-34, are used for a short break. A short break is indicated by solid, freehand lines, and is generally used for rectangular sections. For wooden rectangular sections, the breaks are made sharper (serrated appearance) rather than wavy.

For long breaks, full, ruled lines with freehand zigzags are used, as shown in view (B), figure 3-34. For wider objects, a long break might have more than one pair of zigzag lines.

For drawings made to a large scale, special conventions are used that apply to drawing breaks in such things as metal rods, tubes, or bars. The methods of drawing these breaks are shown in figure 3-35.

PHANTOM LINES

Phantom lines are used most frequently to indicate an alternate position of a moving part, as shown in the left-hand view of figure 3-36. The part in one position is drawn in full lines, while in the alternate position it is drawn in phantom lines.

Phantom lines are also used to indicate a break when the nature of the object makes the use of the conventional type of break unfeasible. An example of this use of phantom lines is shown in the right-hand view of figure 3-36.

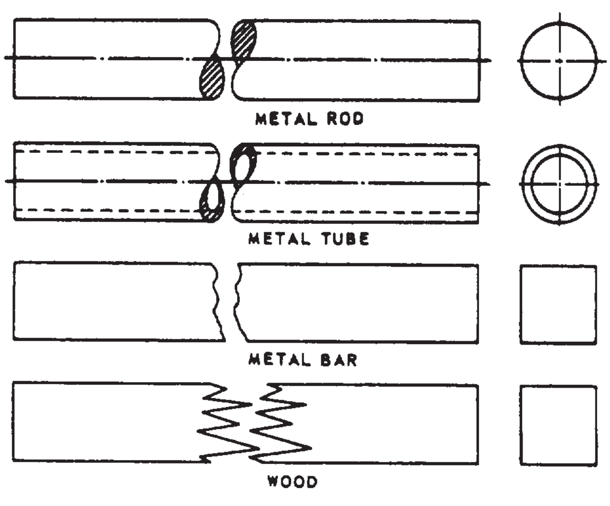


Figure 3-35.-Use of special breaks.

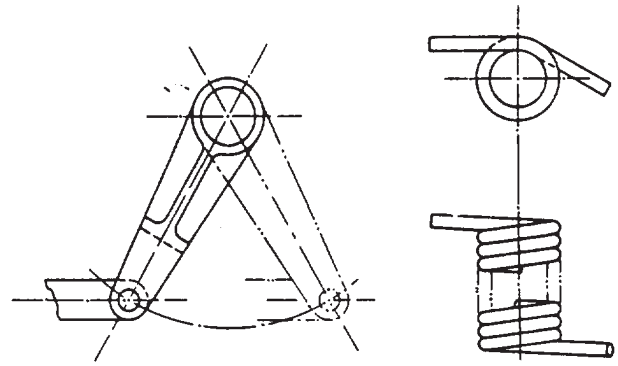


Figure 3-36.-Use of phantom lines.

SECTION LINES

Sometimes the technical information conveyed by a drawing can best be shown by a view that represents the object as it would look if part of it were cut away. A view of this kind is called a section.

The upper view of figure 3-37 shows a plan view of a pipe sleeve. The lower view is a section,

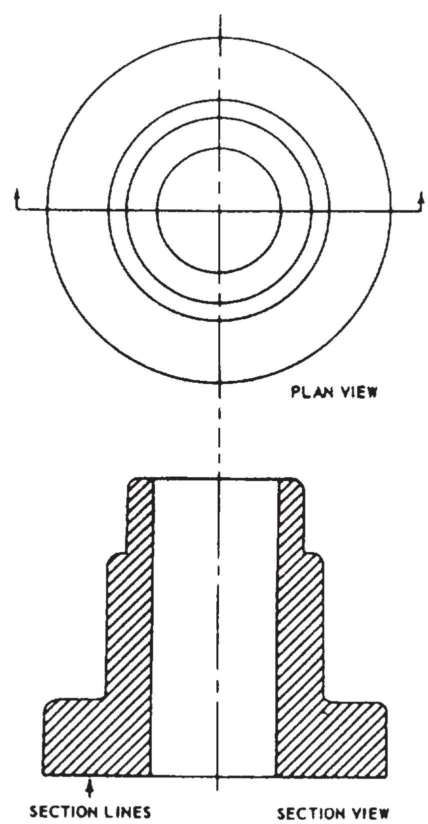


Figure 3-37.-Drawing of a plan view and a full section.

showing the pipe sleeve as it would look, viewed from one side, if it were cut exactly in half vertically. The surface of the imaginary cut is crosshatched with lines called section lines. According to DoD-STD-100C, "section lining shall be composed of uniformly spaced lines at an angle of 45 degrees to the baseline of the section. On adjacent parts, the lines shall be drawn in opposite directions. On a third part, adjacent to two other parts, the section lining shall be drawn at an angle of 30 to 60 degrees."

The cross-hatching shown in figure 3-37 could be used on any drawing of parts made of only one material (like machine parts, for example, which are generally made of metal). The cross-hatching is the symbol for metals and may be used for a section drawing of any type of material.

A section like the one shown in figure 3-37, which goes all the way through and divides the object into halves, is called a full section. If the section showed the sleeve as it would look if cut vertically into unequal parts, or cut only part way through, it would be a partial section. If the cut followed one vertical line part of the way down and then was offset to a different line, it would be an offset section.

VIEWING OR CUTTING PLANE LINES

VIEWING PLANE LINES are used to indicate the plane or planes from which a surface or several surfaces are viewed.

CUTTING PLANE LINES are used to indicate a plane or planes in which a sectional view is taken.

Section views are used to give a clearer view of the interior or hidden feature of an object that normally cannot be clearly observed in conventional outside views.

A section view is obtained by cutting away part of an object to show the shape and construction at the cutting plane.

Notice the CUTTING PLANE LINE AA in figure 3-38, view A. It shows where the imaginary cut has been made. The single view in figure 3-38, view B, helps you to visualize the cutting plane. The arrows point in the direction in which you are to look at the sectional view.

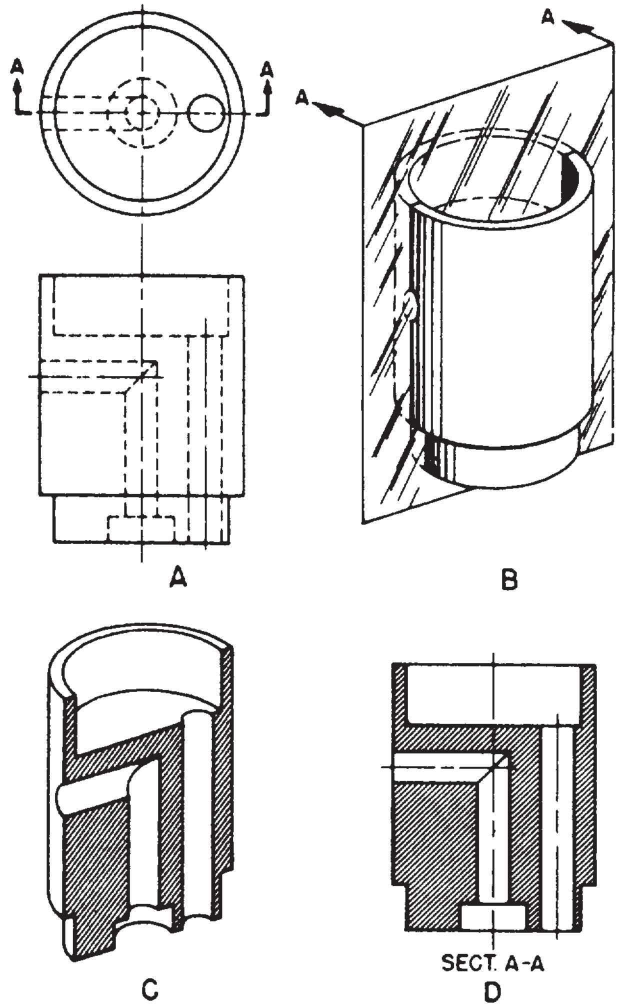


Figure 3-38.-Action of a cutting plane.

Figure 3-38, view C, is a front view showing how the object would look if it were cut in half.

The orthographic section view of section A-A, figure 3-38, view D, instead of the confusing front view in figure 3-38, view A, is placed on the drawing. Notice how much easier it is to read and understand.

Note that hidden lines behind the plane of projection are omitted in the sectional view. These lines are omitted by general custom, the custom being based on the fact that the elimination of hidden lines is the basic reason for making a sectional view. However, lines that would be visible behind the plane projection must be included in the section view.

Cutting plane lines, together with arrows and letters, make up the cutting plane indications. The arrows at the end of the cutting plane lines are used to indicate the direction in which the sections are viewed. The cutting plane may be a single continuous plane, or it may be offset if the detail can be shown to better advantage. On simple views, the cutting plane should be indicated as shown in figure 3-38, view A. On large, complex views or when the cutting planes are offset, they should be shown as in figure 3-39.

All cutting plane indications should be identified by use of reference letters placed at the point of the arrowheads. Where a change in direction of the cutting plane is not clear, reference letters may also be placed at each change of direction. Where more than one sectional view appears on a drawing, the cutting plane indications should be lettered alphabetically.

The letters that are part of the cutting plane indication should always appear as part of the title; for example, SECTION A-A, SECTION B-B, If the single alphabet is exhausted, multiples of letters maybe used. The word *SECTION* may be abbreviated, if desired. Place the title directly under the section drawing.

DATUM LINES

A datum line is a line used to indicate a line or plane of reference, such as the plane from which an elevation is measured. Datum lines consist of one long dash and two short dashes (medium thickness), equally spaced. Datum lines differ from phantom lines only in the way they are used.

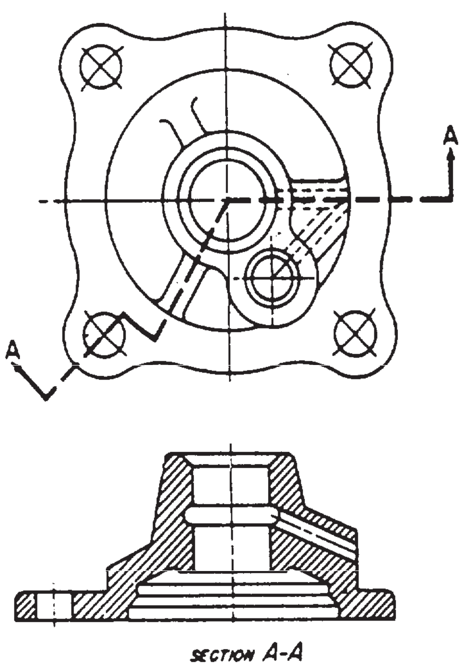


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Figure 3-39.-Use of an offset section.

STITCH LINES

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

MATCH LINES

Match lines are used when an object is too large to fit on a single drawing sheet and must be continued on another sheet. The points where the object stops on one sheet and continues on the next sheet must be identified with corresponding match lines. They are medium weight lines indicated with the words *MATCH LINE* and referenced to the sheet that has the corresponding match line. Examples of construction drawings that may require match lines are maps and road plans where the length is much greater than the width and it is impractical to reduce the size of the drawing to fit a single sheet.

ORDER OF PENCILING

Experience has shown that a drawing can be made far more efficiently and rapidly if all the lines in a particular category are drawn at the same time, and if the various categories of lines are drawn in a specific order or succession. Figure 3-40 shows the order in which the lines of the completed drawing (shown in the last view) were drawn. This order followed the recommended step-by-step procedures, which is as follows:

1. Draw all center lines.
2. Draw the principal circles, arcs, fillets, rounds, and other compass-drawn lines. A fillet is a small arc that indicates a rounded concave joint between two surfaces. A round is a small arc that indicates a rounded convex joint between two surfaces.

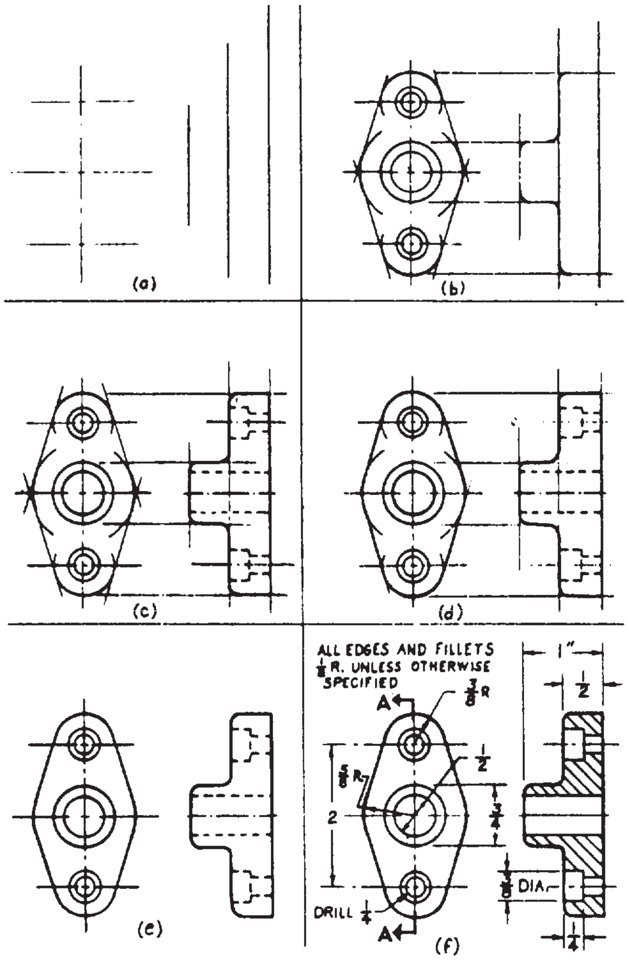

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Figure 3-40.-Order of penciling a drawing.

3. Draw the horizontal and vertical outlines, visible lines, and hidden lines.

4. Draw the nonhorizontal and nonvertical outlines, visible lines, and hidden lines.

5. Clean up the drawing, erasing all excess lines and construction lines. A construction line is a light line used as a drawing guide only.

6. Draw extension lines, dimension lines, section lines, and any other lines required.

7. Inscribe the dimensions and lettering.

To a limited extent you can vary the thickness of a pencil line by varying the extent to which you bear down on the pencil. However, you can't bear down very hard without troughing the paper. Therefore, you can't get much variety in line weight with a pencil. For a drawing that will be inked over, this doesn't make any difference. However, for one that will not be reproduced, or which will be reproduced directly from the pencil original, you must follow, as nearly as you can, the line conventions.

ORDER OF INKING

The beginner is usually frightened at the prospect of trying to ink a drawing without spoiling it. Once you have learned how to use drawing instruments and to follow a definite order of inking, you will have greatly reduced the danger of spoiling a drawing. Nowadays, draftsmen prefer the reservoir pen or rapidograph to the ruling pen for inking straight and curved lines and even for lettering. On the other hand, the ruling pen should NEVER be used to ink freehand lines.

One good way to avoid smeared ink lines is by using SPACE BLOCKS. These strips of tape or thin pieces of plastic, when fastened to both faces of the triangles, french curves, or templates (fig. 3-41), raise their edges from the surface of the drafting paper and prevent ink from running under the edge.

When you use a rapidograph or reservoir pen with a T square or parallel straightedge, make long lines with a whole arm movement and short lines with a finger movement.

Draw horizontal lines from left to right, starting at the top of the drawing and working down. (If you are left-handed, you will, of course, draw these lines from right to left, and similarly reverse many of the directions given in this training manual.)

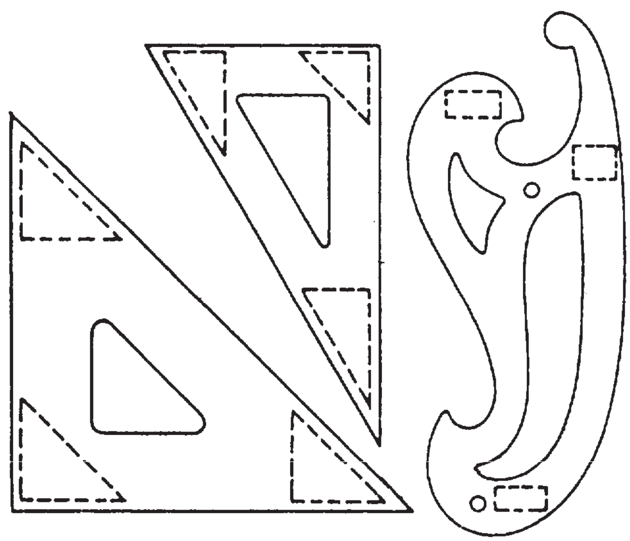

Figure 3-41.-Use of space blocks.

Vertical lines are usually drawn in an upward direction, moving from left to right across the drawing. However, when you have to draw a number of vertical lines or lines slanted in the same direction, the way you draw them will be governed by the source of your light and the way you have found that you can draw vertical lines with greatest control.

Let the first lines dry before starting to draw any intersecting lines. Watch carefully when you draw one line across another line. You vary the thickness of ink lines by selecting a pen unit that matches your desired application and/or line convention.

The order generally recommended for inking is as follows:

1. Inking of a drawing must start from the top of the paper and progress toward the bottom.
2. Start inking all arcs of circles, fillets, rounds, small circles, large circles, and other compass-drawn lines.
3. Ink all irregular curves, using a french curve or a spline as a guide.
4. Ink all thick horizontal lines, then all medium and thin lines.
5. Start at the left edge and ink the thick first, the medium next, and finally the thin vertical lines from left to right.
6. Follow the same procedure described in (4) and (5) for slanting.
7. Ink section lines, dimensions, and arrowheads.
8. Ink notes and title, meridian symbol, and graphic scales.
9. Ink borders and check inked drawing for completeness.
10. Use an art gum or a kneaded eraser to erase pencil marks or for final cleanup of the drawing.

LETTERING

The information that a drawing must present cannot be revealed by graphic shapes and lines alone. To make a drawing informative and complete, you must include lettering in the form of dimensions, notes, legends, and titles. Lettering can either enhance your drawing by making it simple to interpret and pleasant to look at, or it can ruin your drawing by making it difficult to read and unsightly in appearance. Therefore, it is essential that you master the techniques and skills required for neat, legible lettering.

FREEHAND LETTERING

As you work with experienced draftsmen, you will notice that their freehand lettering adds style and individuality to their work. They take great pride in their freehand lettering ability. By learning basic letter forms and with constant practice, you will soon be able to do a creditable job of lettering and acquire your own style and individuality. Anyone who can write can learn to letter. As you practice you will steadily improve both your style and the speed with which you can letter neatly. Don't give up if your first attempts do not produce neat lettering. Don't be afraid to ask your supervisor for a few pointers.

An understanding of the letter shapes and the ability to visualize them can be accomplished by drawing them until the muscles of your hand are accustomed to the pattern of the strokes that make up the letters. You should be able to draw good letters without consciously thinking of this pattern.

Your position and how you hold your pencil will greatly affect your lettering. You should sit up straight and rest your forearm on the drawing board or table. Hold the pencil between the thumb, forefinger, and second finger; the third and fourth fingers and the ball of the palm rest on the drawing sheet. Do not grip the pencil tightly. A tight grip will cramp the muscles in your fingers, causing you to lose control. If you get "writer's cramp" easily, you are probably holding your pencil too tightly. The pencil should be kept sharpened to produce uniform line weights. A conical-shaped pencil point works best for most lettering. Usually, an F or H pencil is used for lettering. A pencil that is too hard may cut into the paper, or it may produce lettering that will not reproduce easily. A pencil that is too soft will require frequent sharpening, and it will produce lettering that may smear easily on a drawing.

GUIDELINES

Figure 3-42, view A, shows the use of light pencil lines called guidelines. Guidelines ensure consistency in the size of the letter characters. If your lettering consists of capitals, draw only the cap line and base line. If lowercase letters are included as well, draw the waist line and drop line.

The waist line indicates the upper limit of the lowercase letters. The ascender is the part of the lowercase letter that extends above the body of the letter; for example, the dot portion of the

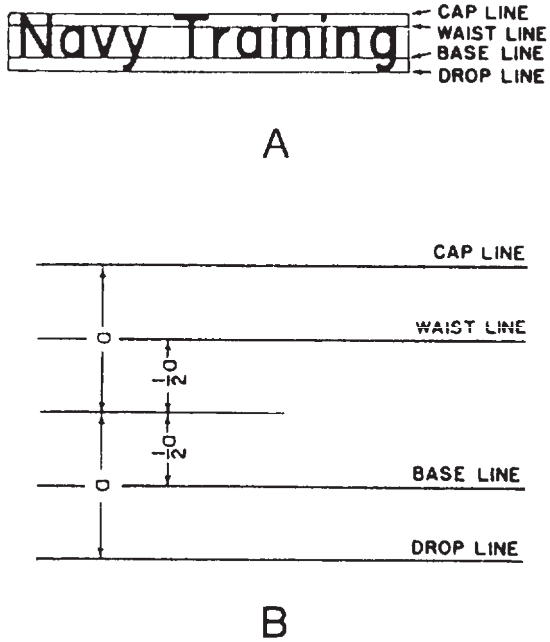

Figure 3-42.-Laying off guidelines.

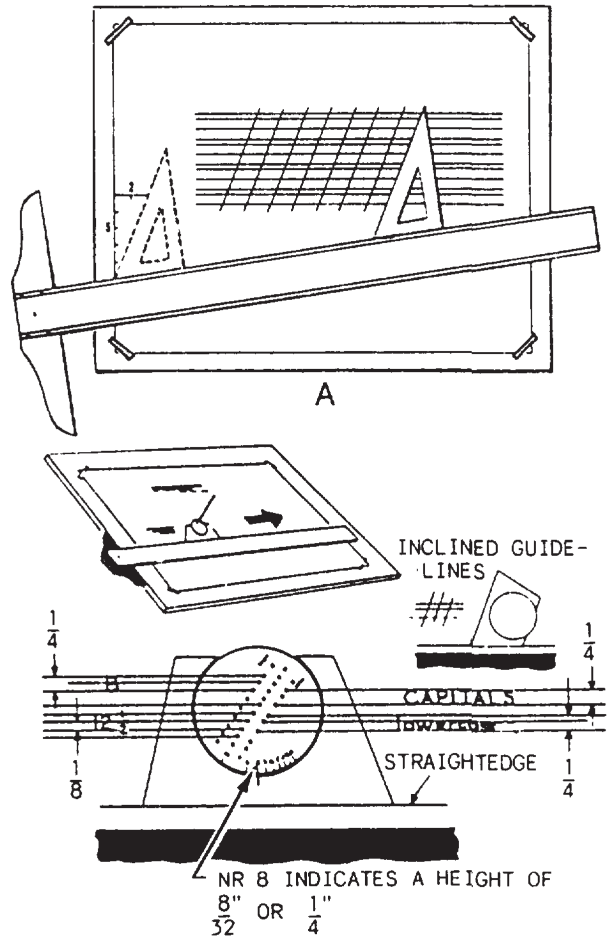

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Figure 3-43.-Laying off lines for lettering.

character *i* in figure 3-42, view A. All ascenders are as high as the caps.

The drop line indicates the lower limit of the lowercase letters. The descender is the part of the lowercase letter that extends below the body of the letter, an example being the tail of the character g in figure 3-42, view A. The vertical distance from the drop line to the base line is the same as the vertical distance from the waist line to the cap line. It is about one third of the vertical distance between the base line and the cap line, or about one half of the vertical distance between the base line and the waist line.

Figure 3-42, view B, shows an easy way to lay out guidelines for caps and lowercase. Let the height of a capital be 1 1/2 times the distance "a." Set a compass or dividers to distance "a," and lay off distance "a" above and below the midline selected for the guidelines, The method locates the cap line and the drop line. Then set the compass or dividers to one half of "a," and lay off this distance above and below the midline. This method locates the waist line and the base line.

To help you keep your lettering vertical, it is a good idea to construct vertical guidelines, spaced at random along the horizontal guidelines. For inclined lettering, lay off lines inclined at the angle you wish your lettering to be slanted. (See fig. 3-43, view A.) Inclined lines are known as direction lines and are normally slanted at a maximum of 68 degrees.

Ames Lettering Instrument

If you have many lines of lettering to do, you will find a lettering instrument, such as the Ames lettering instrument, shown in figure 3-43, view B, quite useful and timesaving. The top-left section of figure 3-43, view B, shows how to use this instrument in conjunction with a T square to draw properly spaced horizontal guidelines. You insert the point of your pencil through one of the holes, and the instrument slides along the T square as you move the pencil across the page. The enlarged drawing of the instrument in the lower part of the figure shows the details of how the instrument is used. Notice the three rows of holes in the circular disc of the instrument. The holes in the center row are equally spaced guidelines. The two outside rows are used for drawing both capital and lowercase guidelines. The left row gives a proportion of 3 to 5 for lowercase and capital letters, and the right row gives a proportion of 2 to 3.

The design of the Ames lettering instrument permits you to use it for lettering ranging in height from 1/16 to 5/16 in. These various heights are attainable by rotating the circular disc within the outer section of the instrument. The numbers along the bottom edge of the disc are used to set the instrument for a particular letter height. A number aligned with the index line on the outer section of the instrument indicates the height of the lettering in 32ds of an inch. In figure 3-43, view B, the number 8 is aligned with the index; therefore, the distance between the capital letter guides produced by this setting is 8/32 in. or 1/4 in.

By standing the Ames lettering instrument on its greater sloping side, you can use it for drawing guidelines for inclined lettering that slope at an angle of 67 1/2 degrees with the horizontal. (See the upper-right portion of fig. 3-43, view B.)

Spacing Between Guidelines

The spacing between two lines of capitals may vary from one half of the height to the full height of a capital. Two thirds of the height is customarily used.

The spacing commonly used between lines of lowercase letters is shown in figure 3-44. The space indicated by the letter *S* equals the vertical distance between the waist line and the cap line.

VERTICAL SINGLE-STROKE GOTHIC LETTERING

The generally accepted style of lettering for SEABEE drawings is the single-stroke Gothic vertical (fig. 3-45) or inclined lettering. The term *Gothic* refers to the style of letters. Gothic lettering is the simplest style to make and the easiest to read on a drawing. Single-stroke means that each stroke of the letter is made by one stroke of the pencil. Figure 3-46 shows the basic strokes required for single-stroke lettering. Vertical strokes are drawn from the top down with an even finger movement. (Inclined strokes are drawn in the same manner.) Horizontal strokes are drawn from left to right with a complete hand movement, pivoting at the wrist. Curved strokes proceed from above downward, using a combined finger and wrist motion. Lettering strokes are drawn, not sketched. It is important that you use the correct direction and sequence of strokes recommended for each letter.

The required shapes of vertical single-stroke Gothic letters and numerals will be shown and discussed in the next several figures and paragraphs. To emphasize the proportions of the letters and numerals, each character is shown in a grid, six units high. The grid serves as a reference for comparing the height of the various characters in proportion to their width as well as locating the individual strokes that compose the characters.

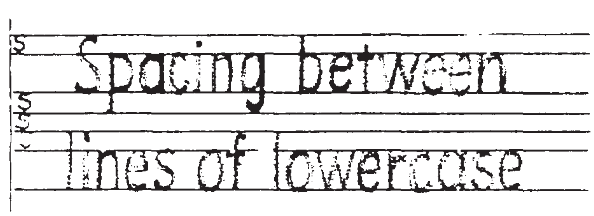

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Figure 3-44.-Spacing between lines of lowercase letters.

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Figure 3-45.-Vertical single-stroke Gothic capitals and numerals.

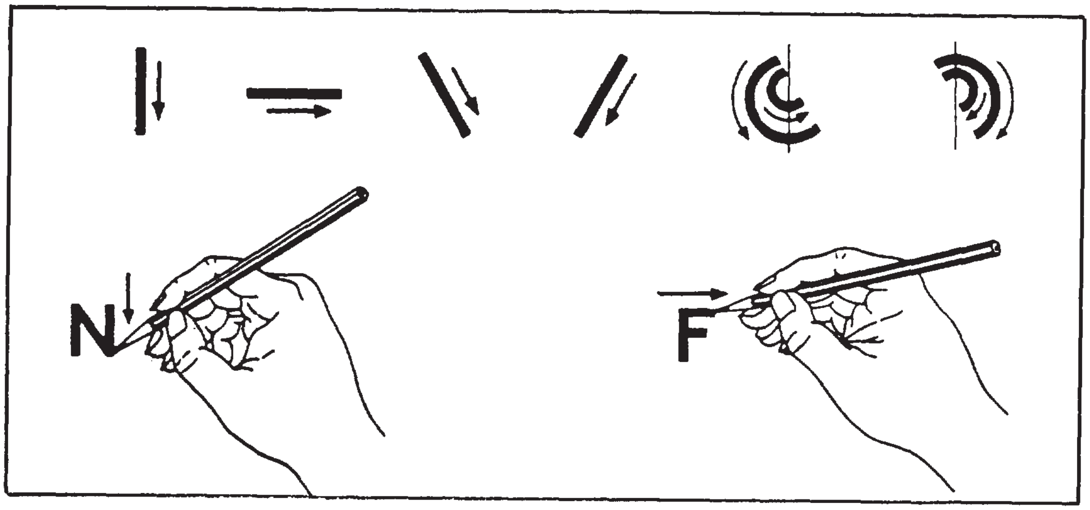

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Figure 3-46.-Basic lettering strokes.

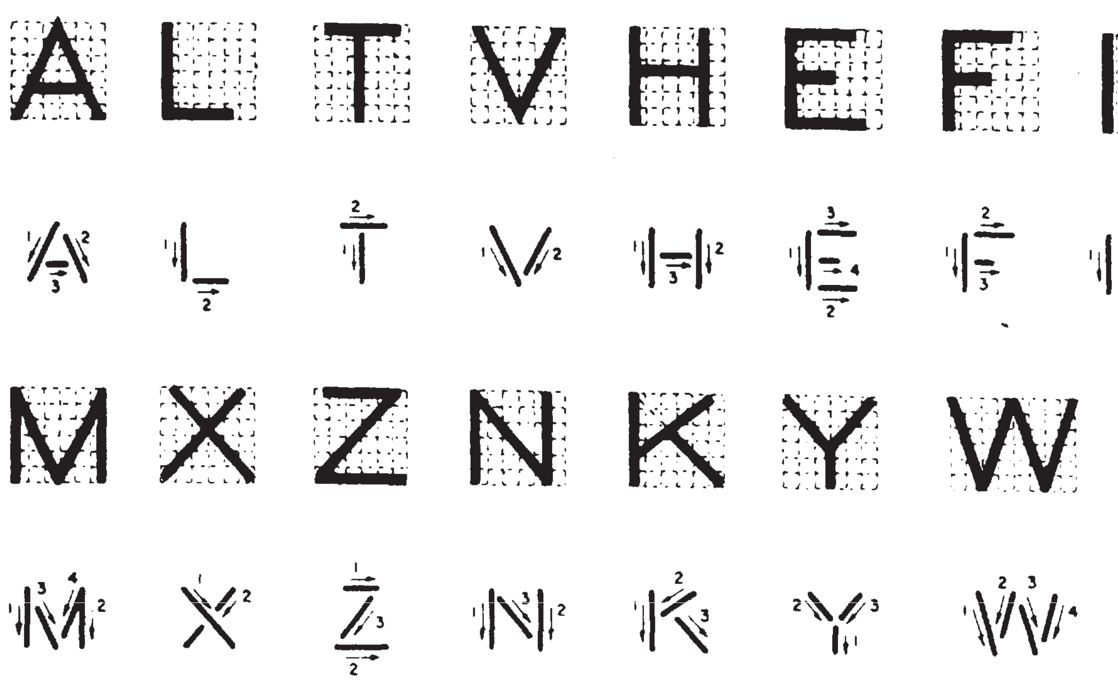

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Figure 3-47.-Lettering vertical straight-line capitals.

For learning purposes, the characters are grouped by the type of strokes required to form each character.

Straight-Line Capitals

The capital letters shown in figure 3-47 are formed with only straight-line strokes.

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

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

H, F, E. In *H, F,* and *E,* the central horizontal bar is placed slightly above the center for stability. In both *E* and *F,* the cap line stroke is four units long and the central stroke is three-fifths of this length. The base line of *E* is one-half unit longer than its cap line.

V, W, M, N. The two inclined strokes of the *V* intersect just below the base line. The *W* is 1 1/3 times the width of a normal letter; note that it is wider than *M.* Strokes 1, 2, 3, and 4 of the *W* intersect below the base line. Strokes 3 and 4 of the *M* and 2 and 3 of the *N* intersect on the base line. Note that the outside strokes of the *M* and *N* are drawn first.

Curved- and Straight-Line Combinations

The capital letters shown in figure 3-48 are formed by either curved line strokes or by a combination of curved- and straight-line strokes.

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

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

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

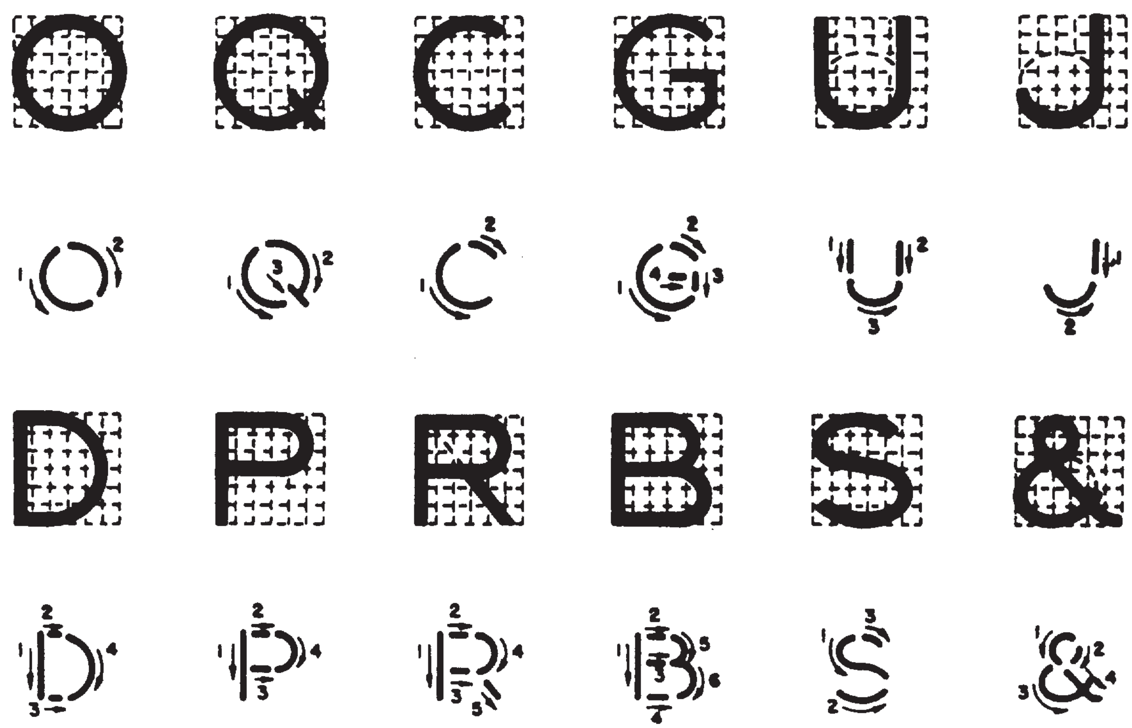

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Figure 3-48.-Lettering vertical capitals, curved- and straight-line combinations.

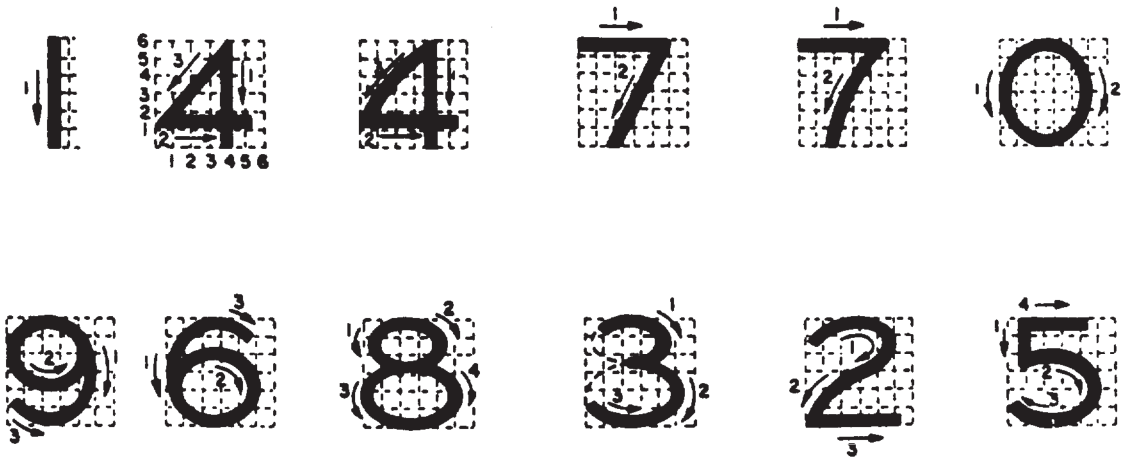

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Figure 3-49.-Lettering vertical numerals.

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

Figure 3-50.-Vertical fractions.

Numerals and Fractions

The need for extreme care in drawing numerals cannot be overstressed, particularly in the preparation of construction drawings in which a poorly drawn numeral can cause costly errors and delays.

Numerals are drawn using the same size guidelines as the capital letters on a drawing. Vertical guidelines are spaced at random. Numerals should not be made so small or be crowded so closely as to impair their legibility.

In figure 3-49 the vertical stroke of the numeral 4 is placed two units from the right side. The horizontal bar is one quarter the height of the number above the base line. Note that the closed curves of *0, 6,* and *9* are elliptical, not circular. The *6* is an inverted *9*. The *8* is composed of two ellipses tangent slightly above the center point. The top ellipse also is narrower. The *3* is the same as the *8* with the left portions of the loops cut off. The curved lines of *2* follow the elliptical contours of *8*. The top portion of the *5* is slightly narrower than the bottom. The bottom ellipse is two thirds of the height of the figure from the base line.

The division bar between the numerator and denominator of the fractions is always drawn parallel to the guidelines, as shown in figure 3-50. The complete height of a fraction is twice that of a whole number. The division bar is centered midway between the base line and cap line. The top guideline of the numerator and the bottom guideline of the denominator are spaced a full number height from the division bar. The numbers composing a fraction are three quarters of the height of a full number. The clear space on either side of the division bar is one quarter of a full number. Numbers in a fraction are centered about a vertical guideline that cuts the fraction bar in half.

Lowercase Letters

Lowercase letters are never used on construction drawings, although it is acceptable to use them for notes on maps or similar drawings.

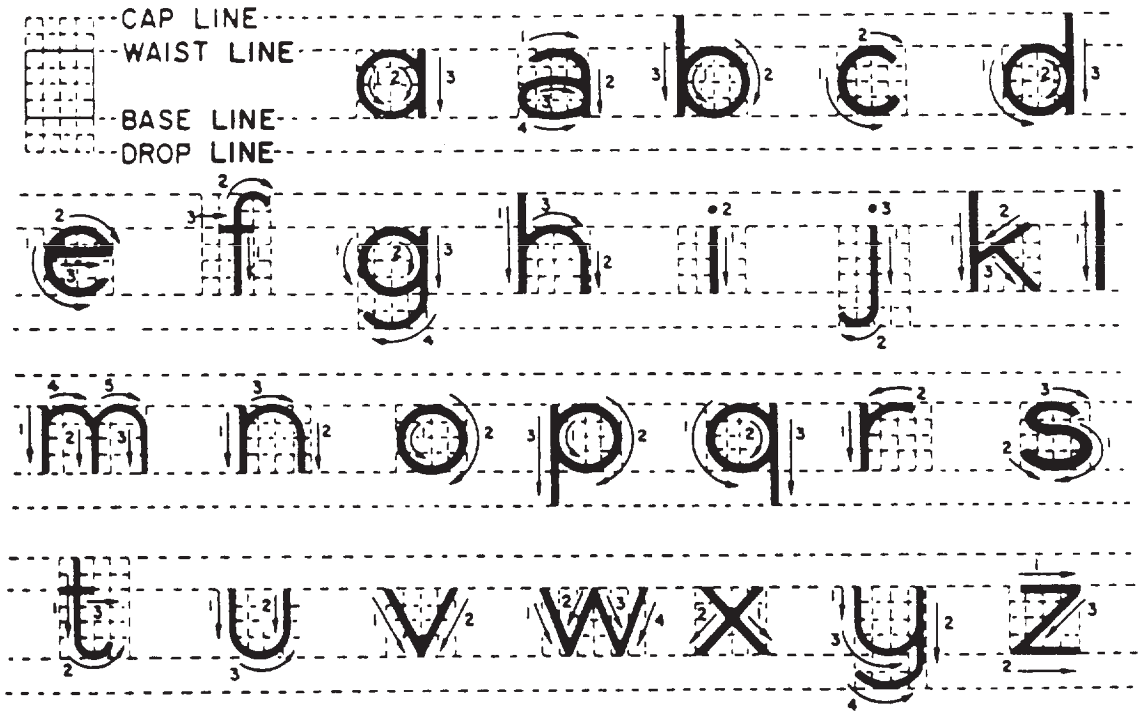

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Figure 3-51.-Lettering vertical lowercase letters.

Lowercase letters should NEVER be used on drawing title blocks. Figure 3-51 shows lowercase letters along with guidelines and strokes used to form each letter.

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

INCLINED LETTERING

Inclined single-stroke Gothic lettering is also acceptable on SEABEE drawings, although it is not recommended for the beginner and should not be attempted until you have mastered vertical lettering techniques. Inclined and vertical lettering should never appear on the same drawing. The lettering style used must always be consistent.

Figures 3-52 and 3-53 show the required formation of inclined letters. The angle of

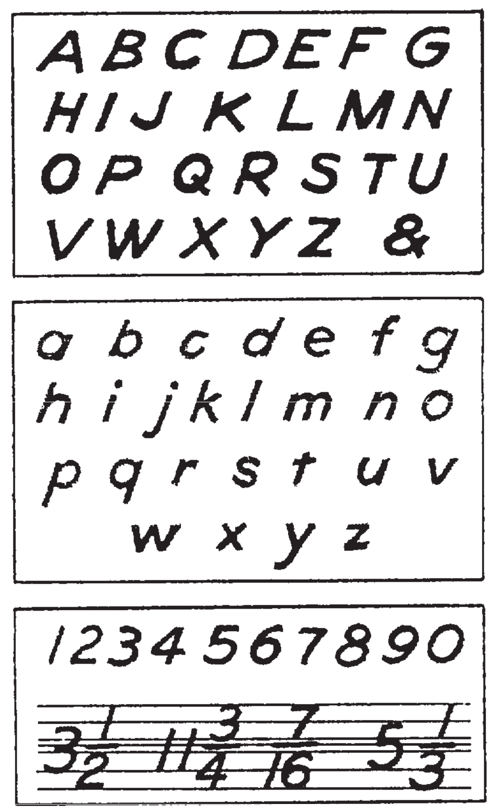

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Figure 3-52.-Inclined single-stroke Gothic.

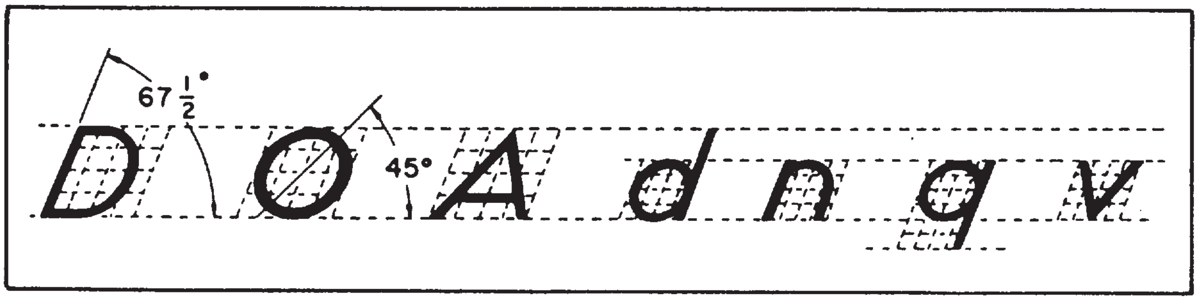

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Figure 5-53.-inclined letter formation.

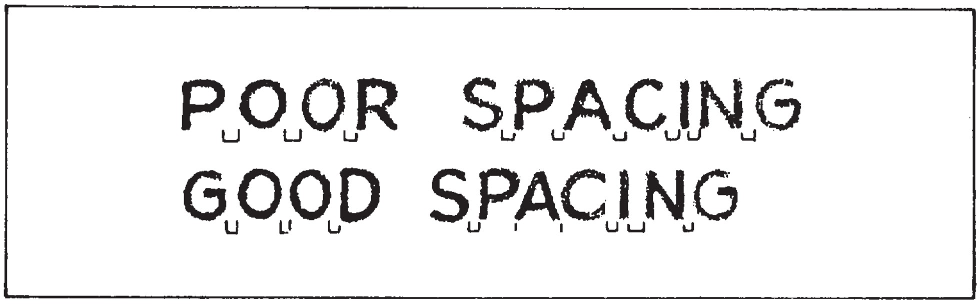

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Figure 3-54.-Letterspacing.

inclination is 67 1/2 degrees from the horizontal. Inclined guidelines may be drawn with the lettering triangle as described, or a line at the proper angle may be laid off with the protractor and parallel lines constructed from it. Horizontal guidelines and sequence of strokes are the same as for vertical letters. Rules of stability, proportion, and balance are similar. The circles and circular arcs used in vertical letters become elliptical in inclined letters, their major axes making angles of 45 degrees with the horizontal. Letters such as *A, M, V,* and *Y* should be made symmetrically about a guideline. Inclined lowercase letters follow the same principles as inclined capitals.

COMPOSITION OF LETTERING

Once you have learned the proper shapes and strokes required to form each letter and numeral, you should concentrate on practicing the composition of words and sentences. Proper spacing of letters and words does more for the appearance of a block of lettering than the forms of the letters themselves. But this does not mean that you should discontinue further practice of correctly forming each letter.

LETTERSPACING

In straight-line lettering, determine the spacing between letters by eye after making the first letter and before making each succeeding letter. To give a word the appearance of having uniformly spaced letters, make the areas between the letters nearly equal, as shown in figure 3-54. The areas between adjacent letters in a word vary with respect to whether the letters have straight sides *(H, I, M, N)* or slanted sides *(A, V, W)* and whether the letters are round *(O, Q, C, G)* or open *(L, J)*. Adjacent straight-sided letters are drawn farther apart than are adjacent round letters. Adjacent slant-sided and open letters are drawn nearer together than are adjacent round letters. Where letters *L* and *T, L* and *V, A* and *V,* and other pairs of like shape come together in a word, the top of one may have to be drawn above the bottom of the other to avoid having the word appear as two or more words. In letterspacing, the six problems listed below are the hardest to solve. The first five problems are solved by moving the letters closer together; the sixth by moving the letters farther apart.

1. Round next to round. (Increasing area at top and bottom where letters curve away from each other, as in figure 3-55A).

2. Round next to slant. (Increasing area at top or bottom where letters move away from each other, as in figure 3-55B).

3. Vertical next to slant. (Increasing area at top or bottom where one letter slants away from the other, as in figure 3-55C).

4. Slant next to slant. (Increasing area at top or bottom where letters slant in opposite directions, as in figure 3-55D).

5. Round next to vertical. (Increasing area at top and bottom where round letter curves away, as in figure 3-55E).

6. Vertical next to vertical. (Decreasing area at top and bottom where stems move together, as in figure 3-55F.)

A good way to evaluate the spacing of letters is to hold the lettering away from you and squint your eyes, observing the gray tone throughout the lettering. If the tone appears spotty or varies too much, the letters are poorly spaced.

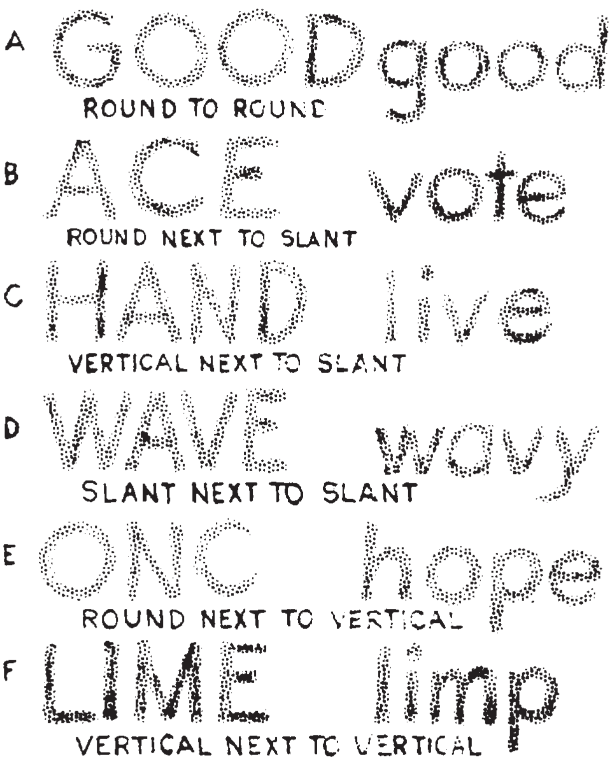

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Figure 3-55.-Common spacing problems.

WORD SPACING

Proper spacing between words is an important factor in making them easy to read. Allow enough space between words and sentences to keep them from running together, but not so much as to cause words to be read one at a time. A good practice to follow is making spaces between words equal to the space that the letter *O* occupies as shown in figure 3-56. If you prefer, you can use the letter *N* or a correctly spaced letter *I* instead.

Naturally, the design of the last letter of a word and of the first letter of the following word must be considered in determining the amount of space you leave between words. You should leave a space equal to a capital *O* between two full-height straight-stemmed letters, such as *H* and *E* or *D* and *B*. Of course, if one or both of the letters are curved, the space should be appropriately reduced. If the two letters involved are lowercase, use the lowercase *o* to determine the width of the space. If one letter is full height and the other is lowercase height, such as the words *bid now or on him,* the space would be equal to half a capital *O* and half a lowercase *o*.

LINE SPACING

In addition to the spacing between letters and words, the spacing between lines of lettering adds to the readability of the lettering. Again your eye and your artistic ability must be your guide. Except when you are trying for a special effect, you should have enough space between the lines to make it easy for the reader to see what he is reading.

The distance between lines may vary from 1/2 to 1 1/2 times the height of the letter, but for the sake of appearance, it should not be exactly

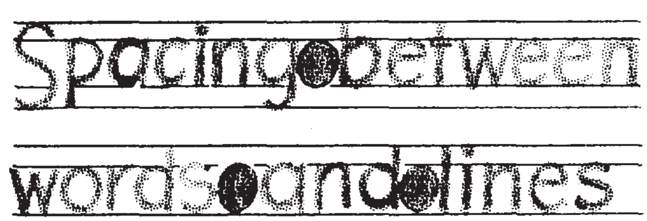

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Figure 3-56.-Spacing between words and lines.

the same as the letter height. As a general rule, two thirds of the letter height is a good distance between lines. This spacing allows room for descenders of lowercase letters and still maintains a clear space of one third of the letter height between the descenders and capital letters, or ascenders of lowercase letters of the following line. Figure 3-56 shows proper word and line spacing.

CENTERING

Since the letters of the alphabet vary in width, it is rather difficult to center a line of lettering. Figure 3-57 shows one way of solving this problem. First, take a piece of scratch paper and letter in the required line. Then, place this lettering above the area in which your lettering is to go and center it. Finally, use the sample as a guide to lettering the desired line.

Ending a line of lettering at a given point is equally difficult. As in centering, first, letter the line on a piece of scratch paper in order to achieve the proper line length.

To make lines of lettering come out to a specified length, you must adjust the word and/or letterspacing. This adjustment in spacing is called JUSTIFYING. A good example of justifying is found in the columns of this manual. Notice how all full lines start and stop on the right- and left-hand margins. Usually, you will only find justified lettering typeset or typewritten by mechanical means. However, if you do have an occasion to justify your lettering, you should try to keep the spacing between the words as uniform as possible. Uneven spacing detracts from the appearance of the job. When it is impossible to divide the spacing evenly, insert wider spacing at points where one word ends and the next begins with tall letters, like *d, b,* and *l.*

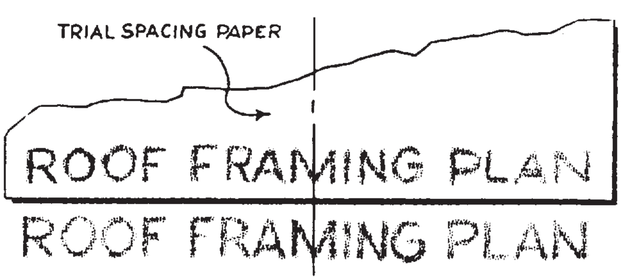

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Figure 3-57.-Centering with trial spacing paper.

If you use too much space between the words, the paragraph will tend to fall apart because it is filled with rivers of white space that will disturb the eye.

When a line is so short that it calls for an undue amount of space between words to lengthen the line, allow more space between the letters in each word. This is known as letterspacing. When words are letterspaced, always allow extra space between words so that they will not seem to run together when they are read.

Letterspacing makes short words in titles or headings appear longer. Though it frequently improves the appearance of words in caps, letter-spacing reduces the legibility of words in lowercase, Therefore, the process must be used with caution.

MECHANICAL LETTERING

In chapter 2 we discussed pens that are used primarily for freehand lettering. At times, however, you will be tasked with preparing drawings, charts, maps, or signs that require the use of mechanical lettering. When we refer to mechanical lettering, we mean standard uniform characters that are executed with a special pen held in a scriber and guided by a template. Mechanical lettering does not normally require the use of lettering guidelines. You will use mechanical lettering principally for title blocks and notes on drawings, marginal data for special maps, briefing charts, display charts, graphs, titles on photographs, signs, and any other time that clear, legible, standardized lettering is required. It should be noted that freehand lettering is the required lettering on most of your drawings; mechanical lettering should be confined to special uses similar to those described above. The availability of mechanical lettering devices should not deter you from the daily practice required to execute freehand lettering. With continuous practice you will become proficient with both mechanical and freehand lettering.

One of the most popular types of mechanical lettering sets is the LEROY lettering set. A

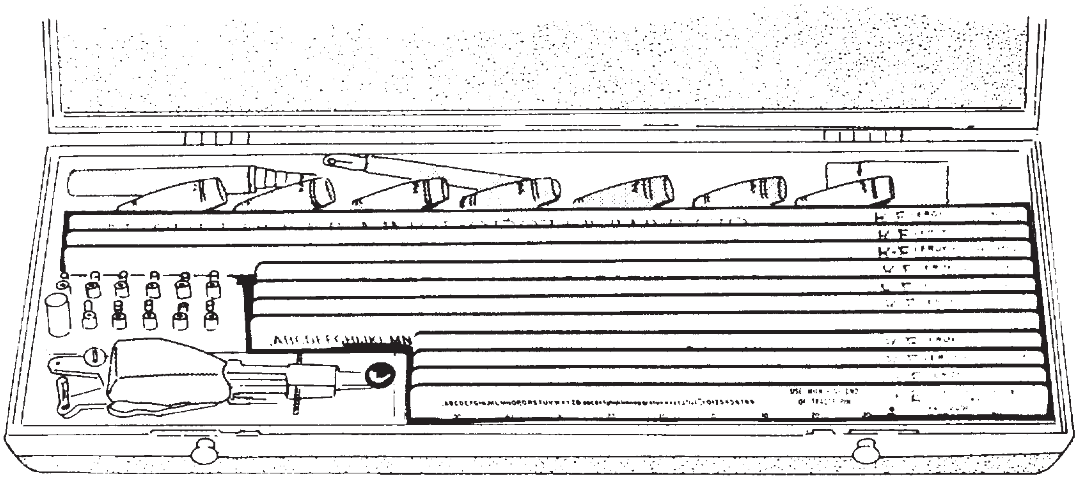

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Figure 3-58.-Leroy lettering set.

standard Leroy lettering set consists of a set of templates, a scriber, and a set of pens. (See fig. 3-58.)

TEMPLATES

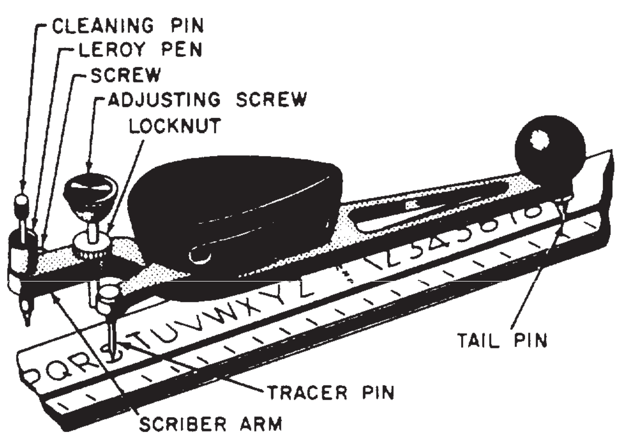
Templates are made of laminated plastic with the characters engraved in the face so that the lines serve as guide grooves for the scriber. The height of the characters, in thousandths of an inch, is given by a number on the upper right-hand side of the template. For example, 3240-500CL indicates a No. 500 template. The entire number and letter designation identifies the template in the manufacturer's catalog. The range of character heights offered by a standard set of templates is from 80 (0.08 in. or 5/64 in.) to 500 (0.5 in. or 1/2 in.). The scale at the bottom of each template has the zero in the center and is arranged for proper spacing in relation to character heights. The distance between each scale division represents the center-to-center distance of normal-width letters.

PENS

A standard set of pens for producing various line weights consists of 11 sizes ranging from 000, the finest, to 8. Each pen is composed of two parts: the ink reservoir and the cleaning pin. The reservoir is a series of connected tubes of decreasing diameters, the smallest establishing line thickness. The cleaning pin acts as a valve, protruding beyond the edge of the bottom tube when the pen is not touching the drawing surface. In this position, no ink flows. When the pen is resting on a drawing surface, the cleaning pin is pushed up, allowing a flow of ink. Action of the pin in the tube minimizes ink clogging.

NOTE: As stated in chapter 2, some reservoir pens are made so the point section will fit in a Leroy scriber. They have become popular with the SEABEEs (and widely used over the standard pens contained in the Leroy lettering set), especially for long hours of uninterrupted lettering.

A SCRIBER holds the pen in alignment and controls its motion as the tracing pin is guided through the character grooves of the template. Two types of scribes are available: adjustable and



45.120

Figure 3-59.-Leroy scriber and template.

fixed. An adjustable scriber produces letters with any slant from vertical to 22 1/2 degrees forward from a single template; a fixed scriber produces only vertical letters. Both scribers consist of a tracing pin, pen socket, socket screw, and a tail pin. Figure 3-59 shows a fixed scriber. The tracing pin on most Leroy scribers is reversible, One point is used with fine groove templates (Nos. 060, 080, and 100), and the other point is for wider groove templates (No. 120 to No. 500).

LINE WEIGHTS

Recommended combinations of template and pen for best proportion between line thickness and letter size are shown below.

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

This list is also found inside the lid of the Leroy lettering set case.

OPERATING PROCEDURES

A certain technique is required to manipulate the Leroy scriber with the template and, at the same time, hold the template against the working edge of the T square or straightedge without slipping.

The T square or straightedge must be held in position with the ball of your left hand resting on the blade, while the fingers of the left hand hold the template against the working edge and change the position of the template when necessary. The scriber is held between the thumb and first three fingers of your right hand. The little finger of the right hand presses the right side of the template against the working edge, preventing the tracing pin from slipping out of the character grooves of the template. Care must be taken to keep the tail pin in the straight-guide groove at the bottom of each template. When you are making long lines of large lettering, you may find it helpful to secure the T square or straightedge at both ends of the drawing board with drafting tape.

Using the above techniques to manipulate the scriber and template, follow the steps listed below to form uniform letters, words, and sentences. As you follow the steps, refer to figure 3-59.

1. Select the template with letters of the desired height. The distance between each graduation at the bottom of the template is equal to the height of the letter that can be made with the template. The numbers in a fraction are made by using a template one size smaller than that used for whole numbers.
2. Lay the template along the top edge of a T square or straightedge.
3. Using the table of recommended template and pen sizes previously mentioned, select the proper pen to give a well-proportioned letter.

NOTE: On drawings with a great deal of lettering, the recommended combinations may be altered by one pen size, either under or over the recommended size, for variation and appearance. Never use a pen size more than two over the recommended size.

4. Insert the selected pen into the socket of the scriber arm until the shoulder of the pen rests on the scriber arm.
5. Tighten the screw on the side of the scriber arm.
6. Loosen the locknut on the adjusting screw in the scriber arm.
7. Set the tail pin of the scriber in the straight-guide groove of the template.
8. Set the tracer pin of the scriber in the groove of a character.
9. Lower the pen gently to the drawing surface.
10. Raise or lower the scriber arm by turning the adjusting screw until the tip of the cleaning

pin within the pen just touches the drawing surface. Tighten the locknut when the desired height is reached. To prevent blotting, you should make this rough adjustment before you put ink into the pen.

11. Remove the scriber from the template.
12. Remove the cleaning pin from the pen.

NOTE: To prevent the ink from flowing straight through the pen, you should not remove the cleaning pin of a Leroy pen No. 4 or larger from the pen.

13. Fill the reservoir of the pen with drawing ink. The Leroy pen should be filled with ink in the same manner as any common drafting inking instrument. The reservoir should be kept from one-fourth to three-fourths full; too low an ink level results in irregular lines.
14. If the cleaning pin was removed, reinsert it into the pen.
15. Wipe the lower tip of the pen with a cloth to remove any excess ink that may have been pushed through by the cleaning pin.
16. Draw a test line on a piece of scratch paper to ensure that the ink will flow smoothly.
17. Gently lower the pen to the drawing surface after inserting the tail and tracer pins in their proper grooves.
18. Proceed with the lettering by moving the tracer pin in the grooves of the characters, keeping the tail pin in the straight-guide groove.

If the ink does not flow properly, turn the cleaning pin inside the pen and wipe the tip with a cloth; also, make any necessary minor adjustments to the adjusting screw to allow the ink to flow properly. Tighten the locknut. When you will not be lettering for short periods of time, place the tip of the pen, still in the socket of the scriber arm, on a piece of moist cotton. This will prevent the ink from drying around the opening of the pen and will help the ink to flow properly when you begin lettering again.

SPACING AND CENTERING

The rules for freehand letterspacing and word spacing also apply to mechanical lettering. Guidelines are not necessary for mechanical lettering; however, when you are making more than one line of lettering, you may draw horizontal base lines at intervals to help you maintain the proper spacing between the lines. Spacing between lines of mechanical lettering is the same as for freehand lettering.

When lettering must be centered above a certain part of a drawing, or within a certain space, use the scales along the bottom edges of the templates. Each space on the scale represents the center-to-center distance of normal-width letters. For example, to center the words *LEROY LETTERING* about a certain line, proceed as follows:

1. Count the letters in each word and the spaces between words. Result: 15.
2. Considering the letter *I* and the space between the words as half value for each, reduce the total by one. Result: 14.
3. Divide the result of No. 2 above by two. Result: 7.

NOTE: If there had been an odd number of half values, you would use the next lower number and allow more space between words than normally required.

4. Set the zero of the scale at the vertical line about which the lettering is to be centered and mark off seven spaces to the left and right of zero.
5. Start the *L* of the word *LEROY* in the title at the left mark and continue to the end. The right edge of the *G* should fall on the mark to the right.

MAINTENANCE OF MECHANICAL LETTERING EQUIPMENT

Pens should be cleaned thoroughly with water after use and stored properly in the lettering set case. Never wash them under running water in a sink. The pen and cleaning pin may accidentally be washed down the drain. If water does not clean a pen satisfactorily, a diluted solution of ammonia may be used. Commercial pen cleaning solutions and pen cleaning kits are available. Caked or dried ink can be removed by soaking the pens overnight in a cleaning solution; however, the pens may corrode if soaked longer. Cleaning pins should be handled with care because they are fragile and easily bent, especially the smaller ones.

The screw that holds the pen in the scriber should never be screwed too tightly, as the fine threads tend to strip very easily.

Templates should be cleaned after every use. Dirt and dried-on ink are very easily transferred onto an otherwise clean drawing. You must ensure that the template grooves are kept free from all foreign matter and that the tracer pin does not cut into the sides of the grooves. In order to form perfect letters every time, you must make sure that the tracer pin slides along the grooves smoothly. When small templates are used, a small sharp tracing pin must be inserted in the scriber. If a sharp tracing pin is used in the larger templates, the grooves of the templates will be damaged.

LETTERING SYSTEM

Today's operating units, training commands, and shore establishments within the Naval Construction Force (NCF) have a great demand for quality graphics to enhance command presentations during management and readiness inspections and during execution and completion reports.

The bulk of the job is commonly handled by the engineering department or branch. As an EA, you will be tasked with producing a variety of quality signs, labels, lettering, tags, and other miscellaneous requests.

It is likely that your office may already have one of the lettering machines used for this job. The pressure lettering machine (fig. 3-60) is just one of the typical tools that produces high-quality lettering faster than press-on type letters and the mechanical letters. This machine uses a pressure process to transfer dry carbon impressions onto a variety of tapes that are used for producing letters, numbers, and symbols. The impressions are made from raised characters on an interchangeable type of disc available in different styles, ranging in size from 8 points to 36 points (table 3-1). Overall, this machine is easy to use. Daily operation and on-the-job training will enhance your efficiency.

Table 3-1.-Size Range of Impressions Made from Characters Used on a Lettering-System Type of Disc

POINT SIZE	≈	INCHES (mm)
8	≈	1/16" (2 mm)
10	≈	3/32" (2.5 mm)
12	≈	1/8" (3 mm)
14	≈	9/64" (3.5 mm)
18	≈	3/16" (4.5 mm)
24	≈	1/4" (6.5 mm)
30	≈	5/16" (7.5 mm)
36	≈	3/8" (9 mm)

RECOMMENDED TYPE SIZE USES:

8 TO 14	POINT-SUBHEADLINES
18 TO 24	POINT-UPPER AND LOWERCASE HEADLINE
30 TO 36	POINT-LARGE, BOLD ALL UPPERCASE HEADLINES

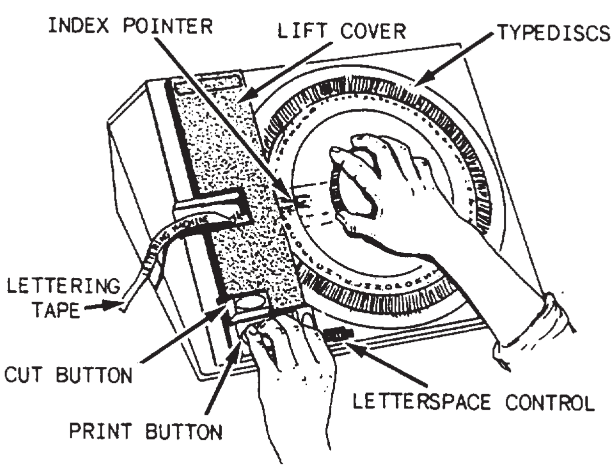


Figure 3-60.-Typical pressure lettering machine.

DRAWING REPRODUCTION

One of the most important skills an EA needs to learn besides drafting is operating reproduction equipment or machines. The quality of a reproduced copy (usually called BLUEPRINT) measures the accuracy, completeness, and conformance to applicable standards of an original or traced drawing. All EAs therefore should be familiar with the aspects of performing this skill and should develop competency through practice and experience. This section discusses the various aspects of the reproduction process and maintenance of a typical reproduction machine.

REPRODUCTION ROOM

Regardless of the type of reproduction machine used, it should be positioned in a room in such a manner as to ensure the best possible ventilation. The machine should be set against an outside wall and an exhaust tube or an exhaust vent provided with a fan should be installed since ammonia is used in the developing process.

If possible, less light is preferable because light-sensitive paper is used. All supplies of sensitized paper and other materials for reproduction should be kept in a dehumidified, cool, and dark storage area. It is good practice to date the supplies so as to use the oldest stock first. Heat is a major factor to consider, no matter what machine is used.

Ventilation should be sufficient throughout the room, since the prints, even after they emerge from the machine, are saturated with ammonia fumes. The fumes from ammonia are very powerful, and personnel should avoid excessive inhalation. Chemicals used in developing solutions that come in powder form should be stored the same as sensitized materials. Ammonia should be stored in shatterproof bottles.

CAUTION

Ammonia fumes are extremely toxic! Burns, as well as temporary blindness, can result if you are careless while handling the solution.

Since reproduction machines are energized with electricity, you need a firm understanding of electrical safety. NEVER touch an energized electrical plug, switch, or any part of electrically operated equipment with wet hands or while standing in water or on a wet floor. If the machine should become wet or be in contact with water while in use, you should disconnect the electrical power source before attempting to clean up the area. It is also important for qualified and certified personnel to inspect electrical outlets and connections frequently for obvious signs of damage.

REPRODUCTION MACHINES

The process most commonly used for reproducing construction drawings by the Navy is the DIAZO or AMMONIA VAPOR PROCESS. Basically, this process produces prints with a white background and blue or black lines after exposure to light. These prints are then dry developed with ammonia vapor. This process uses aqueous ammonia as a developing agent with water vapor as the carrying agent, causing the paper exiting from the chamber to carry residual ammonia vapor with it. In the diazo process, the ammonia chest is saturated with water vapor at all times to help eliminate the toxic ammonia vapors.

Diazo process reproduction machines are made by several manufacturers, such as Blu-Ray Inc. and General Analine Film Corp. (GAF). Machines formerly made by GAF were called Ozalid. The machines presently made are no longer called Ozalid, only labeled GAF. However, old Ozalid equipment is still serviced and repaired by the GAF Corporation.

The basic difference between the various types of diazo machines is the size of paper that they can accommodate. Paper that is 9 in. wide can be used on the smallest machine, and paper that is 54 in. wide can be used on the largest machine.

Blu-Ray Model 842 Whiteprinter

The Blu-Ray Model 842 Whiteprinter, shown in figure 3-61, has most of the capabilities of larger diazo process machines. It is ideally suited for use in battalion engineering offices, because it is easy to set up and is easily moved. It is very simple to operate and easy to maintain.

It is important that all EAs thoroughly understand the manufacturer's instructions covering the operation and maintenance of the Blu-Ray reproduction machine before attempting to use it. Keep a current file for all reference material available for use by the operators. The machine should be located as close as possible to an electrical outlet that supplies adequate power. (Electrical specifications are given in the operation manual.)

After the machine has been assembled and set up according to the manufacturer's instructions, the machine must be placed on a level surface, such as a table or a desk. This is very important for proper ammonia drainage and adequate support for the feet on the bottom of the machine.

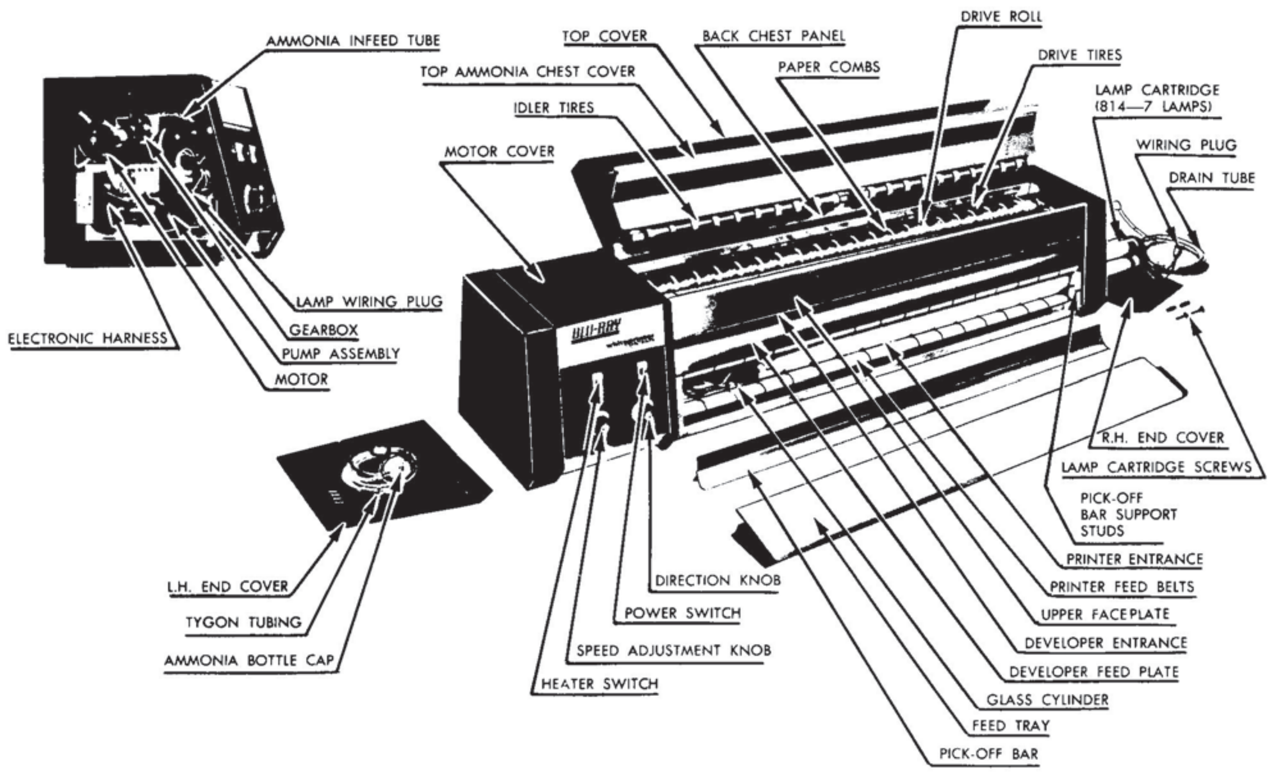


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Figure 3-61.-Exploded view of the Blu-Ray Model 842 Whiteprinter.

The ammonia supply bottle must be placed below the machine so that there will be a short, direct, and unkinked run of the large ammonia discharge tube.

Only the proper aqueous ammonia, as recommended in the operation manual, should be used. Use only fresh ammonia and change it at least once a month for best operation. NEVER reuse the discharged ammonia.

Room temperature is important. Blu-Ray manufacturers recommended a room temperature of 70°F be maintained. A drop in room temperature will cause condensation in the chest, giving wet prints and may, if excessive, jam the developer.

The Blu-Ray is equipped with an ammonia chest heater, which has an independent heater switch. The heater is used to activate the ammonia vapor to improve development when it is necessary. This may be true especially with long, continuous machine operation.

The machine must be kept dust-free and clean. Dust is an abrasive material that can wear out the Teflon gate strips in the developer section, as well as other moving parts.

OPERATION.— A pilot-lighted switch marked POWER on the instrument panel turns the Blu-Ray machine on and off. When it turns the machine on, it actuates the main drive motor and the ammonia pump motor and fan, and it lights the fluorescent tubes.

A pilot-lighted switch marked HEATER on the instrument panel manually turns the heater on and off.

Two knobs on the instrument panel marked SPEED and DIRECTION manually will give a stepless speed range from 0 to 12 ft per min in both directions.

To select the desired speed of operation, manually turn the knob marked SPEED to a number that experience has shown to be proper for the type of paper being printed.

The knob marked DIRECTION has a forward and reverse setting. Keep this knob at forward setting at all times. Use the reverse setting only when the paper is jamming and must be instantly removed. This knob can be snapped from forward to reverse while the machine is running. The Blu-Ray may be turned on and off AT ANY TIME. THERE IS NO WARM-UP OR

COOL-DOWN PERIOD REQUIRED FOR THIS MACHINE. Just turn on the power switch, make your print, and turn the machine off. This is recommended for longer machine and lamp life.

Making prints is extremely simple. Place your original tracing or transparency, face up, on the sensitized reproducing paper, chemical (yellow) side up. Adjust the leading edges of both papers so they are even, uncurled, and uncreased. THIS IS IMPORTANT! Place the two adjusted sheets on the feed table and gently feed them evenly into the printer entrance WITH THE GRAIN of the sensitized paper (see package for grain indication) until they are engaged between the rubber belts and the glass cylinder.

If for any reason the above described entrance of the paper to the printer is erratic, creased, wrinkled, or uneven, turn the direction knob to reverse and the papers will come out of the printer.

As the original and printed sensitized paper exits from the printer over the top of the glass cylinder, manually separate the sensitized paper from the original tracing.

Turn the sensitized paper up and into the entrance of the ammonia developing chest. The finished print will exit from the top of the machine.

If your print is too light, turn the speed knob to a higher number; if too dark, turn to a lower number.

The interior of the ammonia chest of the Blu-Ray machine is readily accessible for inspection or removal of jammed paper. Using finger catches on the top of the machine, lift up the top cover, and the upper chest panel will be exposed. (Before opening, SEE WARNING below.) Two sliding door latch-type fasteners hold the upper chest panel in its closed position. Slide these door latches toward the center of the machine, and open the upper chest panel up and back, exposing the interior of the ammonia chest.

WARNING

DO NOT OPEN THE AMMONIA CHEST WHILE THE MACHINE IS RUNNING. Be sure that all ammonia has drained from the machine. Stand back from the machine when the chest is open. There is a heavy charge of ammonia in the chamber. Be sure to provide ventilation at all times when the ammonia chest is open.

When removing jammed paper from the ammonia chest, do not bend or scratch any of the mechanical parts in the chest.

Because of described qualities of the aqueous ammonia, it is important that a NITE-SHEET be run in the developer section when the machine is not in operation for a period of time (nights, weekends, etc.). This nite-sheet can be a wide sheet of sensitized paper long enough to extend from both the entrance and exit of the developer section. Stop the machine when this is accomplished, allowing the sheet to remain. This sheet will absorb the excess vapor and condensation, leaving a dry chamber when the machine is started again.

MAINTENANCE.— Periodic maintenance and inspection of the Blu-Ray machine are essential. Major maintenance and repairs should be performed only by skilled service personnel.

For maximum light exposure, it is very important that the exterior and interior of the glass cylinder be cleaned frequently. When the glass cylinder needs to be cleaned, follow the steps given below.

1. Disconnect the electrical cord from its power source.
2. Remove both end panels from the machine by removing the panel-holding screws.
3. Back off the locking screw and open the drive-section cover.
4. Disconnect the lamp cartridge wiring. DO NOT PULL THE WIRES; grasp the plug.
5. Unfasten the lamp cartridge by removing the screws at the right-hand end of the lamp cartridge frame. Gently remove the lamp cartridge, ensuring that the wires at the left-hand end of the cartridge do not snag.
6. Thoroughly clean the glass-printing cylinder and lamps. Use the manufacturer's recommended glass cleaner or an ammonia-water solution. NEVER use an abrasive cleaner on the glass cylinder.

It is inherent in the nature of fluorescent lamps to lose brilliancy after months of usage. This requires the machine to be slowed down to produce the desired prints. When this occurs, the lamps should be replaced, Since the lamp cartridge must be removed when the glass-printing cylinder interior is being cleaned, burned out or weak lamps should be replaced at the same time. Lamps, as well as any other parts needed, should be obtained through your supply system.

It is recommended that the lamp starters be replaced when the lamps are being replaced. The lamp starters are located in the ballast panel in the back of the machine. For ease of removal and replacement, a portion of the ballast panel cover must be removed to expose the starters.

Printer feed belts may become slack over a period of time, causing slippage and blurred prints. A simple adjustment may be made as follows:

1. Pull the small Tygon tube out of the ammonia supply bottle cap.
2. Run the machine until the tube is pumped dry and no longer feeding the ammonia tank in the machine.
3. Raise the motor end of the machine a few inches for a moment for complete drainage.
4. Shut off the machine.
5. Tip the machine on its back carefully so the ammonia tubes and power cord that project from the back will not be crushed or kinked. This will expose the two slotted idler take-up brackets.
6. Loosen the two screws in both brackets, and press down approximately one-fourth in, beyond the previous setting to give proper tension to the belts, and re-secure. Make sure that both brackets are set at the same position.

The components in the ammonia chest are readily accessible and easily removed. The top cover is removed by sliding a door-catch type of pivot and then lifting it off of the machine. The back chest panel can be removed independently for internal inspection by removing four screws and sliding the panel out of the machine. Both the upper and lower paper combs are attached to the back chest panel, allowing for inspection and replacement of their combs when the panel is removed. Take out the ammonia tank first. The ammonia tank is independently removed from the ammonia chest by removing the two wing screws on the right-hand end of the machine where the tank drains. Disconnect the Tygon ammonia in-feed tube in the motor end of the machine, and slide the tank out to the right. The grid and drive roll assemblies are easily removed as a unit by unscrewing the plastic drive-roll plug at the right end of the drive roll. Slide the drive roll off of a pin slot connector to the drive shaft, and lift the assembly up and out of the chest.

After 600 hr of operation, the plastic Tygon tube in the ammonia pump will need to be replaced. Extra tubing is supplied with the machine for this purpose. To replace a tube, remove the left-hand end panel by removing the screws holding down the drive-section top cover. This will expose the pump with its motor and all the tube connections. Study how the tube is placed so that after it is removed you can place the new tube properly.

There is a tube coupling on the tube support bracket. Pull the tube lead to the pump from the coupling.

Jog the machine by snapping the power switch ON and OFF. The old tube will move out of the pump by normal rotating pump action. Pull this tube off of the ammonia feed pipe leading into the machine.

Take a piece of replacement tubing and cut the end on a bias (slant) so it will feed through the pump smoothly. Feed the tubing into the coupling end of the pump and jog the machine (as before) so the tube will be pulled through the pump.

When this tube is completely in the pump, cut it to length and reattach as before to the ammonia coupling and ammonia feed pipe.

The upper faceplate and the developer feed plate extrusions are removed by removing two screws from each and lifting them off of the machine. This will expose the lower slider gasket. The lower slider gasket is attached to the gasket retainer angle and is removed as a unit by removing the fastening screws. A replacement gasket unit can then be inserted.

TROUBLESHOOTING.— If the Blu-Ray machine is to operate at peak efficiency, it must be kept in proper working order. In trouble-shooting the machine, use the following summary as a guide:

Loss of printing speed:

1. Glass cylinder dirty.
2. Voltage too low.
3. Fluorescent lamps dirty or past useful life.
4. Overage sensitized paper.
5. Machine not level, causing binding.
6. Printer drive belts loose.
7. Air entrance blocked, causing lamp heating.
8. Flickering or burnt-out lamp, check starters.

Starting or stalling difficulties:

1. Voltage too low.
2. Machine not level, causing binding.
3. Wiring loosened or disconnected. Call dealer.

Ammonia leakage:

1. Developer chamber top not properly latched after inspection.
2. Ammonia drain tube locked.
3. Machine not level, preventing proper drainage.
4. Ammonia bottle improperly capped.
5. Ruptured pump tubing.

Wrinkled prints from developer jamming:

1. Condensation in ammonia chest.
2. Did not use nite-sheet.
3. Sensitized paper damp before using, because of humid storage.
4. Paper placed in developer chamber against the grain.
5. Foreign material in developer chamber.
6. Exit not clear.

Lamps burn out prematurely:

1. Improper voltage.
2. Air entrance blocked causing hot lamps.
3. Improper or defective starters.
4. Shorting in wiring.

Prints do not develop:

1. Weak or exhausted ammonia—replace.
2. Sensitized paper old or exposed.
3. Ammonia pump not operating properly—infeed tube kinked or pinched.
4. Cold ammonia in supply bottle.

Ozalid

Every EA should have a basic understanding of the various functions of the Ozalid (fig. 3-62); therefore, in this section we will discuss printing and developing, as well as the operating principles of the cooling and exhaust system. Information is also given on machine operation, adjustments, and maintenance.

PRINTING SECTION.— Figure 3-63 shows the principles of operation of the printing and developing sections. Of particular interest at this point is the printing section. This section is divided into four basic units: light source, reflector assembly, printing cylinder, and feed belts.

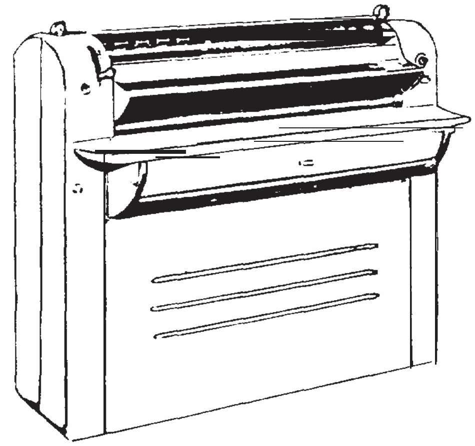

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Figure 3-62.-Ozalid machine.

During the reproduction process, the original and a piece of material, such as paper that has been sensitized (coated with a light, sensitive dye), are inserted into the machine. Sensitized material is placed with the emulsion side up on the feed-board, and the original is placed on top. Originals should be of a transparent or translucent nature with an opaque image on one side only. Feed belts carry this material around the revolving printing cylinder where the dye of the treated paper that is NOT covered by the opaque image of the original is desensitized by the ultraviolet light rays emitted from the mercury-vapor lamp. After exposure, the original and print are picked off of the printing cylinder by the pick-off assembly, and directed towards the developing section.

After pick-off, the guide roller directs the original and print between a printer and tracing separator belt. These belts cause the print and the original to be delivered to two separator tank assemblies where the original and print are separated from each other.

The process of separation is unique and is therefore worthy of further discussion. Critical to the operation of separation are perforations in the walls of the two separator tanks. During

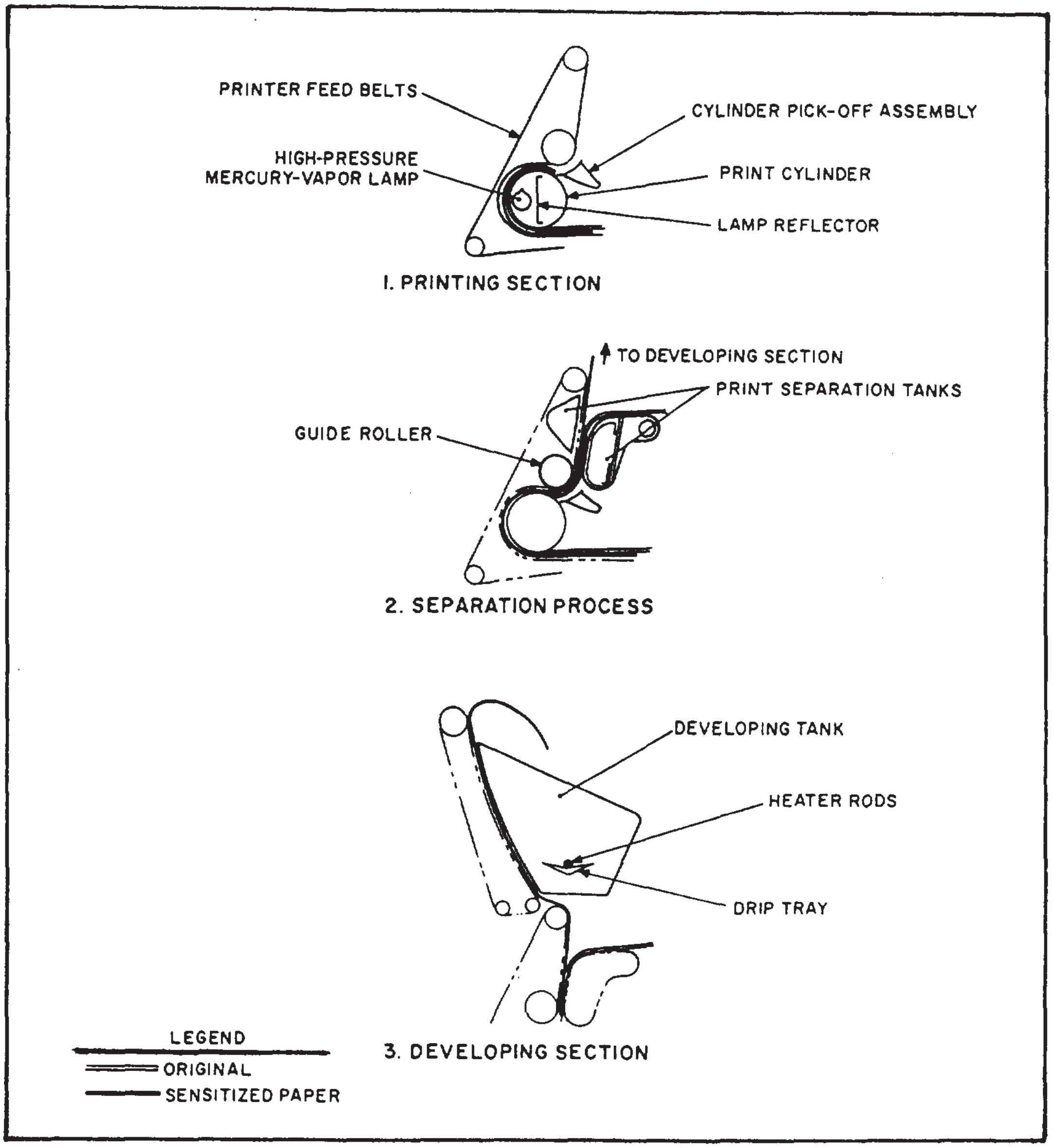


Figure 3-63.-Principles of operation.

operation, air that is drawn through these holes causes a difference in pressure that causes the original to follow the tracing belt and the print to follow the printer belt. Thus, the original and print are separated and directed in different directions. The original moves out of the machine, and the print moves into the developing section where ammonia vapors develop those areas that were not desensitized. It should be noted that it is possible, should the need arise, to direct both the original and the print out of the machine before they go to the developing section. All that is necessary to accomplish this is to operate a lever. When the lever is operated, a group of fingers is extended. These fingers cause the print to be directed out of the machine, along with the original. One instance in which it is desirable to remove the print is when the sensitized paper is coated on both sides. In this instance, the second side will be exposed before any developing takes place.

DEVELOPING SECTION.— The developing section consists of a perforated stainless steel developing tank. This tank is continuously supplied with ammonia from an ammonia supply

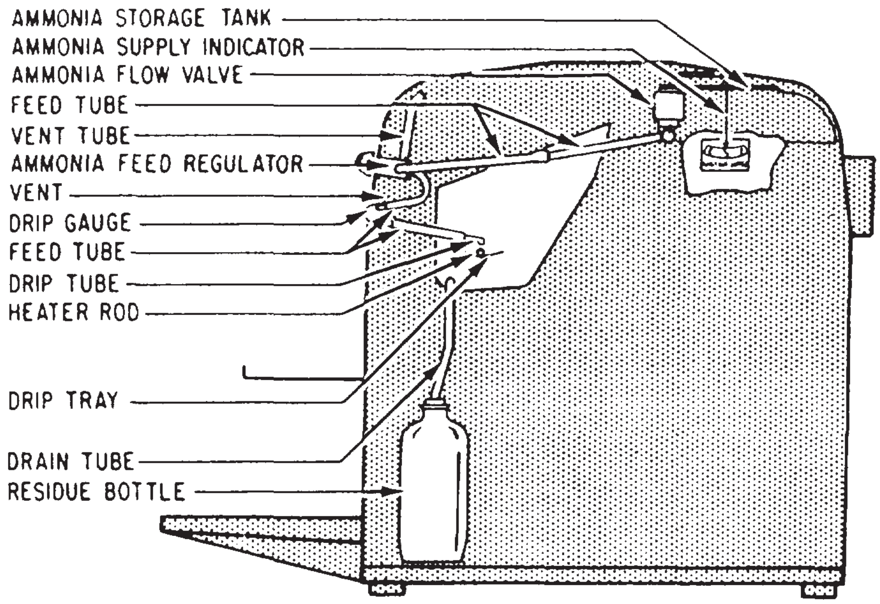


Figure 3-64.-Ammonia flow system.

tank through a gravity-feed system (fig. 3-64). This feed system permits a smooth, even flow of ammonia, thus minimizing the possibility of air or vapor locking of the feed tubing. The amount of ammonia fed into the developer is controlled by a feed regulator at a rate of approximately 50 to 60 drops per minute. The ammonia is directed into evaporating drip trays that are suspended in the developer tank. Fastened to these trays are electric heater rods. These rods, in conjunction with a second thermo-switch controlled heater in the developing tank, serve to heat the ammonia and thereby accelerate the formation of ammonia vapors. These vapors activate the image on the print as they escape through the holes in the upper part of the developer tank. Thus, a semi-permanent image of those areas that were NOT desensitized in the printing section is developed on the print as it passes across the vapors.

To protect the machine from flooding with ammonia when the machine is secured, an automatic shutoff valve is located in the ammonia feedline. This value shuts automatically when the machine is secured and opens automatically when the machine is turned on, thereby remitting ammonia to the feed tray.

A second ammonia supply system being used in some machines is called the anhydrous ammonia system. Cylinders filled with anhydrous ammonia supply the developing section with an ammonia vapor. This vapor is directed into the developer tank where it is distributed with the aid of distilled water that is fed into the drip trays.

For safety reasons, cylinders should be stored away from heat and sunlight. Do not allow the temperature of the cylinders to reach a temperature above 125°F. Position the cylinders upright, and firmly attach them with a chain or strap to a rigid supporting member, such as a wall.

Cylinders are attached to the developing tank through a system of piping and fittings, When changing a cylinder, close the valve on the expended cylinder tightly by turning it clockwise. Bleed off all pressure remaining in the feed line by turning on the ammonia flow in the machine. Disconnect the fitting or yoke cylinder connection. Replace the cylinder and remove the protecting valve cap. Ensure that a Teflon washer is in place. Connect the fitting or yoke cylinder connection. Make sure all connections are tight. Open the cylinder valve. Check for possible leaks on all connections by holding a piece of unexposed and undeveloped diazo paper close to the connections. If the diazo paper discolors, retighten the connections.

A uniform flow of ammonia is maintained by a pressure gauge located between the cylinder and the developing section. In addition, the pressure gauge indicates the amount of available ammonia left in the cylinder. A new cylinder will have a gauge reading of 150, while an empty cylinder will indicate a reading of 50.

After passing through the pressure gauge, the ammonia travels through a flowmeter. The flowmeter is located on the front of the machine, which is within easy reach of the operator. With this meter, the operator is able to turn on or off the ammonia flow. Additionally, the operator is able to adjust the flow obtaining maximum development with a minimum amount of ammonia. Using this type of development system, the operator is able to turn the ammonia supply on only when developing, thus saving ammonia during warm-up and periods of idling or nonuse.

A water supply is used to aid in the distribution of the ammonia vapor within the developing tank. Water is fed into the evaporating drip trays, creating additional vapor, which increases the ammonia's effectiveness. This water supply is controlled by a feed regulator (located on the front of the machine). Also the amount of water being supplied is visible through a tube above the feed regulator. Adjust the water flow to 60 drops per minute, and ensure that a constant dripping of water is reaching the machine, or the drip trays may be damaged.

COOLING AND EXHAUST SYSTEM.— Excessive amounts of heat or ammonia vapors should NOT reach the room in which the machine is located because of the installed exhaust and cooling system. The system consists of twin blowers, driven by a motor that exhausts fumes and hot air from the machine enclosure through a vent to the outside atmosphere. Therefore, a partial vacuum is created within the machine covers, thereby causing air to flow into the machine rather than the counterflow that would otherwise exist. A blower time switch operates the blower motor independently of the rest of the machine thereby ensuring the removal of vapors and hot air after the mercury-vapor lamp is turned off. The switch may be adjusted to operate for any given length of time up to 30 minutes.

MACHINE OPERATION.— A short warm-up period is required before material can be fed into the machine. Always follow the manufacturer's instructions during machine operation. When starting the machine, make sure that the developer drain tube is inserted in the residue bottle (fig. 3-64). Then, fill the storage tank with ammonia. If bubbles are encountered in the feed system because of increased temperature or high altitude, dilute the ammonia with cold water. Usually, a one-eighth to one-fourth dilution is sufficient.

After the ammonia storage tank has been filled, turn on the main switch, and adjust the ammonia feed to 50 to 60 drops per minute. At high speeds (30 ft per minute and above), the rate of drops per minute can be increased. On virtually all modern, large-size diazo machines, ammonia feed is automatically increased and decreased to correspond with variation of machine speed.

CAUTION

During machine operation, the ammonia feed regulator should NEVER be turned completely off. If the machine is left running and no moisture is entering the developer section, the evaporation tray and heater rods are likely to be warped because of excessive heat.

After a short warm-up period, the machine is ready for operation. The machine should be run for approximately 20 min or until the operating temperature is between 180°F and 210°F. Time and temperature may vary; therefore, always follow the manufacturer's instructions. Feed the material into the machine with the original on top, adjusting the speed of the machine so that a clear print is obtained.

Printing speed is dependent on the translucency of the original, the density of the opaque image, and type of sensitized material used.

Running the machine at speeds that are too fast will result in a background on the print.

Running the machine too slowly will cause the image to be weak or missing from the print altogether. The only positive method for obtaining the correct speed for your machine is by running a test because each machine's light intensity changes with age.

When stopping the machine, turn the ammonia flow off, then feed a sheet of porous wrapping paper, 16 in. wide, into the machine. Stop the machine with the paper in position around the printing cylinder and between the sealing sleeve and the perforated tank. This will prevent the sleeve from sticking to the perforated tank top and will also protect the belts from the heat of the cylinder while it is cooling.

ADJUSTMENTS AND MAINTENANCE.— Normally, when the machine is first installed, no adjustments are required. Occasionally, however, some readjustment may be necessary because of atmospheric changes, which may cause shrinkage or expansion of some of the belts. These adjustments should be performed according to the manufacturer's instructions and only then by qualified personnel.

Maintenance is required on a daily, weekly, monthly, semiannually, annually, and whenever necessary basis. The following guide should be followed:

1. Daily requirements:

   a. Empty the residue bottle after at least every 8 hours of operation. Never reuse residue water.

   b. Replenish the ammonia supply.

   c. Clean the outside of the cylinder with glass cleaner. (Operate the machine at slow speed while cleaning the cylinder.)

   d. Clean the feedboard, tracing receiving tray, and print receiving tray. Keep them free of foreign objects.

2. Weekly requirements:

   Clean the inside of the cylinder when the machine is COLD, using the following procedure:

   a. Open the door at each end of the lamp housing.

   b. Remove the lamp connector from each end.

   c. Swing the triangular stop aside and withdraw the lamp assembly.

   d. Clean the inside of the cylinder—wrap a damp, clean cloth around a swab and wipe the cylinder while it is in slow motion. Repeat the procedure with a dry cloth wrapped around the swab until the cylinder is thoroughly clean.

   e. Wipe the lamp assembly with a DAMP cloth.

   f. Reinstall the lamp assembly.

   IMPORTANT: Handle the lamp assembly with great care, as it is fragile and expensive. DO NOT ATTEMPT TO REMOVE THE LAMP FROM THE MACHINE UNTIL IT HAS COOLED. Always rest the lamp assembly flat on a table; never stand it on end.

3. Monthly requirements:

   Lubricate the bearings and drive chain assembly sparingly with No. 10 motor oil.

4. Semiannual requirements:

   Clean all suction holes of the rotating tracing separation drum with pipe stem cleaners.

5. Annual requirements:

   a. Lubricate the bearings and drive chain sparingly with No. 10 motor oil.

   b. Remove all hoses of the airflow system and clean out dust and dirt.

6. Whenever necessary:

   a. If the developer sealing sleeve becomes tacky, remove it from the machine; wash both the inside and the outside thoroughly with soap and water and dry well. NEVER attempt to wash the sealing sleeve while it is in the machine.

   b. It is advisable to clean the perforated side of the developing tank at the same time. Use any commercial cleaning fluid. This will prevent any smudging of prints because of dirt accumulations on the perforated side.

REPRODUCTION MATERIALS

Diazo materials are available from various sources under different trade names and designations, such as K&E, 3M, and GAF. Basically, all diazo reproduction materials have been coated with a light-sensitive dye. The two types commonly used for reproduction of original drawings are standard weight blueprint paper and sepia line intermediates.

Blueprint Paper

Standard weight paper (commonly called blueprint paper) provides a black or blue image on a white background. The printing speed for paper is described as rapid. Paper is available in sheet sizes that range from 8 by 10 in. to 34 by 44 in., or in rolls that range in widths from 11 to 42 in. with lengths of 50 or 100 yd.

Colored paper provides black or blue images on blue, green, pink, or yellow stock.

Plastic-coated papers are now available that give a slightly glossy print with better line density than the standard paper.

Sepia Line Intermediates

Sepia line intermediates are used as duplicate originals. These intermediates are prints from which additional prints can be made, saving wear on the original. When you use the sepia intermediate, it is possible to keep emulsion-to-emulsion contact in each generation, resulting in a sharper image. In addition, sepia has a greater density and is capable of delivering a darker image than the original, particularly when the original is in pencil. Sepia has a rich, mahogany image color that blocks the ultraviolet light rays. Base materials may be a vellum base treated with a plastic transparentizer that allows the passage of the light rays. Sheet and roll sizes are similar to those of the standard paper. You can make corrections on the sepia prints by using a solution of intermediate corrector to remove the image, then adding the pencil or ink correction.

CHAPTER 4

DRAFTING: GEOMETRIC CONSTRUCTION

Knowledge of the principles of geometric construction and its applications are essential to an Engineering Aid, As a draftsman, you must be able to "construct" or draw any of the various types of lines. In a line drawing, a line may be a straight line, a circle, an arc of a circle or a fillet, a circular curve, a noncircular curve, or a combination of these basic types of lines.

You must also be able to construct line drawings at specified angles to each other, various plane figures, and other graphic representations consisting exclusively of lines. This chapter provides information that will aid you in drawing different types of geometric constructions.

STRAIGHT LINES

One method of drawing horizontal and vertical lines, perpendicular and parallel lines, and inclined lines is by using a straightedge (or a T square) with a triangle. Another practical method of constructing straight lines is by using a drafting compass.

Figure 4-1 shows a method of drawing a line parallel to another line. Here, the line is to be drawn through given point C. To draw a line through C parallel to AB, place the needlepoint of the compass on any point D on AB, and strike arc CE. Shift the needlepoint to E, maintaining the same radius, and strike arc DF. Set a compass to a chord of arc CE, and lay off the chord DF from D, thus locating point F. A line drawn through F and C is parallel to AB.

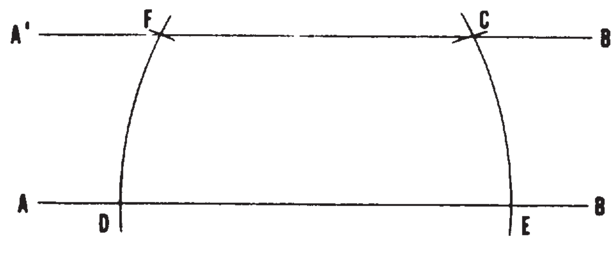


Figure 4-1.-Drawing a line through a given point, parallel to another line.

Figure 4-2 shows another method of drawing one line parallel to another, this one being used when the second line is to be drawn at a given distance from the first. To draw a line parallel to AB at a distance from AB equal to CD, set a compass to the length of CD, and, from any points E and F on AB, strike two arcs. A line A'B' drawn tangent to (barely touching) the arcs is parallel to AB, and located CD distance from AB.

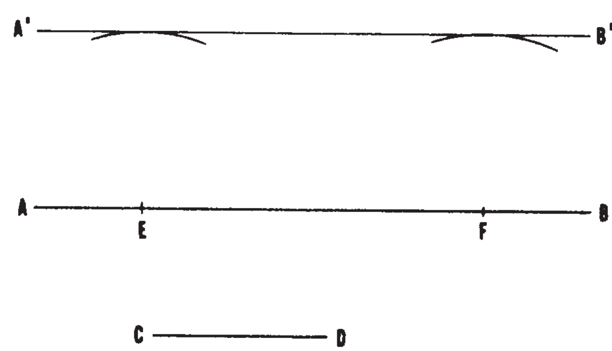


Figure 4-2.-Drawing a parallel line at a given distance from another line.

In the preceding chapter, you learned how to draw a line perpendicular to another by the use of a straightedge and a triangle. Two other methods of solving this problem are explained below.

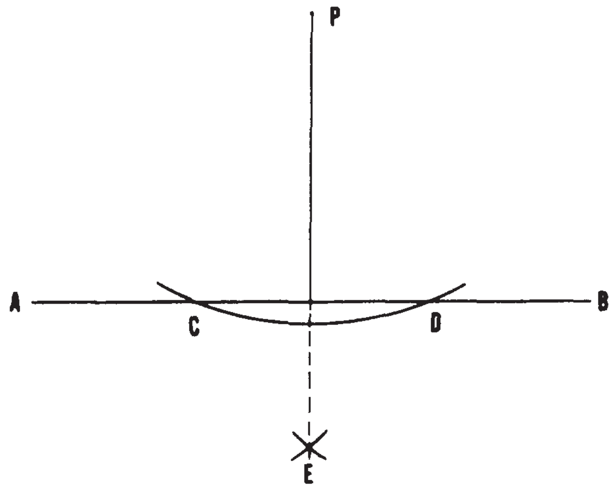


Figure 4-3.-Dropping a perpendicular from a given point to a line.

Figure 4-3 shows a method of dropping a perpendicular from a given point to a line, using a compass. To drop a perpendicular from point P to AB, set the needlepoint of the compass at P and strike an arc intersecting AB at C and D. With C and D as centers and any radius larger than one-half of CD, strike arcs intersecting at E. A line from P through E is perpendicular to AB.

Figure 4-4 shows a method of erecting a perpendicular from a given point on a line. To erect a perpendicular from point P on AB, set a compass to any convenient radius, and, with P as a center, strike arcs intersecting AB at C and D. With C and D as centers and any radius larger than one-half of CD, strike arcs intersecting at E. A line from P through E is perpendicular to AB.

BISECTION OF A LINE

A line can be bisected by trial and error with dividers; that is, by setting the dividers to various

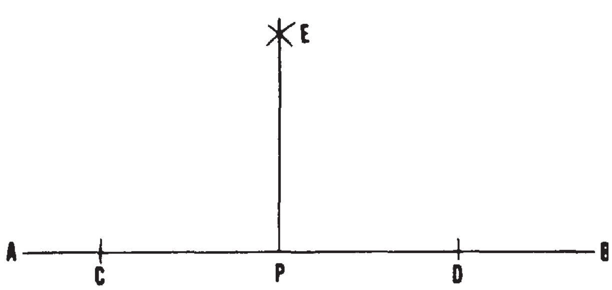


Figure 4-4.-Erecting a perpendicular from a given point on a line.

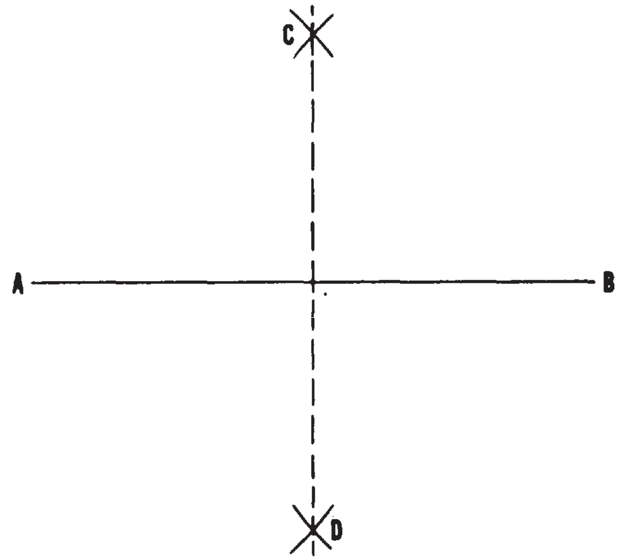


Figure 4-5.-Bisecting a line.

spreads until you find one that correctly measures one-half the length of the line.

Geometric construction for bisecting a line is shown in figure 4-5. To bisect the line AB, use the ends of the line, A and B, as centers; set a compass to a radius greater than one-half the length of AB; and strike arcs intersecting at C and D. A line drawn from C through D bisects AB.

DIVISION INTO ANY NUMBER OF EQUAL PARTS

A line may be divided into more than two equal parts by trial and error with the dividers. Geometric construction for dividing a line into any number of equal parts is shown in figure 4-6. To divide AB into 10 equal parts, draw a ray line CB from B at a convenient acute angle to AB. Set a compass to spread less than one-tenth of the length of CB, and lay off this interval 10 times from B on CB. Draw a line from the 10th interval

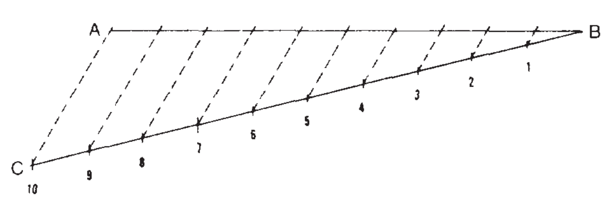


Figure 4-6.-Dividing a line into any number of equal parts.

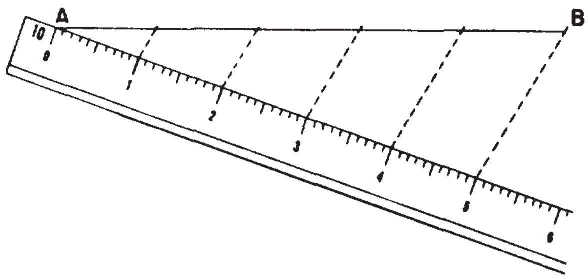


Figure 4-7.-Using a scale to lay off equal intervals on a random line.

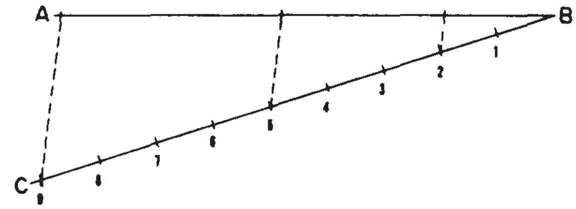


Figure 4-8.-Dividing a line into proportional parts.

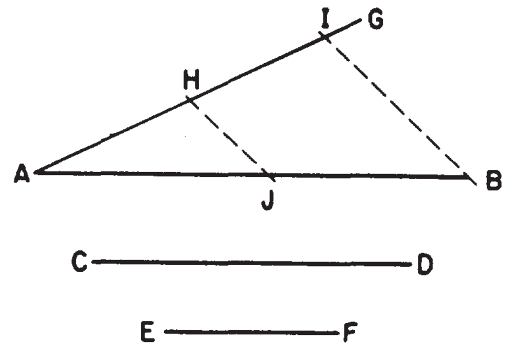


Figure 4-9.-Dividing a line into parts according to a given ratio.

to A, and project the other points of intersection from CB to AB by lines parallel to the first one. The projected points of intersection divide AB into 10 equal parts.

Figure 4-7 shows how you can use a scale to lay off equal intervals on the ray line.

DIVISION INTO PROPORTIONAL PARTS

Figure 4-8 show's a method of dividing a line into given proportional parts. The problem here is to divide the line AB into parts that are proportional as 2:3:4. Lay off ray line CB from B at a convenient acute angle to AB. Set a compass to a convenient spread, and lay off this interval from B on CB the number of times that is equal to the sum of the figures in the proportion (2 + 3 + 4 = 9). Draw a line from the point of intersection of the last interval to A, and use a straightedge and triangle to project the second and fifth intercepts on CB to AB by lines parallel to the first one. The projected intercepts divide AB into segments that are proportional as 2:3:4.

Here again, you could use a scale to lay off nine equal intervals on CB.

DIVISION ACCORDING TO A GIVEN RATIO

You may be required to divide a line into parts so that the ratio between the whole line and one of the parts is the same as that between two other lines. A method of doing this is shown in figure 4-9. Here, it is required that AB be divided so that the ratio between AB and a part of AB is the same as the ratio between CD and EF. From A, draw a ray line AG at a convenient acute angle from AB. On AG, lay off AH equal to EF and AI equal to CD. Draw a line from I to B, and use a straightedge and triangle to project H to J on a line parallel to IB. The ratio of AB to AJ is the same as that of CD to EF.

ANGLES

You already know how to lay off an angle of given size with a protractor, or trigonometrically by the use of the tangent or the chord method.

TRANSFER OF AN ANGLE

There is a geometric construction for laying off, on another part of the same drawing or on a different drawing, an angle

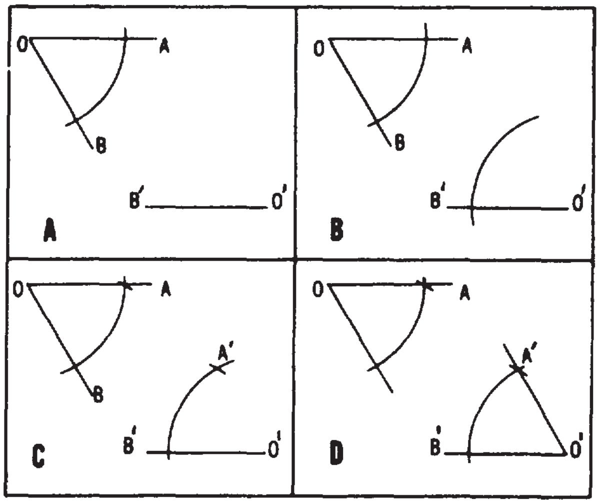


Figure 4-10.-Transferring an angle.

equal in size to one that is already drawn. This procedure, called transferring an angle, is shown in figure 4-10. Here, the draftsman desired to lay off from O´ a line that would make an angle with B´O´ equal to angle BOA. To do this, draw an arc through OB and OA, with O as a center, as shown in figure 4-10, view A. Then, draw an arc of the same radius from B´O´, with O´ as a center, as shown in figure 4-10, view B. Next, measure the length of the chord of the arc between OB and OA and lay off the same length on the arc from B´O´, as shown in figure 4-10, view C. A line drawn from O´ through A´ makes an angle with B´O´ equal to angle BOA, as shown in figure 4-10, view D.

BISECTION OF AN ANGLE

To bisect an angle means to divide it in half. If you know the size of the angle, you can bisect it by simply dividing the size by 2 and laying off the result with a protractor.

Geometric construction for bisecting an angle is shown in figure 4-11, To bisect the angle AOB, first lay off equal intervals from O on OA and OB. With the ends of these intervals as centers, strike intersecting arcs of equal radius at P. Draw a line from O through the point of intersection of the arcs, P. The line OP bisects angle AOB.

PLANE FIGURES

This section explains how to construct certain plane figures, such as the triangle, rectangle, square, and regular polygon. You must understand the geometrical construction of plane figures because they appear in engineering drawings.

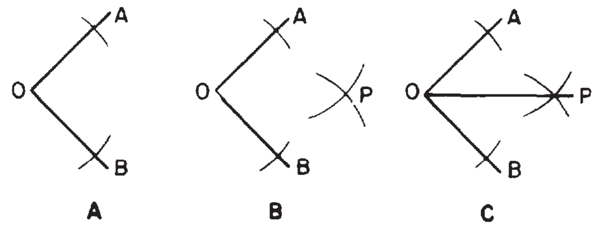


Figure 4-11.-Bisecting an angle.

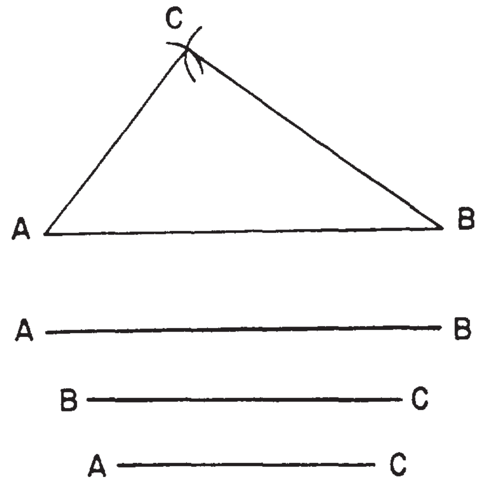


Figure 4-12.-Constructing a triangle with three sides given.

TRIANGLE: THREE SIDES GIVEN

To draw a triangle with three sides given, first draw a straight line AB, equal in length to one of the given sides (fig. 4-12). With A as a center, strike an arc with a radius equal to the given length of the second side. With B as a center, strike an intersecting arc with a radius equal to the length of the third side. Draw lines from A and B to the point of intersection of the arcs.

RIGHT TRIANGLE: HYPOTENUSE AND ONE SIDE GIVEN

Figure 4-13 shows a method of drawing a right triangle when the hypotenuse and one side are given. The line H is the given hypotenuse; the line S is the given side. Draw AB equal to H. Locate the center of AB (by bisection), and, with the midpoint as a center and a radius equal to one-half of AB, draw the semicircle from A to B as shown. Set a compass or dividers to the length of S, and, with A as a center, strike an arc intersecting the semicircle at C. Draw AC and BC.

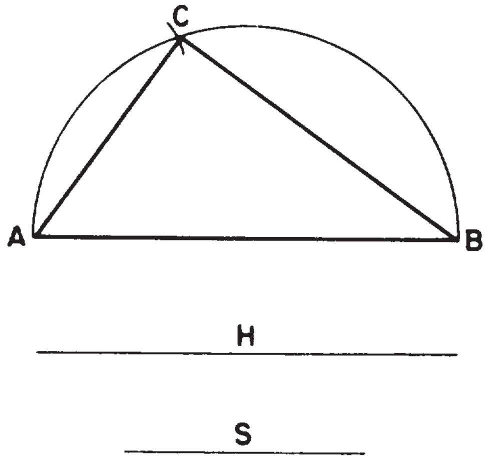


Figure 4-13.-Constructing a right triangle with hypotenuse and one side given.

EQUILATERAL TRIANGLE: LENGTH OF SIDE GIVEN

To construct an equilateral triangle when the length of a side is given, you can follow the method previously described for constructing a triangle when the length of each side is given. The sides of an equilateral triangle are equal in length.

Each angle in an equilateral triangle measures 60°. This fact is applied in the method of constructing an equilateral triangle with given length of side, such as the one shown in figure 4-14. Simply use a 30°/60° triangle and a T square or straightedge to erect lines from A and B at 60° to AB.

EQUILATERAL TRIANGLE IN A GIVEN CIRCUMSCRIBED CIRCLE

A circumscribed plane figure is one that encloses another figure, the circumscribed figure being tangent to the extremities of the enclosed figure. An inscribed plane figure is one that is enclosed by a circumscribed figure.

Figure 4-15 shows you how to inscribe an equilateral triangle within a given circumscribed circle. Draw a vertical center line intersecting the given circle at A and B. With B as a center and a radius equal to the radius of the circle, strike arcs intersecting the circle at C and D. Lines connecting A, C, and D form an equilateral triangle.

EQUILATERAL TRIANGLE ON A GIVEN INSCRIBED CIRCLE

Figure 4-16 shows one method of circumscribing an equilateral triangle on a given inscribed

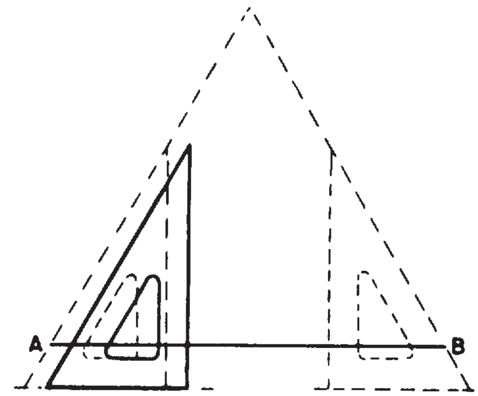


Figure 4-14.-Equilateral triangle with a given length of side AB.

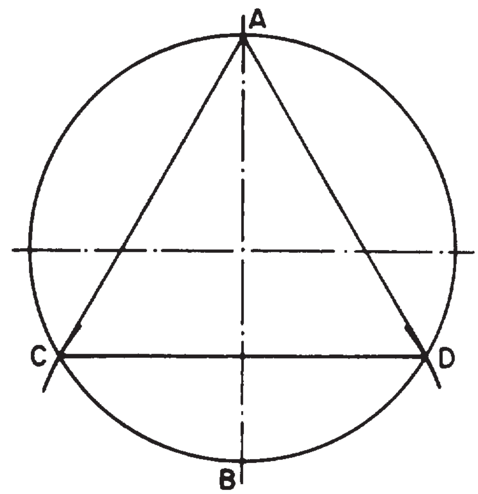


Figure 4-15.-Equilateral triangle in a given circumscribed circle.

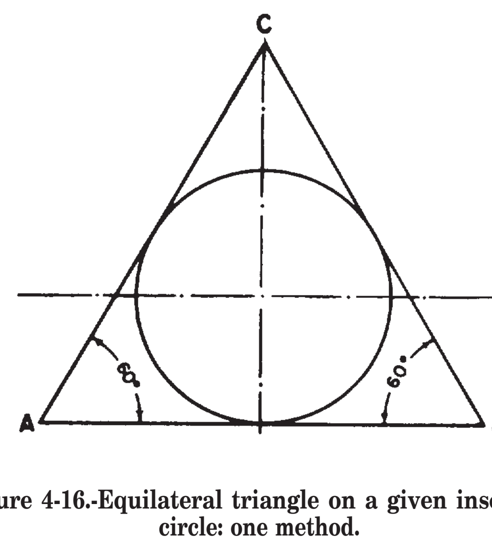


Figure 4-16.-Equilateral triangle on a given inscribed circle: one method.

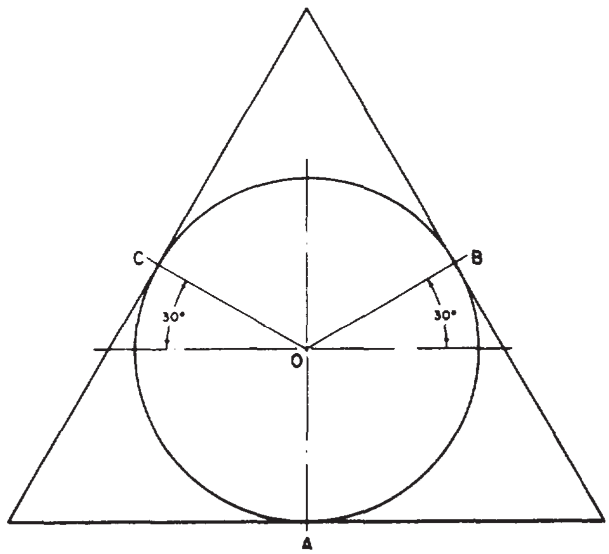


Figure 4-17.-Equilateral triangle on a given inscribed circle: another method.

circle. Draw AB parallel to the horizontal center line of the circle and tangent to the circumference. Then use a 30°/60° triangle to draw AC and BC at 60° to AB and tangent to the circle.

Another method of accomplishing this construction is shown in figure 4-17. Draw radii at 30° to the horizontal center line of the circle, intersecting the circumference at C and B. There is a third point of intersection at A, so you now have three radii: OA, OB, and OC. Draw the sides of the triangle at A, B, and C, tangent to the circle and perpendicular to the relevant radius.

RECTANGLE: GIVEN LENGTH AND WIDTH

To construct a rectangle with a given length and width, draw a horizontal line AB, equal to the given length. With a straightedge and triangle, erect perpendiculars from A and B, each equal to the given width. Connect the ends of the perpendiculars.

SQUARE: GIVEN LENGTH OF SIDE

You can construct a square with a given length of side by the method described for constructing a rectangle. Another method is shown in figure 4-18. With a T square, draw horizontal line AB equal to the given length of side. With a T square and a 45° triangle, draw diagonals from A and B at 45° to AB. Erect perpendiculars from

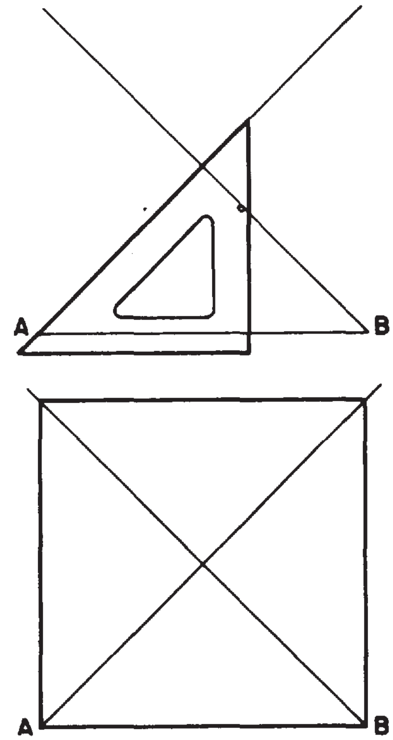


Figure 4-18.-Square with a given length of side.

A and B, intersecting the diagonals. Then connect the points of intersection.

SQUARE: GIVEN LENGTH OF DIAGONAL

Figure 4-19 shows a method of constructing a square with a given length of diagonal. Draw horizontal line AB, equal to the given length of the diagonal. Locate O at the center of AB, and lay off CD through O, perpendicular to and

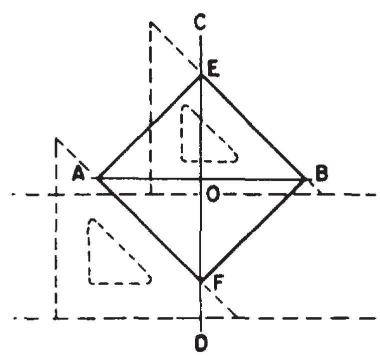


Figure 4-19.-Square with a given length of diagonal.

slightly longer than AB. Use a T square and a 45° triangle to draw AF and EB at 45° to AB and CD, Connect AE and FB.

SQUARE IN A GIVEN CIRCUMSCRIBED CIRCLE

Figure 4-20 shows a method of drawing a square in a given circumscribed circle. Draw the diameters AB and CD at right angles to each other, and connect the points where the diameters intersect the circumference of the circle.

SQUARE CIRCUMSCRIBED ON A GIVEN INSCRIBED CIRCLE

Figure 4-21 shows a method of circumscribing a square on a given inscribed circle, Draw diameters AB and CD at right angles to each other. Then draw each side of the square tangent to the point where a diameter intersects the circumference of the circle and perpendicular to the diameter.

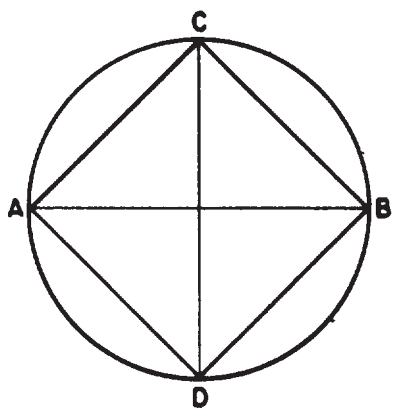


Figure 4-20.-Square in a given circumscribed circle.

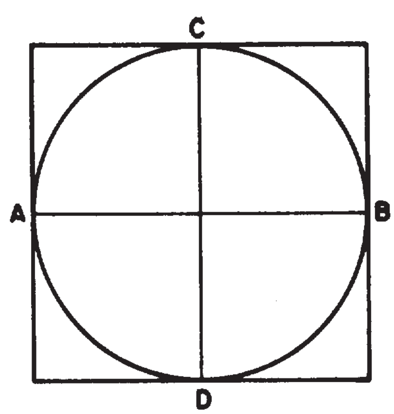


Figure 4-21.-Square on a given inscribed circle.

ANY REGULAR POLYGON IN A GIVEN CIRCUMSCRIBED CIRCLE

You can construct any regular polygon in a given circumscribed circle by trial and error with a drafting compass or dividers as shown in figure 4-22. To draw a nine-sided regular polygon in the circle shown, divide the circumference by trial and error with a compass or dividers into nine equal segments, and connect the points of intersection. To get a trial spread for a compass or dividers, divide the central angle subtended by the entire circle (360) by the number of sides of the polygon, in this case, by nine. Then, lay off the central angle quotient from the center of the circle to the circumference with a protractor.

ANY REGULAR POLYGON ON A GIVEN INSCRIBED CIRCLE

The same method (dividing the circumference into equal segments) can be used to construct a regular polygon on a given inscribed circle. In this case, however, instead of connecting the points of intersection on the circumference, you draw each side tangent to the circumference and

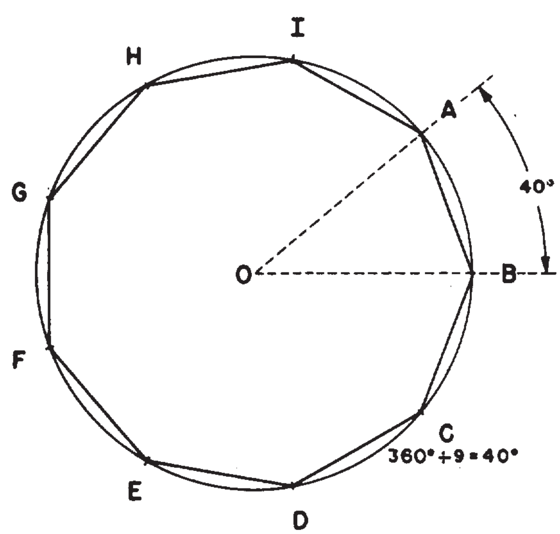


Figure 4-22.-Regular polygon in a given circumscribed circle.

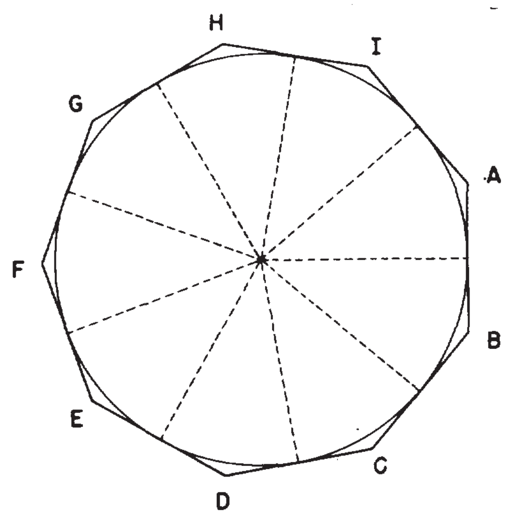


Figure 4-23.-Regular polygon on a given inscribed circle.

perpendicular to the radius at each point of intersection, as shown in figure 4-23.

ANY REGULAR POLYGON WITH A GIVEN LENGTH OF SIDE

Figure 4-24 shows a method of drawing any regular polygon with a given length of side. To draw a nine-sided regular polygon with length of side equal to AB, first extend AB to C, making CA equal to AB. With A as a center and AB (or CA) as a radius, draw a semicircle as shown. Divide the semicircle into nine equal segments from C to B, and draw radii from A to the points of intersection. The radius A2 is always the second side of the polygon.

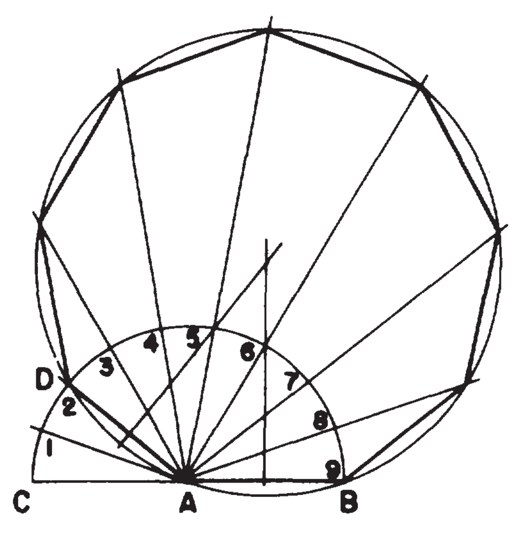


Figure 4-24.-Any regular polygon with a given length of side.

Draw a circle through points A, B, and D. To do this, first erect perpendicular bisectors from DA and AB. The point of intersection of the bisectors is the center of the circle. The circle is the circumscribed circle of the polygon. To draw the remaining sides, extend the radii from the semicircle as shown, and connect the points where they intersect the circumscribed circle.

Besides the methods described for constructing any regular polygon, there are particular methods for constructing a regular pentagon, hexagon, or octagon.

REGULAR PENTAGON IN A GIVEN CIRCUMSCRIBED CIRCLE

Figure 4-25 shows a method of constructing a regular pentagon in a given circumscribed circle. Draw a horizontal diameter AB and a vertical diameter CD. Locate E, the midpoint of the radius OB. Set a compass to the spread between E and C, and, with E as a center, strike the arc CF. Set a compass to the spread between C and F, and, with C as a center, strike the arc GF. A line from G to C forms one side of the pentagon. Set a compass to GC and lay off this interval from C around the circle. Connect the points of intersection.

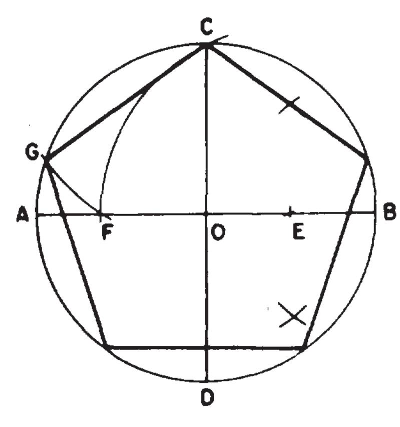


Figure 4-25.-Regular pentagon in a given circumscribed circle.

REGULAR PENTAGON ON A GIVEN INSCRIBED CIRCLE

To construct a regular pentagon on a given inscribed circle, determine the five equal intervals on the circle in the same manner. However, instead of connecting these points, draw each side of the figure tangent to the circle at a point of intersection.

REGULAR HEXAGON IN A GIVEN CIRCUMSCRIBED CIRCLE

Many bolt heads and nuts are hexagonal (six-sided) in shape. Figure 4-26 shows a method of constructing a regular hexagon in a given circumscribed circle. The diameter of the circumscribed circle has the same length as the long diameter of the hexagon. The radius of the circumscribed circle (which equals one-half the long diameter of the hexagon) is equal in length to the length of a side. Lay off the horizontal diameter AB and vertical diameter CD. OB is the radius of the circle. From C, draw a line CE equal to OB; then lay off this interval around the circle, and connect the points of intersection.

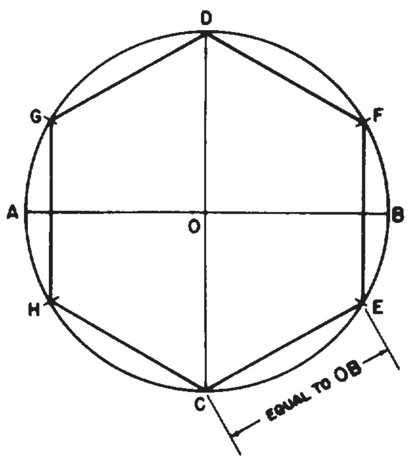


Figure 4-26.-Regular hexagon in a given circumscribed circle: one method.

Figure 4-27 shows another method of constructing a regular hexagon in a given circumscribed circle. Draw vertical diameter AB, and use a T square and a 30°/60° triangle to draw BC from B at 30° to the horizontal. Set a compass to BC, lay off this interval around the circumference, and connect the points of intersection.

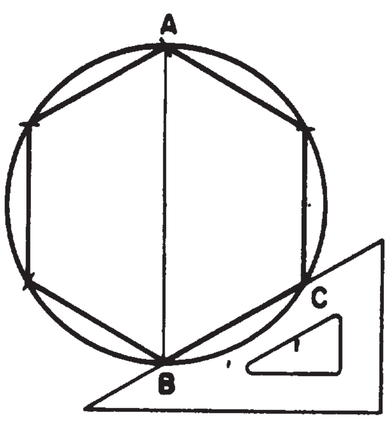


Figure 4-27.-Regular hexagon in a given circumscribed circle: another method.

REGULAR HEXAGON ON A GIVEN INSCRIBED CIRCLE

Figure 4-28 shows a method of constructing a regular hexagon on a given inscribed circle. Draw horizontal diameter AB and vertical center line. Draw lines tangent to the circle and perpendicular to AB at A and B. Use a T square and a 30°/60° triangle to draw the remaining sides of the figure tangent to the circle and at 30° to the horizontal.

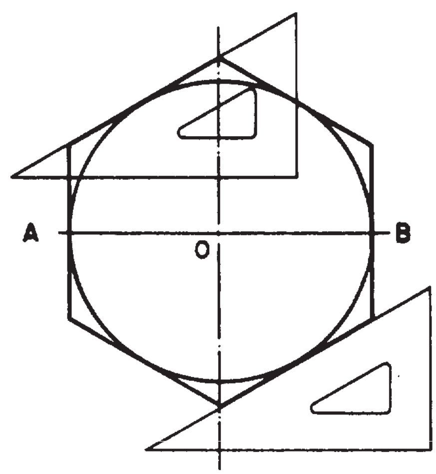


Figure 4-28.-Regular hexagon on a given inscribed circle.

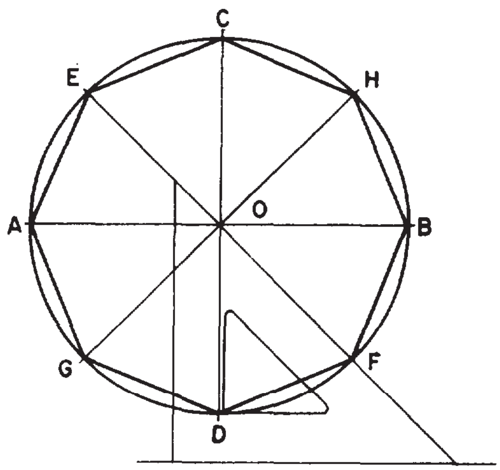


Figure 4-29.-Regular octagon in a given circumscribed circle.

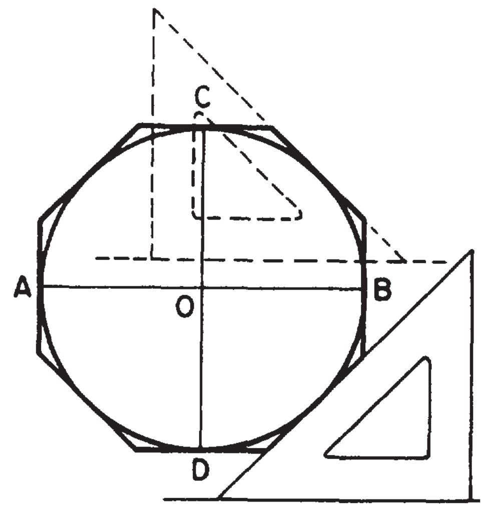


Figure 4-30.-Regular octagon around a given inscribed circle.

REGULAR OCTAGON IN A GIVEN CIRCUMSCRIBED CIRCLE

Figure 4-29 shows a method of constructing a regular octagon in a given circumscribed circle. Draw horizontal diameter AB and vertical diameter CD. Use a T square and a 45° triangle to draw additional diameters EF and GH at 45° to the horizontal. Connect the points where the diameters intersect the circle.

REGULAR OCTAGON AROUND A GIVEN INSCRIBED CIRCLE

Figure 4-30 shows a method of constructing a regular octagon around a given inscribed circle. Draw horizontal diameter AB and vertical diameter CD. Draw tangents at A, B, C, and D perpendicular to the diameters. Draw the remaining sides of the figure tangent to the circle at 45° to the horizontal.

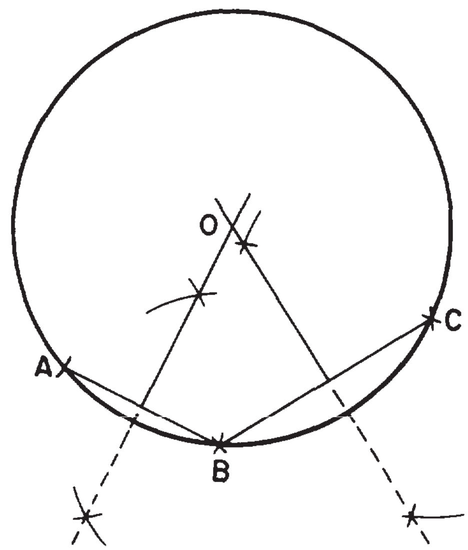


Figure 4-31.-Circle or arc through three points.

CIRCULAR CURVES

Many of the common geometrical constructions occurring in the drafting room are those involving circular curves. This section explains how to construct circular curves that may be required to satisfy varying conditions.

CIRCLE THROUGH THREE POINTS

In figure 4-31 the problem is to draw a circle (or a circular arc) that passes through points A, B, and C. Connect the points by lines and erect perpendicular bisectors as shown. The point of intersection of the perpendicular bisectors (O) is the center of the circle or arc passing through all three points.

LINE TANGENT TO A CIRCLE AT A GIVEN POINT

A line that is tangent to a circle at a given point is perpendicular to the radius that intersects the point. It follows that one method of drawing a line tangent to a circle at a given point is to draw the radius that intersects the point, and then draw the line tangent at the point of intersection and perpendicular to the radius.

Another method is shown in figure 4-32. To draw a line tangent to the circle at P, set a compass to the radius of the circle, and, with P as a center, strike an arc that intersects the circle at A. With the compass still set to the radius of the circle, use A as a center and strike an arc that intersects the first arc at B. With B as a center and the compass still set to the radius of the circle, strike another arc. A line through the point of intersection (0) of the last drawn arc and through P is tangent to the circle at P.

CIRCULAR ARC OF A GIVEN RADIUS TANGENT TO TWO STRAIGHT LINES

Drawing a fillet or round comprises the problem of drawing a circular arc of a given radius tangent to two nonparallel lines.

Figure 4-33 shows a method that can be used when the two nonparallel lines form a right angle. AB is the given radius of the arc. Set a compass to this radius, and, with the point of intersection of the lines as a center, strike an arc intersecting the lines at C and D. With C and D as centers and the same radius, strike intersecting arcs as shown. The point of intersection of these arcs (0) is the center of the circle of which an arc of the given radius is tangent to the lines.

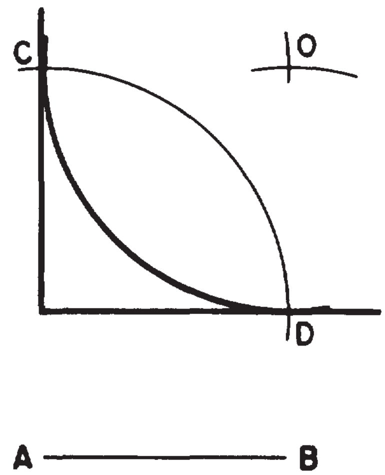


Figure 4-33.-Circular arc tangent to two lines that form a right angle.

Figure 4-34 shows a method that can be used regardless of the size of the angle formed by the lines. Again AB equals the given radius of the arc, and the problem is to draw an arc with radius equal to AB, tangent to CD and EF. Draw GH parallel to CD and at a distance from CD equal to the given radius of the arc. Draw IJ parallel to EF and also at a distance equal to the given radius of the arc. The point of intersection between GH and IJ (P) is the center of the circle of which an arc of the given radius is tangent to CD and EF.

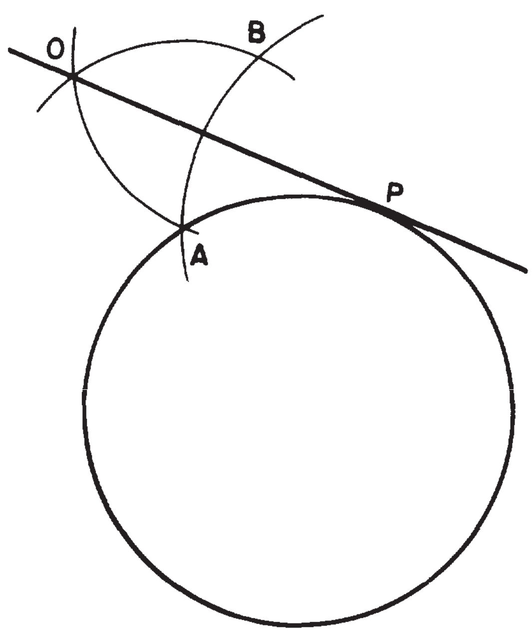


Figure 4-32.-Line tangent to a given point on a circle.

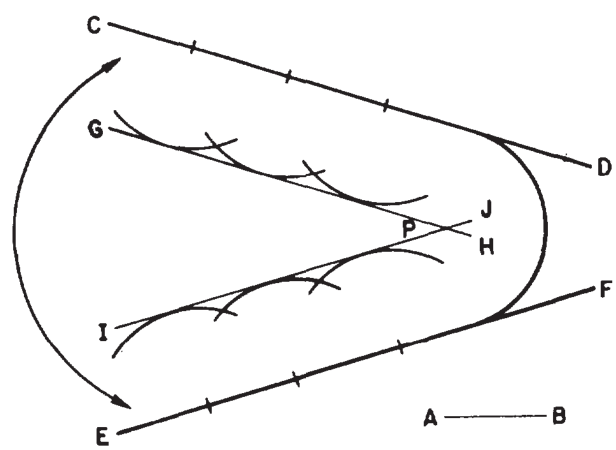


Figure 4-34.-Circular arc tangent to two lines that form any angle.

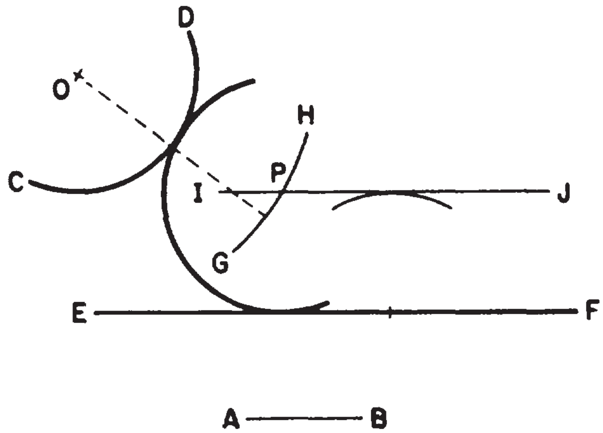


Figure 4-35.-Circular arc tangent to a straight line and another circular arc.

CIRCULAR ARC OF A GIVEN RADIUS TANGENT TO A STRAIGHT LINE AND TO ANOTHER CIRCULAR ARC

The problem in figure 4-35 is to draw a circular arc with a radius equal to AB, tangent to the circular arc CD and to the straight line EF. Set a compass to a radius equal to the radius of the circular arc CD plus the given radius AB (which is indicated by the dashed line shown), and, with O as a center, strike the arc GH. Draw a line IJ parallel to EF at a distance from EF equal to AB. The point of intersection (P) between GH and IJ is the center of the circle of which an arc of the given radius is tangent to CD and EF.

CIRCULAR ARC OF A GIVEN RADIUS TANGENT TO TWO OTHER CIRCULAR ARCS

The problem in figure 4-36 is to draw an arc with a radius equal to AB, tangent to the circular arcs CD and EF. Set a compass to a spread equal to the radius of arc CD plus AB (indicated by the left-hand dashed line), and, with O as a center, strike an arc. Set the compass to a spread equal to the radius of arc EF plus AB (indicated by the right-hand dashed line), and, with O´ as a center, strike an intersecting arc. The point of intersection between the two arcs (P) is the center of the circle of which an arc of given radius is tangent to arcs CD and EF.

In figure 4-36 the circular arcs CD and EF curve in **opposite** directions. In figure 4-37 the problem is to draw an arc with radius equal to AB, tangent to two circular arcs, CD and EF, that curve in the **same** direction.

Set a compass to a radius equal to the radius of EF less AB, and, with O´ as a center, strike an arc. Then, set a compass to a radius equal to the radius of arc CD plus line AB, and, with O as center, strike an intersecting arc at P. The point of intersection of these two arcs is the center of the circle of which an arc of the given radius is tangent to CD and EF.

When a circular arc is tangent to another, it is commonly the case that the two arcs curve in opposite directions. However, an arc may be drawn tangent to another with both curving in the same direction. In a case of this kind, the tangent arc is said to enclose the other.

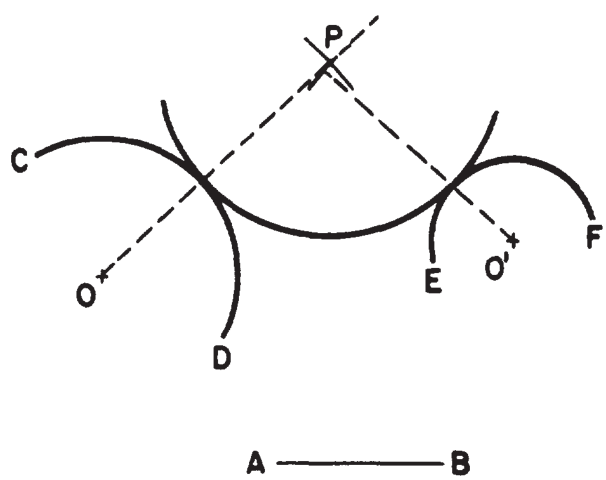


Figure 4-36.-Circular arc tangent to two other circular arcs.

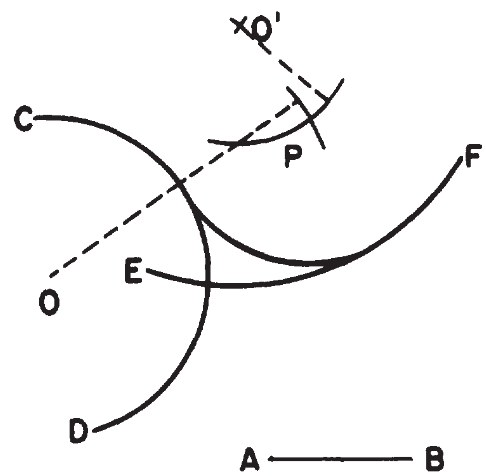


Figure 4-37.-Circular arc tangent to arcs that curve in the same direction.

An arc tangent to two others may enclose both, or it may enclose only one and not the other. In figure 4-38 the problem is to draw a circular arc with a radius equal to AB, tangent to and enclosing both arcs CD and EF. Set a compass to a radius equal to AB less the radius of CD (indicated by the dashed line from O), and, with O as a center, strike an arc. Set the compass to a radius equal to AB less the radius of EF (indicated by the dashed line from O´), and, with O´ as a center, strike an intersecting arc at P. The point of intersection of these two arcs is the center of a circle of which an arc of given radius is tangent to, and encloses, both arcs CD and EF.

In figure 4-39 the problem is to draw a circular arc with a radius equal to AB, tangent to, and enclosing, CD, and tangent to, but NOT enclosing, EF. Set a compass to a radius equal to AB less the radius of arc CD (indicated by the dashed line from 0), and, with O as a center, strike an arc, Set the compass to AB plus the radius of EF (as indicated by the dashed line from O´), and, with O´ as a center, strike an intersecting arc at P. The point of intersection of the two arcs is the center of a circle of which an arc of the given radius is tangent to and encloses arc CD and also is tangent to, but does not enclose, arc EF.

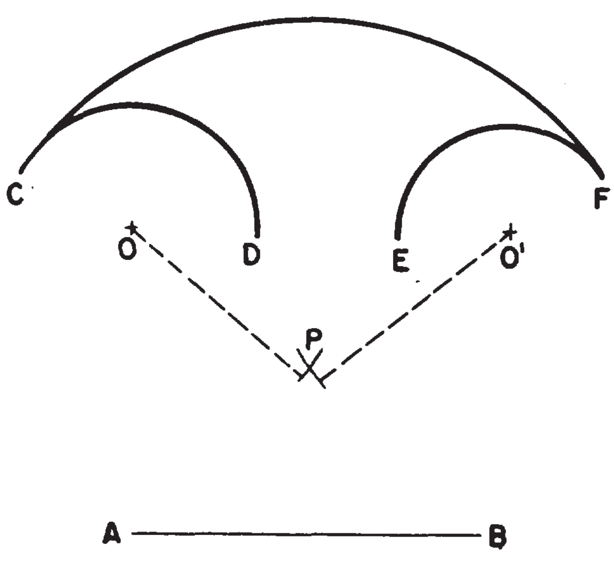


Figure 4-38.-Circular arc tangent to and enclosing two other circular arcs.

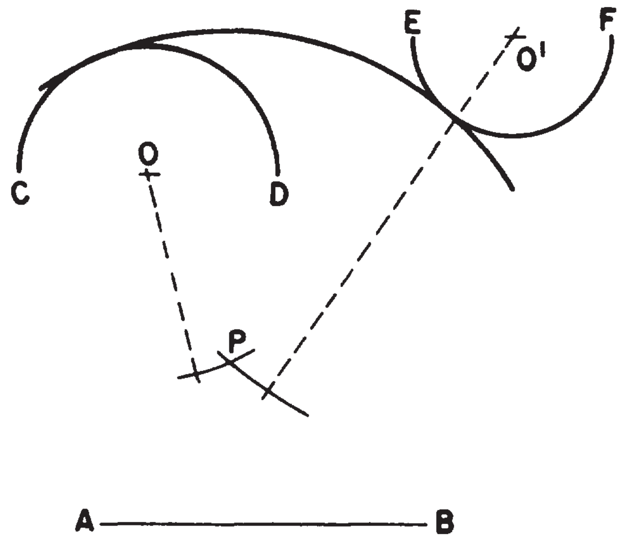


Figure 4-39.-Circular arc tangent to and enclosing one arc and tangent to, but not enclosing, another.

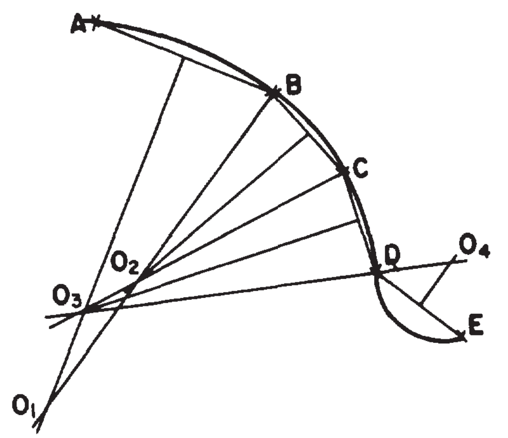


Figure 4-40.-Curve composed of a series of consecutive tangent circular arcs.

COMPOUND CURVES

A curve that is made up of a series of successive tangent circular arcs is called a compound curve. In figure 4-40 the problem is to construct a compound curve passing through given points A, B, C, D, and E. First, connect the points by straight lines. The straight line between each pair of points constitutes the chord of the arc through the points.

Erect a perpendicular bisector from AB. Select an appropriate point O_1 on the bisector as a center, and draw the arc AB. From O_1, draw the radius O_1B. From BC, erect a perpendicular bisector. The point of intersection O_2 between this bisector and the radius O_1B is the center for the arc BC. Draw the radius O_2C, and erect a perpendicular bisector from CD. The point of intersection O_3 of this bisector and the extension of O_2C is the center for the arc CD.

To continue the curve from D to E, you must reverse the direction of curvature. Draw the radius O_3D, and erect a perpendicular bisector from DE on the opposite side of the curve from those previously erected. The point of intersection of this bisector and the extension of O_3D is the center of the arc DE.

REVERSE, OR OGEE, CURVE

A reverse, or ogee, curve is composed of two consecutive tangent circular arcs that curve in opposite directions,

Figure 4-41 shows a method of connecting two parallel lines by a reverse curve tangent to the lines. The problem is to construct a reverse curve tangent to the upper line at A and to the lower line at B.

Connect A and B by a straight line AB. Select on AB point C where you want to have the reverse curve change direction. Erect perpendicular bisectors from BC and CA, and erect perpendiculars from B and A. The points of intersection between the perpendiculars (O_1 and O_2) are the centers for the arcs BC and CA.

Figure 4-42 shows a method of constructing a reverse curve tangent to three intersecting straight lines. The problem is to draw a reverse curve tangent to the three lines that intersect at points A and B. Select on AB point C where you want the reverse curve to change direction. Lay off from A a distance equal to AC to establish point D. Erect a perpendicular from D and another from C. The point of intersection of these perpendiculars (O_1) is the center of the arc DC.

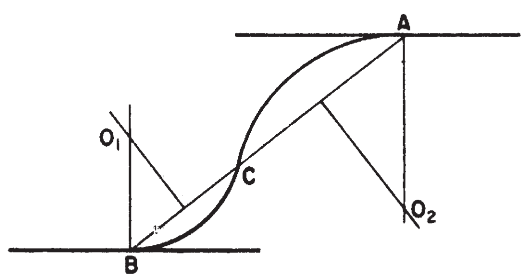


Figure 4-41.—Reverse curve connecting and tangent to two parallel lines.

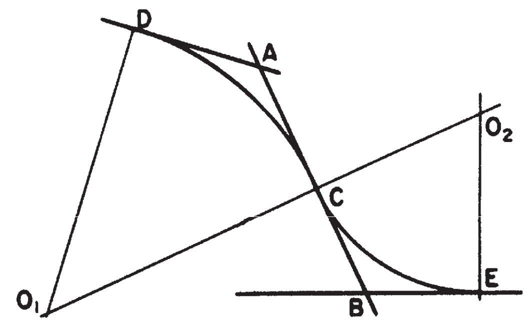


Figure 4-42.—Reverse curve tangent to three intersecting straight lines.

Lay off from B a distance equal to CB to establish point E. Erect a perpendicular from E, and extend O_1C to intersect it. The point of intersection (O_2) is the center of the arc CE.

NONCIRCULAR CURVES

The basic uniform noncircular curves are the ellipse, the parabola, and the hyperbola. These curves are derived from conic sections as shown in figure 4-43. The circle itself (not shown, but a curve formed by a plane passed through a cone perpendicular to the vertical axis) is also derived from a conic section.

This section describes methods of constructing the ellipse only. Methods of constructing the hyperbola are given in *Engineering Drawing* by French and Vierck and in *Architectural Graphic Standards.*

Of the many different ways to construct an ellispe, the three most common are as follows: the pin-and-string method, the four-center method, and the concentric-circle method. The method you should use will depend on the size of the ellipse and where it is to be used.

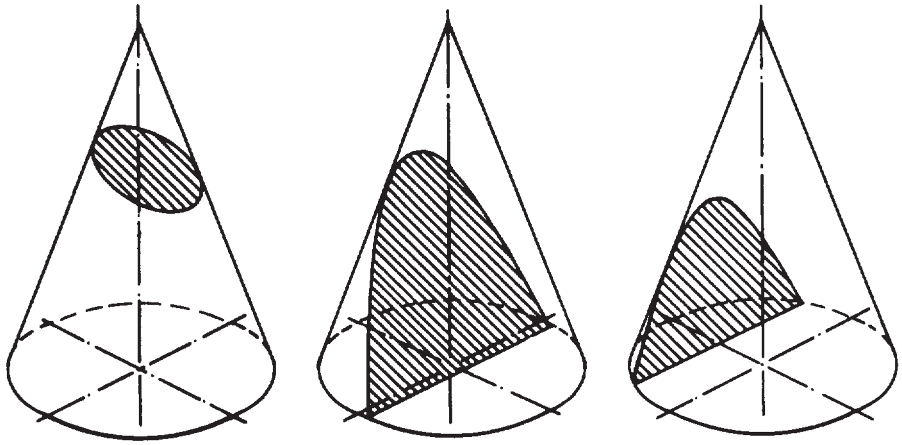


Figure 4-43.-Conic sections: ellipse, parabola, and hyperbula (left to right).

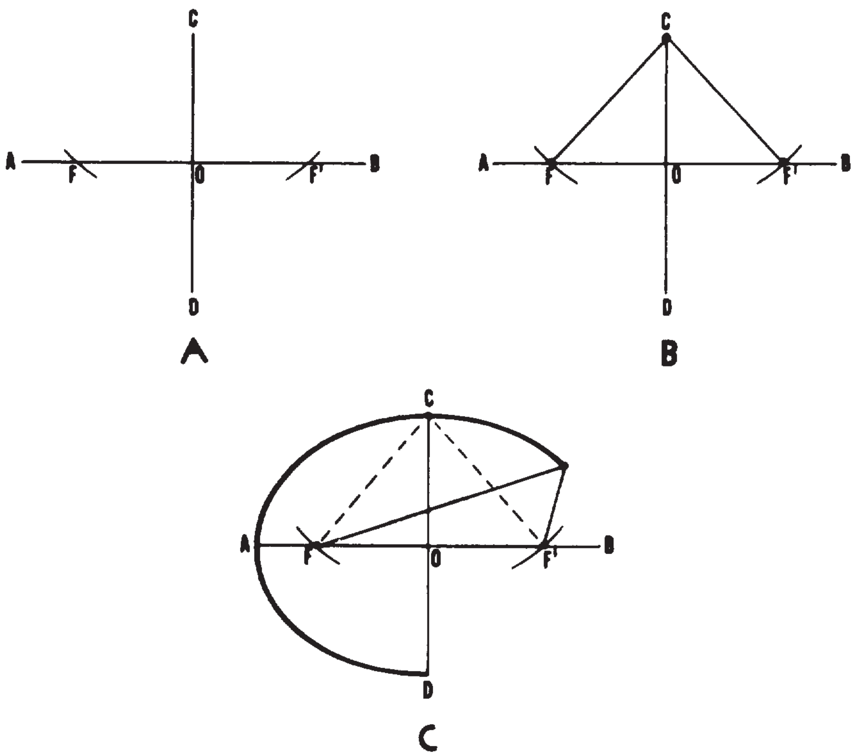


Figure 4-44.-Ellipse by pin-and-string method.

ELLIPSE BY PIN-AND-STRING METHOD

The dimensions of an ellipse are given in terms of the lengths of the major (longer) and minor (shorter) axes. Figure 4-44 shows a method of constructing an ellipse that is called the pin-and-string method. The problem is to construct an ellipse with a major axis, AB, and a minor axis, CD. Set a compass to one-half the length of AB, and, with C as a center, strike arcs intersecting AB at F and F´. The points F and F´ are called the foci of the ellipse. Set a pin at point C, another at F, and a third at F´. Tie the end of a piece of string to the pin at F, pass the string around the pin at C, draw it taut, and fasten it to the pin at F´. Remove the pin at C, place the pencil point in the bight of the string, and draw the ellipse as shown in view C, keeping the string taut all the way around.

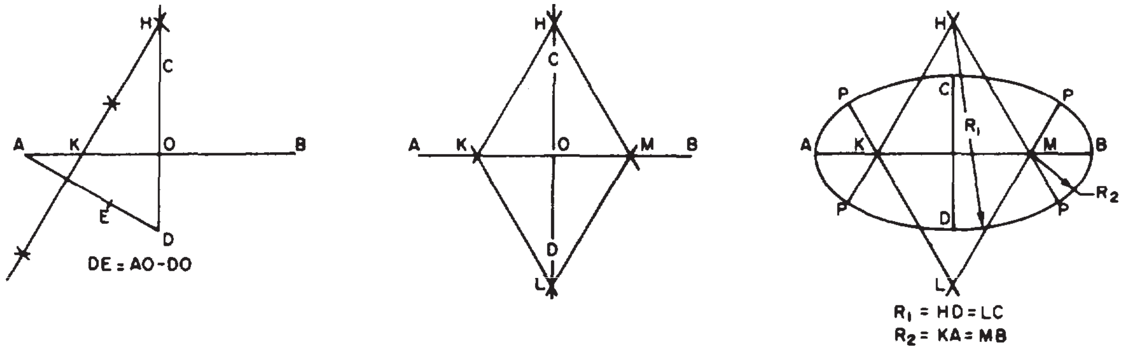


Figure 4-45.-Ellipse by four-center method.

ELLIPSE BY FOUR-CENTER METHOD

The four-center method is used for small ellipses. Given major axis, AB, and minor axis, CD, mutually perpendicular at their midpoint, O, as shown in figure 4-45, draw AD, connecting the end points of the two axes. With the dividers set to DO, measure DO along AO and reset the dividers on the remaining distance to O. With the difference of semiaxes thus set on the dividers, mark off DE equal to AO minus DO. Draw perpendicular bisector AE, and extend it to intersect the major axis at K and the minor axis extended at H. With the dividers, mark off OM equal to OK, and OL equal to OH. With H as a center and radius R_1 equal to HD, draw the bottom arc. With L as a center and the same radius as R_1, draw the top arc. With M as a center and the radius R_2 equal to MB draw the end arc. With K as a center and the same radius, R_2, draw the end arc. The four circular arcs thus drawn meet, in common points of tangency, P, at the ends of their radii in their lines of centers.

ELLIPSE BY CONCENTRIC-CIRCLE METHOD

Figure 4-46 shows the concentric-circle method of drawing an ellipse. With the point of intersection between the axes as a center, draw two concentric circles (circles with a common center), one with a diameter equal to the major axis and the other with a diameter equal to the minor axis, as shown in figure 4-46, view A. Draw a number of diameters as shown in figure 4-46, view B. From the point of intersection of each diameter with the larger circle, draw a vertical line; and from the point of intersection of each diameter with the smaller circle, draw an intersecting horizontal line, as shown in figure 4-46, view C. Draw the ellipse through the points of intersection, as shown in figure 4-46, view D, with a french curve.

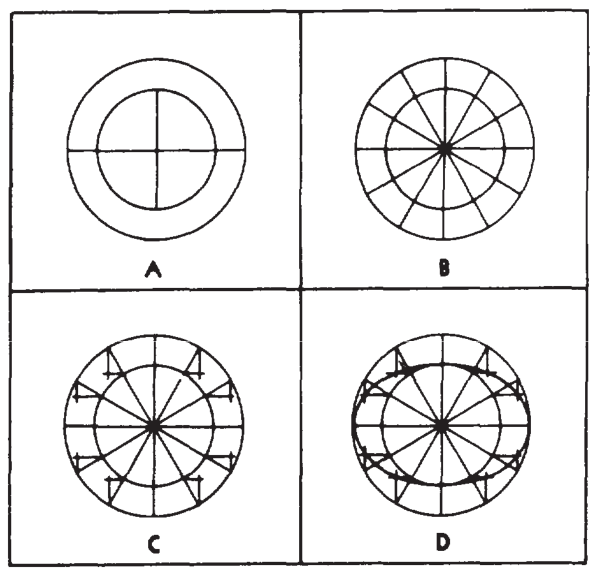


Figure 4-46.-Ellipse by concentric-circle method.

CHAPTER 5

DRAFTING: PROJECTIONS AND SKETCHING

This chapter deals with the theory of projections and methods of preparing projection drawings. By applying basic geometric construction (described in the preceding chapter) to the various projection methods, you should be able to clearly represent any given object or structure on paper. Although the methods discussed here are basic to all drawings, they are easily adapted to construction drawings. This chapter also covers various techniques of freehand sketching. You will learn how to prepare quick sketches to convey or develop your ideas.

Every object or structure you draw has length, width, and depth, regardless of its size. However, you must draw the object or structure on paper, which is a flat two-dimensional plane. To show the three dimensions by lines alone, you must use either a system of related views or a single pictorial projection. You must be able to show clearly the shape of the object, give the exact size of each part, and provide necessary information for constructing the object.

In theory, projection is done by extending lines of sight (called projection lines) from the eye of the observer, through lines and points of an object being viewed, to the plane of projection.

PARALLEL PROJECTION

To satisfy requirements for preparing single- or multi-view drawings, you may use two main types of projection: PARALLEL and PERSPECTIVE (fig. 5-1). PARALLEL projection

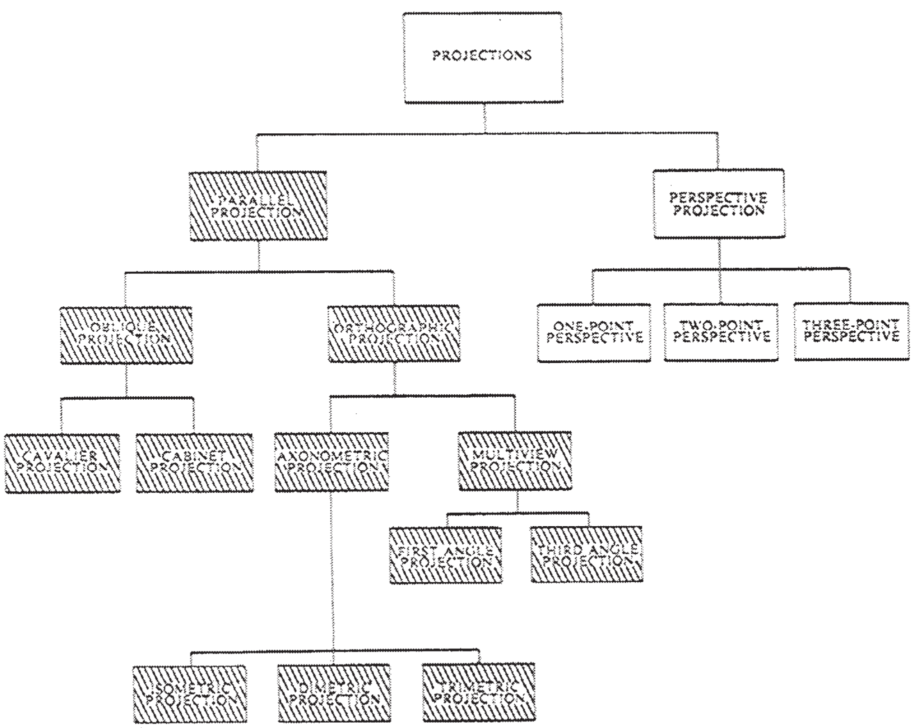


Figure 5-1.—Classification of major projections.

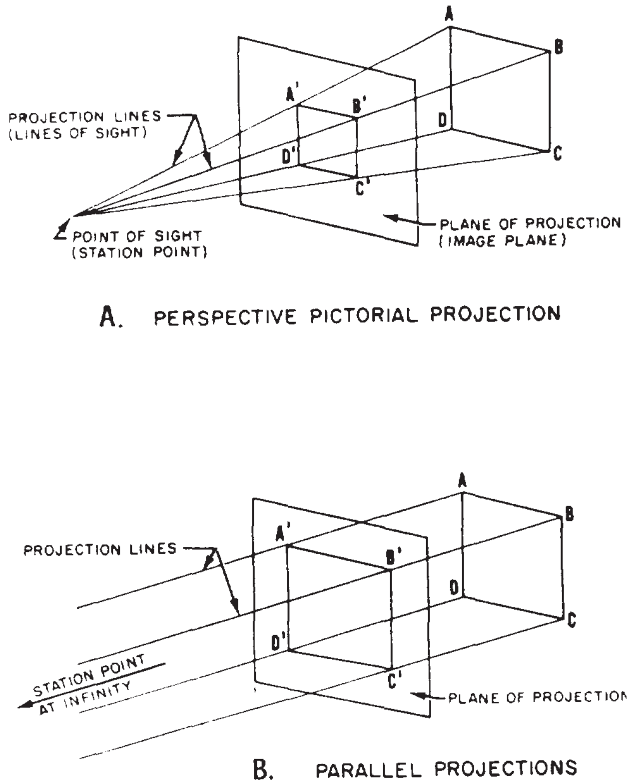


Figure 5-2.-Types of projections.

(fig. 5-2) is further classified into subtypes according to the direction of its projection lines relative to the plane of projection. If the projection lines, in addition to being parallel to each other, are perpendicular (normal) to the plane of projection, the result is an **orthographic** projection. If they are parallel to each other but oblique to the plane of projection, the result is an **oblique** projection.

To better understand the theory of projection, you must become familiar with certain elements that are common to each type of projection. Some of these elements are defined below.

The POINT OF SIGHT (or STATION POINT) is the position of the observer in relation to the object and the plane of projection (fig. 5-2). It is from this point that the view of the object is taken. The point of sight is changed to give different views of the same object; hence, there must be a different point of sight for each view. Imagine yourself looking first at the front of an object, then down at the top, and then at the right or left side, as the case may be. Each additional view requires a new point of sight.

The observer views the features of the object through an imaginary PLANE OF PROJECTION (or IMAGE PLANE). In parallel projection, this theoretical transparent plane is placed between the point of sight and the object, as shown in figure 5-2. For perspective pictorials, it

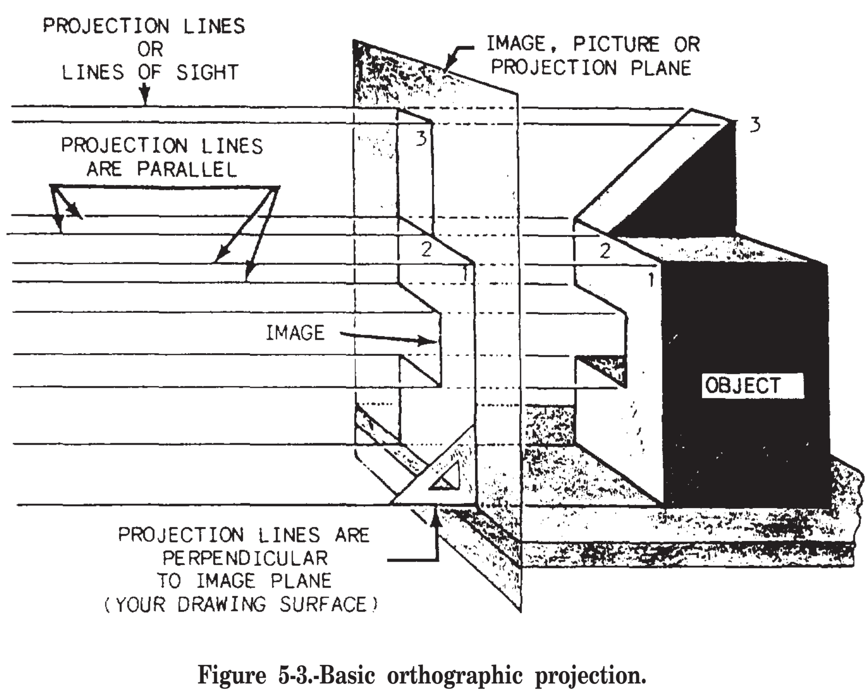


Figure 5-3.-Basic orthographic projection.

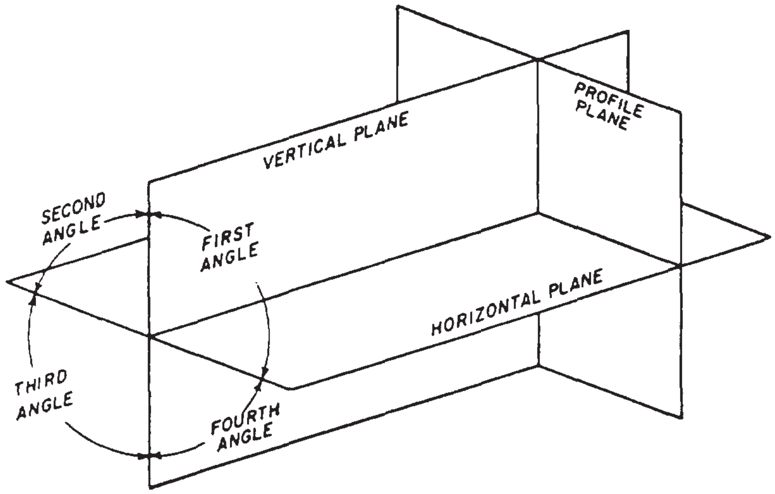


Figure 5-4.-Primary (principal) planes of projections.

is normally placed between the point of sight and the object. For the purpose of studying any type of projection, it must be assumed that the planes of projection are in fixed positions. Once the object is placed in a definite imagined position, it should never be changed. If a different view of the object is desired, the location of the point of sight is changed.

The PROJECTION LINES (or LINES OF SIGHT) are the imaginary lines from the eye of the viewer (point of sight) to points on the object (fig. 5-2). By the use of projection lines, points on the object are projected on the image plane. These points are the points at which the projection lines appear to pierce the image plane. By the projection of the prominent points, lines, and surfaces of an object, a complete view of that object can be projected on the plane of projection.

The relationship between the point of sight (station point), the plane of projection (image plane), the projection lines (lines of sight), and the manner in which they are used for each individual type of projection will be discussed in the following sections.

ORTHOGRAPHIC PROJECTION

When you are called upon to draw a three-dimensional object or figure, it is customary to represent the parts and forms on the flat plane of the drafting paper in such a manner that all features are shown in their true dimensions and in their true relationship with other features on that part of the object. To do this, you must draw a number of views of the object from different angles. Projecting these essential views into a single plane is known as ORTHOGRAPHIC PROJECTION. The term *orthographic is* derived from the word *orthos* meaning perpendicular or right-angular.

Multi-view Projection

When an object is viewed through a plane of projection from a point at infinity, an accurate outline of the visible face of the object is obtained (fig. 5-3). However, the projection of one face usually will not provide an overall description of the object; other planes of projection must be used. Establishing an object's true height, width, and depth requires front, top, and side views, which are called the PRINCIPAL PLANES OF PROJECTION. Figure 5-4 shows the three principal (or primary) planes of projection, known as the VERTICAL, HORIZONTAL, and PROFILE PLANES. The angles formed between the horizontal and the vertical planes are called the FIRST, SECOND, THIRD, and FOURTH ANGLES, as indicated in the figure. Currently, however, for technical reasons, only the use of first- and third-angle projection is practical.

FIRST-ANGLE PROJECTION.— A fine example of first-angle projection using a cube is

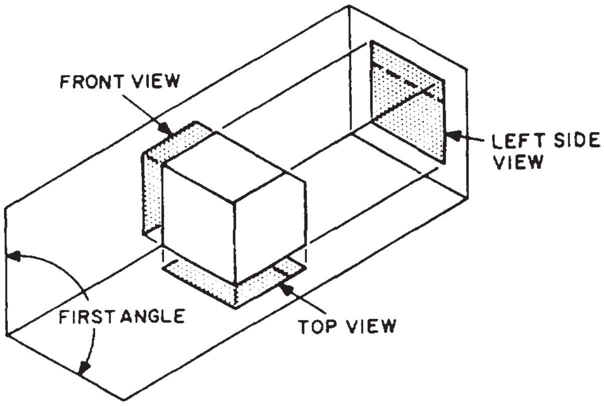


Figure 5-5.-Elample of a first-angle projection.

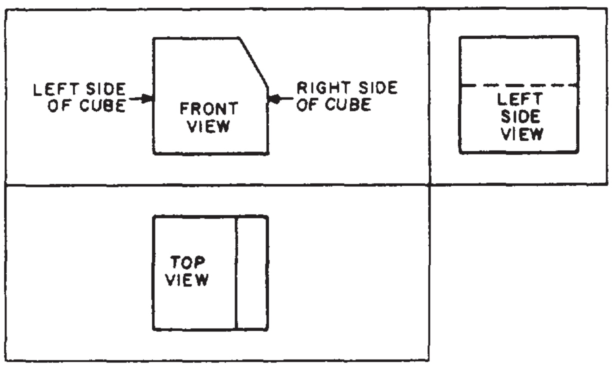


Figure 5-6.-Firsl-angle projection brought into a single plane.

shown in figure 5-5. The cube is supposed to be fronting toward the vertical plane of projection. As you can see, you get a front view on the vertical plane, a left side view on the profile plane, and a top view on the horizontal plane.

Now, to put these views on a sheet of drafting paper, you must get them all into the same plane. You presume that the vertical plane of projection is already in the plane of the paper. To get the other two views into the same plane, you rotate the profile plane counterclockwise and the horizontal plane clockwise. The projection now appears as shown in figure 5-6.

This first-angle projection arrangement of views is considered satisfactory in most European drafting practice. In the United States, it is considered illogical because the top view is below the front view; because the right side of the object, as shown in the front view, is toward the left side view of the object; and because the bottom of the object, as shown in the front view, is toward the top view of the object. For these and other reasons, first-angle projection is not used much in the United States.

THIRD-ANGLE PROJECTION.— Figure 5-7 shows a third-angle projection of a cube. As you can see, you get a front view on the vertical plane, a top view on the horizontal plane, and a right side view on the profile plane.

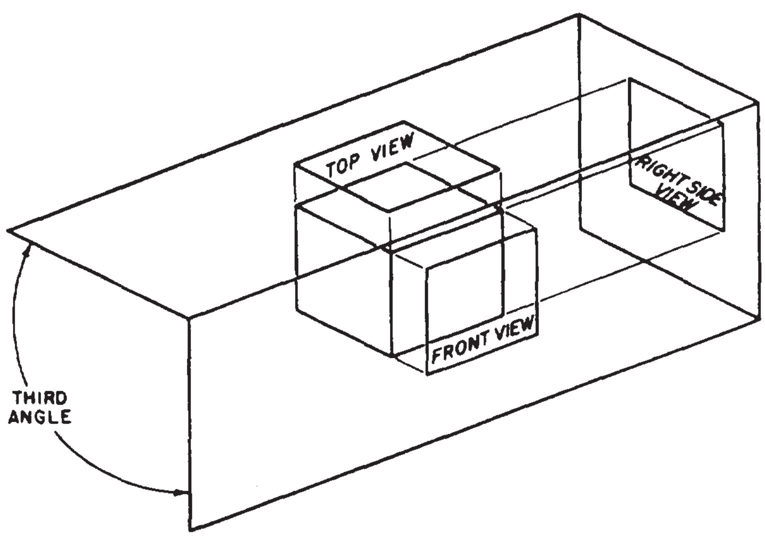


Figure 5-7.-Example of a third-angle projection.

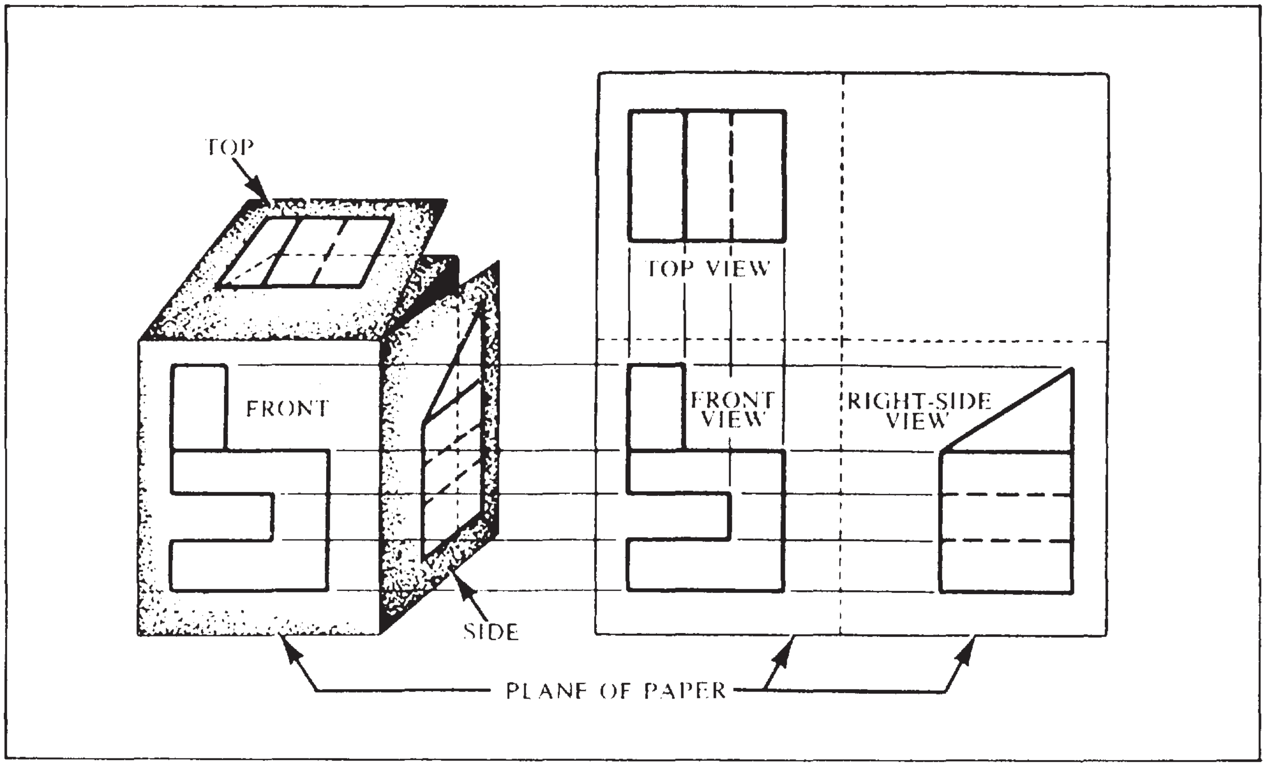


Figure 5-8.-A third-angle projection brought into a single plane.

Again you assume that the vertical plane is already in the plane of your drawing paper. To get the other two views into the same plane, you rotate them both clockwise.

Figure 5-8 shows a third-angle projection of an object brought into a single plane. The top view is above the front view; the right side of the object, as shown in the front view, is toward the right side view; and the top, as shown in the front view, is toward the top view.

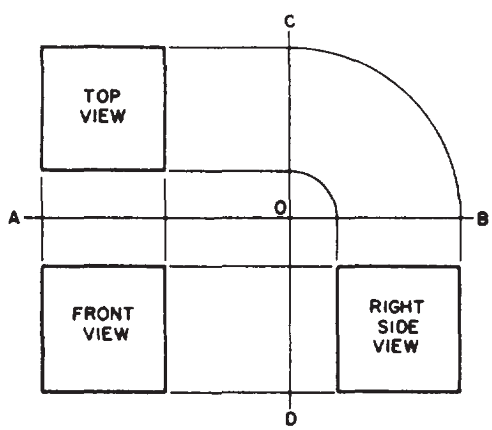


Figure 5-9.-Method of making a third-angle projection.

Figure 5-9 shows the basic principles of the method by which you would actually make the projection shown in figure 5-8. Draw a horizontal line AB and a vertical line CD, intersecting at O. AB represents the joint between the horizontal and the vertical plane; CD represents the joint between these two and the profile plane. Any one of the three views could be drawn first, and the other two projected from it. Assume that the front view is drawn first on the basis of given dimensions of the front face. Draw the front view, and project it upward with vertical projection lines to draw the top view. Project the top view to CD with horizontal projection lines. With O as a center, use a compass to extend these projection lines to AB. Draw the right side view by extending the projection lines from AB vertically downward and by projecting the right side of the front view horizontally to the right.

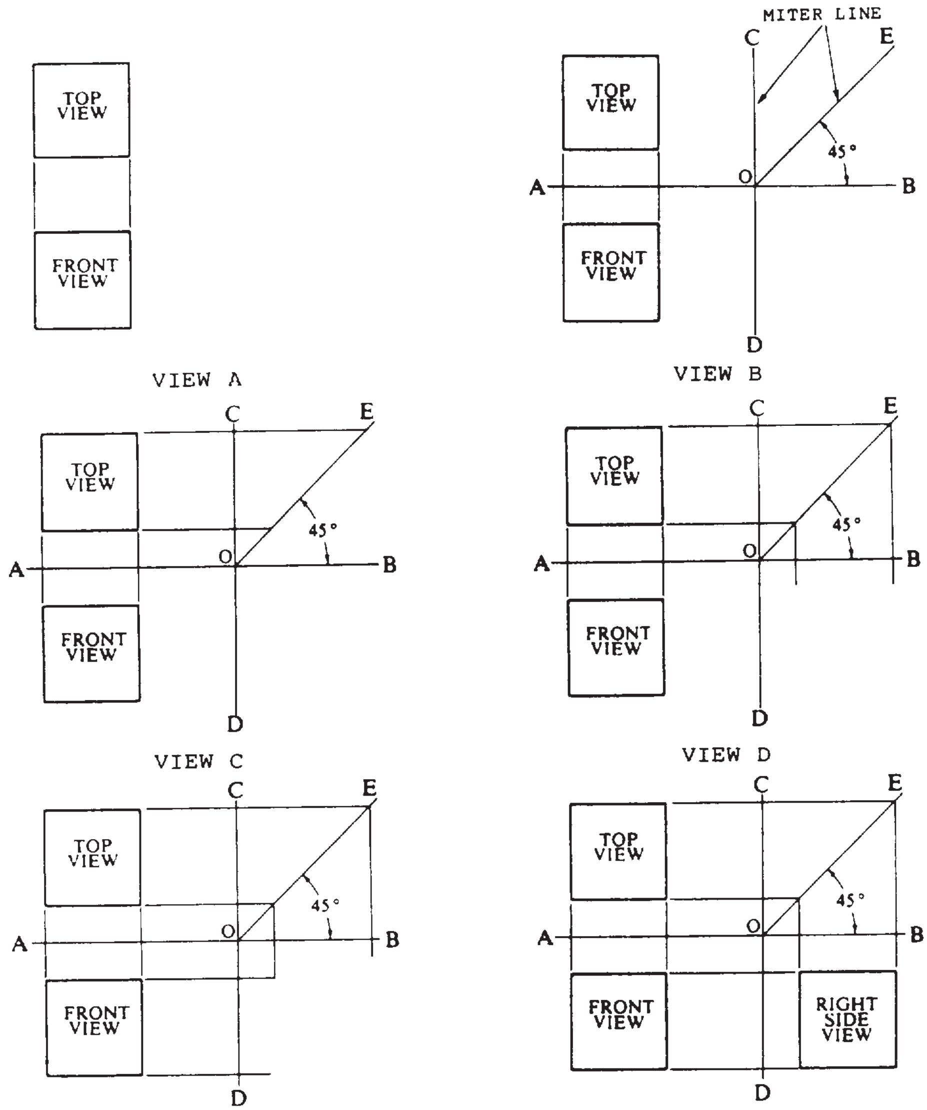


Figure 5-10.-Use of a miter line.

USE OF A MITER LINE.— A miter line (fig. 5-10) offers a convenient method of laying out a third view while you are in the process of drawing two views. Place the miter line (fig. 5-10, view B) to the right of the top view at a convenient distance, keeping the appearance of a balanced drawing. Draw light projection lines from the top view to the miter line (fig. 5-10, view C), then vertically downward (fig. 5-10, view D). Using the front view, draw horizontal projection lines (fig. 5-10, view E) to the right, intersecting the vertical projection lines. The result of this procedure is the outline and placement of the right side view (fig. 5-10, view F).

Some EAs prefer to extend the top view projection lines to the right side view using the alternate method shown in figure 5-11.

ARRANGEMENT OF VIEWS.— The six principal views of an object drawn in a third-angle projection are arranged according to the American standard arrangement of views. This arrangement (practiced since the late 1800s) depicts the relative position of the six principal views and their relationship to each other on a drafting plane.

As shown in figure 5-12, all views (except the front view) are rotated toward the observer as though they are hinged. REMEMBER, the front

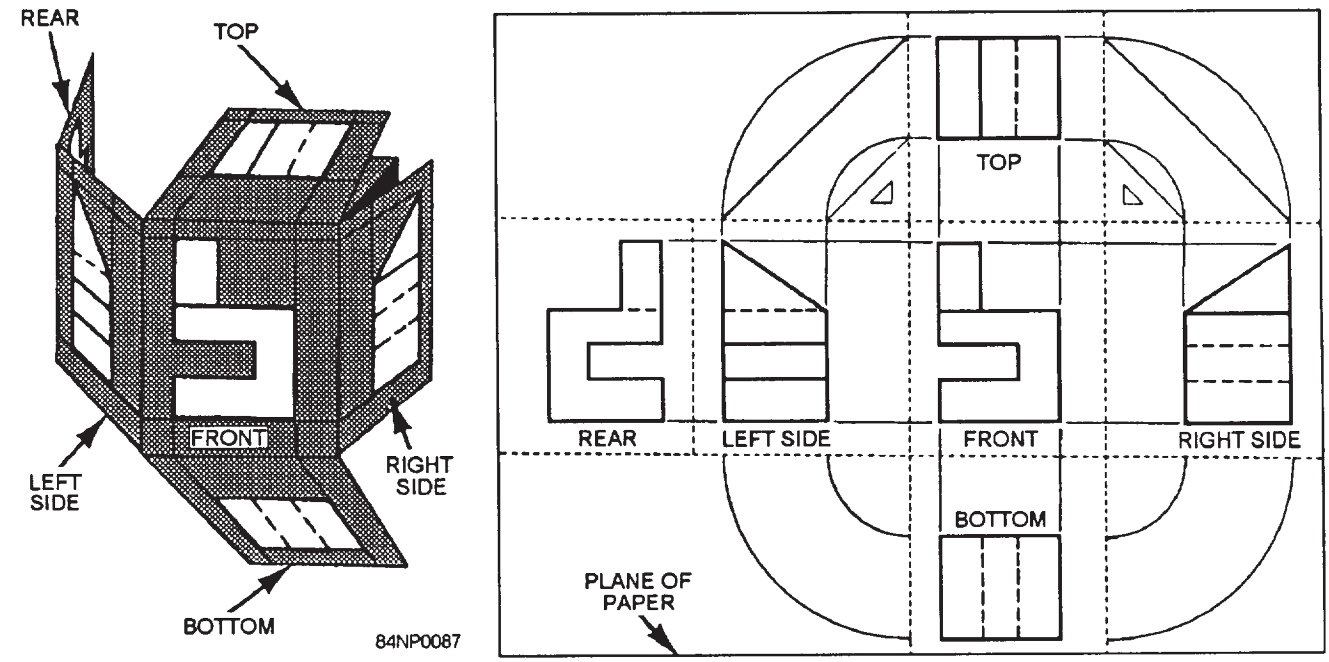
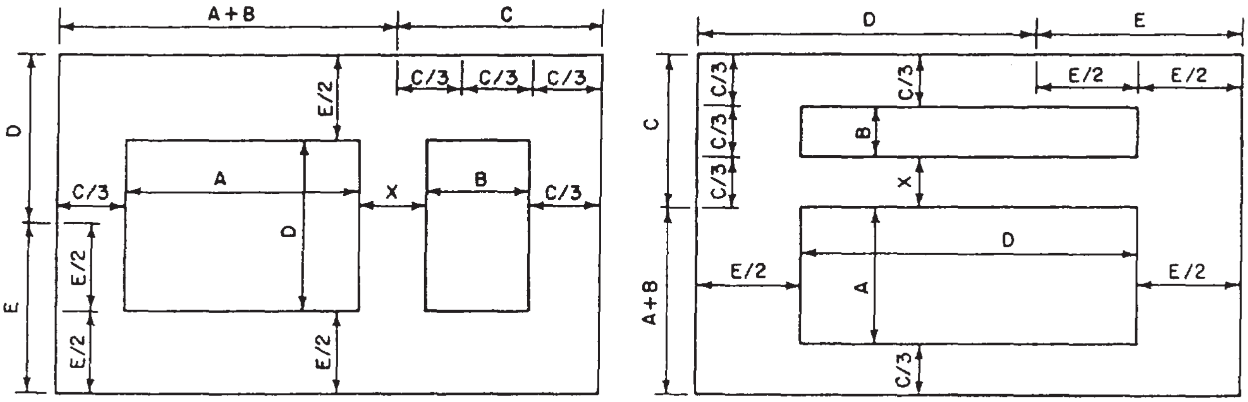


Figure 5-12.-American standard arrangement of views in a six-view third-angle multi-view projection.

view always lies in the plane of the drafting surface and does not require any rotation. Notice that the front, right side, left side, and rear views lineup in direct horizontal projection.

Use the minimum number of views necessary to show an item. The three principal views are the top, front, and right-side. The TOP VIEW (also called a PLAN in architectural drawings) is projected to and drawn on an image plane above the front view of the object. The FRONT VIEW (ELEVATION) should show the most characteristic shape of the object or its most natural appearance when observed in its permanent or fixed position. The RIGHT-SIDE VIEW (ELEVATION) is located at a right angle to the front and top views, making all the views mutually perpendicular.

SPACING OF VIEWS.— Views should be spaced on the paper in such a manner as



A. HORIZONTALLY ALIGNED VIEWS B. VERTICALLY ALIGNED VIEWS

Figure 5-13.-Proper spacing of views.

give the appearance of a balanced drawing. An easy way to locate horizontally aligned views on a standard size drawing sheet is shown in figure 5-13, view A. With a compass or scale, lay off the length plus the width of the object (A + B) from one end of the horizontal margin. Divide the remaining distance, C, into three equal parts (C/3). This will be the approximate distance from either view to the vertical margin. The two views should be equidistant from the vertical margin. The spacing between views should be adjusted so that the apparent area is close to the apparent area between either view and the vertical margin. Basically, the shape of the object will determine the space between views. Generally, the distance from the views to the vertical margins and the distance between views (X) will be approximately equal. To locate the views vertically on the paper, lay off the depth of the object (D) on the vertical margin. Divide the remaining distance (E) into two equal parts (E/2). This will be the approximate distance from the top or bottom of the view to the horizontal margins.

The same method also applies to vertically aligned views on a standard size drawing sheet, as shown in figure 5-13, view B.

Proper spacing of a three-view drawing is shown in figure 5-14. As you can see, the principle is the same as that applied in spacing a two-view drawing. Distances are again equal as indicated, with distance B equal to, or slightly less than, distance A, and distance D equal to, or slightly less than, distance C.

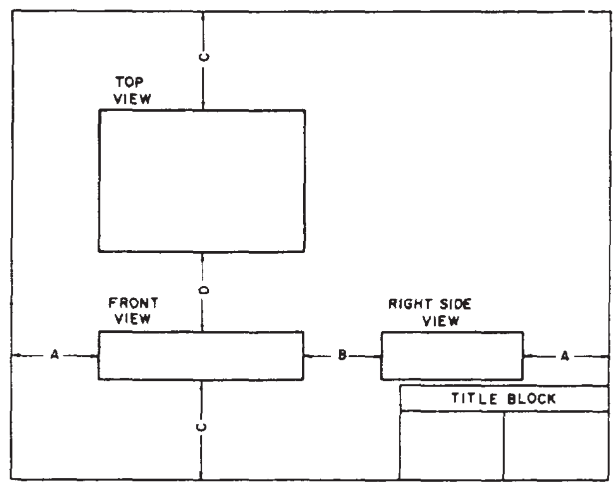


Figure 5-14.-Proper spacing of views on a three-view projection.

While the spacing of views in figure 5-14 is technically correct, the drawing has an unbalanced appearance because of the large area of empty space in the upper right corner and because the right side view crowds the title block. If the drawing will contain a sizeable bill of materials in the upper right corner, this spacing will be satisfactory. If not, it should be improved, if possible.

If the object is one that allows an arbitrary choice with regard to the designation of surfaces as top, front, and so on, the spacing can be improved by changing the designation shown in figure 5-14 and projecting the object as shown in figure 5-15. That which appears as the top in

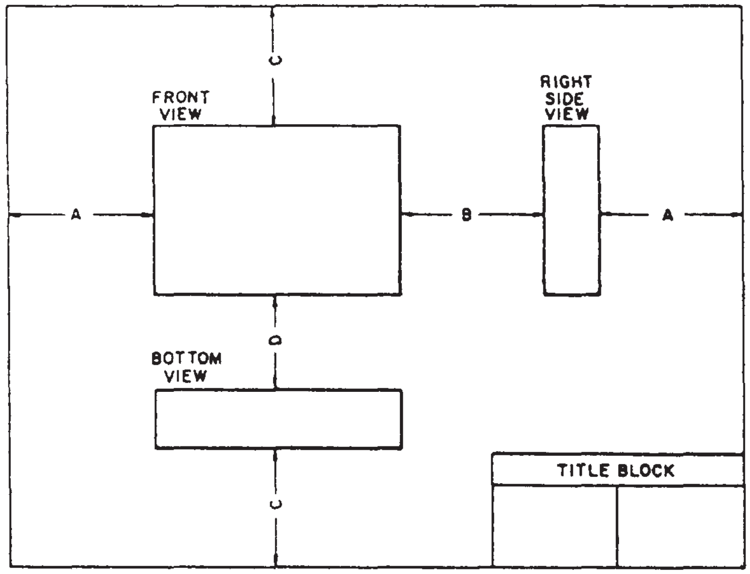


Figure 5-15.-Improved spacing for three-view projection of object shown in figure 5-18.

figure 5-14, you can now call the front; it follows that which appears as the front in figure 5-14 appears as the bottom in figure 5-15. Again the right side view appears, but it now appears in the upper, rather than the lower, right corner and vertically rather than horizontally.

Spacing views in a drawing of a circular object is like spacing letters; you try to equalize the areas of the spaces around and between the views. Figure 5-16 shows properly spaced two-view drawings of a perforated disk. For the views that are horizontally in line, you locate the horizontal center line midway between the horizontal margins; for the views that are vertically in line, you locate it midway between the vertical margins. The other spacing is as indicated. To determine the lengths of distances A and 2/3 A, set a compass to the diameter plus the thickness of the disk, and lay off this distance on the margin. Then divide the remaining segment of the margin into three intervals, two of them being equal, and the third one being 1 1/2 times as long as each of the others.

VIEW ANALYSIS.— You must be able to analyze a multi-view projection or, in other words, to determine what each line in a particular view represents. In this connection, it is helpful to remember that in a third-angle projection, the plane of projection is always presumed to be between the object and the observer, regardless

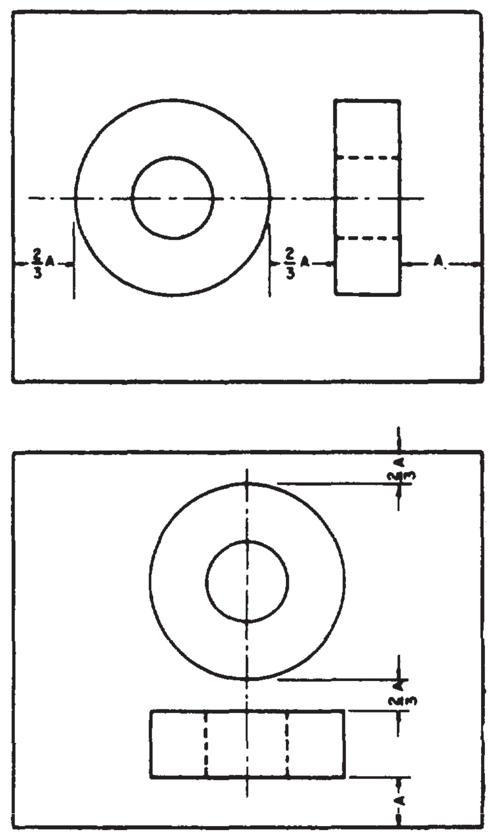


Figure 5-16.-Spacing of views of a circular object,

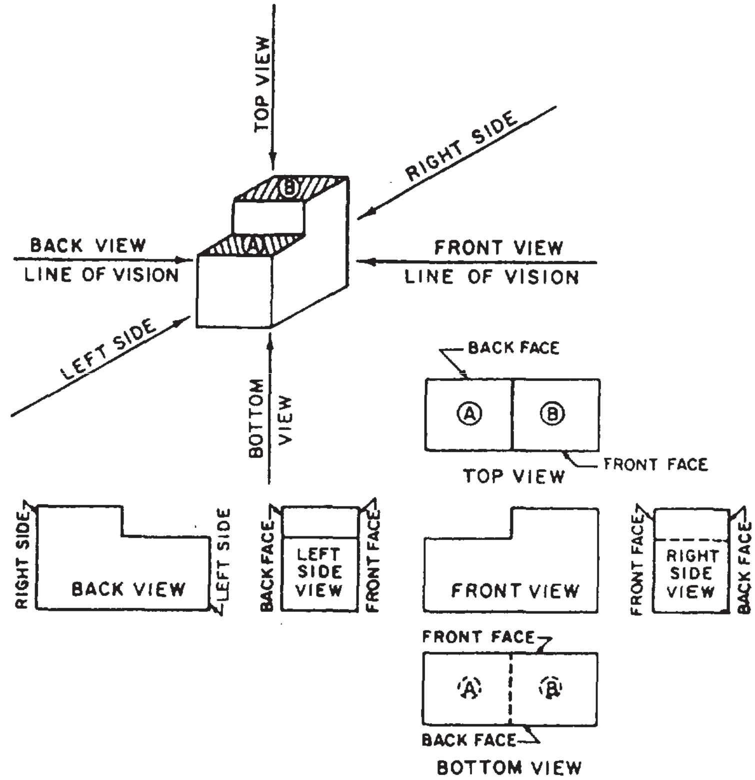


Figure 5-17.-Multi-view analysis of a third-angle orthographic projection.

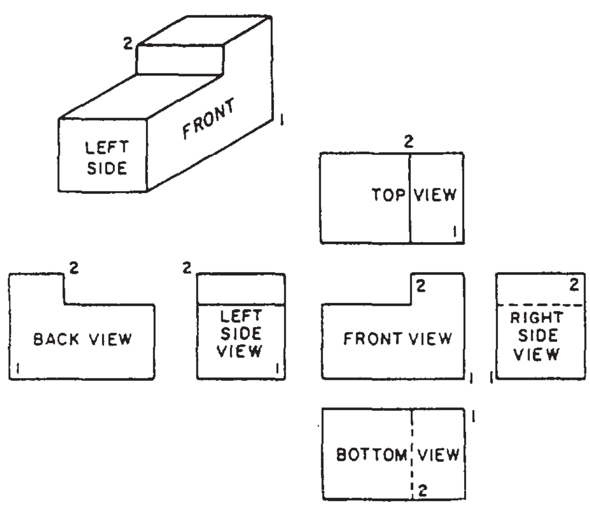


Figure 5-18.-Procedure for numbering hidden and visible corner points.

of which view you are considering. This means that, in a third-angle projection, each view of a surface of an object is a view of that surface as it would appear to an observer looking directly at it.

Figure 5-17 shows a six-view multi-view third-angle projection of the block shown in a single-view projection in the upper left corner of the figure. You should not have any trouble analyzing the front view; you know that the top is up, the bottom is down, the left side is to the left, and the right side is to the right.

In the top and bottom views, it's easy to see that the right-hand vertical line represents the right side and the left-hand vertical line, the left side. But you might have to think a minute to realize that the upper horizontal line in the top view represents the back face of the block, while the upper horizontal line in the bottom view represents the front face of the block. Note, also, that there is a line that appears as a visible line in the top view and as a hidden line in the bottom view.

In the right side and left side views, you can readily see that the upper horizontal line represents the top of the block and the lower horizontal line, the bottom. But you may have to think a minute to realize that the left-hand vertical line in the right side view represents the front face of the block, while the left-hand vertical line in the left side view represents the back face. Again, there is a line that appears as a visible line in the right side view and as a hidden line in the left side view.

In the back view, the block is shown reversed, so that the cutaway part, which appears to the right in the front view, appears to the left in the back view. Similarly, the right-hand vertical line in the front view represents the right side of the block, while the right-hand vertical line in the back view represents the left side.

As a general observation, it is helpful in view analysis to note that in the top, bottom, and side views, the line that represents the front face of the block faces toward the front view of the block. Similarly, in the back view, the line that represents the left side faces toward the left side view of the block. This applies to third-angle projection only.

A point that constitutes a corner on an object is sometimes numbered for purposes of identification in various views of the object. In a particular view of an object, a corner point number may be visible, or it may be hidden, as shown in figure 5-18. In the upper left corner of the figure, there is an oblique projection of a block, with a corner numbered 2. You can see that this corner is visible in top, back, and left side views, but hidden in bottom, front, and right side views.

The rule for numbering is that for a hidden corner point, the number is placed within the outline, and for a visible corner point, outside the outline. You can see how the rule has been followed in figure 5-18.

A multi-view projection should contain only as many views as are required to describe the object fully. If you refer back to figure 5-17, you can see at once that the back view does not convey any information that is not available in the front view; the back view is therefore superfluous and should be omitted. The same applies to the bottom view, which conveys no information not available in the top view. Likewise, the left side view conveys no information not available in the right side view.

You have the choice of omitting either the top or bottom view and either the right side or left side view. One general rule in this instance is that a top view is preferable to a bottom view and a right side view, to a left side view; another rule is that a view with a visible line is preferable to a view with the same line shown as a hidden line. Both rules apply here to eliminate the bottom and the left side views. All you need here is a three-view projection showing the top, front, and right side views.

It is often the case that a two-view projection is all that is required. The view at the top of figure 5-19 shows a single-view projection of an object. It is obvious that a top view of this object tells you everything you need to know except the thickness; a right side view tells you everything you need to know except the length; and a front view tells you everything you need to know except the width. All you need to do, then, is to select a particular view and couple it with another view that gives you the dimension that is missing in the first view.

There are three possible two-dimensional projections of the object shown in A, B, and C. In the selection of one of these three, everything else being equal, the balance of the drawing would be the deciding factor. Either A or B appears better balanced than C, and between A and B, A would look better on a long oblong sheet of paper, and B, better on a shorter oblong sheet.

The object shown in figure 5-19 has a definitely designated top and front; it follows that the right and left sides are also definitely designated. This is the case with many objects; you have no choice, for example, with regard to the top, bottom, front, and back of a house.

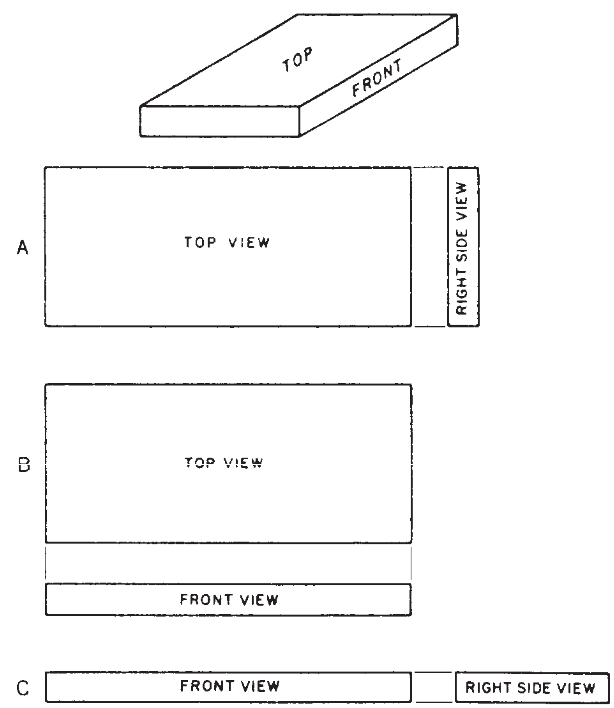


Figure 5-19.-Two-view multi-view projections.

Many objects, however, have no definite top, bottom, front, or back—as many types of machine parts, for example. With an object of this kind, you can select a surface and call it the front, and select another and call it the top, according to convenience. However, it is a general rule that an object should be shown in the position it customarily occupies.

One-view drawings are permissible for objects for which one view and such features as thickness or length, stated as a dimension or note, can completely define the object.

NORMAL AND NON-NORMAL LINES.— In a multi-view orthographic projection, a NORMAL line is one that is parallel to two of the planes of projection and perpendicular to the third. A line that is parallel to a plane of projection will appear on that plane in its true length (to the scale of the drawing). A line that is perpendicular to a plane of projection will appear on that plane as a point.

A line that is perpendicular to one plane of projection must of necessity be parallel to the other two. But a line that is parallel to one plane of projection may be oblique (neither parallel nor perpendicular) to one or both of the others. A line that is oblique to one or more of the planes of projection is called a NON-NORMAL LINE.

If a non-normal line is parallel to a plane of projection, it will appear on that plane in its true length. However, it will appear foreshortened in a view on a plane to which it is oblique. A non-normal line may, of course, be oblique to all three planes of projection, in which case it will appear foreshortened in all regular views of the object. A REGULAR VIEW is a view on one of the three regular planes of projection (horizontal, vertical, or profile). Views on planes other than the regular planes are called AUXILIARY VIEWS. Auxiliary views will be discussed later in this chapter.

A single-view projection of a block is shown in the upper left corner of figure 5-20. This block is presumed to be placed for multi-view projection with the front parallel to the vertical plane, the bottom parallel to the horizontal plane, and the right side parallel to the profile plane. The line AB, then, is parallel to the vertical plane, but oblique to both the horizontal and the profile planes.

In the multi-view projections, you can see that it is only in the views on the vertical plane (the front and back views) that the line AB appears in its true length. In the views on the horizontal

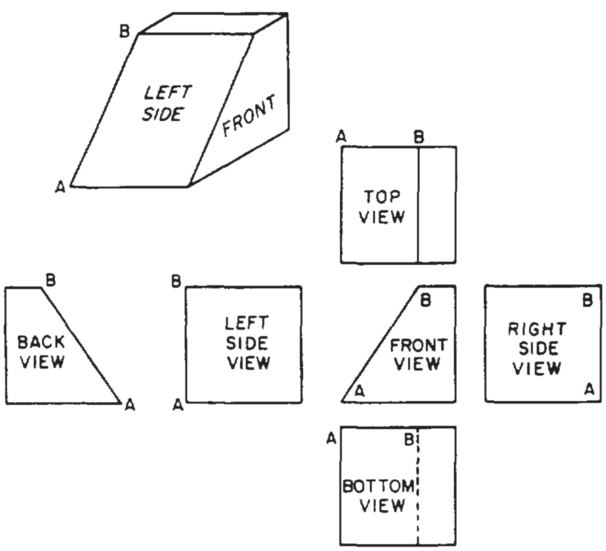


Figure 5-20.-Foreshortening of a line in a multi-view projection.

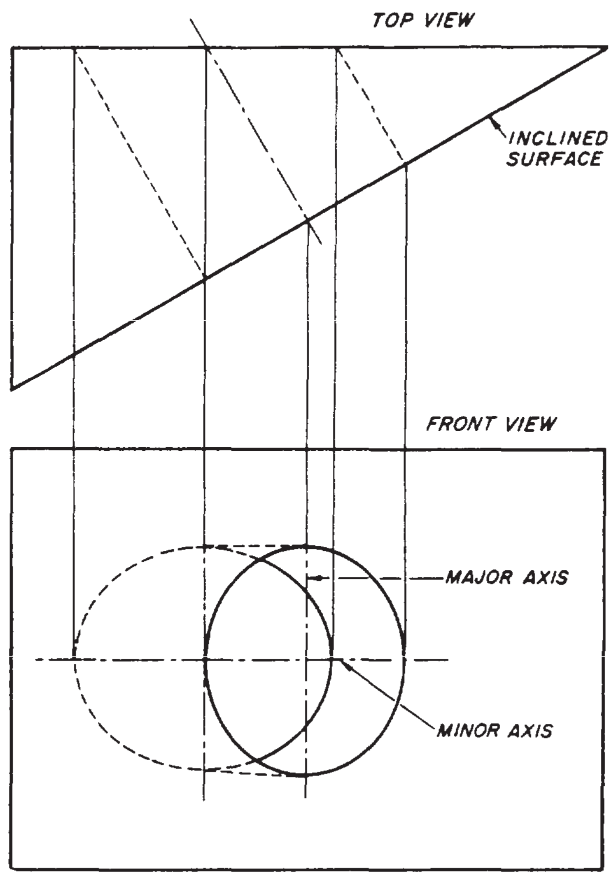


Figure 5-21.-A circle on a surface oblique to the plane of projection projected as an ellipse.

plane (top and bottom views) and in the views on the profile plane (right and left side views), the line appears foreshortened. Note, however, that you don't need to calculate the amount of the foreshortening, since it works itself out as you project the various views.

CIRCLES IN MULTI-VIEW ORTHOGRAPHIC PROJECTION.— A circle on a surface that is parallel to the plane of projection will project as a circle. A circle on a surface that is oblique to the plane of projection, however, will project as an ellipse, as shown in figure 5-21. The upper view in this figure is a top view of a wedge, the wedge having a hole bored through it perpendicular to the inclined face. The outline of this hole on the front face of the wedge projects as an ellipse in the front view. You get the minor axis of the ellipse by projecting downward as shown. The length of the major axis is equal to the diameter of the hole.

Another ellipse is shown in the front view. This is the partly hidden and partly visible outline of the hole as it emerges through the back of the wedge. The back of the wedge is parallel to the front view plane of projection; therefore, this ellipse is the true outline of the hole on the back of the wedge. The outline is elliptical because the hole, though it is circular, is bored obliquely to the back face of the wedge.

To draw these ellipses, you could use any of the methods of drawing an accurate ellipse explained in the previous chapter on geometric construction, or you could use an ellipse template.

AUXILIARY VIEWS.— In theory, there are only three regular planes of projection: the vertical, the horizonal, and the profile. Actually, it is presumed that each of these is, as it were, double; there is, for example, one vertical plane for a front view and another for a back view.

We assume, then, a total of six regular planes of projection. A projection on any one of the six is a regular view. A projection NOT on one of the regular six is an AUXILIARY VIEW.

The basic rule of dimensioning requires that a line be dimensioned only in the view in which its true length is projected and that a plane with its details be dimensioned only in the view in which its true shape is represented. To satisfy this rule, we have to create an imaginary plane that is parallel with the line or surface we want to project in its true shape. A plane of this kind that is not one of the regular planes is called an AUXILIARY PLANE.

In the upper left of figure 5-22, there is a single-view projection of a triangular block, the base of which is a rectangle. This block is presumed to be placed for multi-view projection

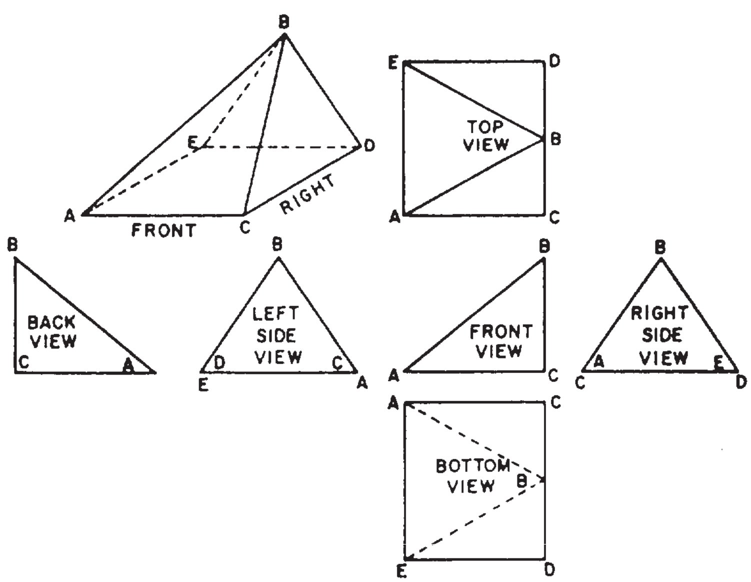


Figure 5-22.-A line oblique to all planes of projection is foreshortened in all views.

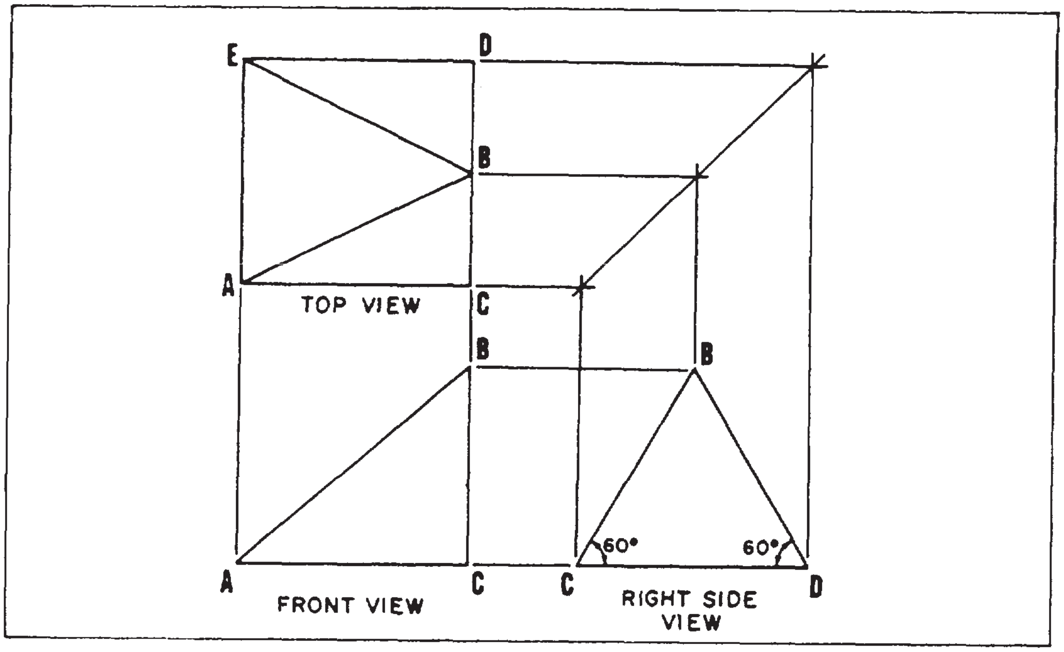


Figure 5-23.-Normal multi-view projection.

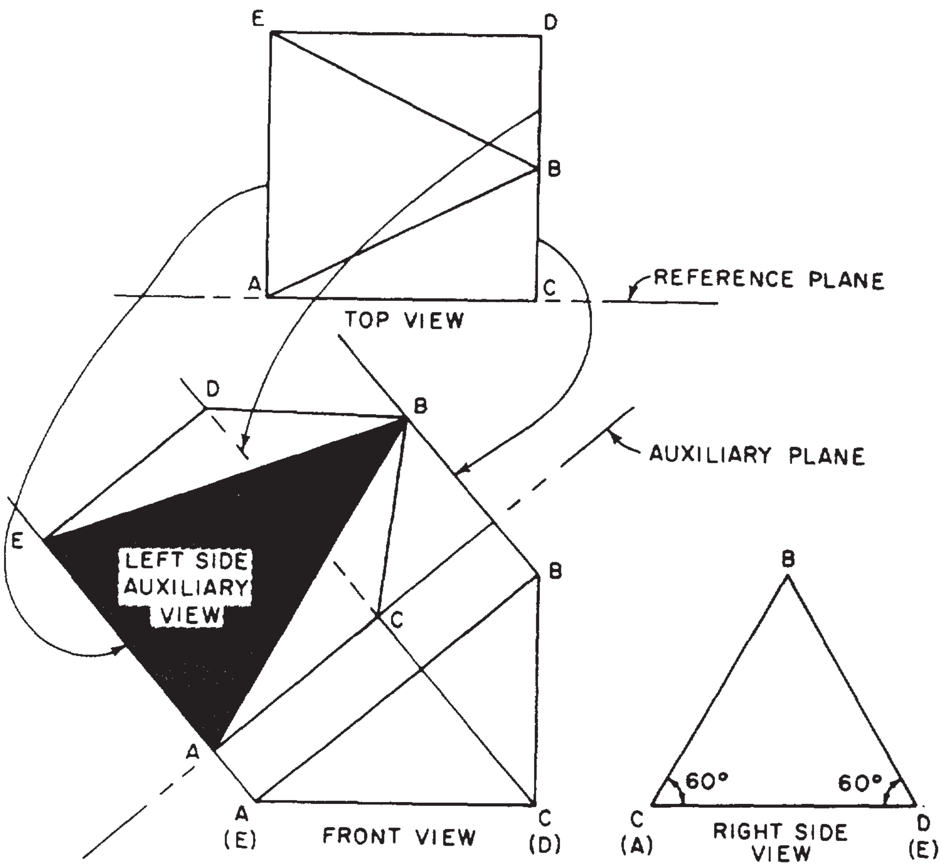


Figure 5-24.-Projection of left side auxiliary view.

with the right side parallel to the profile plane. The block is then drawn, using all six views of multi-view projection.

By careful examination of figure 5-22, you will see that the lines AB, AE, BD and BC and the surfaces ABC, ABE, and BDE are oblique to three regular planes of projection. The lines are foreshortened and the surfaces are not shown in their true shape in any of the six normal views.

The first step in the drawing of any auxiliary view is to draw the object in normal multi-view projection, as shown in figure 5-23. A minimum of two orthographic views is necessary. The space between these views is generally greater than normal. The reason for this will become apparent. Notice in figure 5-23, in the front view, that A is the end point of line AE (top view) and C is the end point of CD.

The second step is to decide which line or surface is to be shown in an auxiliary view and which orthographic view it will be projected from. The following facts must be considered when rendering this decision:

1. Front or rear auxiliary views are always projected from a side view.
2. Right or left auxiliary views are always projected from a front view.
3. An elevation auxiliary view is always projected from the top view.

The third step is to select the auxiliary and reference planes. The auxiliary plane is simply a plane parallel to the desired line or lines representing an edge view of the desired surface. In figure 5-24, the true length of line AB and the true shape of surface ABE are desired. A left side auxiliary view is needed. The auxiliary plane is drawn parallel to line AB in the front view. Line AB actually represents an edge view of surface ABE. The reference plane (top view) represents an edge view of the orthographic view (front view) from which the auxiliary view will be projected. Therefore, when front, rear, or side auxiliary views are desired, the reference plane will always be in the top view. When elevation auxiliary views are drawn, the reference plane may be in any view in which the top view is represented by a straight line. The reference plane in figure 5-24 is the edge of the top view that represents the front view. Remember that, although these planes are represented by lines, they are actually planes running perpendicular to the views.

Step four is to project and locate the points describing the desired line or surface. Draw the projection lines from the orthographic view perpendicular to the auxiliary plane. Then take the distances from the reference plane, whether by scaling or with a compass. The distances are the perpendicular distances from the reference plane to the desired point. In figure 5-24, the projection lines are drawn from points A, B, and C in the front view, perpendicular to the auxiliary plane. The projection line from point A indicates the line on which point E will also be located. The projection line from point C designates the line of both C and D, and that from B locates B only. To transfer the appropriate distances, first, look for any points lying on the reference plane. These points will also lie on the auxiliary plane where their projection lines intersect it (points A and C). To locate points B, D, and E, measure the perpendicular distances they are from the reference plane in the top view and transfer these distances along their respective projection lines in the auxiliary view. The points are equidistant from both the reference and auxiliary planes. Therefore, any line parallel to the reference plane is also parallel to the auxiliary plane and equidistant from it.

The fifth step is to connect these points. When the total auxiliary view is drawn, it is sometimes hard to discern which lines should be indicated as hidden lines. A rule to remember is as follows:

Those points and lines lying furthest away from the auxiliary plane in the orthographic view being projected from are always beneath any point or line that is closer. In figure 5-24, point C (representing line CD) in the front view is further from the auxiliary plane than any line or surface it will cross in the auxiliary view. Therefore, it will appear as a hidden line.

The final step is to label and dimension the auxiliary view. The labeling must include an adequate description. The term AUXILIARY must be included along with the location of the view in relation to the normal orthographic views (LEFT SIDE AUXILIARY VIEW, REAR ELEVATION AUXILIARY VIEW, and so forth). Dimensions are given only to those lines appearing in their true length. In figure 5-24, only lines AB, AE, and BE on the auxiliary view should be dimensioned.

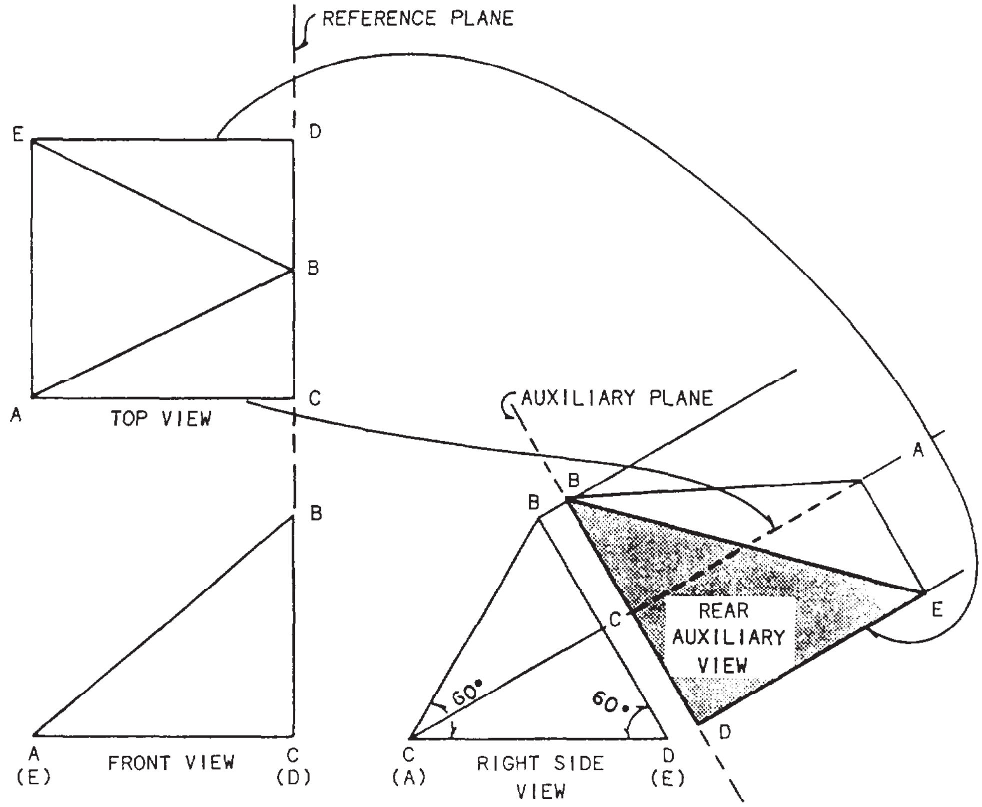


Figure 5-25.-Projection of rear auxiliary view.

Using the procedures previously described, follow the steps taken to project and draw the rear auxiliary view in figure 5-25.

Sometimes the total auxiliary view is not needed. Such a view could possibly even make the drawing confusing. In this case, a PARTIAL AUXILIARY VIEW is used. Only the points or lines needed to project the line or surface desired are used. This reduces the number of projection lines and greatly enhances the clarity of the view. If a partial auxiliary view is used, then it must be labeled PARTIAL to avoid confusion. In figure 5-24, if only the true length of line AB is desired, the points A and B would be projected and connected. The view would be complete after it was labeled and dimensioned.

In some cases the shape of an object will be such that neither the normal orthographic view nor the auxiliary views will show the true size and shape of a surface. When this occurs, a SECONDARY AUXILIARY VIEW is needed to describe the surface. The procedures for projecting and drawing a secondary auxiliary view are the same as those for a normal (or primary) auxiliary view. The reference plane for a secondary auxiliary view is located in the orthographic view from which the primary auxiliary view is projected. Usually, the primary auxiliary plane becomes the secondary reference plane. The secondary auxiliary plane is in the primary auxiliary view, and its location is determined in the same manner that the primary auxiliary plane is determined.

AUXILIARY SECTION.— An auxiliary view maybe a sectional, rather than a surface, view. In the upper left part of figure 5-26, there is a single-view projection of a block. It is desired to show the right side of the block as it would appear if the block were cut away on the plane indicated by the dotted line, the angle of observation to be perpendicular to this plane. The desired view of the right side is shown in the auxiliary section, which is projected from a front view as shown. Because the auxiliary plane of projection is parallel to the cutaway surfaces, these surfaces appear in true dimensions in the auxiliary section.

A regular multi-view of an orthographic drawing is one that is projected on one of the

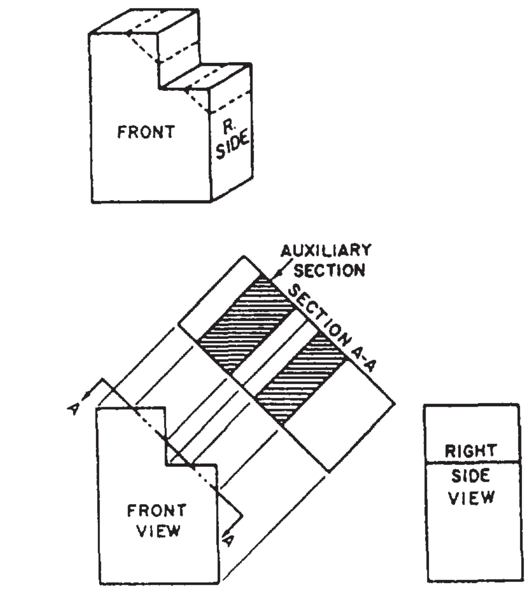


Figure 5-26.-Use of an auxiliary section.

regular planes of projection. An auxiliary view is one that is projected on a plane other than one of the regular planes.

A rectangular object is in normal position for regular multi-view orthographic projection when each of its faces is parallel to one regular plane of projection and perpendicular to the other two. This is the case with the object shown in figure 5-27, view A.

USE OF REVOLUTIONS.— In a REVOLUTION, the object is projected on one or more of the regular planes of projection. However, instead of being placed in normal position, the object is revolved on an axis perpendicular to one of the regular planes.

Figure 5-27, view B, is a three-view multi-view projection showing the block in 5-27, view A, as it would appear if it were revolved 30 degrees on an axis perpendicular to the profile plane of projection. Figure 5-28, view A, shows how the

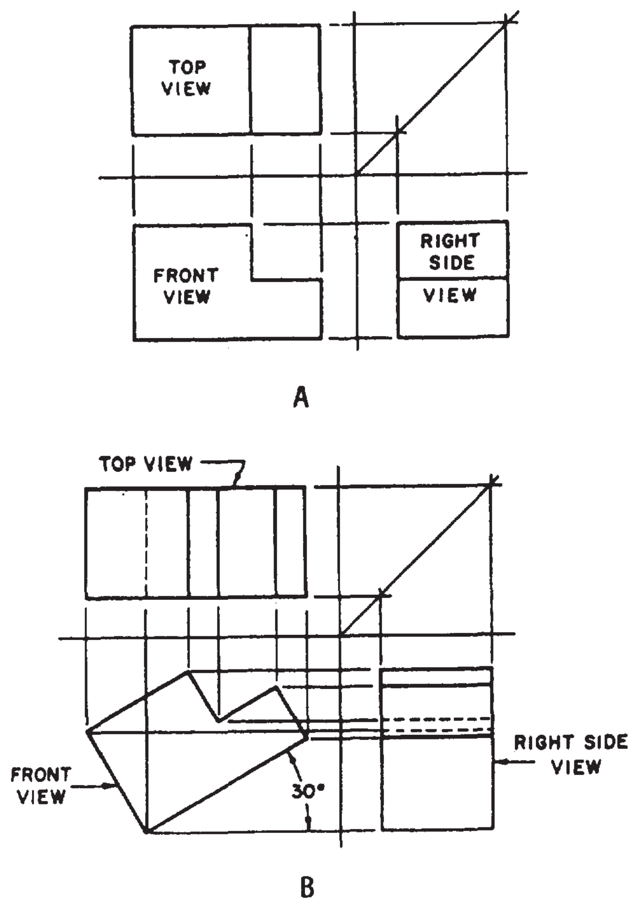


Figure 5-27.-A. Multi-view view of block in normal position; B. Multi-view view of block revolved 30 degrees on axis perpendicular to vertical plane.

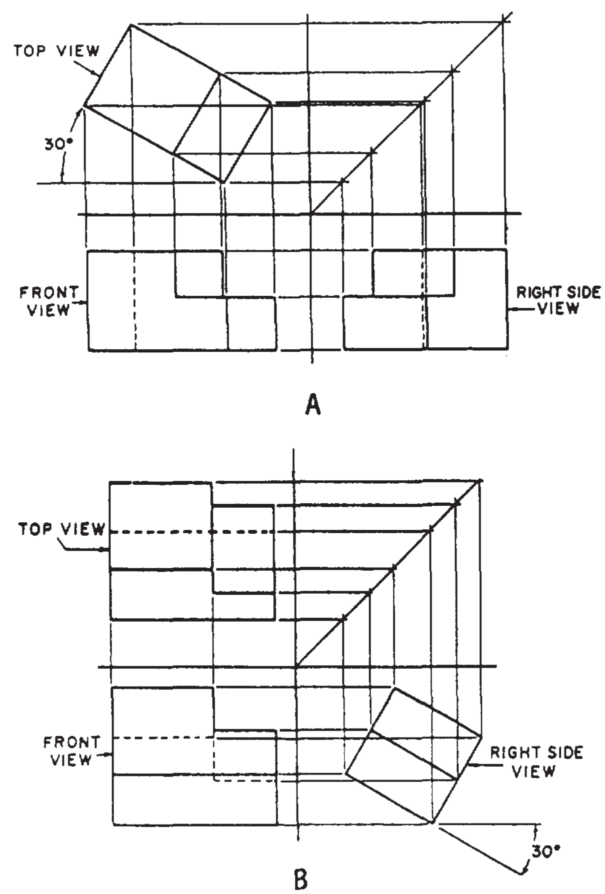


Figure 5-28.-Use of revolution on axis perpendicular to (A) horizontal plane and (B) vertical plane.

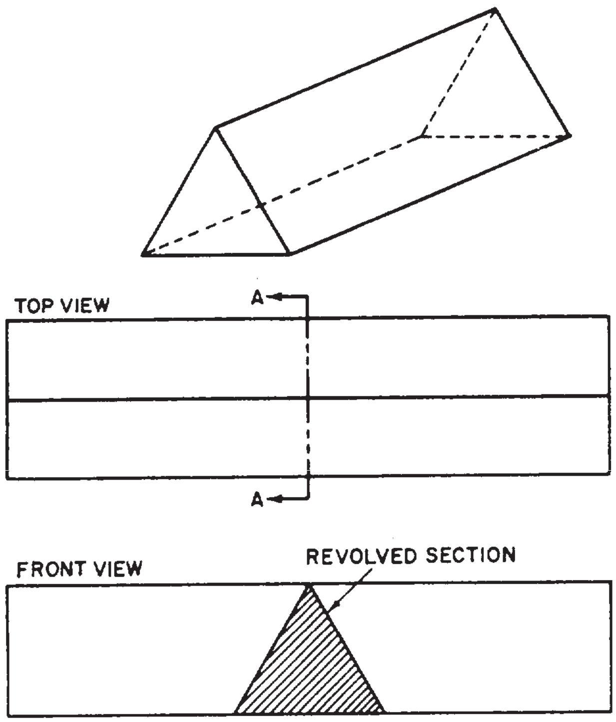


Figure 5-29.-Use of a revolved section (A-A).

block would look if it were revolved 30 degrees on an axis perpendicular to the horizontal plane. Figure 5-28, view B, shows the block as it would appear if it were revolved 30 degrees on an axis perpendicular to the vertical plane.

REVOLVED SECTIONS.— A common use of the revolution is the revolved section, shown in figure 5-29. At the top of this figure, there is a single projection of a triangular block. You can show all required information about this block in a two-view projection by including a revolved section in the front view as shown. You first assume that the block is cut by a plane perpendicular to the longitudinal axis. You then revolve the resulting section 90 degrees on an axis perpendicular to the horizontal plane of projection.

SECTIONING TECHNIQUES.— A sectional view is called for when the internal structure of an object can be better shown in such a view than it can by hidden lines. In the upperpart of figure 5-30, there is a single-view projection of a pulley. The same object is shown below in a two-view multi-view projection. The internal structure of the pulley is shown by the hidden lines in the top view.

In figure 5-31, the internal structure of the pulley is much more clearly shown by a sectional view. Note that hidden lines behind the plane of projection of the section are omitted in the

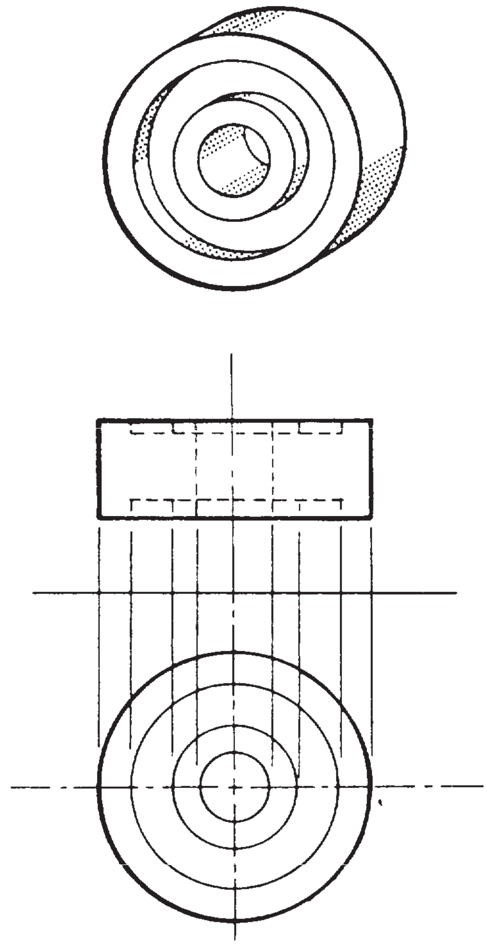


Figure 5-30.-Internal structure of an object shown by hidden lines.

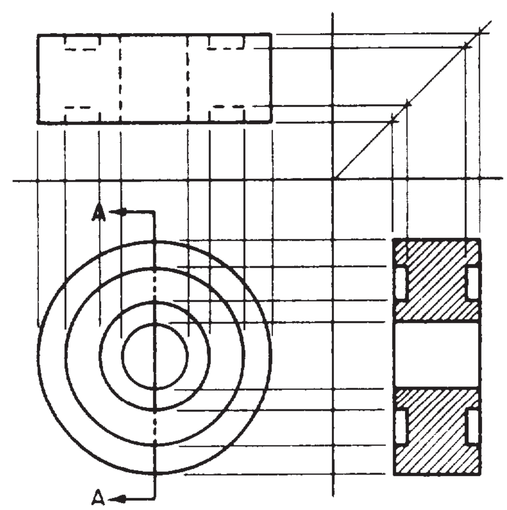


Figure 5-31.-Internal structure of an object more clearly shown by sectional view.

sectional view. These lines are omitted by general custom, the custom being based on the fact that the elimination of hidden lines is the fundamental reason for making a sectional view. However, any lines that would be VISIBLE behind the sectional plane of projection must be included in the sectional view.

The section shown in figure 5-31 is called a FULL SECTION because the cutting plane passes entirely through the object and divides it into two equal parts. Also, the object shown in figure 5-31 is a symmetrical object—meaning, in general, that the shape of one half is identical to the shape of the other. This being the case, you could have used a HALF SECTION like the one shown in figure 5-32. This half section constitutes one half of the full section. Because the other half of the full section would be identical with the half shown, it need not be drawn.

Note that a center line, rather than a visible line, is used to indicate the division between the sectioned and the unsectioned part of the sectional view. A visible line would imply a line that is actually nonexistent on the object. Another term used in place of center line is LINE OF SYMMETRY.

A section consisting of less than half a section is called a PARTIAL SECTION. (See fig. 5-33.) Note that here you use a break line to indicate the division between the sectioned and unsectioned part. For this reason, a partial section is often called a BROKEN SECTION.

The section lines drawn on a sectional surface always serve the basic purpose of indicating the limits of the sectional or cutaway surface. They may also indicate the type of material of which

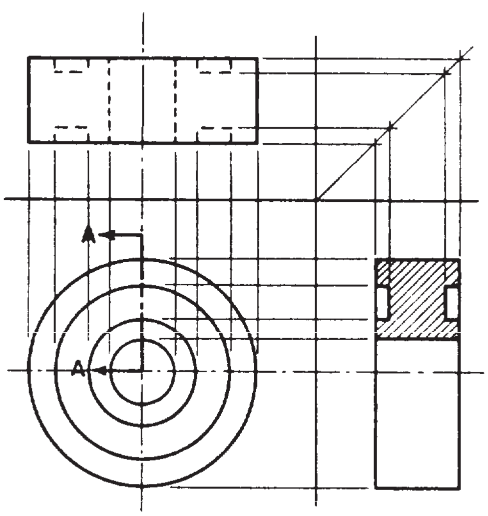


Figure 5-32.-Use of half section.

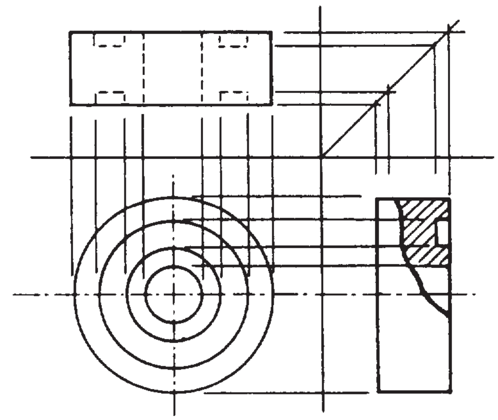


Figure 5-33.-Use of partial or broken section.

the sectioned surface consists. For example, in figure 5-34, view A shows section lining for an object made of cast iron. View B shows two matching parts made of steel, and view C shows three adjacent parts made of brass, bronze, or copper. For other symbolic section lining symbols, refer to ANSI Standard Y14.2.

In view of the vast numbers of different materials, and since drawings must always identify materials by lettered form, such as notes, it is usually more desirable, and it is common practice, to use a general purpose symbol for section lining. The general purpose symbol is the cast iron symbol shown in figure 5-34, view A. The use of other symbols, then, should be limited to those situations when it is truly desirable, or conventional, to graphically differentiate between materials. For example, in an assembly drawing (a drawing showing different papers fitted together), it is often desirable to differentiate materials.

On a regular multi-view section, section lining (sometimes called diagonal hatching or cross-hatching) should be drawn at 45° to the horizontal, as shown in figure 5-34, view A. However, if section liners drawn at 45° to the

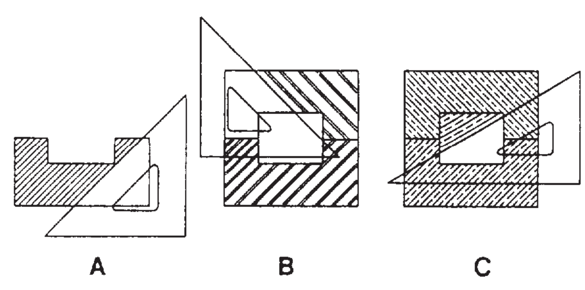


Figure 5-34.-Diagonal hatching on separate sectional surfaces shown in normal position.

horizontal would be parallel or perpendicular (or nearly so) to a prominent visible outline, the angle should be changed to 30°, to 60°, or some other angle. If two adjacent sectioned surfaces are shown, the hatching should be in opposite directions, as shown in figure 5-34, view B. If still a third surface is included, it should be hatched at another suitable angle to make the surface clearly stand out separately from the other surfaces (figure 5-34, view C). Note that the hatching lines on one surface are not permitted to meet those on an adjacent surface.

In drawing section lining, use a sharp, medium-grade pencil (H or 2H). Space the lines as uniformly as possible by eye. As a rule, spacing of the lines should be as generous as possible, yet close enough to distinguish the sectioned surface clearly. For average drawings, space the lines about 3/32 in. or more apart.

Diagonal hatching on an auxiliary section should be drawn at 45 degrees to the horizontal, with respect to the section. Figure 5-35 shows this rule.

In a revolution or other view of an object in other than the normal position, the diagonal hatching on a section should be drawn at 45 degrees to the horizontal or vertical axis of the object as it appears in the revolution. Figure 5-36 shows this rule.

Axonometric Projection

Axonometric single-plane projection is another way of showing an object in all three

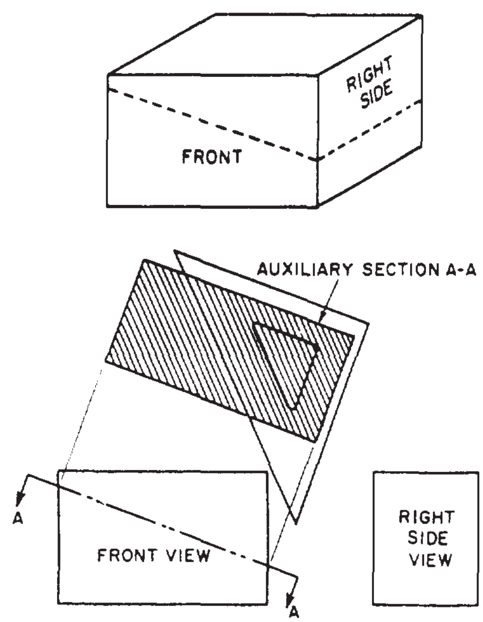


Figure 5-35.-Diagonal hatching on an auxiliary section.

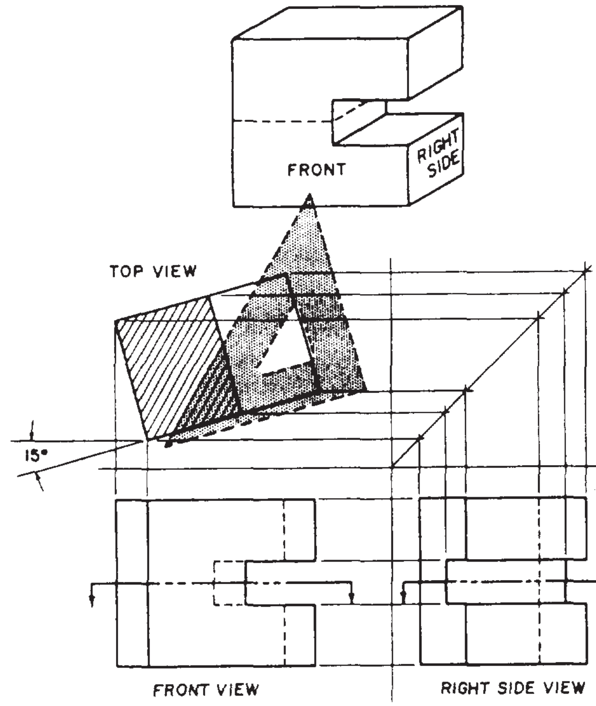


Figure 5-36.-Diagonal hatching on a revolution.

dimensions in a single view. Theoretically, axonometric projection is orthographic projection in that only one plane is used and the projection lines are perpendicular to the plane of projections. It is the object itself, rather than the projection lines, that is inclined to the plane of projection.

ISOMETRIC PROJECTION AND ISOMETRIC DRAWING.— Figure 5-37 shows a cube projected by ISOMETRIC PROJECTION, the most frequently used type of axonometric projection. The cube is inclined so that all of its surfaces make the same angle (35°16´) with the plane of projection. As a result of this inclination, the length of each of the edges shown in the projection is somewhat shorter than the actual length of the edge on the object itself. This reduction is called FORESHORTENING. The degree of reduction amounts to the ratio of 1 to the cosine of 35°16´, or 1/0.8165. This means that if an edge on the cube is 1 in, long, the projected edge will be 0.8165 in. long. As all of the surfaces make the same angle with the plane of projection, the edges all foreshorten in the same ratio. Therefore, one scale can be used for the entire layout; hence the term *isometric,* which literally means "one-scale."

Figure 5-38 shows an isometric projection as it would look to an observer whose line of sight was perpendicular to the plane of projection. Note

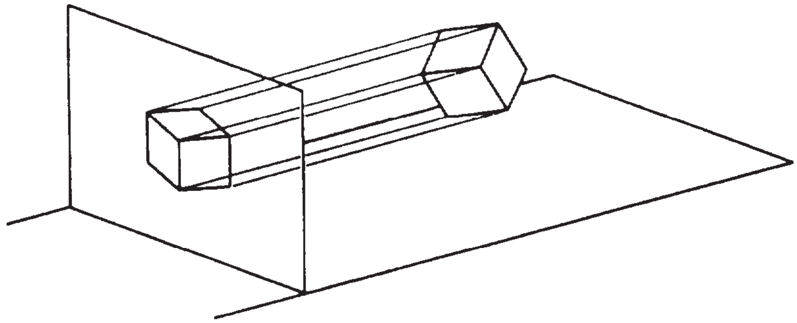


Figure 5-37.-Isometric projection of a cube.

that the figure has a central axis, formed by the lines OA, OB, and OC. The existence of this axis is the origin of the term *axonometric projection.* In an isometric projection, each line in the axis forms a 120-degree angle with the adjacent line, as shown. A quick way to draw the axis is to draw the perpendicular OC, then use a T square and 30°/60° triangle to draw OA and OB at 30 degrees to the horizontal. Since the projections of parallel lines are parallel, the projections of the other edges of the cube will be, respectively, parallel to these axes.

A rectangular object can be easily drawn in isometric by the procedure known as box construction. In the upperpart of figure 5-39, there is a two-view normal multi-view projection of a rectangular block. An isometric drawing of the block is shown below. You can see how you build the figure on the isometric axis and how you lay out the dimensions of the object on the isometric drawing. Because you lay out the identical dimensions, it is an isometric drawing rather than an isometric projection.

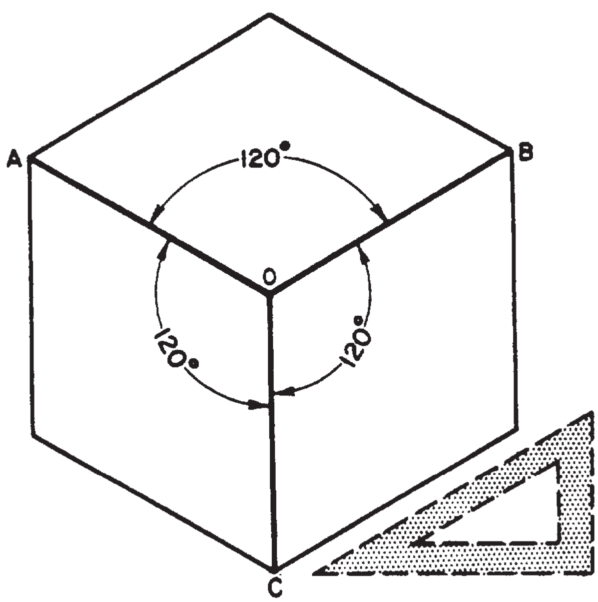


Figure 5-38.-Use of an isometric axis.

Non-isometric Lines.— If you examine the isometric drawing shown in figure 5-39, you will note that each line in the drawing is parallel to one or another of the legs of the isometric axis. You will also notice that each line is a normal line in the multi-view projection. Recall that a normal line is a line that, in a normal multi-view projection, is parallel to two of the planes of projection and perpendicular to the third. Thus,

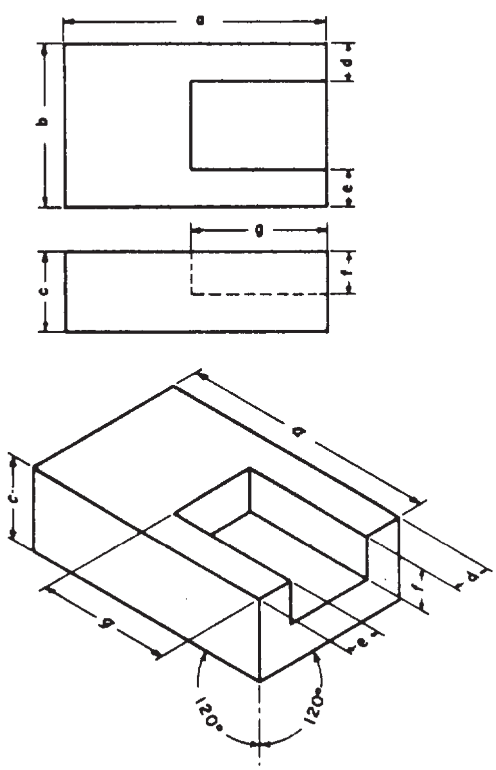


Figure 5-39.-Use of "box construction" in isometric drawing.

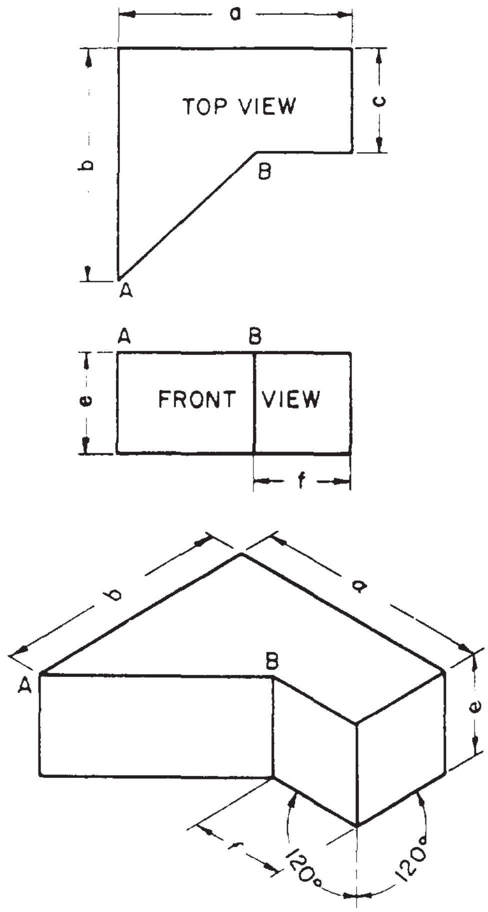


Figure 5-40.-A non-isometric line (AB) in an isometric projection.

a NON-ISOMETRIC LINE is a line that is not parallel to any one of the three legs of the isometric axis. It is not a normal line in a normal multi-view projection of the object.

The upperpart of figure 5-40 shows a two-view normal multi-view projection of a block. Though the line AB is parallel to the horizontal plane of projection, it is oblique to both the vertical and the profile planes. It is therefore not a normal, but an oblique, line in the multi-view projection, and it will be a non-isometric line in an isometric projection or drawing of the same object.

The line AB appears in its true length in the top multi-view view because it is parallel to the plane of the view (the horizontal plane); but it will appear as a non-isometric line, and therefore not in its true length, in an isometric drawing, as shown in the bottom part of figure 5-40. It follows that you cannot transfer AB directly from the multi-view projection to the isometric drawing. You can, however, transfer directly all the normal lines in the multi-view projection, which will be isometric lines appearing in their true lengths in the isometric drawing. When you have done this, you will have constructed the entire isometric drawing, exclusive of line AB and of its counterpart on the bottom face of the block. The end points of AB and of its counterpart will be located, however, and it will only be necessary to connect them by straight lines.

Angles in Isometric.—In a normal multi-view view of an object, an angle will appear in its true size. In an isometric projection or drawing, an angle never appears in its true size, Even an angle formed by normal lines, such as each of the 90-degree corner angles of the block shown in the bottom part of figure 5-41, appears distorted in isometric.

The same principle used in transferring a non-isometric line is used to transfer an angle in isometric. The upperpart of figure 5-41 shows a two-view multi-view projection of a block. On the top face of the block, the line AB makes a 40-degree angle with the front edge. The line AB is an oblique (that is, not normal) line, which will appear as a non-isometric line in the isometric drawing. You locate the end points of AB on the isometric drawing by

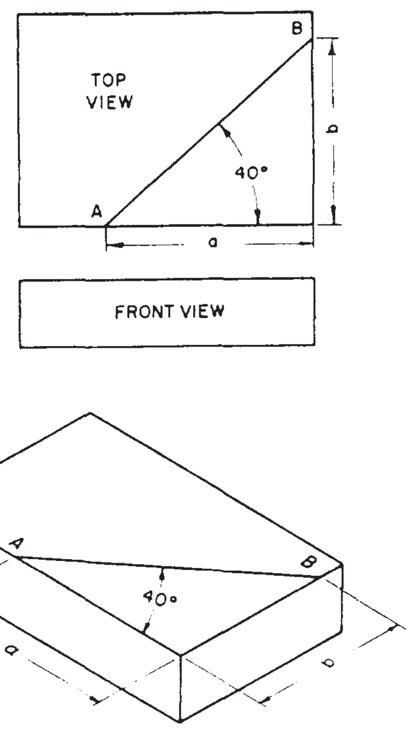


Figure 5-41.-Drawing an angle in isometric.

measuring distances along normal lines on the multi-view projection and laying them off along the corresponding isometric lines on the isometric drawing. The angle that measures 40 degrees on the top multi-view view measures only about 32 degrees on the isometric drawing. Note, however, that it is labeled 40 degrees on the isometric drawing. This is because it actually is a 40-degree angle as it would look on a surface plane at the isometric angle of inclination.

Circles in Isometric.— A circle in a normal multi-view view will appear as an ellipse in an isometric drawing. This is shown in figure 5-42, view A.

A procedure that maybe used to construct an isometric circle is shown in figure 5-42, view B. The steps of that procedure are as follows:

1. Draw the isometric center lines of the circle. Then, using those center lines, lay off an isometric square with sides equal to the diameter of the circle.
2. From the near corners of the box, draw bisectors to the opposite intersections of the center lines and the box. The bisectors will intersect at four points (A, A´, B, B´), which will be the centers of four circular arcs.
3. Draw two large arcs with radius R, using Points A and A´ as centers, Draw the two smaller arcs with radius r, using Points B and B´ as centers.

If the above discussion seems familiar, it should. It is simply an approximation of the four-point method you studied in the previous chapter. However, it can be used only when drawing isometric circles on an isometric drawing.

Noncircular Curves in Isometric.— A line that appears as a noncircular curve in a normal multi-view view of an object appears as a non-isometric line in an isometric drawing. To transfer such a line to an isometric drawing, you must plot a series of points by measuring along normal lines in the multi-view view and transferring these measurements to corresponding isometric lines in the isometric drawing.

The upperpart of figure 5-43 shows a two-view multi-view projection of a block with

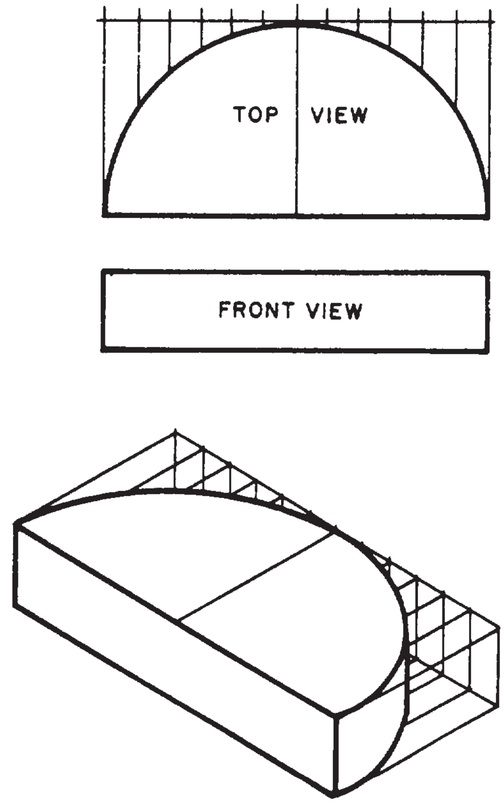
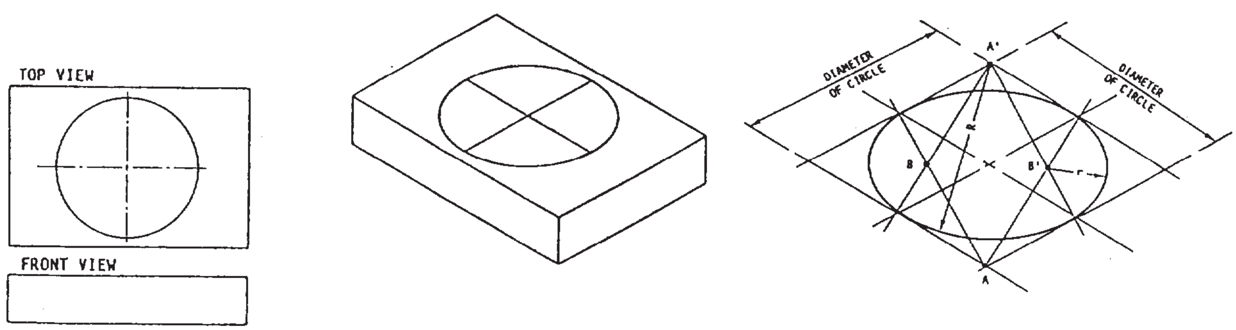


Figure 5-43.-Method of drawing a noncircular curve in isometric.



A B

Figure 5-42.-A circle on a normal multi-view view appears as an ellipse in an isometric drawing.

an elliptical edge. To make an isometric drawing of this block, draw the circumscribing rectangle on the top multi-view view, lay off equal intervals as shown, and draw perpendiculars at these intervals from the upper horizontal edge of the rectangle to the ellipse. Then draw the rectangle in isometric, as shown below, and plot a series of points along the elliptical edge by laying off the same perpendiculars shown in the top multi-view view. Draw the line of the ellipse through these points with a french curve.

Alternate Positions of Isometric Axis.— Up to this point, the isometric axis has been used with the lower leg vertical. The axis may, however, be used in any position, provided the angle between adjacent legs is always 120 degrees. Figure 5-44 shows how varying the position of the axis varies the view of the object.

Diagonal Hatching in Isometric.— Diagonal hatching on a sectional surface shown in isometric should have the appearance of making a 45-degree angle with the horizontal or vertical axis of the surface. If the surface is an isometric surface (one that makes an angle of 35°16’ with the plane of projection), lines drawn at an angle of 60 degrees to the horizontal margin of the paper, as shown in figure 5-45, present the required appearance. To show diagonal hatching on a non-isometric surface, you must experiment to determine the angle that presents the required appearance.

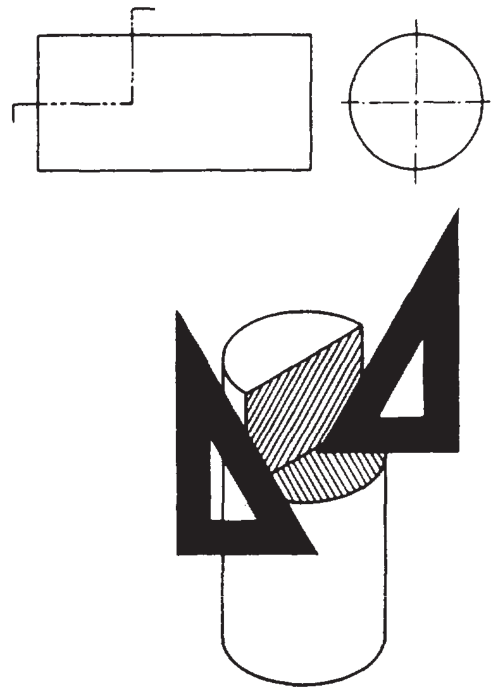


Figure 5-45.-An example of diagonal hatching in isometric.

DIMETRIC AND TRIMETRIC PROJECTION.— TWO other subclassifications of the axonometric projection category are dimetric and trimetric projections; however, these types are used less frequently than isometric projections and will not be discussed further in this training manual.

OBLIQUE SINGLE-PLANE PROJECTION

We have seen that an object may be drawn showing length and width on a single plane. Depth

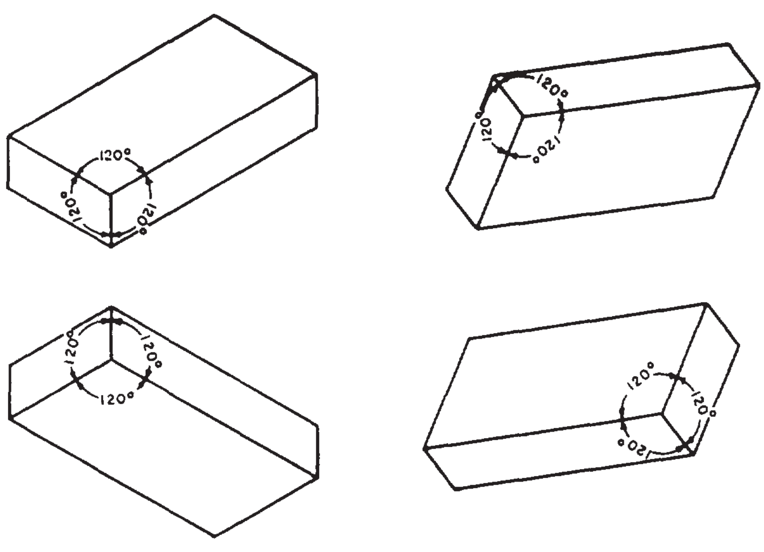


Figure 5-44.-Various positions of isometric axes.

may also be shown on this single plane by constructing the receding projection lines of the object at an angle other than perpendicular to the plane of projection.

Figure 5-46 shows the same object by both orthographic and oblique projection. The block is placed so that its front surface (the surface toward the plane of projection) is parallel to the plane of projection. You can see that the orthographic projection shows only this surface of the block. The oblique projection, on the other hand, shows the front surface and also the top and side surfaces. The orthographic projection shows only two dimensions: length and width. The oblique projection shows three: length, width, and thickness. Oblique projection, then, is one method by which an object can be shown, in a single view, in all three dimensions.

There are two types of oblique single-plane projections: CAVALIER and CABINET.

Cavalier Projection

CAVALIER PROJECTION is a form of oblique projection in which the projection lines are presumed to make a 45-degree vertical and a 45-degree horizontal angle with the plane of projection. Assume that in figure 5-47 the line XX' represents a side-edge view of the plane of projection, and that the square ABCD represents a side of a cube, placed with its front face parallel to, and its top face perpendicular to, the plane of projection. You can see that the projected lengths of AB and AD are the same as the actual lengths.

Now assume that the line XX' in figure 5-47 represents a top-edge view of the plane of projection, and that the square ABCD represents the top of the cube. You can see again that the projected lengths of AB and AD are the same as the actual lengths of AB and AD.

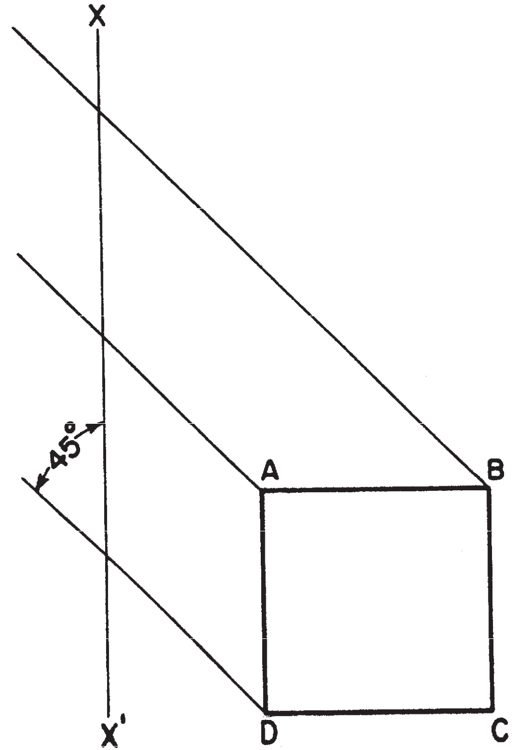


Figure 5-47.—Angle of projection lines in a cavalier projection.

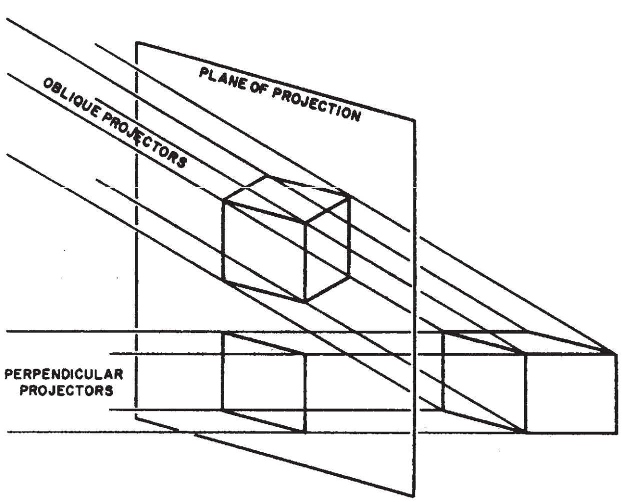


Figure 5-46.—Oblique and orthographic projections of the same object.

In a cavalier projection, then, any line parallel to or perpendicular to the plane of projection is projected in its true length. Figure 5-48 shows a cavalier projection of the cube shown in figure 5-47. You start by drawing the axis, which consists of the front axes OA and OB and the receding axis OC. The front axes are always perpendicular to each other; the receding axis

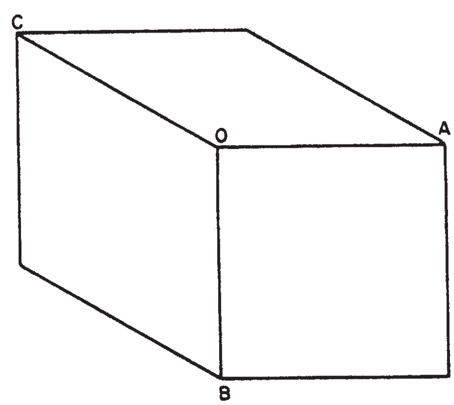


Figure 5-48.—Cavalier projection of a cube.

may be drawn from O at any convenient angle. All three are equal in length, the length being the length of an edge of the original cube (which may be scaled down or up if the drawing is made other than full scale). After you draw the axis, complete the projection by drawing the required parallel lines. All the edges shown in the projection are, like the edges on the original cube, equal in length.

Cabinet Projection

The first thing you notice about the cube shown in figure 5-48 is the fact that it doesn't look like a cube because the depth dimension appears to be longer than the height and width dimensions. The reason for this is the fact that a cavalier projection corrects a human optical illusion—the one that causes an object to appear to become smaller as its distance from the eye increases. This illusion. in turn. causes receding parallel lines to appear to the eye to be shorter-than they really are, and also to be converging toward a point in the distance. But receding parallel lines on a cavalier projection appear in their true lengths, and they remain constantly parallel. Also, the far edges of the cube shown in figure 5-48 are equal in length to the near edges.

The distortion in figure 5-48 is only apparent. It is sometimes desirable to reduce this appearance of distortion. This can be done by reducing the length of the receding axis (OC in fig. 5-39). This axis can be reduced by any desired amount, but it is customary to reduce it by one half.

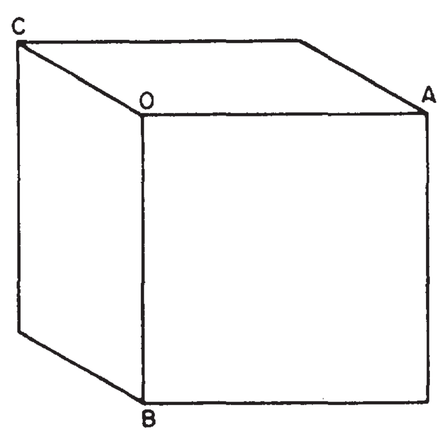


Figure 5-49.-Cabinet projection of the cube in figure 5-48. (Note receding axis OC reduced by one half its length.)

When the receding axis is reduced by one half, the projection is called a CABINET PROJECTION. Figure 5-49 shows a cabinet projection of a cube. The length of the receding axis OC has been reduced by one half. As you can see, this representation looks more like a cube.

Cavalier and cabinet projections are compared in figures 5-50 and 5-51.

Oblique Drawing Techniques

In an oblique projection drawing of a rectangular object, one face (usually the most prominent or most important) is parallel to the plane of projection. All features appearing on this plane, such as circles or oblique lines, are in their true dimension. However, in the side or top views, these same features are somewhat distorted because of the receding axis angle. When drawing these features, you can use various techniques to aid you in their construction.

For convenience, the angles chosen for the receding axis are either 30 degrees, 45 degrees, or

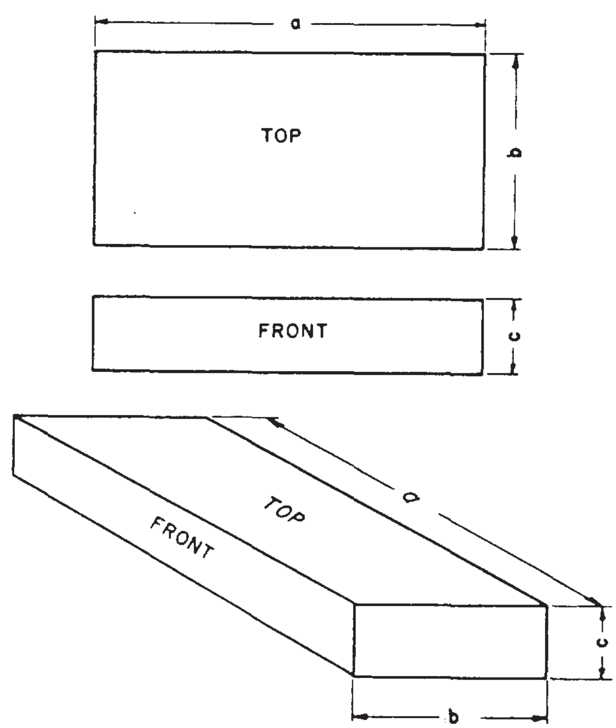


Figure 5-50.-Cavalier projection. Distances along front axis and along receding axis are all true.

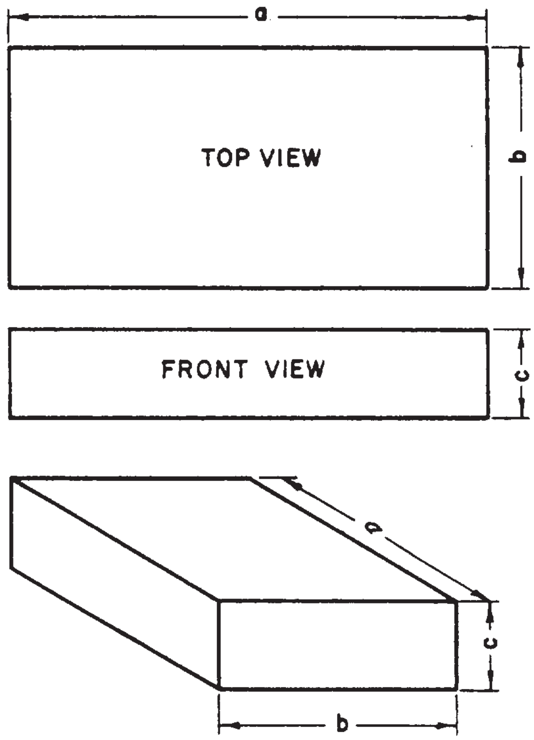


Figure 5-51.-Cabinet projection. Distances along front axis are true; distances along receding axis are reduced by one half.

60 degrees because they are easily constructed with triangles (fig. 5-52).

IRREGULAR LINES.— An irregular line in an oblique drawing is a line that would be an oblique line in a normal multi-view projection. In the upperpart of figure 5-53, there is a two-view multi-view projection of a block; the line AB is an irregular line and will not appear in its true length in an oblique projection. To transfer the line, you draw the projection by transferring measurements taken along regular lines; these measurements locate the end points of the irregular line. Figure 5-53 shows the cavalier projection of an irregular line. The procedure for cabinet projection would be the same except that all measurements along the receding axis would be reduced by one half.

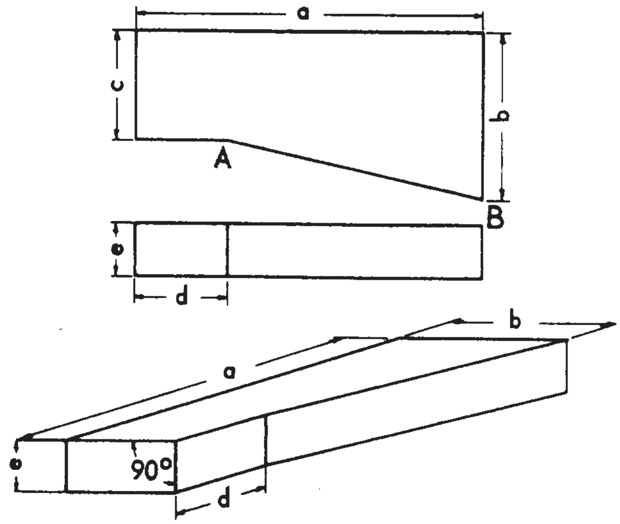


Figure 5-53.-Cavalier projection of an object with irregular lines.

ANGLES IN OBLIQUE.— In an oblique projection, an angle on the surface that is parallel to the plane of projection will appear in its true

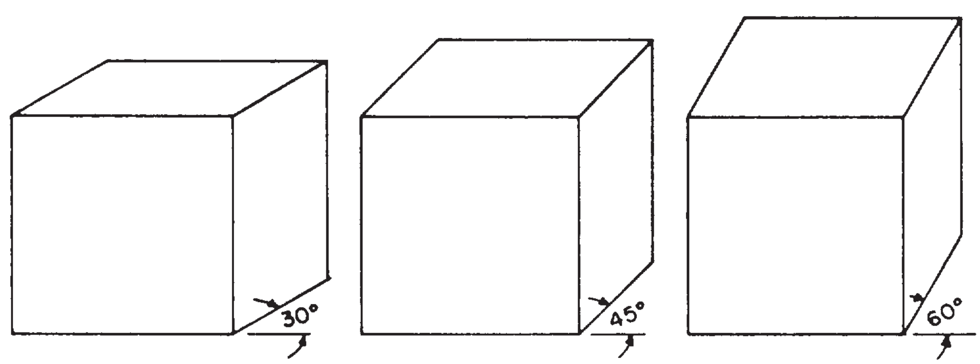


Figure 5-52.-Angles of 30 degrees, 45 degrees, and 60 degrees are normally chosen for the receding axis in oblique projection because they are easily drawn with triangles.

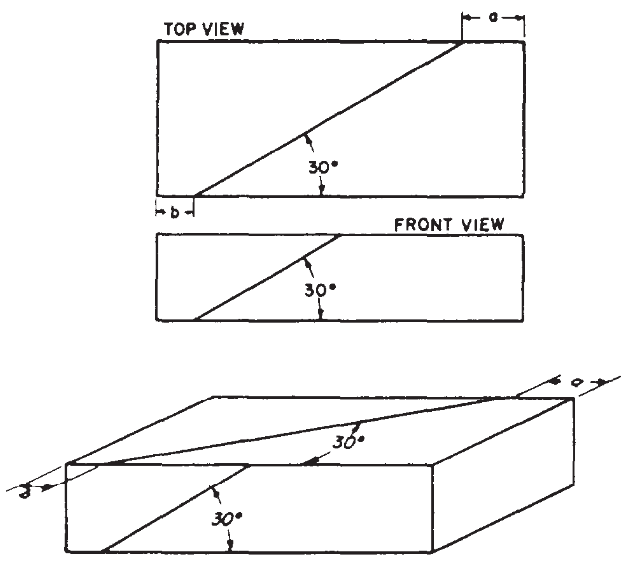


Figure 5-54.-Transferring an angle in oblique projection.

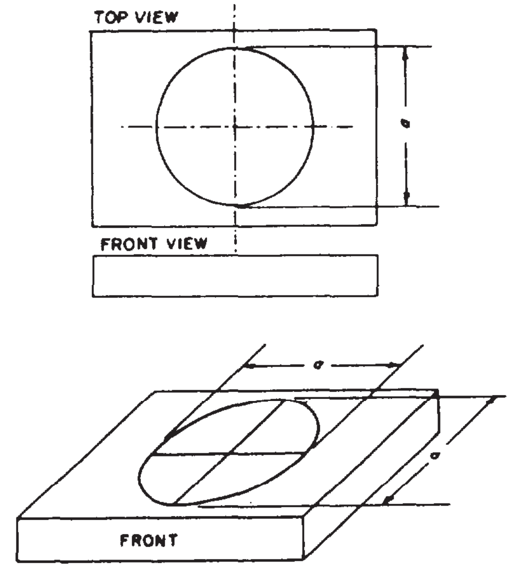


Figure 5-55.-Cavalier projection of a circle on a receding surface.

size; an angle on any other surface will not. The upperpart of figure 5-54 shows a two-view multi-view projection of a block. It has a 30-degree angle on the top face and another on the front face. In the cavalier projection below, the angle on the front face still measures 30 degrees; that on the top face measures only about 9 degrees. You transfer the top face angle by locating the end points of the line by measurements along regular lines.

CIRCLES IN OBLIQUE.— In an oblique projection, a circle on the surface parallel to the plane of projection will appear as a circle. A circle on any other surface will appear as an ellipse, as shown in figure 5-55. The upperpart of this figure shows a two-view multi-view projection of a block with a circle on its upper face. The lower part of this figure shows a cavalier projection in which the circle appears as an ellipse. Each of the conjugate (joined together) diameters of the ellipse is equal to the diameter of the circle.

PERSPECTIVE PROJECTION AND PERSPECTIVE DRAWING

PERSPECTIVE PROJECTION (fig. 5-2) is obtained when the projection lines converge to a point that is at a finite distance from the plane of projection. Each projection line forms a different angle with the plane of projection, giving the viewer a three-dimensional picture of the object. This type of projection, however, cannot accurately convey the structural features of a building; hence, it is not adequate for working drawings.

On the other hand, of all the three-dimensional single-plane drawings, PERSPECTIVE DRAWINGS are the ones that look the most natural. At the same time, they are also the ones that contain the most errors. Lines that have the same length on the object have different lengths on the drawing. No single line or angle on the drawing has a length or size that has any known relationship to its true length or size when projected through perspective projections.

Perspective drawing is used only in drawings of an illustrative nature, in which an object is deliberately made to appear the way it looks to the human eye. Most of the drawings you will prepare will be drawings in which accuracy, rather than eye appearance, will be the chief consideration. Consequently, you will not be concerned much with perspective drawing.

If you are required to prepare perspective drawings, refer to *Illustrator Draftsman*, NAVEDTRA 10472, or civilian publications, such as *Architectural Drawing and Light Construction* and *Architectural Graphic Standards*.

SKETCHING

The EA who is able to make quick, accurate SKETCHES will find this ability a valuable asset when it comes to conveying technical information or ideas. Without this ability you are handicapped in many of your day-to-day situations. Almost every drawing or graphic problem originates with a sketch. The sketch becomes an important thinking instrument, as well as a means of conversing effectively with technically trained people. Sketching is not just another trick of the trade; it is a skill that is essential and should be an important part of your training. To gain proficiency in freehand sketching, invite situations entailing sketching at every opportunity. Do not worry about your first attempts at sketching; appearance will improve with experience.

A sketch is usually thought of as being made freehand, although in practice you may use graph paper or a small triangle for a straightedge. A sketch may be of an object or an idea or a combination of both. Sketches are used to solve graphic problems before an object or structure is put in final form on a drawing. Preliminary sketches are used to plan and organize intelligently the sheet layout of a complete set of drawings for a construction project, which often includes many views and details. There are no set standards for technical freehand sketching; however, you should use standard line conventions for clarity.

A sketch may be drawn pictorially so that it actually looks like the object, or it can be an orthographic sketch of the object showing different views. The degree of perfection required for any sketch will depend upon its intended use.

SKETCHING MATERIALS

One of the main advantages of sketching is that few materials are required. Basically, you need only a pencil and paper. However, the type of sketch prepared and your personal preference will determine the materials used.

You should use a soft pencil in the grade range from F to 3H, with H being a good grade for most sketching. The pencil should be long enough to permit a relaxed but stable grip. As you gain experience, you may even prefer to use fine tip felt pens. (Dark- or bright-colored pens should be used.) Felt tip pens work very well on overlay sketches (discussed later).

Most of your sketches will be done on scratch paper, which can be any type or size of paper. An experienced draftsman will keep a pad of 3 in. by 5 in. or 5 in. by 8 in. scratch paper handy at all times. For planning the layout of a drawing, you will find tracing paper to be convenient. The advantage of sketching on tracing paper is the ease with which sketches can be modified or redeveloped simply by placing transparent paper over previous sketches or existing drawings. Sketches prepared in this manner are referred to as OVERLAY SKETCHES. Cross-section or graph paper may be used to save time when you are required to draw sketches to scale. (See fig. 5-56.) Isometric sketches are easily done on specially ruled isometric paper. (See fig. 5-57.)

An eraser maybe used, but you will probably do very little erasing. Sketches usually can be

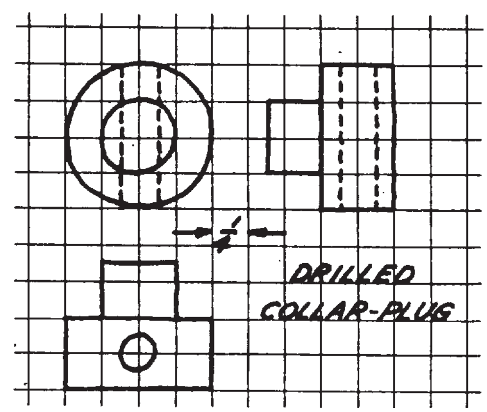


Figure 5-56.-Use of cross-sectional paper in technical sketching.

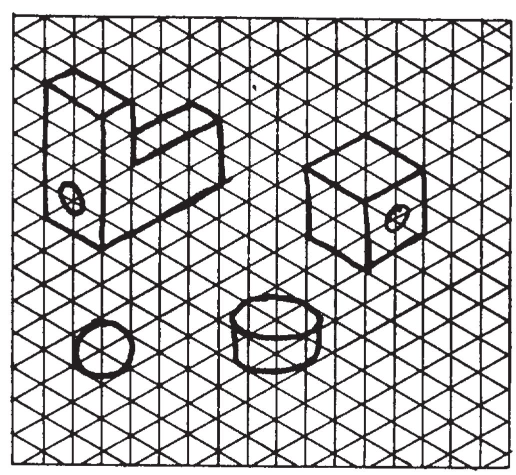


Figure 5-57.-Use of specially ruled isometric paper in technical sketching.

redrawn more quickly than mistakes can be erased.

For making dimensioned sketches in the field, you will need some sort of measuring tape—either a pocket rule or a surveyor's tape, depending on the extent of the measurements taken. If you are required to collect extensive field data, it would be to your benefit to maintain a sketch notebook. A surveyor's field notebook works well for this purpose.

TECHNIQUES OF SKETCHING

The sketch should conform to one of the standard types of projection discussed in this chapter. You must apply correct proportion whenever possible. When you use cross-section paper, its grid will provide a ready scale that will aid you in sketching proportionally. You do this by counting the squares within the object to be drawn. The size of your sketch depends upon the complexity of the object and the size of paper you are using.

Sketching Straight Lines

In sketching lines, place a dot where you want a line to begin and one where you want it to end. In sketching long lines, place one or more dots between the end dots. Then swing your hand in the direction your line should go, and back again a couple of times before you touch your pencil to the paper. In this way you get the feel of the line. Then use these dots to guide your eye and your hand as you draw the line. Draw each line with a series of short strokes instead of with one stroke. Using short strokes, you can better control the direction of your line and the pressure of your pencil on the paper. Hold the pencil about three quarters of an inch to an inch from the point so that you can see what you are doing. Strive for a free and easy movement rather than a cramped finger and wrist movement.

Another useful technique in drawing straight lines is to use the side of the paper, pad, or table as a guide for your hand. Hold the pencil at the desired starting point of the line and place the heel of your hand and one finger on the guide, as shown in figure 5-58. Move the pencil, in this case, with one uniform stroke to complete the line. Try drawing several light horizontal lines and, after each one is drawn, examine it for straightness, weight, and neatness. If it is too light, use either a softer pencil or a little more pressure.

Vertical lines are usually sketched downward on the paper. The same suggestions for using locator dots, free movement of the entire arm, and guides apply to vertical lines as they do to horizontal lines.

Slanting lines may be drawn from either end toward the other. For better control, you might find it helpful to rotate the paper, thus placing the desired slanting line in either the horizontal or vertical position.

To keep your sketch neat, first sketch your lines lightly. Lines not essential to the drawing can be sketched so lightly that you need not erase them. Darken essential lines by running your pencil over them with more pressure. Figure 5-59 shows line conventions drawn with various types of pencil points.

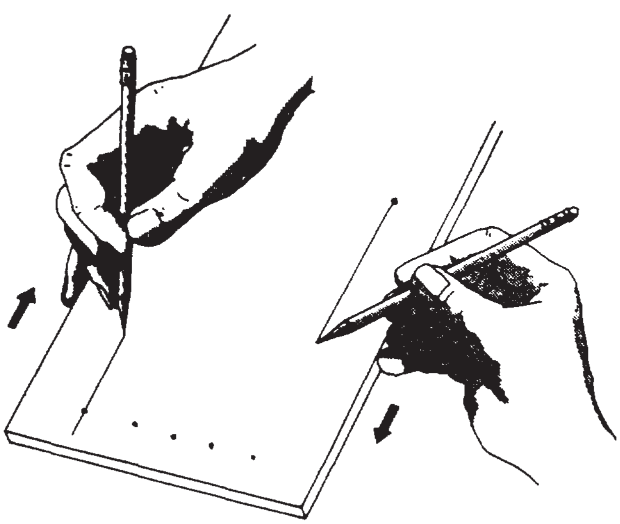


Figure 5-58.-Use of paper, pad, or table as a guide when drawing straight lines.

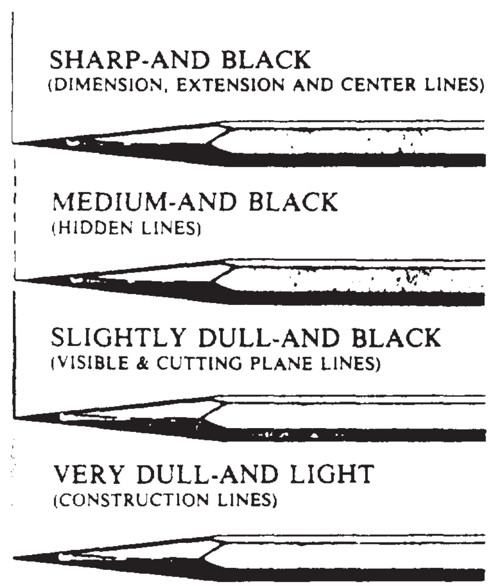


Figure 5-59.-Line conventions drawn with various types of pencil points.

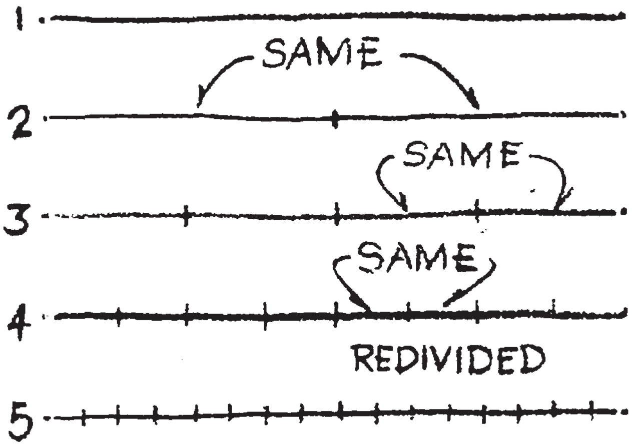


Figure 5-60.-Bisecting a line by visual comparison.

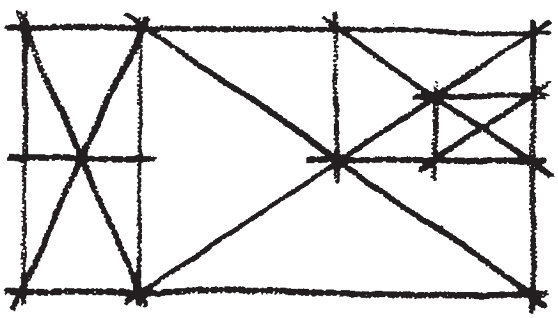


Figure 5-61.-Locating centers by sketching diagonals.

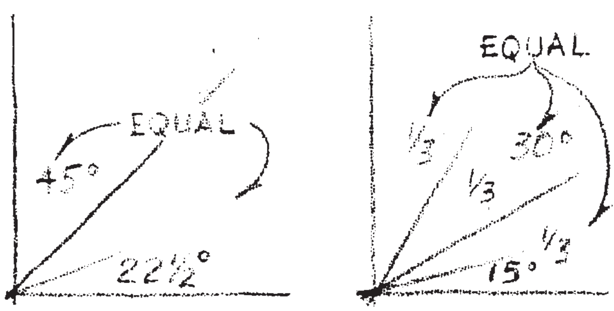


Figure 5-62.-Sketching angles by visual comparison.

Dividing Lines and Areas Equally

Your ability to divide lines and areas into equal parts is necessary in arriving at many of the common geometric forms required in sketching. The simplest method of bisecting lines is by visual comparison, as shown in figure 5-60. The entire line is first observed and weighed optically to determine its fulcrum or point of balance. Each half is compared visually before the bisecting point is placed. This procedure can be repeated any number of times to divide a line into any number of equal divisions, merely by dividing and redividing its line segments.

Centers of rectangular areas are easily determined by drawing their diagonals. If necessary the halves can be divided with diagonals for smaller divisions, as shown in figure 5-61.

Sketching Angles

The 90-degree angle is predominant in the majority of your sketches. Thus it is important that you learn to sketch right angles accurately, even if it entails checking them with the triangle occasionally. Frequently, the perpendicular edges of your paper can serve as a visual guide for comparison. It is also helpful to turn your sketch upside down; non-perpendicular tendencies of horizontal and vertical lines will become evident. Shaping right angles correctly will give your sketch stability, without which effectiveness is lost.

A 45-degree angle is made by dividing a right angle by visual comparison; and a 30-degree or 60-degree angle, by dividing the right angle into three equal parts. The 30-degree or 45-degree angle may be divided into equal parts in the same manner. (See fig. 5-62.) Always start with the right angle for the most accurate estimation of angle shape.

Sketching Circles and Arcs

Perfectly round circles are the most difficult to draw freehand. Figure 5-63 shows methods of

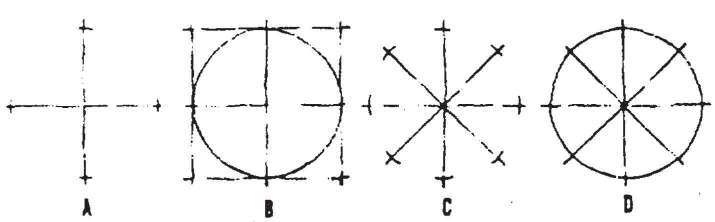


Figure 5-63.-Methods of sketching circles.

drawing circles and curves using straight lines as construction lines. First, draw two straight lines crossing each other at right angles, as in figure 5-63, view A. The point at which they cross will serve as the center of the circle. The four lines radiating from this center will serve as the radii of the circle. You can use a piece of marked scrap paper to measure an equal distance on each radius from the center. Sketch a square, with the center of each side passing through the mark defining a radius. (See fig. 5-63, view B.) Now sketch in your circle, using the angles of the square as a guide for each arc. When larger circles are required, you can add 45-degree angles to the square to form an octagon. This will provide four additional points of tangency for the inscribed circle.

In figure 5-63, view C and view D, four lines, instead of two, are sketched crossing each other. The radii are measured as in constructing the other circle, but a square is not drawn. For this method, you will find it helpful to rotate the paper and sketch the circle in one direction.

For drawing large circles, you can make a substitute for a compass with a pencil, a piece of string, and a thumbtack. Tie one end of the string to your pencil near the tip. Measure the radius of the circle you are drawing on the string, and insert your tack at this point. Now swing your pencil in a circle, taking care to keep it vertical to the paper.

Another technique for drawing circles is shown in figure 5-64. In view A of figure 5-64, observe how the pencil is held beneath the four fingers with the thumb. This grip tends to produce a soft or easy motion for sketching large circles or curves and also makes it possible to sketch small circles, as shown in figure 5-64, views B and C. You notice in figure 5-64, view B, that the second finger rests at the center of the circle

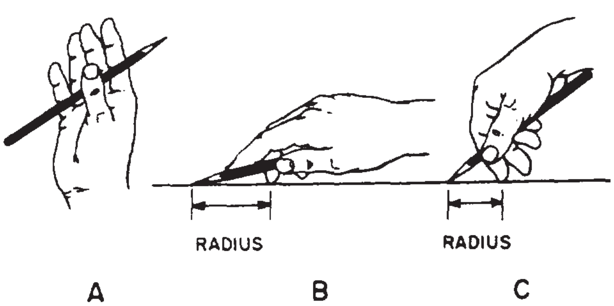


Figure 5-64.-Proper pencil grip in sketching circles and arcs.

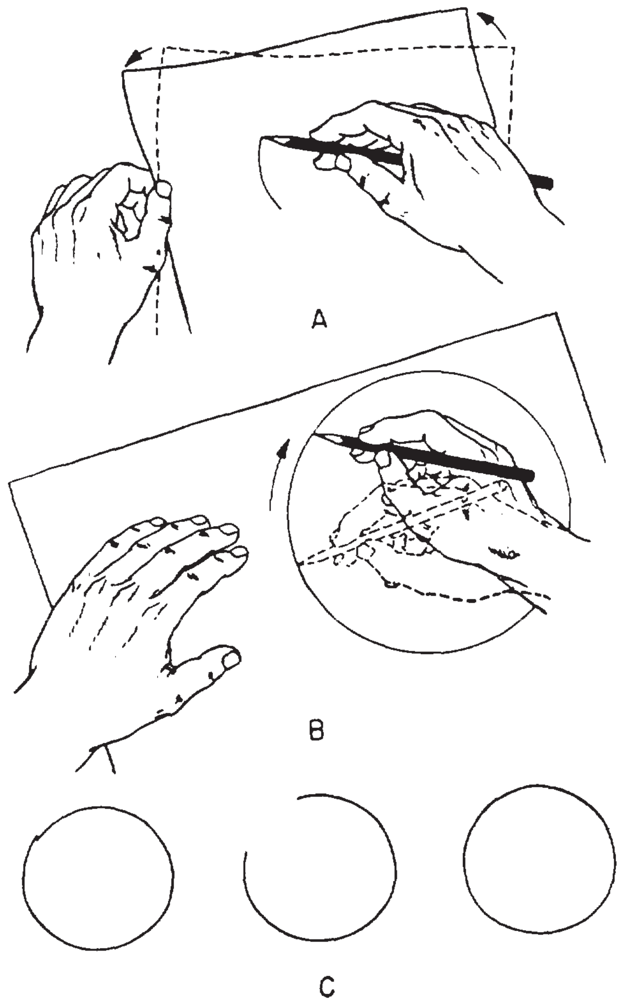


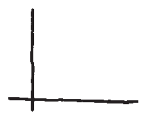
Figure 5-65.-Steps in sketching a circle.

and forms the pivot about which the pencil lead can swing. The distance from the fingertip to the pencil lead determines the radius of the circle. To draw smaller circles, you need to assume a somewhat different grip on the pencil, as shown in view C of figure 5-64, but the principle is the same.

As shown in view A of figure 5-65, the first step in sketching either large or small circles with the grips shown in the previous figure is placing the second finger on the paper at the center of the proposed circle. Then, with the pencil lightly touching the paper, use the other hand to rotate the paper to give you a circle that may look like the one in figure 5-65, view B. To correct the slight error of closure shown in view C, erase a substantial section of the circle and correct it by eye, as shown at the right. You now have a complete and round circle, but with only a very light line, which must be made heavier. Do this as shown in view B. Notice that you DO NOT PIVOT on the second finger during this step. You rest your hand on its side and, keeping it within the circle, trace over the light line with your hand pivoting naturally at the wrist. As you work around the circle in this way, rotate the paper counter-clockwise so that your hand can work in its most natural and easy position. Of course with smaller circles you cannot work with your hand within the circle, but the same general approach can be used with success.

Probably one of the best methods to sketch curves connected to straight lines is the six-step method illustrated and explained below.

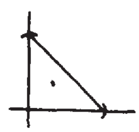
1. Intersect a vertical and horizontal line, lightly.



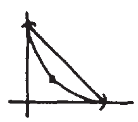
2. Mark off on the horizontal and vertical lines the same distance from the intersection.

3. Draw a light diagonal line through the two points marked.

4. Place an x or a dot in the exact center of the triangle formed.



5. Start your curve from one point of the triangle preferably on the vertical line) touching the x or dot and ending at the other point of the triangle.



6. Erase all unnecessary guide-lines and darken the curve and necessary adjoining straight lines.

A little practice with this method should enable you to improve your ability to sketch curves properly.

Figure 5-66 shows a convenient way to sketch arcs and curves by lightly drawing construction boxes (or blocks).

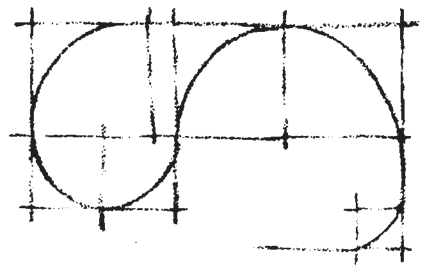


Figure 5-66.-Sketchirrg curves using construction boxes.

Construction Lines

When you are sketching an object, such as that shown in figure 5-67, don't start at one corner and draw it detail by detail and expect it come out with the various elements in correct proportion. It is better to block in the overall size of the object first, (See fig. 5-67, view A.) Then draw light guidelines at the correct angles for the various outlines of the object. (See fig. 5-67, views B and C.)

Finish the sketch by first making an outline of the object and then drawing in the details, as shown in figure 5-67, view D.

Order of Sketching

To make a working sketch, first choose a clean sheet of paper, either plain or ruled. Estimate the size the sketch should be, and select the views that will give the best picture of the object. Then draw the ORTHOGRAPHIC PROJECTIONS of these views, leaving adequate space between them for

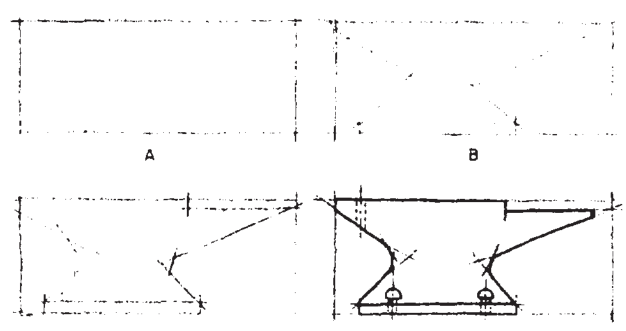


Figure 5-67.-The use of construction lines in sketching an object.

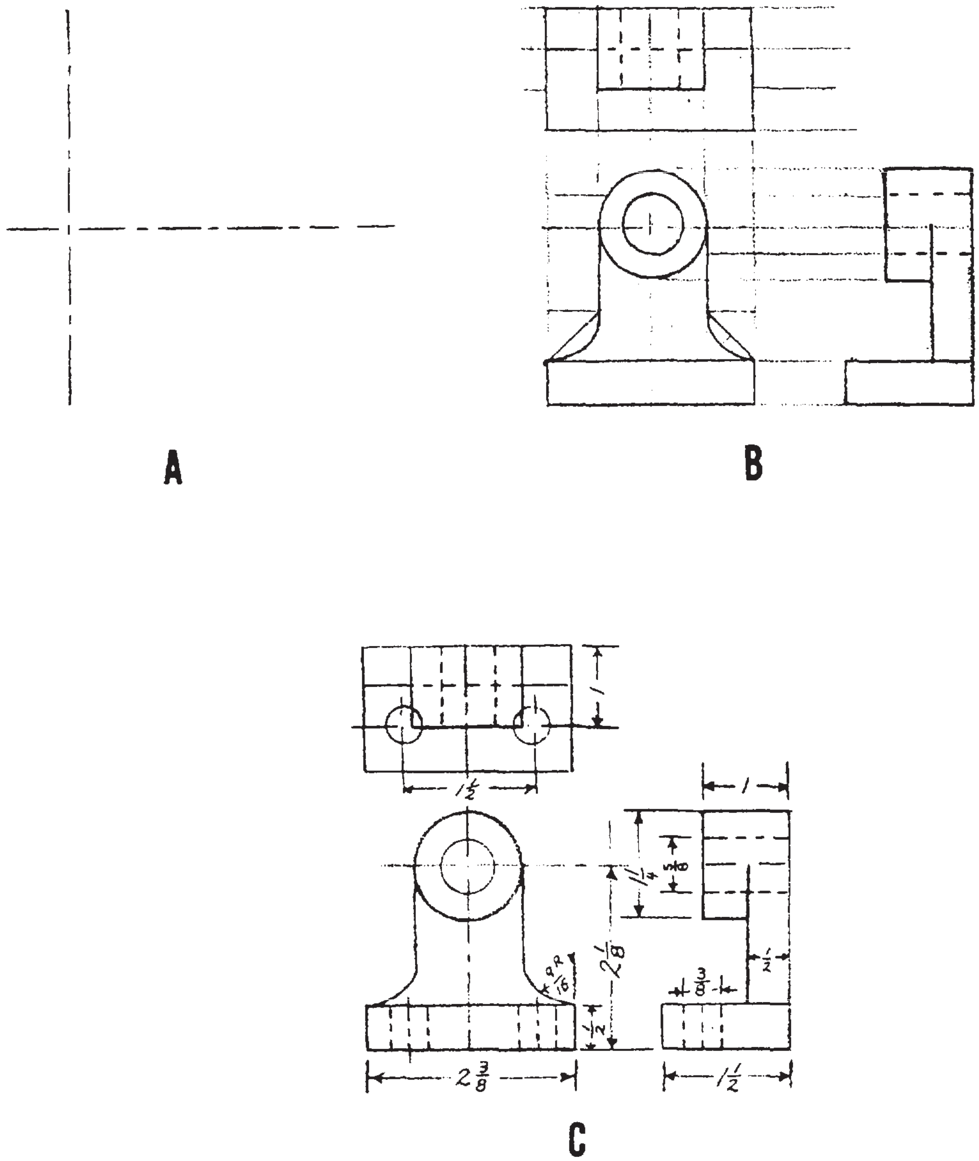


Figure 5-68.-Progress of a working sketch.

dimensions. (Refer to the working sketch in fig. 5-68.) In sketching, progress as follows:

1. Draw the center lines, as shown in figure 5-68, view A.
2. Block in the views.
3. Draw the outlines, aligning them as in figure 5-68, view B.
4. Add the details on the surface of the views.
5. Darken the lines of the finished sketch.
6. Use an art gum or a kneaded eraser to erase the construction lines, which are no longer needed. If necessary, touch up the lines you may have inadvertently erased.
7. Draw all necessary extension and dimension lines.
8. Letter in the dimensions. (See fig. 5-68, view C.)

You can see that a working sketch such as the one shown in figure 5-68 could easily be followed in preparing a finished drawing of the object. The sketch provides you with all the necessary information needed on the finished drawing.

Pictorial Sketches

Often it will be more convenient, or even necessary, to prepare isometric or oblique

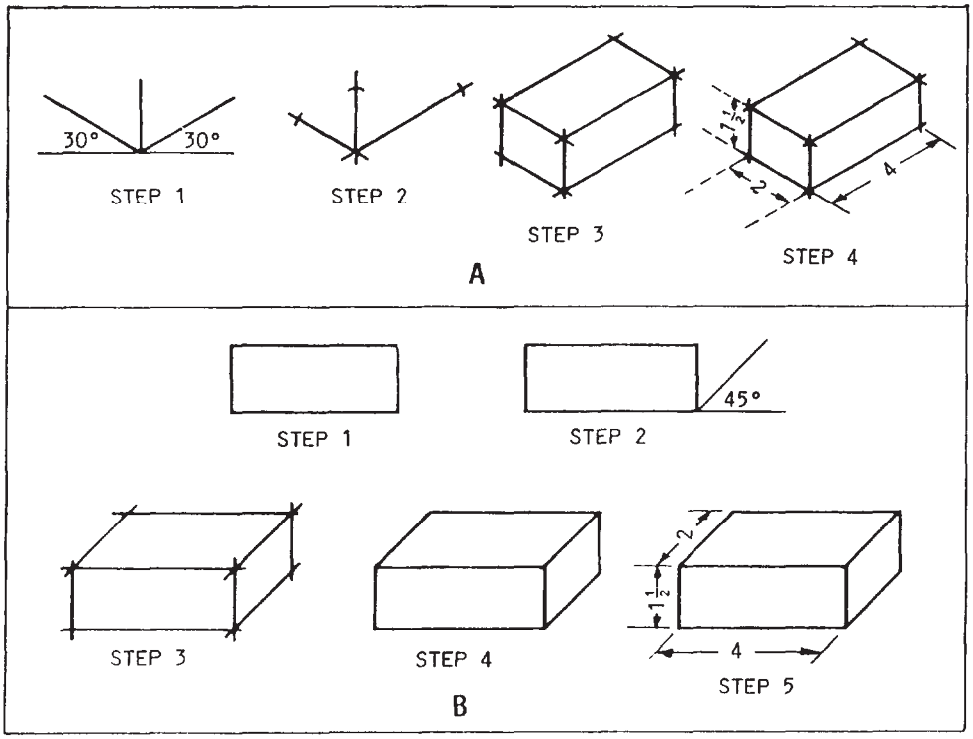


Figure 5-69.-Sketching a rectangular block: A. Isometric; B. Oblique.

PICTORIAL SKETCHES instead of multi-view orthographic sketches. Pictorial sketches provide you with a quick method of examining tentative construction details. A quick pictorial sketch will also help you in the layout of isometric and oblique drawings.

The principles of pictorial and orthographic sketching are similar, except that in pictorial sketching you will be dealing with volumes rather than flat planes. Basically, pictorial sketches and pictorial drawings are practically the same except for the drawing materials used in their development and the fact that pictorial sketches are not normally drawn to scale. By following a few simple steps, based on pictorial drawing construction principles, you should be able to prepare meaningful pictorial sketches.

ISOMETRIC SKETCHES.— Select a position (view) that will show the object to the best advantage. You will know what you want included in your sketch, so move either the object or yourself until you can actually see everything you want to show. If the object is something you have in mind or if you intend to sketch an isometric view from an orthographic drawing, you will have to visualize the object and assume a viewing position. In making your isometric sketch, remember that you start by sketching three isometric axes 120 degrees apart, using two angles of 30 degrees and a vertical axis of 90 degrees. Figure 5-69, view A, shows a step-by-step procedure that can be used in making an isometric sketch of a wooden rectangular block measuring 1 1/2 in. by 2 in. by 4 in.

The first step is to sketch the three isometric axes, as mentioned earlier. The second step is to mark off the 1 1/2 in. for height on the vertical axis, the 2-in. width along the left axis, and the 4-in. length along the right axis. The third step is to draw two vertical lines 1 1/2 in. high (starting with the marks on the right and left axis), then sketch parallel lines from each of the marks on the sketch. Note that the lines that are parallel on the object are parallel on the sketch. The fourth step is to dimension the sketch. The dimensions on an isometric sketch are placed parallel to the ends or edges. The final step is to check the sketch for completeness and accuracy.

OBLIQUE SKETCHES.— The front face or view of an OBLIQUE SKETCH is drawn the same way as an orthographic front view. Using the same wooden block that was sketched

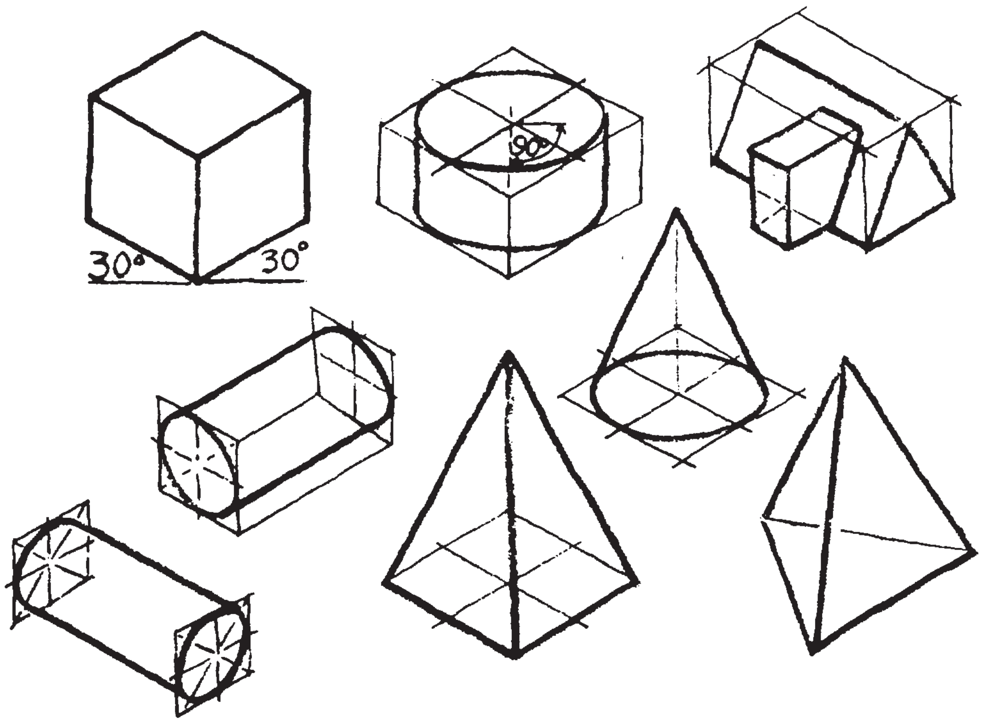


Figure 5-70.-Basic isometric forms.

isometrically for a model, you should draw an oblique sketch following the basic steps shown in figure 5-69, view B.

The first step is to draw a rectangle of the front view (using light lines). Then, second, draw an oblique base line at a 45-degree angle starting at the corner (intersection) of the horizontal and vertical base lines. Third, sketch the remaining horizontal and vertical lines parallel to the other base lines. Fourth, erase any unnecessary lines, and fifth, dimension and darken the completed drawing for easier reading. Remember, place the dimensions so they are parallel to the axis lines. The final step is to check the sketch for completeness and accuracy.

In the above procedures for development of pictorial sketches, a simple rectangular form was used. All objects may be simplified to their basic geometric forms. These forms are the first consideration in the pictorial sketch. Basic volumetric forms are shown in figure 5-70. By carefully analyzing any object you sketch, you will see one or more of the forms shown in figure 5-70. However, at times only a part of a form is present.

Before attempting detailed sketches, practice sketching the basic forms. Then look for these forms in the object you are about to sketch, and concentrate on the basic form representation. Enclose the object in a basic form, or build it up with a series of different forms, depending on the nature of the object. Details are added or "carved" from these forms after shape and proportion have been determined.

Overlay Sketches

To make OVERLAY SKETCHES, sketch freehand on transparent paper placed over existing drawings or other sketches. Sometimes when you make overlay sketches, you merely trace, free-hand, objects or lines from another drawing or sketch. But more often you will prepare overlay sketches by tracing and then adding supplementary sketched lines or objects.

Usually, when this type of sketch is prepared, only the prominent or desired features are traced. Overlay sketches are primarily used for planning purposes.

A suggested procedure for using overlay sketches as a tool for planning is explained in the following example:

The drafting room is being relocated. You are tasked with developing a proposed furniture and equipment layout. You have the latest prints of the floor plan and an electrical plan, and you know what furniture and equipment will be moved to the new area. The steps you take to develop the proposed layout are as follows:

1. Check the floor plan and electrical plan against the actual room layout. If necessary, check the dimensions. Correct any discrepancies with a dark-colored fine tip felt pen or colored pencil.

2. Place a piece of tracing paper over the floor plan on the print and secure it with small strips of drafting tape.

3. Trace the outline of the walls with single freehand lines (preferably with a dark-colored felt tip pen). Terminate the lines, where applicable, to indicate windows and door openings.

4. Remove the tracing paper from the floor plan and place it over the electrical plan, lining the traced wall outlines up with the corresponding walls on the electrical plan. Using appropriate symbols, locate, on the traced floor plan, all electrical outlet locations.

5. You now have a clear overlay sketch of the existing floor plan without the unnecessary dimensions and information that are on the original print of the floor plan. This is your basic planning overlay. Check your overlay with the original prints to make sure that relevant lines were not omitted.

6. Place another sheet of tracing paper over the basic planning overlay. This becomes your second overlay. On this second overlay, sketch in your desired location of all the furniture and equipment. Use simple shapes for each and estimate sizes. Use letters or symbols for identification. Repeating the outline of the walls is not necessary because you can still see the outline from the basic planning overlay.

7. If this first location sketch on the second overlay does not suit you or does not provide an adequate layout, lay another piece of tracing paper over the second layout and sketch another layout. Repeat this procedure with additional overlays until you have developed a good layout.

8. Once you have a good layout, trace the wall outlines from the basic planning overlay. This final overlay sketch is your proposed furniture and equipment layout for the new location of the drafting room.

CHAPTER 6

WOOD AND LIGHT FRAME STRUCTURES

When you prepare an engineering drawing, regardless of type, you are required to apply knowledge of the materials and methods of construction. This chapter describes the uses, kinds, sizes, grades, and other classifications of wood as they apply to light frame building construction; the various structural members and their functions; and the different types of finishing hardwares and fasteners used.

WOOD

Of the different construction materials, wood is probably the most often used and perhaps the most important. The variety of uses of wood is practically unlimited. Few SEABEE construction projects, whether involving permanent or temporary structures, are built without using wood. Temporary uses of wood include scaffolding, shoring, bracing, and miscellaneous concrete forms.

There are several types or species of wood. Each type has its own characteristics and its recommended uses. For most large projects, the types and classifications of wood are given in the project specifications. For smaller projects that DO NOT have written specifications, the types and classifications of wood are included in the drawings. The types, sources, uses, and characteristics of common woods are given in table 6-1. In addition, the species, size classification, and design values of common structural woods are also listed in the *Architectural Graphic Standards.*

LUMBER

In construction, the terms *wood, lumber,* and *timber* have distinct, separate meanings. WOOD is the hard, fibrous substance that forms the major part of the trunk and branches of a tree. LUMBER is wood that has been cut and surfaced for construction use. TIMBER is lumber whose smallest dimension is NOT less than 5 in. Another term, *MILLWORK,* refers to manufactured lumber products, such as doors, window frames, window casings, shutters, interior trim, cabinets, and moldings.

Sizes

Standard lumber sizes have been established in the United States to permit uniformity in planning structures and in ordering materials. Lumber is identified by NOMINAL SIZES. The nominal size of a piece of lumber is larger than the actual DRESSED dimensions. Dressed lumber has been SURFACED (planed smooth) on two or more sides. It is designated according to the number of sides or edges surfaced. If it has been surfaced on two sides only, the designation is S2S (surfaced 2 sides); if surfaced on all four sides, S4S (surfaced 4 sides); or if surfaced on two sides and two edges, S2S2E. Lumber is ordered and designated on drawings by its nominal size rather than by its dressed dimensions. Common widths and thicknesses of lumber in nominal and dressed dimensions are shown in table 6-2.

Classification

Lumber is classified according to its USE, SIZE, and EXTENT OF MANUFACTURE. When classified according to use, lumber falls into three categories:

1. YARD LUMBER—grades, sizes, and patterns generally intended for ordinary construction and general building purposes
2. STRUCTURAL LUMBER—2 or more in. in thickness and width for use where working stresses are required
3. FACTORY AND SHOP LUMBER—produced or selected mainly for manufacture of furniture, doors, cabinets, and other millwork

Table 6-1.-Common Woods

Type	Sources	Uses	Characteristics
Ash	East of Rockies . .	Oars, boat thwarts, benches, gratings, hammer handles, cabinets, ball bats, wagon construction farm implements.	Strong, heavy, hard, tough, elastic, close straight grain, shrinks very little, takes excellent finish, lasts well.
Balsa	Ecuador.	Rafts, food boxes, linings of refrigerators, life preservers, loud speakers, sound-proofing, air-conditioning devices, model airplane construction.	Lightest of all woods, very soft, strong for its weight, good heat insulating qualities, odorless.
Basswood .	Eastern half of U.S. with exception of coastal regions.	Low-grade furniture, cheaply constructed buildings, interior finish, shelving, drawers, boxes, drainboards, woodenware, novelties, excelsior, general millwork.	Soft, very light, weak, brittle, not durable, shrinks considerably, inferior to poplar, but very uniform, works easily, takes screws and nails well and does not twist or warp.
Beech. . . .	East of Mississippi, Southeastern Canada.	Cabinetwork, imitation mahogany furniture, wood dowels, capping, boat trim, interior finish, tool handles, turnery, shoe lasts, carving, flooring.	Similar to birch but not so durable when exposed to weather, shrinks and checks considerably, close grain, light or dark red color.
Birch	East of Mississippi River and North of Gulf Coast States, Southeast Canada, Newfoundland.	Cabinetwork, imitation mahogany furniture, wood dowels, capping, boat trim, interior finish, tool handles, turnery, carving.	Hard, durable, fine grain, even texture, heavy, stiff, strong, tough, takes high polish, works easily, forms excellent base for white enamel finish, but not durable when exposed. Heartwood is light to dark reddish brown in color.
Butternut	Southern Canada, Minnesota, Eastern U. S. as far south as Alabama and Florida.	Toys, altars, woodenware, millwork, interior trim, furniture, boats, scientific instruments.	Very much like walnut in color but softer, not so soft as white pine and basswood, easy to work, coarse grained, fairly strong.

Table 6-1.-Common Woods—Continued

Type	Sources	Uses	Characteristics
Cypress....	Maryland to Texas, along Mississippi valley to Illinois.	Small boat planking, siding, shingles, sash, doors, tanks, silos, railway ties.	Many characteristics similar to white cedar. Water resistant qualities make it excellent for use as boat planking.
Douglas Fir..	Pacific Coast, British Columbia.	Deck planking on large ships, shores, strongbacks, plugs, filling pieces and bulkheads of small boats, building construction, dimension timber, plywood.	Excellent structural lumber, strong, easy to work, clear straight grained, soft, but brittle. Heartwood is durable in contact with ground, best structural timber of northwest.
Elm.......	States east of Colorado.	Agricultural implements, wheel-stock, boats, furniture, crossties, posts, poles.	Slippery, heavy, hard, tough, durable, difficult to split, not resistant to decay.
Hickory.....	Arkansas, Tennessee, Ohio, Kentucky.	Tools, handles, wagon stock, hoops, baskets, vehicles, wagon spokes.	Very heavy, hard, stronger and tougher than other native woods, but checks, shrinks, difficult to work, subject to decay and insect attack.
Lignum Vitae.....	Central America.	Block sheaves and pulleys, waterexposed shaft bearings of small boats and ships, tool handles, small turned articles, and mallet heads.	Dark greenish brown, unusually hard, close grained, very heavy, resinous, difficult to split and work, has soapy feeling.
Live Oak ...	Southern Atlantic and Gulf Coasts of U.S., Oregon, California.	Implements, wagons, ship building.	Very heavy, hard, tough, strong, durable, difficult to work, light brown or yellow sap wood nearly white.
Mahogany ...	Honduras, Mexico, Central America, Florida, West Indies, Central Africa, other tropical sections.	Furniture, boats, decks, fixtures, interior trim in expensive homes, musical instruments.	Brown to red color, one of most useful of cabinet woods, hard, durable, does not split badly, open grained, takes beautiful finish when grain is filled but checks, swells, shrinks, warps slightly.

Table 6-1.-Common Woods—Continued

Type	Sources	Uses	Characteristics
Maple.	All states east of Colorado, Southern Canada.	Excellent furniture, high-grade floors, tool handles, ship construction crossties, counter tops, bowling pins.	Fine grained, grain often curly or "Bird's Eyes," heavy, tough, hard, strong, rather easy to work, but not durable. Heartwood is light brown, sap wood is nearly white.
Norway Pine.	States bordering Great Lakes.	Dimension timber, masts, spars, piling, interior trim.	Light, fairly hard, strong, not durable in contact with ground.
Philippine Mahogany. .	Philippine Islands	Pleasure boats, medium-grade furniture, interior trim.	Not a true mahogany, shrinks, expands, splits, warps, but available in long, wide, clear boards.
Poplar	Virginias, Tennessee, Kentucky, Mississippi Valley.	Low-grade furniture cheaply constructed buildings, interior finish, shelving, drawers, boxes.	Soft, cheap, obtainable in wide boards, warps, shrinks, rots easily, light, brittle, weak, but works easily and holds nails well, fine-textured.
Red Cedar. .	East of Colorado and north of Florida.	Mothproof chests, lining for linen closets, sills, and other uses similar to white cedar.	Very light, soft, weak, brittle, low shrinkage, great durability, fragrant scent, generally knotty, beautiful when finished in natural color, easily worked.
Red Oak . . .	Virginias, Tennessee, Arkansas, Kentucky, Ohio, Missouri, Maryland.	Interior finish, furniture, cabinets, millwork, crossties when preserved.	Tends to warp, coarse grain, does not last well when exposed to weather, porous, easily impregnated with preservative, heavy, tough, strong.
Redwood . .	California.	General construction, tanks, paneling.	Inferior to yellow pine and fir in strength, shrinks and splits little, extremely soft, light, straight grained, very durable, exceptionally decay resistant.

Table 6-1.-Common Woods—Continued

Type	Sources	Uses	Characteristics
Spruce	New York, New England, West Virginia, Central Canada, Great Lakes States, Idaho, Washington, Oregon.	Railway ties, resonance wood, piles, airplanes, oars, masts, spars, baskets.	Light, soft, low strength, fair durability, close grain, yellowish, sap wood indistinct.
Sugar Pine	California, Oregon.	Same as white pine.	Very light, soft, resembles white pine.
Teak	India, Burma, Siam, Java.	Deck planking, shaft logs for small boats.	Light brown color, strong, easily worked, durable, resistant to damage by moisture.
Walnut	Eastern half of U.S. except Southern Atlantic and Gulf Coasts, some in New Mexico, Arizona, California.	Expensive furniture, cabinets, interior woodwork, gun stocks, tool handles, airplane propellers, fine boats, musical instruments.	Fine cabinet wood, coarse grained but takes beautiful finish when pores closed with woodfiller, medium weight, hard, strong, easily worked, dark chocolate color, does not warp or check, brittle.
White Cedar. . . .	Eastern Coast of U.S., and around Great Lakes.	Boat planking, railroad ties, shingles, siding, posts, poles.	Soft, light weight, close grained, exceptionally durable when exposed to water, not strong enough for building construction, brittle, low shrinkage, fragment, generally knotty.
White Oak . .	Virginias, Tennessee, Arkansas, Kentucky, Ohio, Missouri, Maryland, Indiana.	Boat and ship stems, sternposts, knees, sheer strakes, fenders, capping, transoms, shaft logs, framing for buildings, strong furniture, tool handles, crossties, agricultural implements, fence posts.	Heavy, hard, strong, medium coarse grain, tough, dense, most durable of hardwoods, elastic, rather easy to work, but shrinks and likely to check. Light brownish grey in color with reddish tinge, medullary rays are large and outstanding and present beautiful figures when quarter sawed, receives high polish.

Table 6-1.-Common Woods—Continued

Type	Sources	Uses	Characteristics
White Pine.	Minnesota, Wisconsin, Maine, Michigan, Idaho, Montana, Washington, Oregon, California	Patterns, any interior job or exterior job that doesn't require maximum strength, window sash, interior trim, millwork, cabinets, cornices.	Easy to work, fine grain, free of knots, takes excellent finish, durable when exposed to water, expands when wet, shrinks when dry, soft, white, nails without splitting, not very strong, straight grained.
Yellow Pine.	Virginia to Texas.	Most important lumber for heavy construction and exterior work, keelsons, risings, filling pieces, clamps, floors, bulkheads of small boats, shores, wedges, plugs, strongbacks, staging, joists, posts, piling, ties, paving blocks.	Hard, strong, heartwood is durable in the ground, grain varies, heavy, tough, reddish brown in color, resinous, medullary rays well marked.

Nominal, rough, green lumber has three general classifications, according to size, as follows:

1. BOARDS—less than 2 in. thick and 1 **or** more in. wide. If less than 6 in. wide, they may be classified as strips.

2. DIMENSION—at least 2 in. thick, but less than 5 in. thick, and 2 or more in. wide. It may be classified as framing, joists, planks, rafters, studs, and small timbers.

3. TIMBERS—smallest dimension is 5 or more in. They may be classified as beams, stringers, posts, caps, sills, girders, and purlins.

Lumber classified by extent of manufacture consists of three types as follows:

1. ROUGH LUMBER is not dressed (surfaced) but sawed, edged, and trimmed to the extent that saw marks show in the wood on the four longitudinal surfaces of each piece for its overall length.

2. DRESSED LUMBER is surfaced by a planing machine to attain a smooth surface and uniform size.

3. WORKED LUMBER is dressed and also matched, shiplapped, or patterned.

Grading

According to the American Lumber Standards set by the National Bureau of Standards for the U.S. Department of Commerce, lumber is graded for quality. The major grades of yard lumber, in descending order of quality, are SELECT LUMBER and COMMON LUMBER. Each of these grades is subdivided, also in descending order of quality.

SELECT LUMBER has a good appearance and good qualities for finishing. One kind of select lumber is suitable for natural finishes; another kind, for painted finishes. Select lumber for natural finishes is graded A or B. Grade A is nearly free of defects and blemishes, but Grade B contains a few minor blemishes. Select lumber for painted finishes is Grade C or D. The blemishes in Grade C are more numerous and significant than those in Grade B. Grade D has even more blemishes than Grade C does. Either grade, C or D, presents a satisfactory appearance when painted.

COMMON LUMBER is suitable for general construction and utility purposes. It, also, is subdivided by grade in descending order of quality. No. 1 common is sound, tight-knotted stock, containing only a few minor defects. It must be suitable for use as watertight lumber.

Table 6-2.-Nominal and Dressed Sizes of Lumber

Item	Thickness (Inches)		Face Width (Inches)	
	Nominal	Dressed	Nominal	Dressed
			2	1 1/2
			3	2 1/2
			4	3 1/2
			5	4 1/2
	1	3/4	6	5 1/2
			7	6 1/2
Boards	1 1/4	1	8	7 1/4
			9	8 1/4
	1 1/2	1 1/4	10	9 1/4
			11	10 1/4
			12	11 1/4
			14	13 1/4
			16	15 1/4
			2	1 1/2
			3	2 1/2
			4	3 1/2
	2	1 1/2	5	4 1/2
Dimension	2 1/2	2	6	5 1/2
Lumber	3	2 1/2	8	7 1/4
	3 1/2	3	10	9 1/4
			12	11 1/4
			14	13 1/4
			16	15 1/4
			2	1 1/2
			3	2 1/2
			4	3 1/2
			5	4 1/2
Dimension	4	3 1/2	6	5 1/2
Lumber	4 1/2	4	8	7 1/4
			10	9 1/4
			12	11 1/4
Timbers	5 & Thicker		5 & Wider	

No. 2 common contains a limited number of significant defects but no knotholes or other serious defects. It must be suitable for use as grain-tight lumber. No. 3 common contains a few defects, larger and coarser than those in No. 2; for example, occasional knotholes. No. 4 is low-quality material, contains serious defects like knotholes, checks, shakes, and decay. No. 5 common holds together only under ordinary handling.

STRUCTURAL LUMBER is graded according to allowable stresses that determine its safe load-carrying capacity. This capacity is based on various factors, such as species of the wood, density, moisture content, and other characteristics that affect the strength of the lumber. Factory and shop lumber is generally graded by its intended use; the grades vary greatly from use to use.

Board Measure

The basic unit of quantity for lumber is called a BOARD FOOT. It is defined as the volume of

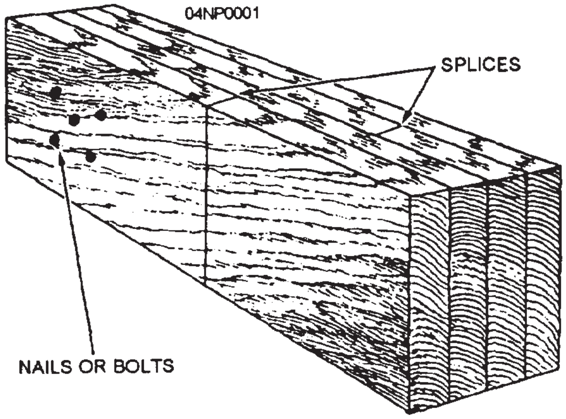


Figure 6-1.-Example of a laminated lumber.

a board 1 ft long by 1 ft wide by 1 in. thick. Since the length of lumber is usually measured in feet, the width in inches, and the thickness in inches, the formula for the quantity of lumber in board feet becomes the following:

$$\frac{\text{Thickness (inches)} \times \text{width (inches)} \times \text{length (feet)}}{12} = \text{board measure (board feet)}$$

Example: Calculate the board measure of a 14-ft length of a 2 by 4. Applying the formula, you get

$$\frac{2 \times 4 \times 14}{12} = 9\ 1/3$$

Lumber less than 1 in. thick is presumed to be 1 in. thick for board measure purposes. Board measure is calculated on the basis of the nominal, not the dressed, dimensions of lumber. The symbol for board feet is bm, and the symbol for a unit of 1,000 is M. If 10,000 board feet of lumber were needed, for example, the quantity would be 10Mbm.

LAMINATED LUMBER

Laminated lumber is commonly used when increased wood load-carrying capacity and rigidity are required. Usually made of several pieces of 1 1/2-in. -thick lumber, called laminations, the pieces are nailed, bolted, or glued together with the grain of all pieces running parallel (fig. 6-1). When extra length is needed, the pieces are spliced with the splices staggered so that no two adjacent laminations are spliced at the same point. Built-up beams and girders are examples of laminated lumber.

Laminations may be used independently or with other materials in the construction of a structural unit. Trusses can be made with laminations for the chords and sawed lumber for the web members (fig. 6-2). Special beams (fig. 6-3) may be constructed with laminations for the flanges and sawed lumber for the webs.

Probably the greatest use of laminations is in the fabrication of large beams and arches. Beams with spans larger than 100 ft and depths of 8 1/2 ft have been constructed with 2-in. boards. Laminations this large are factory-produced. They are glued together under pressure. Most laminations are spliced using scarf joints (fig. 6-4), and the entire piece is dressed to ensure uniform thickness and width.

PLYWOOD

Plywood is a panel product made from thin sheets of wood called veneers. An odd number of veneers, such as three, five, or seven, is generally used so the grains on the face and back of the panel run in the same direction. Cross-lamination (fig. 6-5) distributes the grain strength in both directions, creating a panel that resists splitting and, pound for pound, one of the strongest building materials available.

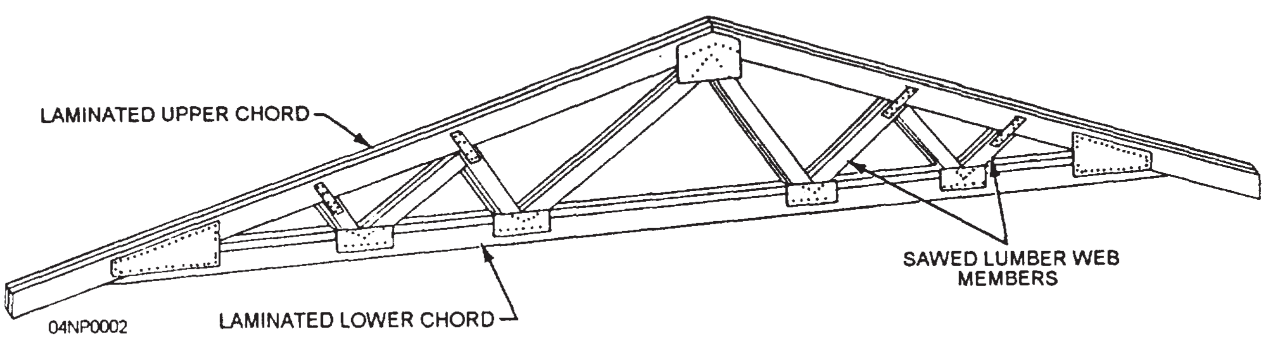


Figure 6-2.-Truss using laminated and sawed lumber.

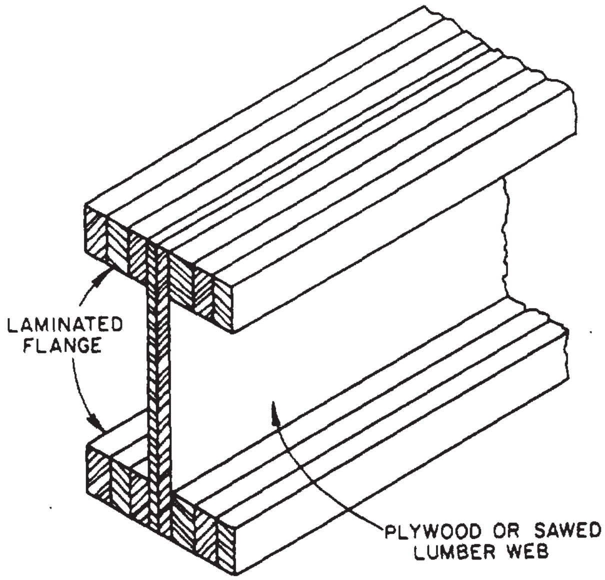


Figure 6-3.-Laminated and sawed lumber or plywood beam.

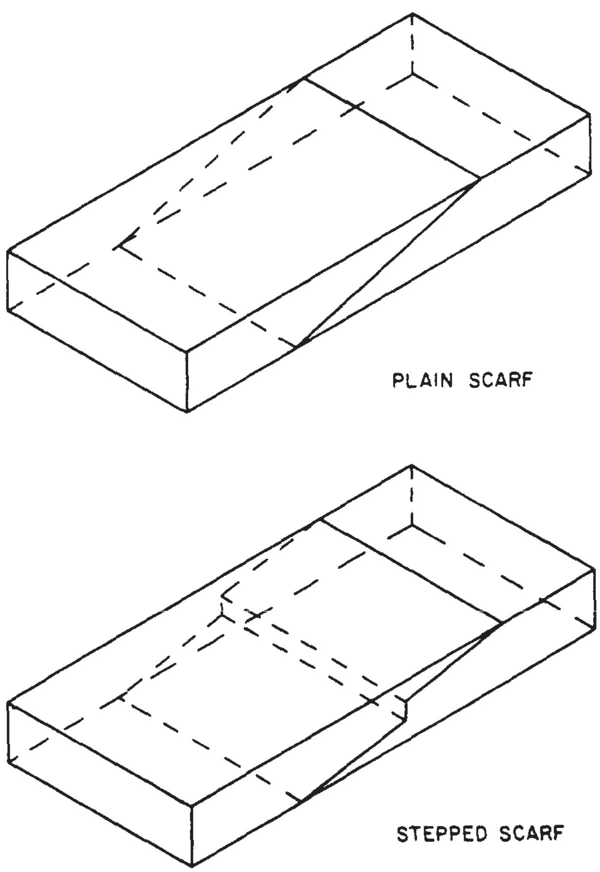


Figure 6-4.-Scarf joints.

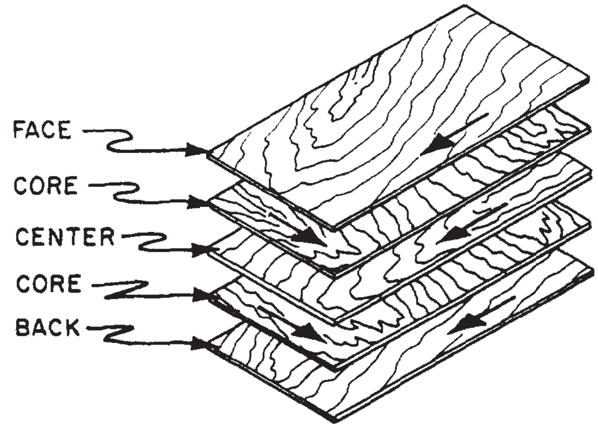


Figure 6-5.-Grain direction in a sheet of plywood.

Dry from the mill, plywood is never "green." From ovendry to complete moisture saturation, a plywood panel swells across or along the grain only about 0.2 of 1 percent and considerably less with normal exposures.

There is probably no building material as versatile as plywood. It is used for concrete forms, wall and roof sheathing, flooring, box beams, soffits, stressed-skin panels, paneling, partitions, doors, furniture, shelving, cabinets, crates, signs, and many other purposes.

Sizes

Plywood is generally available in panel widths of 36, 48, and 60 in. and in panel lengths ranging from 60 to 144 in. in 12-in. increments. Other sizes are also available on special order. Panels 48 in. wide by 96 in. long (4 by 8 ft), and 48 in. wide by 120 in. long (4 by 10 ft), are most commonly available. The 4 by 8 ft and larger sizes simplify construction, saving time and labor.

Nominal thicknesses of sanded panels range from 1/4 to 1 1/4 in. or greater, generally in 1/8-in. increments. Unsanded panels are available in nominal thicknesses of 5/16 to 1 1/4 in. or greater, in increments of 1/8 in. for thicknesses over 3/8 in. Under 3/8 in., thicknesses are in 1/16-in, increments.

Types

Plywood is classified by type as INTERIOR or EXTERIOR. Made of high-quality veneers and more durable adhesives, exterior plywood is better than interior at withstanding exposure to the elements. Even when wetted and dried

N—Special order natural finish veneer. Select all heartwood or all sapwood. Free of open defects. Allows some repairs.

A—Smooth and paintable. Neatly made repairs permissible. Also used for natural finish in less demanding applications.

B—Solid surface veneer. Circular repair plugs and tight knots permitted.

C—Knotholes to 1 in. Occasional knotholes 1/2 in. larger permitted providing total width of all knots and knotholes within a specified section does not exceed certain limits. Limited splits permitted. Minimum veneer permitted in exterior-type plywood.

C—Improved C veneer with splits limited [Plgd] to 1/8 in. in width and knotholes and borer holes limited to 1/4 in. by 1/2 in.

D—Permits knots and knotholes to 2 1/2 in. width and 1/2 in. larger under certain specified limits. Limited splits permitted.

Figure 6-6.-Plywood veneer grades.

repeatedly or otherwise subjected to the weather, exterior plywood retains its glue bond and withstands exposure to the elements. Interior plywood can withstand an occasional wetting but not permanent exposure to the elements.

Grades

The several grades within each type of plywood are determined by the grade of the veneer (N, A, B, C, or D) used for the face and back of the panel (fig. 6-6). Panel grades are generally designated by the kind of glue and by the veneer grade on the back and face. Grading is based on the number of defects, such as knotholes, pitch pockets, splits, discolorations, and patches, in each face of the plywood panel.

Identification Stamps

Stamps are placed on the edges and back of each sheet of plywood so it can be properly identified. Figure 6-7 shows typical back-stamps and edge-marks found on a standard sheet of plywood. It shows all information needed about the sheet, except its actual size.

Figure 6-8 shows the stamps found on the backs of structural and standard sheathing panels. They vary somewhat from the standard stamps.

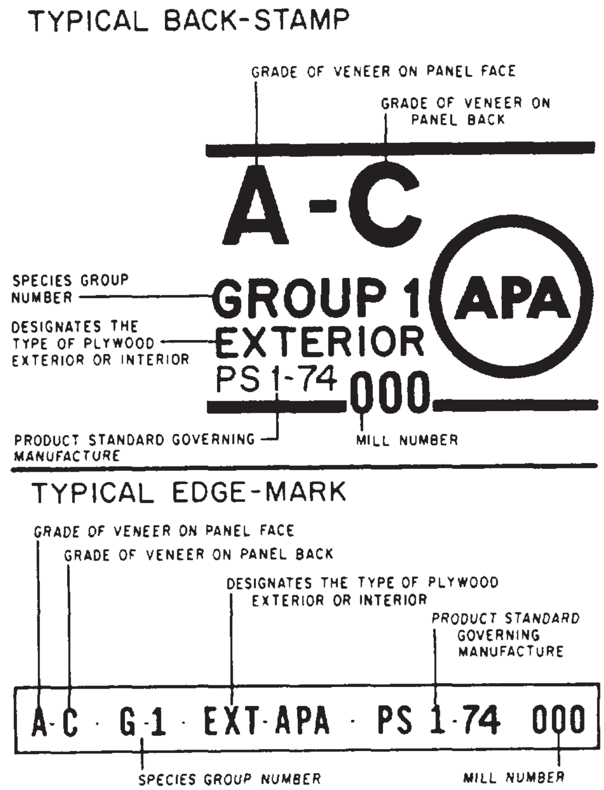


Figure 6-7.-Standard plywood identification symbols.

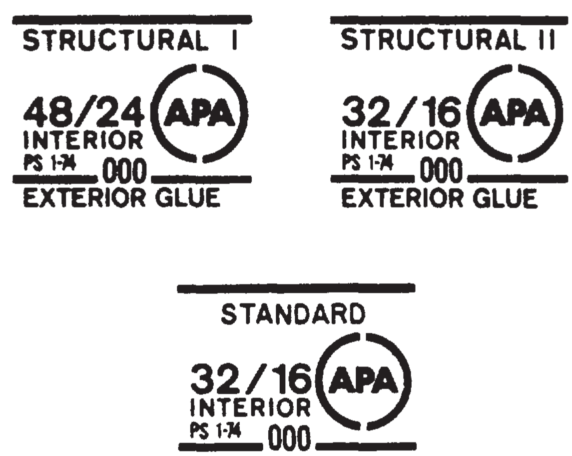


Figure 6-8.-Structural and standard sheathing identification symbols.

The actual grade is NOT given, NOR is the species group. The index numbers 48/24 and 32/ 16 give the maximum spacing in inches of supports. The number to the left of the slash is the maximum O.C. (on-center) spacing of supports for roof decking. The number to the right of the slash is the maximum O.C. spacing of supports for subfloors. A number 0 on the right of the slash indicates that the panel should NOT be used for subflooring. No reference to the index number is needed when the panel is to be used for wall sheathing.

Detailed information on specific types and grades and their uses can be found in commercial standards for the manufacture of plywoods established by the U.S. Department of Commerce. General plywood characteristics and architectural information can be found in the following publications: *American Plywood Association, National Lumber Manufacturing Association,* or the *Architectural Graphic Standards.* The latter book can be found in your unit's technical library.

SPECIAL-PURPOSE PLYWOOD

Other types of plywood are manufactured for specific purposes. Among these types are the structural, sheathing, overlaid panels, decorative panels, and concrete form panels. Table 6-3 lists some of the various types of plywood with their suggested uses.

Structural plywood is recommended for heavy-load application where strength properties are of great importance. Likewise, for box beams, gusset plates, and stressed-skin panels, unsanded grades of C-D plywood are recommended.

Standard plywood sheathing is used for subfloors, roof decks, and wall sheathing. It is

Table 6-3.-Uses of Plywood

SOFTWOOD PLYWOOD GRADES FOR EXTERIOR USES				
GRADE (EXTERIOR)	FACE	BACK	INNER PLYS	USES
A-A	A	A	C	Outdoor where appearance of both sides is important.
A-B	A	B	C	Alternate for A-A, where appearance of one side is less important.
A-C	A	C	C	Siding, soffits, fences. Face is finish grade.
B-C	B	C	C	For utility uses such as farm buildings, some kinds of fences, etc.
C-C (Plugged)	C Plugged	C	C	Excellent base for tile and linoleum, backing for wall coverings.
C-C	C	C	C	Unsanded, for backing and rough construction exposed to weather.
B-B Concrete Forms	B	B	C	Concrete forms. Re-use until wood literally wears out.
MDO	B	B or C	C or C-Plugged	Medium Density Overlay. Ideal base for paint: for siding, built-ins, signs, displays.
HDO	A or B	A or B	C-Plugged	High Density Overlay. Hard surface; no paint; needed. For concrete forms, cabinets, counter tops, tanks.

SOFTWOOD PLYWOOD GRADES FOR INTERIOR USES				
GRADE (INTERIOR)	FACE	BACK	INNER PLYS	USES
A-A	A	A	D	Cabinet doors, built-ins, furniture where both sides will show.
A-B	A	B	D	Alternate of A-A. Face is finish grade, back is solid and smooth.
A-D	A	D	D	Finish grade face for paneling, built-ins, backing.
B-D	B	D	D	Utility grade. One paintable side. For backing, cabinet sides, etc.
STANDARD	C	D	D	Sheathing and structural uses such as temporary enclosures, subfloor. Unsanded.

recommended for use in spaces that may be exposed to moisture during construction, but will be covered when construction is complete.

Overlaid panels have a resin-treated fiber-surfacing material, on one or both sides, to hold paint and finishes more readily. These exterior or interior types of plywood are recommended for use in furniture, cabinets, millwork, and exterior trims.

Decorative panels are used basically for exterior and interior wall sheathing. Both types are manufactured in a multitude of designs and patterns and can be painted, stained, or left to weather naturally.

A concrete form panel has a coating over its exterior face to make it moisture-resistant and nonadhesive to concrete when used as forming material. The exterior coating reduces the number of times the form must be oiled and allows the panel to be reused several times.

COMMON WOOD SUBSTITUTE

For various reasons, many common construction materials are used as wood or plywood substitutes. Some are significantly less expensive than plywood; others are more suitable because of their decorative appearance and weather-resistant qualities.

Particleboard

Particleboard, commonly referred to as chipboard or flakeboard, is produced by mixing a resin-bonding agent with wood particles and bonding them together by means of heat and pressure. The use of particleboard is limited to nonstructural use because of its low strength qualities. The most common size sheets are 4 ft by 8 ft and vary from 1/4 in. to 1 1/2 in. thick.

Hardboard

Hardboard is made of compressed wood fibers subjected to heat and heavy pressure. The finish may be obtained in a plain, smooth surface or in any number of glossy finishes, some of which imitate tile or stone. Its strength is about equal in all directions, and it can be bent into various shapes. Hardboard is available in thicknesses from 1/8 in. to 3/8 in. The most common size sheets are 4 ft by 8 ft.

Fiberboard

Fiberboard is made of wood or vegetable fiber that has been compressed to form sheets or boards. They are comparatively soft and provide good insulation and sound-absorbing qualities. Fiberboard is available in sizes from 1/2 in. to 1 in. thick, 2 ft to 4 ft wide, and 8 ft to 12 ft long.

Gypsum Wallboard

Gypsum wallboard is composed of gypsum between two layers of heavy paper. Some types have unfinished surfaces, while others have finishes that represent wood grain or tile. The most common thickness is 1/2 in. Its width is usually 4 ft, and its length varies from 4 to 14 ft.

Another type of gypsum wallboard has depressed or tapered edges. The joints are filled with special cement and are then taped so that the joints do not show. They can then be painted. This procedure is commonly known as DRY WALL. Dry walls are particularly useful in areas and spaces where sound-deadening and fire-resistant materials are desired.

TREATMENT

When not properly treated and installed, wood can be destroyed by decay, fungi, boring insects, weathering, or fire. Although designed for the specific use of the wood, treatment varies from project to project and from one geographical area to another. The kind and amount of treatment is usually given by the project specifications. Where no written specifications exist, the drawings should indicate the kind and amount of wood treatment.

Manufacturers' commercial standards contain information on wood pretreated by the manufacturer. NAVFAC publications and specifications provide technical information and design requirements for the treatment of wood used in buildings and structures.

WOOD FRAME STRUCTURES

In a wood frame building or structure, the framework consists mostly of wood load-bearing members that are joined together to form an internal supporting structure, much like the skeleton of a human body.

When a complete set of drawings is made for a certain building, large-scale details are usually shown for typical sections, joints, and other unusual construction features. Understanding the different functions of the structural members of a frame building will enable you to make these drawings correctly and promptly.

THEORY OF FRAMING

Generally, a building has two main parts: the FOUNDATION and that part above the foundation, called the SUPERSTRUCTURE. The framework of a wooden superstructure is called the FRAMING of the building. It is subdivided into floor framing, wall framing, and roof framing. FLOOR FRAMING consists, for the most part, of horizontal structural members called joists, and the WALL FRAMING, for the most part, of vertical members called studs. ROOF FRAMING consists of both horizontal and vertical structural members.

The most common framing and construction methods are the PLATFORM (also called WESTERN and STORY-BY-STORY framing) (fig. 6-9) and the BALLOON FRAMING (fig. 6-10). The striking difference between these two methods is

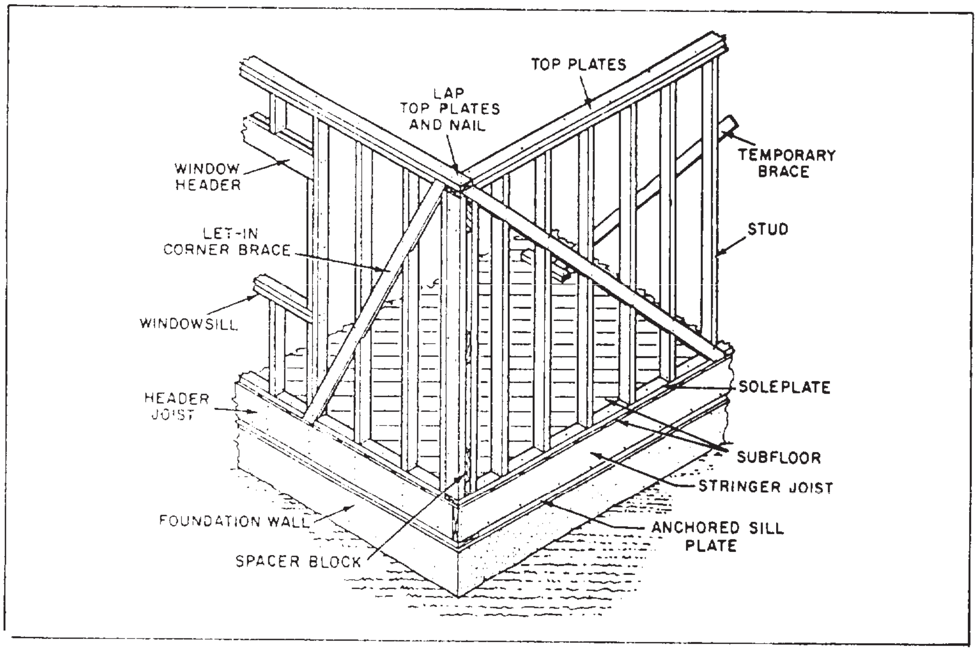


Figure 6-9.-Wall framing used in platform construction.

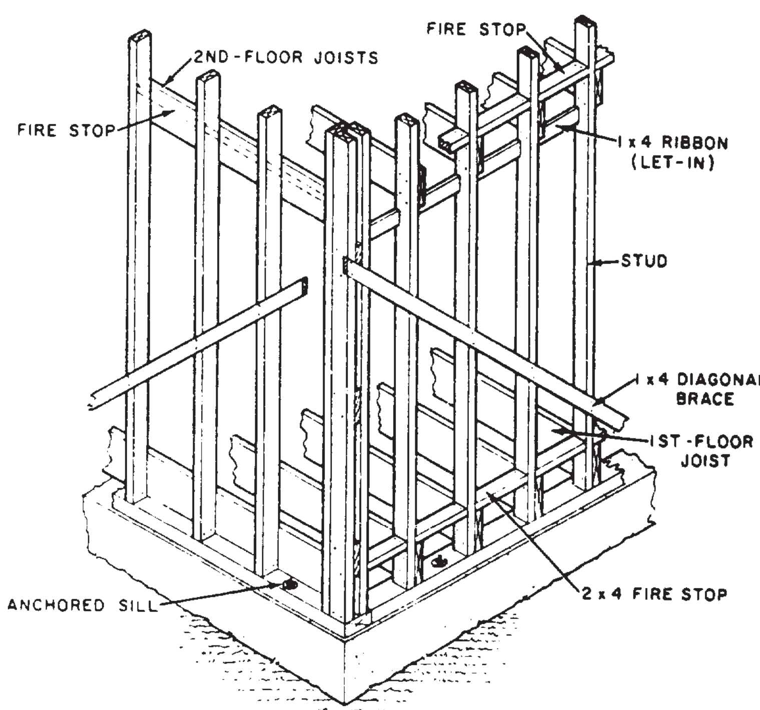


Figure 6-10.-Wall framing used in balloon construction.

that in balloon framing, the studs extend from the sill of the first floor to the top of the soleplate or end rafter of the second floor; whereas the platform framing has separate studs for each floor anchored on the soleplate.

SILL FRAMING AND LAYOUT

The lowest horizontal wood frame structural member is the SILL, a piece of dimensional lumber laid flat and bolted down to the top of the foundation pier or wall. It is the first part of the frame to be set in place and provides a nailing base for the other adjoining members. It may extend all around the building, joined at the corners and spliced when necessary.

The type of sill assembly selected depends upon the general type of construction methods used in the framework. The method of framing

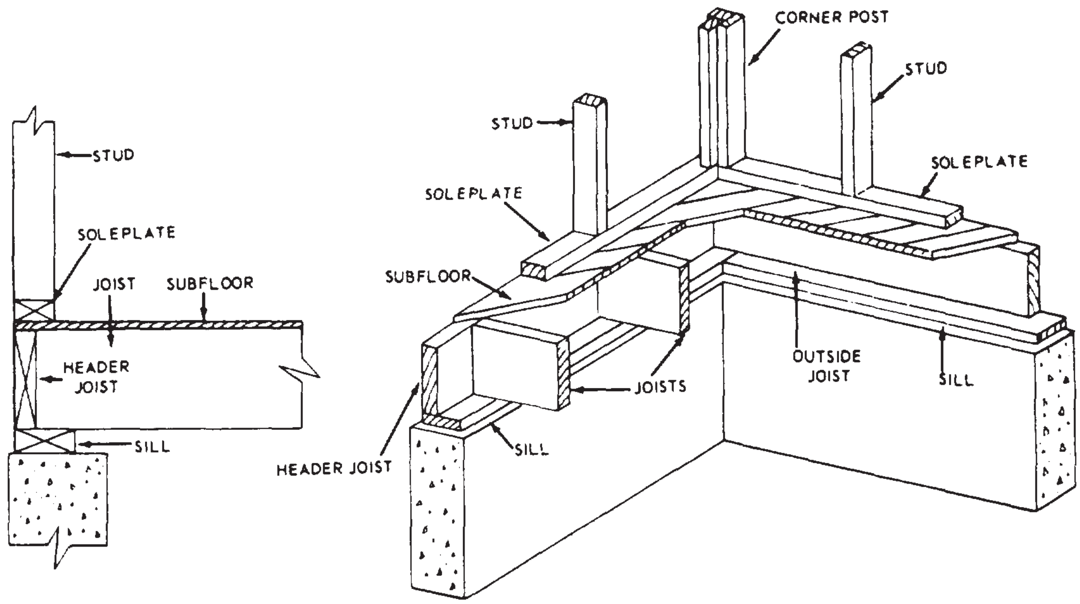


Figure 6-11.-Box-sill assembly for platform framing.

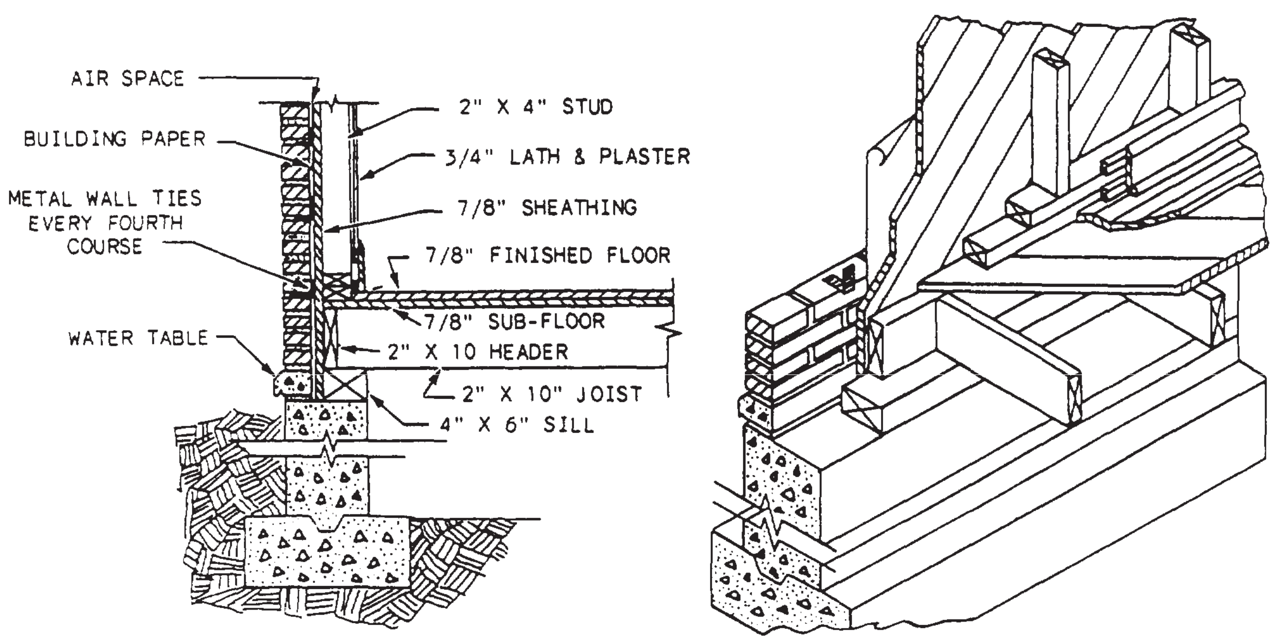


Figure 6-12.-Sill assembly in brick veneer construction.

the studs to the sill is called SILL ASSEMBLY. The BOX-SILL assembly shown in figure 6-11 is the type most frequently used in platform-frame construction. In this type, the ends of the joists are framed against a header-joist, which is set flush with the outer edge of the sill. The construction method for a sill assembly in which brick veneer is used as exterior siding (fig. 6-12) is similar to the box-sill assembly except that the sill is set in the foundation wall to allow enough space for the brick to rest directly on the wall.

Balloon-frame construction uses the T-SILL (fig. 6-13) and EASTERN (fig. 6-14) assemblies. Here, the studs are anchored on the sill and are continuous; that is, in one piece from sill to roof line.

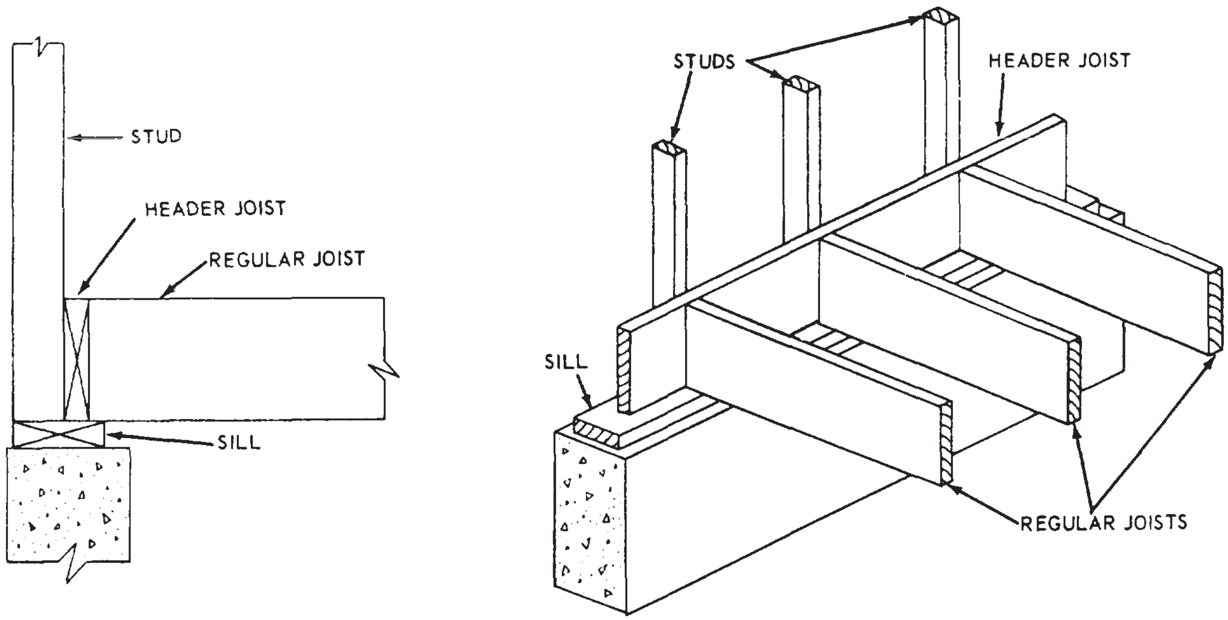


Figure 6-13-T-sill assembly.

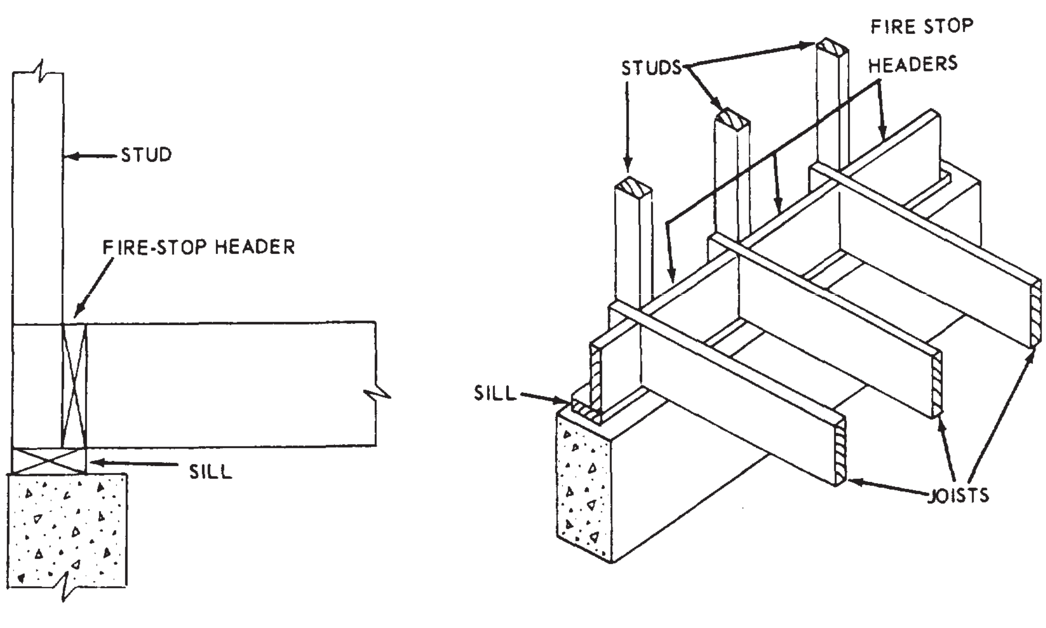


Figure 6-14.-Eastern sill assembly.

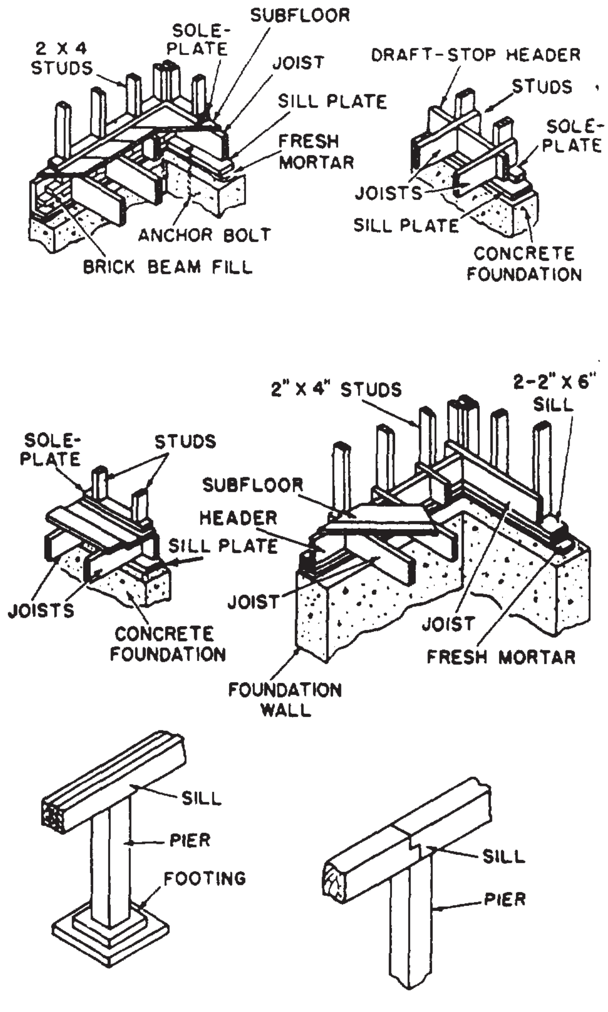


Figure 6-15.-Types of sills.

Other types of sill framing and layout are shown in figure 6-15.

FLOOR FRAMING

Horizontal members that support the floors in wood frame structures are called JOISTS or BEAMS, depending upon the length of the SPAN (distance between the end supports). Members less than 4 ft apart are called joists; members 4 ft or more apart are called beams. The usual spacing for wood frame floor members is either 16 in. or 24 in. O.C. Joists are usually 2 by 8, 2 by 10, or 2 by 12. A COMMON JOIST is a full-length joist that spans from wall to wall or from wall to girder. A CRIPPLE JOIST is similar to a common joist with the exception that it does not

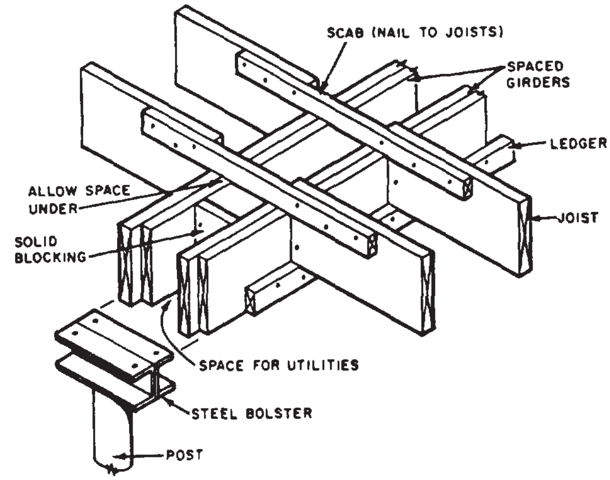


Figure 6-16.-Spaced wood girder.

extend the full span. Cripples are normally interrupted by floor openings.

Girders (fig. 6-16) are horizontal members that support joists at points other than along the outer wall lines. When the span is longer than can be covered by a single joist, a girder must be placed as an intermediate support for joist ends. Ground-floor girders are commonly supported by concrete or masonry pillars and pilasters. A PILLAR is a girder support that is clear of the foundation walls. A PILASTER is set against a foundation wall and supports the end of a girder. Both pillars and pilasters are themselves supported by concrete footings. Upper-floor girders are supported by columns. GIRTS are horizontal wood framing members that help to support the outer-wall ends of upper-floor joists in balloon framing.

Framing Around Floor Openings

A common joist must be cut away to give way for floor openings, such as stairways. The wall-opening ends of cripple joists are framed against HEADERS, as shown in figure 6-17. Specifications usually require that headers be doubled—sometimes tripled. Headers are framed bet ween the full-length joists, also called TRIMMERS, on either side of the floor opening. Headers up to 6 ft in length are fastened with nails, whereas those longer than 6 ft are fastened with joist hangers.

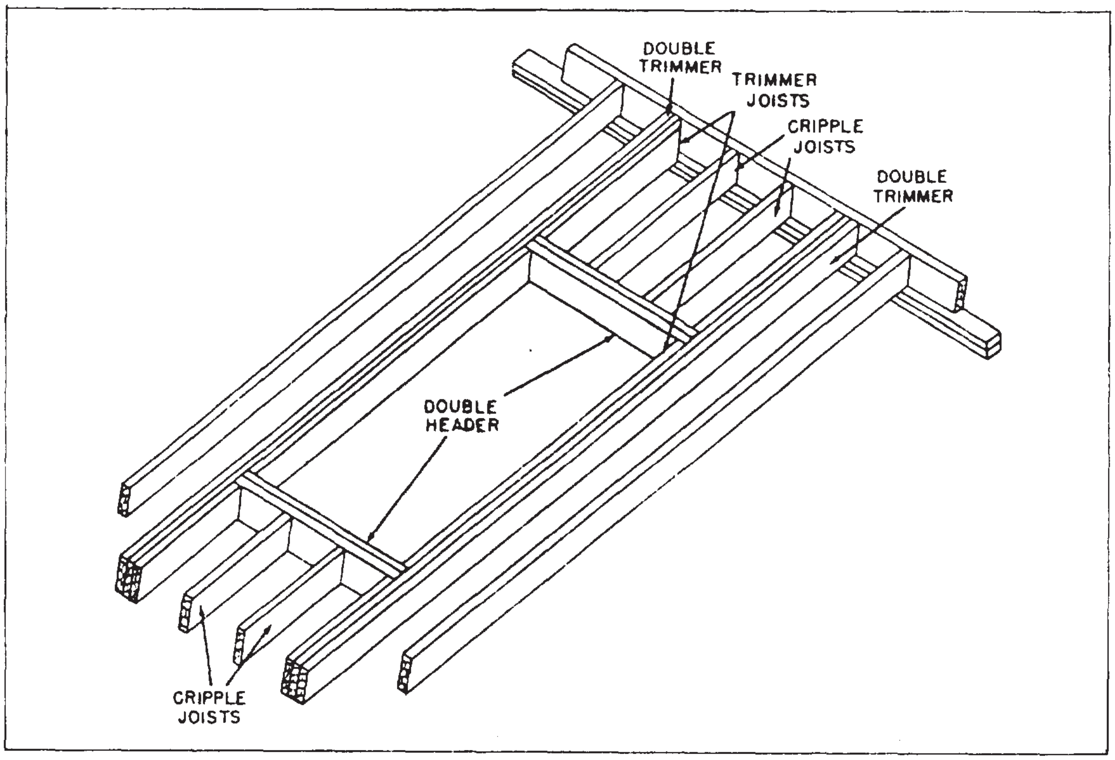


Figure 6-17.-Framing around floor openings.

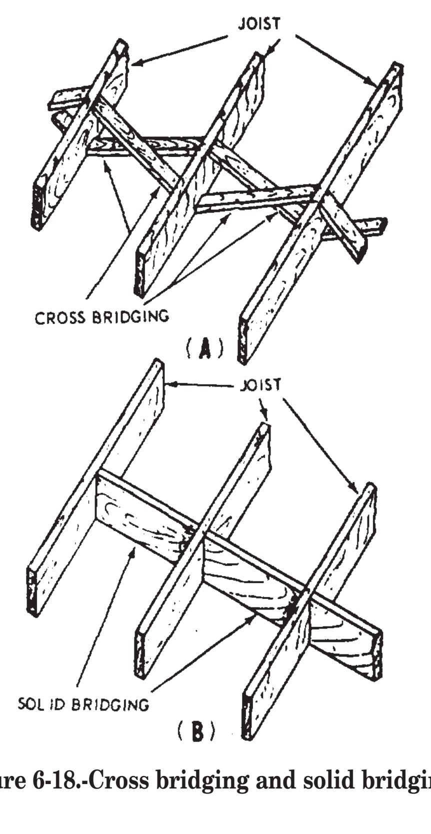


Figure 6-18.-Cross bridging and solid bridging.

Bridging

Bridging is the system of bracing the joists to each other to hold them plumb and aligned. It also serves to distribute part of a concentrated load over several joists next to those directly under the load. There are two types of bridging: CROSS BRIDGING (fig. 6-18, view A) and SOLID BRIDGING (fig, 6-18, view B). Cross bridging consists of pairs of STRUTS set diagonally between the joists. The strut stock comes in sizes of 1 by 3, 1 by 4, 2 by 2, and 2 by 4. Solid bridging consists of pieces of joist-size stock set at right angles to the joists. They can be staggered for easier installation. Cross bridging is more rigid than solid bridging and is more frequently used in construction. Bridging should be provided for all spans greater than 6 ft.

Subflooring

Joists are covered by a layer (or double layer) of boards called SUBFLOORING. It usually consists of square-edge or tongue-and-grooved boards or plywood 1/2 to 3/4 in. thick that serve

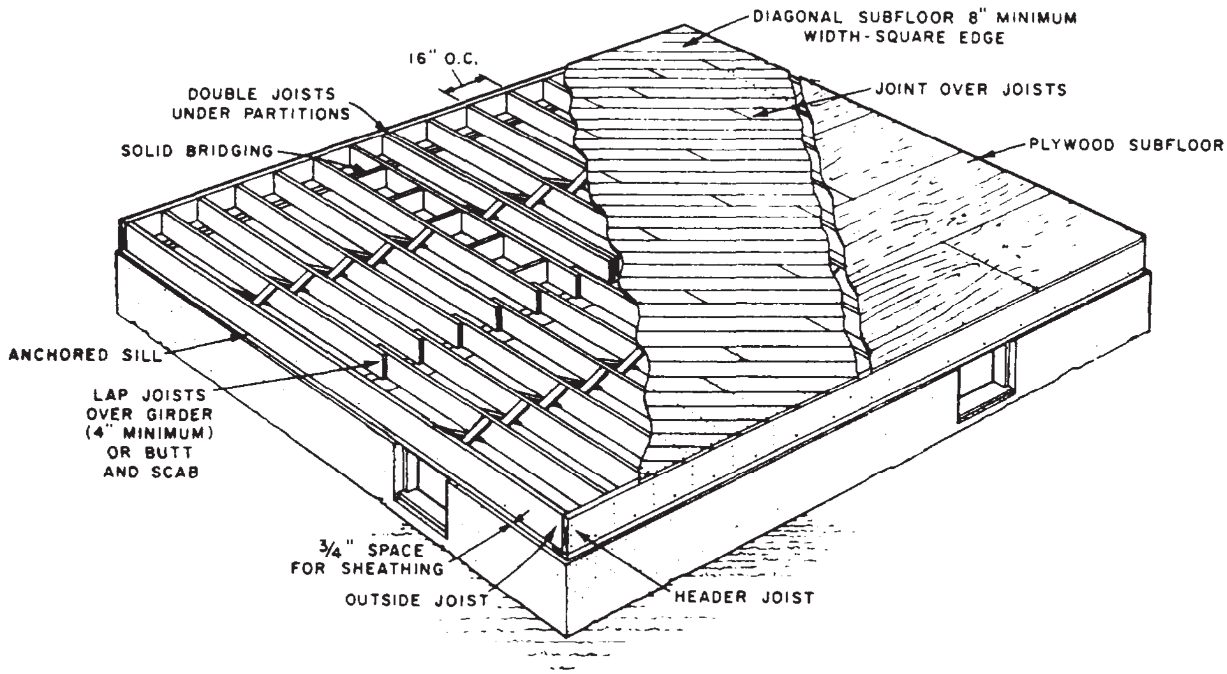


Figure 6-19.-Typical floor framing with subflooring.

as a working platform and base for finish flooring (fig. 6-19). Sub flooring may be applied either diagonally (most common) or at right angles to the joists. Diagonal subflooring permits finish flooring to be laid either parallel to, or, more commonly, at right angles to, the joists. The joist spacing should not exceed 16 in. O.C. when finish flooring is laid parallel to the joists or when parquet finish flooring is used.

WALL FRAMING

As with floor construction, two general types of wall framing are commonly used: platform construction and balloon-frame construction. The platform method shown in figure 6-9 is more often used because of its simplicity.

A typical wall frame (fig. 6-20) is composed of regular studs, cripples, trimmers, headers, and fire stops (fig. 6-10) and is supported by the floor soleplate, The wall framing members used in conventional construction are generally nominal 2 by 4 in. in size. The requirements are good stiffness, good nail-holding ability, freedom from warp, reasonable dryness (about 15-percent moisture content), and ease of working. The closely spaced and slender vertical members of the wall framing are called the STUDS. They support the top plates and provide the framework to which the wall sheathing is nailed on the outside and which supports the lath, plaster, and insulation on the inside. TOP PLATES (or CAPS) are horizontal wood framing members that are nailed to the tops of the wall or partition studs. SOLEPLATES are horizontal wood framing members that serve as nailing bases for studs in platform-framing construction. HEADERS form the upper members of a rough doorframe, or upper or lower members of a rough window frame. Similar members that form the ends of a rough floor or roof opening (as a skylight) are also called headers.

Partition

The inside space of a building is divided by partition walls. In most cases, these walls are framed as part of the building. There are two types of partition walls: BEARING and NONBEARING. Partition walls of the bearing type support the ceiling joists and all other loads imposed upon them; those of the nonbearing type support only themselves and are usually installed after the other framework is put in. Partition walls are framed in the same manner as outside walls, and door openings are framed as outside openings. CORNER POSTS or T-POSTS are used at corners or where one partition wall joins another. They provide nailing surfaces for the inside wall finish (fig. 6-21).

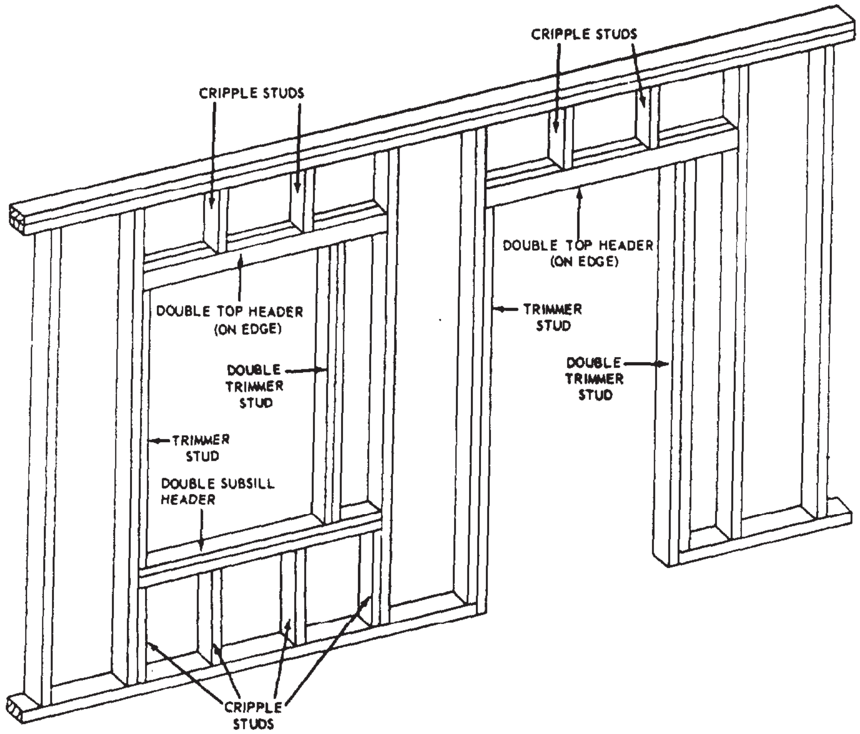


Figure 6-20.-Parts of a wall frame, showing headers.

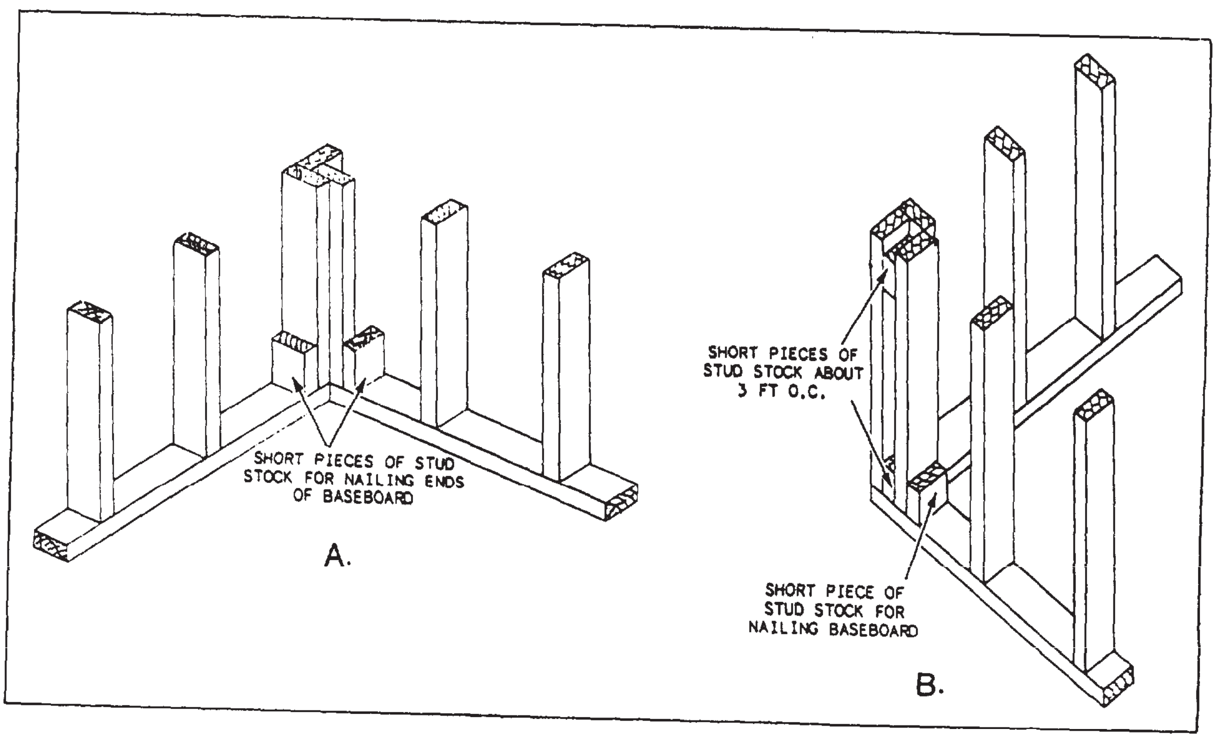


Figure 6-21.-Typical examples of corner posts: A. Simplest type; B. More solid type.

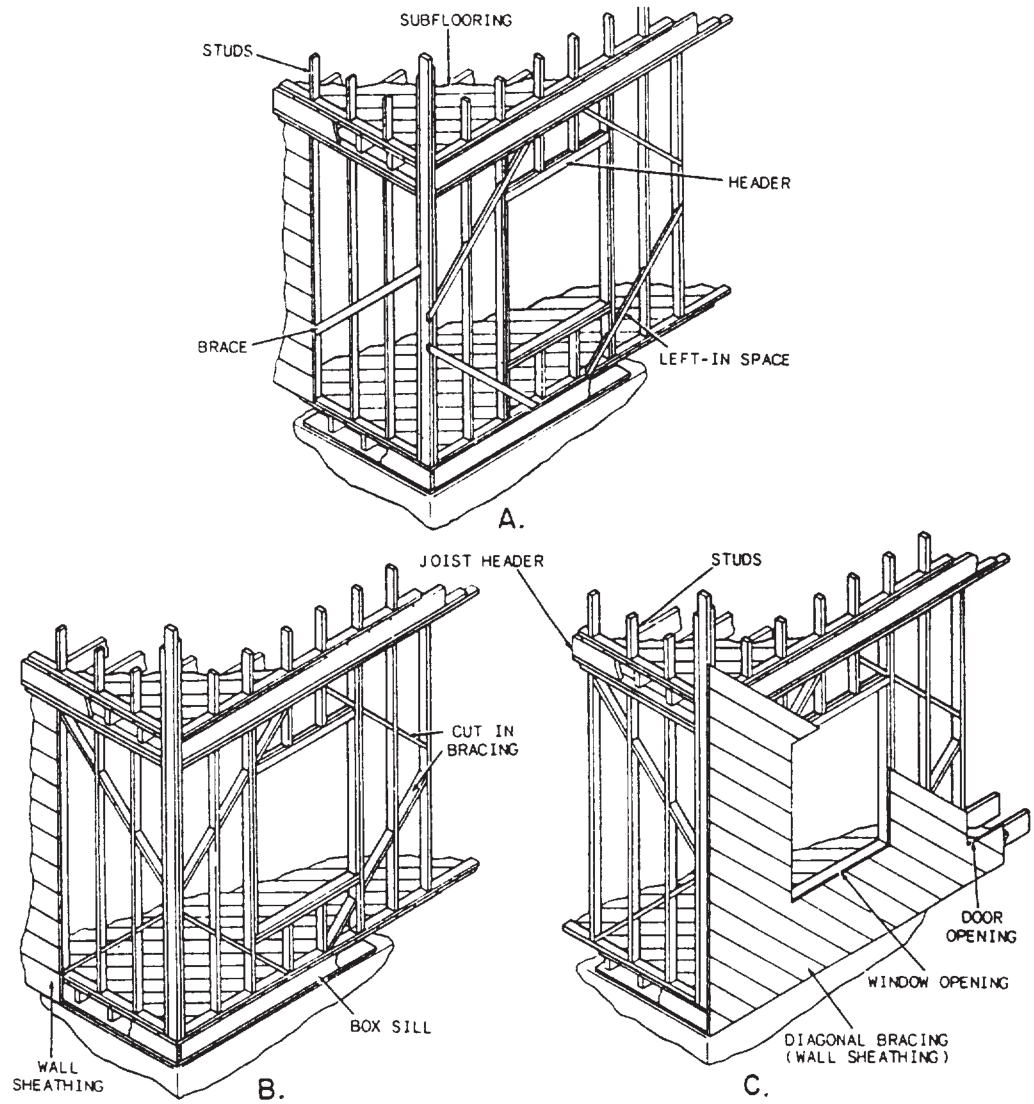


Figure 6-22.-Common types of bracing: A. Let-in bracing; B. Cut-in bracing; C. Diagonal bracing.

Braces

Braces are used to stiffen framed construction and help buildings resist the twisting or straining effects of wind or storm. Good bracing keeps corners square and plumb and prevents warping, sagging, and shifts resulting from lateral and external forces that would otherwise tend to distort the frame. Figure 6-22 shows three common methods of bracing frame structures: (A) let-in bracing, (B) cut-in bracing, and (C) diagonal bracing.

ROOF FRAMING

Roofs must be sloped so that they will shed water. The most common types of roof construction include the intersecting, the shed, the gable, and the hip (fig. 6-23). An INTERSECTING ROOF consists of a gable and valley or hip and valley intersecting each other at right angles. A SHED ROOF has a single surface that slopes downward from a ridge on one side of the structure. A GABLE ROOF has two surfaces sloping downward from a ridge located between the sides of the structure—usually midway between them. A HIP ROOF is pitched on the sides like a gable roof and also is pitched on one or both ends.

Roof Pitch

The PITCH (amount of slope) of a roof is expressed as a FRACTION in which the

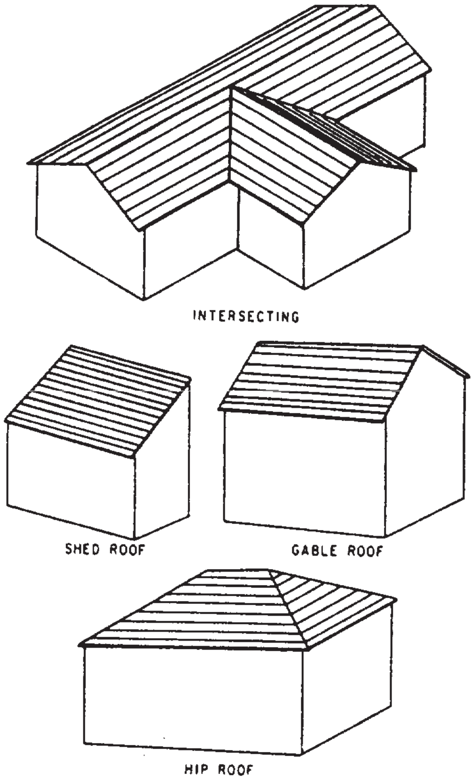


Figure 6-23.-Most common types of pitched roofs.

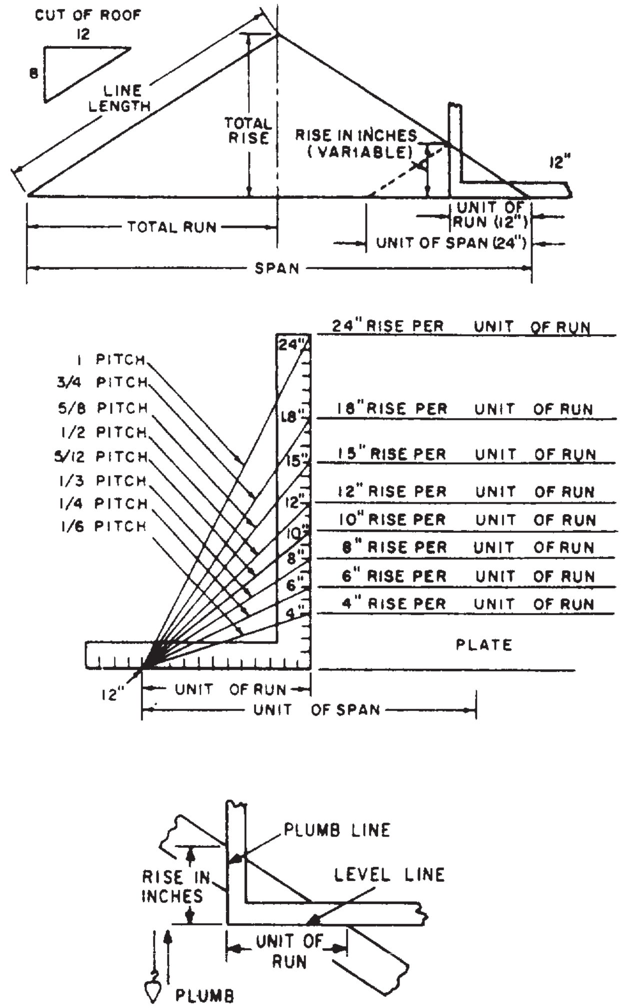


Figure 6-24.-Roof pitch diagram.

numerator is the UNIT RISE and the denominator is the UNIT SPAN. By common practice, unit run is always given as 12. See the roof pitch diagram in figure 6-24. Expressed in equation form,

$$\text{Pitch} = \frac{\text{Unit Rise}}{\text{Unit Span}}$$

$$= \frac{\text{Unit Rise}}{2 \times \text{Unit Run}}$$

Suppose that a roof rises 8 units for every 12 units of run—meaning that unit rise is 8 and unit run is 12. Since the unit span is 24, the pitch of the roof is 8/24, or 1/3. This value is also indicated in the center view of the roof pitch diagram in figure 6-24.

On construction drawings, the pitch of a roof is indicated by a small ROOF TRIANGLE like the one in the upper view of figure 6-24. The triangle is drawn to scale so that the length of the horizontal side equals the unit run (which is always 12), and the length of the vertical side equals the unit rise.

Rafter Layout

RAFTERS are framing members that support a roof. They do for the roof what joists do for the floor and what the studs do for the wall. They are generally inclined members spaced from 16 to 48 in, apart that vary in size, depending on their length and the distance they are spaced.

The tops of the inclined rafters are fastened in one of the various common ways, which is determined by the type of roof. The bottoms of the rafters rest on the plate member, which provides a connecting link between the wall and the roof and is really a functional part of both.

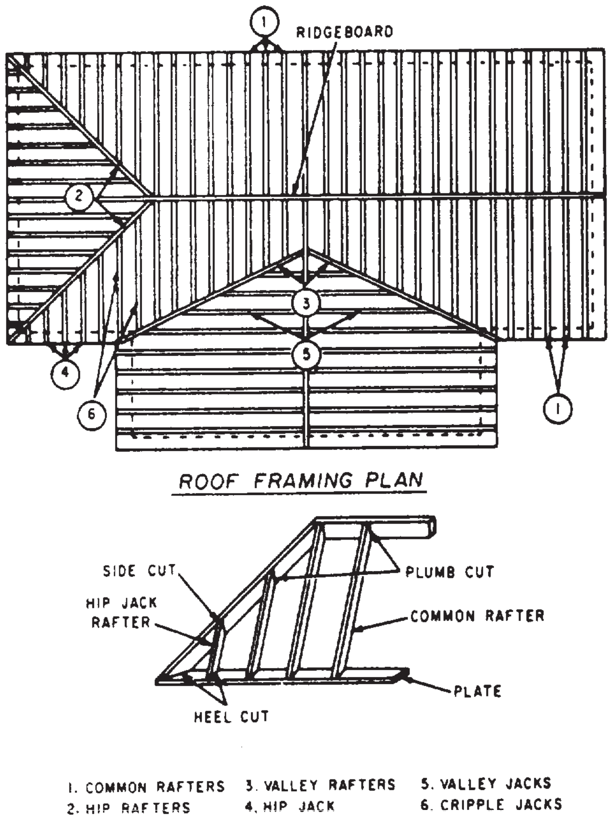


Figure 6-25.-Rafter terms.

The structural relationship between the rafters and the wall is the same in all types of roofs. The rafters are NOT framed into the plate, but simply nailed to it. Some are cut to fit the plate. In hasty construction, rafters are merely laid on top of the plate and nailed in place. Rafters may extend a short distance beyond the wall to form the eaves and protect the sides of the building.

Figure 6-25 shows a typical roof framing plan. The following rafter terms and definitions supplement the notes in the drawing:

COMMON RAFTERS—Rafters that extend from the plates to the ridgeboard at right angles to both.

HIP RAFTERS—Rafters that extend diagonally from the corners formed by perpendicular plates to the ridgeboard.

VALLEY RAFTERS—Rafters that extend from the plates to the ridgeboard along the lines where two roofs intersect.

HIP JACKS—Rafters whose lower ends rest on the plate and whose upper ends rest against the hip rafter.

VALLEY JACKS—Rafters whose lower ends rest against the valley rafters and whose upper ends rest against the ridgeboard.

CRIPPLE JACKS—Rafters that are nailed between hip and valley rafters.

JACK RAFTERS-Hip jacks, valley jacks, or cripple jacks.

TOP OR PLUMB CUT—The cut made at the end of the rafter to be placed against the

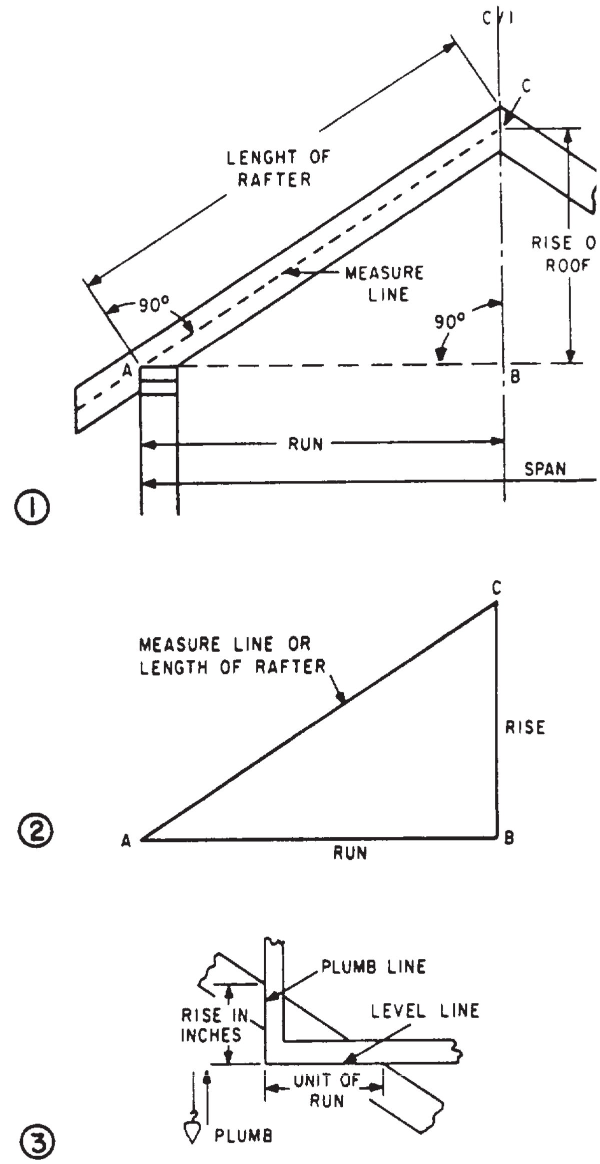


Figure 6-26.-Additional terms used in rafter layout.

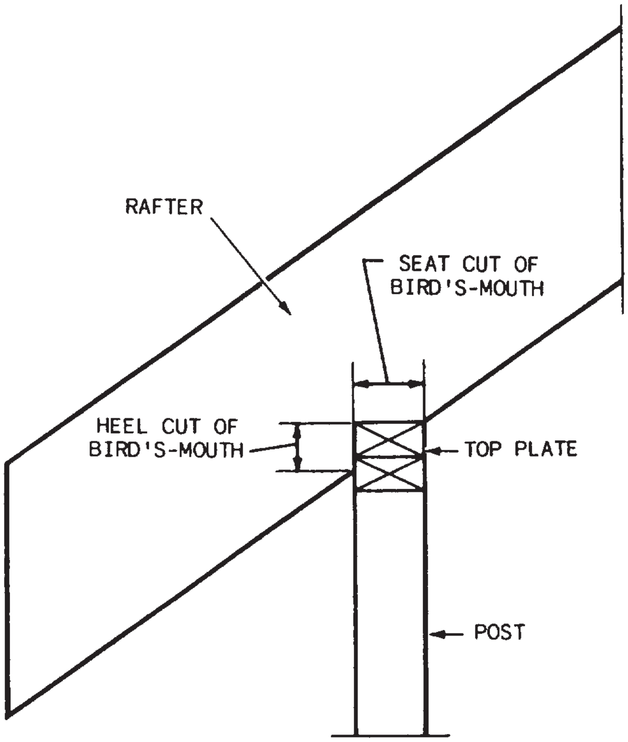


Figure 6-27.-Bird's-mouth on a rafter with projection.

ridgeboard or, if the ridgeboard is omitted, against the opposite rafters (fig. 6-25).

SEAT, BOTTOM, OR HEEL CUT—The cut made at the end of the rafter that is to rest on the plate.

SIDE, OR CHEEK, CUT—A bevel cut on the side of a rafter to fit against another frame member.

EAVE OR TAIL—The portion of the rafter extending beyond the outer edge of the plate.

Figure 6-26 shows additional terms used in connection with rafter layout.

RAFTER LENGTH is the shortest distance between the outer edge of the plate and the center of the ridgeline.

MEASURE LINE is an imaginary reference line laid out down the middle face of the rafter.

PLUMB LINE is any line that is vertical when the rafter is in its proper position.

LEVEL LINE is any line that is horizontal when the rafter is in its proper position.

A rafter with a projection often has a notch in it called a BIRD' S-MOUTH (fig. 6-27). The plumb cut of the bird's-mouth that bears against the side of the rafter plate is called the HEEL CUT, whereas the SEAT CUT bears on top of the bird's-mouth. COLLAR TIES (fig. 6-28) are horizontal members used as reinforcement in gable or double-pitch roof rafters. In a finished attic, these ties may function as ceiling joists.

When the rafters are placed farther apart, horizontal members called PURLINS are placed across them to serve as the nailing or connecting members for the roofing. Purlins are generally used with standard metal roofing sheets, such as galvanized iron or aluminum sheets.

Several methods of roof framing and types of rafter arrangement are further shown in figures 6-29 through 6-36.

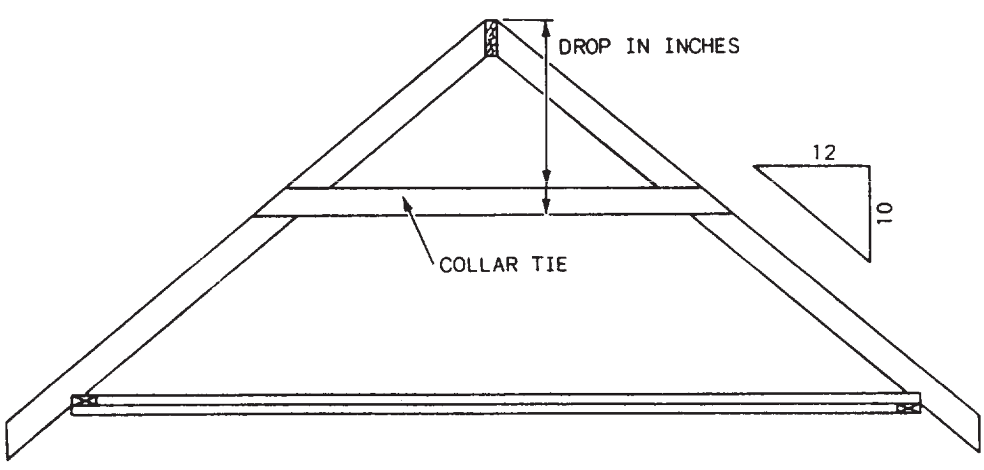


Figure 6-28.-Layout of a collar tie.

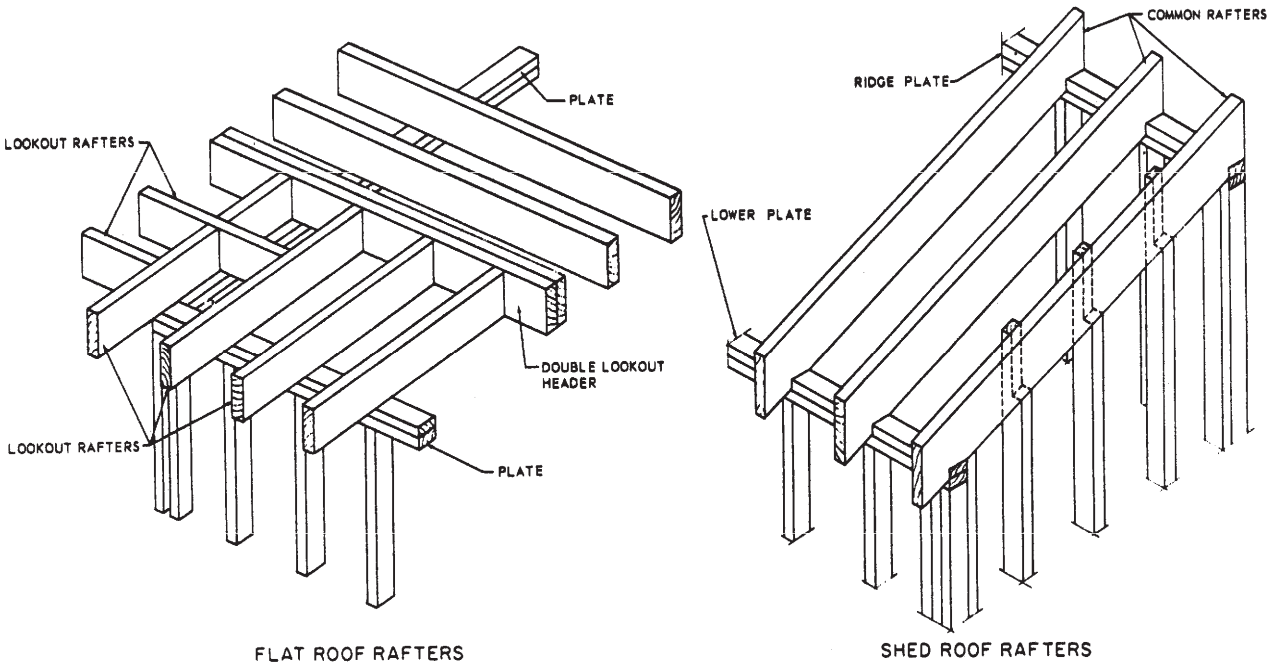


Figure 6-29.—Flat and shed roof framings.

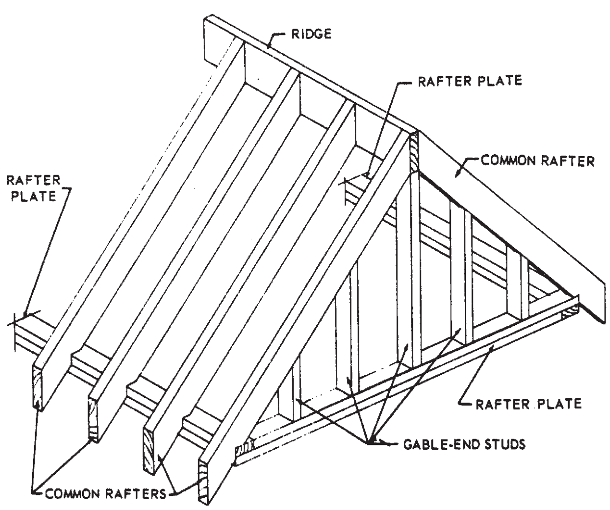


Figure 6-30.—Gable roof framing.

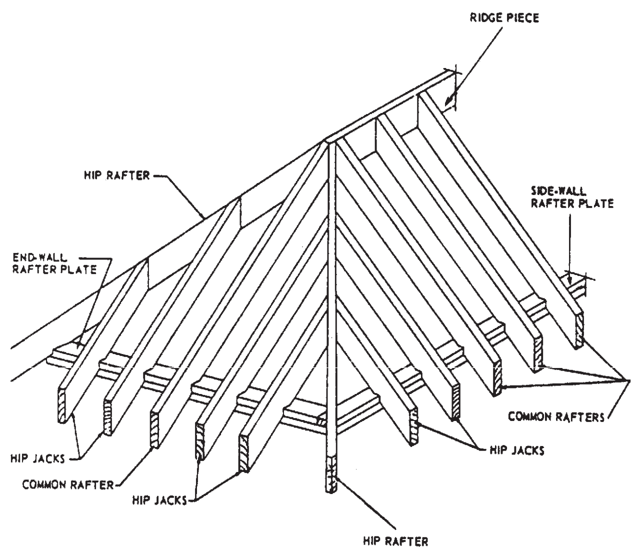


Figure 6-31.—Equal-pitch roof

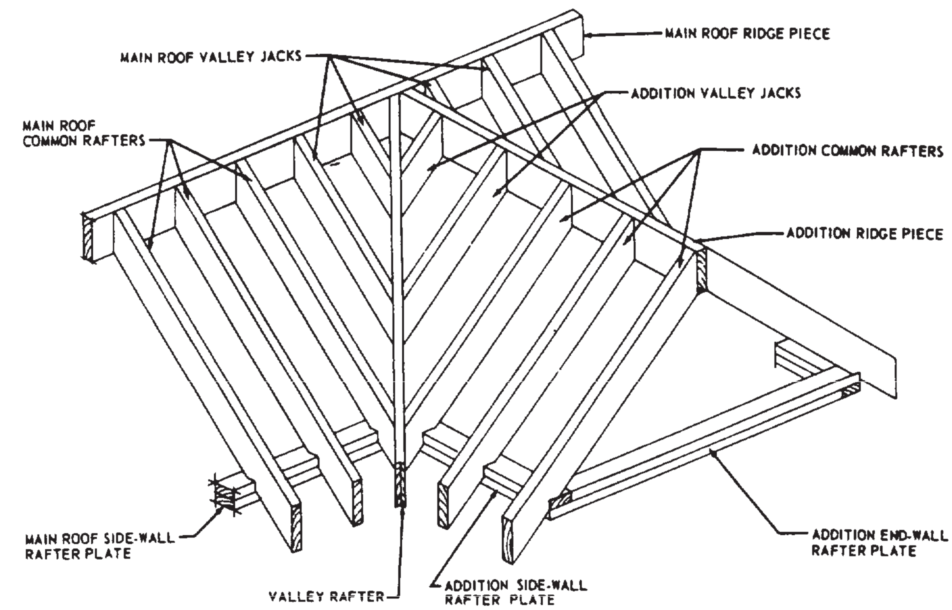


Figure 6-32.-Addition roof framing.

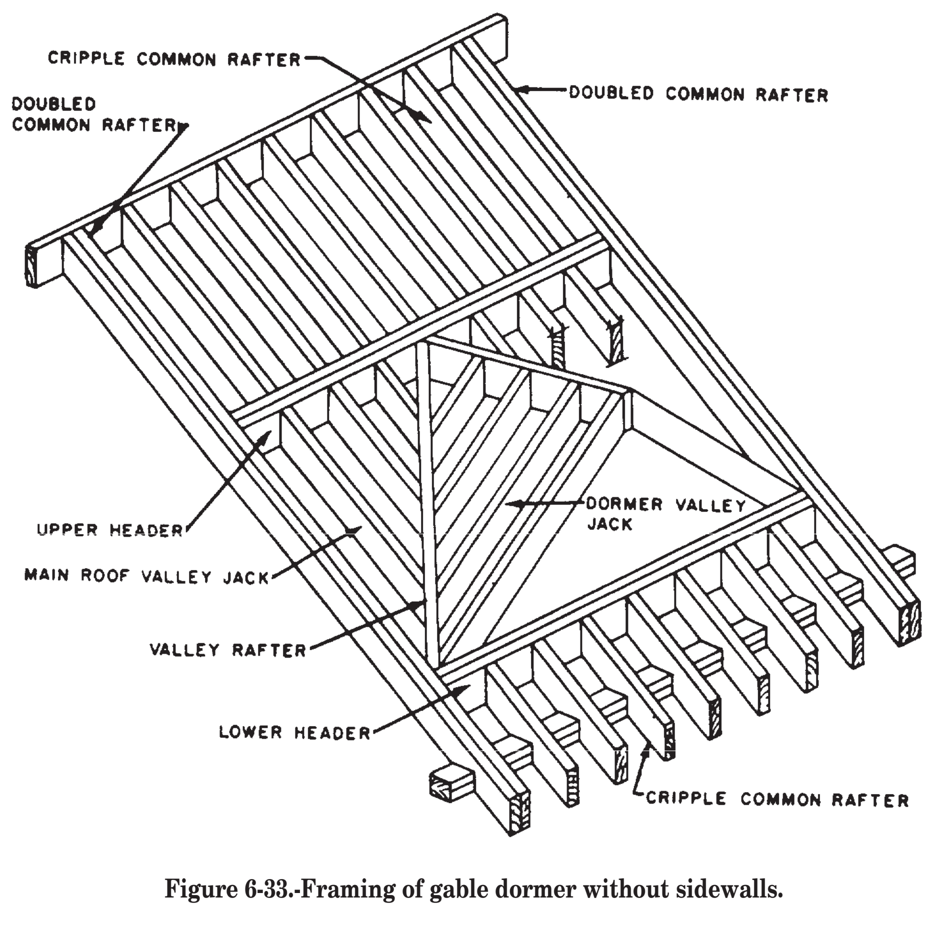


Figure 6-33.-Framing of gable dormer without sidewalls.

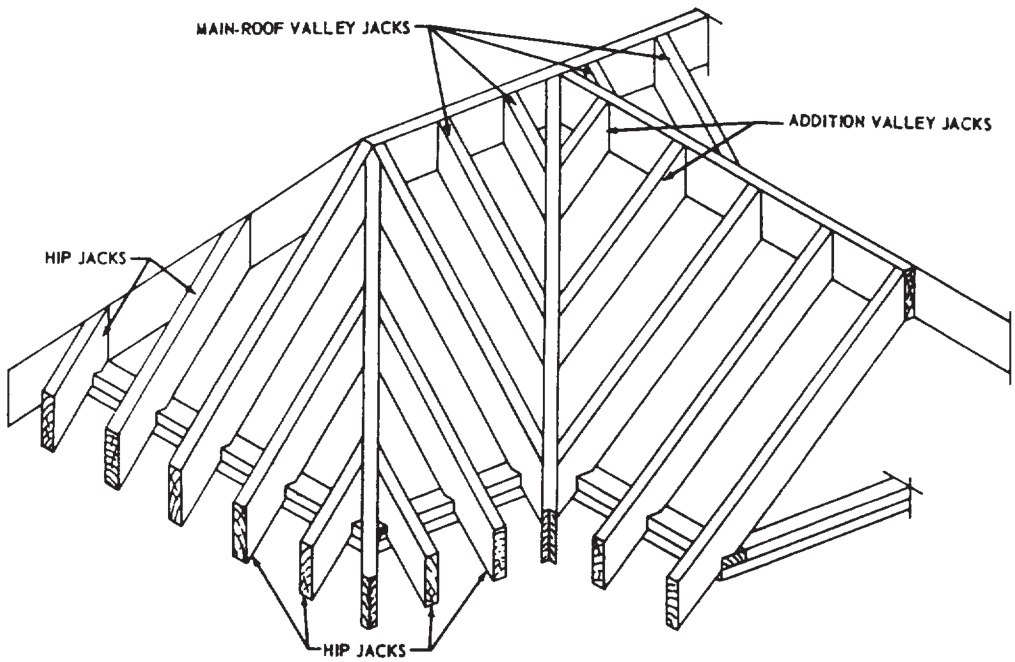


Figure 6-34.-Types of jack rafters.

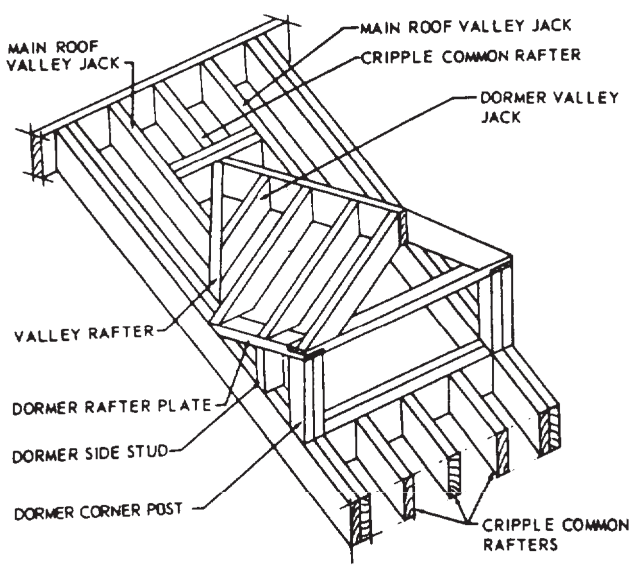


Figure 6-35.-Framing of gable dormer with sidewalls.

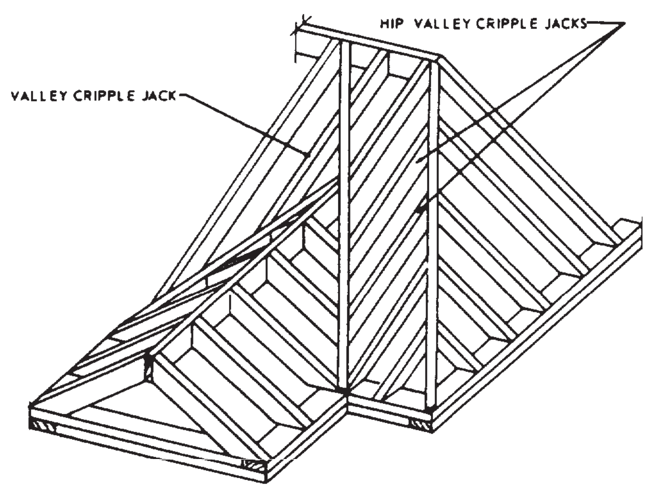


Figure 6-36.-Cripple jacks.

Roof Trusses

A TRUSS is an engineered structural frame that is used to span distances that are too great for single-piece members without intermediate supports. Figure 6-37 shows a roof truss or rafter truss assembly. Chords and webs are connected to one another by GUSSET PLATES—metal plates or plywood pieces that are nailed, glued, or bolted in place. The load that the roof must carry is the important factor to be considered in selecting the type of truss. These loads may consist of the roof itself, forces caused by wind, and the weight of snowfall or ice.

Some of the most common types of light wood trusses are shown in figure 6-38. The W-truss (fig. 6-38, view A) is perhaps the most widely used. It uses four web members assembled in the

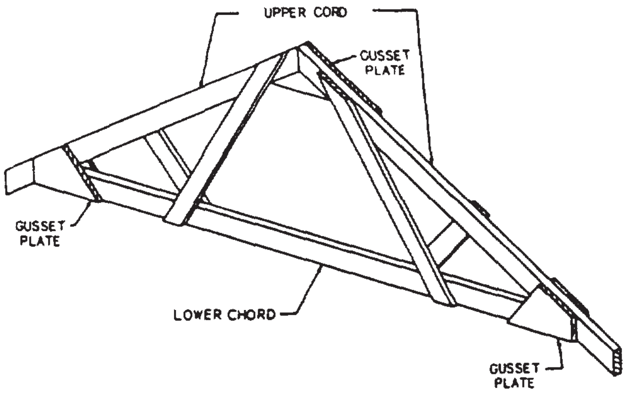


Figure 6-37-Roof or rafter truss.

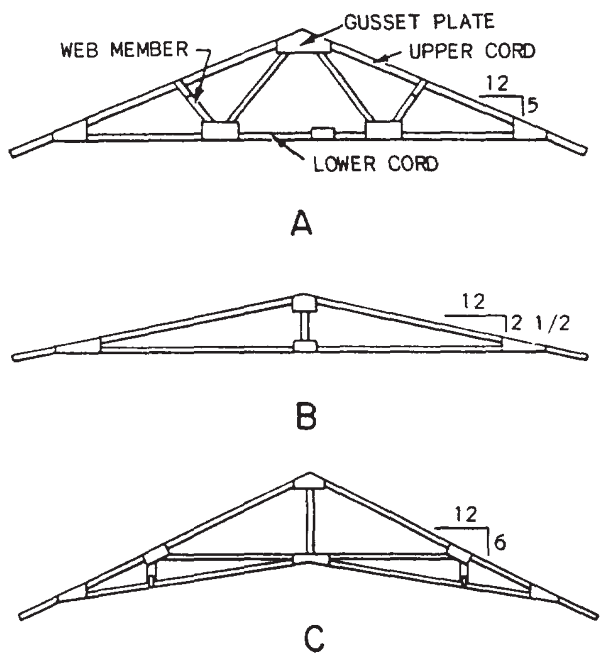


Figure 6-38.-Light wood trusses: A. W-type; B. King post; C. Scissors.

shape of the letter *W* instead of a center post. The KING POST truss is the simplest type of structure. It consists of an upper and lower chord with a vertical center post (fig. 6-38, view B). The SCISSORS truss (fig. 6-38, view C) is used for structures with sloped ceiling room, such as a vaulted ceiling.

BUILDING FINISH

Perhaps the best way to define building finish is to say that it comprises those nonstructural parts of the building. The finish is divided into EXTERIOR finish (located principally on the outside of the structure) and INTERIOR finish (located inside). The work involved in the installation of nonstructural members on the structure is called FINISH CARPENTRY.

EXTERIOR FINISH

The principal items of the exterior finish are the ROOF SHEATHING and COVERING, EXTERIOR TRIM, and WALL SHEATHING. The order in which these items are erected may vary slightly, although in some cases two or more items may be installed at the same time. Normally, roof sheathing is installed as soon as possible to allow work inside a structure to progress during inclement weather.

Roof Sheathing and Roof Covering

Roof sheathing is the covering over the rafters or trusses and usually consists of nominal 1-in. lumber or plywood. In some types of flat or low-pitched roofs, wood roof planking or fiberboard roof decking might be used. Sheathing should be thick enough to span the supports and provide a solid base for fastening the roofing materials. Generally, third grade species of lumber, such as pines, redwoods, and hemlocks, are used as roof sheathing boards.

Board roof sheathing (fig. 6-39) used under asphalt shingles, metal sheet roofing, or other

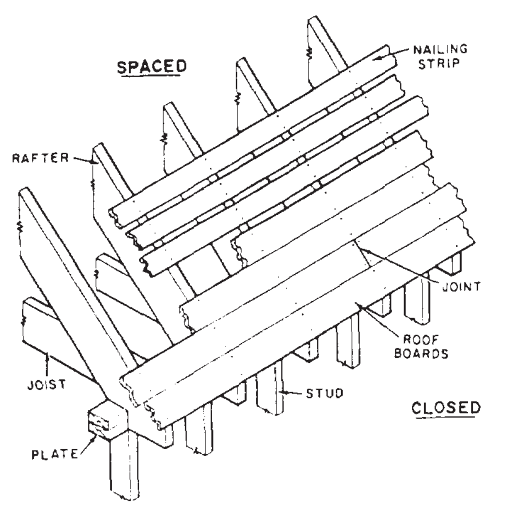


Figure 6-39.-Typical board roof sheathing, showing both closed and spaced types.

roofing materials that require continuous support should be laid closed (without spacing); however, when wood shingles or shakes are used in damp climates, it is common to have spaced roof boards (fig. 6-39). When plywood roof sheathing is used, it should be laid with the grain perpendicular to the rafter (fig. 6-40).

Roof covering materials used for pitched roofs are wood, asphalt shingles, tiles and slate, galvanized iron (GI) sheets, and several other sheet materials. For flat or low-pitched roofs, a built-up construction is also used. An asphalt-saturated felt underpayment called ROOFING FELT is applied over the roof sheathing before the roof covering is installed. The roofing felt serves three basic purposes: It keeps the roof sheathing dry until the shingles can be applied, it acts as a secondary barrier against wind-driven rain and snow, and it protects the shingles from any resinous substance that may be released from the sheathing.

The method of laying an asphalt-shingle roof is shown in figure 6-41. The roofing rolls are usually 36 in. wide with a 2 in. to 4 in. overlap. The shingles are usually laid with 5 in. exposed to the weather. Figure 6-42 shows installation of wood shingles. Wood shingles are available in

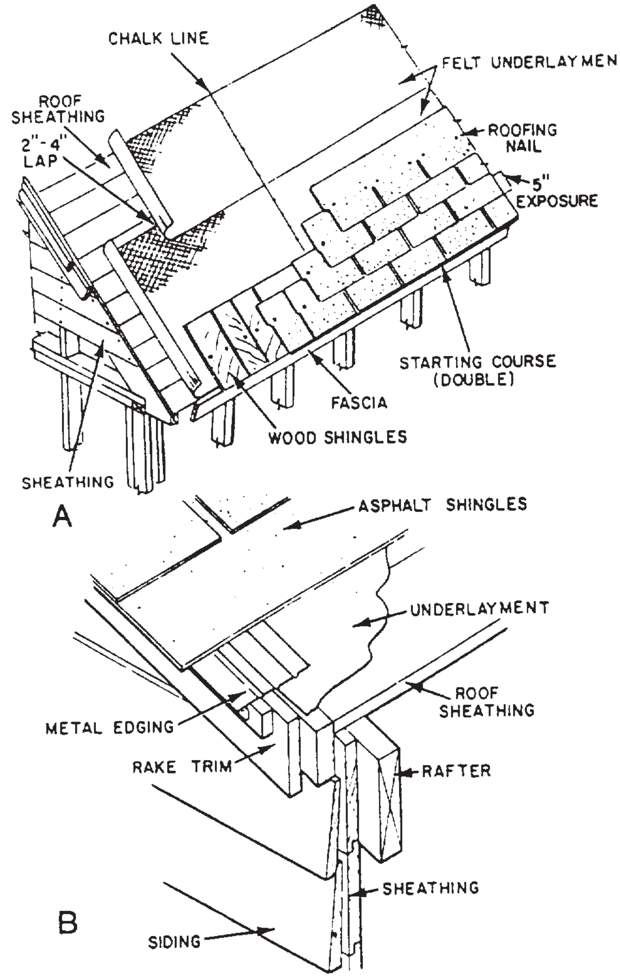


Figure 6-41.-Application of asphalt shingles: A. Common method with strip shingles; B. Metal edging at gable end.

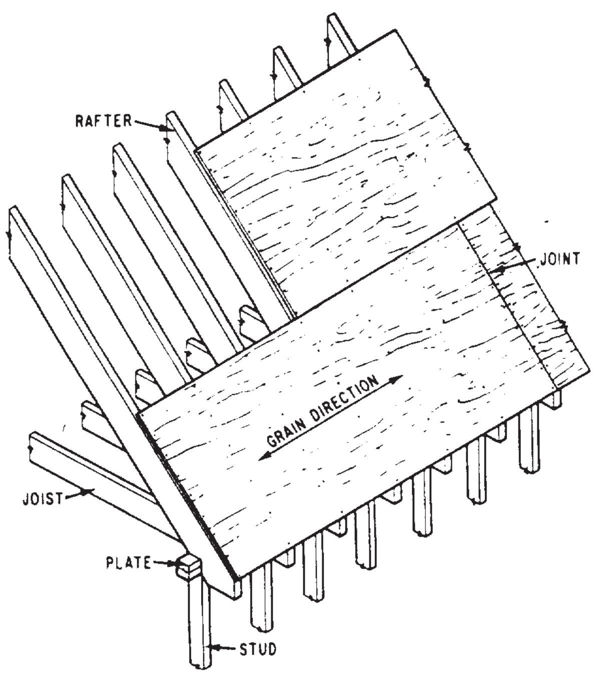


Figure 6-40.-Application of plywood roof sheathing.

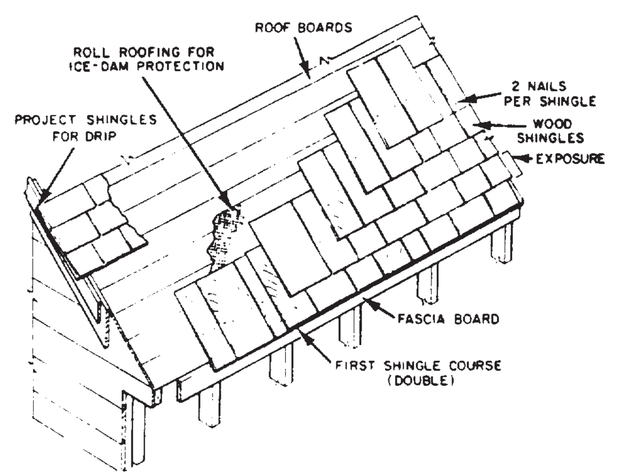


Figure 6-42.-Installation of wood shingles.

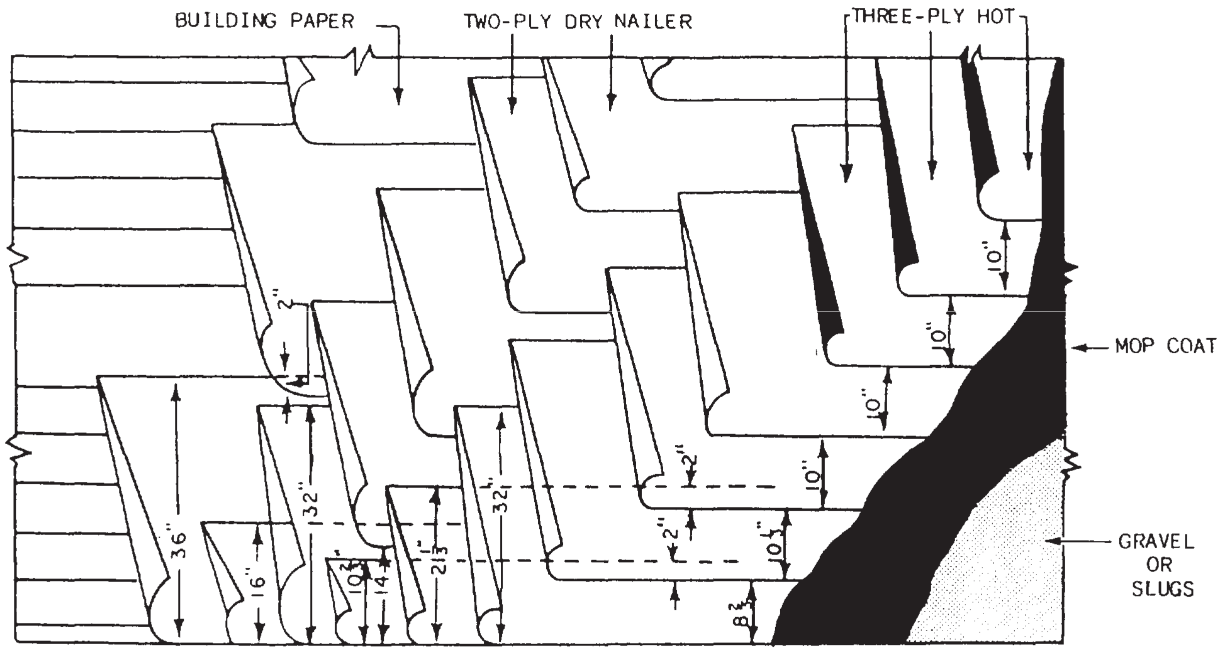


Figure 6-43-A typical building paper and felt on five-ply built-up roof.

three standard lengths: 16, 18, and 24 in. The 16-in. length is perhaps the most popular. Wood shakes are applied in much the same manner as wood shingles.

On flat roofs, the roof covering is usually built up. BUILT-UP ROOFING consists of several layers (plies) of felt, set in a hot binder of melted pitch or asphalt. Built-up roofs are always designated by the number of plies they contain. A five-ply built-up roof is shown in figure 6-43, Notice that aggregate surfacing materials, such as gravel, slag, marble, and other suitable materials, are used in built-up roofing to provide a good weathering surface and protect the bitumens from sunlight and external heat.

Exterior Trim

Before the installation of the roof sheathing is completed, the exterior finish at and just below the eaves of the roof, called CORNICE, can be constructed. The practical purpose of a cornice is to seal the joint between wall and roof against weather penetration. Purely ornamental parts of a cornice are called trim. Figure 6-44 shows a simple type of cornice, used on a roof with no rafter overhang. A roof with a rafter overhang may have the "open" cornice shown in

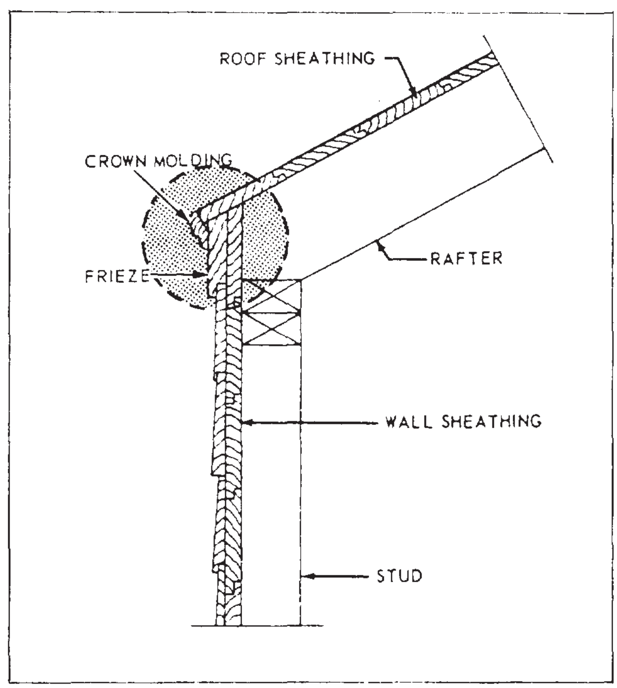


Figure 6-44.-Simple cornice.

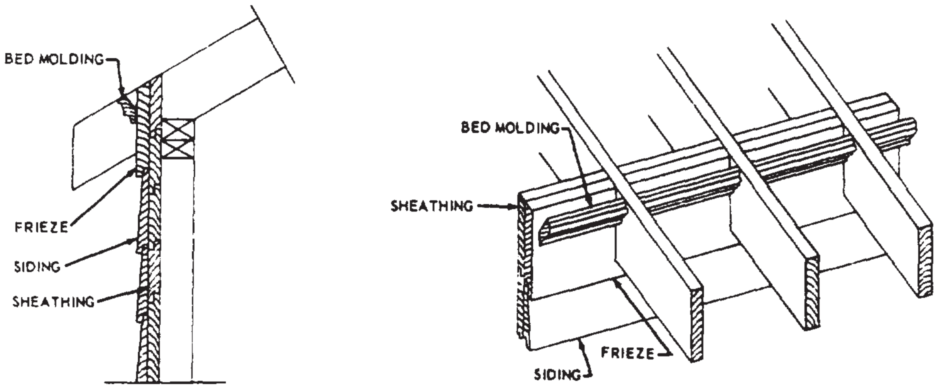


Figure 6-45.-Open cornice without a fascia board.

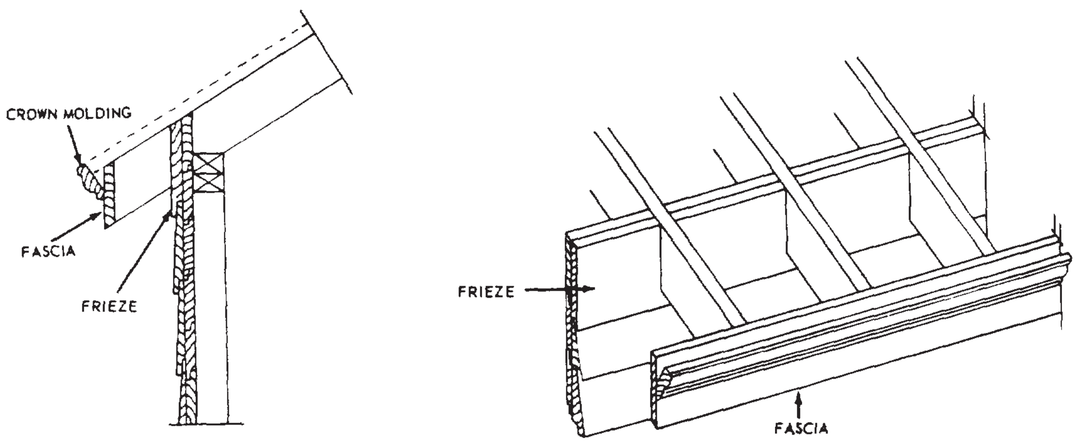


Figure 6-46.-Open cornice with a fascia board.

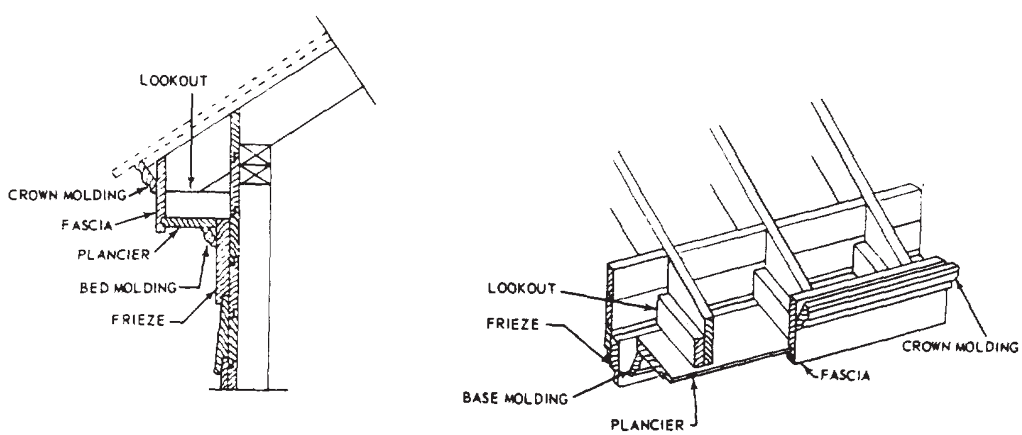


Figure 6-47.-Closed or boxed cornice.

figures 6-45 and 6-46, or the "closed" or "boxed cornice" shown in figure 6-47. A short extension of a cornice along the gable-end wall of a gable-roof structure is called cornice return (fig. 6-48). Finish along the rakes of a gable roof is called the gable cornice trim (fig. 6-49). The rafter-end edges of a roof are called EAVES. A hip roof has eaves all the way around. A gable roof has only two eaves; the gable-end or end-wall edges of a gable roof are called RAKES.

Wall Sheathing

The outside wall sheathing or covering on a frame structure consists of either wood siding or paneling, wood shingles, plywood, fiberboard, hardboard, and/or other types of materials. Masonry, veneers, metal or plastic siding, and other non-wood materials are additional choices. There are two general types of wooden board siding: drop siding and common siding. DROP SIDING (fig. 6-50) is joined edge to edge (rather than overlapping). COMMON SIDING consists of boards that overlap each other single-wise. Boards not more than 4 ft long are called clapboard; boards in longer lengths but not more than 8 in. wide are called bevel siding. A number of drop board and common sidings can be used horizontally or vertically (fig. 6-51), and some

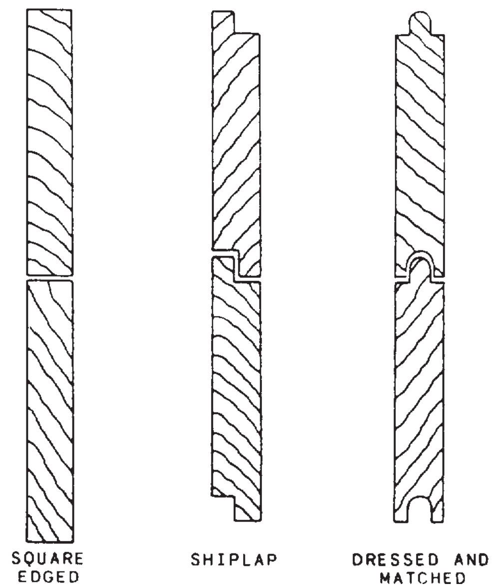


Figure 6-50.-Types of drop siding.

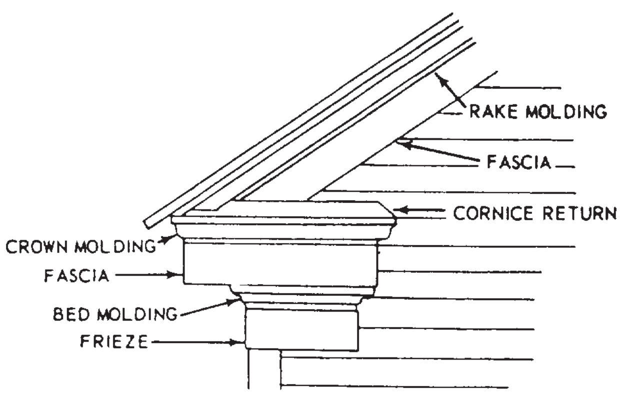


Figure 6-48.-Cornice return.

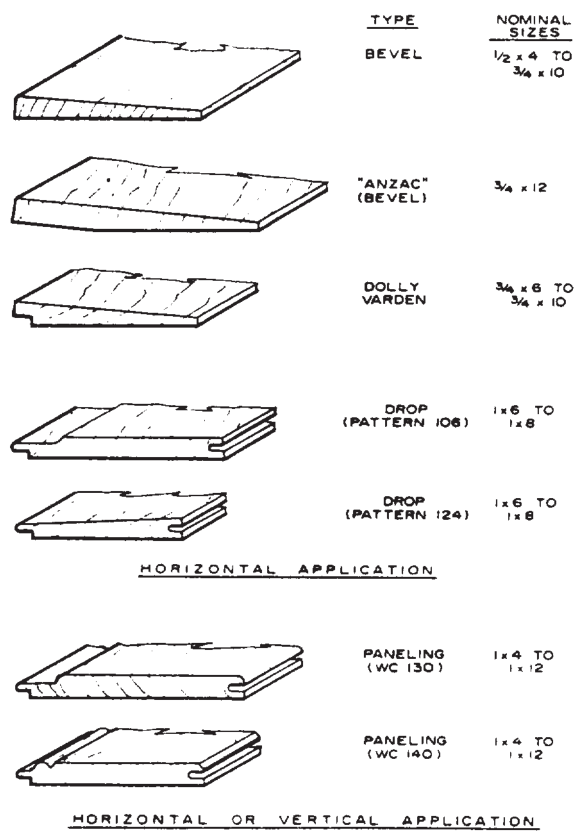


Figure 6-51.-Wood siding types.

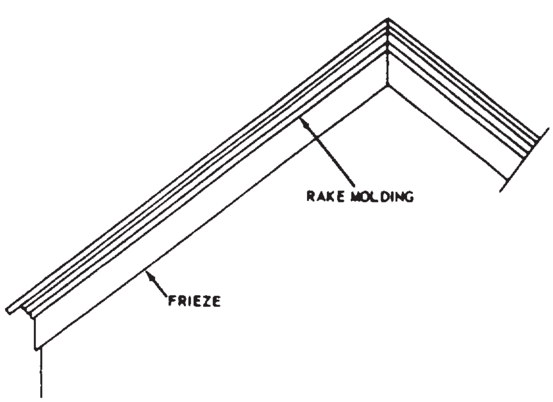


Figure 6-49.-Gable cornice trim.

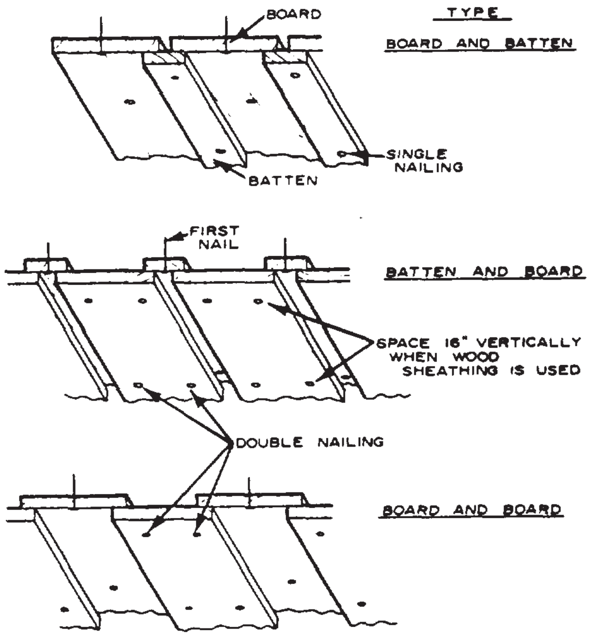


Figure 6-52.-Vertical board siding.

may be used in either manner if adequate nailing areas are provided. Figure 6-52 shows a method of vertical siding application.

Masonry veneers are used effectively with wood sidings in various exterior finishes to enhance the aesthetic appearance of the structure. Other non-wood materials, such as stucco or a cement plaster finish, are favored for an exterior cover because they require a minimum of maintenance. Plastic films on wood sidings or plywood are also used because little or no refinishing is necessary for the life of the building.

Flashing

FLASHING is specially constructed pieces of corrosion-resistant metal or other materials used to protect buildings from water seepage. Flashing should be installed to prevent penetration of water and other moisture in the form of rain or melted snow at the junction of material changes, chimneys, and roof-wall intersection. Flashing should also be used over exposed doors, windows, and roof ridges. Figures 6-53 through 6-57 show areas or locations in which some type of flashing is required.

Flashing materials used on roofs may be asphalt-saturated felt, metal, or plastic. Felt flashing is generally used at ridges, hips, and valleys. However, metal flashing made of aluminum, galvanized steel, or copper, is considered superior to felt.

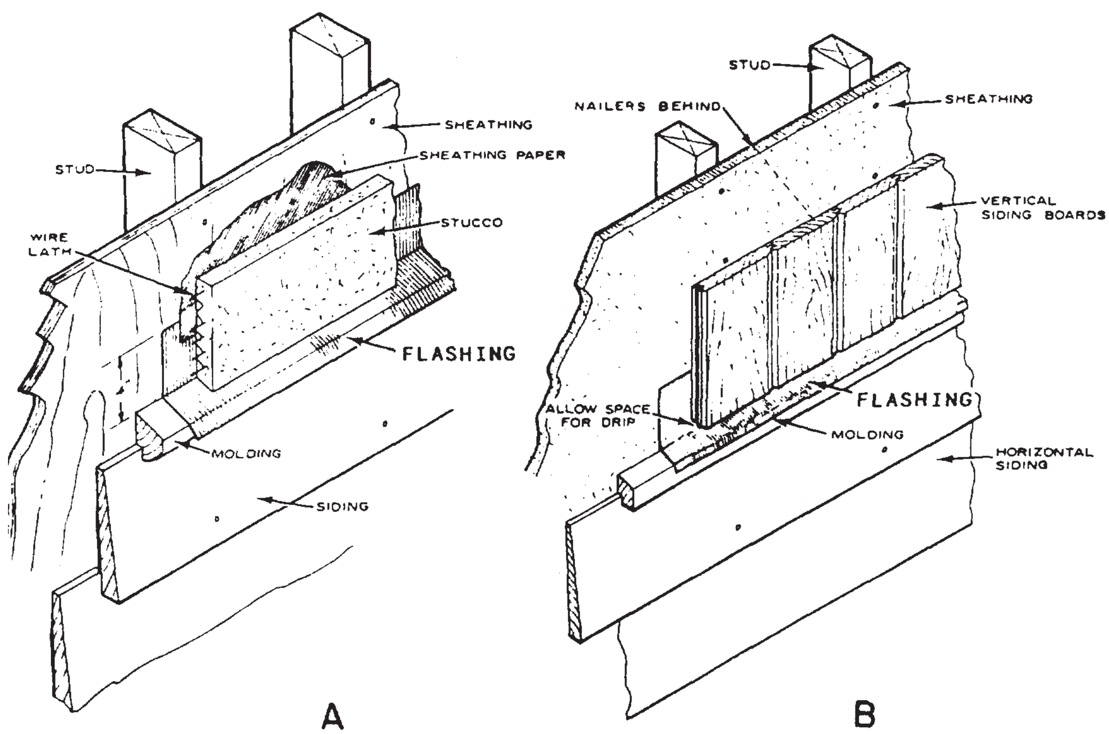


Figure 6-53.-Use of flashing at material changes: A. Stucco above, siding below; B. Vertical siding above, horizontal below,

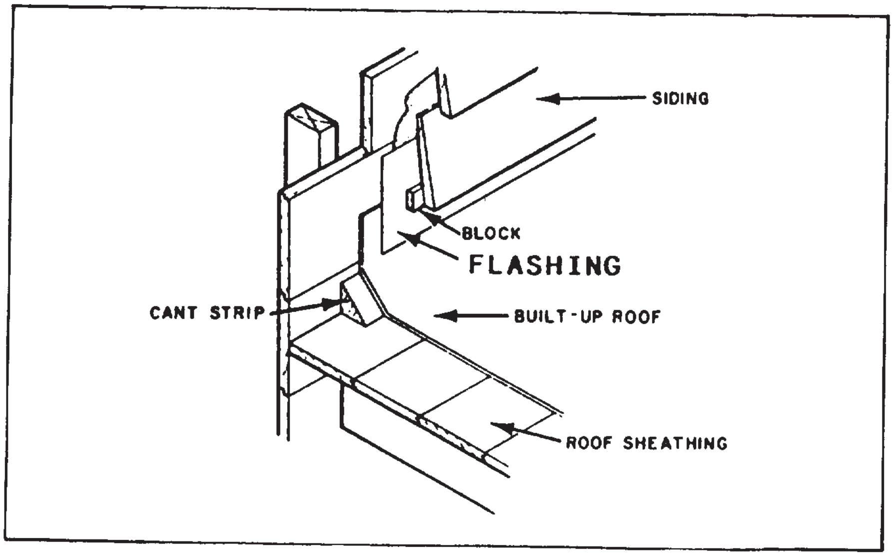


Figure 6-54.-Use of flashing at building line on built-up roof.

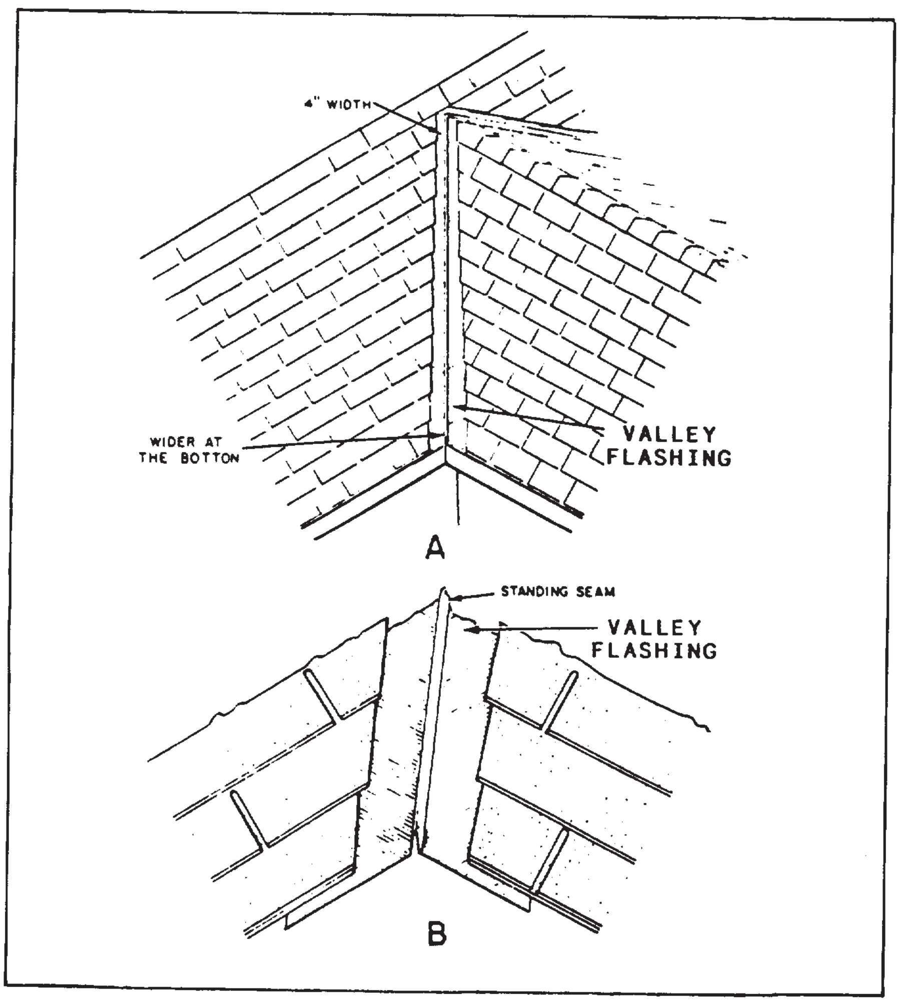


Figure 6-55.-Valley flashing: A. Valley; B. Standing seam.

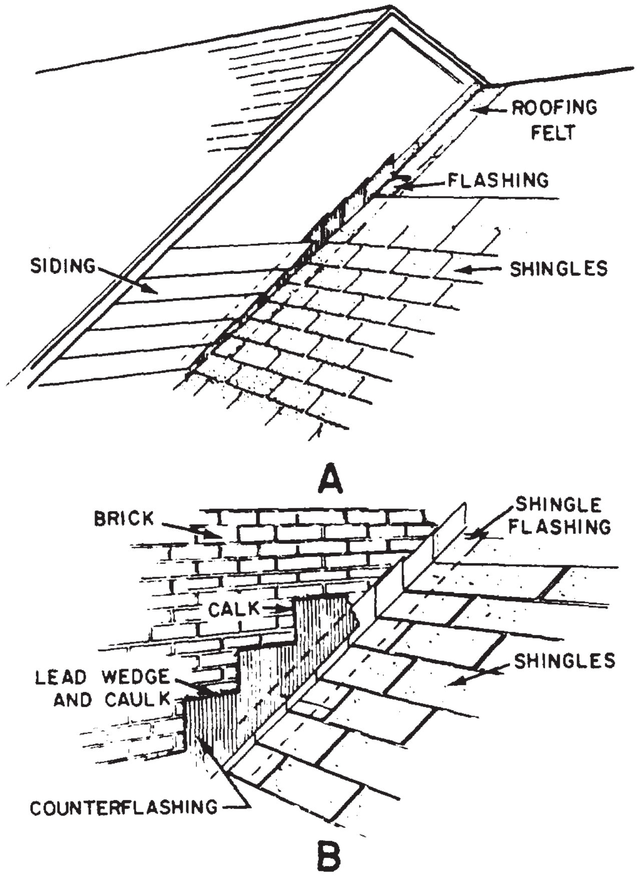


Figure 6-56-Flashing at roof and wall intersection: A. Wood siding wall; B. Brick wall.

Gutters and Downspouts

GUTTERS and DOWNSPOUTS should be installed to keep rainwater away from the foundation of the building (fig. 6-58). Some gutters are built in the cornice and connected to the downspouts (fig. 6-59). The most common types of gutters used are shown in figure 6-60. Gutters and downspouts may be made of galvanized metal, copper, or aluminum. Some have a factory-applied enamel finish. Plastic gutters and downspouts are also available.

INTERIOR FINISH

The INTERIOR FINISH consists mainly of the coverings applied to the rough inside walls, ceiling, and subfloors. Other interior finish items are ceiling and wall coverings, doorframes and window frames, stairs, floor covering, and wood trims. When required, installation of kitchen and built-in cabinets are considered part of the interior finish.

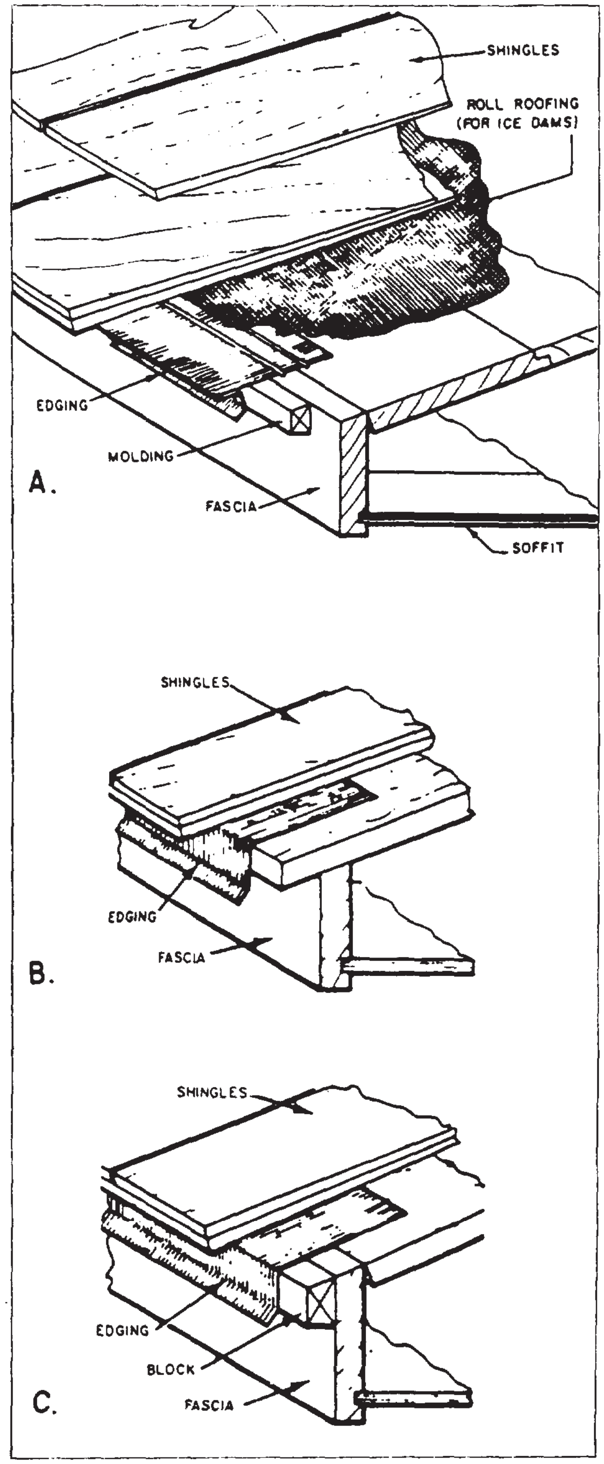


Figure 6-57.-Cornice flashing: A. Formed flashing; B. Flashing without wood blocking; C. Flashing with wood blocking.

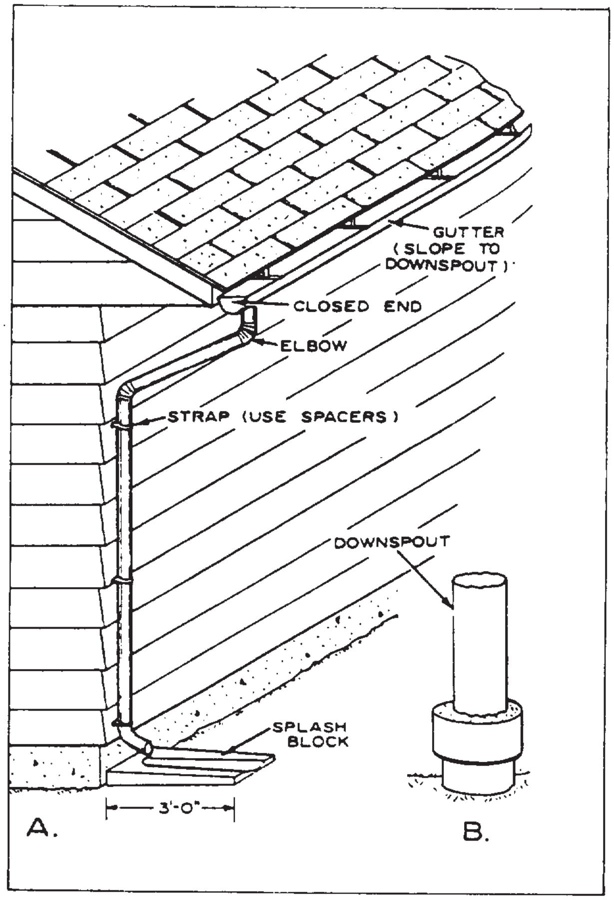


Figure 6-58-Use of gutter and downspout: A. Downspout with splash block; B. Drain to storm sewer.

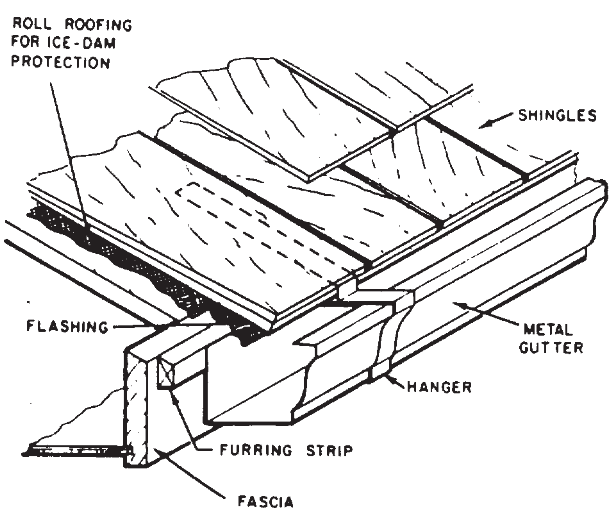


Figure 6-59.-Formed metal gutters.

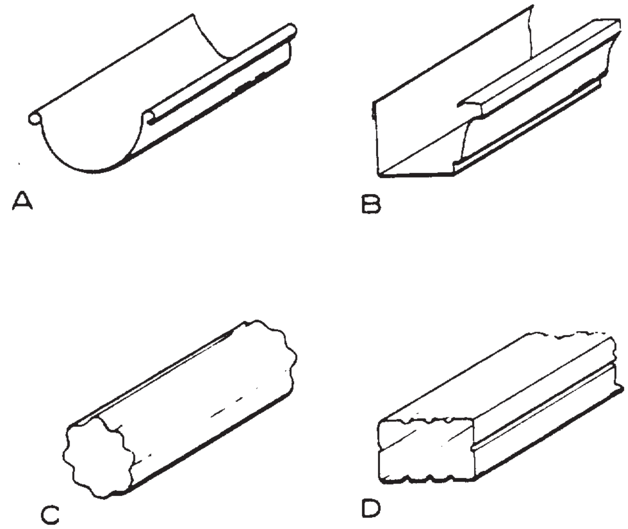


Figure 6-60.-Gutters and downspouts: A. Half-round gutter; B. Formed gutter; C. Round downspout; D. Rectangular downspout.

Ceiling and Wall Covering

Ceiling and wall covering may be broadly divided into PLASTER and DRY-WALL covering. Dry-wall covering is a general term applied to sheets or panels of wood, plywood, gypsum, fiberboard, and the like. A plaster and/or ceiling covering requires a "plaster base" and a "plaster ground" before it is installed. The plaster base, such as gypsum, fiberboard, or metal lath, provides a plane-surface base to which the plaster can be applied. Wooden strips of the same thickness as the combined thickness of the lath and plaster, called plaster ground, are installed before the lath is applied to serve as guides for the plasterers to ensure uniform plaster thickness around doorframes and window frames and behind casings.

The use of dry wall over the lath-and-plaster finish is rapidly increasing. Installation or construction time is faster with the application of dry wall. Being wet, plaster requires drying time before other interior work can be started. Gypsum is one of the most widely used types of dry-wall finishes. It is made up of a gypsum filler faced with paper or with a foil back that serves as a vapor barrier on exterior walls. It is also available with vinyl or other prefinished surfaces. It comes in 4- by 8-ft sheets and in lengths of up to 16 ft for horizontal application. Notice in

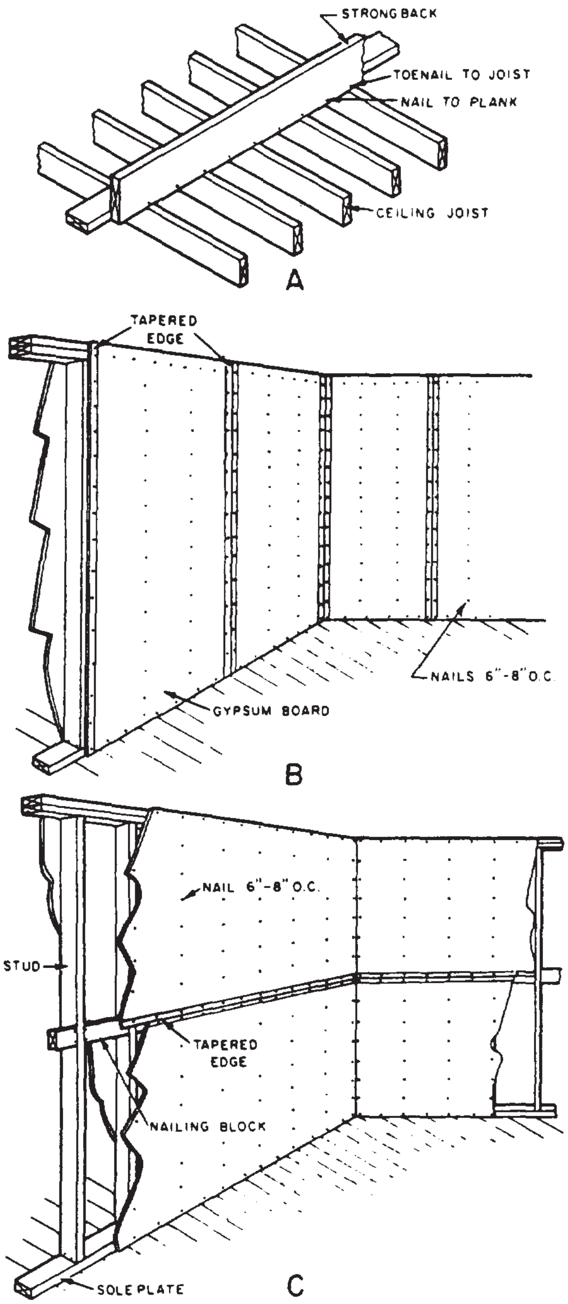


Figure 6-61—Application of gypsum board finish: A. Strongback B. Vertical application; C. Horizontal application.

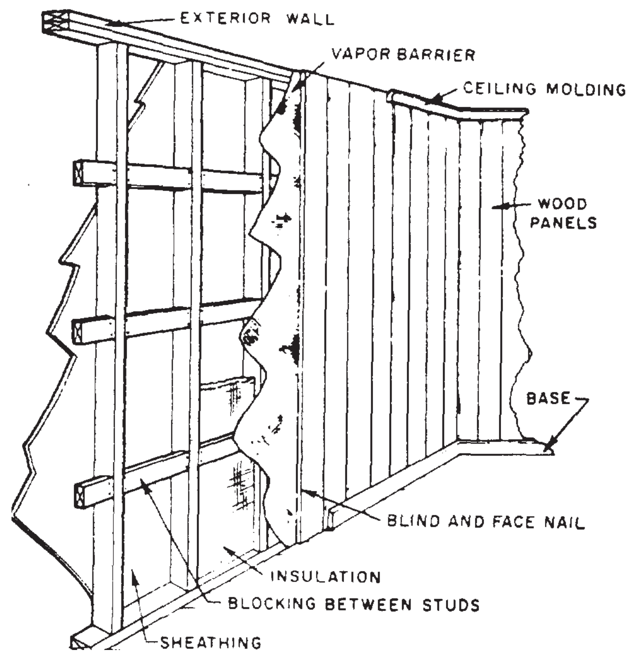


Figure 6-62.-Application of vertical paneling.

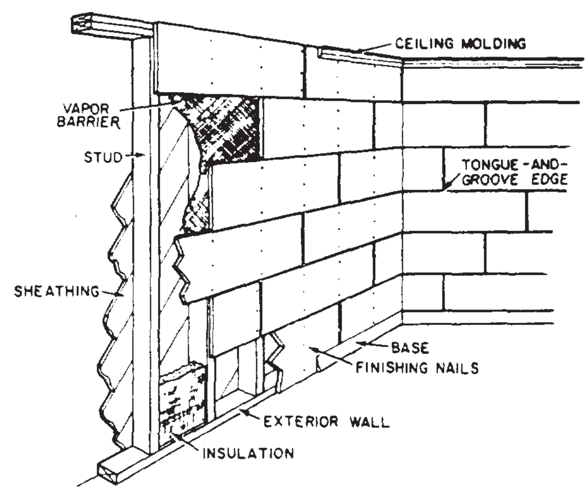


Figure 6-63.-Application of tongued-and-grooved paneling over studs.

figure 6-61, view A, a "strongback" is usually used for aligning ceiling joists or studs to provide a smooth, even surface. Figures 6-62 and 6-63 show typical application of paneling using other types of dry-wall finishes.

A variety of ceiling systems can also be used to change the appearance of a room, lower a ceiling, finish off exposed joints, or provide acoustical control. Suspended acoustical ceiling systems are designed to integrate the functions of lighting, air distribution, and fire protection. Acoustical tiles, available in 12-to 30-in. widths, 12- to 60-in. lengths, and 3/16- to 3/4-in. thicknesses, are used with the other grid system components (fig. 6-64). Depending on the type of ceiling or roof construction, ceiling tiles may be installed in various ways, such as with the use of wood strips nailed across the ceiling joists or roof trusses (fig. 6-65).

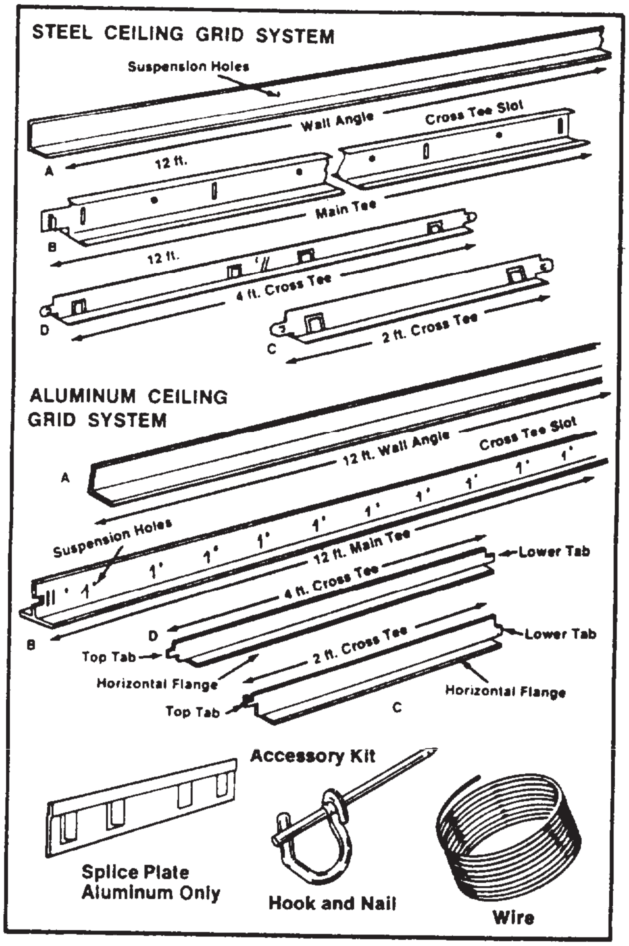


Figure 6-64.-Grid system components.

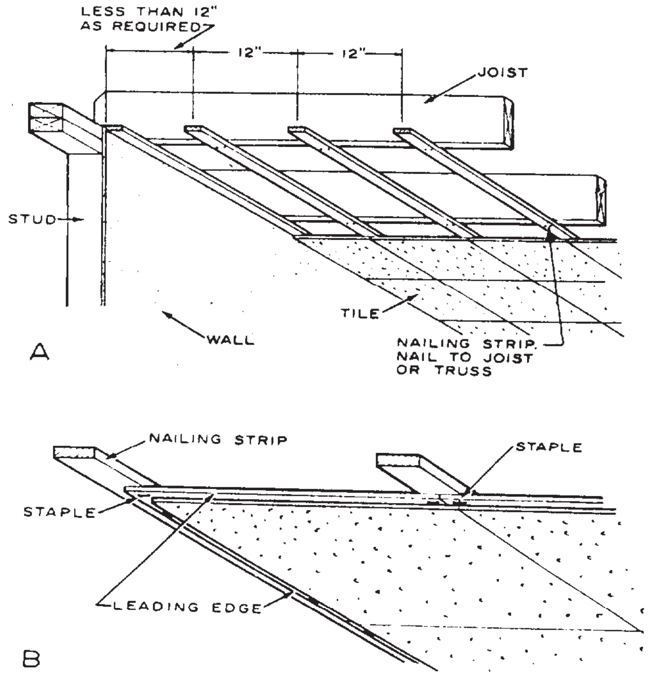


Figure 6-65.-Ceiling tile assembly: A. Nailing strip location; B. Stapling.

Insulation and Vapor Barriers

Heat inflow or outflow has important effects upon the occupants of a building. The use of insulation improves comfort conditions and savings in fuel. The materials commonly used for insulation may be classified as blanket, batt, loose-fill, reflective, and rigid. These materials are manufactured in a variety of forms and types, and their insulating values vary with the type of construction, kinds of construction materials used, and thickness of insulation. Figure 6-66 shows different types of insulation commonly used in construction.

Vapor barriers should be used to keep moisture from seeping through walls, floors, and ceiling materials. Among the effective vapor-barrier materials are asphalt laminated papers, aluminum foil, and plastic film. Most blanket and batt insulations (fig. 6-66) have paper-backed aluminum foil on one side to serve as a vapor

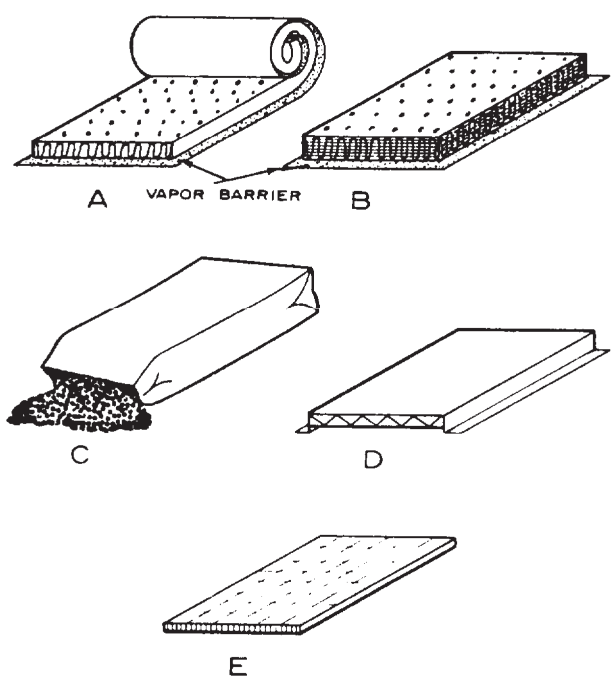


Figure 6-66.-Types of insulation: A. Blanket; B. Batt; C. Fill; D. Reflective (one type); E. Rigid.

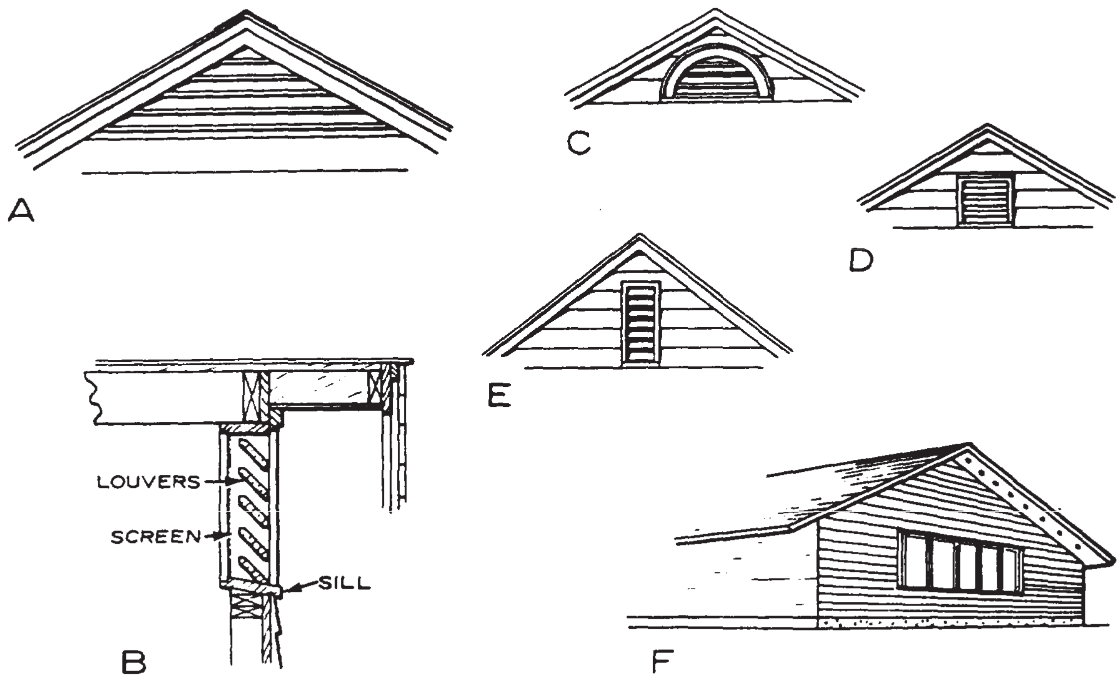


Figure 6-67.-Outlet ventilators: A. Triangular; B. Typical cross section; C. Half-circle; D. Square; E. Vertical; F. Soffit.

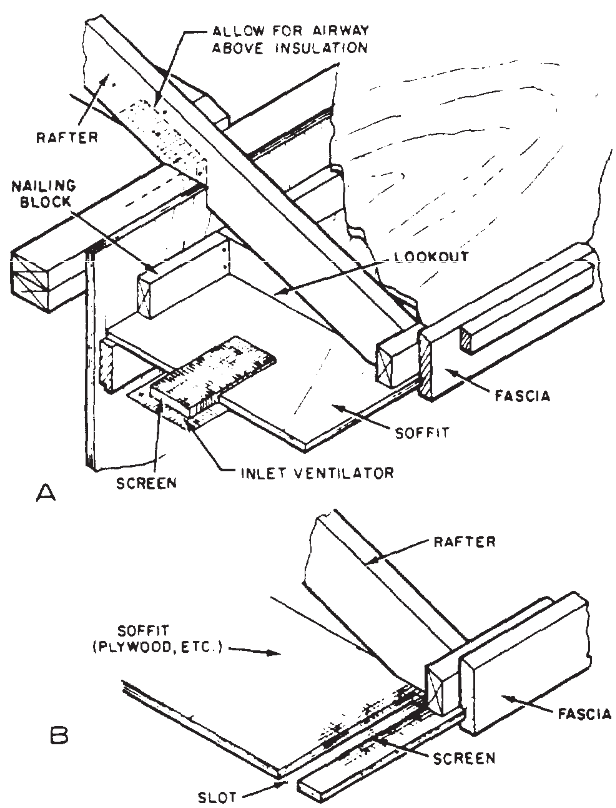


Figure 6-68.-Inlet ventilators: A. Small insert ventilator; B. Slot ventilator.

barrier. Foil-backed gypsum lath or gyspum boards are also available and serve as excellent vapor barriers. Where other types of membrane vapor barriers were not installed during construction, several coats of paint do provide some protection. Aluminum primer and then several coats of flat wall or oil paint are effective in retarding vapor transmission.

Even where vapor barriers are used, condensation of moisture vapor may occur in the attic, in roof spaces, and in crawl spaces, if any, under the building or porch. In such spaces, VENTILATION is the most practical method of removing condensed or hot air that may otherwise facilitate decay to the structure. It is common practice to install ventilators, several types of which are shown in figures 6-67 and 6-68.

Stairs

The two principal elements in a stairway are the TREADS, which people walk on, and the STRINGERS (also called springing trees, strings, horses, and carriages), which support the treads. The simplest type of stairway, shown at the left in figure 6-69, consists of these two elements alone.

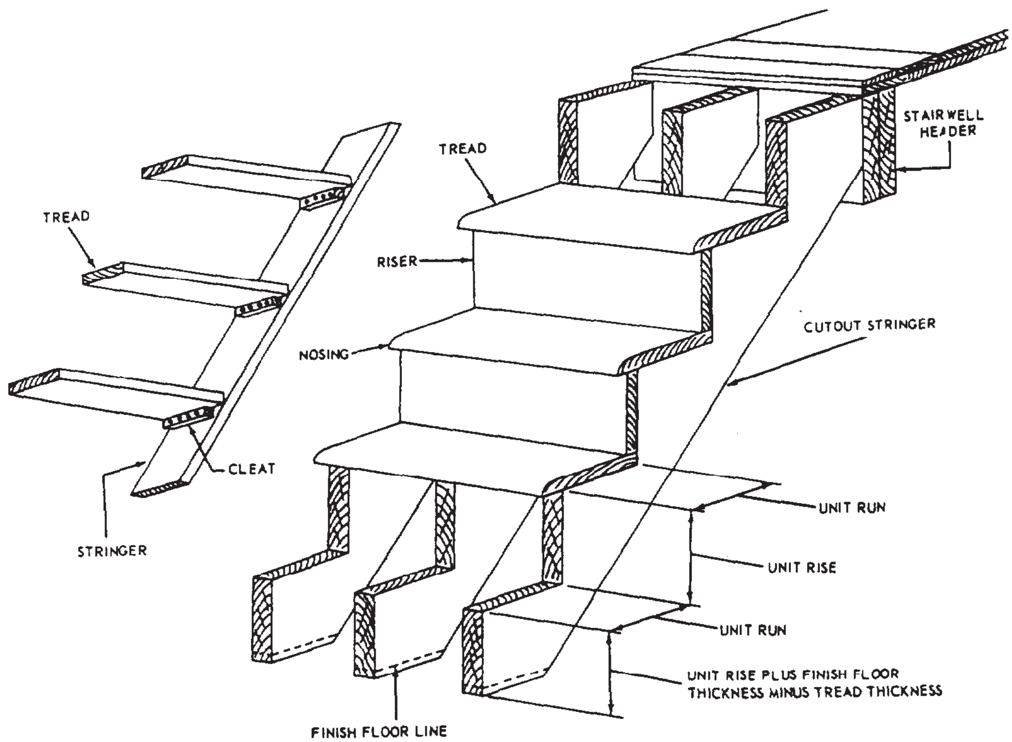


Figure 6-69.-Parts of a stairway.

Additional parts commonly used in a finished stairway are shown at the right in figure 6-69. The stairway shown here has three stringers, each of which is sawed out of a single timber. For this reason, a stringer of this type is commonly called a CUTOUT or SAWED stringer. On some stairways, the treads and risers are nailed to triangular stair blocks attached to straight-edged stringers.

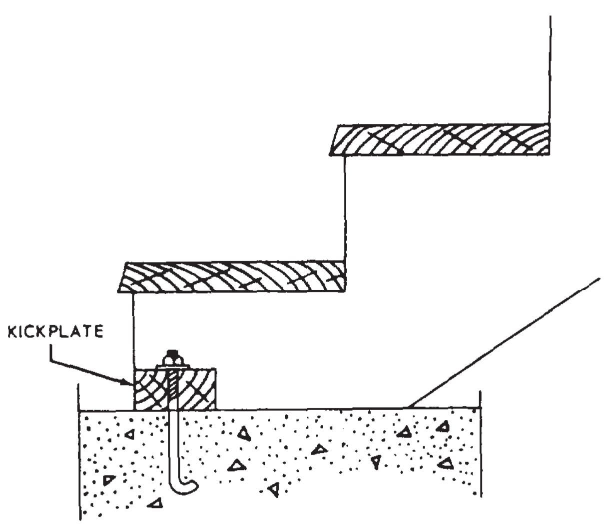


Figure 6-70.-Kickplate for anchoring stairs to concrete.

A stairway that continues in the same straight line from one floor to the next is called a STRAIGHT-FLIGHT stairway. When space does NOT permit the construction of one of these, a CHANGE stairway (one that changes direction one or more times between floors) is installed. A change stairway in which there are platforms between sections is called a PLATFORM stairway.

Stairs in a structure are divided into PRINCIPAL STAIRS and SERVICE STAIRS. Principal stairs are those extending between floors above the basement and below the attic floor. Porch, basement, and attic stairs are service stairs. The lower ends of the stringers on porch, basement, and other stairs anchored on concrete are fastened with a kickplate (fig. 6-70).

Finish Flooring

Finish flooring is broadly divided into wood finish flooring and resilient finish flooring. Most wood finish flooring comes in strips that are

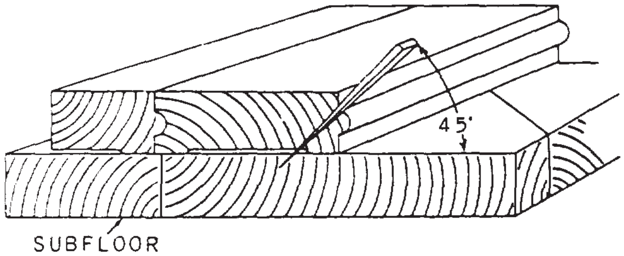


Figure 6-71.-Toenailing wood finish flooring.

side-matched; that is, tongue-and-grooved for edge-joining; some is end-matched as well. Wood flooring strips are usually recessed on the lower face and toenailed through the subflooring into joists, as shown in figure 6-71.

In Navy structures, wood finish flooring has been largely supplanted by various types of resilient flooring, most of which is applied in the form of 6 by 6, 9 by 9, or 12 by 12 floor tiles. Materials commonly used are asphalt, linoleum, cork, rubber, and vinyl. With each type of tile, the manufacturer recommends an appropriate type of adhesive for attaching the tile to the subflooring.

On other areas subject to a high degree of dampness, ceramic or glazed interior tile is most commonly used. Ceramic tiles are used to cover all or part of the bathrooms, shower rooms, and some kitchen floors.

Doors

Standard doors and combination doors (storm and screen) are millwork items that are usually fully assembled at the factory and ready for use in the building. All wood components are treated with a water-repellent preservative to provide protection against the elements. Doors are manufactured in different styles, as shown in figure 6-72.

Exterior doors, outside combination doors, and storm doors may be obtained in a number of designs to fit the style of almost any building. Doors in the traditional pattern are usually of the panel type (fig. 6-72, view A). A PANEL DOOR consists of stiles (solid vertical members), rails (solid cross members), and filler panels in a number of designs. Exterior FLUSH DOORS use a solid-core, rather than hollow-core type to minimize warping. (Warping is caused by a difference in moisture content on the exposed and unexposed faces of the door.) Weatherstripping should be installed on exterior doors to reduce both air infiltration and frosting of the glass on the storm door during cold weather. Flush doors consist of thin plywood faces over a framework of wood with a wood block or particleboard core.

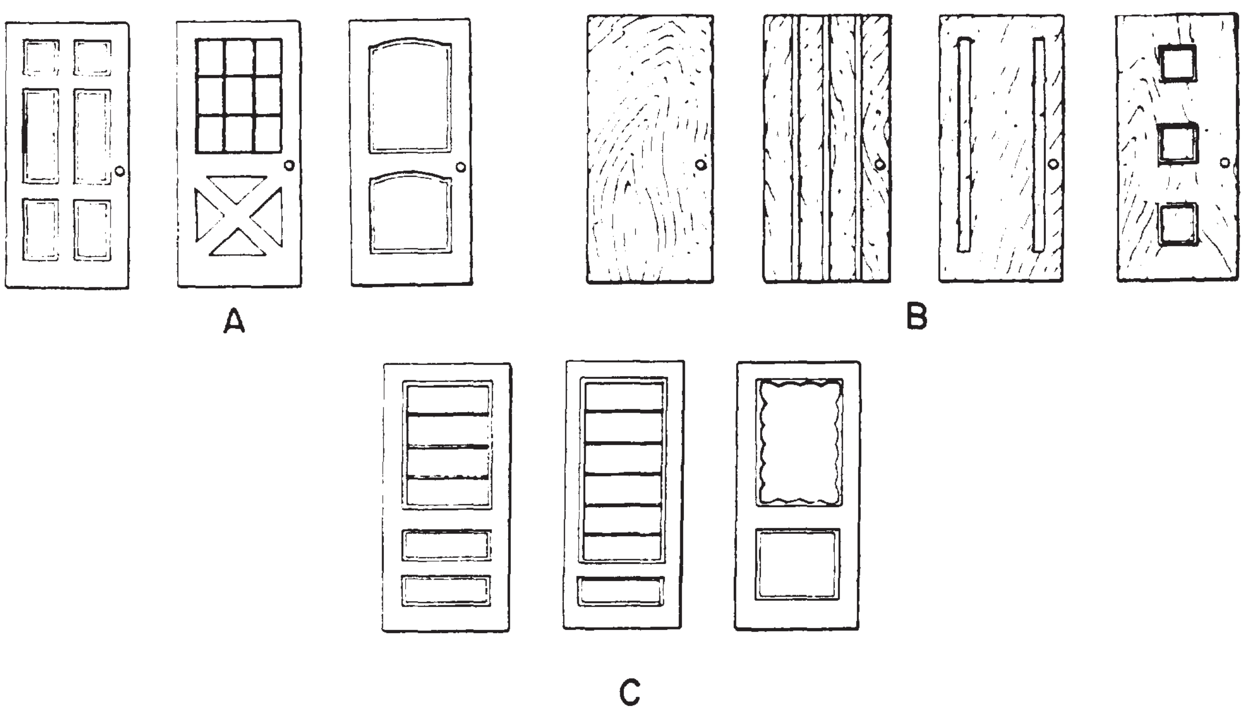


Figure 6-72.-Exterior doors: A. Traditional panel; B. Flush; C. Combination.

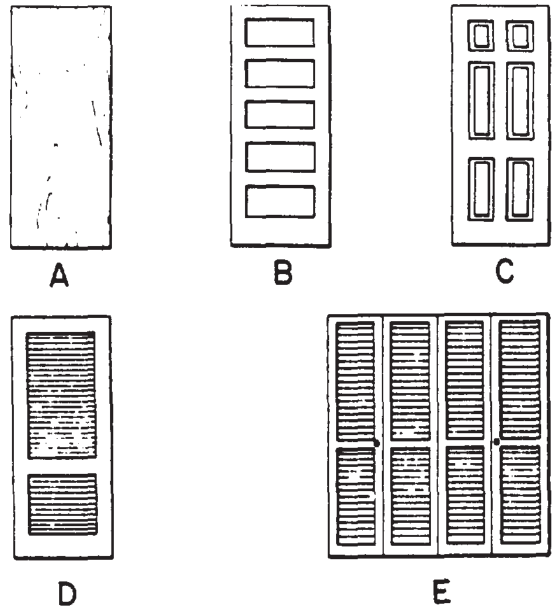


Figure 6-73-Interior doors: A. Flush; B. Panel (five-cross); C. Panel (colonial); D. Louvered; E. Folding (louvered).

Exterior doors are usually 1 3/4 in. thick and not less than 6 ft 8 in. high. The main entrance door is 3 ft wide, and the side or rear door is normally 2 ft 8 in. wide. The exterior trim used can vary from a simple CASING (the trim used around the edges of door openings and also as a finishing trim on the room side of windows and exterior door-frames) to a molded or plain pilaster.

Similarly, interior doors also come in many styles (fig. 6-73). The two principal types are flush and panel doors. Interior panel doors (colonial and five-cross type) are manufactured to be similar to the exterior doors, Novelty doors, such as the folding door unit, are commonly used for closets because they provide ventilation. The interior flush door is usually made up with a hollow core of light framework covered with thin plywood or hardboard. Most standard interior doors are 1 3/8 in. thick.

Hinged doors should open or swing in the direction of natural entry, against a blank wall, and should not be obstructed by other swinging doors. Doors should NEVER be hinged to swing into a hallway.

Figure 6-74 shows the principal parts of a finish doorframe. On an outside door, the frame

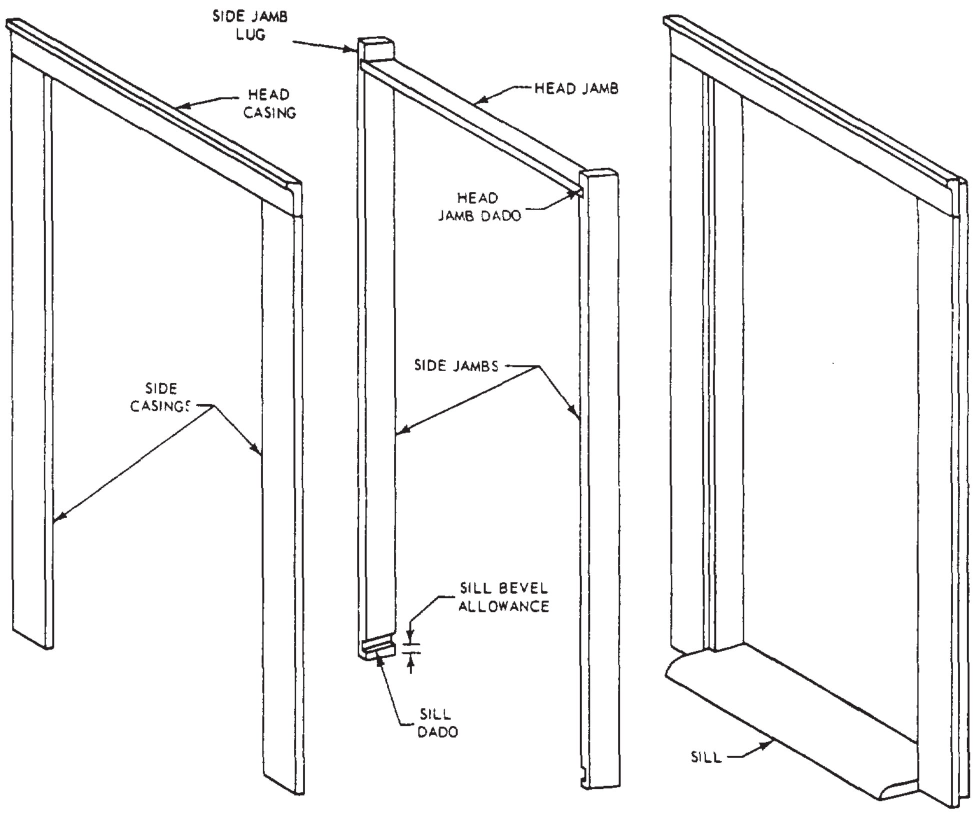


Figure 6-74.-Principal parts of a finish doorframe.

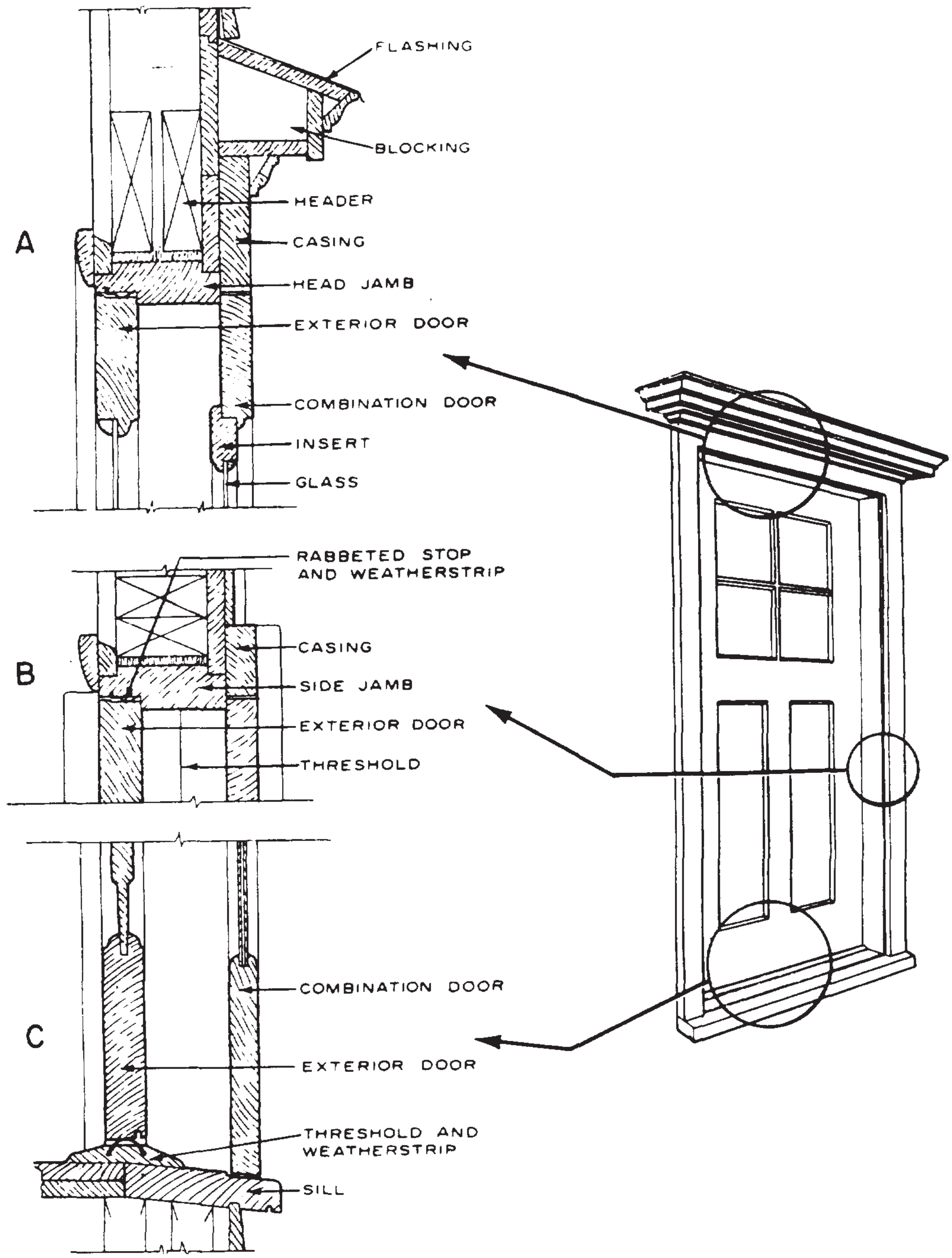


Figure 6-75.-Exterior door and frame. Exterior door and combination door (screen and storm) cross sections: A. Head jamb; B. Side jamb; C. Sill.

includes the side and head casings. On an inside door. the frame consists only of the side and head jambs; the casings are considered part of the inside-wall covering.

Figure 6-75 shows section drawings of exterior doorframe details.

Windows

The part of a window that forms a frame for the glass is called sash, and window sash is considered part of the interior, not the exterior, finish. However, a window with a sash that is

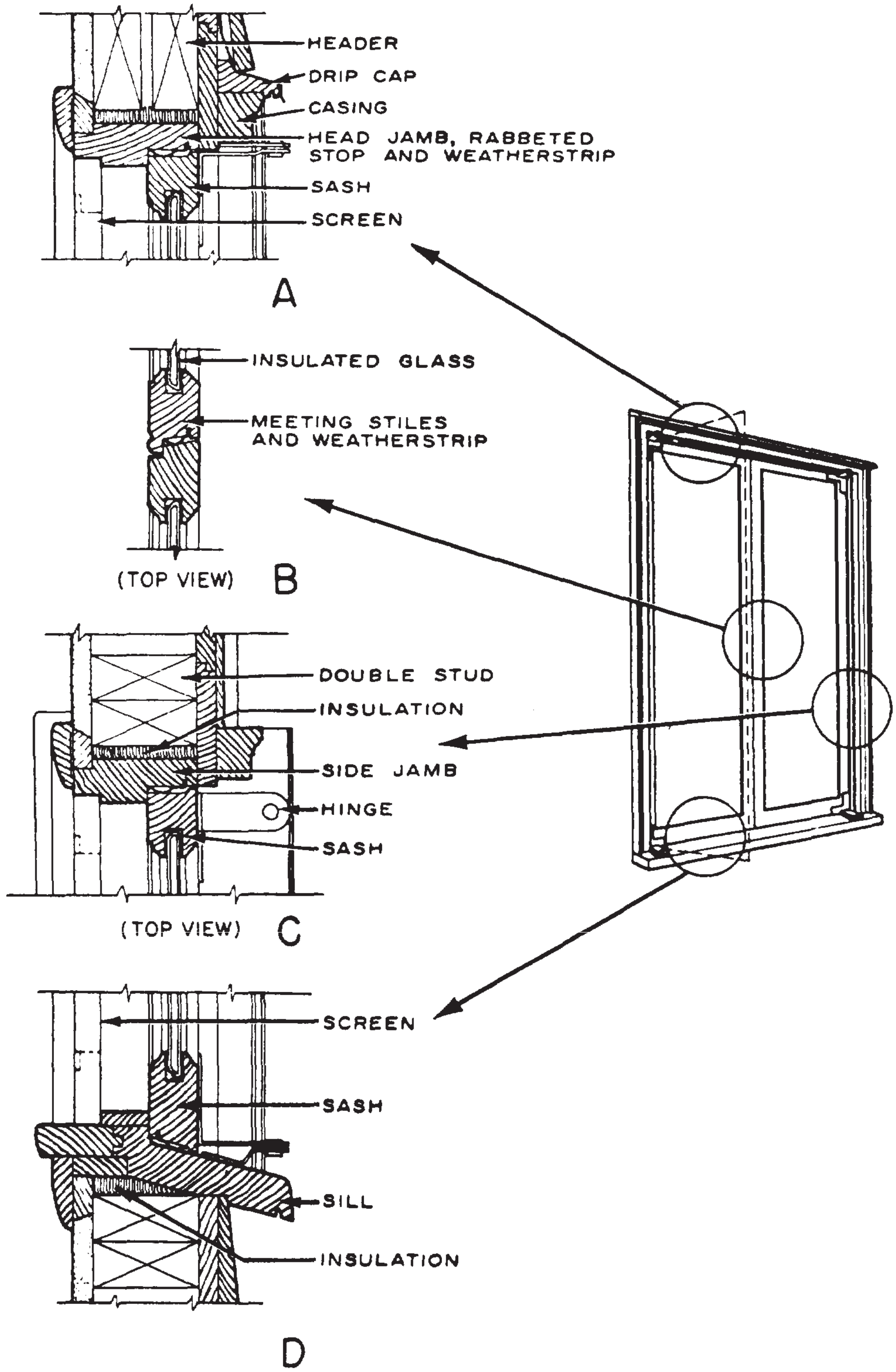


Figure 6-76.-Outswinging casement sash. Cross sections: A. Head jamb; B. Meeting stiles; C. Side jambs; D. Sill.

hinged at the side is called a casement window (fig. 6-76)—single casement if there is only one sash, double casement if there are two. A window that is hinged at the top or bottom is called a transom window. One with a number of horizontally hinged sashes that open and close together like the slats in a venetian blind is a jalousie window. A window having two sashes that slide vertically past each other is a double-hung window.

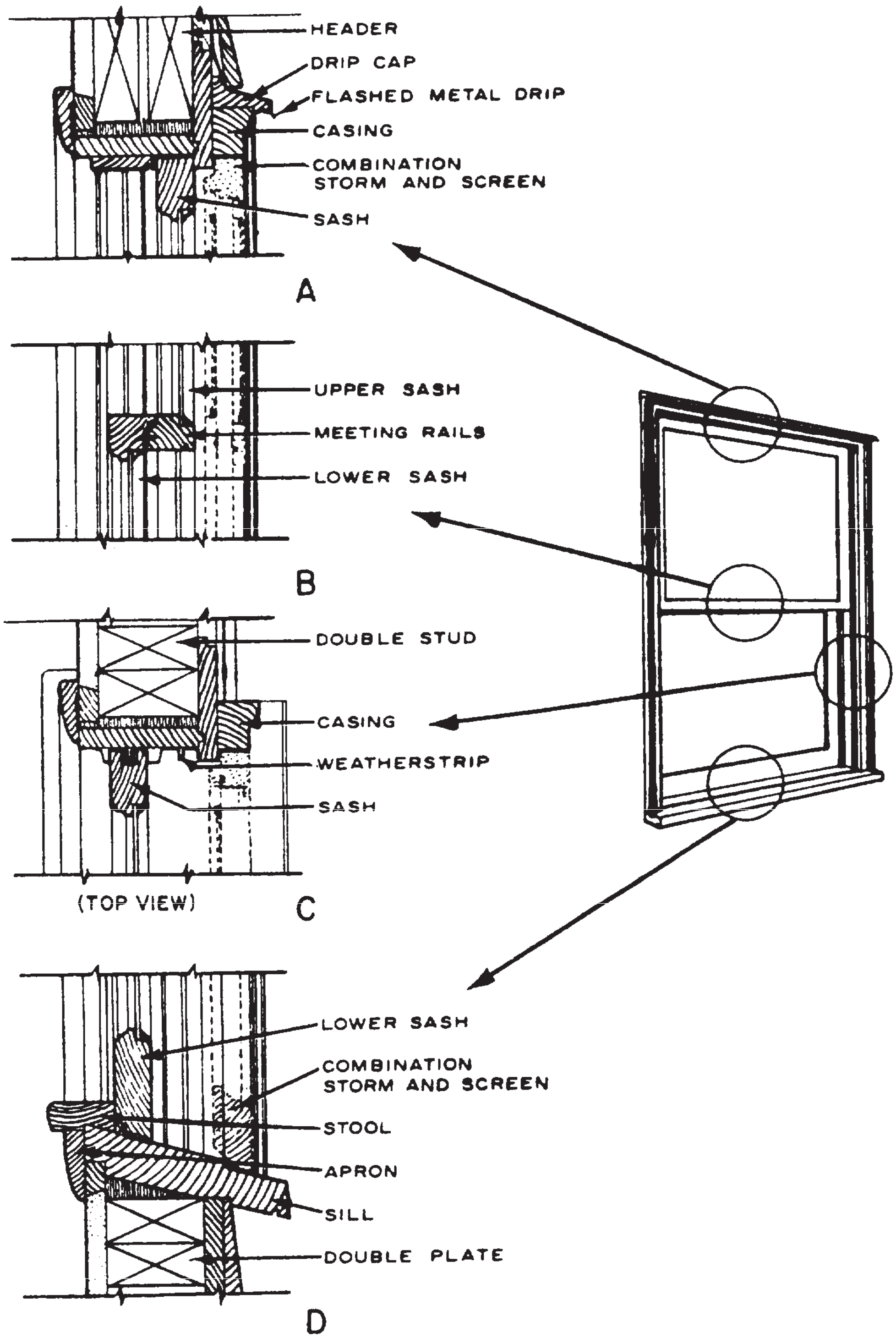


Figure 6-77.-Double-hung windows. Cross sections: A. Head jamb; B. Meeting rails; C. Side jambs; D. Sill.

Basically, the finish frames for all of these are much alike, consisting principally, like a finish doorframe, of side jambs, head jamb, sill, and outside casing (the inside casing being considered part of the inside-wall covering). However, a double-hung window frame contains some items that are NOT used on frames for other types of windows. Section drawings showing head- and side-jamb details for a double-hung window are shown in figure 6-77. Sill details are shown in figure 6-78.

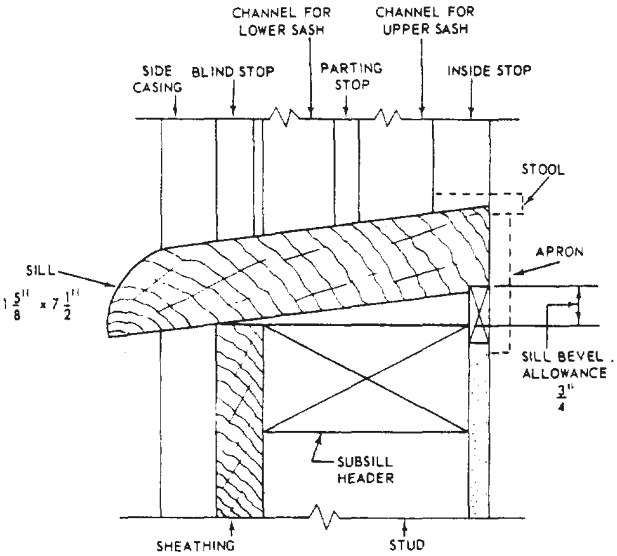


Figure 6-78.-Sill detail for a double-hung window.

A window schedule on the construction drawings gives the dimensions, type, such as casement, double-hung, and so forth, and the number of lights (panes of glass) for each window in the structure. A window might be listed on the schedule as, for example, No. 3, DH, 2 ft 4 in. by 3 ft 10 in, 12 LTS. This means that window No. 3 (it will have this number on any drawing in which it is shown) is a double-hung window with a finished opening, measuring 2 ft 4 in. by 3 ft 10 in. and having 12 lights of glass. In any view in which the window appears, the arrangement of the lights will be shown. On one of the lights, a figure such as 8/10 will appear. This means that each light of glass has nominal dimensions of 8 by 10 in.

Figure 6-79 shows a double-hung window sash and the names of its parts.

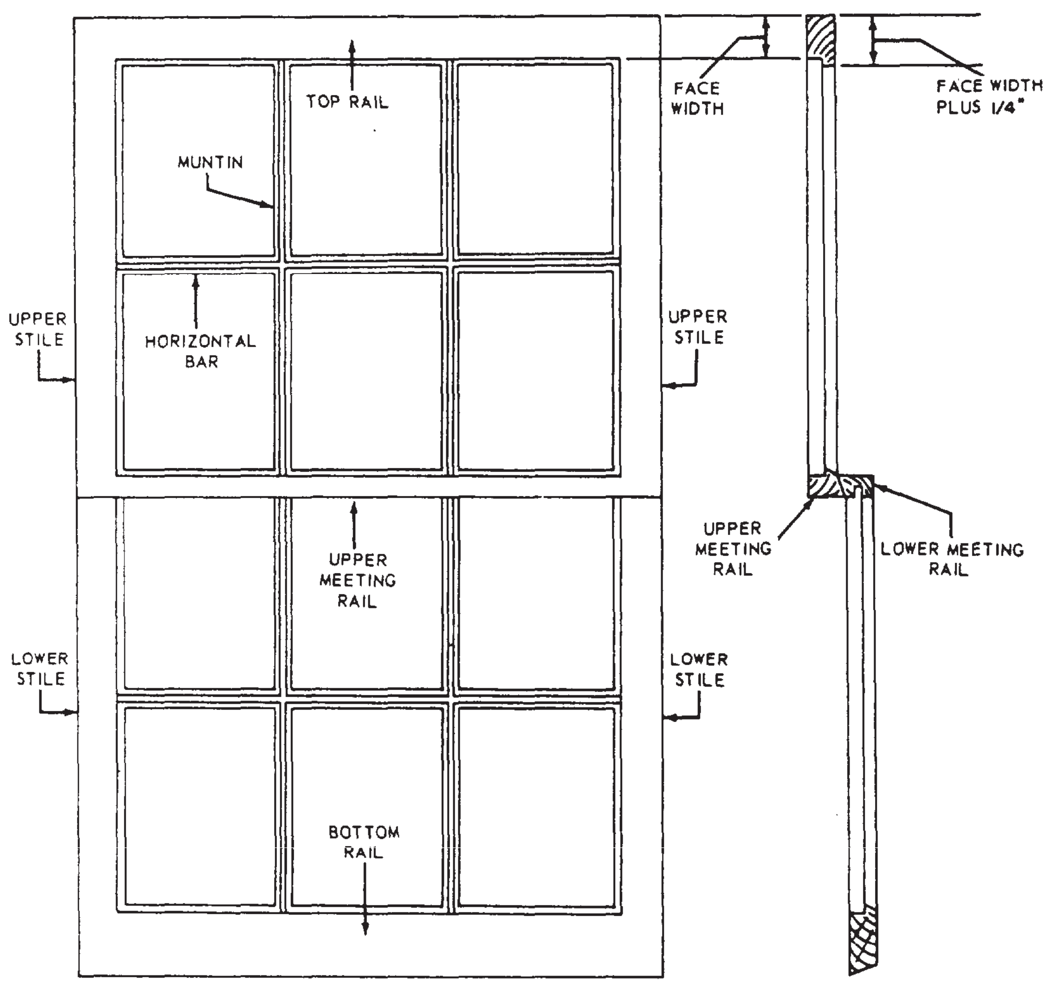


Figure 6-79.-Parts of a double-hung window sash.

Wood Trims

The most prominent items in the interior trim are the inside door and the window casings, which may be plain-faced or ornamentally molded in various ways. Another item is the baseboard, which covers the joint between an inside wall and finish floor (fig. 6-80). Baseboards or base molding are available in several widths and forms. Figures 6-81 and 6-82 show areas where some types of molding are desirable.

HARDWARE

HARDWARE is a general term covering a wide variety of accessories that are usually made of metal or plastic and ordinarily used in building construction. Hardware includes both finishing and rough hardware.

FINISHING HARDWARE consists of items that are made in attractive shapes and finishes and are usually visible as an integral part of the finished structure. Included are locks, hinges, door pulls, cabinet hardware, window fastenings, door closers and checks, door holders, and automatic exit devices. In addition, there are the lock-operating trim, such as knobs and handles, escutcheon plates, strike plates, and knob rosettes. There are also push plates, push bars, kickplates, doorstops, and flush bolts.

ROUGH HARDWARE consists of items that are NOT usually finished for an attractive appearance. These items include casement and special window hardware, sliding and folding door supports, and fastenings for screens, storm windows, shades, venetian blinds, and awnings.

Other items may be considered hardware. If you are not sure whether an item is hardware or what its function is, refer to a commercial text, such as the *Architectural Graphic Standards.*

FASTENERS

The devices used in fastening or connecting members together to form structures depend on the kinds of material the members are made of.

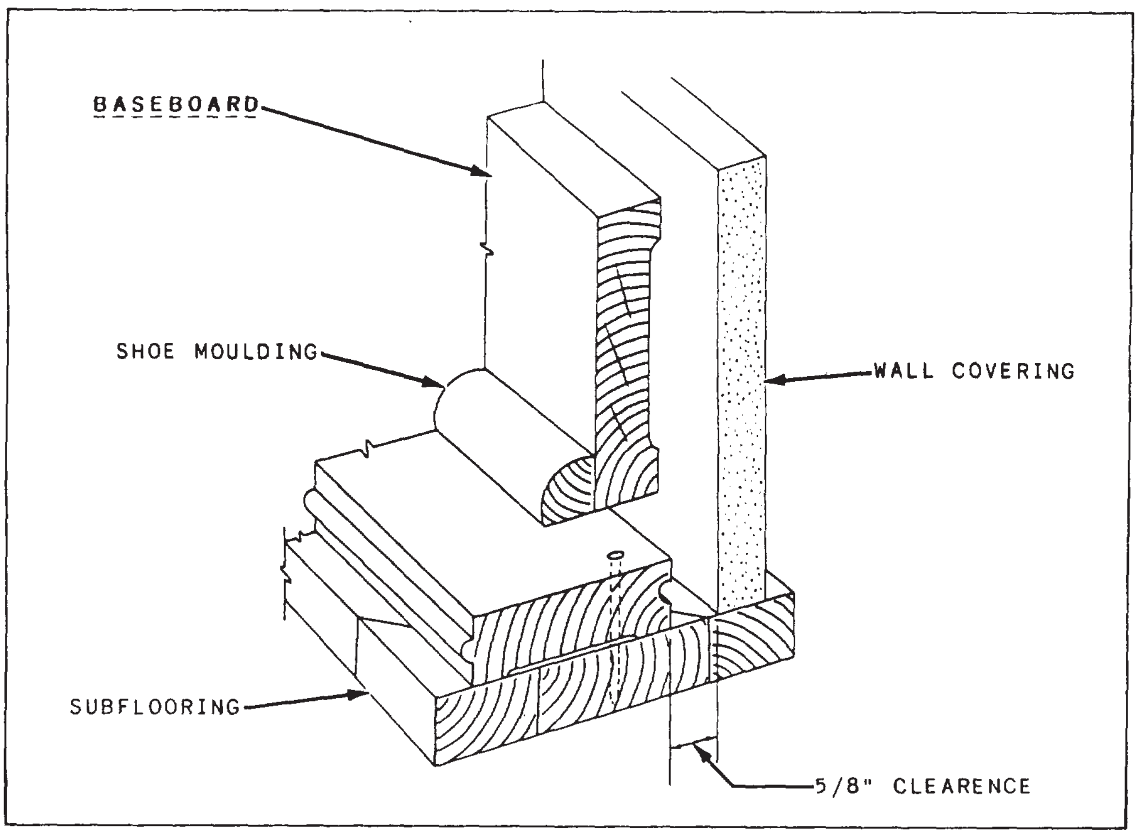


Figure 6-80.-Baseboard.

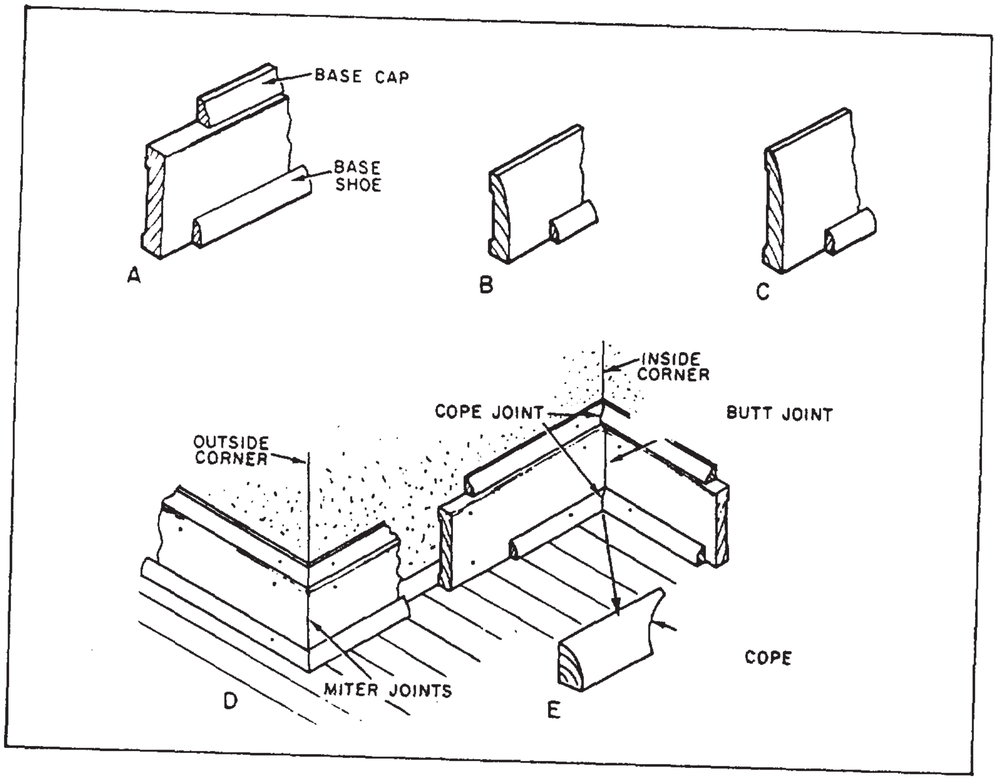


Figure 6-81.-Base moldings: A. Square-edge base; B. Narrow ranch base; C. Wide ranch base; D. Installation; E. Cope.

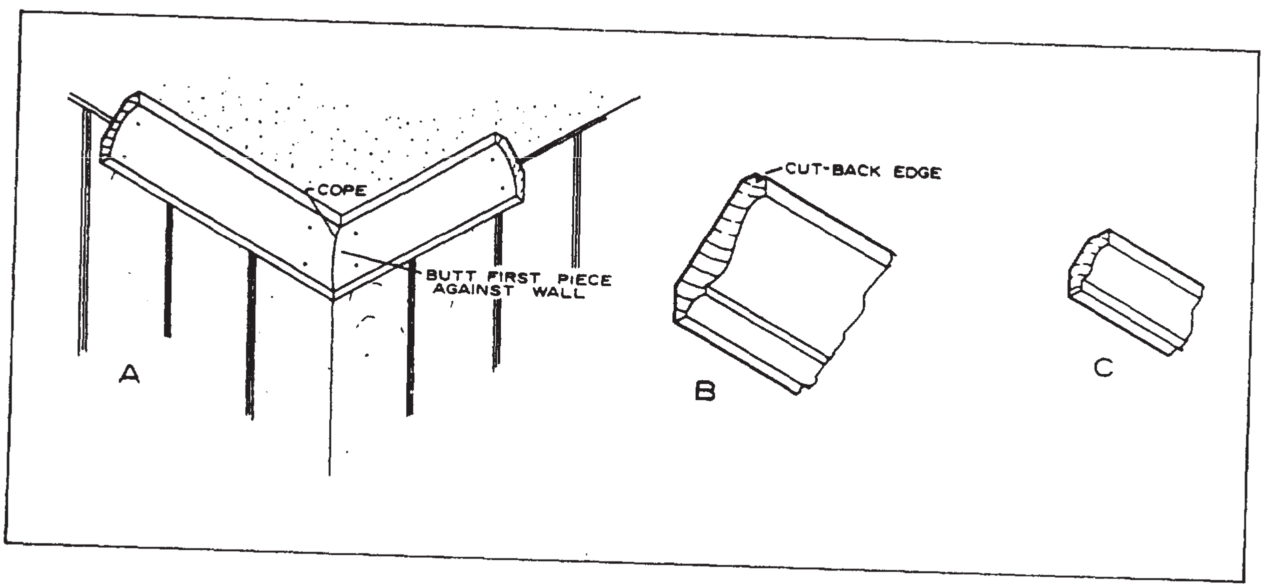
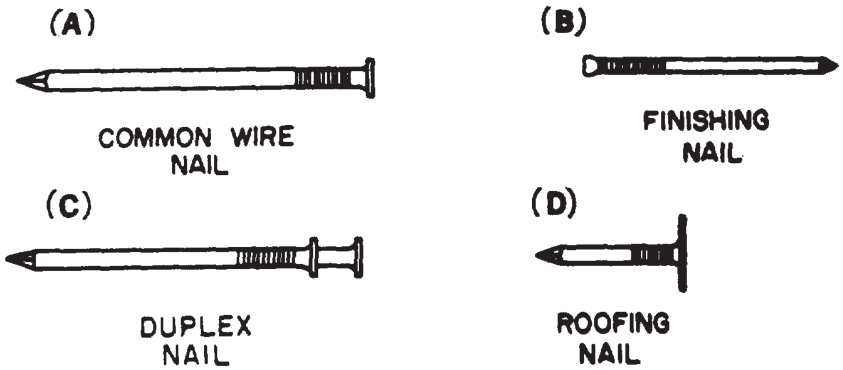
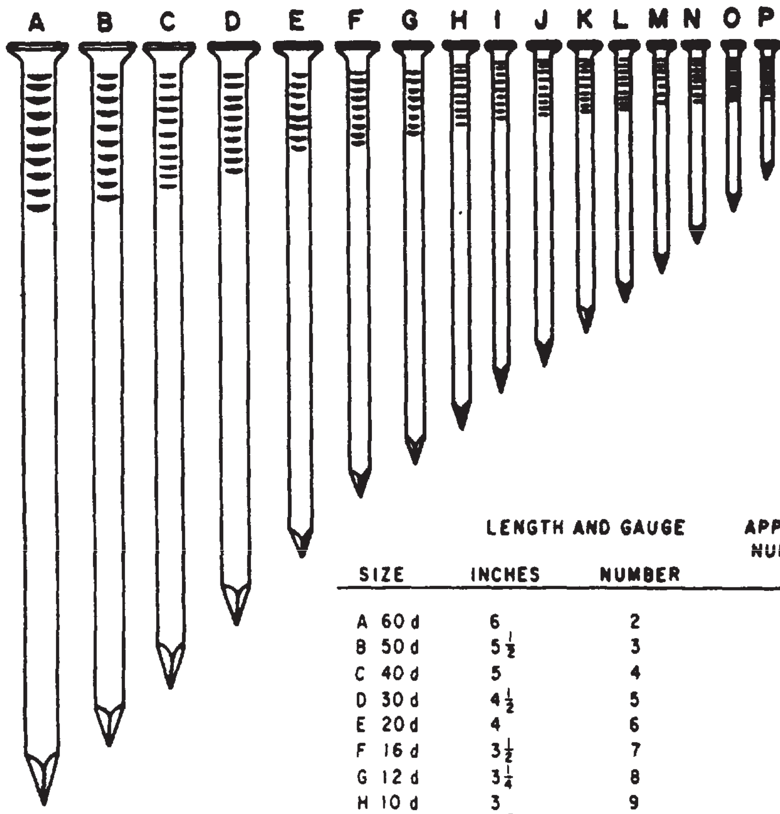


Figure 6-82.-Ceiling moldings: A. Installation (inside corner); B. Crown molding; C. Small crown molding.





SIZE	LENGTH AND GAUGE INCHES	LENGTH AND GAUGE NUMBER	APPROXIMATE NUMBER TO POUND
A 60 d	6	2	11
B 50 d	5 1/2	3	14
C 40 d	5	4	18
D 30 d	4 1/2	5	24
E 20 d	4	6	31
F 16 d	3 1/2	7	49
G 12 d	3 1/4	8	63
H 10 d	3	9	69
I 9 d	2 3/4	10 1/4	96
J 8 d	2 1/2	10 1/4	106
K 7 d	2 1/4	11 1/2	161
L 6 d	2	11 1/2	181
M 5 d	1 3/4	12 1/2	271
N 4 d	1 1/2	12 1/2	316
O 3 d	1 1/4	14	568
P 2 d	1	15	876

Figure 6-83.-Types and sizes of common wire nails and other nails.

The most common fastening devices are nails, screws, and bolts.

Nails

There are many types of nails—all of which are classified according-to their use and form. The standard nail is made of steel wire. The wire nail is round-shafted, straight, pointed, and may vary in size, weight, size and shape of head, type of point, and finish. The holding power of nails is. less than that of screws or bolts.

The COMMON WIRE nail and BOX nail (fig. 6-83, view A) are the same, except that the wire sizes are one or two numbers smaller for a given length of the box nail than they are for the common nail. The FINISHING nail (fig. 6-83, view B) is made from finer wire and has a smaller head than the common nail, Its head may be driven below the surface of the wood, which leaves only a small hole that is easily puttied. The DUPLEX nail (fig, 6-83, view C) seems to have two heads. Actually one serves as a shoulder to give maximum holding power while the other projects above the surface of the wood to make withdrawal simple. The ROOFING NAIL (fig. 6-83, view D) is round-shafted and galvanized. It has a relatively short body and comparatively large head. Like the common wire, finishing, or duplex nail, it has a diamond point.

Besides the general-purpose nails shown in figure 6-83, there are special-purpose nails. Examples include wire brads, plasterboard nails, concrete nails, and masonry nails. The wire brad has a needlepoint; the plasterboard nail has a large-diameter flathead. The concrete nail is specially hardened for driving in concrete. So is the masonry nail, although its body is usually grooved or spiraled.

Lengths of wire nails NOT more than 6 in. long are designated by the penny system, where the letter *d* is the symbol for a penny. Thus, a 6d nail means a sixpenny nail. The thickness of a wire nail is expressed by the number, which relates to standard wire gauge. Nail sizes (penny and length in inches), gauges, and approximate number of nails per pound are given in figure 6-83. Nails longer than 6 in. (called SPIKES) are not designated by the penny. The general size and type of nail preferable for specific applications are shown in table 6-4.

Table 6-4.-Size, Type, and Use of Nails

SIZE	LGTH (IN.)[1]	DIAM (IN.)	REMARKS	WHERE USED
2d	1	.072	SMALL HEAD	FINISH WORK, SHOP WORK.
2d	1	.072	LARGE FLATHEAD	SMALL TIMBER, WOOD SHINGLES, LATHES.
3d	1¼	.08	SMALL HEAD	FINISH WORK, SHOP WORK.
3d	1¼	.08	LARGE FLATHEAD	SMALL TIMBER, WOOD SHINGLES, LATHES.
4d	1½	.098	SMALL HEAD	FINISH WORK, SHOP WORK.
4d	1½	.098	LARGE FLATHEAD	SMALL TIMBER, LATHES, SHOP WORK.
5d	1¾	.098	SMALL HEAD	FINISH WORK, SHOP WORK.
5d	1¾	.098	LARGE FLATHEAD	SMALL TIMBER, LATHES, SHOP WORK.
6d	2	.113	SMALL HEAD	FINISH WORK, CASING, STOPS, ETC., SHOP WORK.
6d	2	.113	LARGE FLATHEAD	SMALL TIMBER, SIDING, SHEATHING, ETC., SHOP WORK.
7d	2¼	.113	SMALL HEAD	CASING, BASE, CEILING, STOPS, ETC.
7d	2¼	.113	LARGE FLATHEAD	SHEATHING, SIDING, SUBFLOORING, LIGHT FRAMING.
8d	2½	.131	SMALL HEAD	CASING, BASE, CEILING, WAINSCOT, ETC., SHOP WORK.
8d	2½	.131	LARGE FLATHEAD	SHEATHING, SIDING, SUBFLOORING, LIGHT FRAMING, SHOP WORK.
8d	1¼	.131	EXTRA-LARGE FLATHEAD	ROLL ROOFING, COMPOSITION SHINGLES.
9d	2¾	.131	SMALL HEAD	CASING, BASE, CEILING, ETC.
9d	2¾	.131	LARGE FLATHEAD	SHEATHING, SIDING, SUBFLOORING, FRAMING, SHOP WORK.
10d	3	.148	SMALL HEAD	CASING, BASE, CEILING, ETC., SHOP WORK.
10d	3	.148	LARGE FLATHEAD	SHEATHING, SIDING, SUBFLOORING, FRAMING, SHOP WORK.
12d	3¼	.148	LARGE FLATHEAD	SHEATHING, SUBFLOORING, FRAMING.
16d	3½	.162	LARGE FLATHEAD	FRAMING, BRIDGES, ETC.
20d	4	.192	LARGE FLATHEAD	FRAMING, BRIDGES, ETC.
30d	4½	.207	LARGE FLATHEAD	HEAVY FRAMING, BRIDGES, ETC.
40d	5	.225	LARGE FLATHEAD	HEAVY FRAMING, BRIDGES, ETC.
50d	5½	.244	LARGE FLATHEAD	EXTRA-HEAVY FRAMING, BRIDGES, ETC.
60d	6	.262	LARGE FLATHEAD	EXTRA-HEAVY FRAMING, BRIDGES, ETC.

[1]THIS CHART APPLIES TO WIRE NAILS, ALTHOUGH IT MAY BE USED TO DETERMINE THE LENGTH OF CUT NAILS.

Screws

A wood screw is a fastener that is threaded into the wood. Wood screws are designated by the type of head (fig. 6-84) and the material from which they are made; for example, flathead brass or round-head steel. The size of a wood screw is designated by its length in inches and a number relating to its body diameter—meaning the diameter of the unthreaded part. This number runs from 0 (about 1/15-in. diameter) to 24 (about 3/8-in. diameter).

Lag screws, called LAG BOLTS (fig. 6-84), are often required where ordinary wood screws are too short or too light, or where spikes do not hold securely. They are available in lengths of 1 to 16 in. and in body diameters of 1/4 to 1 in. Their heads are either square or hexagonal.

Sheet metal, sheet aluminum, and other thin metal parts are assembled with SHEET METAL screws and THREAD-CUTTING screws (fig. 6-84). Sheet metal screws are self-tapping; they can fasten metals up to about 28 gauge. Thread-cutting screws are used to fasten metals that are 1/4 in. thick or less.

Bolts and Driftpins

A steel bolt is a fastener having a head at one end and threads at the other, as shown in figure 6-85. Instead of threading into wood like a screw, it goes through a bored hole and is held by a nut. Stove bolts range in length from 3/8 to 4 in. and in body diameter from 1/8 to 3/8 in. Not especially strong, they are used only for fastening light pieces. CARRIAGE and MACHINE bolts are strong enough to fasten load-bearing members, such as trusses. In length, they range from 3/4 to 20 in.; in diameter, from 3/16 to 3/4 in. The carriage bolt has a square section below its head which embeds in the wood as the nut is set up, keeping the bolt from turning. An expansion bolt is used in conjunction with an expansion shield to provide anchorage in a position in which a threaded fastener alone is useless,

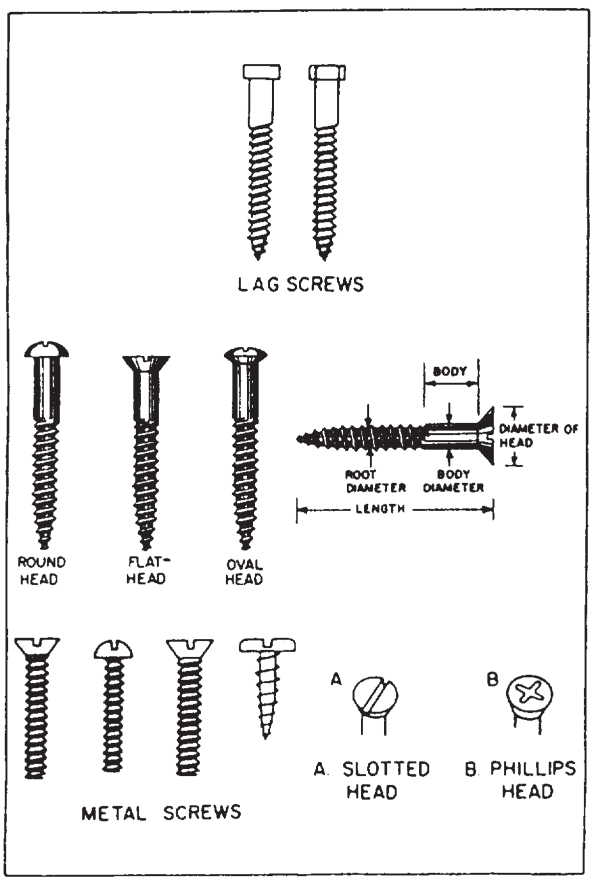


Figure 6-84.-Types of screws.

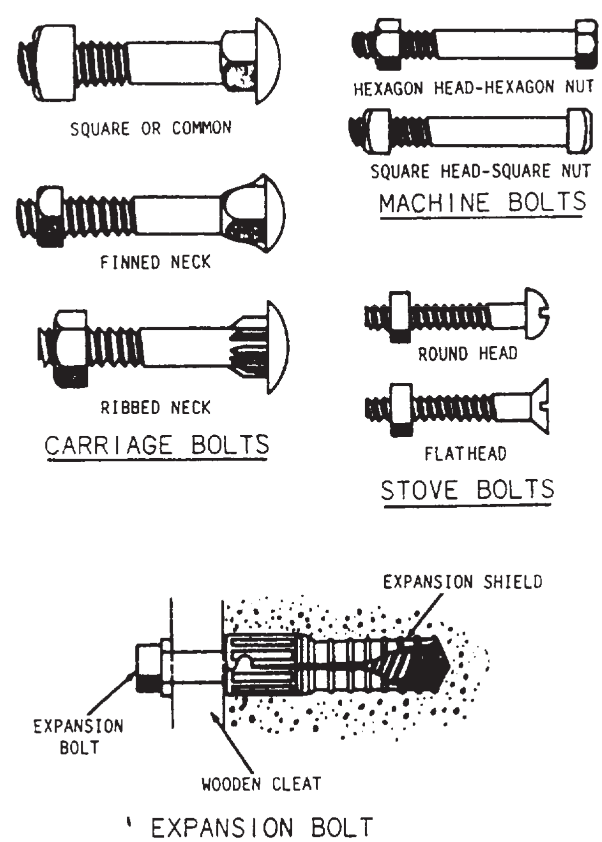


Figure 6-85.-Types of bolts.

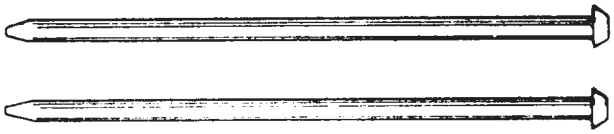


Figure 6-86.-Driftpins (driftbolts).

Driftpins (driftbolts) (fig. 6-86) are long, heavy, threadless bolts used to hold heavy pieces of timber together. Corrugated fasteners (fig.. 6-87) are used in a number of ways; for example, to fasten joints (miter) and splices together and as a substitute for nails where nails may split the timber.

Glue

Glue, one of the oldest materials for fastening, if applied properly, will form a joint that is stronger than the wood itself. Probably one of the best types of glue for joint work and furniture construction is animal glue, made from hides. Other types of glue are extracted from fish, vegetables, casein, plastic resin, and blood albumin. Glue can be obtained commercially in a variety of forms—liquid, ground, chipped, flaked, powdered, or formed into sticks.

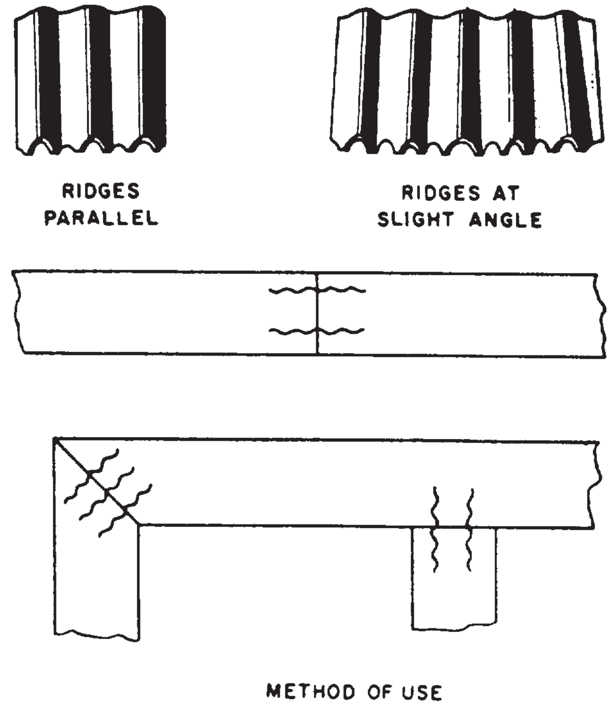


Figure 6-87.-Use of corrugated fasteners.

CHAPTER 7

CONCRETE AND MASONRY

This chapter provides information and guidance for the Engineering Aid engaged in or responsible for drawing structural and architectural layouts from existing plans, engineering sketches, or specifications, It includes information on basic materials commonly used in concrete and masonry construction.

Basic principles and procedures associated with the construction of reinforced, precast, and prestressed concrete and tilt-up construction are also discussed in this chapter. Terminology as it applies to masonry units is used to acquaint the Engineering Aid with the various terms used in this type of construction.

CONCRETE

CONCRETE is a synthetic construction material made by mixing CEMENT, FINE AGGREGATE (usually sand), COARSE AGGREGATE (usually gravel or crushed stone), and WATER together in proper proportions; the product is not concrete unless all four of these ingredients are present. A mixture of cement, sand, lime, and water, without coarse aggregate, is NOT concrete, but MORTAR or GROUT.

Mortar is used mainly for bonding masonry units together. The term grout refers to a water-cement mixture (called neat-cement grout) or water-sand-cement mixture (called sand-cement grout) used to plug holes or cracks in concrete, to seal joints, and for similar plugging or sealing purposes.

The fine and coarse aggregates in a concrete mix are called the INERT ingredients; the cement and water are the ACTIVE ingredients. The inert ingredients and the cement are thoroughly mixed together first. As soon as the water is added, a chemical reaction between the water and the cement begins, and it is this reaction (which is called HYDRATION) that causes the concrete to harden.

Always remember that the hardening process is caused by hydration of the cement by the water, not by a DRYING OUT of the mix. Instead of being dried out, the concrete must be kept as moist as possible during the initial hydration process. Drying out would cause a drop in water content below the amount required for satisfactory hydration of the cement.

The fact that the hardening process has nothing whatever to do with a drying out of the concrete is clearly shown by the fact that concrete will harden just as well under water as it will in the air.

Concrete may be cast into bricks, blocks, and other relatively small building units that are used in concrete MASONRY construction.

The proportion of concrete to other materials used in building construction has greatly increased in recent years to the point where large, multistory modern building are constructed entirely of concrete, with concrete footings, foundations, columns, walls, girders, beams, joists, floors, and roofs.

REQUIREMENTS FOR GOOD CONCRETE

The first requirement for good concrete is a supply of good cement of a type suitable for the work at hand. Next is a supply of satisfactory sand, coarse aggregate, and water; all of which must be carefully weighed and measured. Everything else being equal, the mix with the best graded, strongest, best shaped, and cleanest aggregate will make the strongest and most durable concrete.

The best designed, best graded, and highest quality mix in the world will NOT make good concrete if it is not WORKABLE enough to fill the form spaces thoroughly. On the other hand, too much fluidity will result in certain defects. Improper handling during the whole concrete-making process (from the initial aggregate handling to the final placement of the mix) will cause segregation of aggregate particles by sizes, resulting in nonuniform, poor concrete.

Finally, the best designed, best graded, highest quality, and best placed mix in the world will not produce good concrete if it is not properly CURED—meaning, properly protected against loss of moisture during the earlier stages of setting.

As you can see, the important properties of concrete are its strength, durability, and watertightness. These factors are controlled by the WATER-CEMENT RATIO or the proportion of water to cement in the mix.

Strength

The COMPRESSIVE strength of concrete is very high, but its TENSILE strength (meaning its ability to resist stretching, bending, or twisting) is relatively low. Consequently, concrete that must resist a good deal of stretching, bending, or twisting, such as concrete in beams, girders, walls, columns, and the like, must be REINFORCED with steel. Concrete that must resist compression only may not require reinforcement.

Durability

The DURABILITY of concrete means the extent to which the material is capable of resisting the deterioration caused by exposure to service conditions. Ordinary structural concrete that is to be exposed to the elements must be watertight and weather resistant. Concrete that is subject to wear, such as floor slabs and pavements, must be capable of resisting abrasion. It has been found that the major factor controlling durability is strength—in other words, the stronger the concrete is, the more durable it will be. As mentioned previously, the chief factor controlling strength is the water-cement ratio, but the character, size, and grading (distribution of particle sizes between the largest permissible coarse and the smallest permissible fine) of the aggregate also have important effects on both strength and durability. Given a water-cement ratio that will produce maximum strength consistent with workability requirements, maximum strength and durability will still not be attained unless the sand and coarse aggregate consist of well-graded, clean, hard, and durable particles, free from undesirable substances (fig. 7-1).

Watertightness

The ideal concrete mix would be one made with just the amount of water required for complete hydration of the cement. This would be a DRY mix, however, too stiff to pour in the forms. A mix that is fluid enough to be poured into forms always contains a certain amount of water over and above the amount that will combine wit h the cement, and this water will eventually evaporate, leaving voids or pores in the concrete.

Even so, penetration of the concrete by water would still be impossible if these voids were not interconnected. They are interconnected, however, as a result of a slight sinking of solid particles in the mix during the hardening period. As these particles sink, they leave water-filled channels, which become voids when the water evaporates.

The larger and more numerous these voids are, the more the watertightness of the concrete will be impaired. Since the size and number of the voids vary directly with the amount of water used in excess of the amount required to hydrate the cement, it follows that to keep the concrete as watertight as possible, you must not use more water than the minimum amount required to attain the necessary degree of workability.

PLAIN CONCRETE

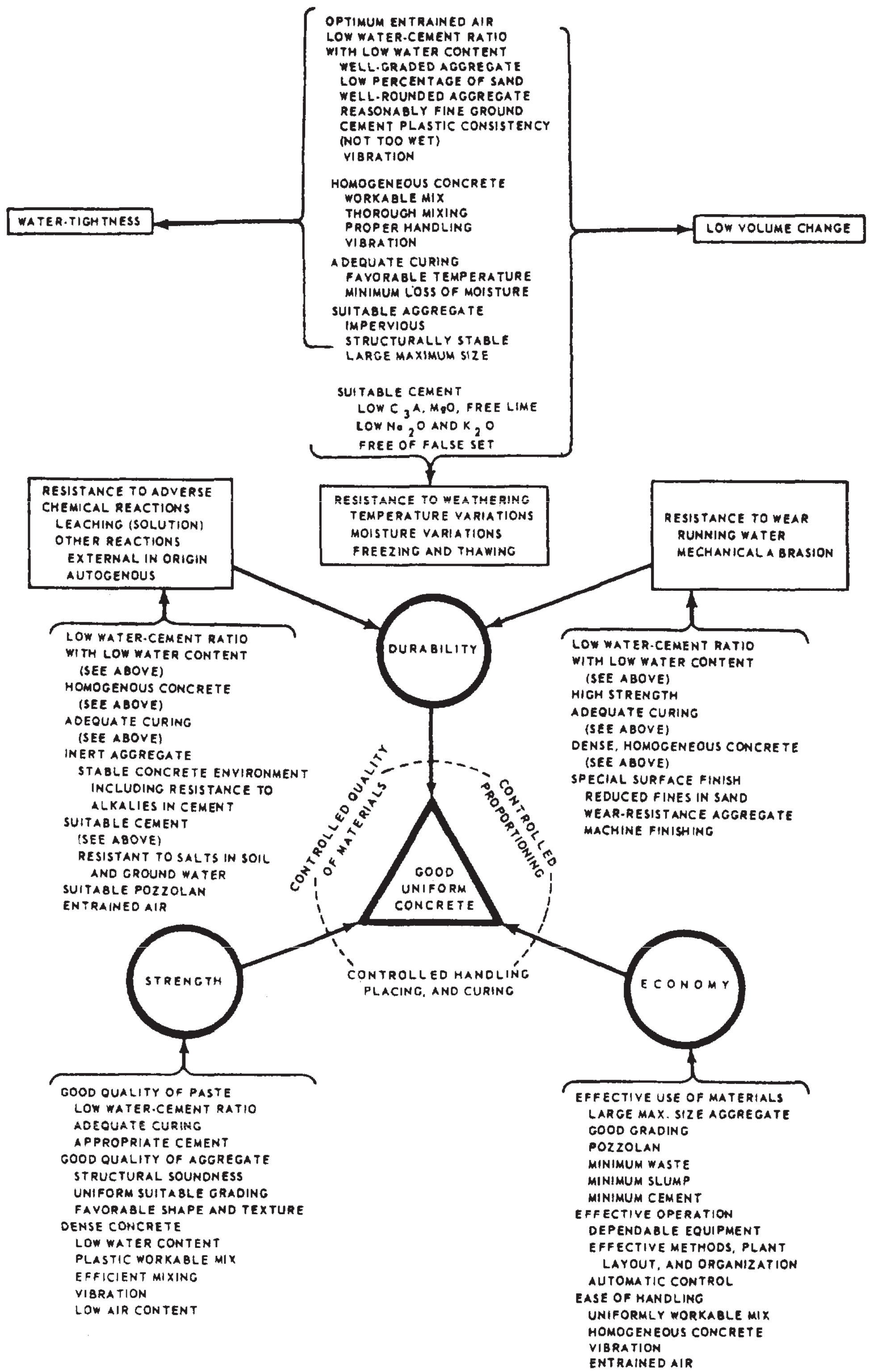
Plain concrete is defined as concrete with no reinforcement, This type of concrete is most often used where strength is not essential and stresses are minimal, such as sidewalks or driveways and floors where heavy loads are not anticipated.

REINFORCED CONCRETE

Reinforced concrete refers to concrete containing steel (bars, rods, strands, wire, and mesh) as reinforcement and designed to absorb tensile and shearing stresses, Concrete structural members, such as footings, columns and piers, beams, floor slabs, and walls, must be reinforced to attain the necessary strength in tension.

Reinforced Concrete Structural Members

A reinforced concrete structure is made up of many types of reinforced structural members, including footings, columns, beams, slabs, walls, and so forth. Their basic functions are briefly described below.



117.83

Figure 7-1.-The principal properties of good concrete.

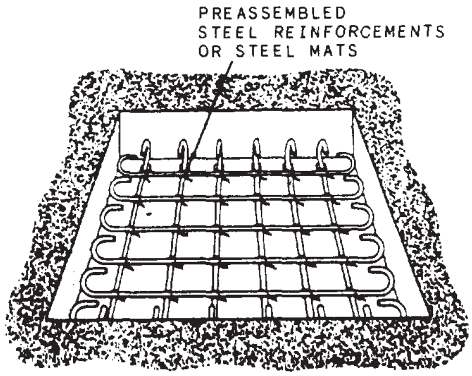


Figure 7-2.-Typical small footing.

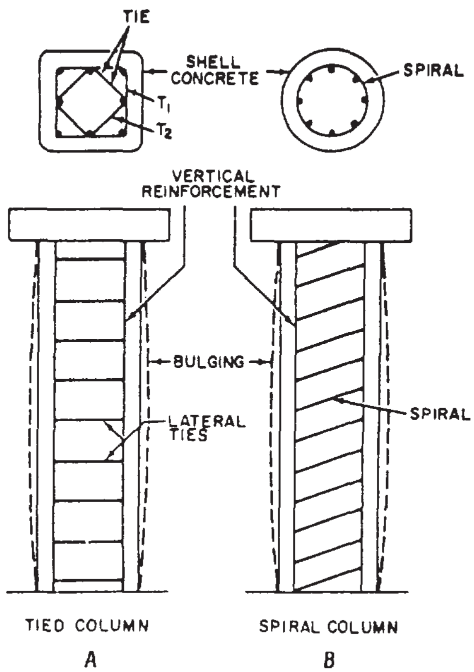


Figure 7-3.-Reinforced concrete columns.

FOOTING AND FOOTING REINFORCEMENT.— Footings support the entire structure and distribute the load to the ground. The size and shape of a footing depend upon the design of the structure. In a small footing (fig. 7-2), "steel mats" or reinforcements are generally preassembled and placed after the forms have been set. In large or continuous footings, such as those found under bearing walls, steel mats are constructed in place.

COLUMN AND COLUMN REINFORCEMENT.— A column is a slender, vertical member that carries a superimposed load. Concrete columns, especially those subjected to bending stresses, must always be reinforced with steel. A PIER or PEDESTAL is a compressive member that is short (usually the height is less than three times the least lateral dimension) in relation to its cross-sectional area and carries no bending stress.

In concrete columns, vertical reinforcement is the principal reinforcement. However, a loaded column shortens vertically and expands laterally; hence, lateral reinforcements in the form of lateral ties are used to restrain the expansion. Columns reinforced in this manner are called tied columns (fig. 7-3, view A). If the restraining reinforcement is a continuous winding spiral that encircles the core and longitudinal steel, the column is called a spiral column (fig, 7-3, view B).

BEAM AND BEAM REINFORCEMENT.— Beams are the principal load-carrying horizontal members. They take the load directly from the floor and carry it to the columns. Concrete beams can either be cast in place or precast and transported to the jobsite. Figure 7-4 shows several common types of beam reinforcing steel shapes. Both straight and bent-up principal

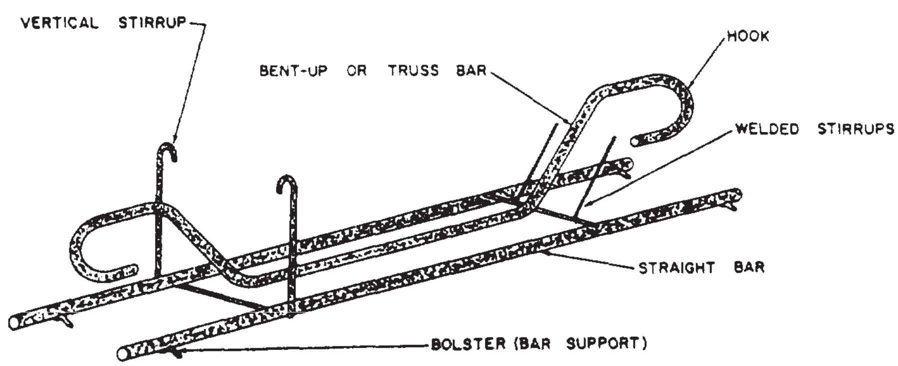


Figure 7-4.-Typical shapes of reinforcing steel.

reinforcing bars are needed to resist the bending tension in the bottom over the central portion of the span. Fewer bars are necessary on the bottom near the ends of the span where the bending moment is small. For this reason, some bars may be bent so that the inclined portion can be used to resist diagonal tension. The reinforcing bars of continuous beams are continued across the supports to resist tension in the top in that area.

SLAB AND SLAB REINFORCEMENT.— Concrete slabs come in a variety of forms depending on their locations. Ground slabs take the load directly to the ground. Plain slabs (similar in shape to ground slabs) take the load directly from the floor and transmit it to the beams. In other cases, joists, poured as part of plain slabs, carry the loads to the beams. Joists are used to strengthen the middle portion of the slab. Concrete slab reinforcements (fig. 7-5) are supported by reinforcing steel in configurations called slab bolster and high chair. Concrete blocks made of sand-cement mortar can be used in place of the slab bolster. The height of the slab bolster is determined by the concrete protective cover required. If the concrete surface is to be in contact with the ground or exposed to the weather after removal of the forms, the protective covering of concrete over the steel should be 2 in. Other devices used to support horizontal reinforcing bars are shown in figures 7-6, 7-7, and 7-8. Wood blocks should be

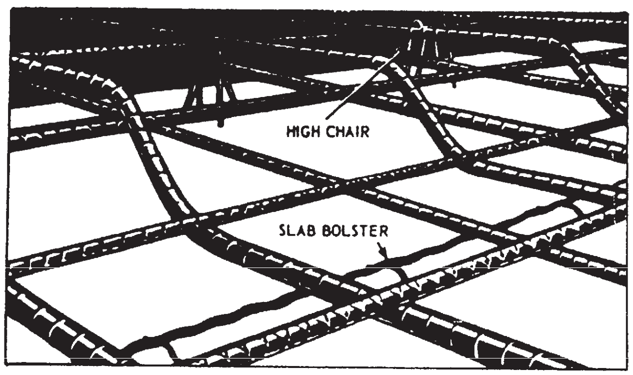


Figure 7-5.—Reinforcing steel for a floor slab.

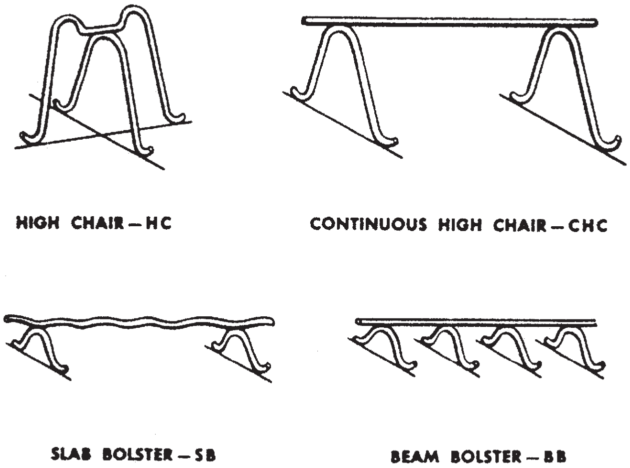


Figure 7-6.—Devices used to support horizontal reinforcing bars.

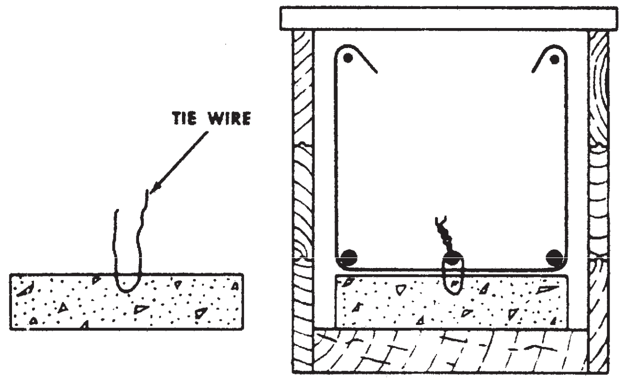


Figure 7-7.—Precast concrete block used for reinforcing steel support.

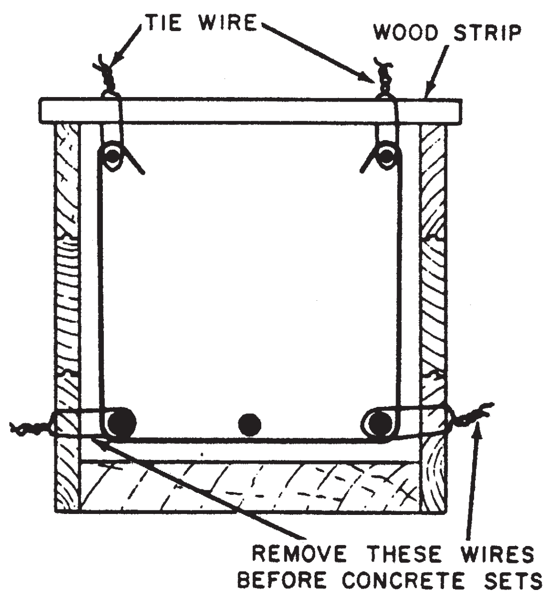


Figure 7-8.—Beam-reinforcing steel hung in place.

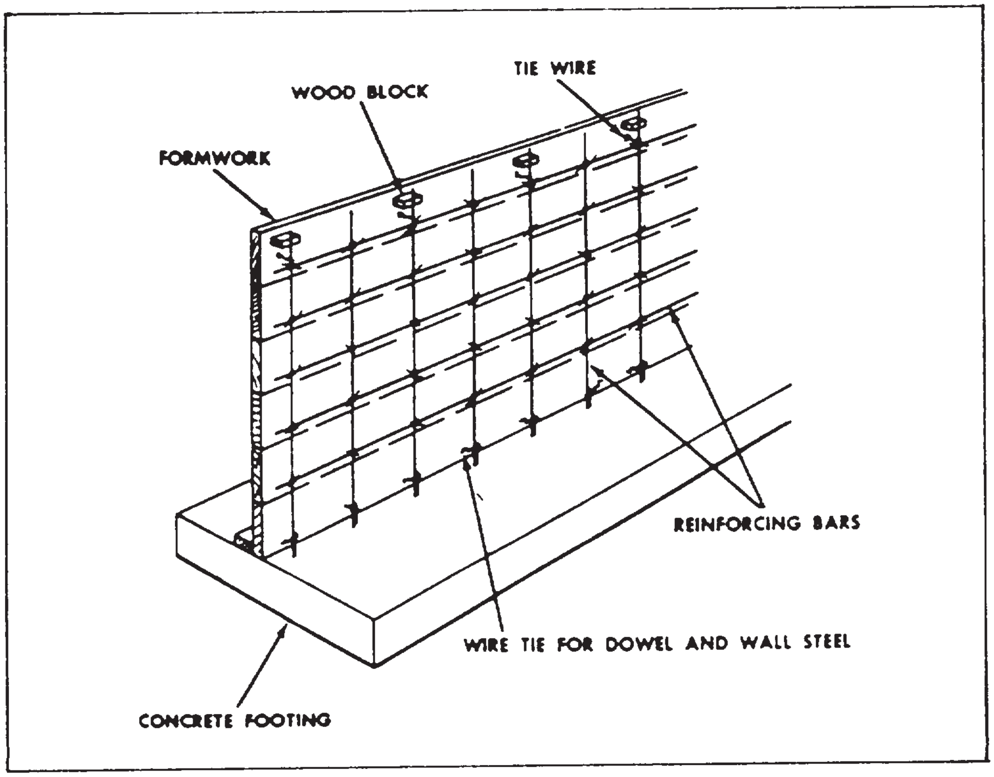


Figure 7-9.-Steel in place in a wall.

substituted for the metal supports only if there is no possibility of the concrete becoming wet or if the construction is known to be temporary.

WALL REINFORCEMENT.— Placement of steel reinforcement in load-bearing walls is the same as for columns except that the steel is erected in place and not preassembled. Horizontal steel is tied to vertical steel at least three times in any bar length. The wood block is removed when the form has been filled up to the level of the block, as shown in figure 7-9.

Reinforcing Steel

Steel is the best material for reinforcing concrete because the coefficients of expansion of the steel and the concrete are considered almost the same; that is, at a normal temperature, they will expand and contract at an almost equal rate. (At very high temperatures, steel will expand more rapidly than the concrete, and the two materials will separate.)

Steel also works well as a reinforcement for concrete because it makes a good bond with the concrete. This bond strength is proportional to the contact area surface of the steel to the concrete. In other words, the greater the surface of steel exposed to the adherence of the concrete, the stronger the bond. A deformed reinforcing bar

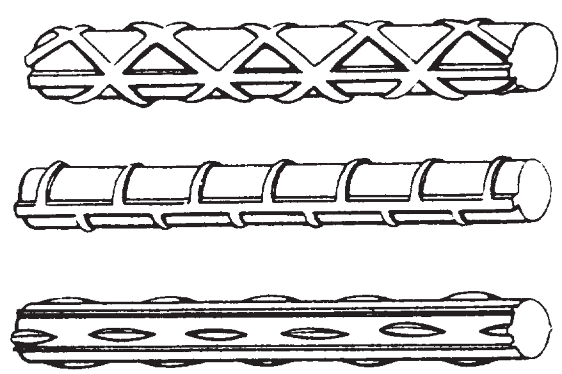


Figure 7- 10.-Types of deformed reinforcing bars.

is better than a plain round or square one. In fact, when plain bars of a given diameter are used instead of deformed bars, approximately 40 percent more plain bars must be used.

The adherence of the concrete depends on the roughness of the steel surface: the rougher the steel, the better the adherence. Thus, steel with alight, firm layer of rust is superior to clean steel, but steel with loose or scaly rust is inferior. Loose or scaly rust may be removed from the steel by rubbing the steel with burlap.

The requirements for reinforcing steel are that it be strong in tension and, at the same time, ductile enough to be shaped or bent cold.

Reinforcing steel may be used in the form of bars or rods that are either PLAIN or DEFORMED or in the form of expanded metal, wire, wire fabric, or sheet metal. Each type is useful for a different purpose, and engineers design structures with these purposes in mind.

Plain reinforcing bars are usually round in cross section. They are used as main tension reinforcement for concrete structures. They are the least used of the rod type of reinforcement because they offer only smooth, even surfaces for the adherence of concrete. Reinforcing bars or rods are commonly referred to as rebars.

Deformed bars are like the plain bars except that they have either indentations in them or ridges on them, or both, in a regular pattern. The twisted bar, for example, is made by twisting a plain square bar cold. The spiral ridges along the surface of the deformed bar increase its bond strength with concrete. Other forms used are the round- and square-corrugate d bars. These bars are formed with projections around the surface that extend into the surrounding concrete and prevent slippage. Another type is formed with longitudinal fins projecting from the surface to prevent twisting. Figure 7-10 shows a few of the various types of deformed bars available. In the United States, deformed bars are used almost exclusively, while in Europe, both deformed and plain bars are used.

There are 11 standard sizes of reinforcing bars. Table 7-1 lists the bar numbers, weight, and nominal diameters of the 11 standard sizes. Bars No. 3 through No. 18, inclusive, are deformed bars. Remember that bar numbers are based on the nearest number of 1/8 in. (3. 175 mm) included in the nominal diameter of the bar. To measure rebar, you must measure across the roundsquare portion where there is no deformation.

Table 7-1.-Standard Reinforcing Bars

BAR NUMBERS	WEIGHT	NOMINAL DIAMETER	
	POUNDS PER FOOT	INCHES	MILLI-METERS
#3	0.376	0.375	9.5
#4	0.668	0.500	12.7
#5	1.043	0.625	15.8
#6	1.502	0.750	19.0
#7	2.044	0.875	22.2
#8	2.670	1.000	25.4
#9	3.400	1.128	28.5
#10	4.303	1.270	31.7
#11	5.313	1.410	35.9
#14	7.650	1.693	43.0
#18	13.600	2.257	57.3

05NP0001

The raised portion of the deformation is not considered in measuring the rebar diameter.

BENDS.— Frequently, it is required that reinforcing bars be bent into various shapes. There are several reasons for this. First, let us go back to the reason for using reinforcing steel in concrete—to increase the tensile and compressive strength of concrete. You might compare the hidden action within abeam from live and dead loads to breaking a stick over your knee. You have seen how the splinters next to your knee push toward the middle of the stick when you apply force, while the splinters from the middle to the opposite side pull away from the middle. This is similar to what happens inside the beam.

For instance, take a simple beam (a beam resting freely on two supports near its ends). The dead load (weight of the beam) causes the beam to bend or sag. Now, from the center of the beam to the bottom, the forces tend to stretch or lengthen the bottom portion of the beam. This part is said to be in tension, and that is where the steel reinforcing bars are needed. As a result of the combination of the concrete and steel, the tensile strength in the beam resists the force of the load and keeps the beam from breaking apart. At the exact center of the beam, between the compressive stress and the tensile stress, there is no stress at all—it is neutral.

In the case of a continuous beam, it is a little different. The top of the beam may be in compression along part of its length and in tension along another part. This is because a continuous beam rests on more than two supports. Thus, the bending of the beam is NOT all in one direction but is reversed as it goes over intermediate supports.

To help the concrete resist these stresses, engineers design the bends of reinforcing steel so that the steel will set into the concrete just where the tensile stresses take place. That is why some reinforcing rods are bent in almost a zigzag pattern. The joining of each bar with the next, the anchoring of the bar ends with concrete, and the anchoring by overlapping two bar ends together are some of the important ways to increase and keep bond strength. Some of the bends you will encounter are shown in figure 7-11.

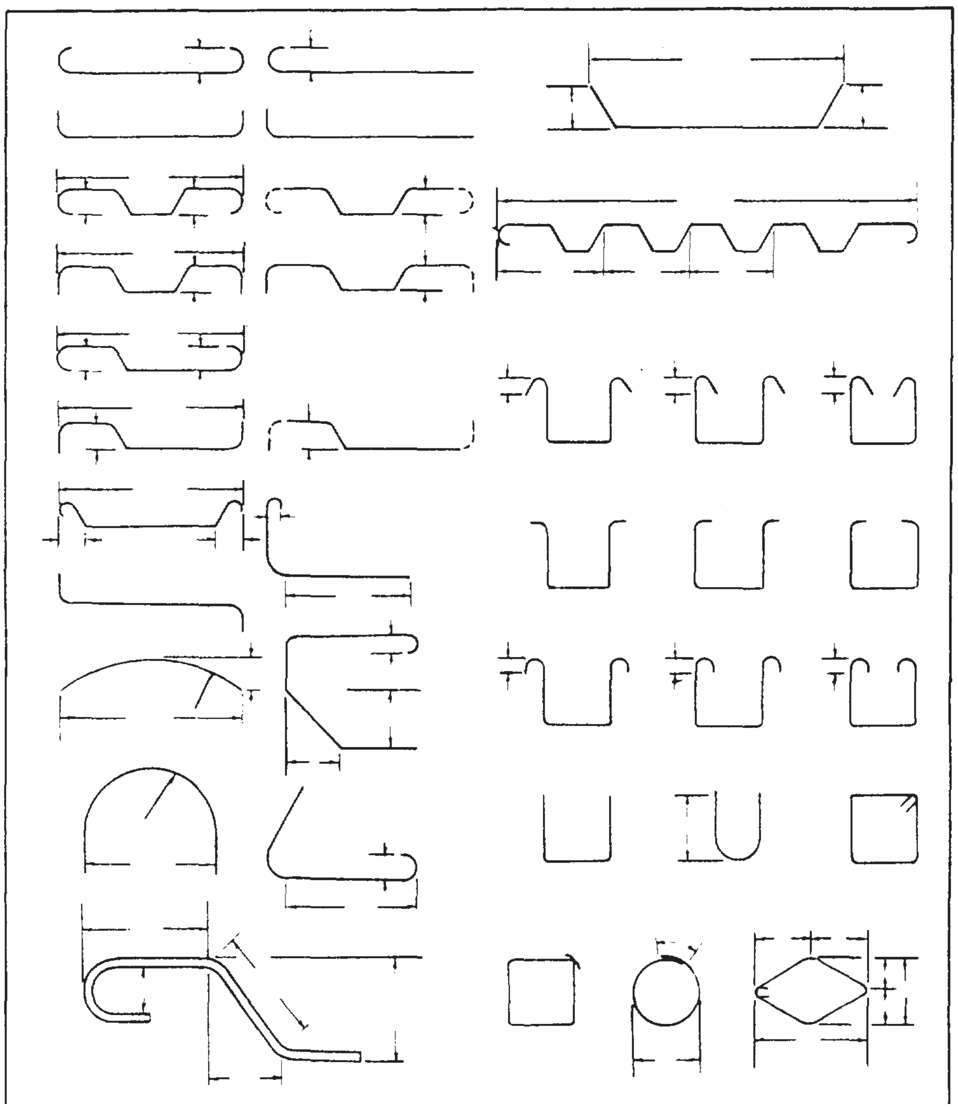
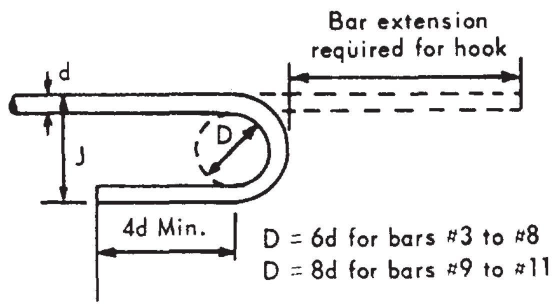


Figure 7-11.-Typical reinforcement bar bends.

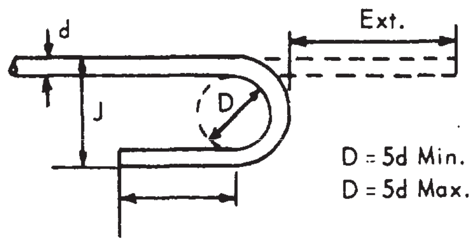
When reinforcing bars are bent, caution must be exercised to ensure the bends are not too sharp. If too sharp a bend is put into the bars, they may crack or be weakened. Therefore, certain minimum bend diameters have been established for the different bar sizes and for the various types of hooks. These bending details are shown in figure 7-12. There are many different types of bends, depending on where the rods are to be placed. For example, there are bends on heavy

Recommended sizes - 180° hook



Bar size d	Bar exten.	J
#2	4	2
3	5	3
4	6	4
5	7	5
6	8	6
7	10	7
8	11	8
9	1-3	11¼
10	1-5	1-0¾
11	1-7	1-2¼

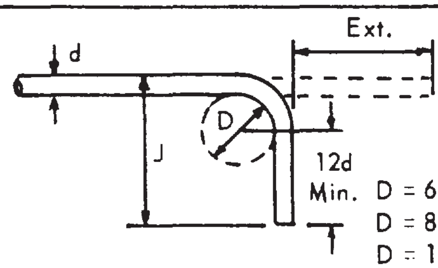
Minimum sizes - 180° hook



Note: Minimum size hooks to be used only for special conditions.

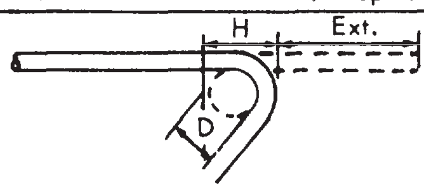
Bar size d	Bar exten.	J
#2	4	1¾
3	5	2¾
4	5	3½
5	6	4¼
6	7	5¼
7	9	6
8	10	7
9	11	8
10	13	9
11	14	10

Recommended minimum sizes - 90° hook



Bar size d	Bar exten.
#2	3½
3	6
4	8
5	10
6	1-0
7	1-2
8	1-4
9	1-7
10	1-10
11	2-0

Recommended sizes - 135° stirrup hook



D = 6d

Bar size d	Bar exten.
#2	3½
3	4
4	4½
5	5½

Note: Stirrup hooks may be bent to the diameter of the supporting bars.

Figure 7-12.-Standard hook details.

beam and girder bars, bends for reinforcement of vertical columns at or near floor levels, stirrup and column ties, slab reinforcement, and bars or wire for column spiral reinforcement.

SPLICES.— Where splices in reinforcing steel are not dimensioned on the drawings, the bars should be lapped not less than 30 times the bar diameter, nor less than 12 in. The stress in a tension bar can be transmitted through the concrete and into another adjoining bar by a lap splice of proper length. The "lap" is expressed as the number of bar diameters. If using the No. 2 bar, make the lap at least 12 in.

EXPANDED METAL AND WELDED WIRE FABRIC.— Expanded metal or wire mesh is also used for reinforcing concrete. Expanded metal is made by partly shearing a sheet of steel, as shown in figure 7-13, view A. The sheet steel has been sheared in parallel lines and then pulled out or expanded to form a diamond shape between each parallel cut. Another type is square rather than diamond shaped, as shown in figure 7-13, view B. Expanded metal is frequently used during plastering operations.

Welded wire fabric is available both in rolls (fig. 7-14) for light building construction and sheets for highways and use in buildings when roll sizes will not give ample reinforcement. Wire fabric is furnished in both square and rectangular patterns, welded at each intersection. The rectangular sizes range from 2 by 4 in. to 6 by 12 in. The square patterns are available in 2 by 2 in., 3 by 3 in., 4 by 4 in., and 6 by 6 in. Both are furnished in a wide variety of wire gauges. The square pattern has the same gauge in both directions, while the rectangular type may have the same gauge in both directions or the larger gauge running longitudinally. Specifications and designs are usually used when wire fabric (mesh) is being lapped; however, a minimum of 2 in. between laps is usually sufficient.

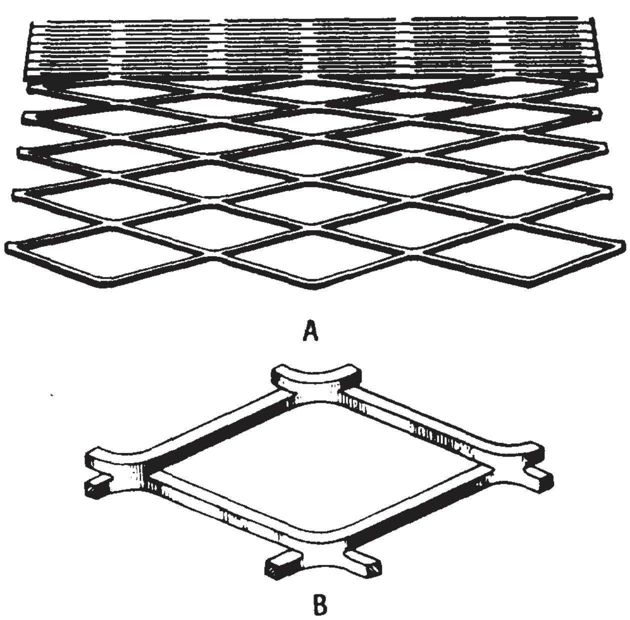


Figure 7-13.-Expanded or diamond mesh steel reinforcement.

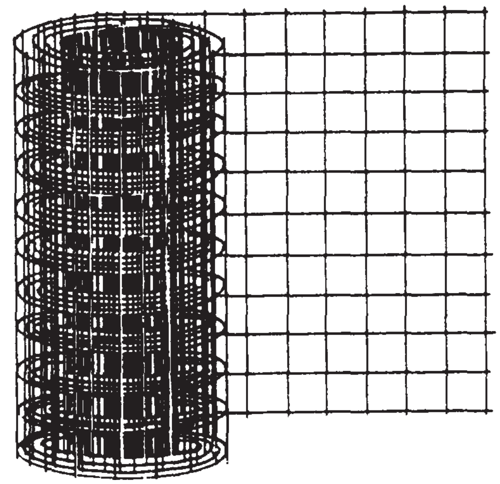


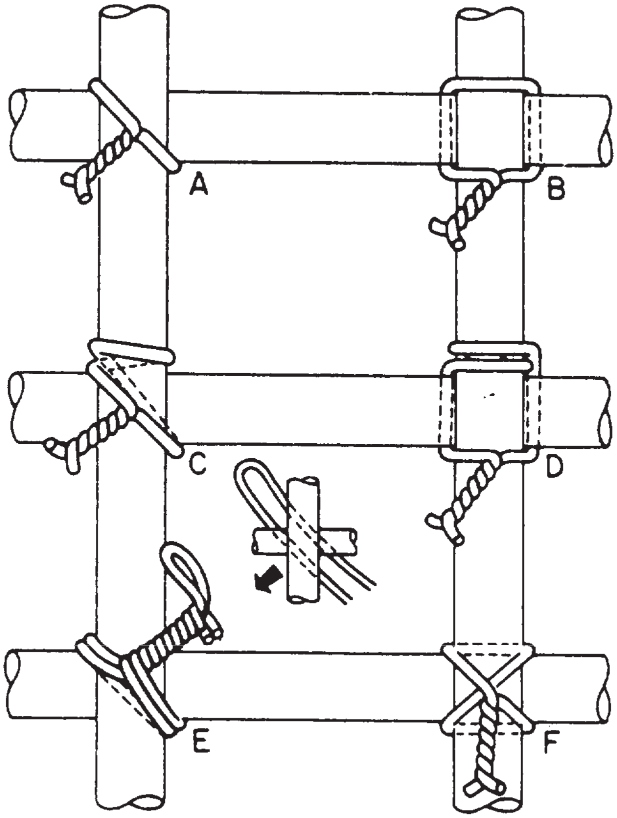
Figure 7-14.-Welded wire fabric.

Reinforcing bars can be joined together by different types of ties. Figure 7-15 shows six types used by the SEABEEs.

PRECAST CONCRETE

Precasting is the fabrication of a structural member at a place other than its final position of use. It can be done anywhere, although this procedure is best adapted to a factory or yard. Jobsite precasting is not uncommon for large projects. Precast concrete can be produced in several different shapes and sizes, including piles, girders, and roof members. Prestressed concrete is especially well adapted to precasting techniques.

Generally, structural members including standard highway girders, poles, electric poles, masts, and building members are precast by factory methods unless the difficulty or



A. Snap or simple tie.
B. Saddle tie.
C. Wall tie.
D. Saddle tie with twist.
E. Double-strand single-tie.
F. Cross tie.

Figure 7-15.-Types of ties.

impracticability of transportation makes jobsite casting more desirable. On the other hand, concrete that is cast in the position that it is to occupy in the finished structure is called cast-in-place concrete.

Precast Concrete Floors, Roof Slabs, Walls, and Partitions

The most commonly used precast slabs or panels for FLOOR and ROOF DECKS are the channel and double-T types (fig. 7-16, views A and B).

The channel slabs vary in size with a depth ranging from 9 to 12 in., width 2 to 5 ft, and a thickness of 1 to 2 in. They have been used in spans up to 50 ft. If desired or needed, the legs of the channels may be extended across the ends

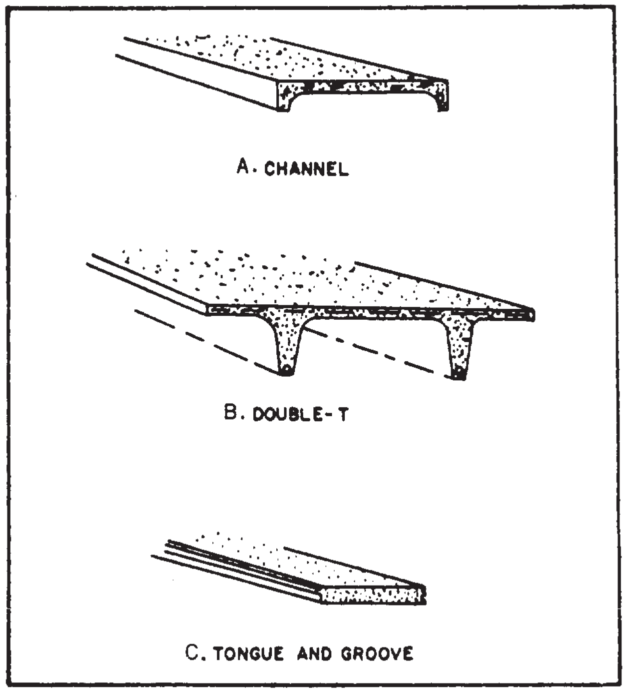


Figure 7-16.-Typical precast panels.

and, if used in combination with the top slabs. may be stiffened with occasional cross ribs. Wire mesh may be used in the top slabs for reinforcement. The longitudinal grooves located along the top of the channel legs may be grouted to form keys between adjacent slabs.

The double-T slabs vary in size from 4 to 6 ft in width and 9 to 16 ft in depth. They have been used in spans as long as 50 ft. When the top-slab size ranges from 1 1/2 to 2 in. in thickness, it should be reinforced with wire mesh.

The tongue-and-groove panel (fig. 7-16, view C) could vary extensively in size, according to the design requirement. They are placed in position much like tongue-and-groove lumber; that is, the tongue of one panel is placed inside the groove of an adjacent panel. They are often used as decking panels in large pier construction.

Matching plates are ordinarily welded and used to connect the supporting members to the floor and roof slabs.

Panels precast in a horizontal position, in a casting yard, or on the floor of the building, are ordinarily used in the makeup of bearing and nonbearing WALLS and PARTITIONS. These panels are placed in their vertical positions by cranes or by the tilt-up procedure, as shown in figures 7-17 and 7-18.

Usually, these panels are solid, reinforced slabs, 5 to 8 in. in thickness, with the length varying according to the distances between columns or other supporting members. When windows and door openings are cast in the slabs, extra reinforcements should be installed around the openings.

A concrete floor slab with a smooth, regular surface can be used as a "casting surface." When this smooth surface is used for casting, it should be covered with some form of liquid or sheet material to prevent bonding between the surface and the wall panel. The upper surface of the panel may be finished as regular concrete is finished by troweling, floating, or brooming.

SANDWICH PANELS are panels that consist of two thin, dense, reinforced concrete-face slabs separated by a core of insulating material, such as lightweight concrete, cellular glass, plastic foam, or some rigid insulating material.

These panels are sometimes used for exterior walls to provide additional heat insulation. The thickness of the sandwich panels varies from 5 to 8 in., and the face slabs are tied together with wire, small rods, or in some other manner. Welded or bolted matching plates are also used to connect the wall panels to the building frame, top and bottom. Caulking on the outside and grouting on the inside should be used to make the points between the wall panels watertight.

Precast Concrete Joists, Beams, Girders, and Columns

Small, closely spaced beams used in floor construction are usually called JOISTS; however, these same beams when used in roof construction

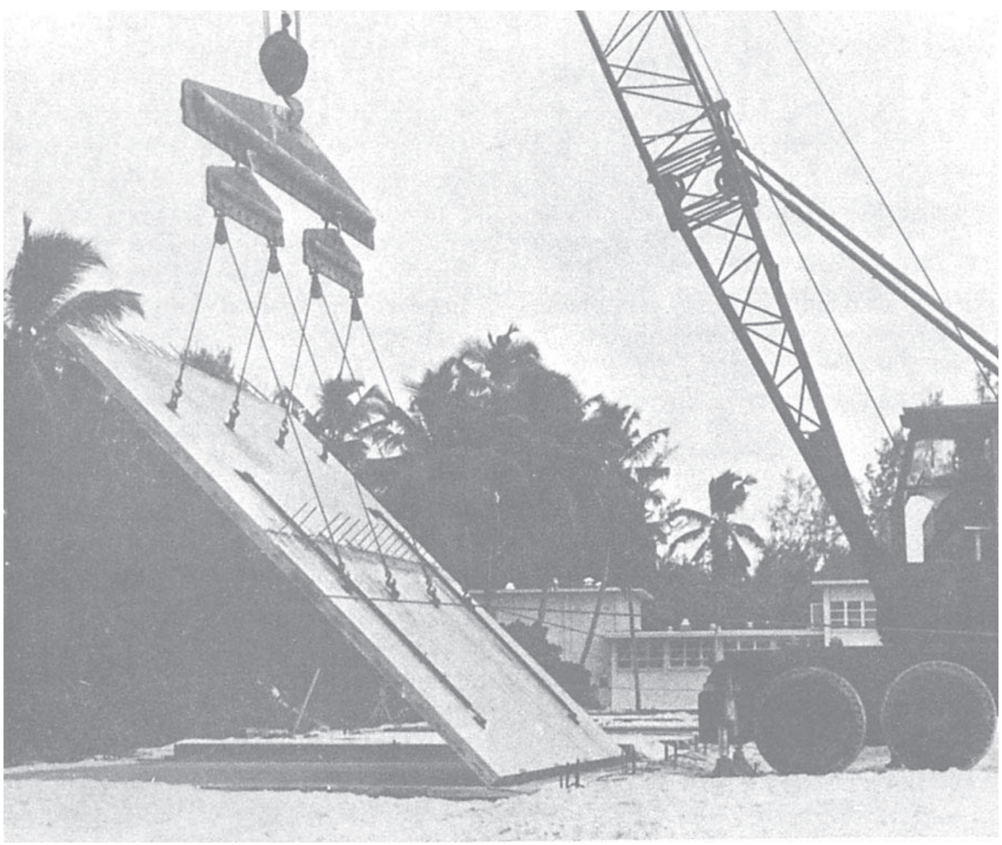


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Figure 7-17.-Precast panels being erected by use of crane and spreader bars.

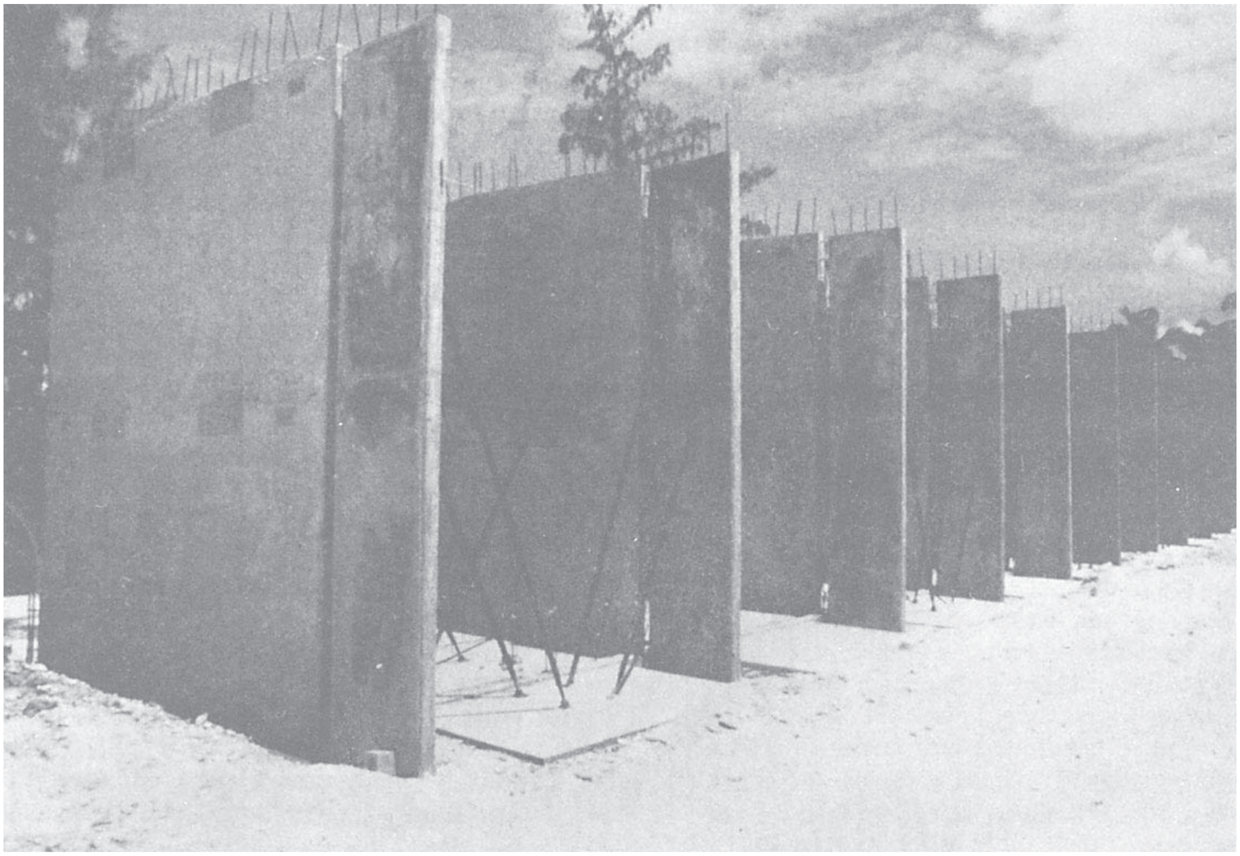

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Figure 7-18.-Precast panels in position.

are called PURLINS. The cross sections of these beams are shaped like a T or an I. The ones with the inverted T-sections are usually used in composite construction where they support cast-in- place floor or roof slabs.

BEAMS and GIRDERS are terms usually applied to the same members, but the one with the longer span should be referred to as the girder. Beams and girders may be conventional precast design or prestressed. Most of the beams will be I-shaped unless the ends are rectangular. The T-shaped ones can also be used.

Precast concrete COLUMNS may be solid or hollow. If the hollow type is desired, heavy card-board tubing should be used to form the core. A looped rod is cast in the column footing and projects upward into the hollow core to help hold the column upright. An opening should be left in the side of the column so that the column core can be filled with grout. This causes the looped rod to become embedded to form an anchor. The opening is dry packed.

Advantages of Precast Concrete

Precast concrete has the greatest advantage when identical members are to be cast because the same forms can be used several times. Some other advantages are listed below.

Control of the quality of concrete.

Smoother surfaces, and plastering is not necessary.

Less storage space is needed.

Concrete member can be cast under all weather conditions.

Better protection for curing.

Weather conditions do not affect erection.

Faster erection time.

PRESTRESSED CONCRETE

A prestressed concrete unit is one in which engineered stresses have been placed before it has been subjected to a load. When PRETENSIONING is used, the reinforcement (high-tensile-strength steel strands) is stretched through the form between the two end abutments or anchors. A predetermined amount of stress is applied to the steel strands. The concrete is then poured, encasing the reinforcement. As the concrete sets, it bonds to the pretensioned steel. When it has reached a specified strength, the tension on the reinforcement is released. This prestresses the concrete, putting it under compression, thus creating a built-in tensile strength.

POST-TENSIONING involves a precast member that contains normal reinforcing in addition to a number of channels through which the prestressing cables or rods maybe passed. The channels are usually formed by suspending inflated tubes through the form and casting the concrete around them. When the concrete has set, the tubes are deflated and removed. Once the concrete has reached a specified strength, prestressing steel strands or TENDONS are pulled into the channels and secured at one end. They are then stressed from the opposite end with a portable hydraulic jack and anchored by one of several automatic gripping devices.

Post-tensioning may be done where the member is poured or at the jobsite. Each member may be tensioned, or two or more members may be tensioned together after erection. In general, post-tensioning is used if the unit is over 45 ft long or over 7 tons in weight. However, some types of pretensioned roof slabs will be considerably longer and heavier than this.

When a beam is prestressed, either by pretensioning or post-tensioning, the tensioned steel produces a high compression in the lower part of the beam. This compression creates an upward bow or camber in the beam (fig. 7-19). When a load is placed on the beam, the camber is forced out, creating a level beam with no deflection.

Those members that are relatively small or that can be readily precast are normally pretensioned. These include precast roof slabs, T-slabs, floor slabs, and roof joists.

SPECIAL TYPES OF CONCRETE

Special types of concrete are essentially those with unique physical properties or those produced with unusual techniques and/or reproduction processes. Many special types of concrete are made with portland cement as a binding medium; some use binders other than portland cement.

Lightweight Concrete

Conventional concrete weighs approximately 150 lb per cubic foot. Lightweight concrete weighs 20 to 130 lb per cubic foot, depending on its intended use. Lightweight concrete can be made by using either gas-generating chemicals or

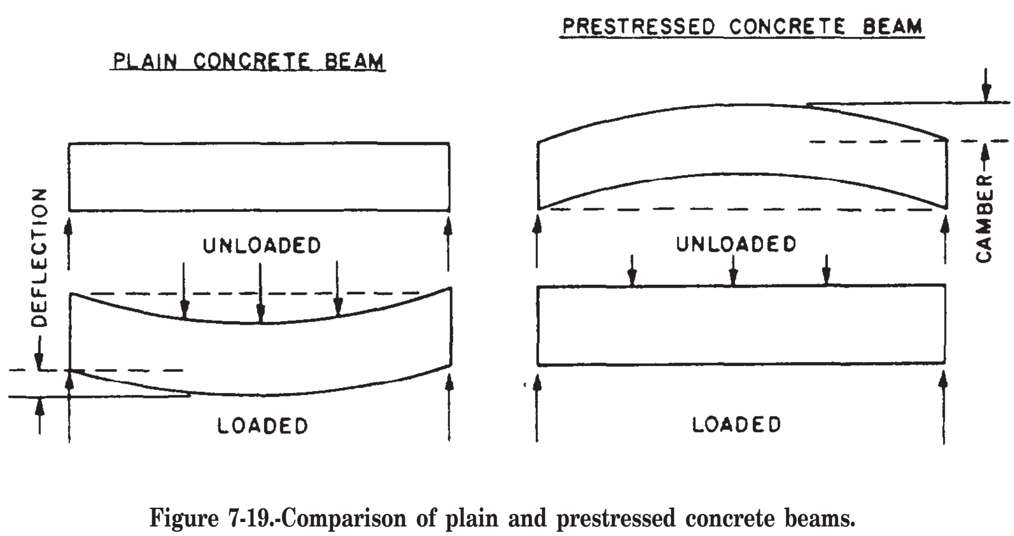


Figure 7-19.-Comparison of plain and prestressed concrete beams.

lightweight aggregates, such as expanded shale, clay, or slag. Concrete containing aggregates like perlite or vermiculite is very light in weight and is primarily used as insulating material. Lightweight concrete is usually classified according to its weight per cubic foot.

Semi-lightweight concrete has a unit weight of 115 to 130 lb per cubic foot and an ultimate compressive strength comparable to normal concrete. Sand of normal weight is substituted partially or completely for the lightweight fine aggregate.

Insulating lightweight concrete has a unit weight ranging from 20 to 70 lb per cubic foot, and its compressive strength seldom exceeds 1,000 psi. This type of concrete is generally used for insulating applications, such as fireproofing.

Structural lightweight concrete has a unit weight up to 115 lb per cubic foot and a 28-day compressive strength in excess of 2,000 psi. This type is used primarily to reduce the dead-load weight in concrete structural members, such as floors, walls, and the roof section in high-rise structures.

Heavyweight Concrete

Heavyweight concrete is produced with special heavy aggregates and has a density of up to 400 lb per cubic foot. This type is used principally for radiation shielding, for counterweights, and for other applications where higher density is desired. Except for density, the physical properties of heavyweight concrete are similar to those of normal- or conventional-weight concrete.

TILT-UP CONSTRUCTION

Tilt-up concrete construction is a special form of precast concrete building. This method consists basically of jobsite prefabrication, in which the walls are cast in a horizontal position, tilted to a vertical position, and then secured in place. Tilt-up construction is best suited for large one-story buildings, but it can be used in multistory structures. Usually, multistory structures are built by setting the walls for the first story, placing the floor above, then repeating the procedure for each succeeding floor. An alternate method is to cast two- to four-story panels.

The wall panels are usually cast on the floor slab of the structure. Care must be exercised to ensure the floor slab is smooth and level and that all openings for pipes and other utilities are temporarily plugged. The casting surface is treated with a good bond-breaking agent to ensure the panel does not adhere when it is lifted.

Reinforcement of Tilt-Up Panels

The steel in a tilt-up panel is set in the same manner as it is in a floor slab. Mats of reinforcement are placed on chairs and tied as needed. Reinforcement should be as near the center of the panel as possible. Reinforcing bars are run through the side forms of the panel. When welded wire fabric or expanded wire mesh is used, dowel bars are used to tie the panels and their vertical supports together. Additional reinforcement is generally needed around openings.

The panel is picked up or tilted by the use of PICKUP INSERTS. These inserts are tied into the reinforcement. As the panel is raised into its vertical position, the maximum stress will occur; therefore, the location and number of pickup inserts is extremely important. Some engineering manuals provide information on inserts, their locations, and capacities.

Tilt-Up Panel Foundations

An economical and widely used method to support tilt-up panels is a simple pad footing. The floor slab, which is constructed first, is NOT poured to the perimeter of the building to permit excavating and pouring the footings. After the panel is placed on the footing, the floor slab is completed. It may be connected directly to the outside wall panel, or a trench may be left to run mechanical, electrical, or plumbing lines.

Another method that is commonly used, as an alternative, is to set the panels on a grade beam or foundation wall at floor level. Regardless of the type of footing, the panel should be set into a mortar bed to ensure a good bond between the foundation wall and the panel.

Panel Connections

The panels may be tied together in a variety of ways. The location and use of the structure will dictate what method can or can NOT be used. The strongest method is a cast-in-place column with the panel-reinforcing steel tied into the column. However, this does NOT allow for expansion and contraction. It may be preferable to tie only the corner panels to the columns and allow the remaining panels to move.

A variety of other methods of connecting the panels are also used. A BUTTED connection, using grout or a gasket, can be used if the wall does NOT contribute any structural strength to the structure. Steel columns are welded to steel angles or plates secured in the wall panel. Precast columns can also be used. Steel angles or plates are secured in both the columns and plate and welded together to secure the panel.

When panel connections that do not actually hold the panels in place are used, the panels are generally welded to the foundation and to the roof by using steel angles or plates. All connections must provide waterproof joints. This is accomplished by the use of expansion joint material.

Finishes

Tilt-up panels may be finished in a variety of ways similar to any other concrete floor or wall. Some finishes may require the panel to be poured face up; others will require face-down pouring. This may affect the manner in which the panels are raised and set.

CONCRETE CONSTRUCTION JOINTS AND CONNECTIONS

Construction joints are divisions between concrete work done at intervals spaced widely enough to allow partial hardening. They are used between the units of structure and placed where they will cause the minimum amount of weakness to the structure. It is safe to assume that construction joints are located where the shearing stresses and bending moments are relatively small or where the joints will be supported by other structural members. For horizontal work, such as floor slabs, construction joints should be in a vertical plane; whereas, for vertical work, such as columns, the joints should lie in a horizontal plane (fig. 7-20).

Foundation walls are bonded to footings with vertical reinforcing steel called "dowels, " which are placed in footings and extend about 3 to 4 ft up into the wall. A wedge-shaped through, called a keyway, is built into the footing to strengthen the bond between footings and walls (fig. 7-21).

Contraction Joints

The purpose of contraction joints is to control cracking caused by temperature changes

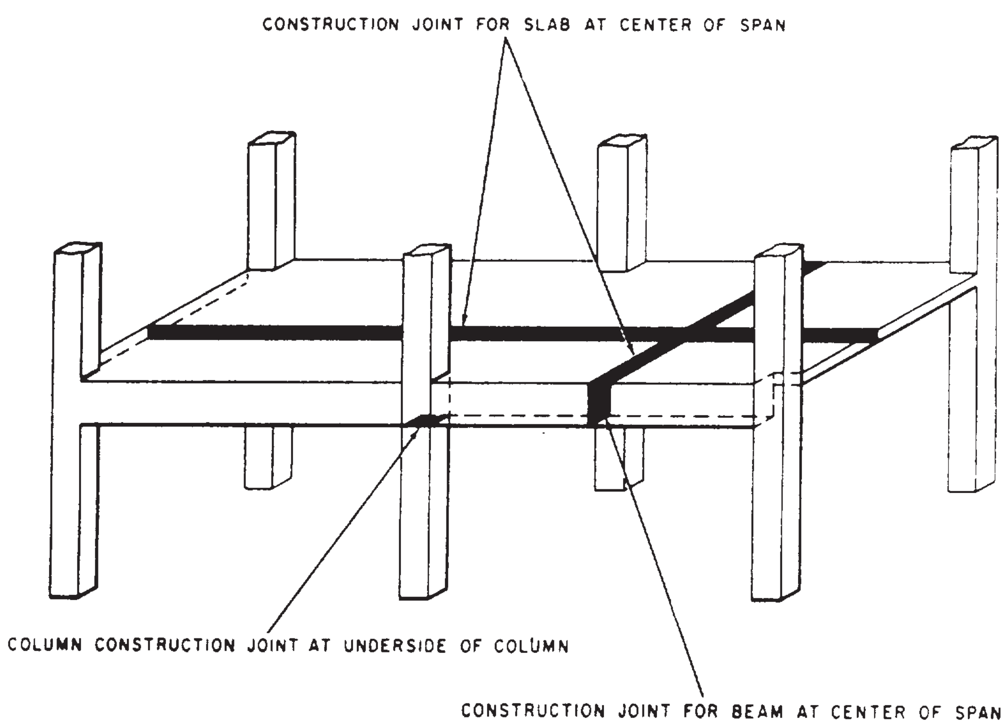


Figure 7-20-Location of construction joints in beams, columns, and floor slabs.

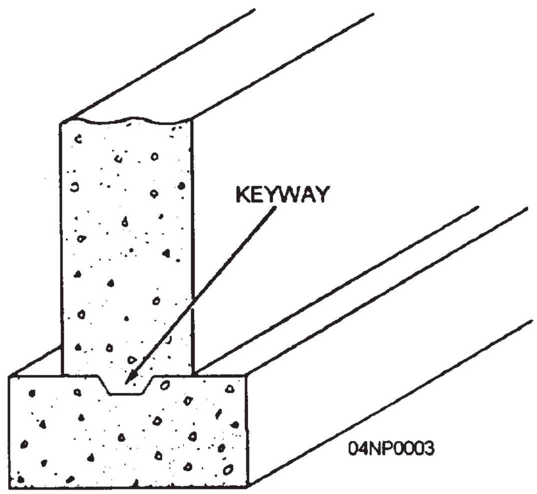


Figure 7-22.-Use of a contraction Joint.

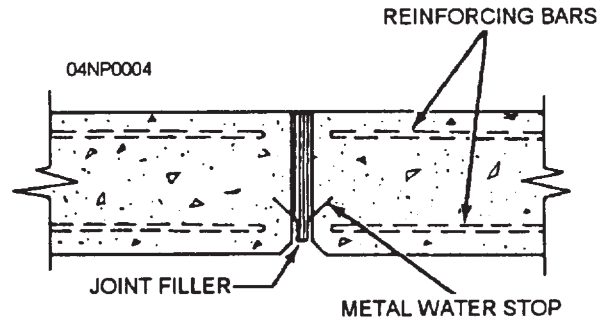


Figure 7-23.-Expansion joint for a wall.

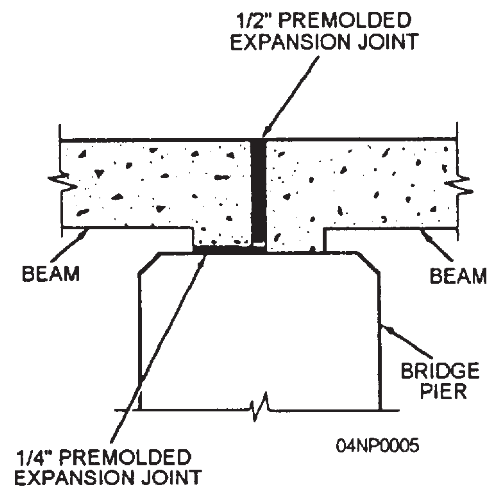


Figure 7-24.-Expansion joint for a bridge.

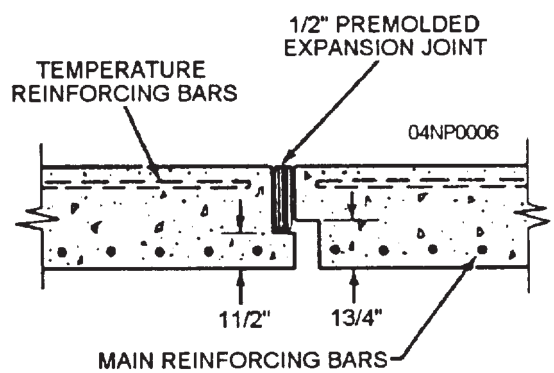


Figure 7-25.-Expansion joint for a floor slab.

incident to shrinkage of the concrete. A typical dummy contraction joint (fig. 7-22) is usually formed by cutting a depth of one third to one fourth the thickness of the section. Some contracting joints are made with no filler or with a thin coat of paraffii or asphalt and/or other materials to break the bond. Depending on the extent of local temperature, joints in reinforced concrete slabs may be placed at 15-to 25-ft intervals in each direction.

Expansion Joints

Wherever expansion might cause a concrete slab to buckle because of temperature change, expansion joints (also called isolation joints) are required. An expansion joint is used with a pre-molded cork or mastic filler to separate sections from each other, thus allowing room for expansion if elongation or closing of the joint is anticipated. Figures 7-23, 7-24, and 7-25 show expansion joints for a variety of locations. Expansion joints may be installed every 20 ft.

CONCRETE FORMS

Most structural concrete is made by placing (also called CASTING) plastic concrete into

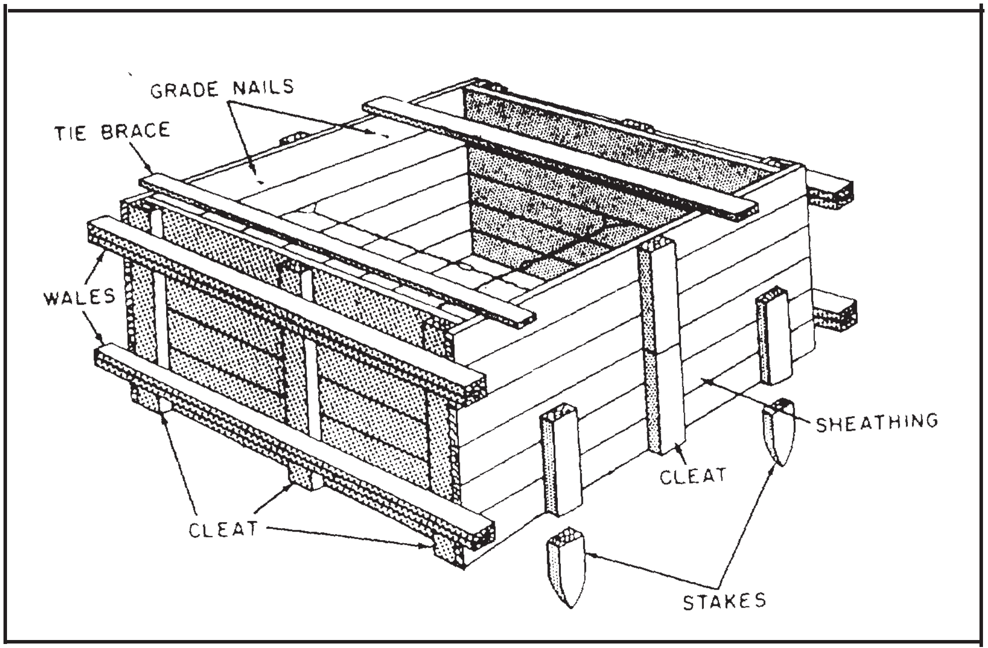


Figure 7-26. Typical large footing form.

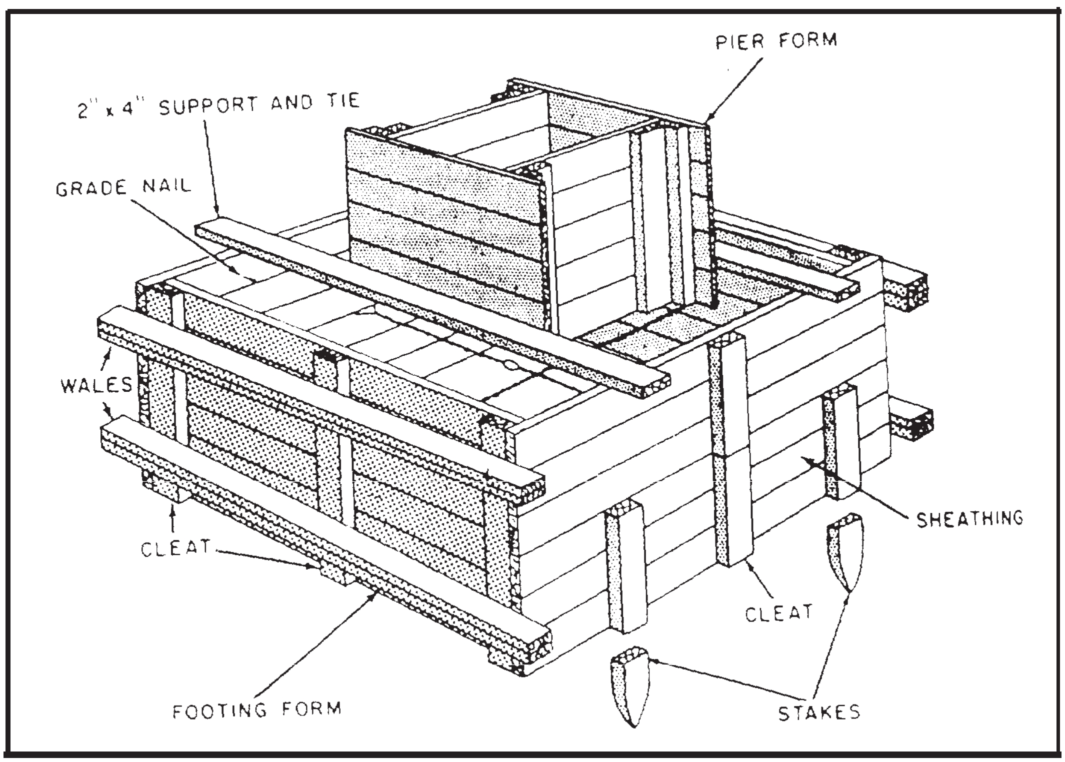


Figure 7-27.-Typical footing and pier form.

spaces enclosed by previously constructed FORMS. These forms are usually removed once the plastic concrete hardens into the shape outlined by the forms.

Forms for concrete structures must be tight, rigid, and strong. If the forms are NOT tight, loss of water and paste may cause sand streaking as well as weakness to the concrete. The forms must be strong enough to resist the high pressure exerted by the concrete.

Form Materials

Undisturbed soil or clay, if sufficiently rigid and excavated to proper dimensions, maybe used as EARTH FORMS. Design, specifications, and construction methods, however, dictate what kind of form materials are to be used on certain structures. Wood, plywood, steel, fiber glass, and other approved materials are commonly used as form materials. Forms for concrete pavement and curves should be metal; surfaces exposed to view in the finished structure and those requiring special finishes should be wood, plywood, or other approved material.

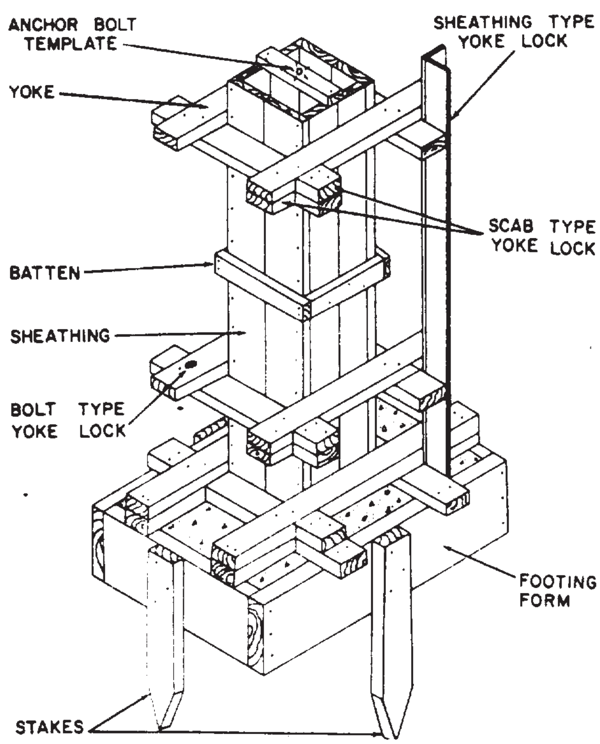


Figure 7-28.-Form for concrete column.

Foundation Forms

Foundation forms may include forms or parts of forms for column footings, pier footings, and wall footings. Whenever possible, the earth should be excavated and the hole used to contain the foundation of footing forms. In most cases, FOOTINGS are cast directly against the earth, and only the sides are molded in forms. In some cases where there is a firm natural earth surface that is capable of supporting and molding the concrete, parts of forms are often omitted. Figure 7-26 shows a typical large footing form. Figures 7-27 and 7-28 show typical footing forms for a concrete pier and a concrete column, respectively.

Wall Forms

Wall forms are made up of five basic parts. They are as follows: (1) sheathing, to shape and retain the concrete until it sets; (2) studs, to form a framework and support the sheathing; (3) wales, to keep the form aligned and support the studs; (4) braces, to hold the forms erect under lateral pressure; and (5) ties and spreaders or tie-spreader units, to hold the sides of the forms at the correct spacing (fig. 7-29).

Wall forms may be built in place or prefabricated, depending on the shape and the desirability for reuse.

Wall forms are usually reinforced against displacement by the use of TIES. Two types of

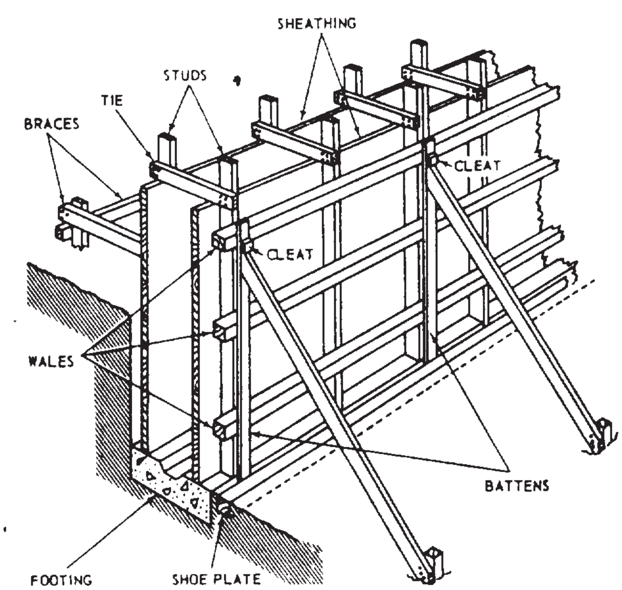


Figure 7-29.-Parts of a typical wall form.

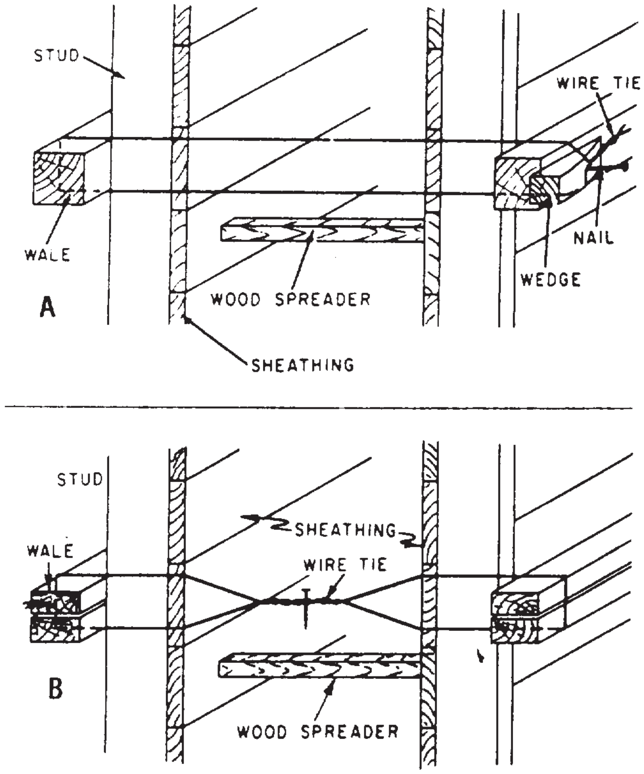


Figure 7-30.-Wire ties for wall forms.

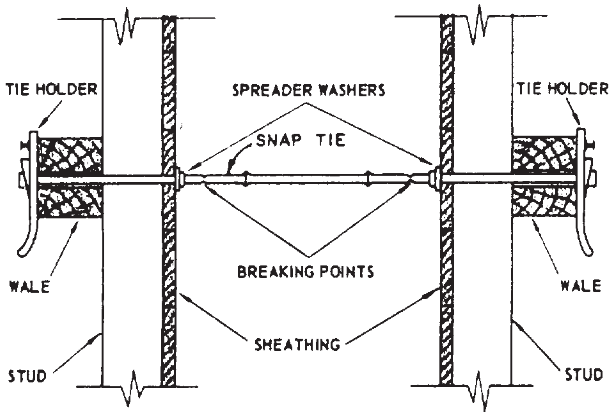


Figure 7-31.-Snap tie.

simple wire ties, used with wood SPREADERS, are shown in figure 7-30. The wire is passed around the studs and wales and through small holes bored in the sheathing. The spreader is placed as close as possible to the studs, and the tie is set taut by the wedge shown in the upper view or by twisting with a small toggle, as shown in the lower view. When the concrete reaches the level of the spreader, the spreader is knocked out and removed. The parts of the wire that are inside the forms remain in the concrete; the outside surplus is cut off after the forms are removed.

Wire ties and wooden spreaders have been largely replaced by various manufactured devices that combine the functions of the tie and spreader. Figure 7-31 shows one of these, called a SNAP TIE. These ties are made in various sizes to fit various wall thicknesses. The tie holders can be removed from the tie rod. The rod goes through small holes bored in the sheathing and also through the wales, which are usually doubled for that purpose. Tapping the tie holders down on the ends of the rod brings the sheathing to bear solidly against the spreader washers. After the concrete has hardened, the tie holders can be detached to strip the forms. After the forms are stripped, a special wrench is used to break off the outer sections of rod; they break off at the breaking points, located about 1 in. inside the surface of the concrete. Small surface holes remain, which can be plugged with grout, if necessary.

Another type of wall form tie is the TIE ROD, as shown in figure 7-32. The rod in this type consists of three sections: an inner section, which is threaded on both ends, and two threaded outer sections. The inner section, with the cones set to the thickness of the wall, is placed between the forms, and the outer sections are passed through the wales and sheathing and threaded into the cone nuts. The clamps are then threaded up on the outer sections to bring the forms to bear against the cone nuts. After the concrete hardens, the clamps are loosened, and the outer sections of rod are removed by threading them out of the cone nuts. After the forms are stripped, the cone nuts are removed from the concrete by threading

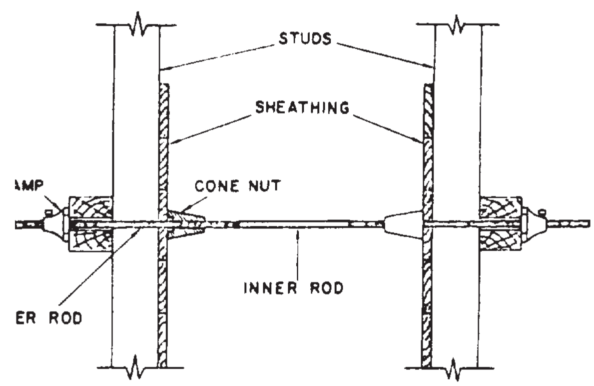


Figure 7-32.-Tie rod.

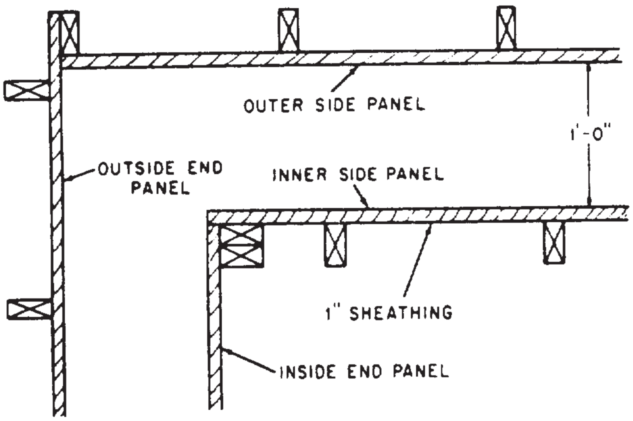


Figure 7-33.-Method of joining wall form panels at a corner.

them off the inner sections of rod with a special wrench leaving the cone-shaped surface holes. The outer sections and the cone nuts may be reused indefinitely.

The use of prefabricated panels for formwork has recently been on the increase. These panels can be reused many times, thus reducing the time and labor required for erecting forms on the site.

Many types of prefabricated form panels are in use. Contractors sometimes build their own panels from wood framing covered with plywood sheathing (fig. 7-33). The standard size is 2 ft by 8 ft, but panels can be sized to suit any particular situation.

Panels made with a metal frame and plywood sheathing are also in common use and are available in a variety of sizes. Special sections are produced to form inside corners, pilasters, and so forth. Panels are held together by patented panel clamps. Flat bar ties, which lock into place between panels, eliminate the need for spreaders. Forms are aligned by using one or more doubled rows of 2 by 4's, secured to the forms by a special device that is attached to the bar ties.

Form panels made completely of steel are also available. The standard size is 24 by 48 in., but various other sizes are also manufactured. Inside and outside corner sections are standard, and insert angles allow odd-sized panels to be made up as desired.

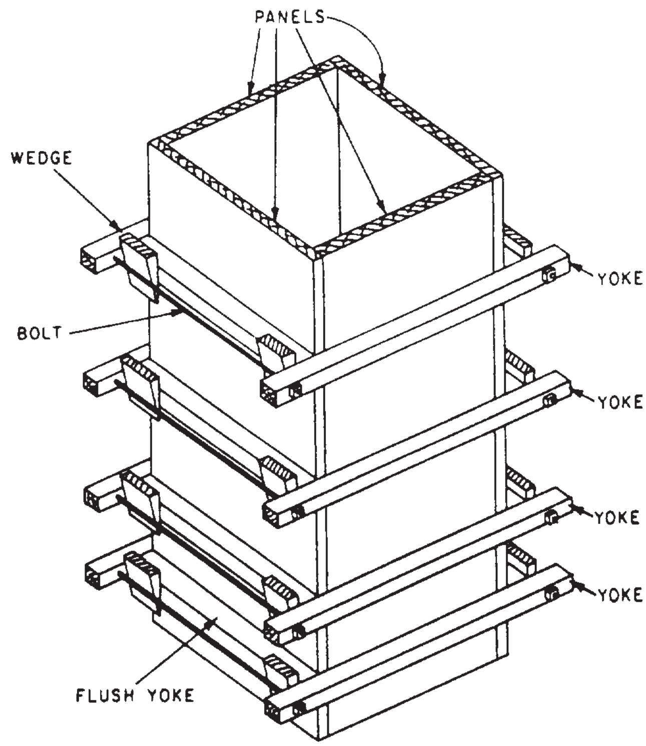


Figure 7-34.-Column form.

Large projects requiring mass concrete placement are often formed by the use of giant panels or ganged, prefabricated forms. Cranes usually raise and place these large sections, so their size is limited only by the available equipment. These large forms are built or assembled on the ground, and their only basic difference from regular forms is the extra bracing required to withstand handling.

Special attention must be given to corners when forms are being erected. These are weak points because the continuity of sheathing and wales is broken. Forms must be pulled tightly together at these points to prevent leakage of concrete.

Column Forms

A typical concrete column form (fig. 7-34) is securely braced by YOKES to hold the sheathing together against the bursting pressure exerted on the form by the plastic concrete. Since the bursting pressure is greater at the bottom than the top, the yokes are placed closer together at the bottom. Notice, in figure 7-34, that on two panels, the

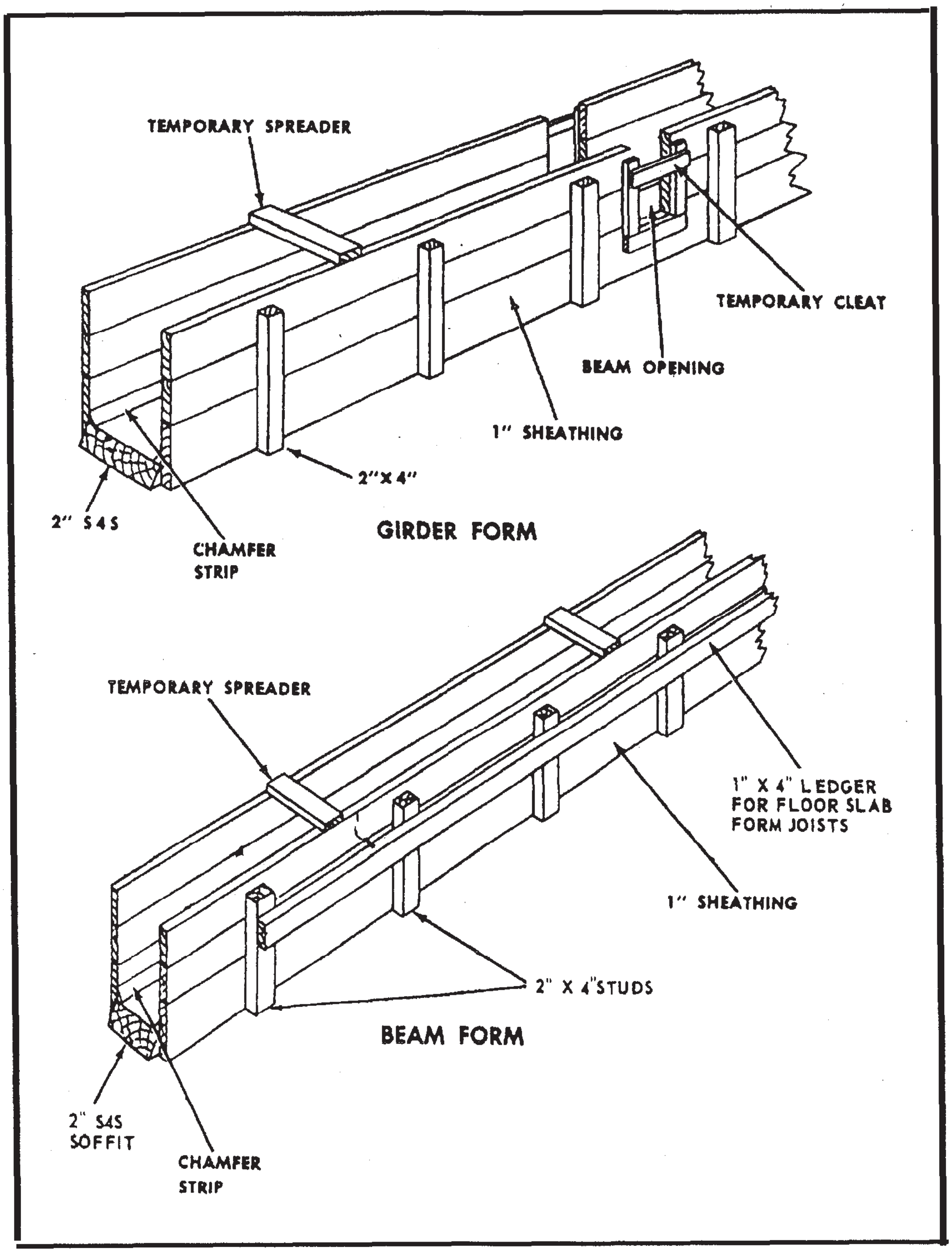


Figure 7-35.-Typical beam and girder forms.

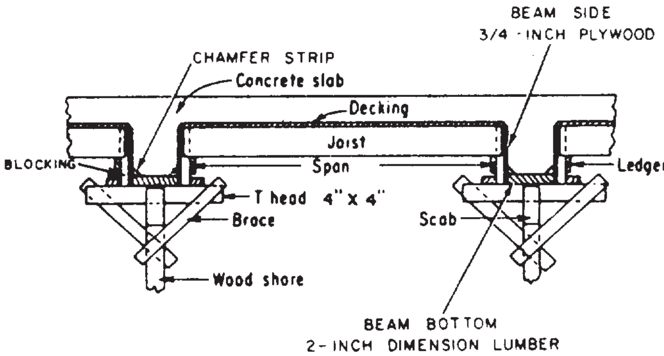


Figure 7-36.-Typical components of beam formwork with slab framing in.

yoke members come flush with the edges of the sheathing; on the other two, they project beyond the edges. Bolt holes are bored in these projections, and bolts are inserted to backup the wedges that are driven to tighten the yokes.

Beam and Girder Forms

The type of construction to be used for beam forms depends upon whether the form is to be removed in one piece or whether the sides are to be stripped and the bottom left in place until such time as the concrete has developed enough strength to permit removal of the shoring. The latter type of beam form is preferred, and details for this type are shown in figure 7-35. Beam forms are subjected to very little bursting pressure but must be shored up at frequent intervals to prevent sagging under the weight of the fresh concrete.

Figure 7-36 shows atypical interior beam form with slab forms supported on the beam sides. This drawing indicates that 3/4-in. plywood serves as the beam sides and that the beam bottom is a solid piece of 2-in. dimensioned lumber supported on the bottom by 4- by 4-in. T-head shores. The vertical side members, referred to in the figure as blocking, are placed to assist in transmitting slab loads to the supporting shores.

MASONRY

MASONRY is that form of construction composed of stone, concrete, brick, gypsum, hollow clay tile, concrete brick, tile, or other similar building units or materials or a combination of these materials, laid up unit by unit and set in mortar. This section will discuss the basic masonry materials commonly used in construction.

CONCRETE MASONRY

Concrete masonry has become increasingly important as a construction material. Important technological developments in the manufacture and utilization of the units have accompanied the rapid increase in the use of concrete masonry. Concrete masonry walls properly designed and constructed will satisfy various building requirements including fire, safety, durability, economy, appearance, utility, comfort, and good acoustics.

The most common concrete masonry unit is the CONCRETE BLOCK. It is manufactured from both normal and lightweight aggregates. There are two types of concrete block: heavyweight and lightweight. The heavyweight block is manufactured from cement, water, and aggregates, such as sand, gravel, and crushed limestone. The lightweight blocks use a combination of cement, water, and a lightweight aggregate. Cinders, pumice, expanded shale, and vermiculite are a few of the aggregates used in lightweight block production. The lightweight units weigh about 30 percent less than the heavyweight units.

Concrete blocks are made to comply with certain requirements, notably compressive strength, absorption, and moisture content. Compressive strength requirements provide a measure of the blocks' ability to carry loads and withstand structural stresses. Absorption requirements provide a measure of the density of the concrete while moisture content requirements indicate if the unit is sufficiently dry for use in wall construction.

Block Sizes and Shapes

Concrete block units are made in sizes and shapes to fit different construction needs. Units are made in full- and half-length sizes, as shown

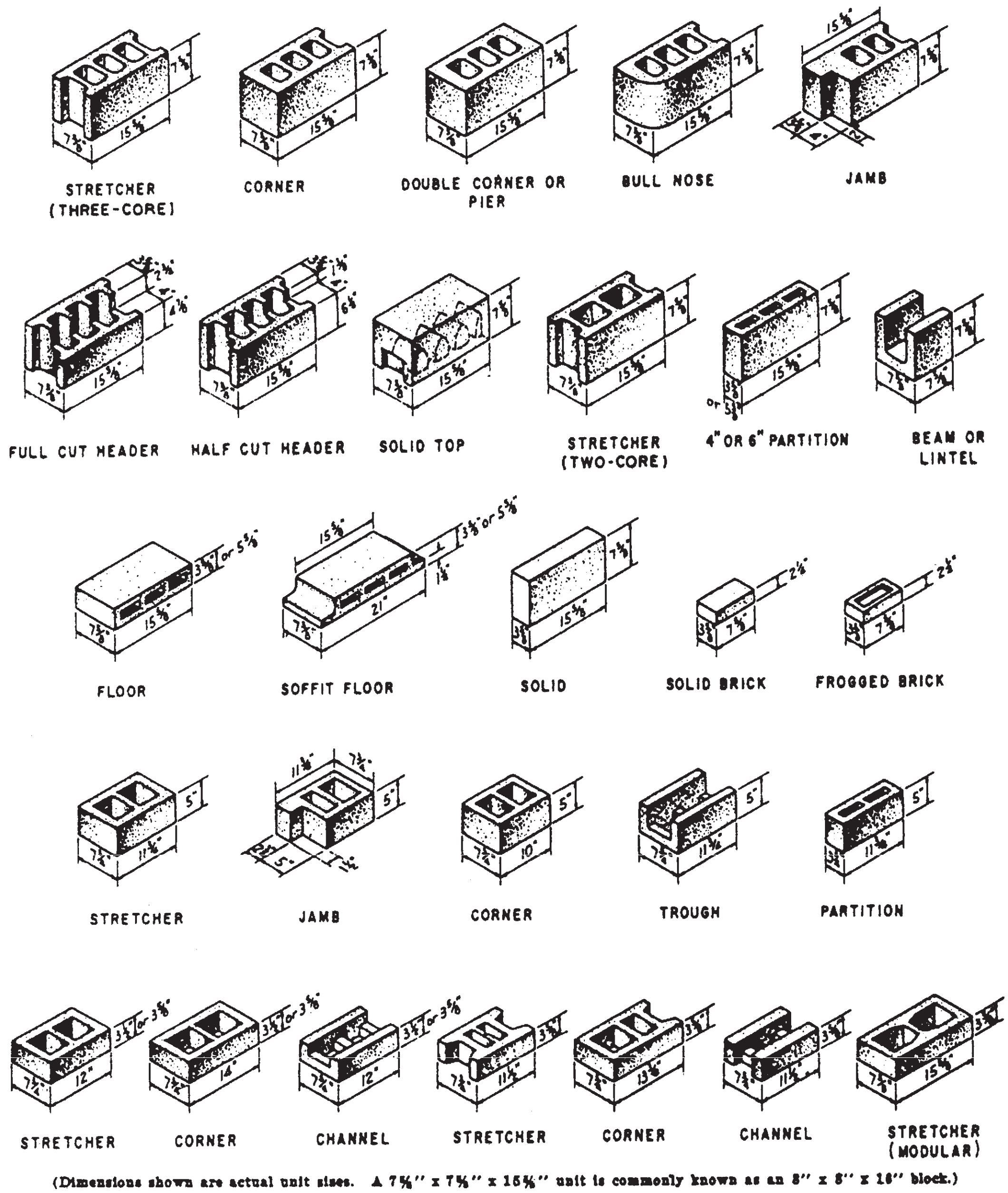


Figure 7-37.—Typical sizes and shapes of concrete masonry units.

in figure 7-37. Concrete unit sizes are usually referred to by their nominal dimensions. A unit measuring 7 5/8 in. wide, 7 5/8 in. high, and 15 5/8 in. long is referred to as an 8- by 8- by 16-in. unit. When it is laid in a wall with 3/8-in. mortar joints, the unit will occupy a space 16 in. long and 8 in. high. Besides the basic 8- by 8- by 16-in. units, the illustration shows a smaller partition unit and other units that are used much as cut brick are in brick masonry.

The corner unit is laid at a corner or at some similar point where a smooth, rather than a recessed, end is required. The header unit is used in a backing course placed behind a brick face tier header course. Part of the block is cut away to admit the brick headers. The uses of the other shapes shown are self-evident. Besides the shapes shown in figure 7-37, a number of smaller shapes for various special purposes are available. Units may be cut to the desired shapes with a bolster or, more conveniently and accurately, with a power-driven masonry saw.

The sides and the recessed ends of a concrete block are called the SHELL (fig. 7-38). The

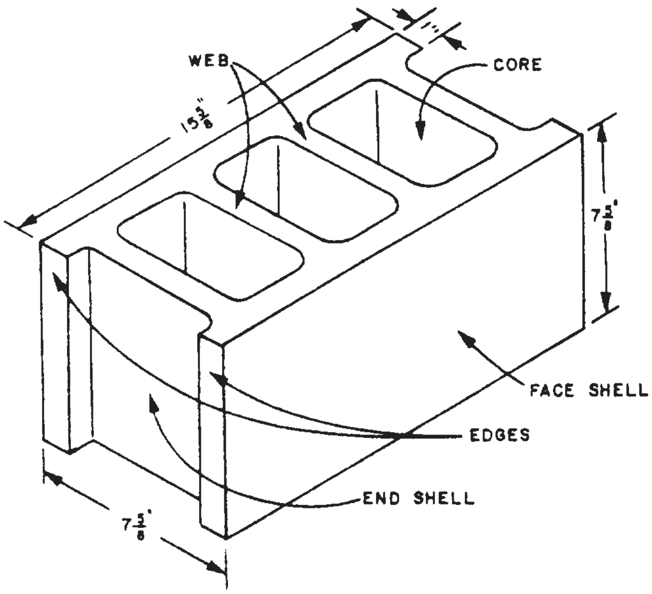


Figure 7-38.-Concrete block.

material that forms the partitions between the cores is called the WEB, and the holes between the webs are called CORES. Each of the long sides of a block is called a FACE SHELL, and each of the recessed ends is called an END SHELL. The vertical ends of the face shells, on either side of the end shells, are called the EDGES.

Wall Patterns

The large number of shapes and sizes of concrete blocks lend themselves to a great many uses. Figure 7-39 shows only a few of the wall patterns that can be developed using various pattern bonds and block sizes. Commercial publications from the Portland Cement Association show many more. Figure 7-40 shows some of the styles of SCREEN BLOCKS (blocks with patterned holes). This type of block is used to

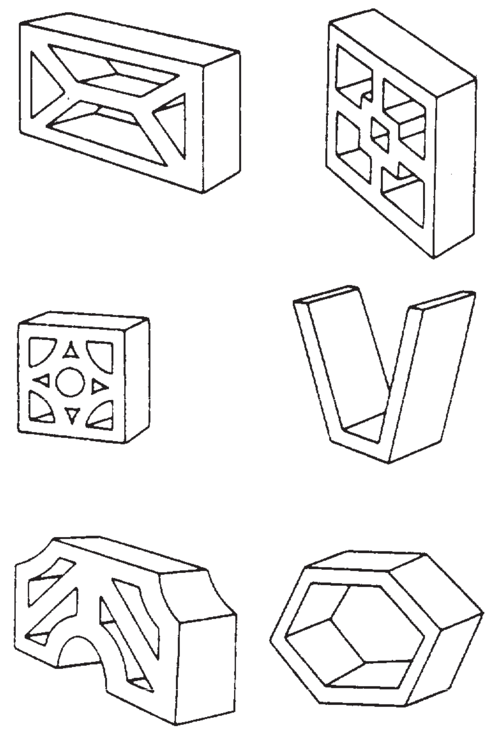


Figure 7-40.-Screen block designs.

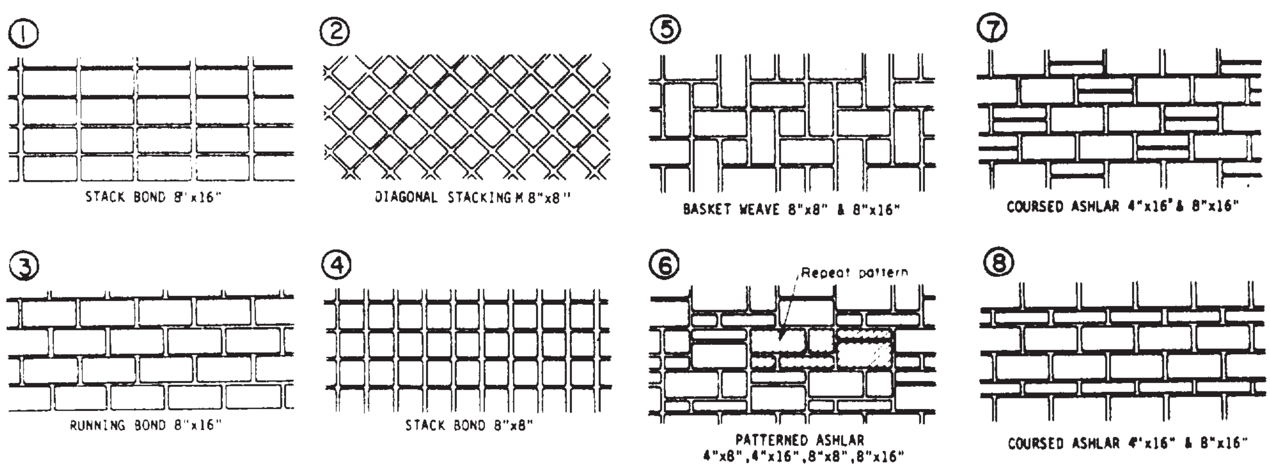


Figure 7-39.-Wall patterns.

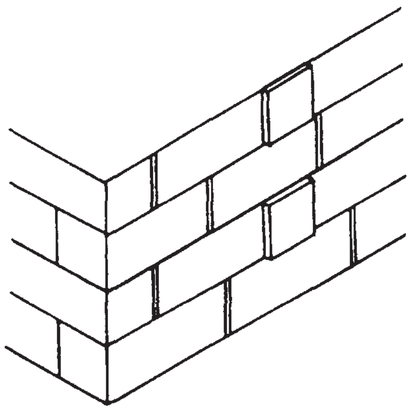


Figure 7-41.-Blocks laid in relief.

make a decorative wall called a PIERCED or SCREEN wall. Other architectural effects can be achieved by laying some block in relief (fig. 7-41) or by varying the type of mortar joint.

Modular Planning

Concrete masonry walls should be laid out to make maximum use of full- and half-length units, thus minimizing cutting and fitting of units on the job. Length and height of walls, width and height of openings, and wall areas between doors, windows, and corners should be planned to use full-size and half-size units, which are usually available (fig. 7-42). This procedure assumes that window frames and doorframes are of modular dimensions that fit modular full- and half-size units. Then, all horizontal dimensions should be in multiples of nominal full-length masonry units, and both horizontal and vertical dimensions should be designed to be in multiples of 8 in. Table 7-2 lists nominal lengths of concrete masonry walls by stretchers, and table 7-3 lists nominal heights of concrete masonry walls by courses. When units 8 by 4 by 16 are used, the horizontal dimension should be planned in multiples of 8 in. (half-length units), and the vertical dimensions, in multiples of 4 in. If the thickness of the wall is greater or less than the length of a half unit, a special length unit is required at each corner in each course.

STRUCTURAL CLAY TILE MASONRY

Hollow masonry units made of burned clay or shale are called, variously, structural tiles,

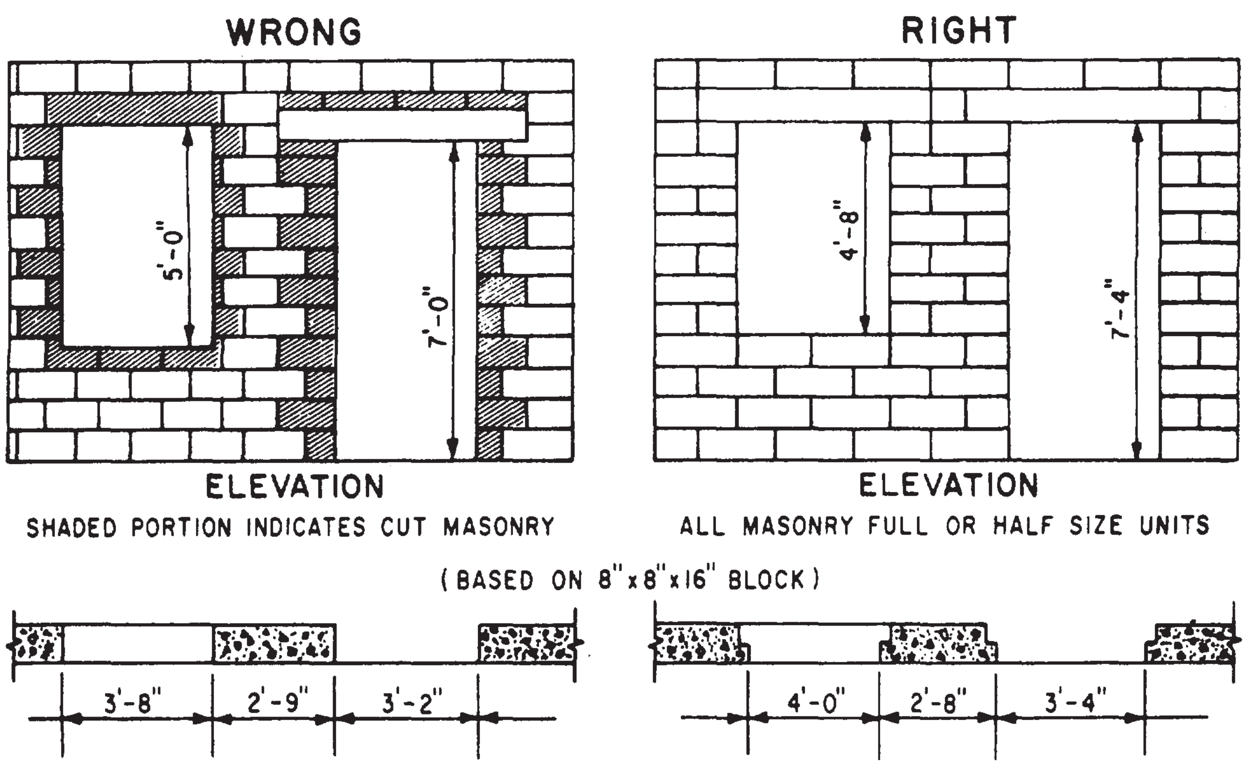


Figure 7-42.-Use of modular dimensions in concrete masonry wall openings.

Table 7-2.-Nominal Length of Concrete Masonry Walls by Stretchers

(Actual length of wall is measured from outside edge to outside edge of units and is equal to the nominal length minus ⅜" (one mortar joint).)

No. of stretchers	Nominal length of concrete masonry walls: Units 15⅝" long and half units 7⅝" long with ⅜" thick head joints.	Nominal length of concrete masonry walls: Units 11⅝" long and half units 5⅝" long with ⅜" thick head joints.
1	1' 4"	1' 0".
1½	2' 0"	1' 6".
2	2' 8"	2' 0".
2½	3' 4"	2' 6".
3	4' 0"	3' 0".
3½	4' 8"	3' 6".
4	5' 4"	4' 0".
4½	6' 0"	4' 6".
5	6' 8"	5' 0".
5½	7' 4"	5' 6".
6	8' 0"	6' 0".
6½	8' 8"	6' 6".
7	9' 4"	7' 0".
7½	10' 0"	7' 6".
8	10' 8"	8' 0".
8½	11' 4"	8' 6".
9	12' 0"	9' 0".
9½	12' 8"	9' 6".
10	13' 4"	10' 0".
10½	14' 0"	10' 6".
11	14' 8"	11' 0".
11½	15' 4"	11' 6".
12	16' 0"	12' 0".
12½	16' 8"	12' 6".
13	17' 4"	13' 0".
13½	18' 0"	13' 6".
14	18' 8"	14' 0".
14½	19' 4"	14' 6".
15	20' 0"	15' 0".
20	26' 8"	20' 0".

Table 7-3.-Nominal Height of Concrete Masonry Walls by Courses

(For concrete masonry units 7⅝" and 3⅝" in height laid with ⅜" mortar joints. Height is measured from center to center of mortar joints.)

No. of courses	Nominal height of concrete masonry walls: Units 7⅝" high and ⅜" thick bed joint	Nominal height of concrete masonry walls: Units 3⅝" high and ⅜" thick bed joint
1	8"	4".
2	1' 4"	8".
3	2' 0"	1' 0".
4	2' 8"	1' 4".
5	3' 4"	1' 8".
6	4' 0"	2' 0".
7	4' 8"	2' 4".
8	5' 4"	2' 8".
9	6' 0"	3' 0".
10	6' 8"	3' 4".
15	10' 0"	5' 0".
20	13' 4"	6' 8".
25	16' 8"	8' 4".
30	20' 0"	10' 0".
35	23' 4"	11' 8".
40	26' 8"	13' 4".
45	30' 0"	15' 0".
50	33' 4"	16' 8".

hollow tiles, structural clay tiles, structural clay hollow tiles, and structural clay hollow building tiles, but most commonly called building tile. In building tile manufacture, plastic clay is pugged through a die, and the shape that emerges is cut off into units. The units are then burned much as bricks are burned.

The apertures in a building tile, which correspond to the cores in a brick or a concrete block, are called CELLS. The solid sides of a tile are called the SHELL and the perforated material enclosed by the shell is called the WEB. A tile that is laid on one of its shell faces is called a SIDE-CONSTRUCTION tile; one that

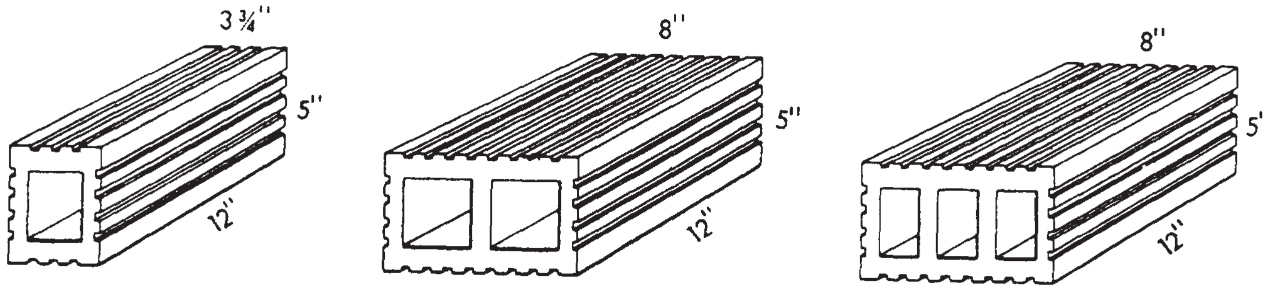


Figure 7-43.-Standard shapes of side-construction building tiles.

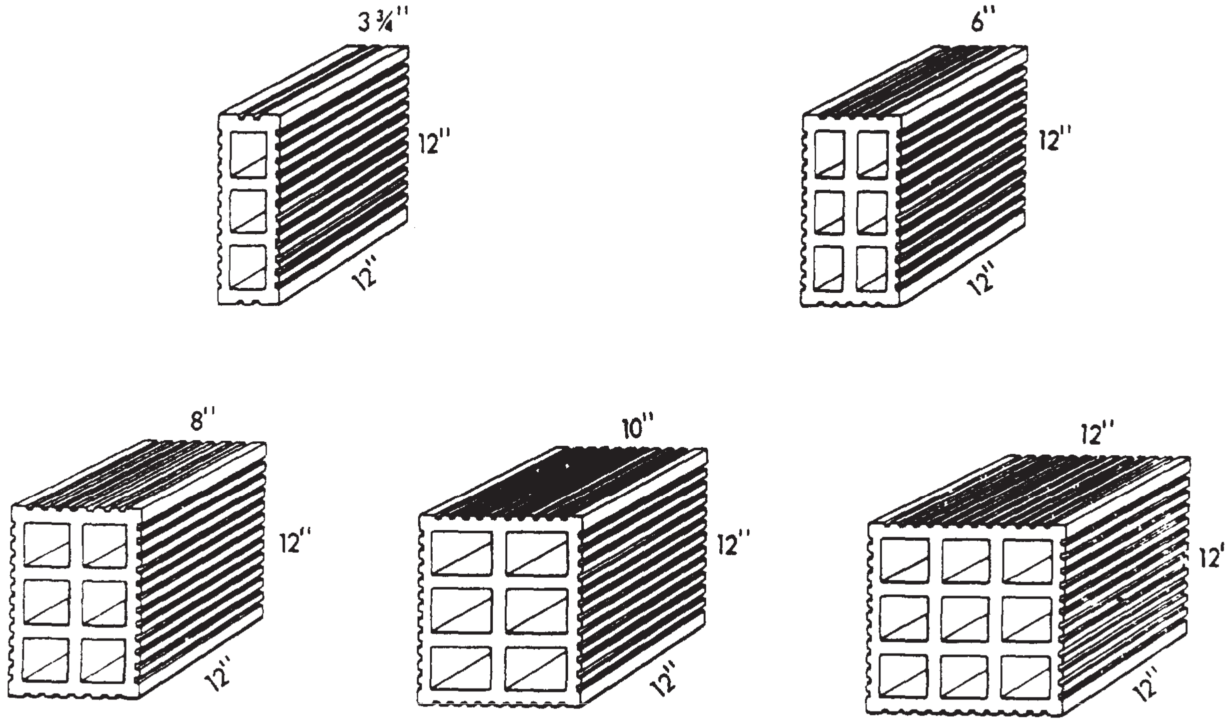


Figure 7-44.-Standard shapes of end-construction building tiles.

is laid on one of its web faces is called an END-CONSTRUCTION tile. Figures 7-43 and 7-44 show the sizes and shapes of basic side- and end-construction building units. Special shapes for use at corners and openings, or for use as closures, are also available.

Physical Characteristics

The compressive strength of the individual tile depends upon the materials used and upon the method of manufacture, in addition to the thickness of the shells and webs. A minimum compressive strength of tile masonry of 300 lb per square in, based on the gross section may be expected. The tensile strength of structural clay tile masonry is small. In most cases, it is less than 10 percent of the compressive strength.

The abrasion resistance of clay tile depends primarily upon its compressive strength. The stronger the tile, the greater its resistance to wearing. The abrasion resistance decreases as the amount of water absorbed increases.

Structural clay facing tile has excellent resistance to weathering. Freezing and thawing action produces almost no deterioration. Tile that will absorb no more than 16 percent of its weight of water have never given unsatisfactory performance in resisting the effect of freezing and thawing action. Only portland cement-lime mortar or mortar prepared from masonry cement should be used if the masonry is exposed to the weather.

Walls containing structural clay tile have better heat-insulating qualities than walls composed of solid units because of the dead air space that exists in tile walls. The resistance to sound penetration of this type of masonry compares favorably with the resistance of solid masonry walls, but it is somewhat less.

The fire resistance of tile walls is considerably less than the fire resistance of solid masonry walls. It can be improved by applying a coat of plaster to the surface of the wall. Partition walls of structural clay tile 6 in, thick will resist a fire for 1 hr provided the fire produces a temperature of not more than 1700°F.

The solid material in structural clay tile weighs about 125 lb per cubic foot. Since the tile contains hollow cells of various sizes, the weight of the tile varies, depending upon the manufacturer and type. A 6-in. tile wall weighs approximately 30 lb per square foot, while a 12-in. tile weighs approximately 45 lb per square foot.

Uses for Structural Clay Tile

Structural clay tile may be used for exterior walls of either the load-bearing or nonload-bearing type. It is suitable for both below-grade and above-grade construction.

Structural load-bearing tile is made from 4- to 12-in. thicknesses with various face dimensions. The use of these tiles is restricted by building codes and specifications, so consult the project specification.

Nonload-bearing partition walls from the 4- to 12-in. thicknesses are frequently made of structural clay tile. These walls are easily built, light in weight, and have good heat- and sound-insulating properties.

Figure 7-45 shows the use of structural clay tile as a back unit for a brick wall.

Figure 7-46 shows the use of 8- by 5- by 12-in. tile in wall construction. Exposure of the open end of the tile can be avoided by the application of a thin tile called a SOAP at the corner.

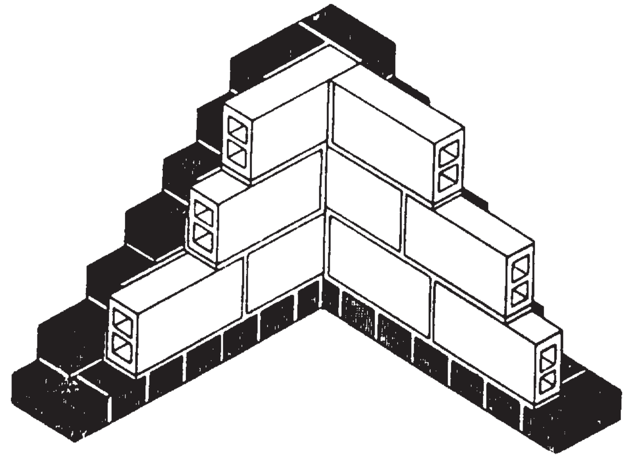


Figure 7-45.-Structural tile used as a backing for bricks.

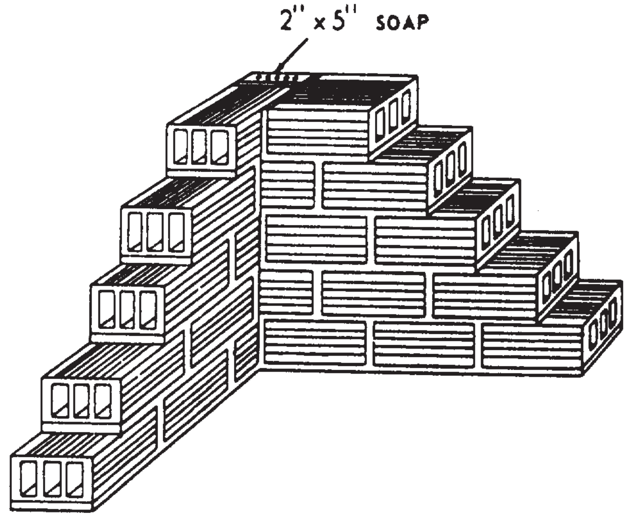


Figure 7-46.-Eight-inch structural clay tile wall.

STONE MASONRY

Stone masonry is masonry is which the units consist of natural stone. In RUBBLE stone masonry, the stones are left in their natural state, without any kind of shaping. In ASHLAR masonry, the faces of stones that are to be placed in surface positions are squared so that the surfaces of the finished structure will be more or less continuous plane surfaces. Both rubble and ashlar work may be either RANDOM or COURSED.

Random rubble is the crudest of all types of stonework. Little attention is paid to laying the

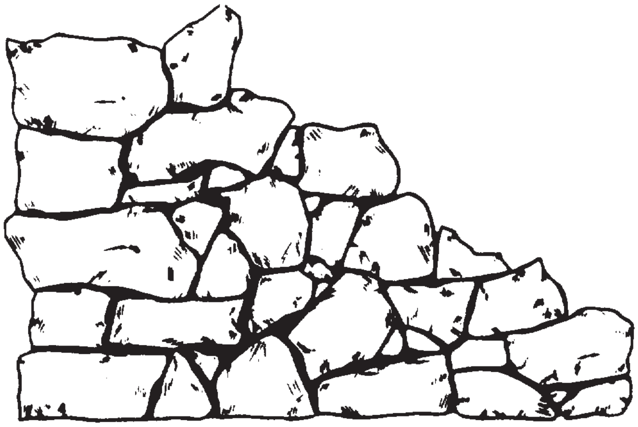


Figure 7-47.-Random rubble stone masonry.

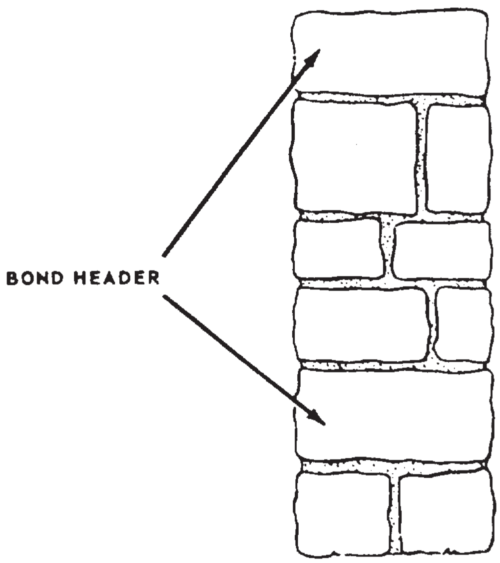


Figure 7-48.-Layers of bond stones in random stone masonry.

stones in courses, as shown in figure 7-47. Each layer must contain bonding stones that extend through the wall, as shown in figure 7-48. This produces a wall that is well tied together. The bed joints should be horizontal for stability, but the “builds” or head joints may run in any direction.

Coursed rubble consists of roughly squared stones assembled in such a manner as to produce approximately continuous horizontal bed joints, as shown in figure 7-49.

The stone for use in stone masonry should be strong, durable, and cheap. Durability and strength depend upon the chemical composition and physical structure of the stone. Some of the more commonly found stones that are suitable are limestone, sandstone, granite, and slate. Unsquared stones obtained from nearby ledges or quarries or even fieldstone maybe used. The size of the stone should be such that two people can easily handle it. A variety of sizes is necessary to avoid using large quantities of mortar.

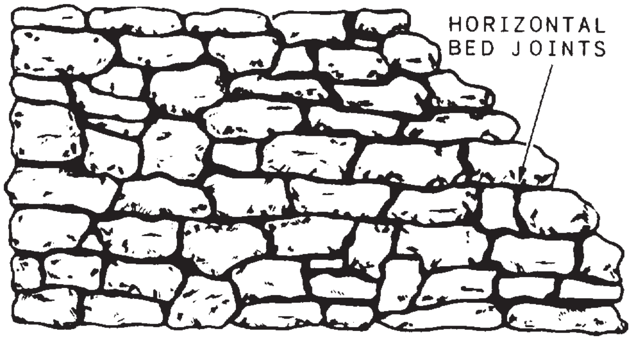


Figure 7-49.-Coursed rubble masonry.

The mortar for use in stone masonry may be composed of portland cement and sand in the proportions of one part cement to three parts sand by volume. Such mortar shrinks excessively and does not work well with the trowel. A better mortar to use is portland cement-lime mortar. Mortar made with ordinary portland cement will stain most types of stone. If staining must be prevented, nonstaining white portland cement should be used in making the mortar. Lime does not usually stain the stone.

BRICK MASONRY

In brick masonry construction, units of baked clay or shale of uniform size are laid in courses with mortar joints to form walls of virtually unlimited length and height. These units are small enough to be placed with one hand. Bricks are kiln-baked from various clay and shale mixtures. The chemical and physical characteristics of the ingredients vary considerably; these and the kiln temperatures combine to produce brick in a variety of colors and harnesses. In some regions, pits are opened and found to yield clay or shale that, when ground and moistened, can be formed and baked into durable brick; in other regions, clays or shales from several pits must be mixed.

The dimensions of a U.S. standard building brick are 2 1/4 by 3 3/4 by 8. The actual dimensions of brick may vary a little because of shrinkage during burning.

Brick Nomenclature

Frequently, the Builder must cut the brick into various shapes. The most common shapes are shown in figure 7-50. They are called half or bat, three-quarter closure, quarter closure, king closure, queen closure, and split. They are used to fill in the spaces at corners and such other places where a full brick will not fit.

The six surfaces of a brick are called the cull, the beds, the side, the end, and the face, as shown in figure 7-51.

Brick Classification

A finished brick structure contains FACE brick (brick placed on the exposed face of the structure) and BACKUP brick (brick placed behind the face brick). The face brick is often of higher quality than the backup brick; however, the entire wall may be built of COMMON brick.

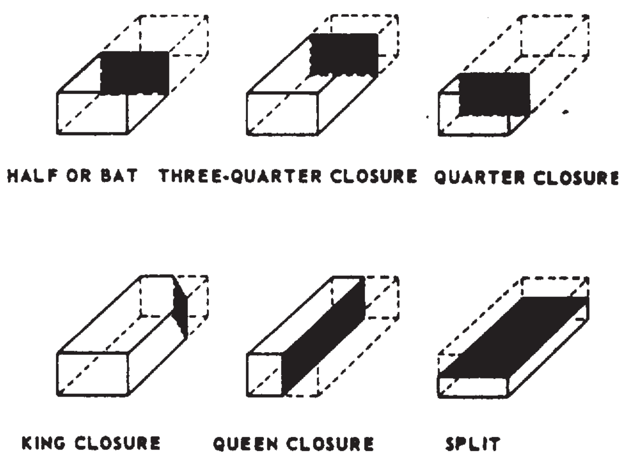


Figure 7-50.-Nomenclature of common shapes of cut brick.

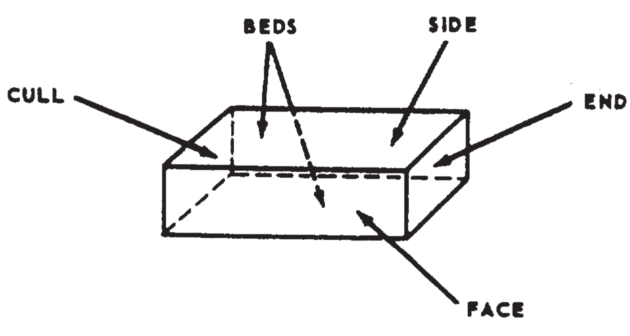


Figure 7-51.-Brick surfaces nomenclature.

Common brick is brick that is made from pit-run clay, with no attempt at color control and no special surface treatment like glazing or enameling. Most common brick is red.

Although any surface brick is a face brick as distinguished from a backup brick, the term *face brick* is also used to distinguish high-quality brick from brick that is of common-brick quality or less. Applying this criterion, face brick is more uniform in color than common brick, and it may be obtained in a variety of colors as well. It may be specifically finished on the surface, and in any case, it has a better surface appearance than common brick. It may also be more durable, as a result of the use of select clay and other materials, or as a result of special manufacturing methods.

Backup brick may consist of brick that is inferior in quality even to common brick. Brick that has been underburned or overburned, or brick made with inferior clay or by inferior methods, is often used for backup brick.

Still another type of classification divides brick into grades according to the probable climatic conditions to which it is to be exposed. These are as follows:

GRADE SW is brick designed to withstand exposure to below-freezing temperatures in a moist climate like that of the northern regions of the United States.

GRADE MW is brick designed to withstand exposure to below-freezing temperatures in a drier climate than that mentioned in the previous paragraph.

GRADE NW is brick primarily intended for interior or backup brick. It maybe used exposed, however, in a region where no frost action occurs, or in a region where frost action occurs, but the annual rainfall is less than 15 in.

Types of Bricks

There are many types of brick. Some are different in formation and composition while others vary according to their use. Some commonly used types of brick are described in the following paragraphs.

COMMON brick is made of ordinary clays or shales and burned in the usual manner in the kilns. These bricks do not have special scorings or markings and are not produced in any special color or surface texture. Common brick is also known as hard- and kiln-run brick. It is used generally for backing courses in solid or cavity brick walls. The harder and more durable kinds are preferred for this purpose.

FACE bricks are used in the exposed face of a wall and are higher quality units than backup brick. They have better durability and appearance. The most common colors of face brick are various shades of brown, red, gray, yellow, and white.

CLINKER bricks are bricks that have been overburned in the kilns. This type of brick is usually hard and durable and may be irregular in shape. Rough hard corresponds to the clinker classification.

PRESS bricks are made by the dry press process. This class of brick has regular smooth faces, sharp edges, and perfectly square corners. Ordinarily, all press brick are used as face brick.

GLAZED bricks have one surface of each brick glazed in white or other colors. The ceramic glazing consists of mineral ingredients that fuse together in a glass-like coating during burning. This type of brick is particularly suited for walls or partitions in hospitals, dairies, laboratories, or other buildings where cleanliness and ease of cleaning are necessary.

FIREBRICK is made of a special type of fire clay that will withstand the high temperatures of fireplaces, boilers, and similar usages without cracking or decomposing. Firebrick is larger than regular structural brick, and often, it is hand molded.

CORED BRICK are made with two rows of five holes extending through their beds to reduce weight. There is no significant difference between

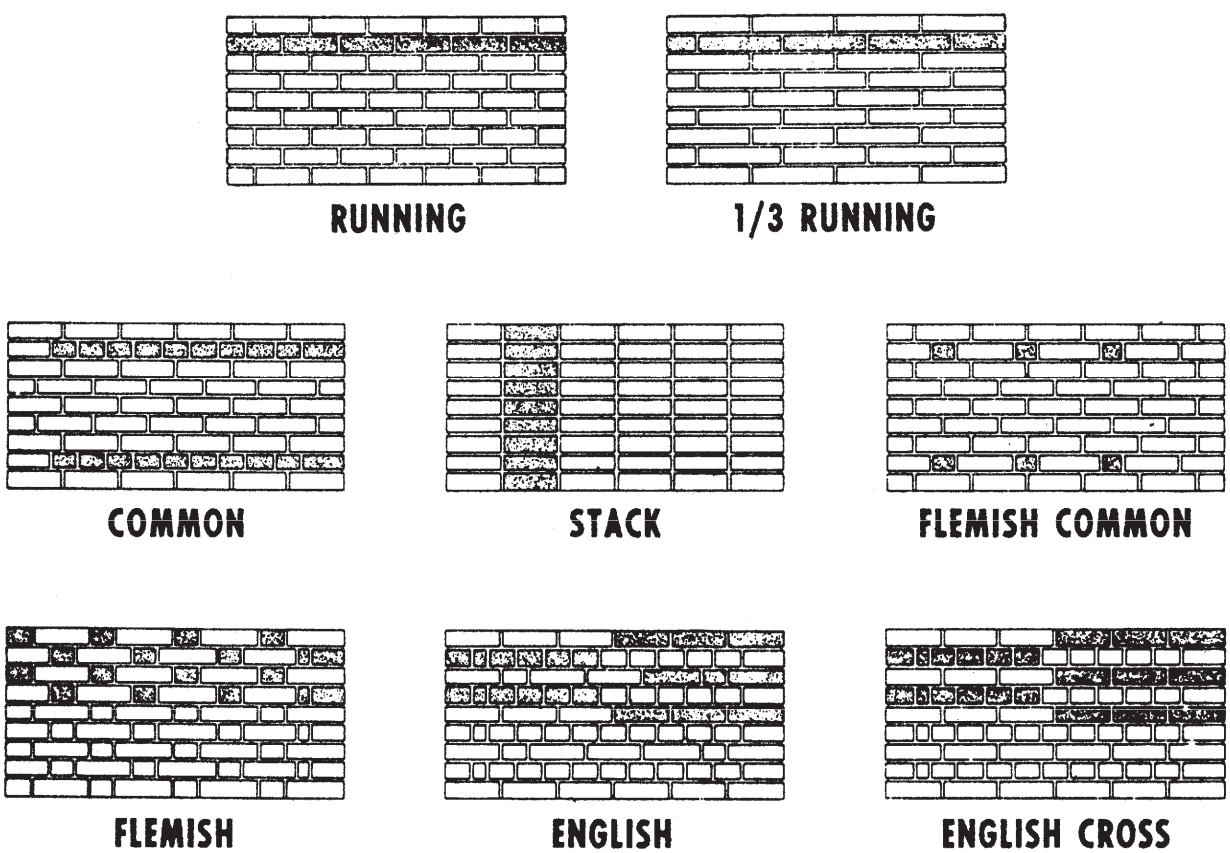


Figure 7-52.—Types of brick masonry bond.

the strength of walls constructed with cored brick and those constructed with solid brick. Resistance to moisture penetration is about the same for both types of walls. The most easily available brick that will meet the requirements should be used whether the brick is cored or solid.

SAND-LIME bricks are made from a lean mixture of slaked lime and fine silicious sand, molded under mechanical pressure and hardened under steam pressure.

Types of Bonds

When the word *bond* is used in reference to masonry, it may have three different meanings:

STRUCTURAL BOND is a method of interlocking or tying individual masonry units together so that the entire assembly acts as a single structural unit. Structural bonding of brick and tile walls may be accomplished in three ways: first, by overlapping (interlocking) the masonry units; second, by the use of metal ties embedded in connecting joints; and third, by the adhesion of grout to adjacent wythes of masonry.

MORTAR BOND is the adhesion of the joint mortar to the masonry units or to the reinforcing steel.

PATTERN BOND is the pattern formed by the masonry units and the mortar joints on the face of a wall. The pattern may result from the type of structural bond used or may be purely a decorative one in no way related to the structural bond. Five basic pattern bonds are in common use today, as shown in figure 7-52. These are running bond, common bond, stack bond, Flemish bond, and English bond.

RUNNING BOND is the simplest of the basic pattern bonds; the running bond consists of all stretchers. Since there are no headers used in this bond, metal ties are usually used. Running bond is used largely in cavity wall construction and veneered walls of brick and often in facing tile walls where the bonding may be accomplished by extra width stretcher tile.

COMMON or AMERICAN BOND is a variation of running bond with a course of full-length headers at regular intervals. These headers provide structural bonding, as well as pattern. Header courses usually appear at every fifth, sixth, or seventh course, depending on the structural bonding requirements. In laying out any bond pattern, it is important that the corners be started correctly. For common bond, a three-quarter brick must start each header course at the corner. Common bond may be varied by using a Flemish header course.

STACK BOND is purely a pattern bond. There is no overlapping of the units, all vertical joints being aligned. Usually, this pattern is bonded to the backing with rigid steel ties, but when 8-in.-thick stretcher units are available, they may be used. In large wall areas and in load-bearing construction, it is advisable to reinforce the wall with steel pencil rods placed in the horizontal mortar joints. The vertical alignment requires dimensionally accurate units, or carefully prematched units, for each vertical joint alignment. Variety in pattern may be achieved by numerous combinations and modifications of the basic patterns shown.

FLEMISH BOND is made up of alternate stretchers and headers, with the headers in alternate courses centered over the stretchers in the intervening courses. Where the headers are not used for structural bonding, they may be obtained by using half brick, called blind-headers. Two methods are used in starting the corners. Figure 7-52 shows the so-called FLEMISH corner in which a three-quarter brick is used to start each course and the ENGLISH corner in which 2-in. or quarter-brick closures must be used.

ENGLISH BOND is composed of alternate courses of headers and stretchers. The headers are centered on the stretchers and joints between stretchers. The vertical (head) joints between stretchers in all courses line up vertically. Blind headers are used in courses that are not structural bonding courses. The English cross bond is a variation of English bond and differs only in that vertical joints between the stretchers in alternate courses do NOT line up vertically. These joints center on the stretchers themselves in the courses above and below.

Masonry Terms

Specific terms are used to describe the various positions of masonry units and mortar

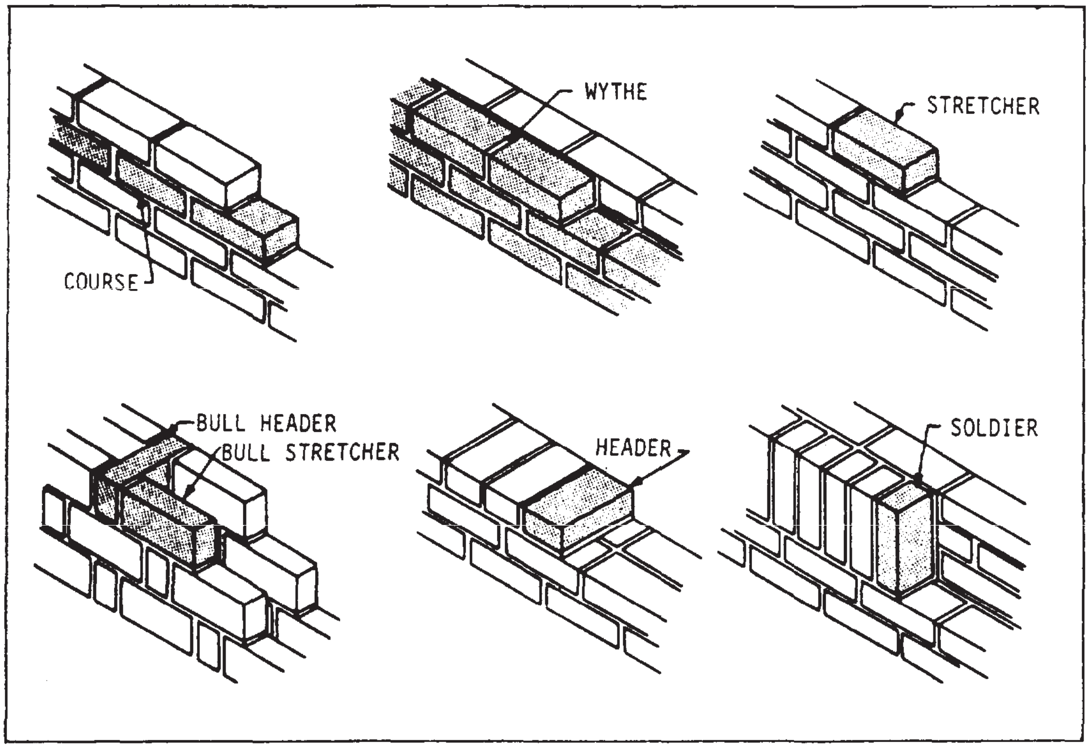


Figure 7-53.-Various positions of wall masonry units and mortar joints.

joints in a wall (fig. 7-53). These are as follows:

Course. One of the continuous horizontal layers (or rows) of masonry that, bonded together, form the masonry structure.

Wythe. A continuous single vertical wall of brick

Stretcher. A masonry unit laid flat with its longest dimension parallel to the face of the wall.

Bull-Stretcher. A rowlock brick laid with its longest dimension parallel to the face of the wall.

Bull-Header. A rowlock brick laid with its longest dimension perpendicular to the face of the wall.

Header. A masonry unit laid flat with its longest dimension perpendicular to the face of the wall. It is generally used to tie two wythes of masonry together.

Rowlock. A brick laid on its edge (face).

Soldier. A brick laid on its end so that its longest dimension is parallel to the vertical axis of the face of the wall.

CHAPTER 8

MECHANICAL SYSTEMS AND PLAN

To be able to prepare workable construction. drawings, EAs should have the ability to recognize and describe the materials used in mechanical systems, to understand their uses and functions, and to discuss the purpose and the development of a mechanical plan in the context of plumbing for water distribution and drainage systems.

This chapter will discuss only the plumbing and drainage portions of the mechanical systems and the various materials used. You will not be expected to design the system; however, as an EA, you may be called upon to prepare construction drawings from sketches and specifications.

MECHANICAL SYSTEMS (PLUMBING)

In general, plumbing refers to the system of pipes, fixtures, and other appurtenances used inside a building for supplying water and removing liquid and waterborne wastes. In practice, the term also includes storm water or roof drainage and exterior system components connecting to a source, such as a water main, and a point of disposal, such as a domestic septic tank or cesspool.

The purpose of plumbing systems is, basically, to bring a supply of safe water into a building for drinking, washing, and cooking, distribute the water within the building, and carry off the discharge of waste material from various receptacles on the premises to sewers, leech basins, and so forth, without causing a hazard to the health of the occupants. Codes, regulations, and trade practices define the plumbing specifications, which vary from one location or place of application to another. Although the National Plumbing Code is widely accepted as a guideline for the minimum requirements for plumbing designs, you must also be familiar with applicable local codes, especially when working with mechanical drawings and plans.

WATER DISTRIBUTION SYSTEM

The purpose of a water distribution system is to carry potable COLD and HOT WATER throughout a building for domestic or industrial use. A typical water supply system (fig. 8-1) consists of service pipe, distribution pipe, connecting pipe, fittings, and control valves. The water service pipe begins at the WATER MAIN. The water distribution pipe starts at the end of the service pipe and supplies the water throughout the building.

Piping Materials

Several types of pipe are used in water distribution systems, but only the most common types used by the SEABEEs will be discussed. These piping materials include copper, plastic, galvanized steel, and cast iron. Some of the main characteristics of pipes made from these materials are presented below.

COPPER PIPE AND TUBING.— Copper is one of the most widely used materials for tubing. This is because it does not rust and is highly resistant to any accumulation of scale particles in the pipe. This tubing is available in three different

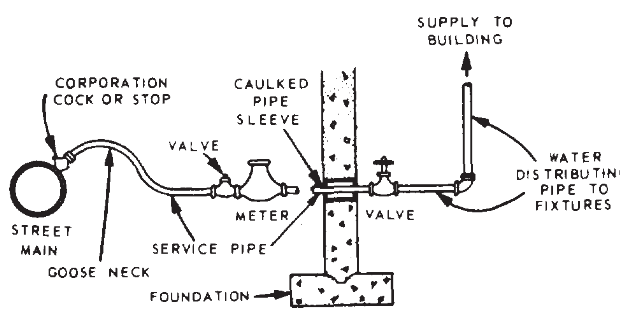


Figure 8-1.-Cross-sectional diagram of a water supply and distribution system.

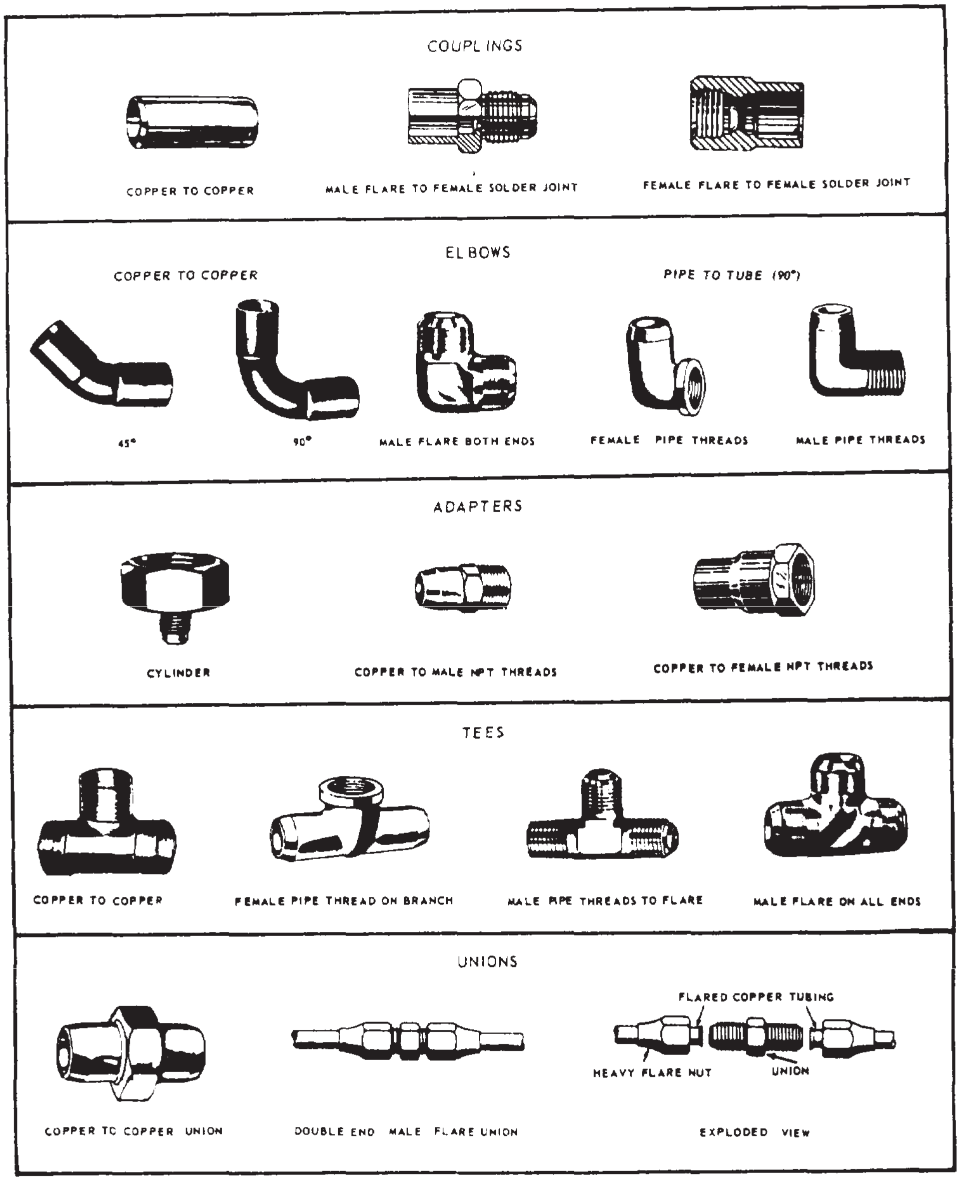


Figure 8-2.-Typical copper fittings.

types: K, L, and M. K has the thickest walls, and M, the thinnest walls, with L's thickness in between the other two. The thin walls of copper tubing are soldered to copper fittings. Soldering allows all the tubing and fittings to be set in place before the joints are finished. Generally, faster installation will be the result.

Type K copper tubing is available in either rigid (hard temper) or flexible (soft temper) and is primarily used for underground service in the water distribution systems. Soft temper tubing is available in 40- or 60-ft coils, while hard temper tubing comes in 12- and 20-ft straight lengths.

Type L copper tubing is also available in either hard or soft temper and either in coils or in straight lengths. The soft temper tubing is often used as replacement plumbing because of the tube's flexibility, which allows easier installation. Type L copper tubing is widely used in water distribution systems.

Type M copper tubing is made in hard temper only and is available in straight lengths of 12 and 20 ft. It has a thin wall and is used for branch supplies where water pressure is low, but it is NOT used for mains and risers. It is also used for chilled water systems, for exposed lines in hot-water heating systems, and for drainage piping.

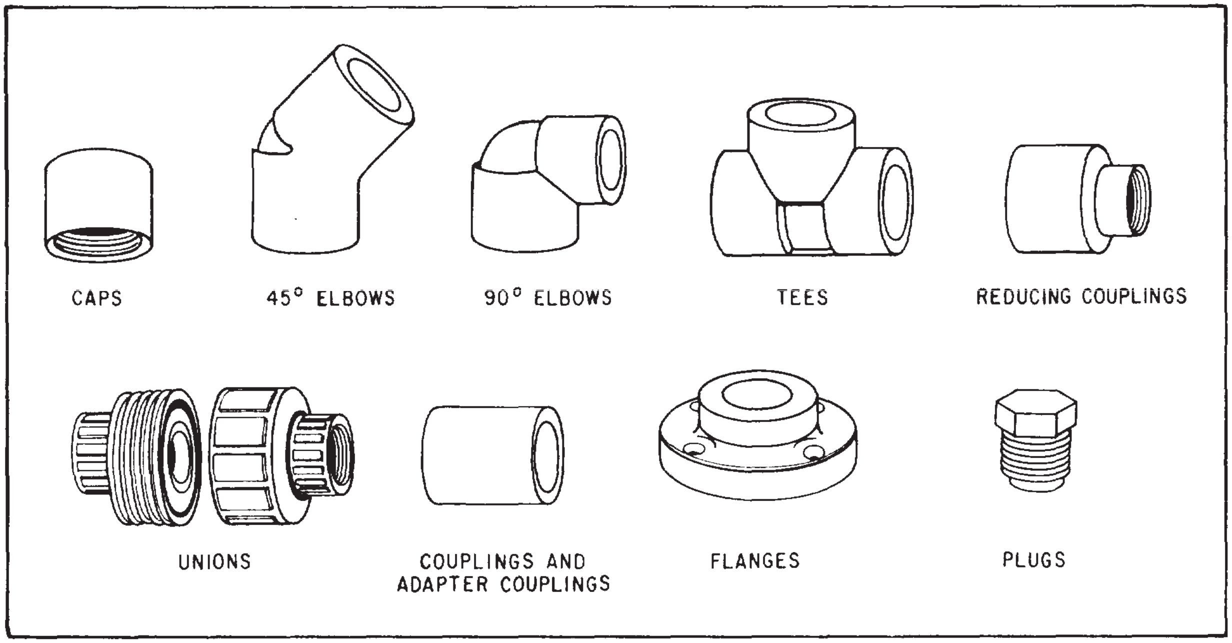


Figure 8-3.-Plastic pipe fittings.

PLASTIC PIPE.— Plastic pipe has seen extensive use in current Navy construction. Available in different lengths and sizes, it is lighter than steel or copper and requires no special tools to install. Plastic pipe has several advantages over metal pipe: it is flexible; it has superior resistance to rupture from freezing; it has complete resistance to corrosion; and, in addition, it can be installed aboveground or belowground.

One of the most versatile plastic and polyvinyl resin pipes is the polyvinyl chloride (PVC). PVC pipes are made of tough, strong thermoplastic material that has an excellent combination of physical and chemical properties. Its chemical resistance and design strength make it an excellent material for application in various mechanical systems. Sometimes polyvinyl chloride is further chlorinated to obtain a stiffer design, a higher level of impact resistance, and a greater resistance to extremes of temperature. A CPVC pipe (a chlorinated blend of PVC) can be used not only in cold-water systems, but also in hot-water systems with temperatures up to 210°F.

Economy and ease of installation make plastic pipe popular for use in either water distribution and supply systems or sewer drainage systems.

GALVANIZED PIPE.— Galvanized pipe is commonly used for the water distributing pipes inside a building to supply hot and cold water to the fixtures. This type of pipe is manufactured in 21-ft lengths. It is GALVANIZED (coated with zinc) both inside and outside at the factory to resist corrosion. Pipe sizes are based on nominal INSIDE diameters. Inside diameters vary with the thickness of the pipe. Outside diameters remain constant so that pipe can be threaded for standard fittings.

CAST-IRON WATER PIPE.— Cast-iron pipe, sometimes called cast-iron pressure pipe, is used for water mains and frequently for service pipe up to a building. Unlike cast-iron soil pipe, cast-iron water pipe is manufactured in 20-ft lengths rather than 5-ft lengths. Besides bell-and-spigot joints, cast-iron water pipes and fittings are made with either flanged, mechanical, or screwed joints. The screwed joints are used only on small-diameter pipe.

Fittings

Fittings vary according to the type of piping material used. The major types commonly used in water service include elbows, tees, unions, couplings, caps, plugs, nipples, reducers, and adapters. Some typical copper pipe fittings are shown in figure 8-2. Plastic pipe fittings (fig. 8-3) that are similar in appearance to those used with metal piping are available. Some plastic pipes can

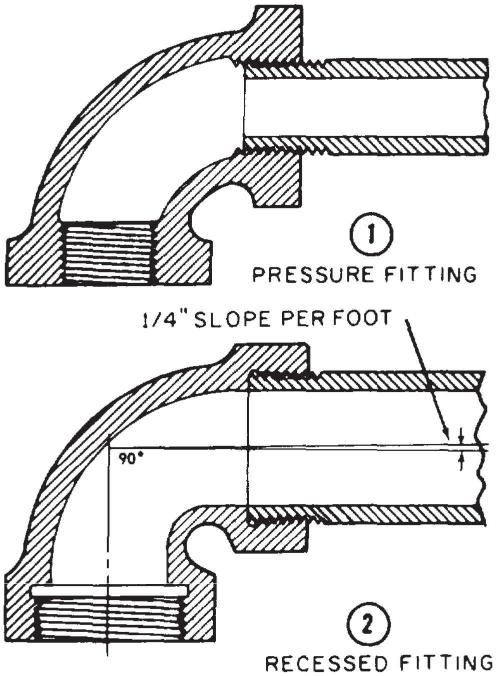


Figure 8-4.-Comparison of pressure and recessed (Durham) types of fittings.

also be adapted to metal pipe fittings. The fittings used on either steel pipe or wrought iron are generally made of malleable iron or cast iron. There are two types of iron pipe fittings used: the PRESSURE type and the RECESSED type (fig. 8-4).

The pressure type of fitting is the standard fitting used on water pipe. The recessed type of fitting, also known as a cast-iron drainage or Durham fitting, is generally required on all drainage lines. The recessed type is most suitable for a smooth joint; it reduces the probability of grease or foreign material remaining in the joint and causing a stoppage in the line. Recessed fittings are designed so that horizontal lines entering them will have a slope of one-fourth in. per foot.

ELBOWS (OR ELLS) 90° AND 45°.— These fittings (fig. 8-5, close to middle of figure) are used to change the direction of the pipe either 90 or 45 degrees. REGULAR elbows have female threads at both outlets. STREET elbows change the direction of a pipe in a close space where it would be impossible or impractical to use an elbow and nipple. Both 45- and 90-degree street elbows are available with one female and one male threaded end. The REDUCING elbow is similar to the 90-degree elbow except that one opening is smaller than the other.

TEES.— A tee is used for connecting pipes of different diameters or for changing the direction of pipe runs. A common type of pipe tee is the STRAIGHT tee, which has a straight-through portion and a 90-degree takeoff on one side. All three openings of the straight tee are of the same size. Another common type is the REDUCING tee, similar to the straight tee just described, except that one of the threaded openings is of a different size than the other.

UNIONS.— There are two types of pipe unions. The GROUND JOINT UNION consists of three pieces, and the FLANGE UNION is made in two parts. Both types are used for joining two pipes together and are designed so that they can be disconnected easily.

COUPLINGS.— The three common types of couplings are straight coupling, reducer, and eccentric reducer. The STRAIGHT COUPLING is for joining two lengths of pipe in a straight run that does not require additional fittings. A run is that portion of a pipe or fitting continuing in a straight line in the direction of flow. A REDUCER is used to join two pipes of different sizes. The ECCENTRIC REDUCER (also called a BELL REDUCER) has two female (inside) threads of different sizes with centers so designed that when they are joined, the two pieces of pipe will not be in line with each other, but they can be installed so as to provide optimum drainage of the line.

CAPS.— A pipe cap is a fitting with a female (inside) thread. It is used like a plug, except that the pipe cap screws on the male thread of a pipe or nipple.

PLUGS.— Pipe plugs are fittings with male (outside) threads. They are screwed into other fittings to close openings. Pipe plugs have various types of heads, such as square, slotted, and hexagonal sockets.

NIPPLES.— A nipple is a short length of pipe (12 in. or less) with a male thread on each end. It is used for extension from a fitting.

At times, you may use the DIELECTRIC or INSULATING TYPE of fittings. These fittings connect underground tanks or hot-water tanks. They are also used when pipes of dissimilar metals

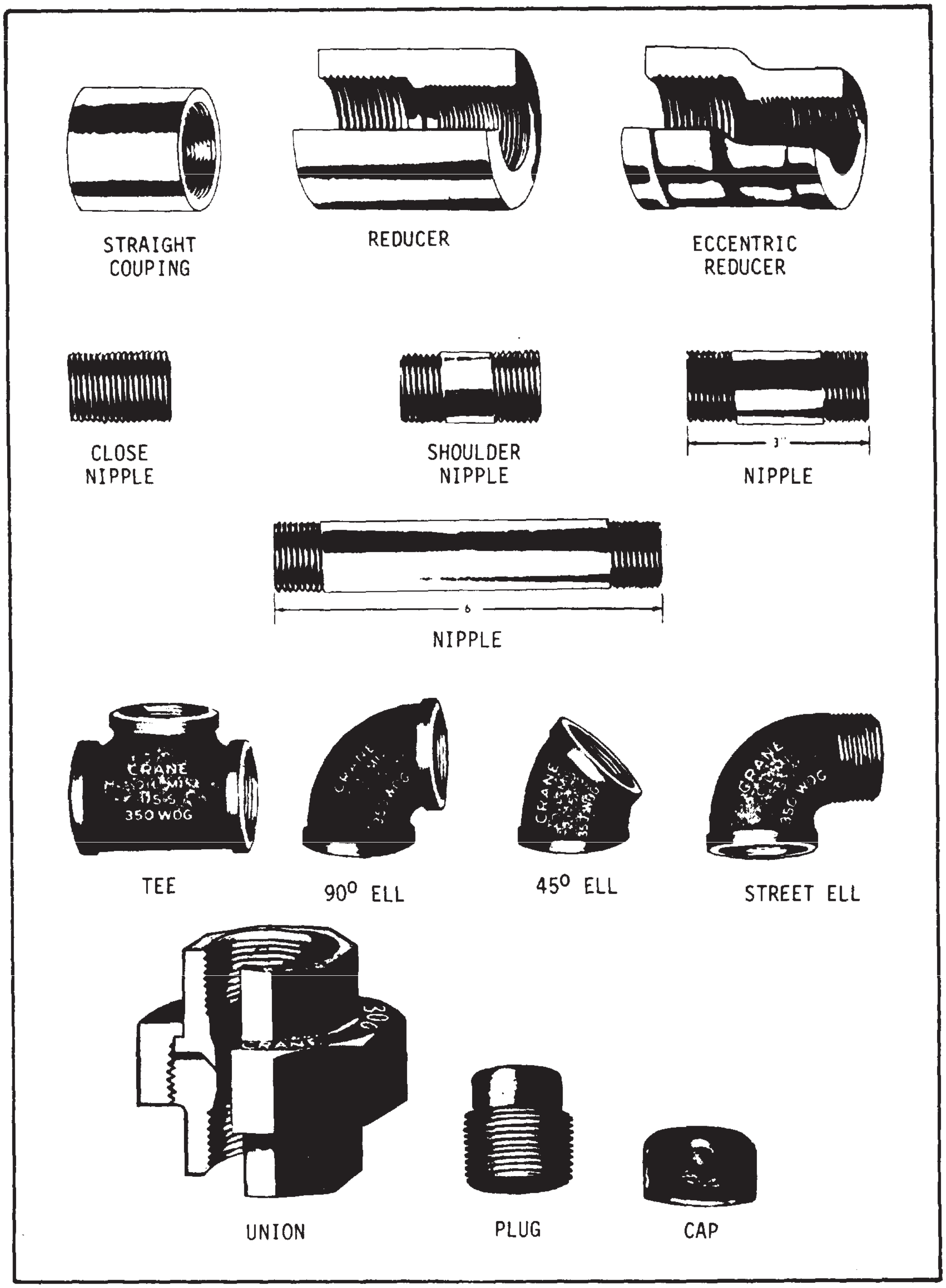


Figure 8-5.-Types of pipe fittings.

are to be joined. The purpose of dielectric fittings is to curtail galvanic or electrolytic action. The most common dielectric fittings are the union, coupling, and bushing.

Fittings are identified by the sizes of pipe that are connected to their openings. For example, a 3- by 3- by 1 1/2-in. tee is one that has two openings for a 3-in. run of pipe and a 1 1/2-in. reduced outlet. If all openings are the same size, only one nominal diameter is designated. For example, a 3-in. tee is one that has three 3-in. openings.

Joints and Connections

There are various methods of joining pipes for water distribution systems. Each method used is designed to withstand internal (hydrostatic) pressure in the pipe and normal soil loads if joints and connections are belowground. Some of these methods produce the types of joints and connections described below.

FLARED AND SWEATED JOINTS.— These joints are generally used with copper pipe and tubing. The end of a copper pipe is formed into a funnellike shape so that it can be held in a threaded fitting when a line joint is being made. This method is called FLARING, and the result is called a FLARED JOINT. A SWEATED JOINT is made with soft solder instead of threads or flares. In plumbing, copper pipe or tubing is occasionally fused by heating with a gas flame and silver-aIloy filler metal called SILVER BLAZING (also called HARD SOLDERING).

SOLVENT WELDED, FUSION WELDED, FILLET WELDED, THREADED, AND FLANGED JOINTS.— These types of joints are common to plastic pipes. In the production of a SOLVENT WELDED JOINT, a solvent cement with a primer is used. Before solvent is applied, the pipe and fitting must be thermally balanced (caused to have similar temperatures). This process should not be undertaken when the temperature is below 40°F or above 90°F or when the pipes are exposed to direct sunlight.

FUSION WELDED JOINTS are produced by the use of a gas- or an electric-heated welding tool. The process consists of simultaneously heating the meeting surfaces of the pipe and fitting to a uniform plastic state, joining the components together, and then allowing the two surfaces to fuse into a homogeneous bond as the materials cool to room temperature.

FILLET WELDED JOINTS are made by the use of a uniform heat and pressure on the welding rod during application of the bead. This process can also be applied to repair leaks in thermoplastics.

In plastic pipes, THREADED JOINTS are commonly used for temporary and low-pressure piping since threading reduces the pipe wall thickness. Only certain heavy pipes can be threaded with a special strap wrench. Teflon tape is often used for pipe joint compound when this method of joining pipes is used.

FLANGED JOINTS are extensively used for process lines that are dismantled frequently. Plastic pipes are joined together by the use of plastic flanges with soft rubber gaskets.

BELL-AND-SPIGOT AND MECHANICAL JOINTS.— These types of joints are most commonly used with cast-iron pressure pipe and fittings for water mains. These service lines are joined by the use of lead, lead wool, or sometimes a sulfur compound. Mechanical joints are made with rubber sealing rings held in place by metal follower rings that are bolted to the pipe. These are designed to permit expansion and contraction of the pipe without injury to the joints.

THREADED PIPE JOINTS are commonly used on galvanized steel, galvanized wrought iron, and black-iron pipe. The process includes connecting threaded male and female ends. Nontoxic compounds are used for t bread lubricant on water pipes, while powdered graphite and oil are used for steam pipes.

Valves

Valves are devices that are used to stop, start, or regulate the flow of water into, through, or from pipes. Essentially, valves consist of a body containing an opening and a means of closing the opening with a valve disk or plug that can be tightly pressed against a seating surface around or within the opening. Many different valve designs are available; however, only the three most common types of valves will be discussed here. They are the gate, check, and globe valves.

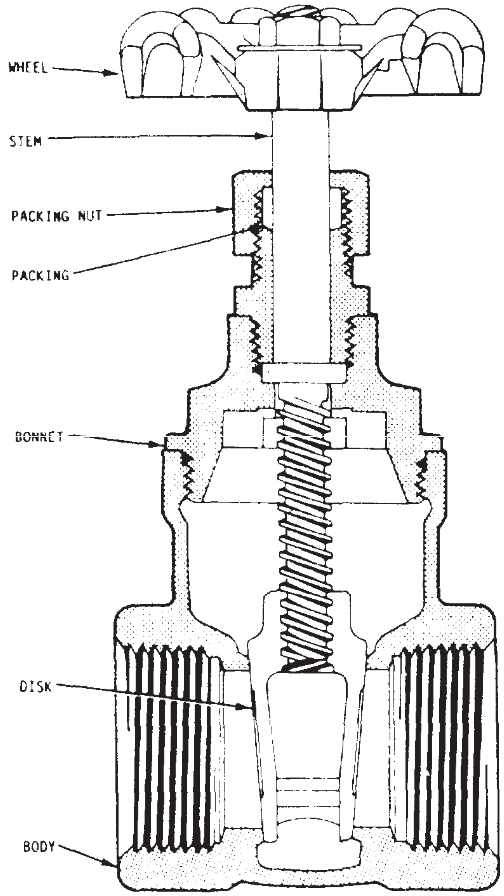


Figure 8-6.-Crow section of a gate valve.

GATE VALVE.— The gate valve (fig. 8-6) has a wedge-shaped, movable plug, called a gate, that fits tightly against the seat when the valve is closed. When the gate is opened, an unrestricted flow passage is provided. It allows fluid to flow through in a straight line with little resistance and less friction and pressure drop, provided the valve gate or disk is kept fully opened. The gate valve releases a variable amount with each turn of the gate.

Gate valves must always be operated in either their fully opened or fully closed position, never in any position to adjust the rate of flow. A partly closed gate will cause vibration and chattering, damaging the seating surfaces.

CHECK VALVE.— The check valve is used principally to prevent backflow in pipelines automatically. The valves are entirely automatic and are used where flow of liquids, vapors, or

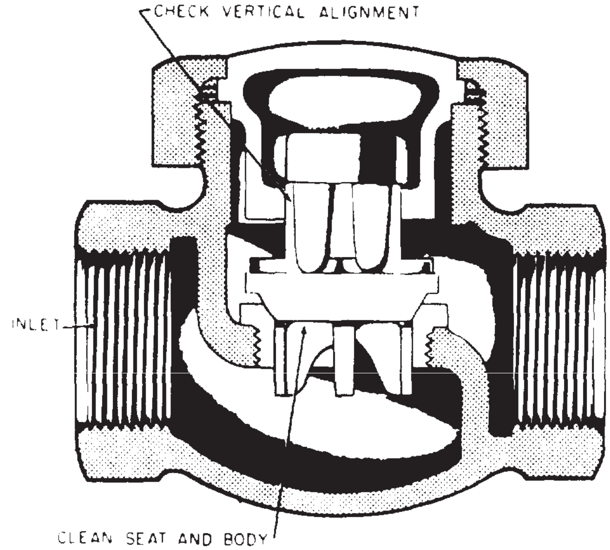


Figure 8-7.-Cross section of a swing check valve.

gases in one direction only is required. Check valves fall into two main groups: swing check valves and lift check valves. A SWING CHECK VALVE, shown in figure 8-7, is used where an unrestricted flow is desired. A LIFT CHECK VALVE is usually used for air or gases or when operation of the check valve is frequent (fig. 8-8).

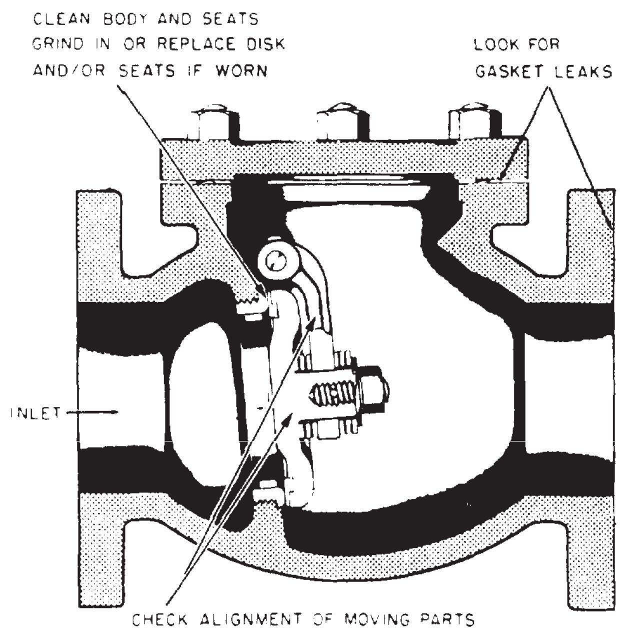


Figure 8-8.-Lift check valve.

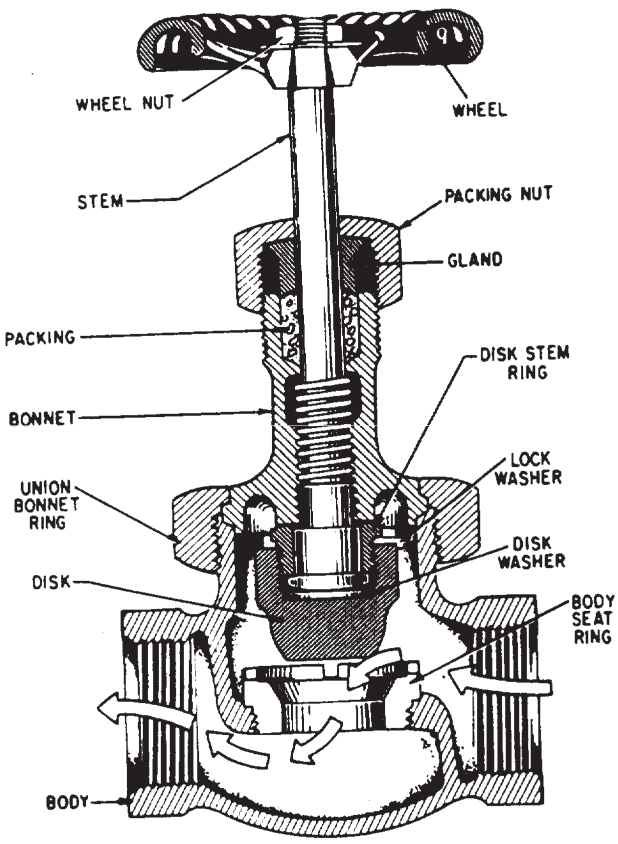


Figure 8-9.-Cross section of a globe valve.

GLOBE VALVE.— The globe valve (fig. 8-9), so-called because of its globular-shaped body, is used for regulating liquids, gases, and vapor flow by means of throttling (adjusting rate of flow). They are well suited for services requiring regulated flow and/or frequent valve settings (throttling).

Pipe Supports

Pipes are designed to be used for structural applications only to the extent of withstanding normal soil loads and internal pressures up to their hydrostatic pressure rating. Therefore, any pipe supplying air, water, or steam, when exposed aboveground and in the interior of buildings must be supported adequately to prevent sagging.

The weight of the pipes plus the weight of fluid contained in them may produce strained joints and breaks that can cause leaks in the valves. Figure 8-10 shows several methods of supporting pipe in both horizontal and vertical positions. On water mains, standard thrust blocks (fig. 8-11), made of concrete or other applicable materials, are installed at all changes of direction to prevent pipe displacement caused by high water pressure.

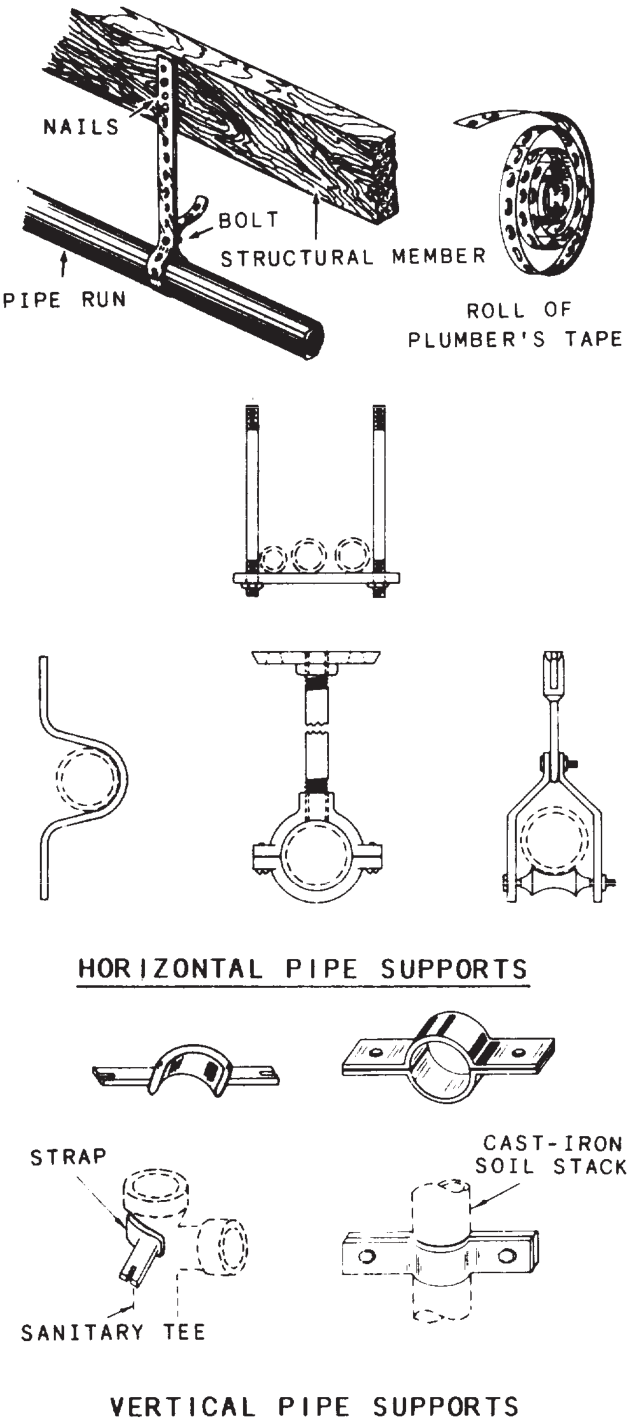
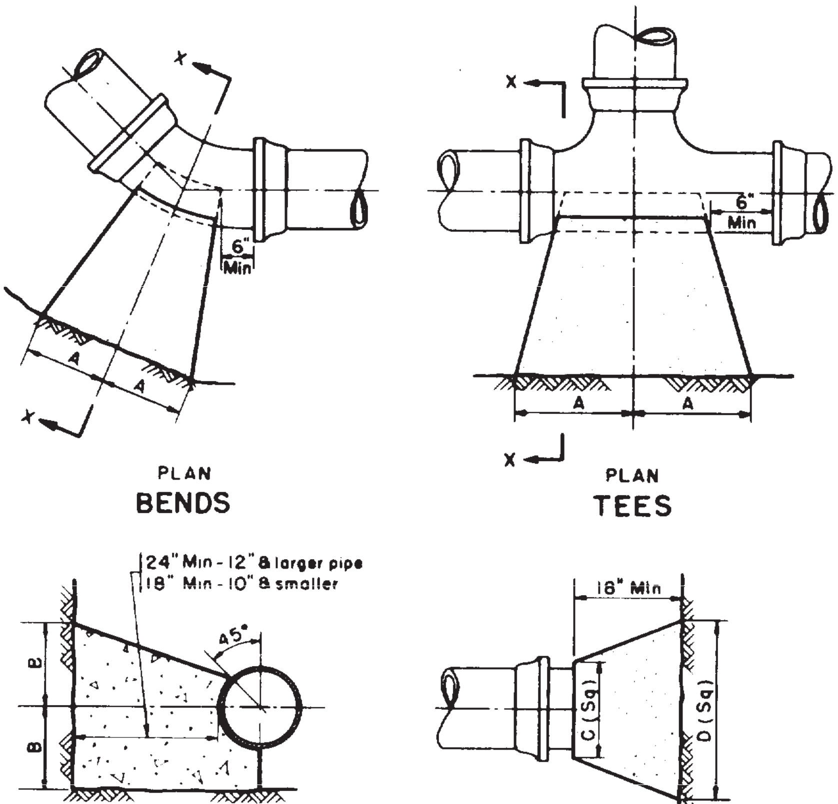


Figure 8-10.-Methods of supporting pipe.



TYPE	SIZE	1/4 BENDS A	1/4 BENDS B	1/8 BENDS A	1/8 BENDS B	1/16 BENDS A	1/16 BENDS B	TEES A	TEES B	PLUGS C	PLUGS D
TYPE I 4000 PSF SOIL	6"	8"	10"	6"	8"	3"	8"	8"	8"	10"	15"
	8"	12"	12"	8"	10"	5"	9"	9"	12"	12"	20"
	10"	16"	14"	10"	12"	6"	10"	11"	14"	14"	25"
	12"	19"	16"	12"	14"	8"	11"	14"	16"	16"	30"
	14"	23"	18"	14"	16"	10"	12"	16"	18"	18"	34"
	16"	26"	20"	16"	18"	11"	13"	18"	20"	20"	38"
TYPE II 2000 PSF SOIL	6"	16"	10"	9"	10"	6"	8"	10"	12"	10"	21"
	8"	22"	13"	12"	13"	8"	10"	13"	16"	12"	29"
	10"	26"	17"	14"	17"	10"	13"	16"	20"	14"	36"
	12"	29"	21"	16"	21"	11"	16"	18"	24"	16"	41"
	14"	35"	24"	19"	24"	12"	20"	22"	27"	18"	48"
	16"	38"	27"	21"	27"	12"	24"	24"	30"	20"	54"

NOTE: Based on 100 p.s.i. static pressure plus AWWA water hammer
All bearing surfaces to be carried to undisturbed ground

STANDARD THRUST BLOCKS
FOR WATER MAINS

Figure 8-11.-Uses of thrust blocks.

Pipe Insulation

The main purpose of insulating pipelines is to prevent heat passage from steam or hot-water pipes to the surrounding air or from the surrounding air to cold-water lines. In some cold regions, insulation also prevents water from freezing in a pipe, especially when the pipe runs outside a building. Thus, hot-water lines are insulated to prevent loss of heat from the hot water, while potable waterlines are insulated to prevent absorption of heat in drinking water. Insulation also subdues noise made by the flow of water inside pipes, such as water closet discharges. Common types of pipe insulating materials are shown in figure 8-12.

SANITARY DRAINAGE SYSTEM

The purpose of a drainage system is to carry sewage, rainwater, or other liquid wastes to a point of disposal. Although there are three types of drainage systems—storm, industrial, and sanitary—only the latter, which is the most common drainage system installed by the SEABEEs, will be discussed.

The SANITARY DRAINAGE SYSTEM carries sanitary and domestic wastes from a source (or collection system) to a sewage treatment plant or facility. Surface waters and groundwaters must be excluded from this system to prevent overload of the sewage treatment facilities.

Piping Materials

The types of materials actually used will depend upon whether the installation is underground, outside buildings, underground within buildings, or aboveground within buildings. The availability of certain types of desired piping materials and fittings may also govern the type of pipe actually used.

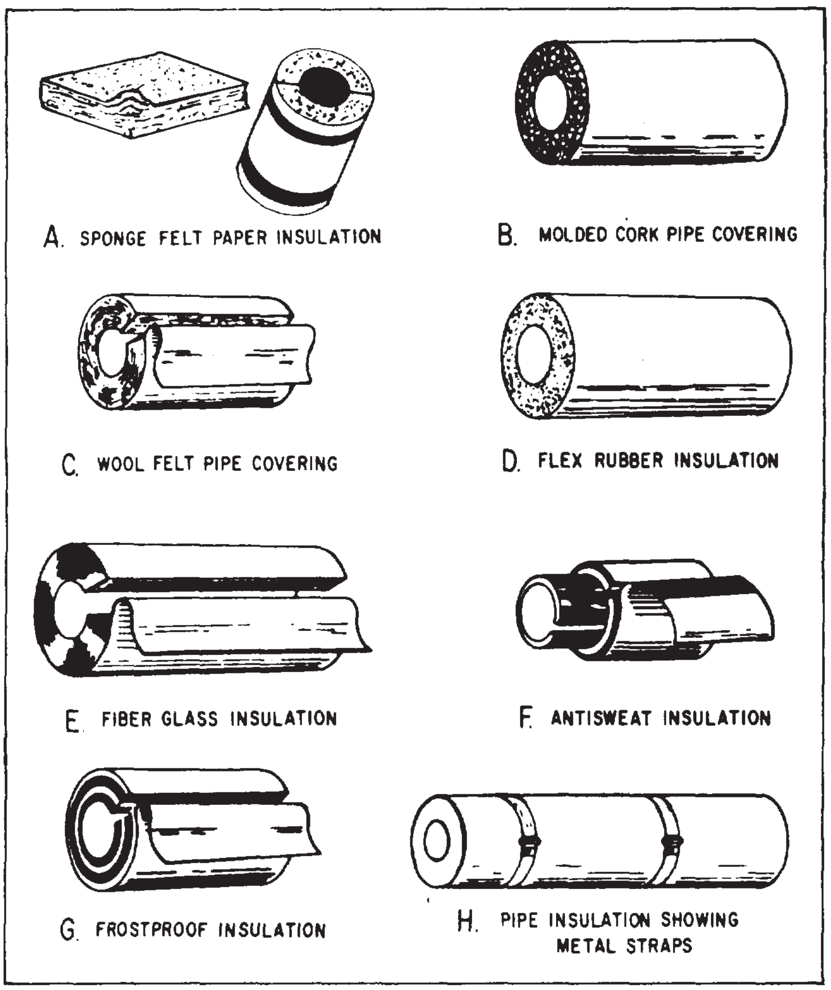


Figure 8-12.-Types of pipe insulation.

Underground piping outside of buildings may be cast-iron soil pipe, vitrified clay or concrete, or plastic polyvinyl chloride (PVC) pipe, but PVC pipes are the most common. Underground piping within buildings may also be of cast iron, galvanized steel, lead, or PVC; however, cast iron and PVC are the most popular materials used.

Aboveground sewage piping within buildings consists of either one or a combination of the following: brass or copper pipe, cast iron or galvanized wrought iron, galvanized steel or lead, and PVC pipe. Again, the reason for the growing popularity of plastic PVC piping is the unique combination of chemical and physical properties it has, ease of installation, and cost effectiveness. Descriptions and characteristics of some of the most common piping materials used in a sanitary drainage system follow.

CAST-IRON SOIL PIPE (CISP).— This type of pipe is composed of gray cast iron made of compact, close-grained pig iron; scrap iron and steel; metallurgical coke; or limestone. Cast-iron soil pipe is normally used in or under buildings, protruding at least 5 ft from the building. Here, it connects into a concrete or clay sewer line. Cast-iron soil pipe is also used under roads or other places of heavy traffic. If the soil is unstable or contains cinder and ashes, vitrified clay pipe is used instead of cast-iron soil pipe.

Cast-iron soil pipe comes in 5-ft and 10-ft lengths, with nominal inside diameters of 2, 3, 4, 5, 6, 8, 10, 12, and 15 in. It is available as single-hub or double-hub in design, as indicated in figure 8-13. Note that single-hub pipe has a hub at one end and a spigot at the other, while a double-hub pipe has a hub on each end. Hubs or bells of cast-iron soil pipe are enlarged sleevelike fittings that are cast as a part of the pipe to make watertight and pressure-tight joints with oakum and lead.

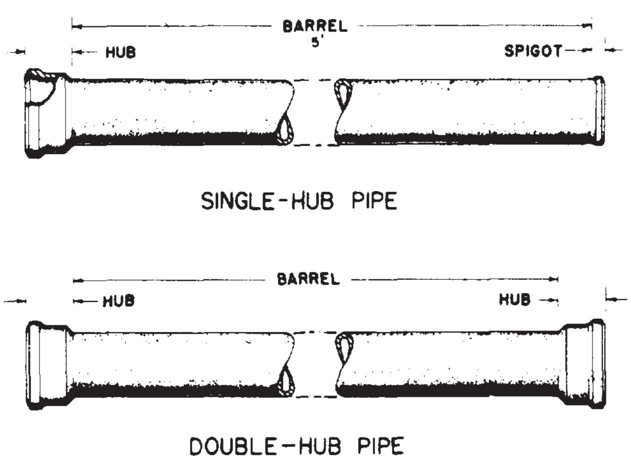


Figure 8-13.-Single-hub and double-hub cast-iron soil pipe.

VITRIFIED CLAY AND CONCRETE PIPE.— Vitrified clay pipe is made of moistened, powdered clay. It is available in laying lengths of 2, 2 1/2, and 3 ft and in diameters ranging from 4 to 42 in. Like cast-iron soil pipe, it has a bell end and a spigot end to facilitate joining. Vitrified clay pipe is used for house sewer lines, sanitary sewer mains, and storm drains.

Precast concrete pipe may be used for sewers in the smaller sizes—those less than 24 in. This pipe is not reinforced with steel. Dimensions of concrete pipe are similar to those of vitrified clay pipe.

PLASTIC PIPE.— The use of rigid plastic pipe has expanded greatly over the years. Years ago, plastic piping was used extensively for farm water systems, lawn sprinklers, and some other domestic and industrial uses. Now, plastic pipe is used for all kinds of water and drainage applications.

Plastic piping has outstanding resistance to nearly all acids, caustics, salt solutions, and other corrosive liquids and gases. It does not rust, corrode, scale, or pit inside or outside. It is also nontoxic, nonconductive, and not subject to electrolytic corrosion—a major cause of failure when metal pipe is installed underground. Another important advantage of plastic pipe is low resistance to abrasion because of its smooth inner wall, resulting in maximum flow rate and minimum buildup of sludge and slime.

Fittings

The types of fittings, joints, and connections used by water distribution are strikingly similar to those used by waste drainage systems. In sanitary or waste drainage systems, fittings also vary according to the type of piping materials used; however, special mechanical seal adapters are available for joining different types of pipes, such as cast-iron soil pipes to vitrified clay, or vice versa. Some of the fittings commonly

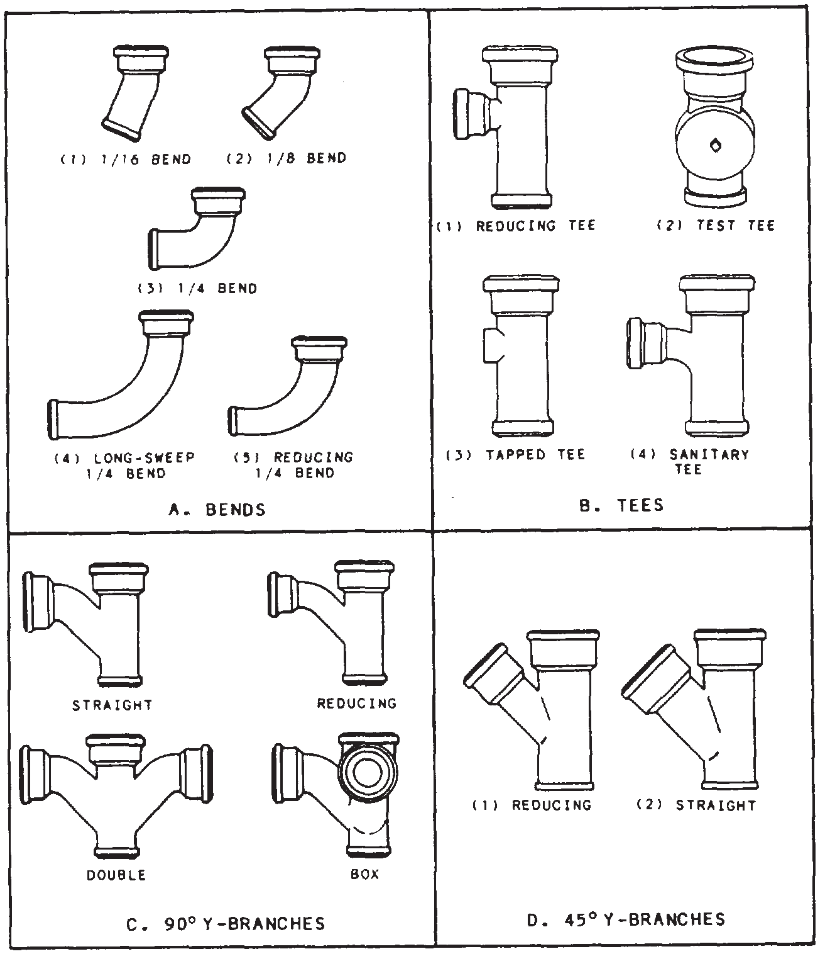


Figure 8-14.-Common cast-iron soil pipe fittings.

used are shown in figure 8-14 and described below.

BENDS.— The 1/16 bend (fig. 8-14, view A) is used to change the direction of cast-iron soil pipe 22 1/2°. A 1/8 bend changes the direction 450. The direction is changed 90° in a close space when the SHORT-SWEEP 1/4 bend is used. The LONG-SWEEP 1/4 bend is used to change the direction 90° more gradually than a quarter bend. The REDUCING 1/4 bend changes the direction of the pipe gradually 90°, and in the sweep portion, it reduces nearly one size.

TEES.— Tees (fig. 8-14, view B) are used to connect branches to continuous lines. For connecting lines of different sizes, REDUCING tees are often used. The TEST tee is used in stack and waste installations where the vertical stack joins the horizontal sanitary sewer. It is installed at this point to allow the plumber to insert a test tee and fill the system with water while testing for leakage. The TAPPED tee is frequently used in the venting system where it is called the main vent tee. The SANITARY tee is commonly used in a main stack to allow the takeoff of a cast-iron pipe branch.

NINETY-DEGREE Y-BRANCHES.— Four types of cast-iron soil pipe 90° Y-branches generally used are shown in figure 8-14, view C. These are normally referred to as COMBINATION Y AND 1/8 BENDS. The STRAIGHT type of 90° Y-branch is used in sanitary sewer systems where a branch feeds into a main, and it is desirable to have the incoming branch feeding into the main as nearly as possible in a line parallel to the main flow. The REDUCING 90° Y-branch is the same as the straight type, except that the branch coming into the main is a smaller size pipe than the main. The DOUBLE 90° Y-branch (or DOUBLE

COMBINATION Y and 1/8 BEND) is easy to recognize since there is a 450 takeoff bending into a 90° takeoff on both sides of the fitting. It is especially useful as an individual vent. The BOX type 90° Y-branch has two takeoffs. It is designed so that each takeoff forms a 90° angle with the main pipe. The two takeoffs are spaced 900 from each other.

FORTY-FIVE-DEGREE Y-BRANCHES.— The two types of 45° Y-branches (fig. 8-14, view D) are the reducing and straight types. They are used to join two sanitary sewer branches at a 45° angle. The REDUCING type is a straight section of pipe with a 45° takeoff of a smaller size branching off one side. The STRAIGHT type of 45° Y-branch, or true Y, is the same as the reducing type except that both bells are the same size.

Figure 8-15 shows some common fittings used with vitrified clay and concrete pipes. It should be noted that these types of pipes are used outside the building, which greatly reduces the number of different types of fittings. Joints on vitrified clay and concrete pipe are made of cement or bituminous compounds. Cement joints might be made of grout—a mixture of cement, sand, and water.

Plastic pipe fittings for waste drainage are shown in figure 8-16.

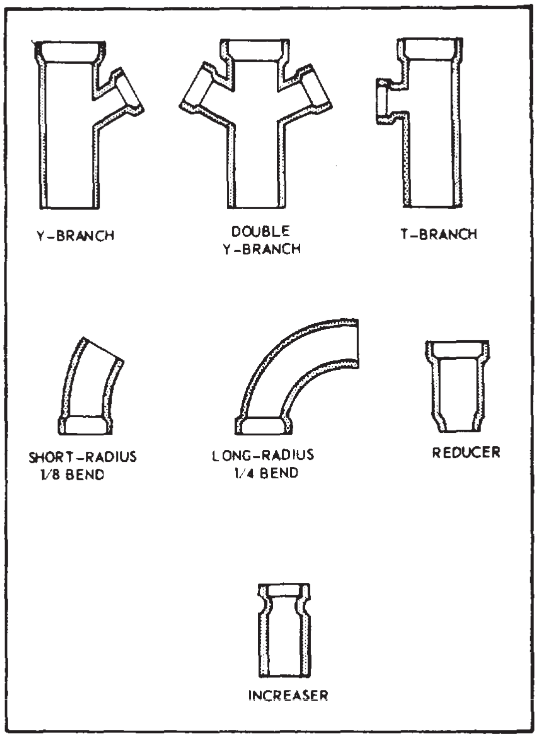


Figure 8-15.-Cross section of vitrified clay or concrete pipe fittings.

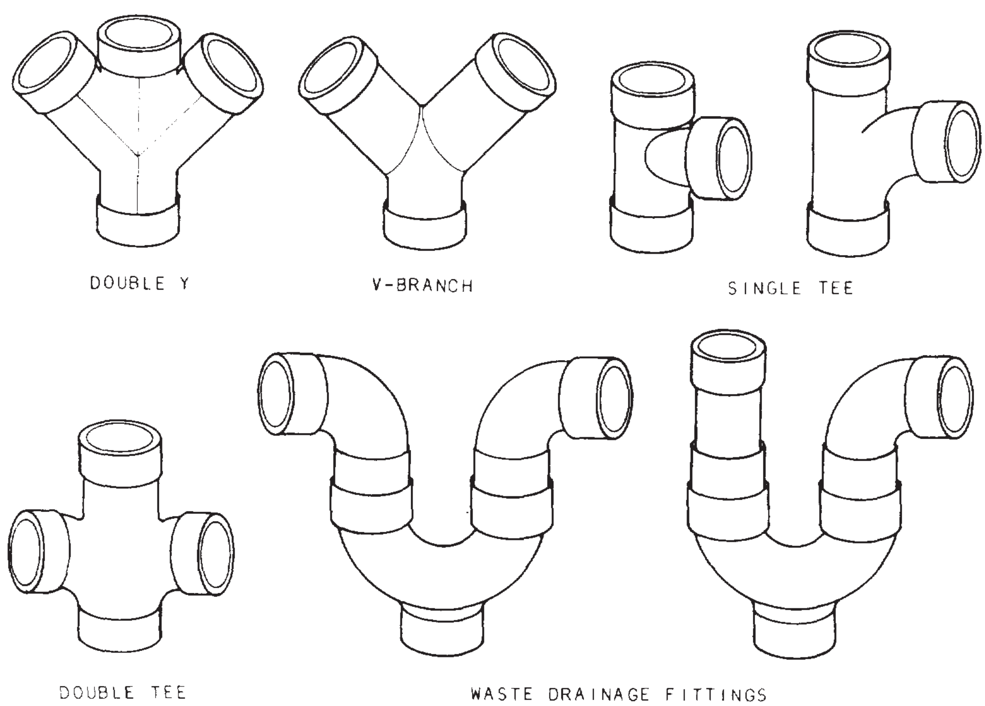


Figure 8-16.-Typical plastic pipe fittings.

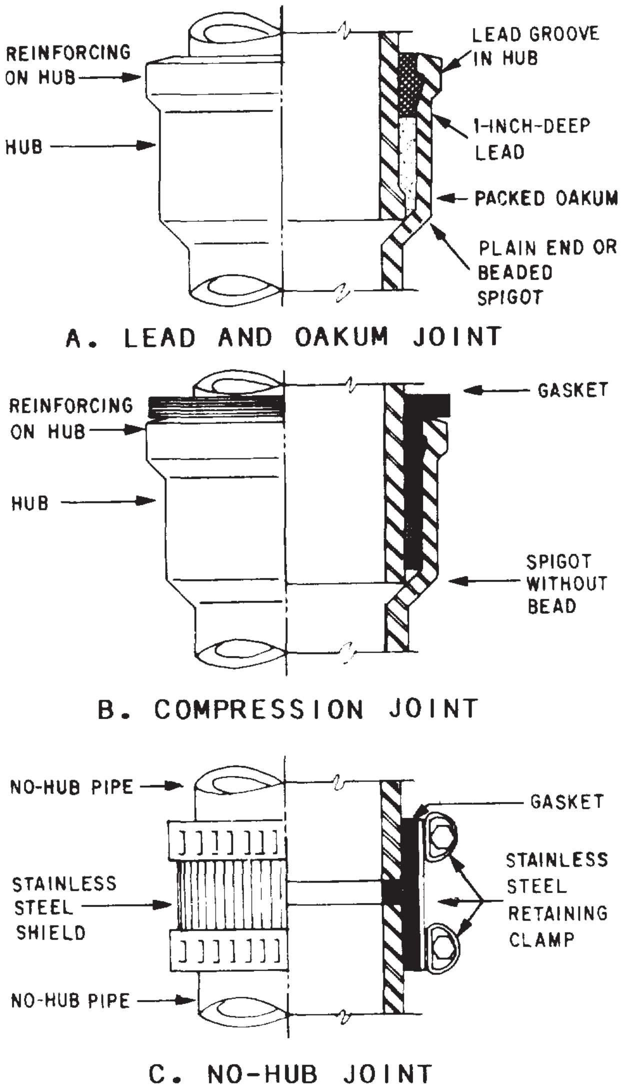


Figure 8-17.-Various joints currently used to connect CISP and fittings.

Joints and Connections

Various types of joints and connections used in waste drainage systems are described below.

LEAD AND OAKUM JOINT, COMPRESSION JOINT, AND NO-HUB JOINT.— These types of joints (fig. 8-17) are used to connect cast-iron soil pipes (CISP) and fittings. In lead and oakum joints, oakum (made of hemp impregnated with bituminous compound and loosely twisted or spun into a rope or yarn) is packed into the hub completely around the joint, and melted lead is poured over it (fig. 8-17, view A).

In compression joints, an assembly tool is used to force the spigot end of the pipe or fitting into the lubricated gasket inside the hub (fig. 8-17, view B). A no-hub joint uses a gasket on the end of one pipe and a stainless steel shield and clamp assembly on the end of the other pipe (fig. 8-17, view C).

MORTAR OR BITUMINOUS JOINTS.— This type of joint is common to vitrified clay and concrete pipes and fittings. Mortar joints may be made of grout (a mixture of cement, sand, and water).

The use of SPEED SEAL JOINTS (rubber rings) in joining vitrified clay pipe has become widespread. Speed seal joints eliminate the use of oakum and mortar joints for sewer mains. This type of seal is made a part of the vitrified pipe joint when manufactured. It is made of polyvinyl chloride and is called a plastisol joint connection.

Traps

A trap is a device that catches and holds a quantity of water, thus forming a seal that prevents the gases resulting from sewage decomposition from entering the building through the pipe. A number of different types of traps are available; however, the trap mainly used with plumbing fixtures is the P-TRAP (fig. 8-18). It comes in sizes from 1 1/4 in. to 6 in. in diameter. P-traps are usually made of nickel or chrome-plated brass, malleable galvanized or wrought iron, copper, other metal alloys, and plastic.

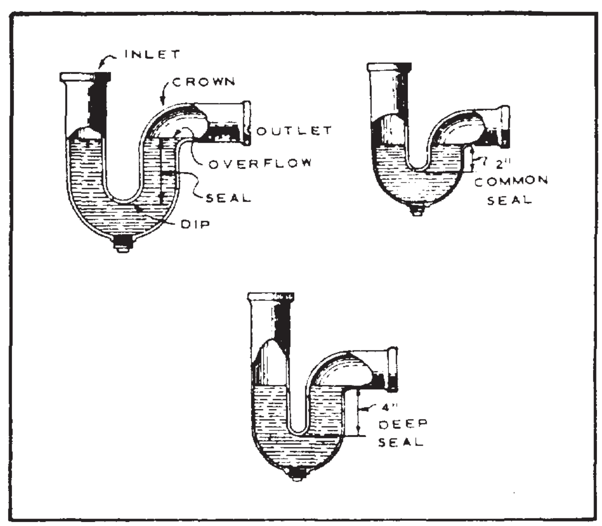


Figure 8-18.-P-traps.

Traps are commonly installed on fixtures, such as lavatories, sinks, and urinals. At times, the P-trap may also be suitable in shower baths and other installations that do not require wasting of large amounts of water.

Vents

A VENT (pipe) allows gases in the sewage drainage system to discharge to the outside. It also allows sufficient air to enter, reducing the air turbulence in the system. Without a vent, once the water is discharged from the fixture, the moving waste tends to siphon the water from the other fixture traps as it goes through the pipes. This means that the vent piping must serve the various fixtures, as well as the rest of the sewage drainage system. The vent from a fixture or group of fixtures ties in with the main vent. A MAIN VENT is the principal artery of the venting system to which vent branches maybe connected and run undiminished in size as directly as possible from the building drain to the open air above (fig. 8-19).

The MAIN SOIL AND WASTE VENT or VENT STACK, installed in a vertical position, refers to the portion of the stack that extends above the highest fixture branch, through the roof, and to the exterior of the building.

Various types of vents are used in the ventilation of fixtures. The selection of a particular type depends largely on the manner in which the plumbing fixtures are to be located and grouped.

An INDIVIDUAL VENT, also known as a BACK VENT, connects the main vent with the individual trap underneath or behind a fixture. This method of venting is shown in figure 8-19.

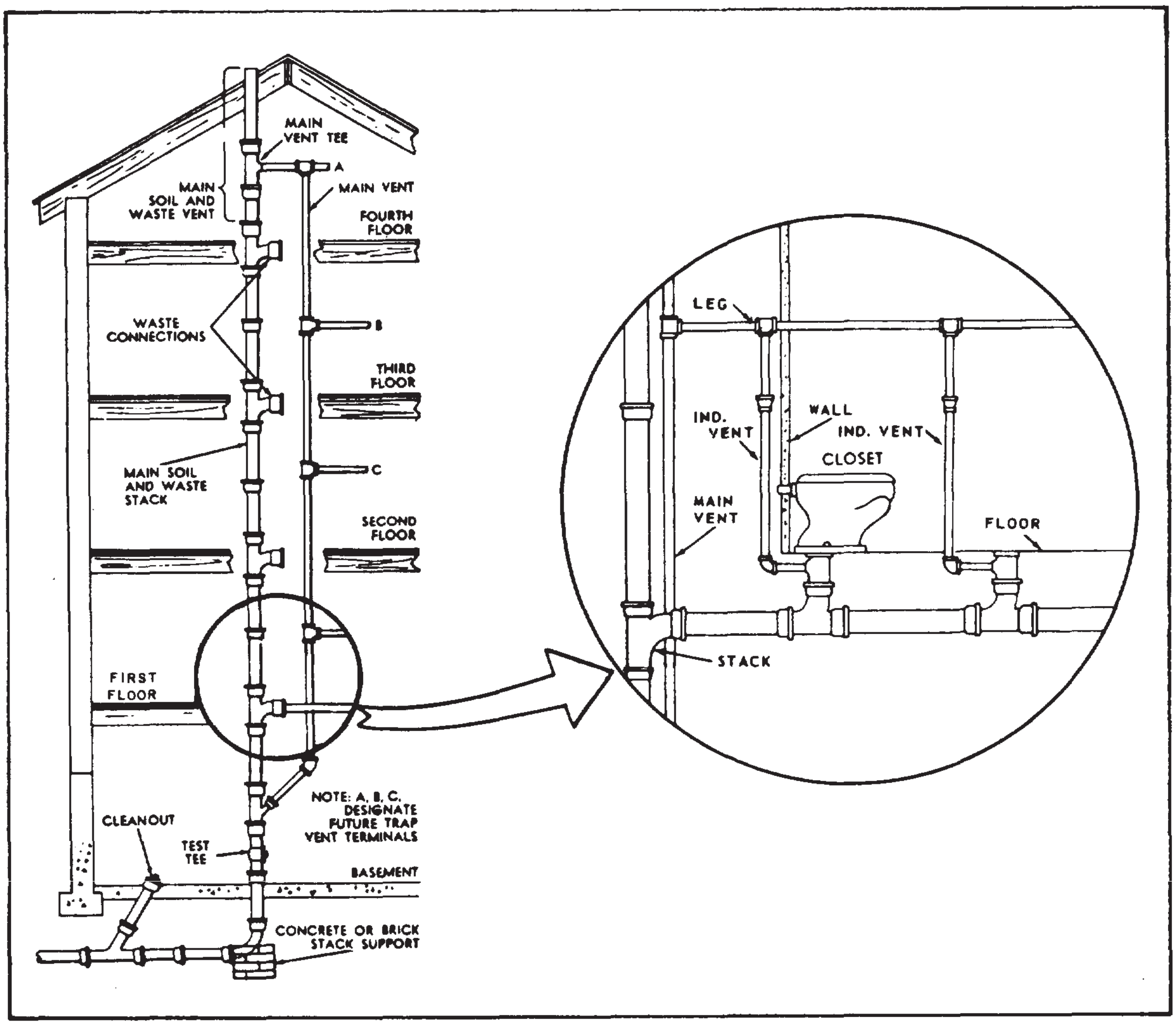


Figure 8-19.-Typical stack and vent installation.

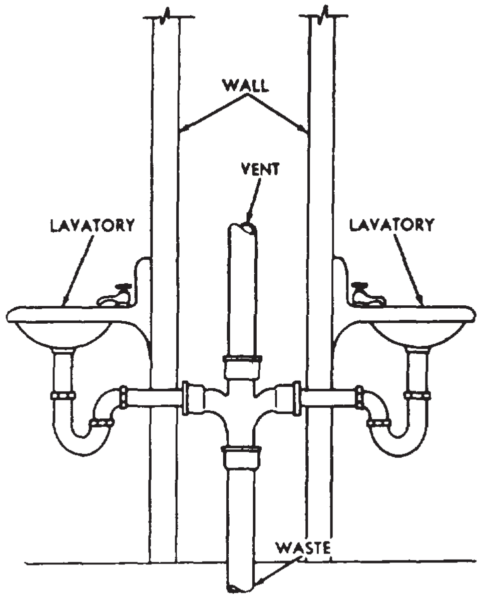


Figure 8-20.-Two fixture units sharing a common vent.

A COMMON VENT vents two traps to a single vent pipe, as shown in figure 8-20. The unit vent can be used when a pair of lavatories is installed side by side, as well as when they are hung back to back on either side of a partition (as shown in the figure). A point to note is that the waste from both fixtures discharges into a double sanitary tee.

A CIRCUIT VENT serves a group of fixtures. As shown in figure 8-21, a circuit vent extends from the main vent to a position on the horizontal branch between the last two fixture connections. If more than eight fixtures are to be vented, an additional circuit vent is to be installed. In this type of vent, water and waste discharged by the last fixture tend to scour the vents of other fixtures on the line.

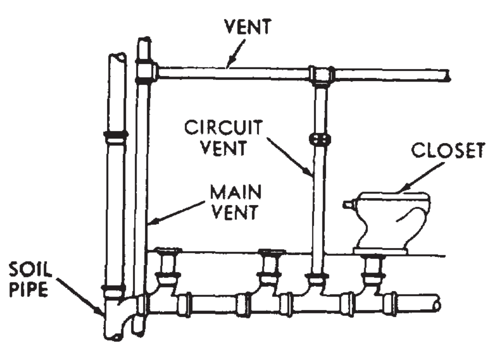


Figure 8-21.-Use of a circuit vent.

When liquid wastes flow through a portion of a vent pipe, the pipe is known as a WET VENT. A LOOP VENT is the same, except that it connects into the stack unit to form a loop. This type may be used on a small group of bathroom fixtures, such as a lavatory, water closet, and shower, as shown in figure 8-22. The pipe for a wet vent installation should be sized to take care of the lavatory, water closet, and shower.

NOTE: The pipe for a wet vent installation should never be under 2 in. in diameter when it will be draining more than four fixture units. A water closet should not drain into a wet vent.

As shown in figure 8-22, the lavatory should be individually vented. This is necessary to prevent loss of the trap seal through indirect siphonage. Another point to note is that the relatively clean water discharged from the lavatory will tend to scour the wet vent, preventing an excessive buildup of waste material in the vent.

Materials used in vent piping ordinarily include galvanized pipe, cast-iron soil pipe, and, at times, brass, copper, and plastic piping.

In all phases of the venting system, it is best to use proper-sized piping. Remember that the diameter of the vent stack or main vent must be no less than 2 in. The actual diameter depends on the developed length of the vent stack and on the number of fixture units installed on the soil or waste stack. The diameter of a vent stack should be at least as large as that of the soil or waste stack.

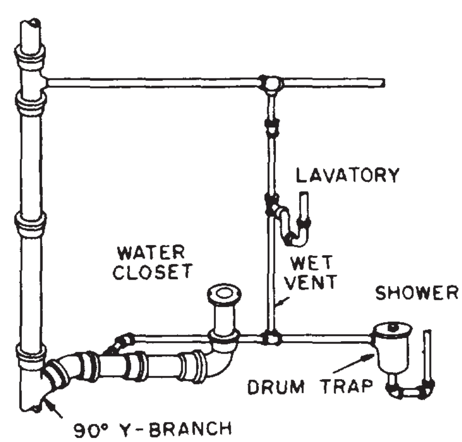


Figure 8-22.-Use of a wet vent.

Branches

Solid and waste pipe BRANCHES are horizontal branch takeoffs that connect various fixtures and the vertical stack (fig. 8-19). One method of installing a branch takeoff from the vertical stack is to use a Y-branch with a 1/8 bend caulked into it. Another method is to use a sanitary tee, which is an extra-short-pattern 900 Y-branch. Of these two methods, the sanitary tee is better because you eliminate one fitting and an extra caulked joint, both of which arc required for the 1/8 bend takeoff.

In some cases, however, the combination Y and 1/8 bend is used more often than the sanitary tee when local codes allow more fixture units to be connected to a stack of a given size.

Generally, waste pipes are graded downward to ensure complete drainage. Horizontal vents are also pitched slightly to facilitate discharge of condensation.

MECHANICAL PLAN

A mechanical plan, as used in this chapter, includes drawings, layouts, diagrams, and notes that refer only to water distribution and sanitary drainage systems. Heating and air conditioning, refrigeration, and other like systems will not be discussed in this section. In the Navy, mechanical systems vary, depending on whether these systems are aboard ship or shore-based. As an EA, you will be mainly concerned with the shore-based systems, which may be permanent installations with the most modern fixtures, equipment, and appurtenances, or temporary installations at advanced bases. For temporary installations, the most economical materials that will serve the purpose are normally used.

WATER SUPPLY AND DISTRIBUTION DIAGRAM

The water supply system for a building starts from a single source—the water main. Water is tapped from this source with a self-tapping machine (fig. 8-23, view B), and a corporation stop (fig. 8-23, view A) is installed. Cold water enters the building through a cold-water service

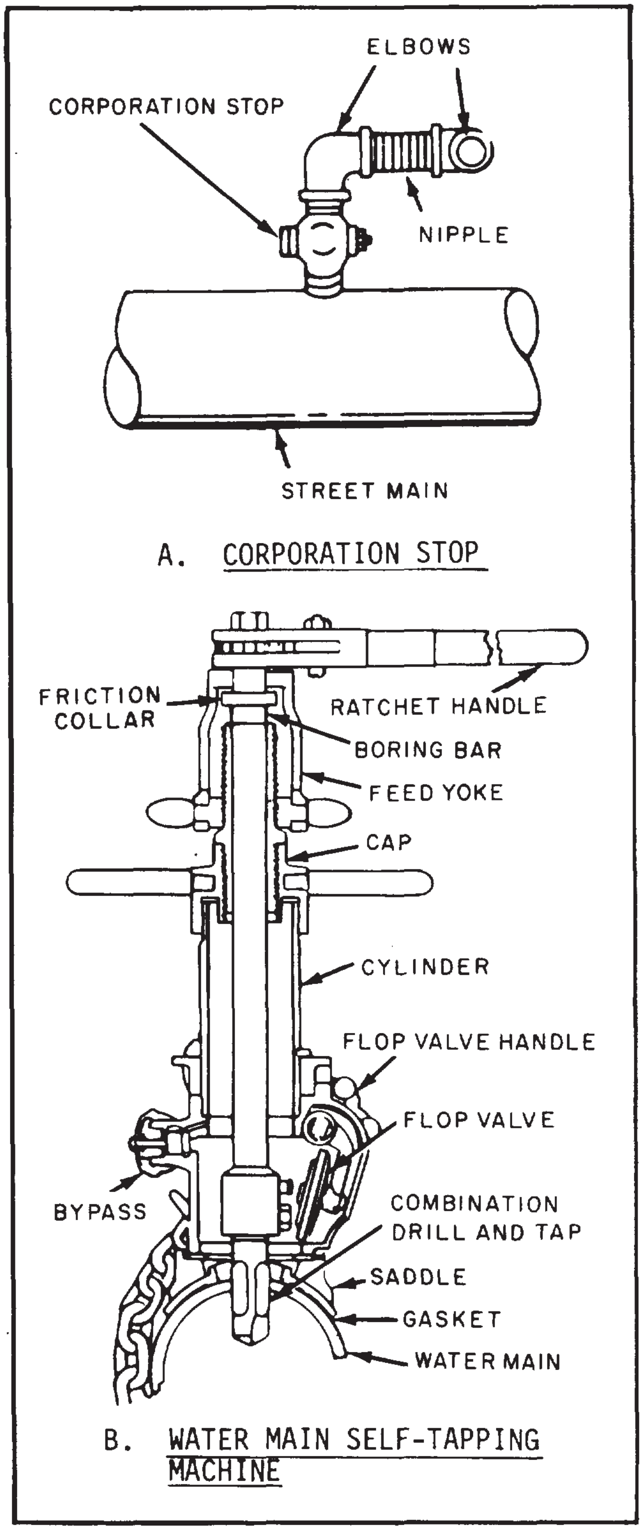


Figure 8-23.-Use of corporation stop and self-tapping machine.

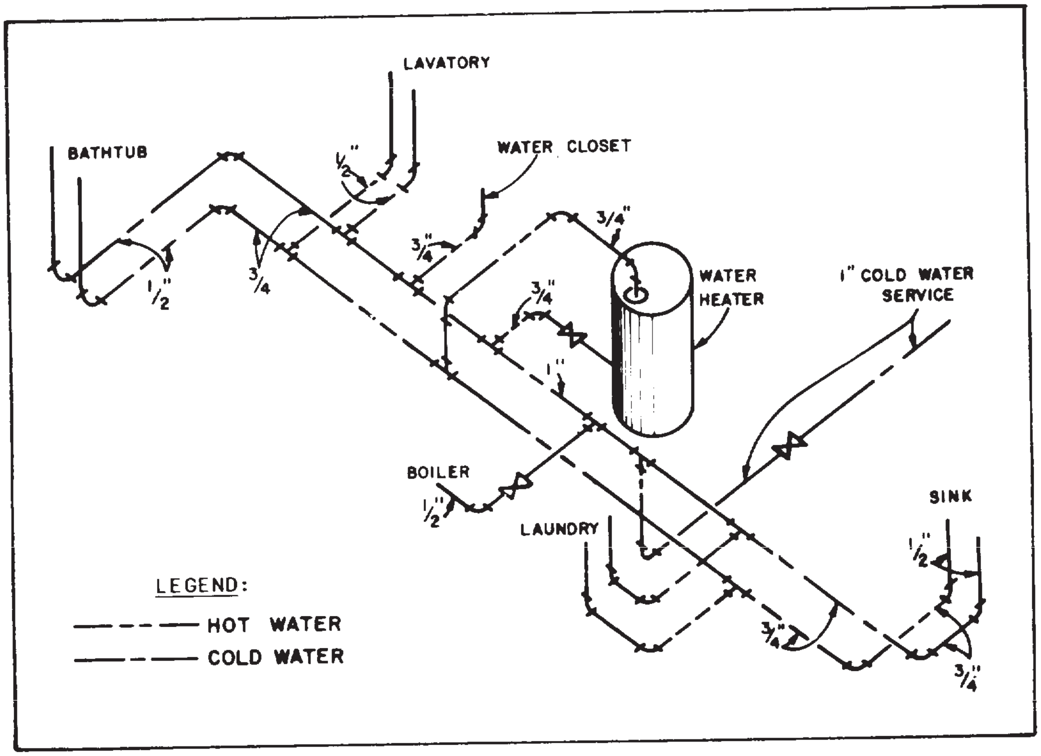


Figure 8-24.-Typical hot and cold water risers diagram.

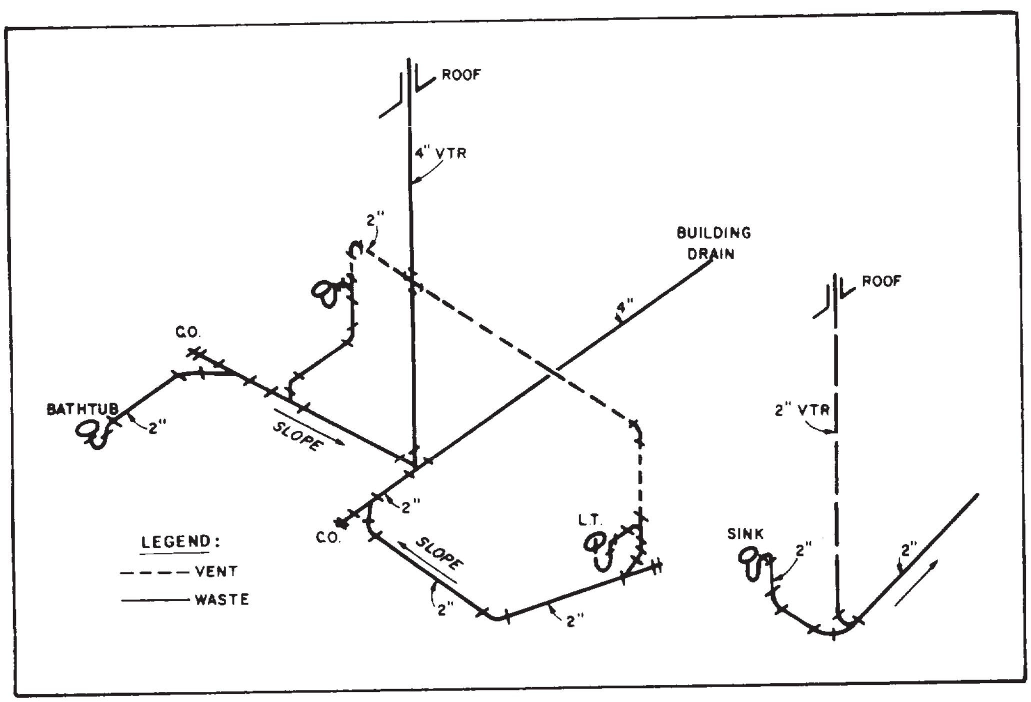


Figure 8-25.-Example of a waste and soil risers diagram.

line. Figure 8-24 shows typical hot- and cold-water service lines for a single-story residential building and how they are connected to feed the fixtures. This type of layout is often called a RISER DIAGRAM. This diagram, in isometric, is a method of visualizing or showing a three-dimensional picture of the pipes in one drawing.

WASTE AND SOIL DRAINAGE DIAGRAM

Figure 8-25 shows the waste and soil pipes and. associated fitting symbols in a riser diagram. The arrow represents the direction of flow. If you notice, all the pipes are sloping towards the building drain. Figure 8-26 further shows the basic layout of a drainage system. The function of each part is as follows:

● FIXTURE BRANCHES are horizontal drainpipes connecting several fixtures to the stack.

● A FIXTURE DRAIN extends from the P-trap of a fixture to the junction of that drain with any other drainpipe.

● SOIL AND WASTE FIXTURE BRANCHES feed into a vertical pipe, referred to as a stack. If the waste carried by the fixture branch includes human waste (coming from water closets or from a fixture with similar functions), the stack is called a SOIL STACK. If a stack carries waste that does not include human waste, it is referred to as a WASTE STACK. These stacks service all the fixture branches beginning at the top branch and go vertically to the building drain.

● A BUILDING DRAIN (also referred to as a house drain) is the lowest piping part of the drainage system. It receives the discharge from the soil, waste, and other drainage pipes inside the building and extends to a point 3 ft outside the building wall. (Most local codes require that the house drain extend at least 3 ft beyond the building wall, but a few local requirements range from 2 to 10 ft.)

● A BUILDING SEWER is that part of the horizontal piping of a drainage system that extends from the end of the building drain. It

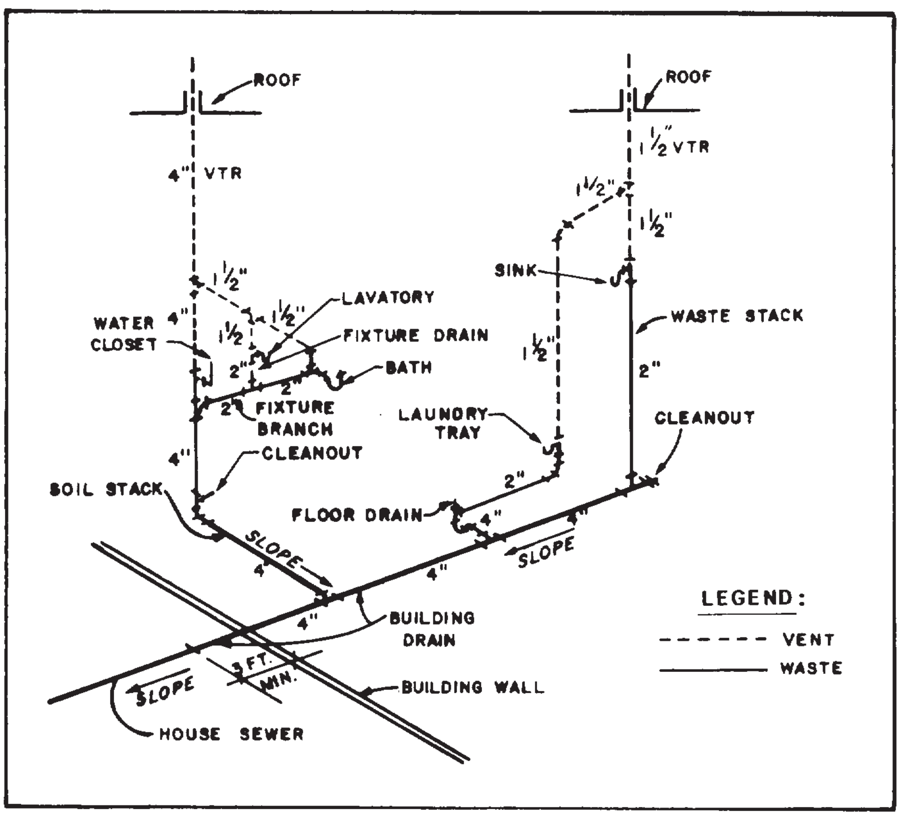


Figure 8-26.-Basic layout of a drainage system.

conveys the waste to the community sewer or an independent disposal unit.

● A FLOOR DRAIN is a receptacle used to receive water to be drained from the floors into the drainage system. Floor drains are usually located near the heating equipment and in the vicinity of the laundry equipment or any unit subject to overflow or leakage.

● A CLEANOUT is a unit with a removable plate or plug that provides access into plumbing or other drainage pipes for cleaning out extraneous material.

PLUMBING LAYOUT

In construction drafting, a mechanical (or utility) plan normally includes both water

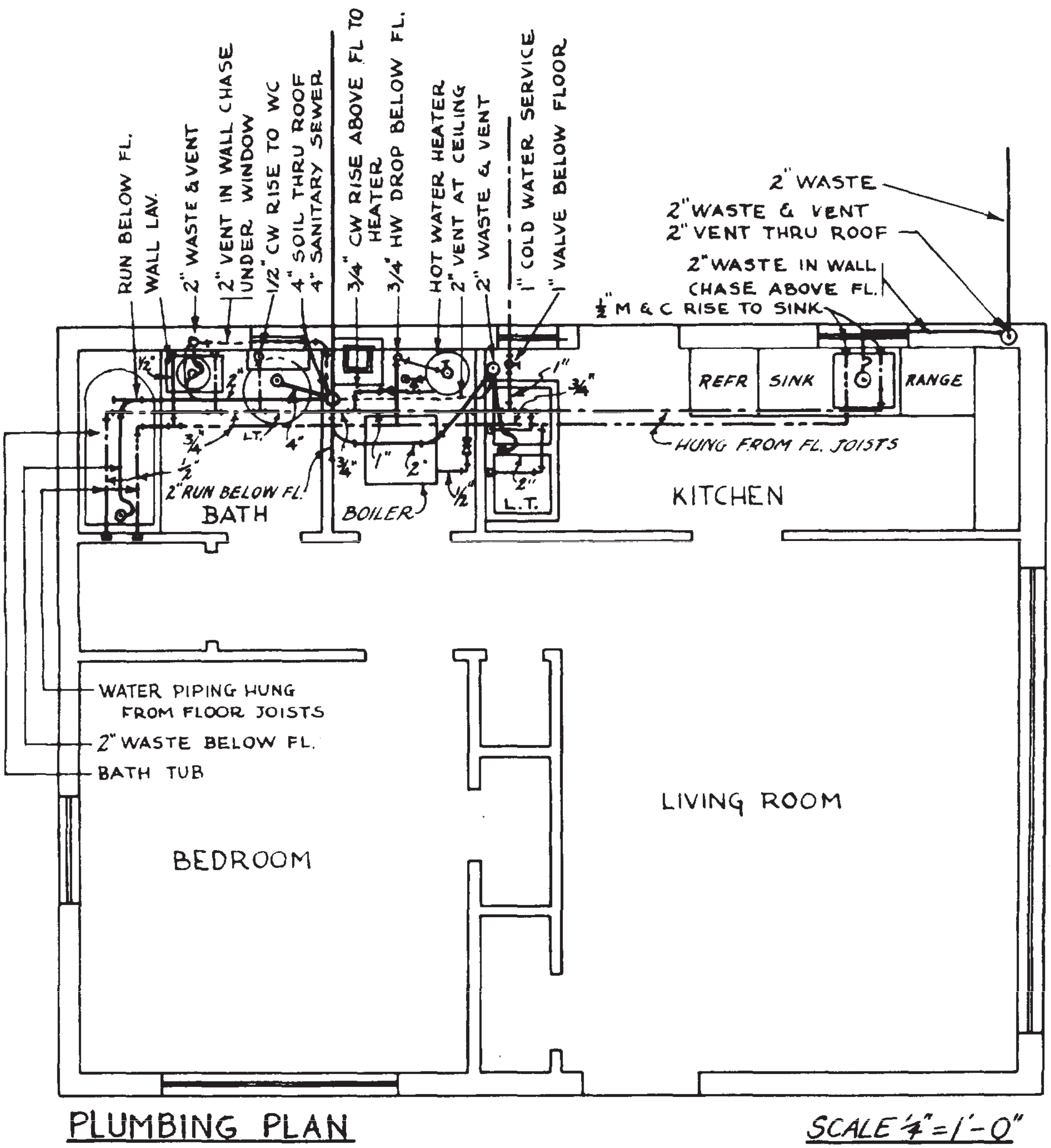


Figure 8-27.-Typical plumbing layout for a small residential building.

distribution and sanitary drainage systems combined, especially on smaller buildings or houses. The plumbing layout is usually drawn into a copy of the floor plan for proper orientation with existing plumbing fixtures, walls and partition outlines, and other utility features. Figure 8-27 shows a typical plumbing layout. The reproduction is, unfortunately, too small to be easily studied, but you can see that it uses the mechanical symbols. Refer to ANSI Y32.4-1977, *Graphic Symbols Used in Architectural and Building Construction* and MIL- STD-17-1, *Mechanical Symbols.*

As shown in figure 8-27, the cold-water service line, which enters the building near the laundry trays, is indicated by a broken dash-and-single-dot line, while the waste pipes are indicated by solid lines. If you follow the cold-water service line, you will see how it passes, first, a 1-in. main shutoff valve below the floor and just inside the building wall. From here, it proceeds to a long pipe running parallel to the building wall and hung under the floor joists, which services, beginning at the right-hand end, the cold-water spigot in the sink, the cold-water spigot in the laundry, the hot-water heater, the boiler for the house heating system, the flushing system in the water closet (W.C.), the cold-water spigot in the bathroom washbasin, and the cold-water spigot in the bathtub. The below-the-floor line is connected to the spigots by vertical RISERS. Valves at the hot-water heater and boilers are indicated by appropriate symbols.

From the hot-water heater, you can trace the hot-water line (broken dash-and-double-dot line) to the hot-water spigots in the sink, laundry, bathroom washbasin, and bathtub. This line is also hung below the floor joists and connected to the spigots by risers.

You can see the waste line (solid line) for the bathtub, washbasin, and W.C. (with traps indicated by bends) running under the floor from the bathtub by way of the washbasin and W.C. to the 4-in. sanitary sewer. Similarly, you can see the waste line from the laundry running to the same outlet. However, the kitchen sink has its own, separate waste line. The bathroom utilities waste lines vent through a 4-in. pipe running through the roof; the sink waste line vents through a 2-in. pipe running up through the roof.

MECHANICAL SYMBOLS

As stated earlier in this chapter, the Engineering Aid is not expected to design the system, but the main objective is to draw a workable plumbing plan for use by the plumbing crew or any other interested parties. In order to accomplish this, the EA must be familiar with the terms, symbols, definitions, and the basic concepts of the plumbing trade.

As a rule, plumbing plans should show the location of the fixtures and fittings to be installed and the size and the route of the piping. The basic details are left to the plumber (UT), who is responsible for installing a properly connected system according to applicable codes, specifications, and good plumbing and construction practices. Generally, plumbing plans consist of four types of symbols: piping, fittings, valves, and fixtures.

Piping Symbols

The line symbols for piping shown in figure 8-28 are composed of solid or dashed lines that indicate the type and location of that particular

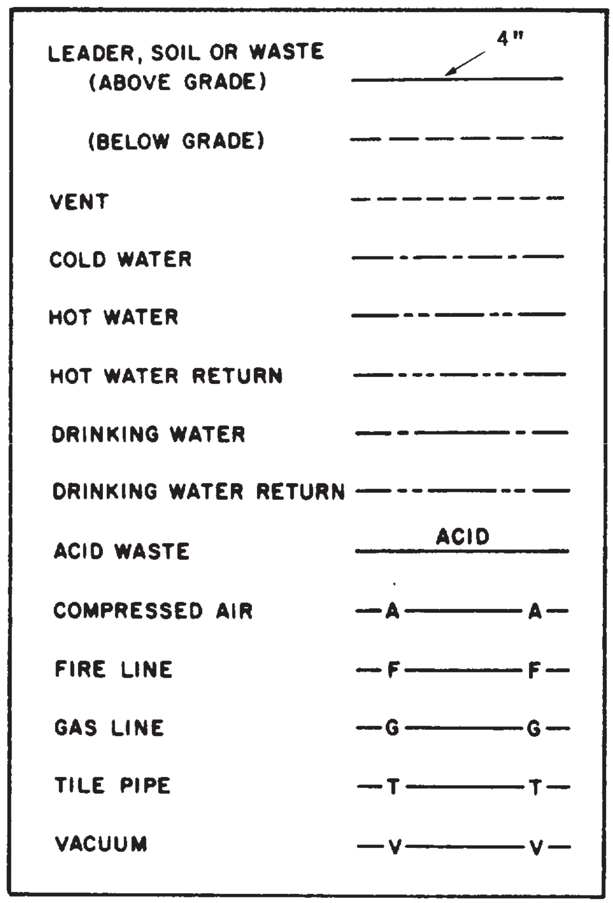


Figure 8-28.-Line symbols for piping.

pipe on the plan. Other line symbols identify the proposed use of the pipes. The size of the required piping should also be noted alongside each route of the plan. Piping up to 12 in. in diameter is referred to by its nominal size, which is approximately equal to the inside diameter (I.D.). The exact inside diameter depends on the classification of the pipe. Heavy types of piping have smaller inside diameters because their wall thickness is greater. Piping over 12 in. in diameter is referred to by its outside diameter (O.D.).

Fitting Symbols

The pipe-fitting symbols shown in figure 8-29 are the basic line symbols used for pipes, in

ITEM	SYMBOL	SAMPLE APPLICATION (S)	ILLUSTRATION
PIPE	SINGLE LINE IN SHAPE OF PIPE—USUALLY WITH NOMINAL SIZE NOTED		
JOINT—FLANGED	DOUBLE LINE		
SCREWED	SINGLE LINE		
BELL AND SPIGOT	CURVED LINE		
OUTLET TURNED UP	CIRCLE AND DOT		
OUTLET TURNED DOWN	SEMICIRCLE		
REDUCING OR ENLARGING FITTING	NOMINAL SIZE NOTED AT JOINT		
REDUCER CONCENTRIC	TRIANGLE		
ECCENTRIC	TRIANGLE		
UNION SCREWED	LINE		
FLANGED	LINE		

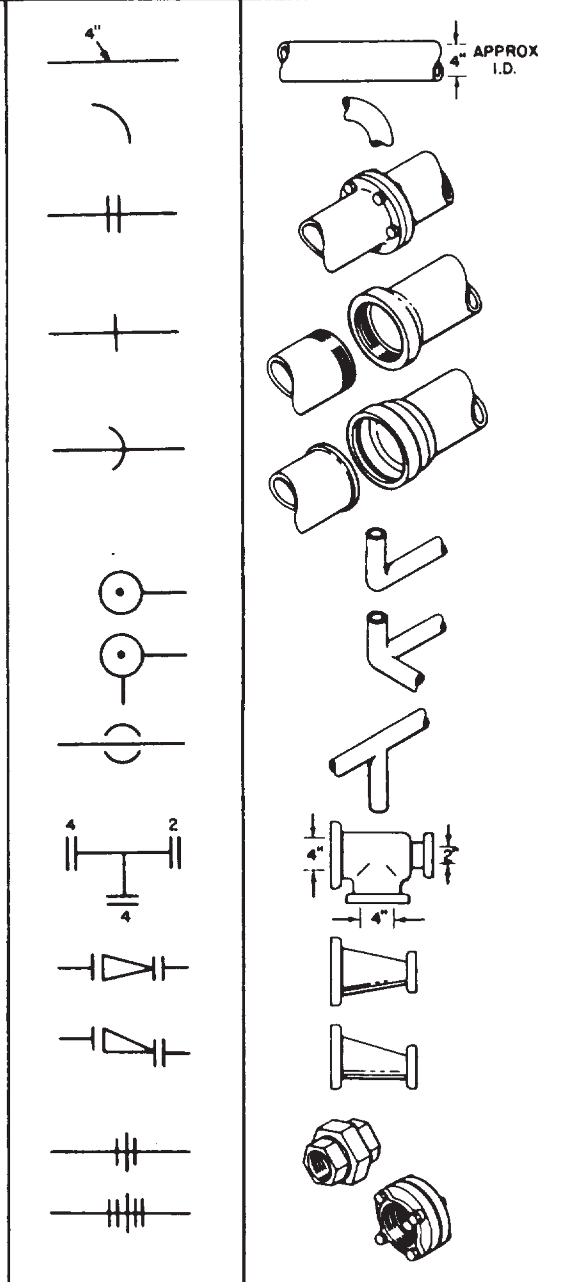


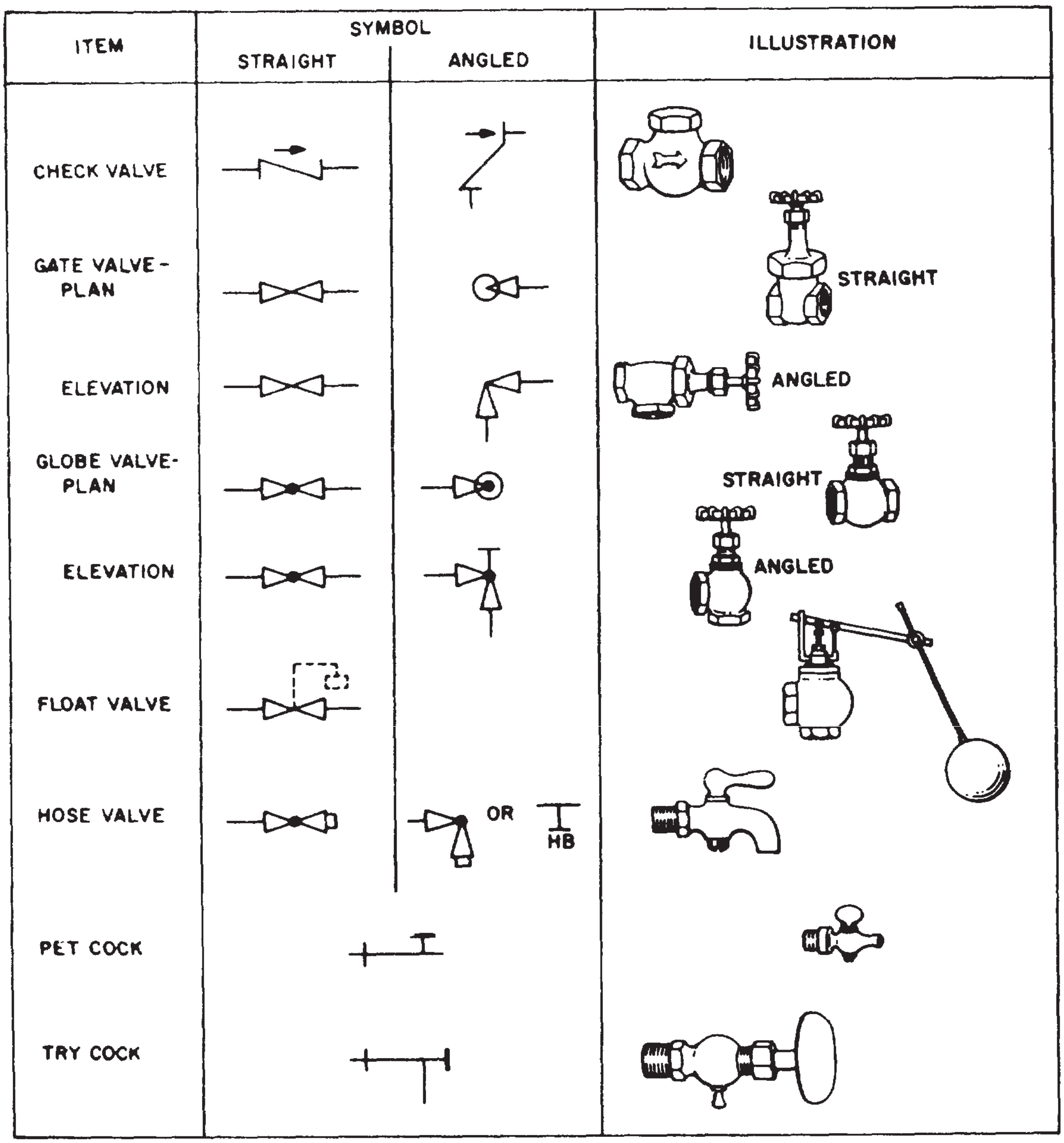
Figure 8-29.-Pipe-fitting symbols.

conjunction with the symbology of pipe fittings or valves. They define not only the size of the pipe and the method of branching and coupling, but also the purpose for which the pipe will be used. This is important because the type of material from which the pipe is made deter-mines how the pipe should be used.

Figure 8-29 covers only a few of the symbols for fittings, joints, and connections used in the plumbing system. For additional symbols on welded and soldered joints, refer to the appendices on plumbing symbols found in the back of this book .

Valve Symbols

Figure 8-30 shows the symbols used for the most frequently encountered valves. The type of material and size of valves are normally not noted on mechanical drawings but must be assumed from the size and material of the connected pipe.



NOTE: SYMBOLS ARE SHOWN FOR SCREWED FITTINGS – SYMBOLS FOR JOINTS ARE ADDED FOR OTHER TYPES

Figure 8-30.-Valve symbols.

However, when specified on the lists of materials or plumbing takeoff, valves are called out by size, type of material, and working pressure; for example, 2-in. gate valve, PVC, 175-lb working pressure.

Fixture Symbols

The symbols shown in figure 8-31 are for general appurtenances, such as drains and sumps, but other fixtures, such as sinks, water closets, and shower stalls, are shown on the plans by pictorial or block symbols. The extent to which the symbols are used depends on the nature of the drawing. In many cases, the fixtures will be specified on a bill of materials or other schedules keyed to the plumbing plan. When the fixtures are described on the schedule, the EA can use symbols that closely resemble the actual fixtures or obtain mechanical symbol templates that are available commercially.

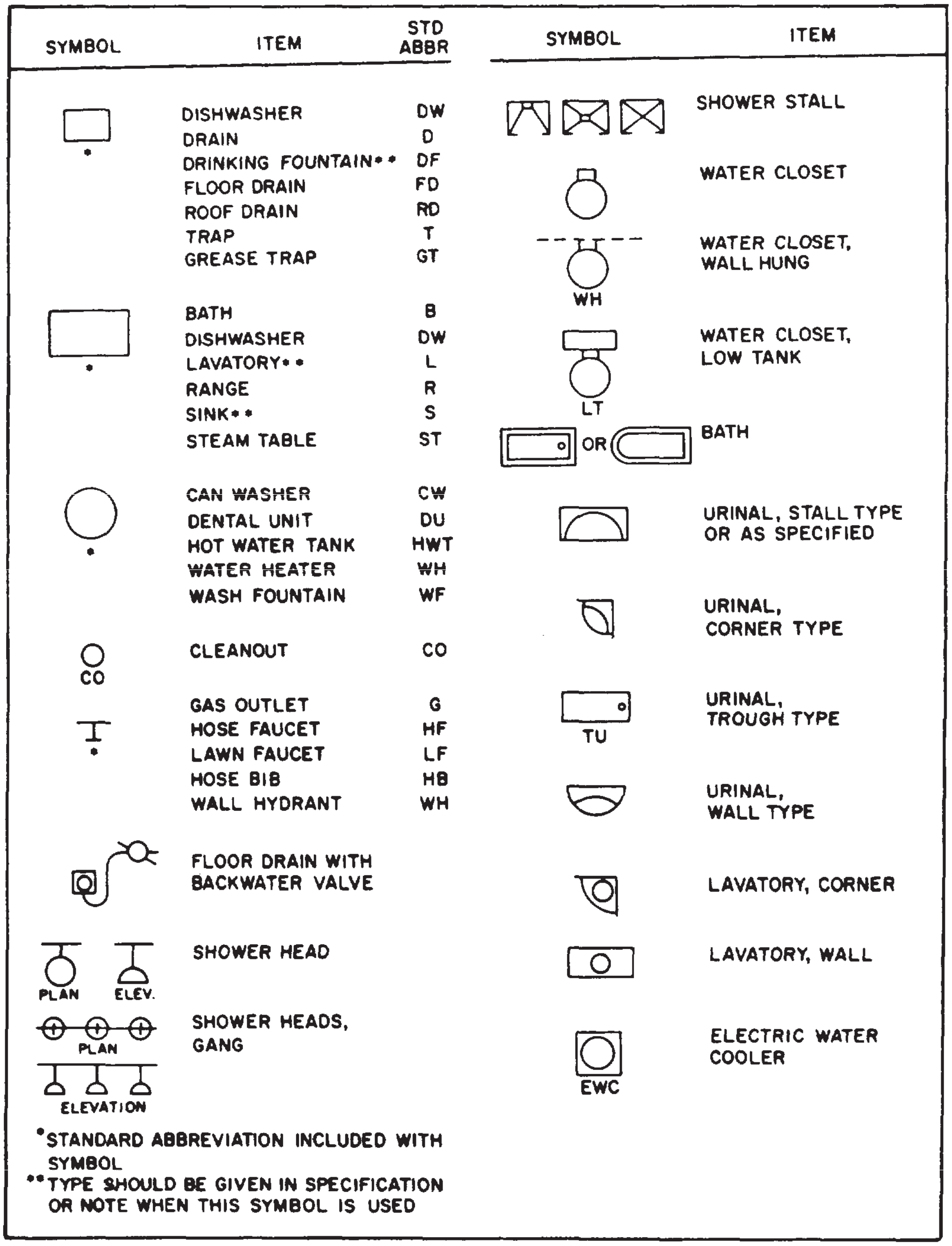


Figure 8-31.-Symbols for plumbing fixtures.

CHAPTER 9

ELECTRICAL SYSTEMS AND PLAN

It is important for an EA working on a set of drawings or plans to convey his ideas (or instructions) effectively to a skilled craftsman (CE) who is to install the electrical system. It is also equally important for you, as an EA, to understand and be thoroughly familiar with the methods and basic functions associated with the different materials and fixtures used in the installation of an electrical system.

This chapter, when used in conjunction with the previous chapters on wood, concrete and masonry, and mechanical systems and plan, will enable you to prepare construction drawings (discussed in the next chapter), revise as-built drawings in the field, and incorporate minor design changes with ease.

ELECTRICAL SYSTEM

Each building requires an electrical system to provide power for the lights and to run various appliances and equipment. At Navy bases, the electrical (or power) system consists of three main parts: the power plant that supplies the electrical power, the electrical distribution system (external) that carries the electrical current from the generating station to the various buildings, and the interior electrical wiring system that illuminates the building and feeds the interior electrical power to the appliances and equipment within the building.

In this section, we will discuss only the external power distribution and the various materials and fittings used in the installation of an electrical system. For more information, refer to the latest edition of *Construction Electrician 3 & 2,* NAVEDTRA 10636, *National Electrical Code*®(NEC®), and Army Technical Manuals (TMs).

ELECTRICAL (POWER) DISTRIBUTION SYSTEM

Electrical distribution is defined as the delivery of power to building premises, on poles or placed underground, from the power plant or substation through feeders and mains.

The power system is generally considered to be a combination of two sections: the transmission and the distribution. The difference between the two sections depends on the function of each at that particular time.

At times, in a small power system, the difference tends to disappear, and the transmission section merges with the distribution section. The delivery network, as a whole, is referred to as the distribution section and is normally used to designate the outside lines and frequently continues inside the building to include power outlets.

Most land-based power systems use alternating current (ac) rather than direct current (dc), principally because transformers can be used only with ac. An ac distribution system usually contains one or more generators (technically known as ALTERNATORS in an ac system); a wiring system of FEEDERS, which carry the generated power to a distribution center; and the DISTRIBUTION CENTER, which distributes the power to wiring systems called PRIMARY MAINS and SECONDARY MAINS. A representative transmission and distribution system is shown in figure 9-1.

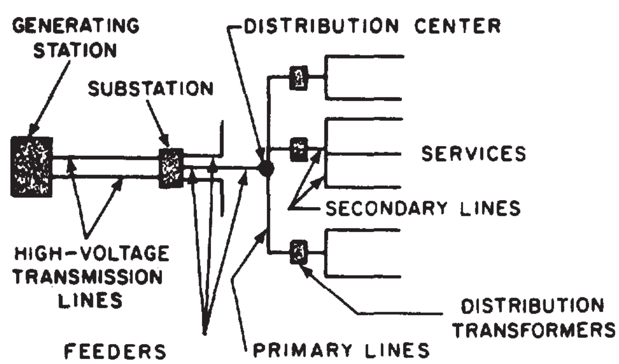


Figure 9-1.-Electrical transmission and distribution system.

Power from the generating station may be carried to the various points of consumption by overhead transmission and distribution lines, by underground cable, or by a combination of both. At most advanced bases, OVERHEAD feeder lines are commonly used because such lines are cheaper to build, simpler to inspect, and easier to maintain than UNDERGROUND cables. Obviously, the use of underground cables is preferred at airports and runways to prevent hazardous flight conditions.

Overhead Power Distribution

Figure 9-2 shows a three-phase, three-wire OVERHEAD power distribution system. Assume that the system has an alternator generating 220 V (fig. 9-3). From the generating station, three-phase, three-wire feeders carry the power overhead to the distribution points (or centers), from which two primary mains branch off. One of these mains carries power to a lighting system and a single-phase motor in a motor pool, each of which is designed to operate on 110 V, and to a three-phase motor designed to operate on 220 V. The 220-V, three-phase motor is connected directly to the 220-V, three-phase primary main. However, for the lighting system and 110-V motor, two wires in the primary main are tapped off to a transformer, which reduces the 220-V primary main voltage to 110 V. The use of two wires creates a single-phase voltage in the secondary main to the motor pool. Similarly, power to secondary mains running to the operational headquarters, living quarters, and the mess hall is reduced to 110 V and converted to single phase.

A system may be a THREE-WIRE or a FOUR-WIRE system, depending upon whether the alternators are connected DELTA (A) or WYE (Y). Figure 9-4 is a schematic diagram showing a delta connection. The coil marked

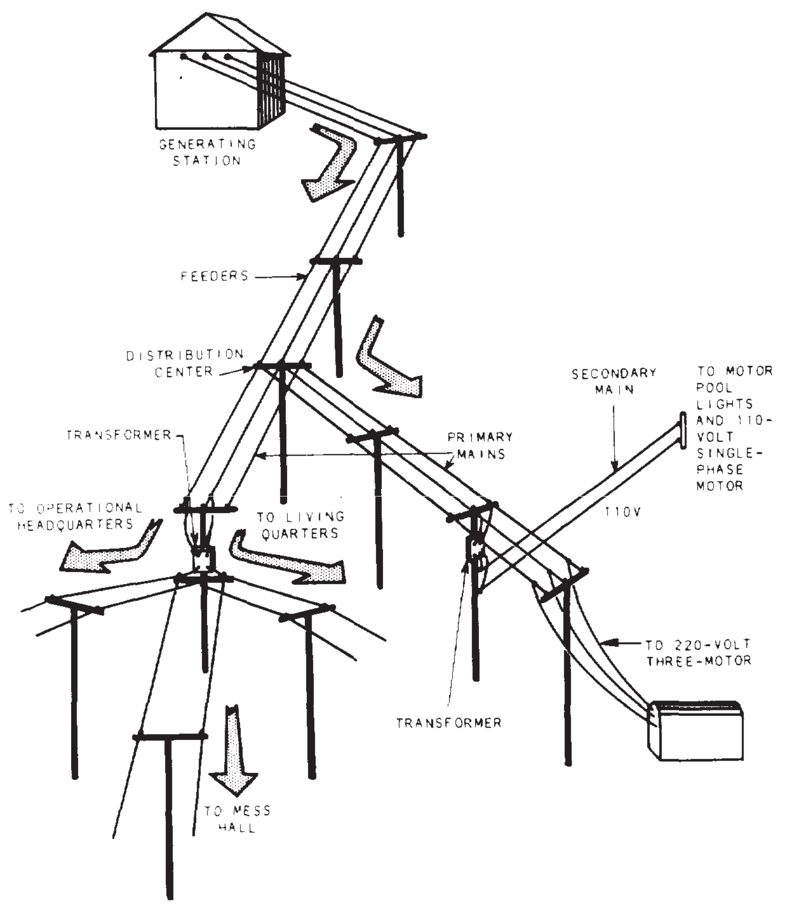


Figure 9-2.-A typical overhead power distribution system.

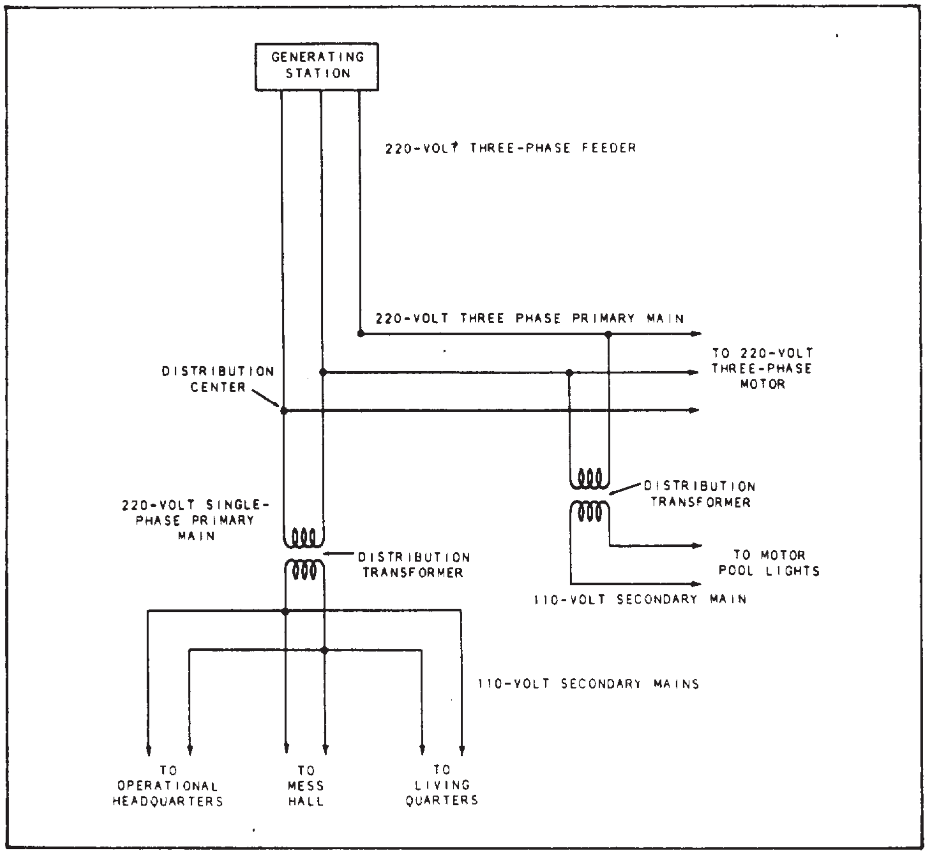


Figure 9-3.-Wiring diagram of the three-phase, three-wire distribution system in figure 9-2.

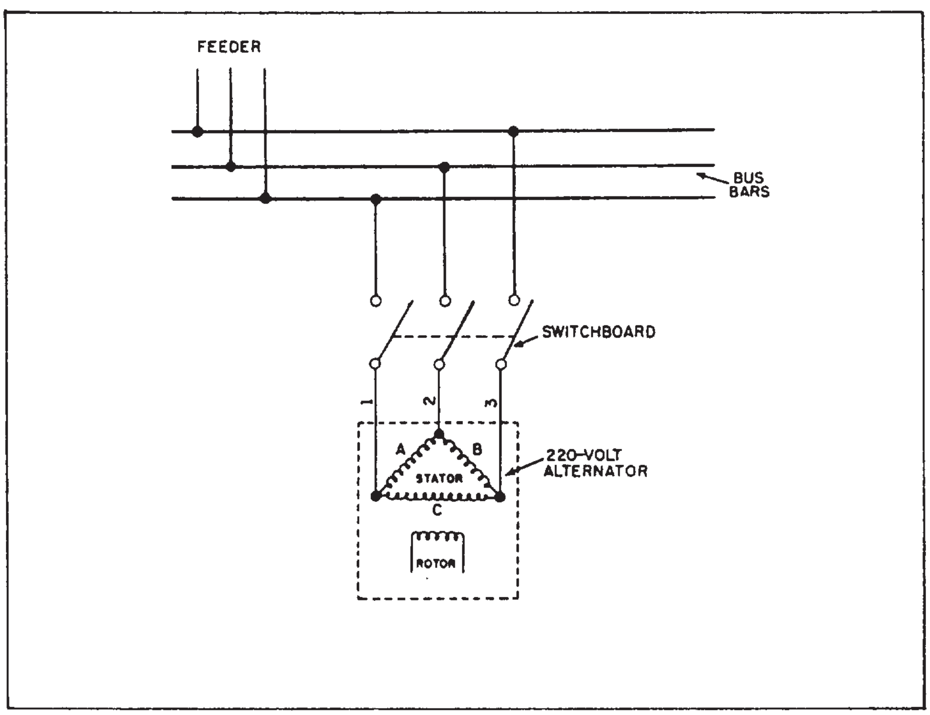


Figure 9-4.-Schematic diagram of a delta-connected alternator.

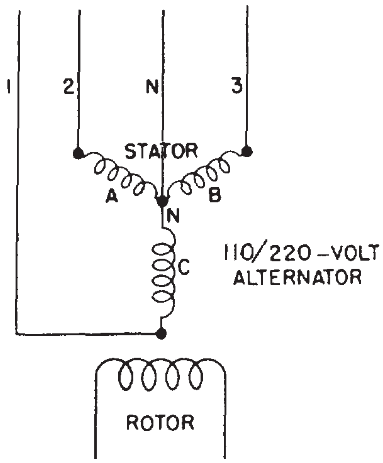


Figure 9-5.-Y-connected alternator (three-phase, four-wire).

STATOR represents the stationary coils of wire in the alternator; the one marked ROTOR represents the coils, which rotate on the armature. You can see that the power is taken off the stator from three connections, which in the drawing form a triangle or delta. All three wires are live (called HOT) wires.

Figure 9-5 shows a Y-connected alternator (three-phase, four-wire). N represents a common or NEUTRAL point to which the stator coils are all connected. The current is taken off the stator by the three lines (wires), 1, 2, and 3, connected to the stator coil ends; and also by a fourth line, N, connected to the neutral point. Lines 1, 2, and 3 are hot wires; line N is NEUTRAL.

The voltage developed in any pair of wires, or in all three wires, in a delta-connected alternator is always the same; therefore, a

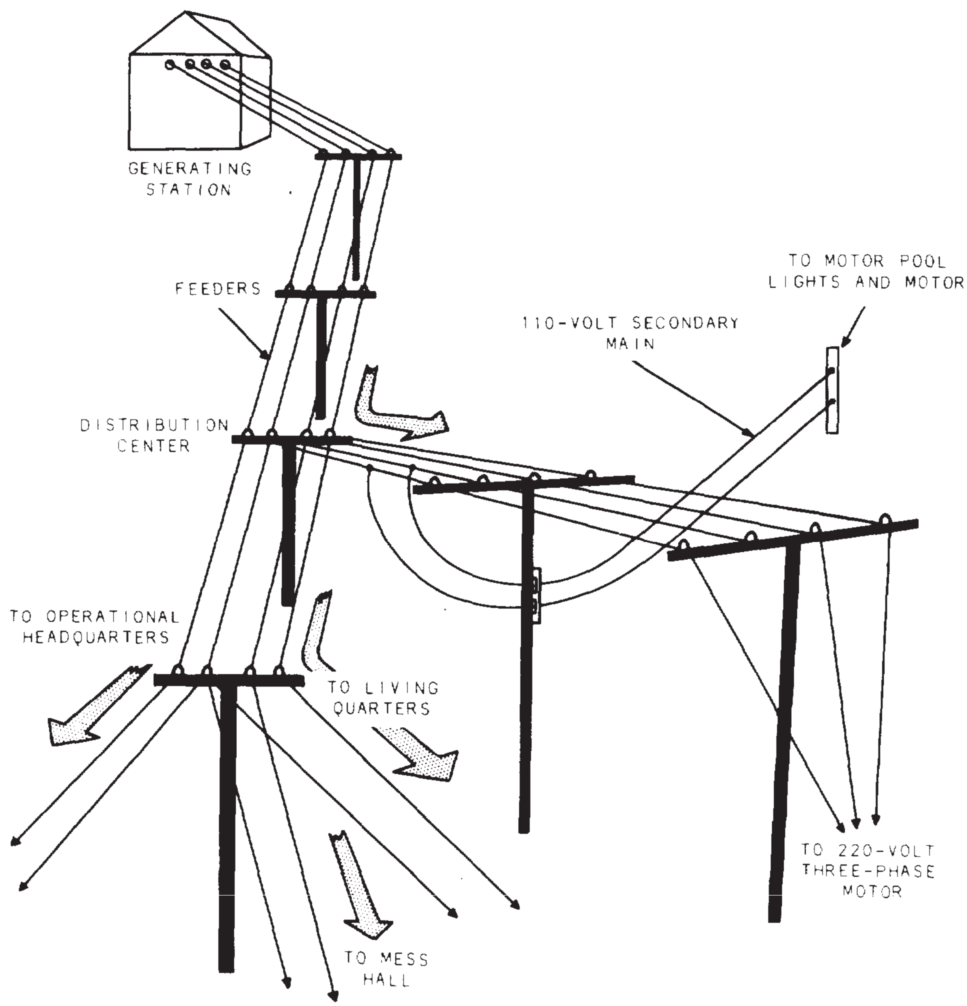


Figure 9-6.-A pictorial view of a four-wire overhead distribution system.

delta-connected system has only a single voltage rating (220 V in fig. 9-4). However, in a Y-connected system, the voltage developed in different combinations of wires is different. In figure 9-5, you can see that lines 1 and 2 take power from two stator coils (A and C). The same applies to lines 1 and 3 (power from coils C and B) and lines 2 and 3 (power from coils A and B). However, the neutral (N) and line 2 take power from coil A only; neutral (N) and line 1, from coil C only; and neutral (N) and line 3, from coil B only.

It follows from this that a Y-connected alternator can produce two different voltages: a higher voltage in any pair of hot wires, or in all three hot wires, and a lower voltage in any hot wire paired with the neutral wire.

Output taken from a pair of wires is SINGLE-PHASE voltage; output from three wires is THREE-PHASE voltage. The practical significance of this lies in the fact that some electrical equipment is designed to operate only on single-phase voltage, while other equipment is designed to operate only on three-phase voltage. This equipment includes the alternators themselves, and a system with a three-phase alternator is called a three-phase system. However, even in such a system, single-phase voltage can be obtained by tapping only two of the wires.

Figure 9-6 shows a four-wire system serving the same facilities. Here there is a Y-connected alternator rated at 110/220 V. You can see that to get 110 V single phase for the secondary mains, no transformers are necessary. These mains are simply tapped into pairs of wires, one of each pair being a hot wire and the other, the neutral wire. The 220-V, three phase motor is tapped into the three hot wires that develop 220 V, three-phase. You can see that the neutral wire in a four-wire system exists to make it possible for a lower voltage to be used in the system.

Figure 9-7 shows a wiring diagram for the system shown in figure 9-6.

Now, let's discuss the device called a DISTRIBUTION TRANSFORMER. A transformer is simply a device for increasing or reducing the voltage in an electrical circuit. It ranges in size from one that is portable (those used for appliances inside the building) to heavy ones that are mounted permanently on platforms or

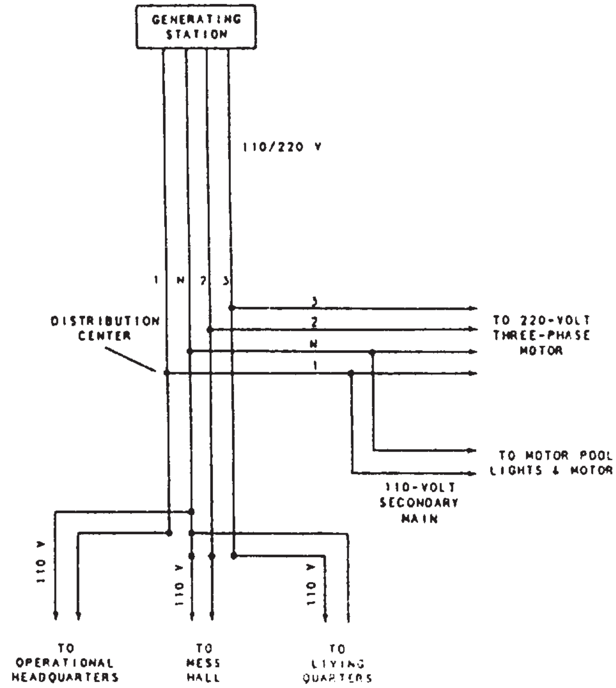


Figure 9-7.-Wiring diagram of the four-wire system in figure 9-6.

hung with crossarm brackets attached to an electric pole. Ask one of the CES to show you a transformer. It is very probable that one is nearby.

Now, for long-distance power transmission, a voltage higher than that normally generated is required. A transformer is used to step the voltage up to that required for transmission. Then at the service distribution end, the voltage must be reduced to that required for lights and equipment. Again a transformer is used; but this time it is to step down the voltage.

The reason for stepping up the voltage in a line lies in the fact that the greater the distance, the more resistance there will be to the current flow; and a much greater force will be required to push the current through the conductor. Perhaps you can best understand this reasoning if you examine Ohm's Law.

$$I = \frac{E}{R}.$$

(Refer to chapter 1 of this book.)

You can see from the formula above that the CURRENT (I) varies inversely to the RESISTANCE (R). To maintain the required current flow as the resistance increases, one must increase the VOLTAGE, or ELECTROMOTIVE FORCE (E), accordingly. The increase in voltage makes it possible to use smaller wires or cables, thus minimizing the support for aboveground transmission lines, and consequently minimizing the cost of the system.

Underground Distribution

The Navy uses UNDERGROUND power distribution systems on most shore facilities for several reasons: underground lines are secure against damage that high winds and storms inflict on overhead lines in some areas; underground lines leave clear areas and open spaces for the operations of heavy mobile equipment; and underground lines are much more secure against enemy attack than overhead lines.

There are three principal categories of underground lines: duct lines, cables buried directly, and conduits located in tunnels. The system most frequently installed by construction battalions is the underground duct system, which consists of manholes, handholes, duct lines, and cables. In general, a representation of the system layout and a list of materials needed to install the system can be found in a standard set of drawings.

INTERIOR ELECTRICAL WIRING SYSTEM

In general, the term *service* means the electrical system that brings the power from the pole or other point on the exterior power distribution line to the point on or inside the building from which it is distributed to the building circuits. Service for a building consists of two parts: the service conductors and the service equipment.

The SERVICE CONDUCTORS supply power from the pole or other point on the exterior distribution system to the building. These conductors may be SERVICE DROP conductors for overhead service, or they may be SERVICE LATERAL conductors for underground service. From the service conductors, electrical power is brought into the building through a SERVICE ENTRANCE to the SERVICE EQUIPMENT on or inside the building. The service equipment is the necessary equipment, usually consisting of a circuit breaker or switch or fuses, that is located near the entry point of the supply conductors to the building. This equipment is the main control and means of cutting off the power supply to the building.

Service Conductors

The SERIVCE DROP CONDUCTORS (fig. 9-8) run from the pole to the building. These conductors may consist of an approved multiconductor cable or individual (single) conductor. In either case, they must have thermoplastic, rubber, or other weatherproof insulation. The current-carrying capacity of the service drop conductors must be sufficient to ensure that ample current for the prospective maximum load may be conducted without a temperature rise to a point high enough to damage the insulation. The NEC® specifies the minimum size conductors that may be used for different load (amperage) requirements.

Figure 9-9 shows an UNDERGROUND SERVICE that brings power into a building. the conductors, corresponding to the service drop that

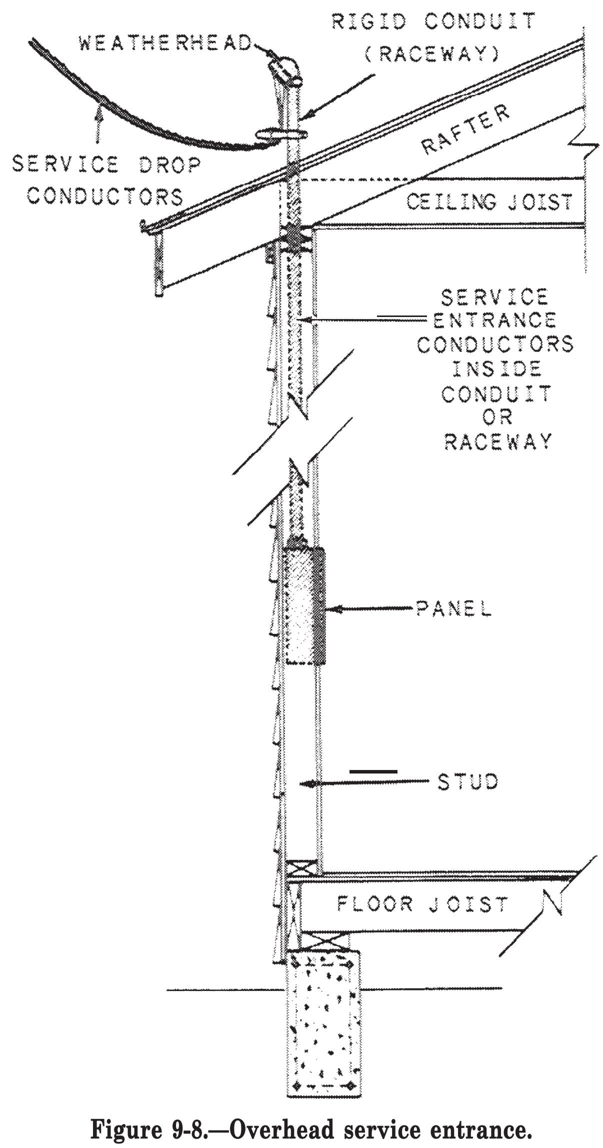


Figure 9-8.—Overhead service entrance.

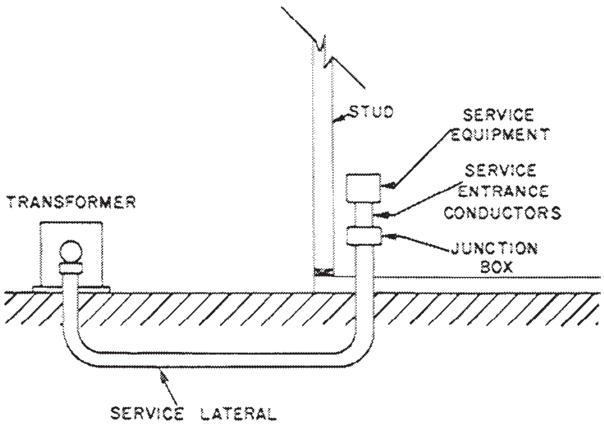


Figure 9-9.—Underground service to building.

brings the power to the building, are called the service lateral. Sometimes these conductors are tied to an overhead distribution system, and they run down the pole into the ground before they are run to the building. In other cases, the entire distribution system, except for the transformers, is underground. The service lateral may be connected to a secondary main, or, if the building is served by separate transformers, it is connected to the transformers.

The service lateral may be installed in rigid conduit, either metallic or nonmetallic, or it can be installed with underground service entrance (USE) cable. The figure shows the layout of an underground service lateral run from the transformer to the junction box and to the service equipment.

Service Entrance

The starting point for interior wiring is the SERVICE ENTRANCE, which brings power from the service conductors to the service equipment. Refer again to figure 9-8. As shown in this figure, the service entrance conductors are connected to the service drop at a point just outside the building. These conductors may be approved single conductors run through a protective raceway, such as rigid metallic or nonmetallic conduit. The service entrance conductor may also be an approved type of service entrance cable that does not need raceway protection unless it is likely to be damaged by abrasions or from being struck by passing equipment. Where single conductors are used, they must be insulated as require by the NEC®. The NEC® also specifies the size wire that may be used as service entrance cable.

Also shown in figure 9-8 is a SERVICE HEAD. A service head, frequently called a WEATHERHEAD, is used with a raceway to provide an entrance for the conductors into the building. The weatherhead is designed to prevent the entrance of rain into the raceway. It is also designed to reduce abrasion to the insulation.

A SERVICE ENTRANCE SWITCH (left-hand side of fig. 9-10) provides a means of

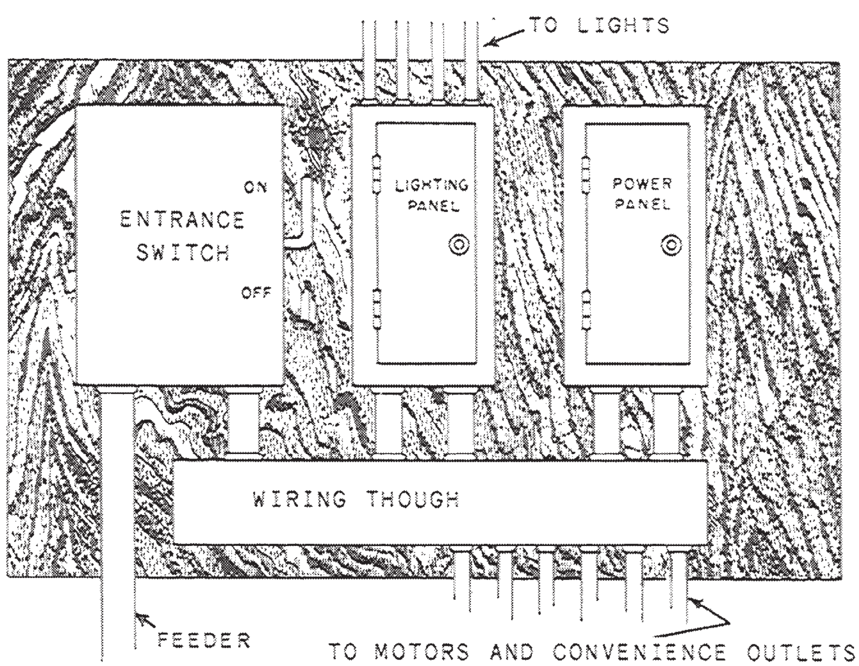


Figure 9-10.—Typical layout for entrance switch, lighting panel, and power panel.

disconnecting the service conductors from the supply source. It may consist of a single manually operated switch or a circuit breaker. The NEC® sets a minimum size for entrance switches at 60 A for the fuse type and 50A for the circuit breaker type. A CIRCUIT BREAKER is a protective device that automatically opens the circuit, rather than burning out like a fuse, when the amperage exceeds that rated for the circuit breaker. The NEC® recommends a minimum size of 100-A service for individual residences. However, when not more than two two-wire branch circuits are installed, a 30-A entrance switch may be used.

Panelboard

A PANELBOARD (fig. 9-10) is defined by the NEC® as a single panel, or a group of panel units designated for assembly in the form of a single panel, including buses. It comes with or without switches and/or automatic overcurrent protective devices for the control of light, heat, or power circuits of small individual as well as aggregate capacity; it is designed to be placed in a cabinet or a cutout box and placed in or against a wall or partition and is only accessible from the front.

A BREAKER PANEL uses a thermal unit built into the switch with the breaker being preset at the factory to open automatically at a predetermined

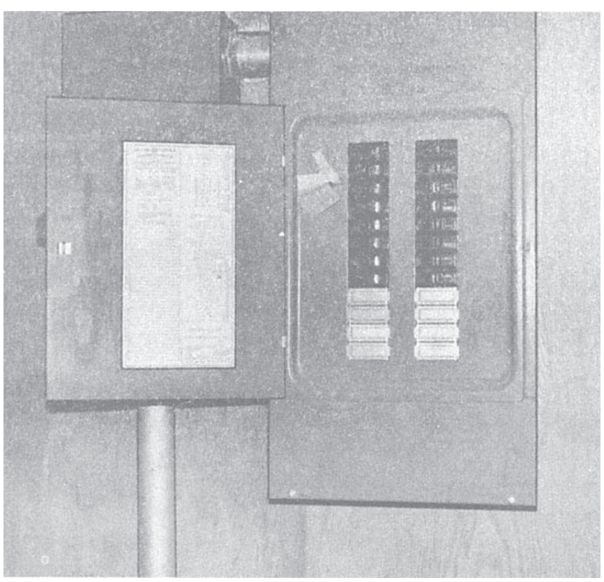


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Figure 9-11.-Lighting panel.

ampere setting. It maybe reset to the ON position after a short cooling-off period.

LIGHTING PANELS (fig. 9-11) are normally equipped with 15-A single-pole automatic circuit breakers, while the power panels may have one-, two-, or three-pole automatic circuit breakers with a capacity to handle the designated load. In most buildings, the entrance switch and panelboards can be mounted close to each other; however, they must be placed where service and maintenance can be easily performed. They should not block any passage that is supposed to be open, and they should not be in a place where exposure to corrosive fumes and dampness is imminent. Panelboards should be located as near as possible to the center of the electrical load.

Conductors

ELECTRICAL CONDUCTORS generally consist of drawn copper or aluminum formed into wire. They provide paths for the flow of electrical current. Conductors are usually covered with insulating materials (fig. 9-12) to minimize the

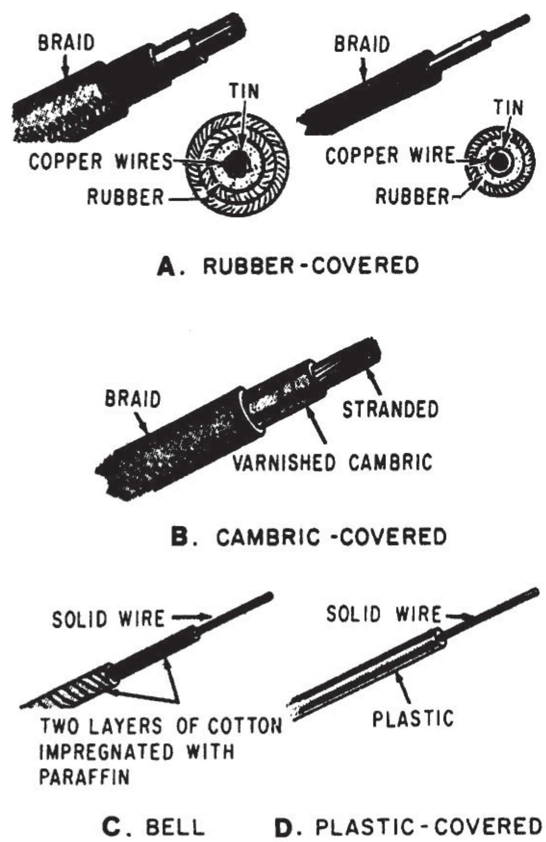


Figure 9-12.-Types of single insulated conductors.

chances for short circuits and to protect personnel. Atmospheric conditions, voltage requirements, and environmental and operating temperatures are factors to consider in selecting the type of insulating material for a particular job.

SINGLE CONDUCTORS.— A single conductor may consist of one solid wire or a number of stranded, uncovered, solid wires that share in carrying the total current. A stranded conductor has the advantage of being more flexible than a solid conductor, making it more adaptable for pulling through any bends in a conduit. Common types of single conductors are shown in figure 9-12.

Conductors vary in diameter. Wire manufacturers have established a numerical system, called the American Wire Gage (AWG) Standard, to eliminate the necessity for cumbersome circular mil or fractional-inch diameters in describing wire sizes. Figure 9-13 shows a comparison of one-half actual wire diameters to their AWG numerical designations. Notice that the wire gauge number increases as the diameter of the wire decreases.

The wire size most frequently used for interior wiring is No. 12 AWG and is a solid conductor. No. 8 and larger wires are normally used for heavy power circuits or as service entrance leads to buildings.

The type of wire used to conduct current from outlet boxes to sockets in the lighting fixtures is called "fixture wire." It is stranded for flexibility and is usually size 16 or 18 AWG.

AWG NUMBER	½ ACTUAL SIZE	DIAMETER (INCHES)
18	•	.0403
16	•	.0508
14	•	.0640
12	•	.0808
10	•	.1018
8	•	.1284
6	•	.184
4	•	.232
2	•	.292
1	•	.332
1/0	•	.373
2/0	•	.419
3/0	•	.470
4/0	•	.528

Figure 9-13.—Comparison of standard wire gauge number to wire diameters.

MULTIWIRE (CABLE) CONDUCTORS.— A multiwire conductor, called a CABLE, is an assembly of two or more conductors insulated from each other with additional insulation or a protective shield formed or wound around the group of conductors. The covering or insulation for individual wires is color coded for proper identification. Figure 9-14 shows common types of multiwire conductors.

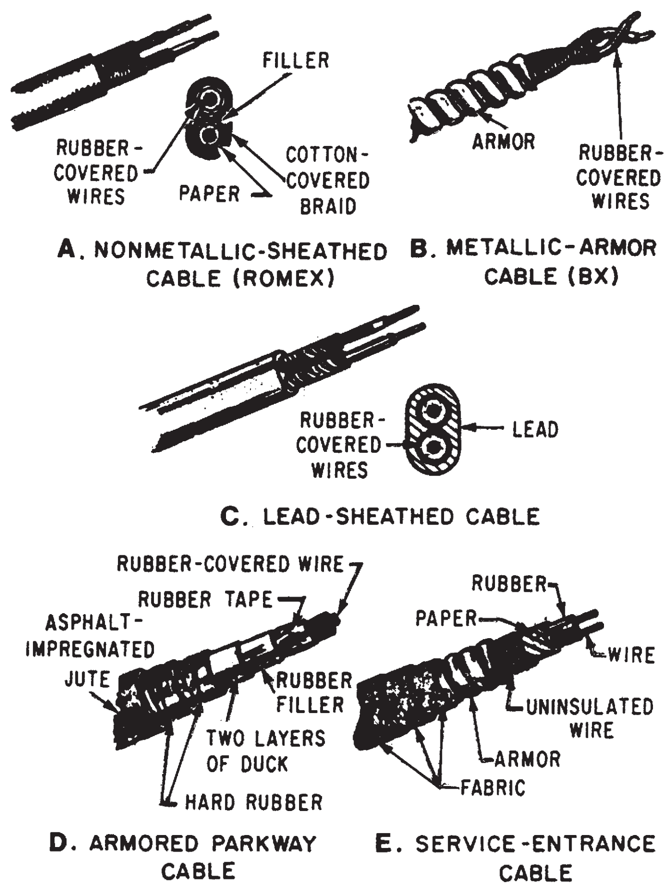


Figure 9-14.—Types of multiwire insulated conductors (cables).

Nonmetallic-sheathed cable (NMC) (fig. 9-14, view A) is more commonly called by the trade name "ROMEX," ROMEX (NMC) comes in sizes No. 14 through 2 for copper conductors and No. 12 through 2 for aluminum or copper-clad aluminum conductors. This type of cable comes with a bare (uninsulated) ground wire. The ground wire is laid in the interstices (intervals) between the circuit conductors and under the outside braid. The ground wire is used to ensure the grounding of all metal boxes in the circuit, and also to furnish the ground for the grounded type of convenience outlets that are required in Navy installations. Nonmetallic-sheathed cable is used for temporary wiring in locations where the use of conduit would be unfeasible. The use of Romex as service entrance cable, in garages, in storage battery rooms, imbedded in poured concrete, or in any hazardous area is NOT authorized.

Metallic-armored cable (fig. 9-14, view B), also called BX cable, is used in naval installations for temporary wiring, but unlike Romex, its use in commercial installation is restricted. Most city building codes restrict the use of BX cables to oil burner control circuits and the like. A difficulty with BX is the fact that it tends to ground after installation. Small metal burrs on, the armor can, because of vibration, penetrate the insulation and cause a ground.

BX cables come in sizes from No. 14 to 2 AWG, and each cable may contain one, two, three, or four conductors. The armor on the cable furnishes a continuous ground between boxes.

Insulation

As mentioned earlier, electrical conductors are available with various kinds of insulating materials. Some of these are rubber, thermoplastic, and varnished cambric. Special types of paper, glass, silk, and enamel are also used to insulate conductors, but with less frequency than those previously mentioned. The NEC® recommends insulation of certain kinds for use in dry, damp, and wet locations. Underground installations, those in concrete slabs and masonry, those in direct contact with the earth, and those subject to saturation with water or other liquids are considered wet-location installations.

Another factor to consider in the choice of insulation is temperature. Different insulations have different maximum temperature ratings. Check the NEC® and applicable LOCAL CODES to be sure you are using the appropriate insulation for the location and temperature considered in the plans. Some examples of the composition of insulation, the location that applies, and their maximum temperature rating follow:

Type RH is a heat-resistant compound, that will stand higher temperature than Type R. This type is commonly used in dry locations. The maximum temperature rating is 167°F.

Type RHW is a moisture-resistant rubber compound for use where the wire may be subject to wet conditions. This type is used in both wet and dry locations. The maximum temperature rating is 167°F.

Type RUH is a high grade rubber compound, consisting of 90-percent latex. This type is often used for direct burial in dry locations. The maximum temperature rating is 140°F.

Thermoplastic insulation has the advantage of long life, toughness, and a dielectric strength (that is, a capacity for insulating) equal to that of rubber. It requires no protective covering over the insulation. Common types of thermoplastic insulation are Types T, TW, and TA. Type T is suitable only for dry locations with a maximum temperature rating of 140°F. Type TW is moisture-resistant, and again, with a temperature rating of 140°F. Type TA is a thermoplastic-asbestos compound that combines the characteristics of Types T and TW. This type has a maximum temperature rating of 194°F. Its use is restricted to switchboard wiring.

Varnished cambric insulation has an insulating quality midway between that of rubber and paper. It is more flexible than paper; its dielectric strength is greater than that of rubber. This type is not adversely affected by ordinary oil and grease. It is manufactured in either standard type (black finish), or in the heat-resistant type with a yellow finish. Varnished insulation is restricted to dry locations in areas such as motor leads, transformer leads, and high-voltage cables.

Conduits and Fittings

An electrical conduit is a pipe, tube, or other means in which electrical wires are installed for protection from accidental damage or from the elements. If pipes or tubing is used, the fittings depend upon the pipe or tubing material. The conduit used in Navy construction is generally classified as RIGID, THIN-WALL, or FLEXIBLE conduit. The three types of conduit and their associated fittings are shown in figure 9-15.

RIGID CONDUIT.— Rigid galvanized steel or aluminum conduit is made in 10-ft lengths. It is threaded on both ends and comes with a coupling on one end. It comes in sizes from 1/2 in. to 6 in. in diameter. Various fittings used

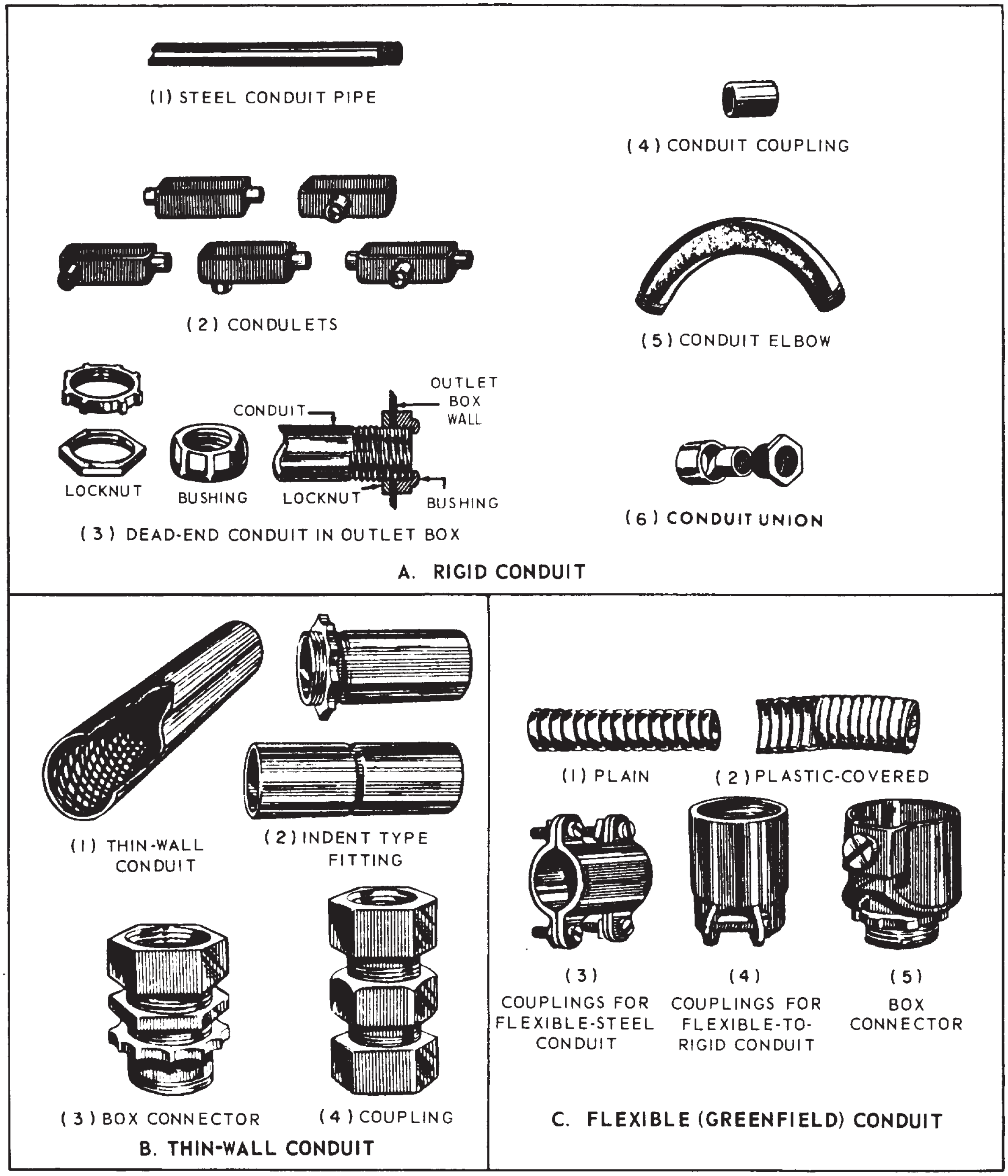


Figure 9-15.-Types of conduit and their associated fittings.

for connecting rigid metal conduit are shown in figure 9-15, view A. The use of rigid conduit involves a good deal of cutting, bending, and threading of lengths. An ordinary hacksaw or special wheel pipe cutter is used for cutting, while a ratchet type of mechanical die is used for thread-cutting conduit pipes. Bending of pipes can be undertaken both manually, using a bending tool commonly called a hickey, and hydraulically. A hydraulic bender is recommended for making smooth and accurate bends.

CONDULETS (fig. 9-15, view A (2)) are a convenient way of making bends, especially in conduit that will be exposed to the elements. They are heavily used on sharp corners and also to reduce the number of bends made in a run of conduit.

Another type of rigid conduit approved for use by NAVFAC is the polyvinyl chloride (PVC) pipe. This now popular plastic conduit is specially suitable for use in areas where corrosion of metal conduits has been a problem. Some of the advantages of PVC conduit are as follows: light handling weight, ease of installation, and leakproof joints. This conduit is primarily intended for underground wire and cable raceway use and is made in two forms. Type I is designed for concrete encasement, and Type II is designed for direct earth burial. Rigid plastic conduit and fittings are joined together by a solvent-type adhesive welding process. It also comes in sizes of 1/2 to 6 in. in diameter. PVC fittings are also available from the manufacturer. (For more information on PVC fittings, refer to Article 370 of the NEC®.)

THIN-WALL CONDUIT.— Electric metallic tubing (EMT) or thin-wall conduit, as it is better known, is a type of conduit with a wall thickness quite a bit less than the rigid conduit. It is made in sizes from 1/2 to 2 in. in diameter. Thin-wall conduit cannot be threaded; therefore, special types of fittings (fig. 9-15, view B) must be used for connecting pipe to pipe to boxes.

FLEXIBLE CONDUIT.— Flexible conduit (fig. 9-15, view C), also called Greenfield, is a spirally wrapped metal band wound upon itself and interlocking in such a manner as to provide a round cross section of high mechanical strength and flexibility. It is used where rigid conduit would not be feasible to install and requires no elbow fittings. It is made in sizes from 1/2 to 3 in. in diameter. Greenfield is available in two types: the plain or standard unfinished-metal type and a moisture-resistant type called sealtite, which has a plastic or latex jacket. The moisture-resistant type is not intended for general use but only for connecting motors or portable equipment in damp or wet locations and where flexibility of connections is desired.

Wire Connectors

Figure 9-16 shows various types of connectors that are used to join or splice conductors. The type used will depend on the type of installation and the wire size. Most connectors operate on the same principle, that of gripping or pressing the conductors together. WIRE NUTS are used extensively for connecting insulated single conductors installed inside of buildings.

Outlet Boxes

OUTLET BOXES bind together the elements of a conduit or cable system in a continuous

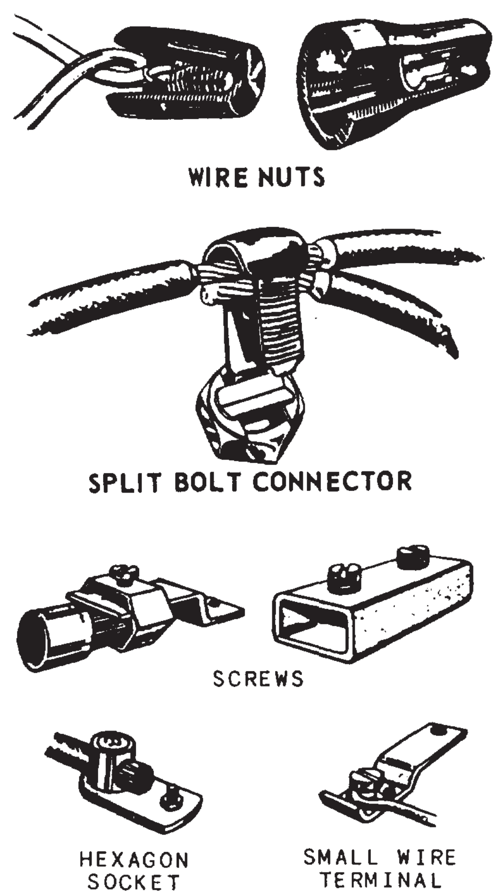


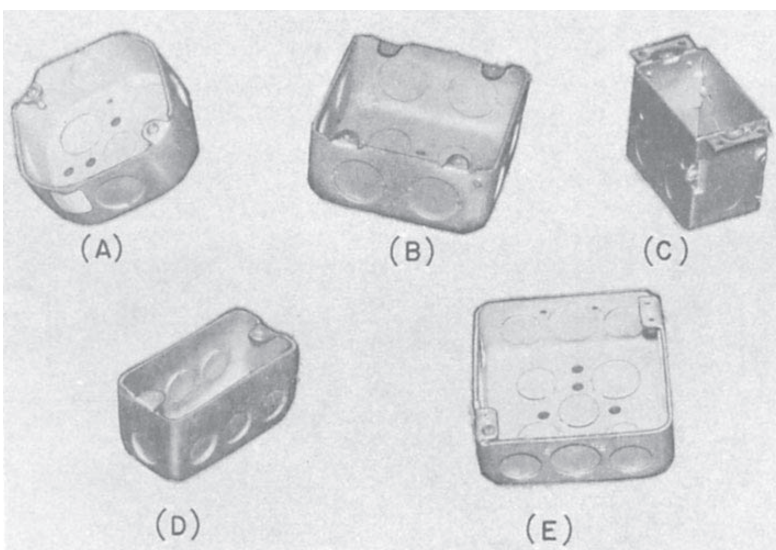
Figure 9-16.-Types of cable and wire connectors.

grounded system. They provide a means of holding the conduit in position, space for mounting such devices as switches and receptacles, protection for these devices, and space for making splices and connections. Outlet boxes used in Navy construction are usually made of galvanized steel; however, nonmetallic boxes, such as rigid plastic compounds, are being used for approved installation. Boxes are either round, octagonal, square, or rectangular in shape. Commonly used outlet boxes are shown in figure 9-17.

An outlet box is simply a metal container, set flush or nearly flush with the wall, floor, or ceiling, into which the outlet receptacle or switch will be inserted and fastened. Figure 9-17, view A, is a 4-in. octagon box used for ceiling outlets. This box is made with 1/2- or 3/4-in. KNOCKOUTS—indentations that can be knocked out to make holes for the admission of conductors and connectors. Figure 9-17, view B, shows a 4 11/16-in. square box used for heavy duty, such as for a range or dryer receptacle. It is made with knockouts up to 1 in. in diameter. Figure 9-17, view C, is a sectional or GEM BOX used for switches or receptacles. By loosening a screw, you can remove the side panel on the gem box so that two or more boxes can be GANGED (combined) to install more than one switch or receptacle at a location. Figure 9-17, view D, is a UTILITY BOX, called a handy box, made with 1/2- or 3/4-in. knockouts and used principally for open-type work. Figure 9-17, view E, is a 4-in. square box with 1/2- or 3/4-in. knockouts, used quite often for switch or receptacle installation. It is equipped with plastic rings having flanges of various depths so that the box may be set in plaster walls of various thicknesses.

Besides the boxes shown, there are special boxes for switches when more than two switches at one location are required. These are called CONDUIT GANG BOXES, and they are made to accommodate three, four, five, or six switches. Each size box has a cover to fit.

The NEC® requires that outlet boxes be 1 1/2 in. deep except when the use of a box of this depth will result in injury to the building structure or is impractical, in which case a box not less than 1/2 in. deep may be used. For switch boxes, the 2 1/2-in. depth is the most widely



73.15

Figure 9-17.-Types of outlet boxes.

used. The NEC® also requires that the outside edges of outlet and switch boxes without flush plates NOT be recessed more than 1/4 in. below the surface of the finished wall.

Receptacles

RECEPTACLES are used to plug in lights and appliances around the building. Some of the types of receptacle commonly used in interior wiring are discussed in the following paragraphs in the order of their frequency of use.

A CONVENIENCE OUTLET (fig. 9-18) is a duplex receptacle with two vertical or T-slots and a round contact for the ground. This ground is connected to the frame of the receptacle and is grounded to the box by way of screws that secure the receptacle to the box.

A RANGE RECEPTACLE (fig. 9-19) maybe either a surface type or a flush type. It has two slanted contacts and one vertical contact and is rated at 50 A. Receptacles for clothes dryers are similar but are rated at 30 A. Range and dryer receptacles are rated at 250 V and are used with three-wire, 115/230 V, two hot wires and a neutral. A receptacle for use with an air-conditioner taking 230 V is made with two horizontal slots and one round contact for the ground.

Also used in the Navy are strips that allow movement of the receptacle to any desired location. These strips are available in 3-ft and 6-ft lengths and may even be used around the entire room. This type of outlet is particularly desirable in rooms where portable equipment or fixtures, such as drafting tables and audio-visual equipments, are used. Specialty outlets (weather-proof are used in all exterior locations because they resist weather damage.

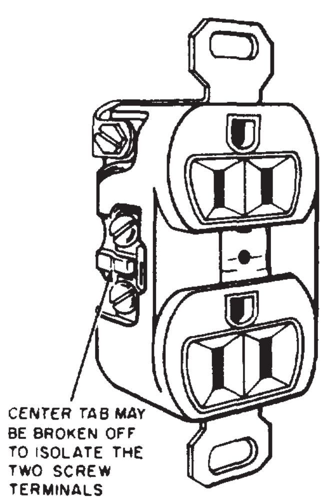


Figure 9-18.-A typical duplex convenience outlet.

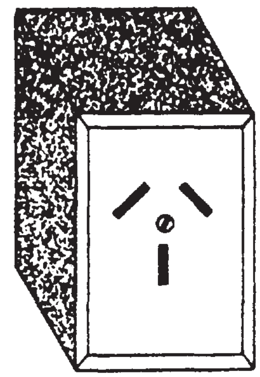


Figure 9-19.-Range receptacle.

Switches

For interior wiring, single-pole, three- or four-way toggle switches are used. Most of the switches will be single-pole, but occasionally a three-way system is installed, and on rare occasions, a four-way system.

A single-pole switch (fig. 9-20) is a one-blade, on-and-off switch that may be installed singly or in multiples of two or more in the same metal box.

In a three-way switch circuit (fig. 9-21), there are two positions, either of which may be used to turn a light ON or OFF. The typical situation is one in which one switch is at the head of a stairway and the other at the foot.

A four-way switch (fig. 9-22) is an extension of a three-way circuit by the addition of a four-way switch series.

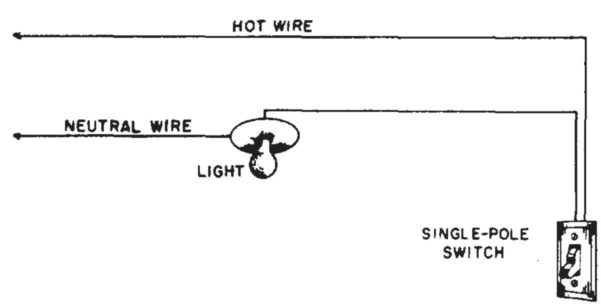


Figure 9-20.-Single-pole switch circuit.

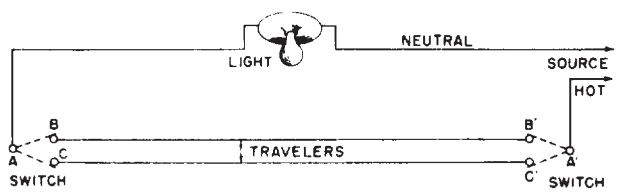


Figure 9-21.-Three-way switch circuit.

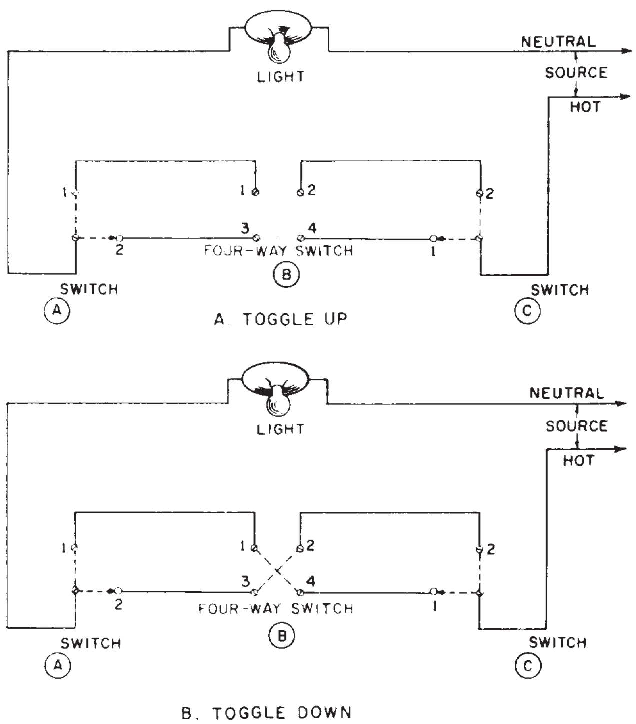


Figure 9-22.-Four-way switch circuit.

Note that three- and four-way switches can be used as single-pole switches, and four-way switches can be used as three-way switches. Some activities may install all small-wattage, four-way switches for all lighting circuits to reduce their inventories. However, three- and four-way switches are usually larger than single-pole switches and take up more box room. The size of a switch depends on its ampacity (related maximum amperage). The ampacity and maximum allowable voltage are stamped on the switch.

ELECTRICAL PLAN

The electrical information and layouts in construction drawings, just as the mechanical plan, are generally superimposed on the building plan and the plot plan.

In this chapter, we will address electrical plans as those drawings that pertain to the ELECTRICAL (POWER) DISTRIBUTION SYSTEM, which indicate outside power lines and appurtenances for multibuilding installations, and the INTERIOR ELECTRICAL WIRING SYSTEM.

As an EA3, the electrical layout for both light and power is your main concern. You will be required to draw electrical drawings and layouts from notes, sketches, and specifications provided by the designing engineer. Although you are not required to design the electrical wiring system, you must be familiar with the methods, the symbols, and the nomenclature, as well as the basic functions of the components associated with the electrical systems, its transmission and distribution, and the circuits hookup. In addition, you must also be familiar with the codes (both NEC® and local) and standards and specifications, and be able to apply that knowledge in drawing electrical plans.

STANDARDS AND SPECIFICATIONS REQUIREMENTS

Because the safety of the electrical system is of prime importance, it is imperative that all Navy electrical installations ashore conform to rigid standards and specifications. When preparing construction drawings, the EAs, like the CES, are required to follow the specifications issued by the Naval Facilities Engineering Command (NAVFACENGCOM). In particular, an EA working on electrical wiring and layout diagrams for electrical plans should refer to the latest edition of ANSI Y32.9 and ANSI Y14.15.

Codes

Code requirements and installation procedures offer protection for the consumer against unskilled electrical labor. Among other functions, the NEC® serves as a basis for limiting the type and wiring to be used, the circuit size, the outlet spacings, the conduit requirements, and the like. In addition, local codes are also used when separate electrical sections are applicable to the locale in which the building will be built. Be certain that you always have a copy of the latest edition of the NEC® available for your use.

Similarly, all of the types of electrical devices and fixtures included in the materials list prepared for electrical plans are to meet certain specifications and minimum requirements. An independent organization called Underwriters

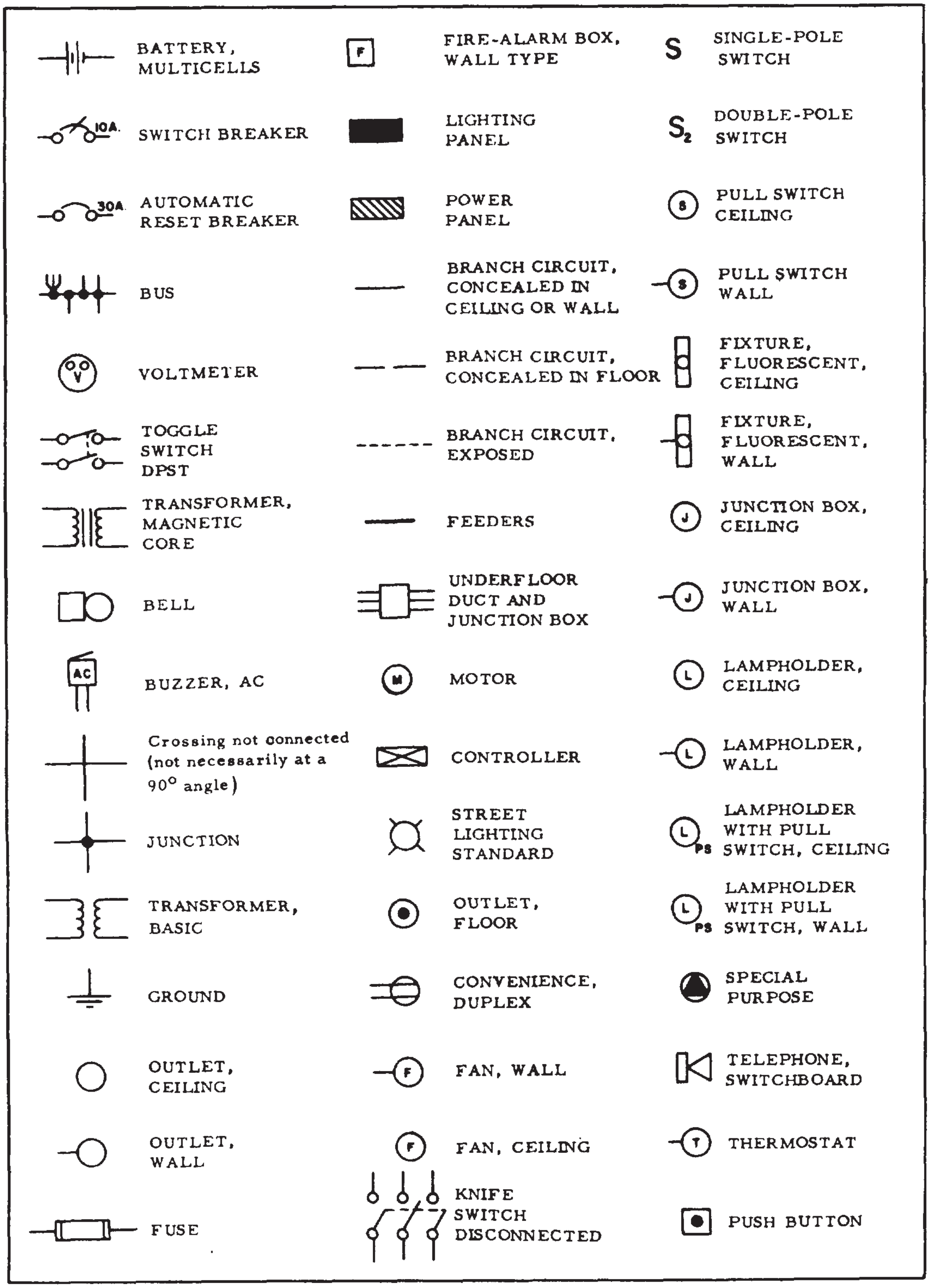


Figure 9-23.-Common types of electrical symbols.

Laboratories (UL) tests various electrical fixtures and devices to determine if they meet minimum specification and safety requirements as set up by UL. Those fixtures and devices that are approved may then bear UL labels.

Permit

In the SEABEEs, utility drawings (both mechanical and electrical) are thoroughly reviewed before an excavation (or digging) permit is granted and issued to the project subcontractor. Such action minimizes the hazards to personnel and underground structures during the construction process. All of the minor design changes and field adjustments must be noted and reflected on as-built and working drawings. Therefore, close coordination and cooperation must develop within and among all of the parties involved in the project to maintain periodic checks on red-lined prints so that information can be compared and verified as up to date.

ELECTRICAL SYMBOLS

The conventions used on the electrical plan are SYMBOLS that indicate the general layout, units, related equipment, fixtures and fittings, and routing and interconnection of various electrical wiring. The most common types of symbols used in electrical drawings are shown in figure 9-23. To see additional or special symbols, refer to the appendix section of this book and/or to ANSI Y32.9.

To draw in electrical symbols in an electrical drawing, as in drawing a mechanical plan, it is best to use templates. For example, a wiring symbol is generally drawn as a single line but with slanting "tick marks" to indicate the number of wires in an electrical circuit.

EXTERIOR ELECTRICAL LAYOUT (PLAN)

Exterior distribution lines (or network) deliver electrical power from the source (generating station or transmission substation) to various points of use. Figure 9-24 shows a typical layout, extracted from NAVFAC P-437, *Facilities Harming Guide,* of an exterior electrical network of buildings for a 100-man camp. This layout, in condensed form, shows a site plan of the camp area with facilities and the location of the electrical component system. Included in the electrical plan is a list of facilities (upper right-hand corner of fig. 9-24) that describes the corresponding item symbol, facility number, and quantity. An electrical load data table is also included in the drawing.

As an EA, you will be called upon to trace, modify, revise, and even review the workability of the drawing. It is therefore to your advantage not only to study and become familiar with the electrical plans, but also to gain a working knowledge of how the system works. NAVFAC P-437 offers a wide variety of plans, drawings, and applications for the Advanced Base Functional Component (ABFC) System for use in SEABEE construction.

INTERIOR ELECTRICAL LAYOUT (PLAN)

As we mentioned earlier, the electrical information on exterior electrical distribution is generally shown in the regular site or plot plan. The INTERIOR ELECTRICAL LAYOUT, however, is, for small buildings, drawn into a print made from the floor plan. On larger projects, additional separate drawing sheets are necessary to accommodate detailed information needed to meet construction requirements.

Figure 9-25 shows an electrical layout of a typical public works shop. Once again, note that the electrical information is superimposed on an outline taken from an architectural floor plan. In addition to the list of assemblies and electrical load table, a wiring diagram and panel schedule of a 225-A, three-phase circuit breaker is drawn. The underground service entrance (item 10 on the list of assemblies) delivers a four-wire, 120/208-V power into the building. Lighting circuits use a three-wire, No. 12 AWG (TW).

The following basic steps are suggested to guide you in the development of an interior electrical plan:

1. Show the location of the service panel and its rating in amps.
2. Show all of the wall and ceiling outlets.
3. Show all of the special-purpose outlets, such as telephones, communications, doorbells, and so forth.
4. Show all of the switches and their outlet connections.
5. Show convenience outlets.
6. If required, complete a schedule of electrical fixtures, symbols, legends, and notes necessary to clarify any special requirements in the drawing that are not stipulated in the specifications.

The steps suggested above can be put to practice in the next chapter following mastery of civil and architectural drawings.

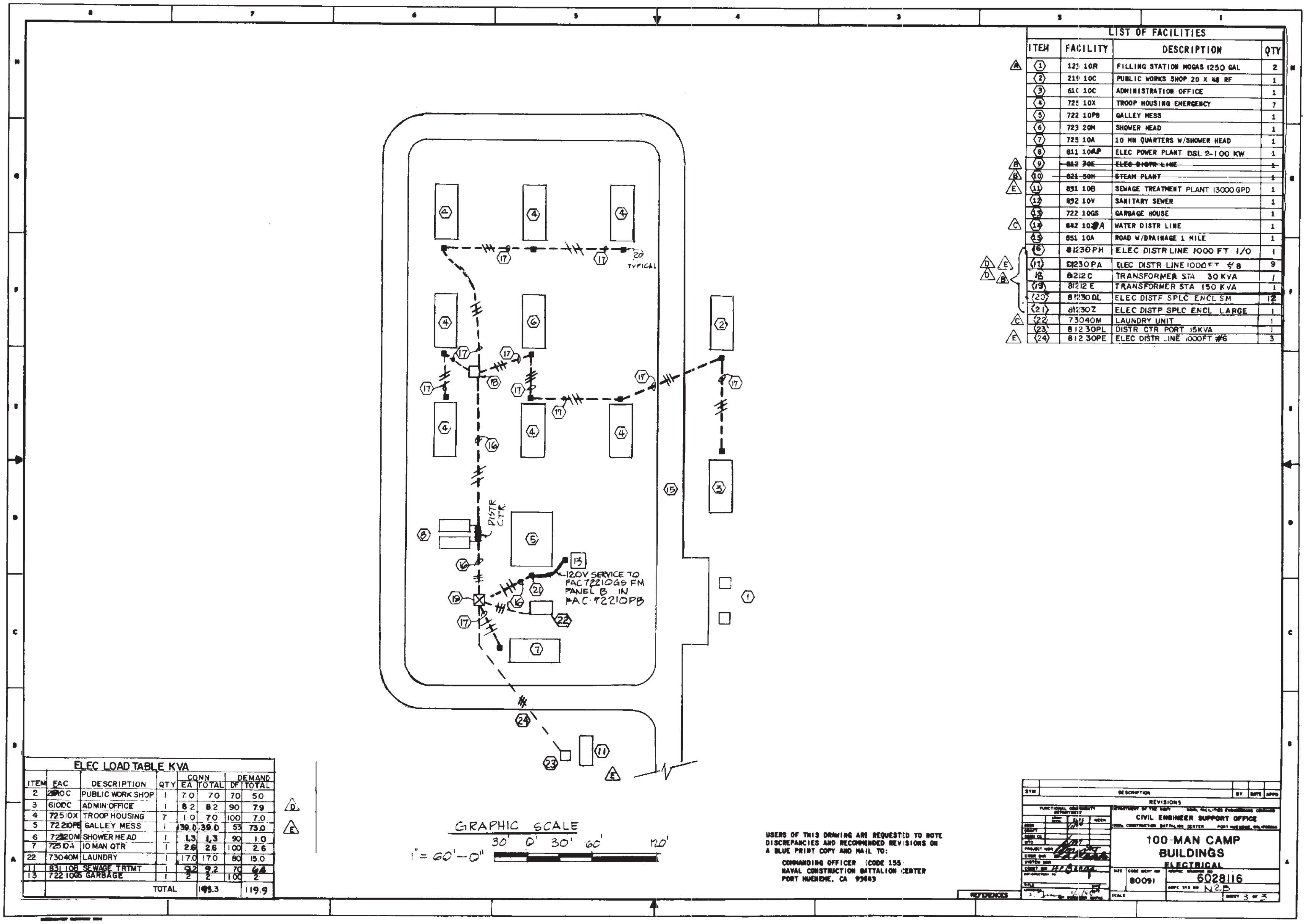


Figure 9-24.—Example of an exterior electrical plan.

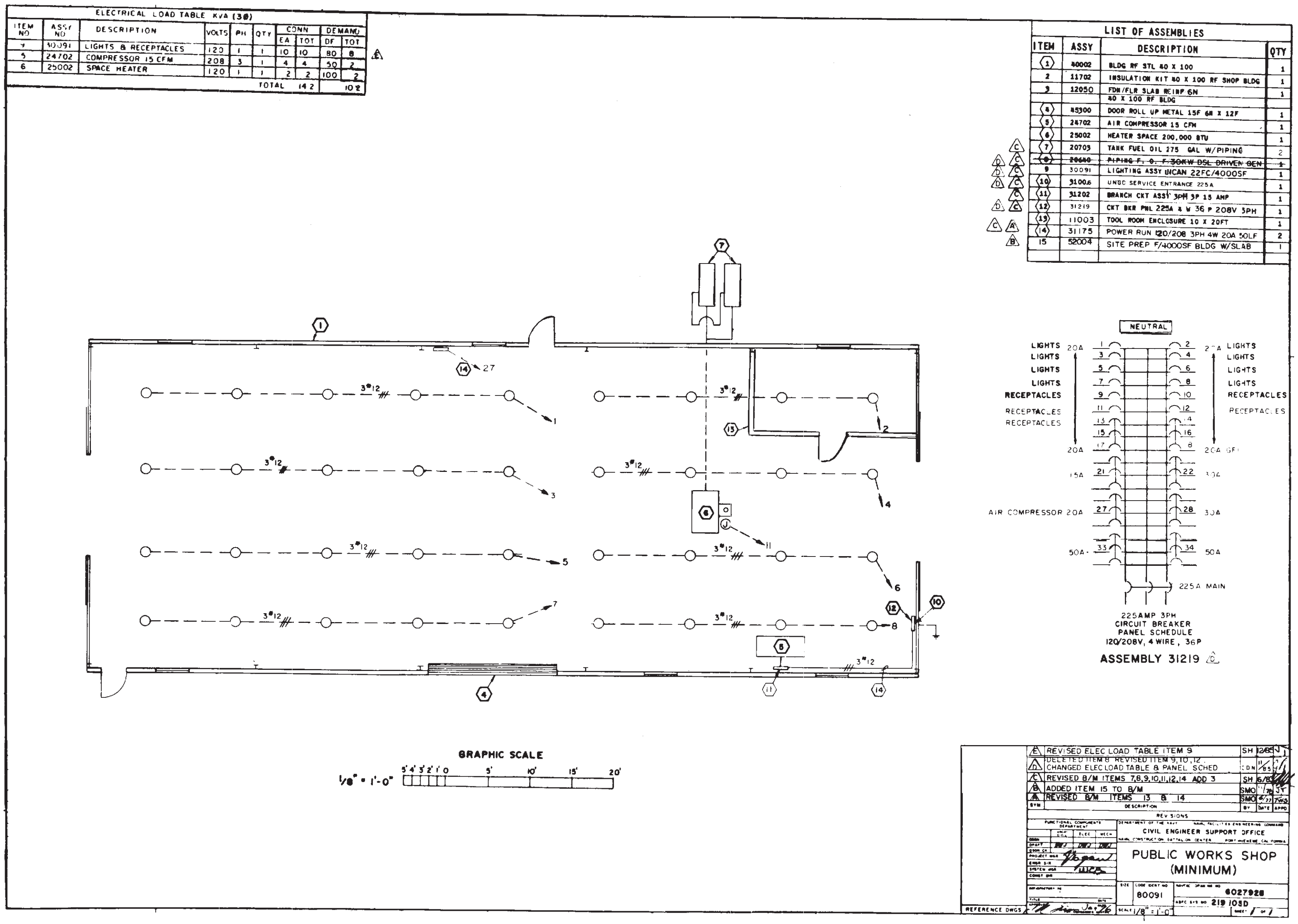


Figure 9-25.—Example of an interior electrical plan.

CHAPTER 10

CONSTRUCTION DRAWINGS

The construction of any structure or facility is described by a set of related drawings that give the SEABEEs a complete sequential graphic description of each phase of the construction process. In most cases, a set of drawings shows the location of the project, boundaries, contours, and outstanding physical features of the construction site and its adjoining areas. Succeeding drawings give further graphic and printed instructions for each phase of construction.

TYPES OF CONSTRUCTION DRAWINGS

Generally, construction drawings are categorized according to their intended purpose. Some of the types commonly used in military construction are discussed in this chapter.

PRESENTATION DRAWINGS

The purpose of the PRESENTATION DRAWINGS is to present the proposed building or facility in an attractive setting in its natural surrounding at the proposed site. They often consist of perspective views complete with colors and shading. Since presentation drawings are actually used to "sell" an idea or design concept, an EA assigned to the drafting section is rarely required to develop them.

SHOP DRAWINGS

SHOP DRAWINGS are drawings, schedules, diagrams, and other related data to illustrate a material, a product, or a system for some portion of the work prepared by the construction contractor, subcontractor, manufacturer, distributor, or supplier. Product data include brochures, illustrations, performance charts, and other information by which the work will be judged. As an EA, you will be required to draft shop drawings for minor shop and field projects. You may draw shop items, such as doors, cabinets, and small portable structures (prefabricated berthing quarters, and modifications of existing buildings), or perhaps you may be drawing from portions of design drawings, specifications, or from freehand sketches given by the design engineer.

MASTER PLAN DRAWINGS

MASTER PLAN DRAWINGS are commonly used in the architectural, topographical, and construction fields. They show sufficient features to be used as guides in long-range area development. They usually contain section boundary lines, horizontal and vertical control data, acreage, locations and descriptions of existing and proposed structures, existing and proposed surfaced and unsurfaced roads and sidewalks, streams, rights-of-way and appurtenances, existing utilities, north point indicator (arrow), contour lines, and profiles. Master plan and general development drawings on existing and proposed Navy installations are maintained and constantly upgraded by the resident officer in charge of construction (ROICC) and by the public works department (PWD).

WORKING DRAWINGS

A WORKING DRAWING (also called project drawing) is any drawing that furnishes the information required by the craftsmen to manufacture a machine part or by a builder crew to erect a structure; it is prepared from a freehand sketch or a design drawing. Complete information is presented in a set of working drawings, complete enough that the user will require no further information. Project drawings include all the drawings necessary for the different SEABEE ratings to complete the project. These are the drawings that show the size, quantity, location, and relationship of the building components.

A complete set of project drawings consists of general drawings, detail drawings, assembly drawings, and always a bill of materials. GENERAL DRAWINGS consist of "plans" (views from above) and elevations (side or front views) drawn on a relatively small defined scale, such as 1/8 in. = 1 ft or 1/4 in. = 1 ft. Most of the general drawings are drawn in orthographic projections, though sometimes details may be shown in isometric or cavalier projections. A DETAIL DRAWING shows a particular item on a larger scale than that of the general drawing in which the item appears, or it may show an item too small to appear at all on a general drawing. An ASSEMBLY DRAWING is either an exterior or a sectional view of an object showing the details in the proper relationship to one another. Usually, assembly drawings are drawn to a smaller scale than are detail drawings. This procedure provides a check on the accuracy of the design and detail drawings and often discloses errors.

Depending on the space available on the drafting sheet, you may incorporate the BILL OF MATERIALS in the drawing; otherwise, you are to list it on a separate sheet. The bill of materials contains a list of the quantities, types, sizes, and units of the materials required to construct the object presented in the drawing.

In a typical military construction, working (project) drawings go through stages of review and evaluation for design and technical adequacy by NAVFACENGCOM to ensure good quality, consistency, and cost effectiveness of the design. Special terms discussed in the following paragraphs describe these stages, from the initial development of the project to the final phase of construction.

Preliminary Drawings

PRELIMINARY DRAWINGS are the initial plans for projects prepared by the designer or architects and engineers (A/E) firm during the early planning or promotional stage of the building development. They provide a means of communication between the designer and the user (customer). These drawings are NOT intended to be used for construction, but they are used for exploring design concepts, material selection, preliminary cost estimates, approval by the customer, and a basis for the preparation of finished working drawings.

You will notice that most of the design work incorporated into the preliminary drawings at the 35-percent stage of completion contain, as a minimum, the following information: site plans, architectural floor plans, elevations, building sections, preliminary finish schedule and furniture layouts, interior and exterior mechanical and electrical data, and civil and structural details. All of the preliminary project drawings scheduled for use by the SEABEEs are reviewed by the COMCBPAC or COMCBLANT, as appropriate, for construction methods or procedures, whereas preliminary contract drawings are reviewed by ROICC.

Final Drawings

FINAL DRAWINGS are 100 percent complete, signed by the contracting officer, and used forbidding purposes. This set of plans becomes official contract drawings once the contract is awarded. Final drawings are often revised to show changes made by a scope change or by a change order with the concurrence of both the contractor and contracting officer. At this stage of completion, no further functional input may be introduced into the final drawings because of time constraints. In general, final drawings, together with project specifications, cost estimates, and all of the calculations, comprise the final stages of design requirements.

Red-lined Drawings

These are the official contract drawings that you will mark up during construction to show as-built conditions. RED-LINED DRAWINGS are marked in color "red" to indicate either a minor design change or a field adjustment.

As-built Drawings

These are the original contract drawings (or sepia copies) that you will change to show the AS-BUILT conditions from the red-lined drawings. Upon completion of facilities, the construction contractor or the military construction force (NMCB) is required to provide the ROICC with as-built drawings indicating construction deviations from the contract drawings. All of the as-built marked-up prints must reflect exact as-built conditions and show all features of the project as constructed. After completion of the project, as-built marked-up prints are transmitted by the ROICC to the engineering field division (EFD).

Record Drawings

The original contract drawings, corrected according to the marked prints, provide a permanent record of as-built conditions upon completion of the instruction work on a project. The original RECORD DRAWINGS may be retained in the custody of the EFD or they may be transferred to stations with public works.

CONCEPTUAL DEFINITIVE DESIGNS

These are prepared designs or drawings defining various functional, engineering, and logistical requirements for structures and facilities needed on a repetitive basis. These drawings are intended to provide a uniform basis for planning and design. CONCEPTUAL DESIGNS commonly used in the Navy include both definitive and standard designs.

Definitive Designs

DEFINITIVE DESIGNS are drawings of typical buildings and structures you will find in NAVFAC P-272, *Definitive Designs for Naval Shore Facilities, Part 1.* These drawings contain floor plan arrangements, building sections and elevations, and utility requirements for general guidance to A/E contractors or in-house staff who prepare project drawings and specifications. Part 2 of P-272 contains advance designs of more complex facilities that may include equipment layouts, piping diagrams, electrical schematics, and other critical requirements for specific guidance in preparing project designs. Both parts, however, are used in conjunction with NAVFACENGCOM criteria manuals, handbooks, and guide specifications listed in P-34, *Engineering and Design Criteria for Navy Facilities.*

Included in the facility type of designs are single-line schematics, bubble diagrams, or graphics based on definitive drawings called FACILITY PLATES. These plates (fig. 10-1) are used to show functional relationships or building layouts, such as detailed information concerning the design of individual rooms within a specific type of facility. Facility plates may show the location of all of the equipment and furnishings within a room, the location of utilities serving the room, the location and size of doors and windows, a ceiling plan reflecting the location of lighting fixtures, and other technical design information about the room. Facility plates are used instead of the definitive design whenever the plates effectively convey the necessary design data or whenever definitive are scheduled to be revised, developed, or validated. You will find most of the facility plates within the pages of criteria or design manuals (DMs).

Standard Designs

These designs are detailed working drawings of predominantly specialized structures for unique naval facilities, such as waterfront structures, aircraft operations and maintenance facilities, ammunition storage facilities, and fleet moorings. STANDARD DESIGNS form a part of the construction documents requiring only supplemental drawings for adapting the facility to the specific site. You can modify these drawings (except for ammunition facilities) as necessary to meet on-site requirements. Ammunition and explosive design standards may NOT be modified without the approval of the Naval Facilities Engineering Command (NAVFACENGCOM). When standard designs are used for a construction project, with or without modifications, a new title block and drawing number are required. The cognizant EFD assigns these numbers.

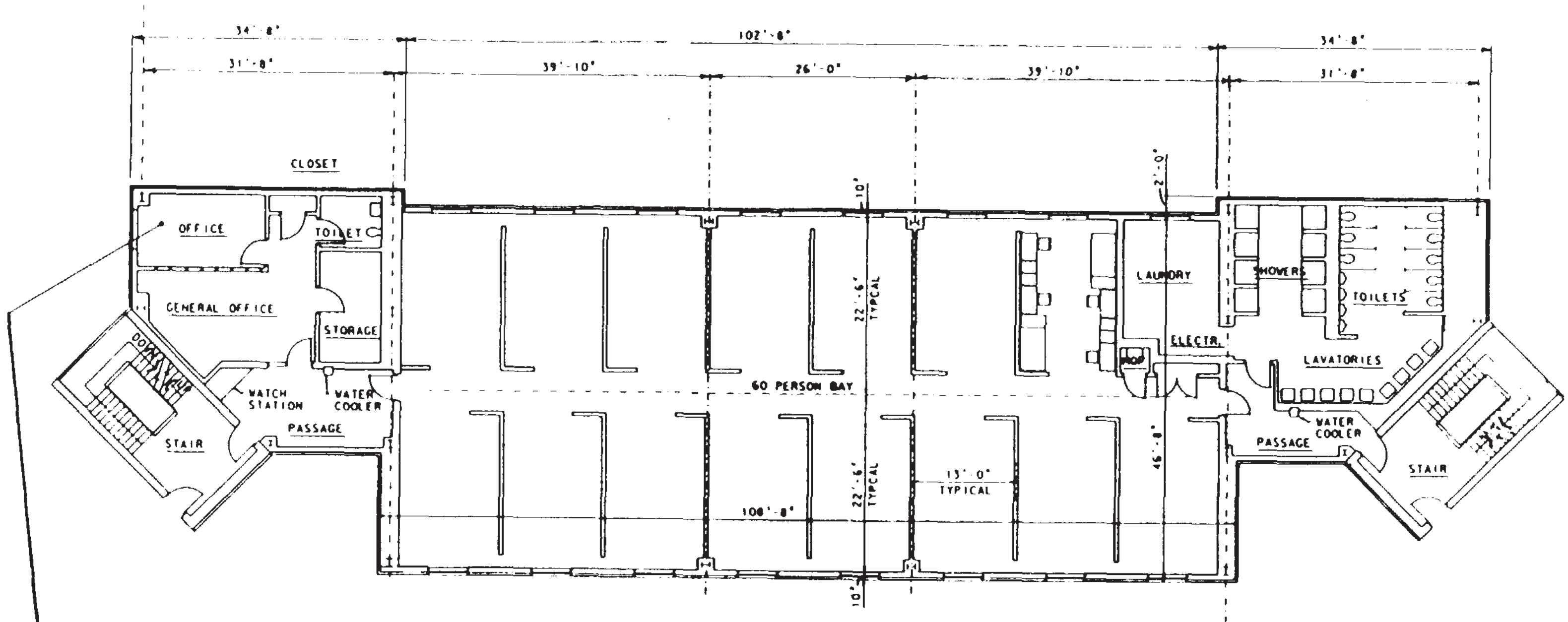
Another source of detailed construction drawings, NOT definitive, is found in NAVFAC P-437, *Facilities Planning Guide, Vol. 1.* These facility and assembly drawings contain reproducible drawings of pre-engineered structures used to satisfy the Naval Construction Force (NCF) at advanced bases in peacetime and during contingency operations. Thus, if a facility is required to meet tactical and strategic situations, construction planners can easily and readily identify and determine specific requirements and provide support. Other useful information for SEABEE planners, such as crew size, man-hours by skill, land area, and fuel necessary to make a component, facility, or assembly operational, is contained within the guide. As an EA, you should realize the importance of becoming familiar with the contents of NAVFAC P-437.

PROJECT DRAWING PREPARATION

All NAVFACENGCOM project drawings are prepared according to DOD-STD-100. The policy and procedures for preparing and developing these drawings are outlined in the military handbook MIL-HDBK-1006/1. Project drawings must be complete, accurate, and explicit since they (together with the design specifications) form the basic ingredients used in contracts for the construction of naval facilities. EAs and in-house planners also benefit from clear and consistent project drawings, especially when revising project drawings.

POLICY AND STANDARDS

The design criteria for project drawings are set by NAVFACENGCOM. These criteria also



2nd Floor	COMPANY OFFICE
3rd Floor	COMPANY DAY ROOM
4th Floor	COMPANY TV/GAME ROOM

TYPICAL 60 PERSON SEMI-OPEN BAY PLAN
Scale: 1/8" = 1'-0"

Above drawing not to scale.
Reference: DD-1404366

GRAPHIC SCALE
10 0 10 20

TITLE	DATE	FACILITY PLATE NO.	SHEET
BACHELOR ENLISTED QUARTERS- CLASS "A" SCHOOL STUDENTS	OCT 86	721 - 14	1

Figure 10-1.—Example of a facility plate (based on Definitive Design 1404366).

apply to definitive designs and standard drawings and also to project specifications. EFDs and A/Es are allowed latitude in new concepts, creative thinking, and the use of new materials; however, when deviations from mandatory criteria are considered, they need to obtain prior clearance from NAVFACENGCOM headquarters.

For dimensions on project drawings, you may use customary U.S. dimensions unless the project is in an area in which System International (SI) is normally used. The International System of Units is the internationally accepted "metric" system. Use of the word metric is no longer an accepted practice. For details of the proper use of SI units, refer to ASTM E380-82, *Standard for Metric Practice,* for generic conversions, and ASTM E621-79, *Recommended Practice for the Use of Metric (SI) Units in Building Design and Construction,* for conversions in engineering and design.

ORDER OF DRAWINGS

Project drawings for buildings and structures are arranged in the following order:

1. TITLE SHEET AND INDEX—Contains specific project title and an index of drawings. (Used only for projects containing 60 or more drawings).
2. PLOT OR VICINITY PLANS—Contain either plot or vicinity plans or both, as well as civil and utility plans. For small projects, this sheet should include an index of the drawings.
3. LANDSCAPE AND IRRIGATION (if applicable).
4. ARCHITECTURAL (including interior design as applicable).
5. STRUCTURAL.
6. MECHANICAL (heating, ventilation, and air conditioning).
7. PLUMBING.
8. ELECTRICAL.
9. FIRE PROTECTION.

DRAWING SHEET SIZE AND FORMAT

The following should be used for NAVFACENGCOM drawings:

TYPE	SIZE (IN INCHES)
Flat	17 x 22 (C size) - When small sheets are required
Flat	22 x 34 (D size) - for project and other drawings
Flat	28 x 40 (F size) - option to 22 x 34

Refer to chapter 3, figure 3-14 for finished drawing and format and margins.

Title Blocks

The title block indicates the name and location of the activity preparing the drawing, drawing title and number, approval within the activity and by an activity other or different than the source preparing the drawing, and other information relative to preparation of the drawing, such as the predominant scale used, drawing size letter designation, and sheet number for multiple sheet drawings. The code identification number or Federal Supply Code for Manufacturers (FSCM) "80091" is required in the title block of all NAVFACENGCOM drawings. Vertical title block format is used for all 22- by 34-in. (D-size) drawings; whereas, use of vertical title block is optional for 28- by 40-in. (F-size) drawings. The layout and format for title blocks are shown in chapter 3, figures 3-15 to 3-21, and in ANSI Y14.1-1980.

Drawing Numbers

NAVFACENGCOM drawing numbers issued to individual engineering field divisions are within the following limits:

NORTHERN DIVISION . . . . . .2 000 000 to 2 999 999

CHESAPEAKE DIVISION . . .3 000 000 to 3 999 999

ATLANTIC DIVISION . . . . .4 000 000 to 4 999 999

SOUTHERN DIVISION . . . . . . .5 000 000 to 5 999 999

WESTERN DIVISION . . . . .6 000 000 to 6 999 999

PACIFIC DIVISION . . . . .7 000 000 to 7 999 999

NAVFACENGCOM headquarters retains custody of all of the numbers up to and including 1 999 999 and all other drawing numbers not assigned. Each cognizant EFD is responsible for the control of assigned numbers for issuing, assigning, and recording these numbers for its own use or the use of activities within its geographical area. Each activity maintains an assignment record including locations and drawing titles of drawing numbers assigned to it.

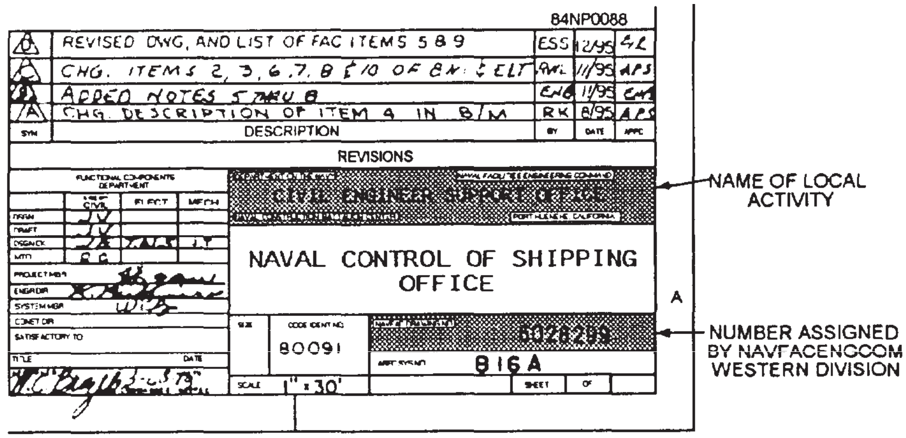


Figure 10-2.-A title block showing a drawing number assigned by NAVFACENGCOM.

(Figure 10-2 is an example of a local activity, such as the Civil Engineering Support Office (CESO), using a drawing number assigned by the Western Division (WESTDIV).)

Figure 10-2.A title block showing a drawing number assigned by NAVFACENGCOM.

You may not use a NAVFACENGCOM assigned number for any other drawing, even though the drawing to which it has been assigned is not being used. Sometimes, because of extensive revision on a particular drawing, it becomes necessary to prepare a new drawing and to assign a new NAVFACENGCOM drawing number. A cross-reference note to be placed directly above or adjacent to the title block is shown below.

Old Drawing Note:	New Drawing Note:
THIS DRAWING SUPERSEDED BY DRAWING NO. ____________	THIS DRAWING SUPERSEDES DRAWING NO. ____________

Drawing Revisions

Revisions to NAVFACENGCOM project drawings are to be made according to DOD-STD-100C. The revision block may include a separate "PREPARED BY" column to indicate the organization, such as an A/E firm, that prepared the revision. The layout of the modified revision block is to be as shown in chapter 3, figure 3-22, views A and B.

Graphic Scales

Graphic scales are located in the lower right-hand corner of each drawing sheet, with the words Graphic Scales directly over them. The correct graphic scales must be shown prominently on each drawing because, as drawings are reduced in size, the reductions are often NOT to scaled proportions.

Line Conventions and Lettering

You should pay close attention to the opaqueness and uniform weight of lines. To provide contrasting division and use of thick and thin lines, refer to chapter 3, figure 3-23, and ANSI Y14.2M, *Line Conventions and Lettering, Engineering Drawing and Related Documentation Practices.* Uppercase lettering is to be used except for notes on maps and similar drawings, where lowercase lettering may be used. The minimum allowable height of freehand letters is 5/32 (0.156) in., and of mechanical or computer graphics is 0.150 in. For abbreviations on drawings, use MIL-STD-12, *Abbreviations.*

DIMENSIONING AND TOLERANCING

All dimensions and tolerances are to clearly define engineering intent and be prepared according to ANSI Y14.5M, *Dimensioning and Tolerancing for Engineering Drawings.* Some of the fundamental rules that apply to dimensioning and tolerancing drawings are as follows:

1. A dimension having a tolerance may have it applied directly to the dimension or indicated by a general note on the drawing sheet.

2. Dimensioning for size, form, and location of features are to be complete; however, no more dimensions than those necessary for complete definition should be given. Neither the use of "sealing" (measuring the size of a feature directly from an engineering drawing) nor assumption of a distance or size is permitted. The use of a reference dimension on a drawing should also be minimized.

3. Dimensions should be arranged to provide optimum readability to obtain required

information. Dimensions should be selected to suit the function and should not be subject to more than one interpretation.

Detailed dimensioning format and standards will be discussed freely in this chapter to meet specific requirements. You will notice that dimensioning construction or project drawings differs in some applications from dimensioning general technical drawings. This occurs primarily because of the materials and methods of construction.

Units of Measure

As we stated earlier, the unit of measurement selected should be according to the policy of the user and the geographical area in which the project plans will be used. The U.S. linear unit commonly used on project drawings is the inch, while that of SI (metric) linear units is the millimeter. On drawings where all dimensions are either in millimeters or inches, individual linear unit identification is NOT required. However, when this is the case, your drawing should contain a note stating "UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES" (or "IN MILLIMETERS," as applicable). Millimeter dimension values shown on an inch-dimensioned drawing must be followed by the symbol mm, while inch dimension values shown on a millimeter-dimensioned drawing will be followed by the abbreviation IN.

Similarly, dimensions for angular units are expressed in either degrees and decimal parts of a degree or in degrees, minutes, and seconds. Refer to figure 10-3 for guidance, as applicable.

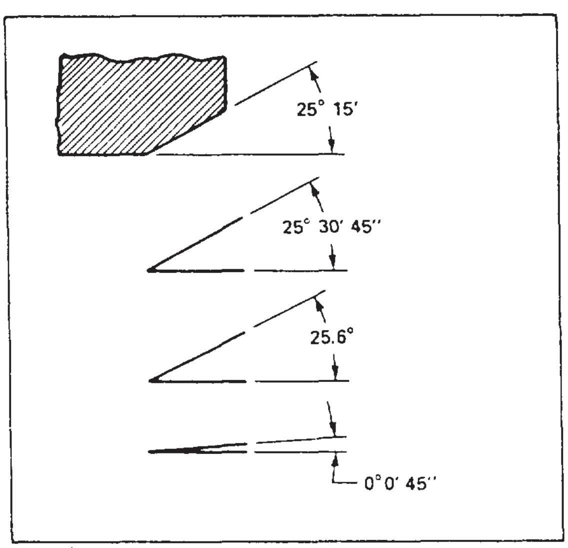


Figure 10-3.-Dimensioning angular units.

Application of Dimensions

Dimensions are applied by means of dimension lines, extension lines, or a leader from a dimension, note, or specification directed to the appropriate feature. Some of the standard rules to be followed when you are drawing DIMENSION LINES are as follows:

1. The breaking of dimension lines for insertion of numerals, as shown in figure 10-4,

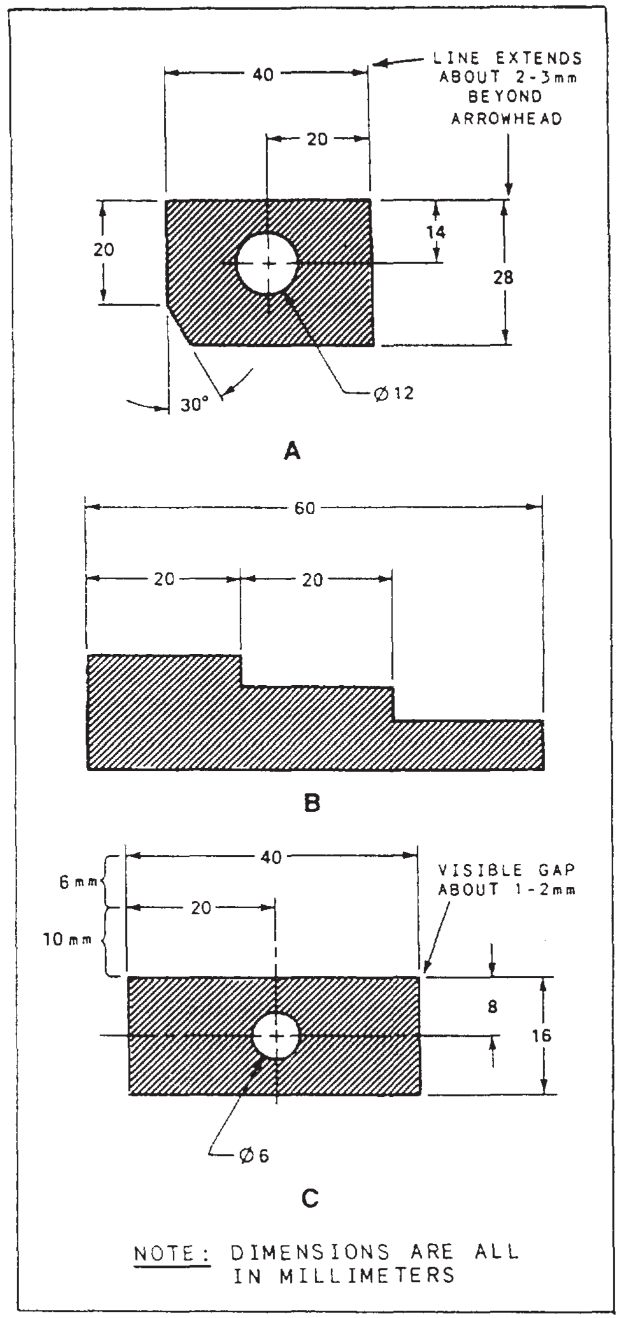


Figure 10-4.-Applications of dimensions and dimension lines: A. Breaking dimension lines for insertion of numerals; B. Grouping lines for uniform appearance; C. Proper spacing of dimension lines from object.

view A, is the preferred method of drawing dimension lines in many forms of drafting. However, for construction drawings, it is permissible, and in fact customary, to draw dimension lines from one extension line to another without breaking them. The numerals are then placed above the dimension line and parallel to the direction of measurement. This method is easier and saves considerable time.

2. Dimension lines are to be aligned if practical and grouped for uniform appearance, as shown in figure 10-4, view B. The space between the first dimension line and the object line should be not less than 10 mm, minimum; the space between succeeding parallel dimension lines should be not less than 6 mm, minimum, as shown in figure 10-4, view C. Where there are several parallel dimension lines, you may stagger the numerals for easier reading.

When using U.S. standards, you should ensure that the minimum space between the first dimension line and the object line is 3/8 in., and the succeeding parallel dimension lines are spaced at least 1/4 in. apart.

3. An angle is to be dimensioned with an arc drawn so that its center is at the apex of the angle and the arrowheads terminate at the extension of the two sides, as shown in figure 10-3.

4. Crossing dimension lines should be avoided insofar as possible. If crossing them is unavoidable, dimension lines are to be unbroken. Figure 3-23, chapter 3, shows the characteristics of dimension lines.

As explained in chapter 3, extension lines (also called projection lines) are used to indicate the extension of a surface or point to a location outside the outline of the object (or view). They are usually drawn perpendicular to dimension lines. Where space is limited, you may draw extension lines at an oblique angle. Figure 10-5, view A, clearly shows this application. You should also minimize the crossing of extension lines over one another and over dimension lines by placing the shortest dimension line closest to the outline of the object, as shown in figure 10-5, view B. Where extension lines cross arrowheads or dimension lines close to arrowheads (fig. 10-5, view C), a break in the extension line is advisable. For examples in the proper use of extension lines, refer to chapter 3, figures 3-30 and 3-31. LEADERS (or leader lines), also explained in chapter 3, direct dimensions, notes, or symbols to the intended place on the drawing.

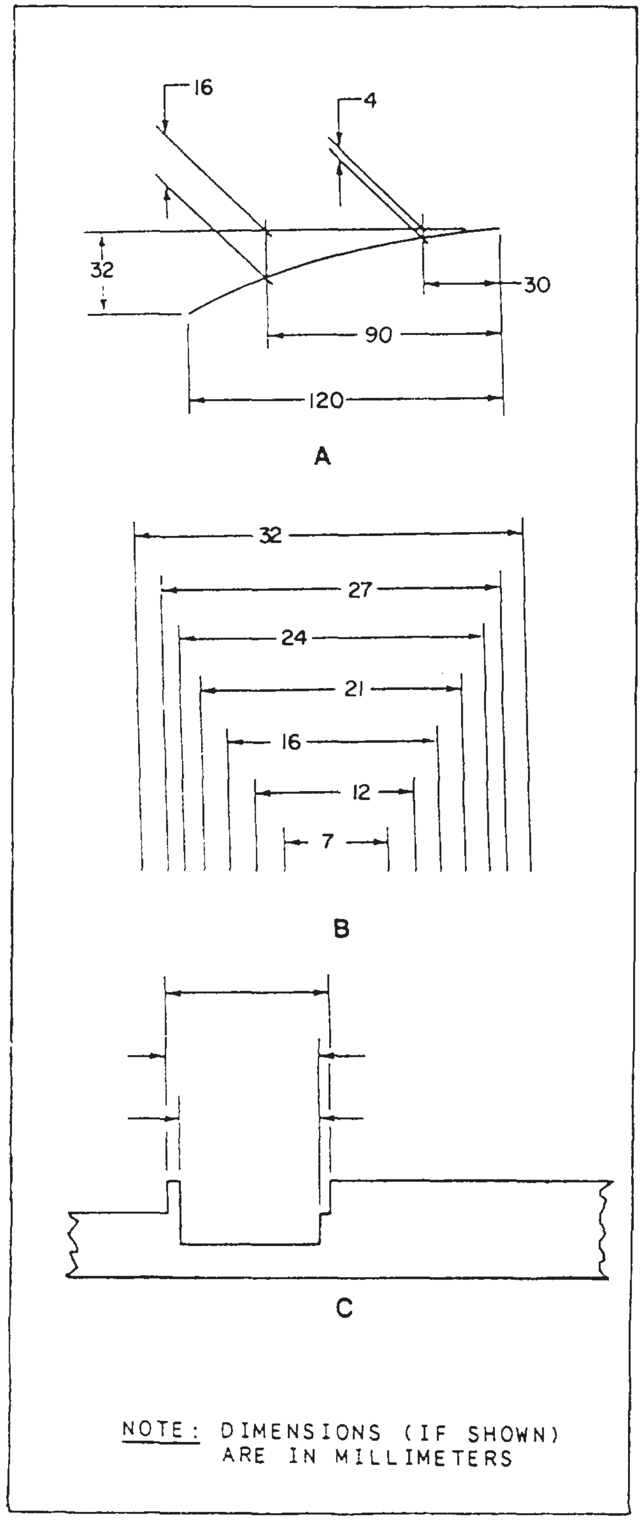


Figure 10-5.-Applications of extension lines: A. Where space is limited; B. Minimizing crossing of extension lines; C. Where extension lines break.

DRAWING SYMBOLS

Because of the small scale used in most drawings, standard graphic symbols are used to present complete information concerning construction items and materials. These typical symbols are used so frequently in construction drawings that their meanings must be familiar not only to the preparer, but to the user as well. The main information sources for a particular symbol are the Military (Drawing) Standards (MIL-STD) and the American National Standards Institute (ANSI). Refer to these standards before you use other references. Listed below are some of the most commonly used military standards and the particular symbols they carry.

Standard	Description
MIL-STD-14	Architectural Symbols (latest revision)
MIL-STD-17-1	Mechanical Symbols (latest revision)
MIL-STD-18	Structural Symbols (latest revision)
ANSI Y32.9-1972	Graphic Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction
ANSI Y32.4-1977	Graphic Symbols for Plumbing Fixtures for Diagrams Used in Architecture and Building Construction
ANSI/AWS A2.4-1986	Symbols for Welding

Sometimes you may notice that other symbols are not included in any of the standards mentioned earlier. These symbols, like the ones shown in figure 10-6, can be found in one of the military handbooks developed by NAVFACENGCOM for project drawings. As an EA, you will find that your knowledge of applicable symbols will greatly assist you in accomplishing the job correctly and promptly, and, above all, with confidence. Some of the basic architectural and welding symbols are shown in figures 10-7 through 10-10. Other types of symbols are shown in the appendix section of this book.

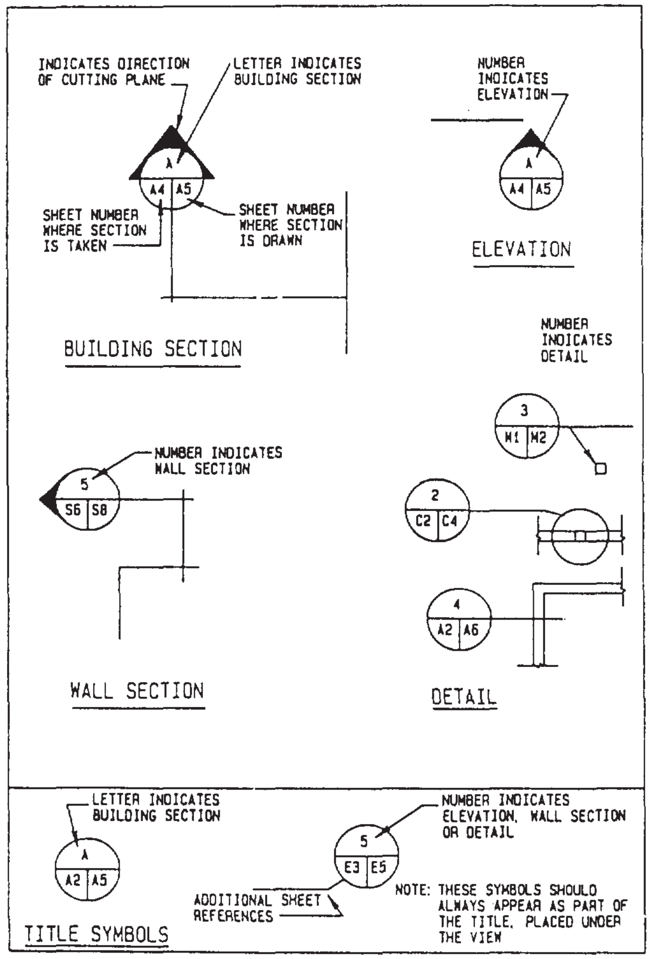


Figure 10-6.-Symbols used to identjfy sections, elevations, and details.

DRAWING NOTES

NOTES are brief, clear, and explicit statements regarding material use and finish and construction methods. Notes in a construction drawing are classified as specific and general.

SPECIFIC notes are used either to reflect dimensioning information on the drawing or to be explanatory. As a means of saving space, many of the terms used in this type of notes are often expressed as abbreviations.

GENERAL notes refer to all of the notes on the drawing not accompanied by a leader and an arrowhead. As used in this book, general notes for a set of drawings covering one particular type of work are placed on the first sheet of the set. They should be placed a minimum of 3 in. below the space provided for the revision block when the conventional horizontal title block is used. When the vertical title block is used, you may place the general notes on the right side of the drawing. General notes for architectural and structural drawings may include, when applicable,

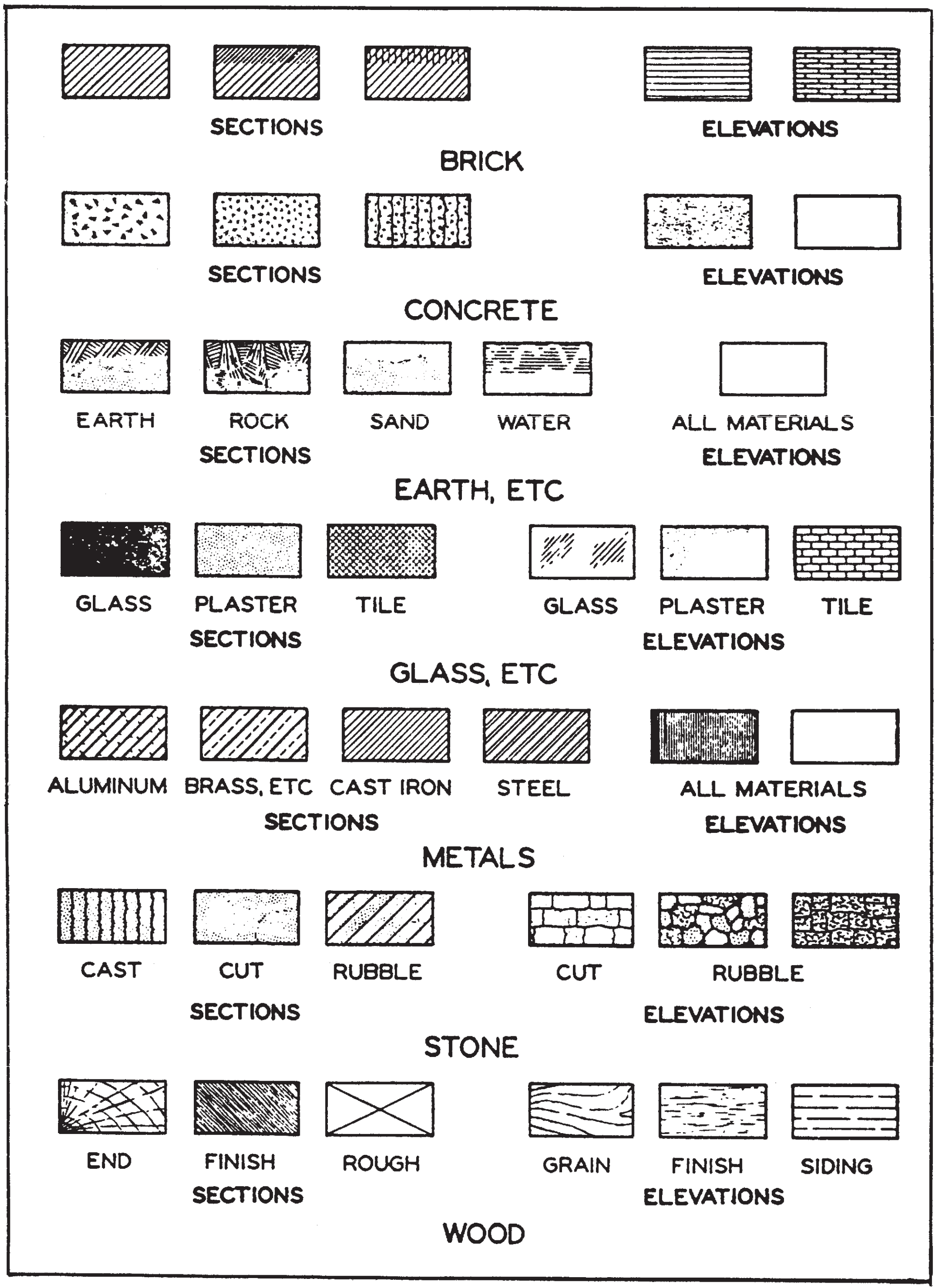


Figure 10-7.—Common architectural symbols (for various materials) used in drawing sections and elevations.

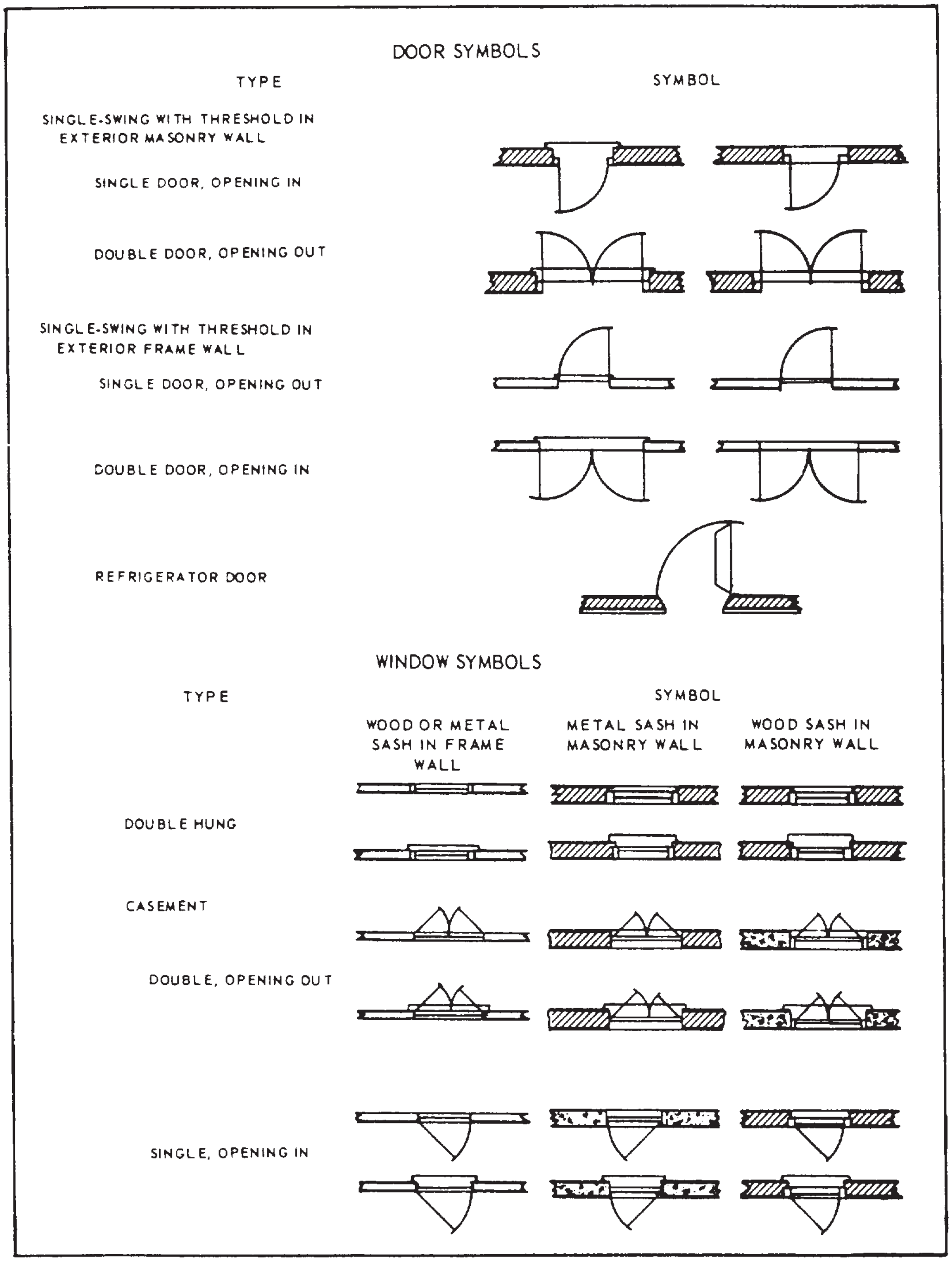


Figure 10-8.-Architectural symbols (doors and windows).

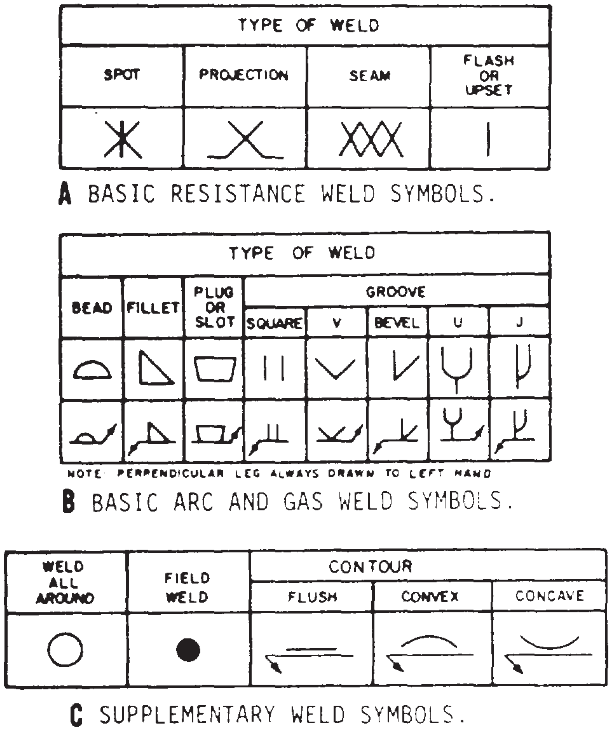


Figure 10-9.-Weld symbols.

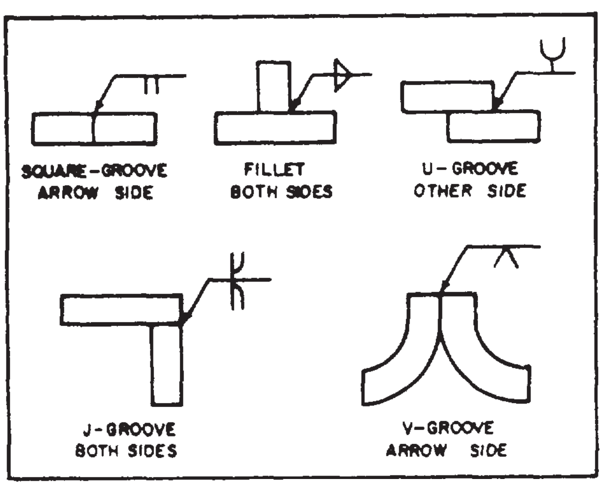


Figure 10-10.-Application of weld symbols.

roof, floor, wind, seismic, and other loads, allowable soil pressure or pile-bearing capacity, and allowable unit stresses of all the construction materials used in the design. Notes for civil, mechanical, electrical, sanitary, plumbing, and similar drawings of a set may include, when applicable, references for vertical and horizontal control (including soundings) and basic specific design data.

General notes may also refer to all of the notes grouped according to materials of construction in a tabular form called a SCHEDULE. Schedules for items like doors, windows, rooms, and footings are somewhat more detailed. Their formats will be presented later in this chapter.

MAIN DIVISIONS OF PROJECT DRAWING

Generally, working or project drawings may be divided into the following major categories: civil, architectural, structural, mechanical, electrical, and fire protection. In SEABEE construction, however, the major categories most commonly used are as follows: CIVIL, ARCHITECTURAL, STRUCTURAL, MECHANICAL, and ELECTRICAL sets of drawings.

Regardless of the category, working drawings serve the following functions:

- They provide a basis for making material, labor, and equipment estimates before construction begins.
- They give instructions for construction, showing the sizes and locations of the various parts.
- They provide a means of coordination between the different ratings.
- They complement the specifications; one source of information is incomplete without the others.

CIVIL DRAWINGS

Civil working drawings encompass a variety of plans and information to include the following:

- Site preparation and site development
- Fencing
- Rigid and flexible pavements for roads and walkways
- Environmental pollution control
- Water supply units (that is, pumps and wells)

Depending on the size of the construction project, the number of sheets in a set of civil drawings may vary from a bare minimum to several sheets of related drawings. Generally, on an average-size project, the first sheet has a location map, soil boring log, legends, and sometimes site plans and small civil detail drawings. (Soil boring tests are conducted to determine the water table of the construction site and classify the existing soil.) Civil drawings are often identified with the designating letter C on their title blocks.

A SITE PLAN (fig. 10-11) furnishes the essential data for laying out the proposed building lines. It is drawn from notes and sketches based upon a survey. It shows the contours, boundaries,

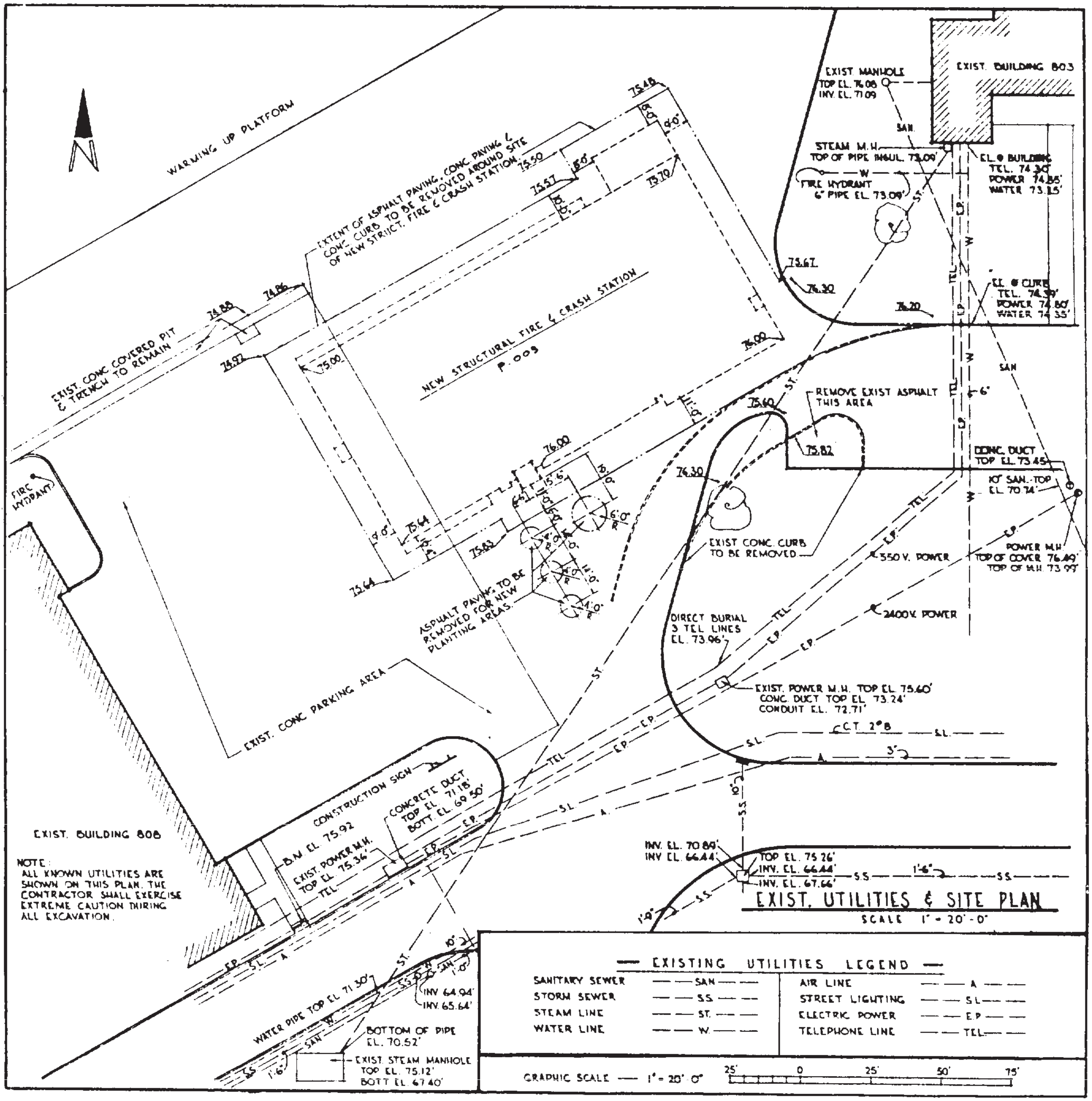


Figure 10-11.-Example of a site plan with existing utilities.

roads, utilities, trees, structures, references, and other significant physical features on or near the construction site. By showing both existing and finished contours, the field crew (Equipment Operators) is able to estimate and prepare the site for construction and to finish the site (including landscaping) upon completion of construction. As an EA, you should be familiar with the methods and symbols used on maps and topographic drawings.

Site plans are drawn to scale. In most instances, the engineer's scale is used rather than the architect's scale. For buildings on small lots, the scales normally used are 1 in. = 10 ft or 1 in. = 20 ft. This means that 1 in. on the drawing is equal to 10 or 20 ft, whichever the case may be, on the ground. Since the engineer's scale is the principal means of making scaled site plans, you, as an EA, should be thoroughly familiar with its uses.

On a set of project drawings prepared by an A/E firm, the physical information given on the site plan is taken from surveyor-prepared field notes or sketches. Other information contained on the site plan may also be used by the planners and estimators when figuring quantities of materials required, labor needed, and areas available for staging of equipment and materials.

As an EA, you may be tasked with drawing a site plan or revising one. Outlines of some of the basic procedures in the development of a site plan follow.

1. Lay out the site plan from the surveyor's drawing, showing boundary lines or limits of construction and existing trees and construction. Also note any existing features that must be removed.

2. Draw contour lines with dashed lines. Notice that if contour lines are placed on the reverse side of the drafting sheet, they make future changes or revisions easier.

3. Draw the proposed building and all surrounding construction, such as sidewalks and parking areas. Show the outline of the building wall with solid lines and the outline of the roof overhang with dashed lines.

4. Give the finished floor elevations of the building or buildings, garages (if any), and finished elevations desired on sidewalks and parking areas.

5. Review the existing contour lines. It is important that surface water not run into the buildings and other constructions, but rather towards a storm drainage system.

6. Place the dimensions. Locate the building and other constructions by a minimum of two location dimensions. If the building is not positioned parallel with the property line, more than two dimensions are required. Dimensions should be from the property line to the exterior wall of the building, not the overhang. Other dimensions necessary to be included are distances to road center lines, utility lines, easements, and any restrictions or obstructions to the site, such as utility poles and hydrants.

7. Double-check your drawing, taking a second look at the finish grade elevations, datum point, and other related information. A good technique is keeping a site plan checklist handy to make sure information given is complete and accurate.

ARCHITECTURAL DRAWINGS

ARCHITECTURAL WORKING DRAWINGS (sometimes identified with the designating letter *A* on their title blocks, as shown in chapter 3, figure 3-17) consist of all the drawings that describe the architectural design and composition of the building. A set of architectural drawings includes floor plans, building sections, exterior and interior elevations, millwork, door and window details and schedules, interior and exterior finish schedules, and special architectural treatments. For small, uncomplicated buildings, the architectural drawings might also include foundation and framing plans, which are generally included as part of the structural drawings.

Floor Plan

A FLOOR PLAN is a horizontal section through a building, showing the outline or arrangement of the floor. An offset cutting plane is often required to pass through low and high features on the wall in order to reveal doors, windows, fireplaces, stair openings, and other features located in the building.

The floor plan is usually the first drawing worked on by the EA. It is considered the key drawing in a set of project drawings—the drawing that all of the construction personnel will look at. Hence, the purpose of the floor plan is to show information about the location and type of construction, location and size of doors, windows, built-in fireplaces, stairs, rooms, and exterior and interior features.

Figure 10-12 shows the manner in which a floor plan is developed. Imagine that after the

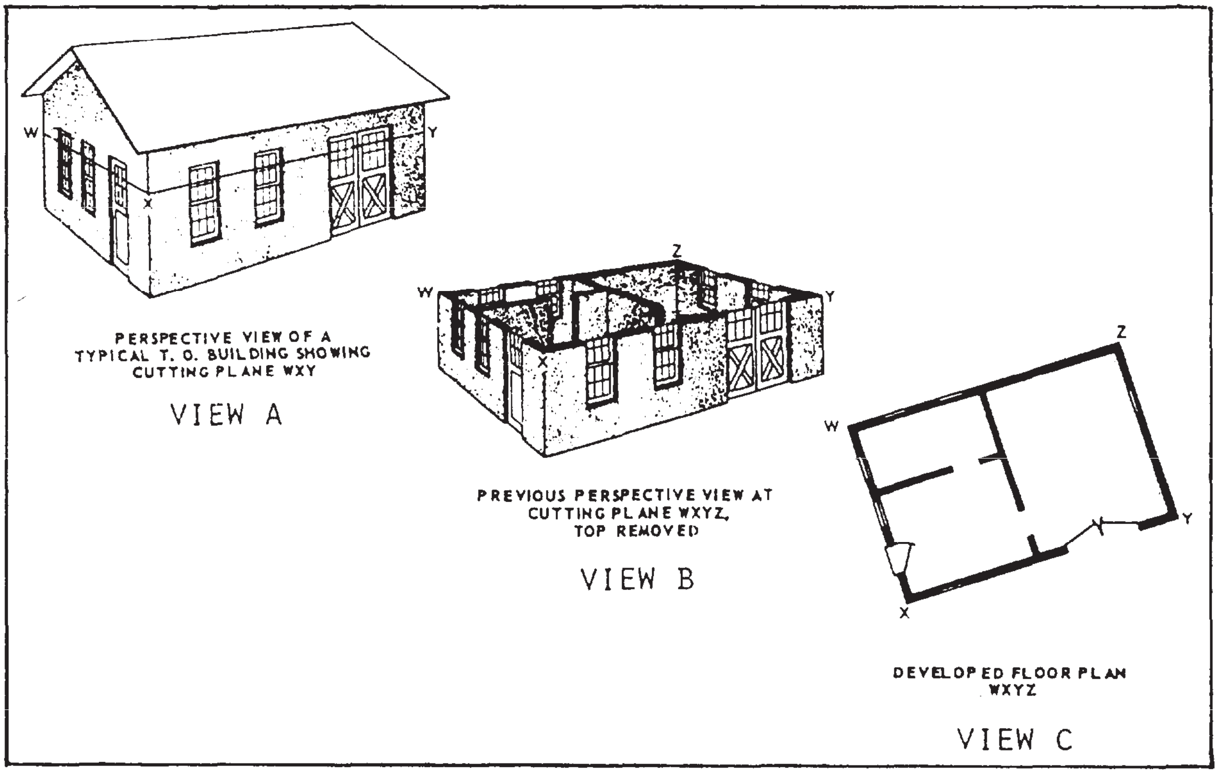


Figure 10-12.-Development of a floor plan.

building has been constructed, a cutting plane is used and cuts through the structure passing through the plane WXYZ (view A) and that the upper portion has been removed (view B). You would then be able to look down on the floor from above, and the drawing of what you see would be the floor plan (view C).

Figure 10-13 shows a floor plan of a concrete-masonry construction. It gives the lengths, thicknesses, and character of the outside walls and partitions at the particular floor level. It also shows the dimensions and arrangement of the rooms, the widths and locations of the doors and windows, and the locations and character of the rest rooms and other utility features. Study figure 10-13 carefully!

DRAWING A FLOOR PLAN.— Proper scale selection and sheet layout should be done to achieve the best results on the drawing. Before doing the actual drawing, you should draw up preliminary sketches to include the approximate size of the building, room dimensions, wall thicknesses, corridor widths, and so forth. Ideally, a scale of 1/4 in. = 1 ft should be used for easy readability. Smaller scales, such as 3/16 in. = 1 ft and 1/8 in. = 1 ft, are sometimes used for large buildings and in cases in which the size of the sheet is limited.

After you have selected the proper scale and sheet layout, you should follow the procedures outlined below.

1. Lay out construction lines (after taping the sheet to the drafting board surface) for borders, title block, and exterior limits of the building at any one side. Lay out the rooms and walls from left to right, with the exterior wall thickness being drawn first. Since the wall thickness varies with the materials used, it is impossible to accurately draw actual dimensions of each material selected. An EA would use a "nominal" wall thickness dimension of 6 in. for a wall frame exterior wall that has no brick or stone veneer. In a wall, a VENEER is a thin covering of material, such as brick, placed over a backing material of wood frame or block. Nominal wall thicknesses found in the *Architectural Graphics Standards* (AGS) should be used as a guide. Lay out the interior walls across the building,

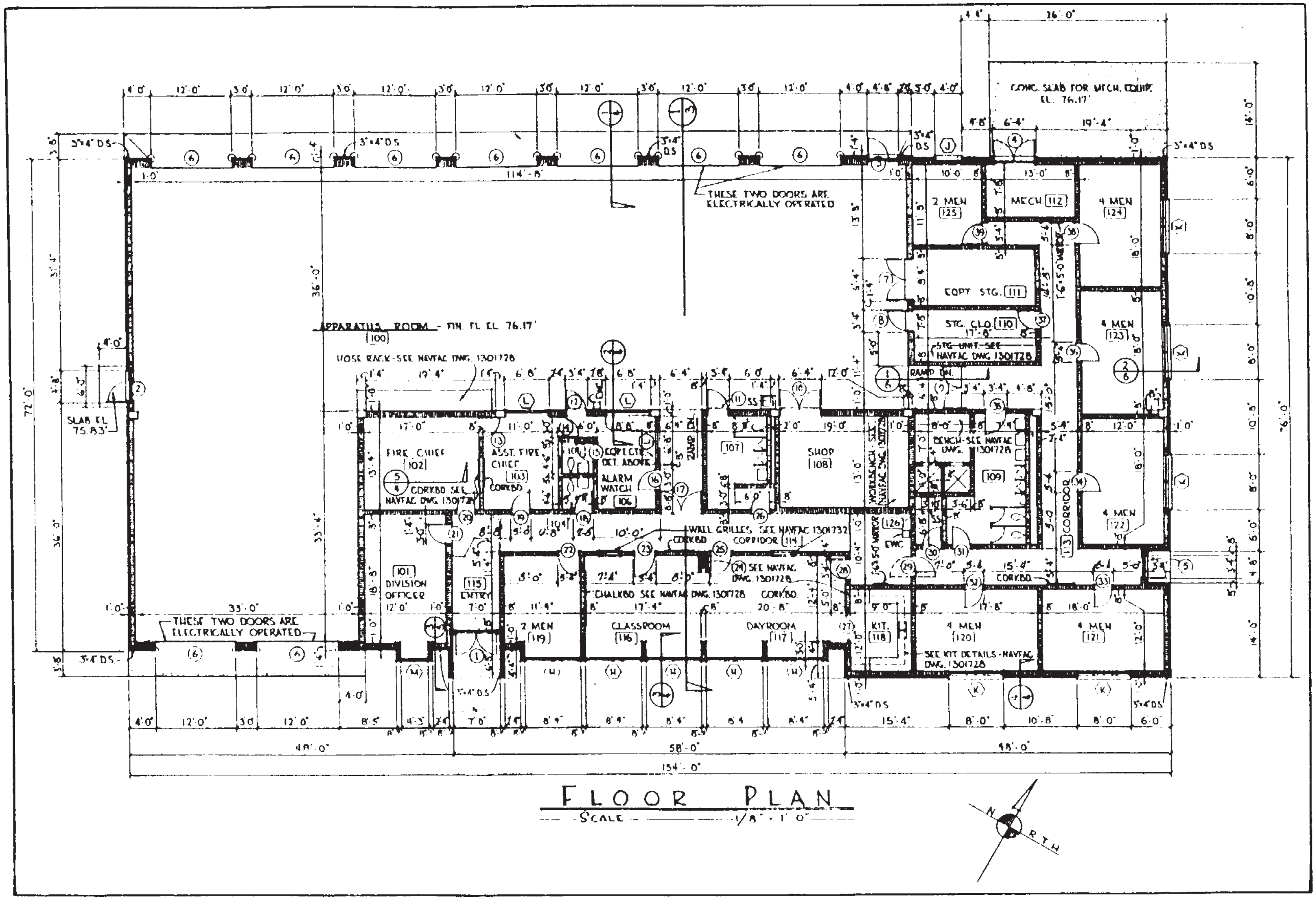


Figure 10-13.—Example of a floor plan for a concrete-masonry construction.

checking rooms, closets, bathrooms, corridors, and so on, as you proceed. Notice that a wider wall is required to allow room for a plumbing pipe to be contained within the wall.

2. Locate all doors. Both exterior and interior doors can be drawn easily if you use an architectural template. Notice that exterior doors in residential houses generally swing inward, whereas those of commercial buildings are often required by building or fire codes to swing outward. Some people prefer a full or 90-degree door swing over the 30-degree swing because they can check to be certain that it will not interfere with any equipment, walls, or appurtenances in the room.

3. Draw in and locate all windows, using proper window symbols and conventions. Next, draw the stairs (and handrails, if any) and other exterior and interior features, fixtures, equipments, appliances, and cabinets, using their proper symbols.

4. Lay out the guidelines for dimensions and the dimension lines. Now that the building basic floor plan is lightly laid out, double-check and review the accuracy and completeness of the information drawn in. You are now ready to darken in the plan. Remember that, other than the construction lines (which need not be erased), all of the lines must be drawn darkly and will vary only in the width of their lines. As an EA, you must develop a systematic approach in pursuing a fast and orderly darkening of lines. Darkening from left to right and then from top to bottom is common practice. To help keep the drawings clean, EAs often cover a partial section of their finished drawing with a clean sheet of paper while darkening the exposed section.

5. Draw in section markings on the floor plan and indicate where the wall sections have been taken. If at this point neither the section nor detail markings have been decided upon, they may be placed on the plan later. Complete the drawing by adding all the material symbols, title, graphic scale, and other relative information. Go over your floor-plan checklist for completeness.

One of your challenges as an EA (and a measure of drafting competency) is to apply your dimensioning technique to the various types of materials and construction methods used on the building. Although the principles of dimensioning and general locations of dimensions are the same, a difference exists in which dimensions are shown, and how the walls, openings, and partitions are dimensioned.

DIMENSIONING A FLOOR PLAN.— Generally, dimensions should be laid out on sketch paper before they are placed on the drawing. Besides dimensions for interior partitions, as many dimensions as possible are placed outside the plan to avoid overcrowding. Moreover, exterior dimensions are kept far enough away from the plan to avoid interfering with roof overhangs, notes, porches, or other features. In DIMENSIONING FLOOR PLANS, proceed as follows:

1. For wood-frame construction, locate the extension line of the exterior wall dimension at the outside face of the studs or stud line (fig. 10-14, view A). Partitions are measured from the

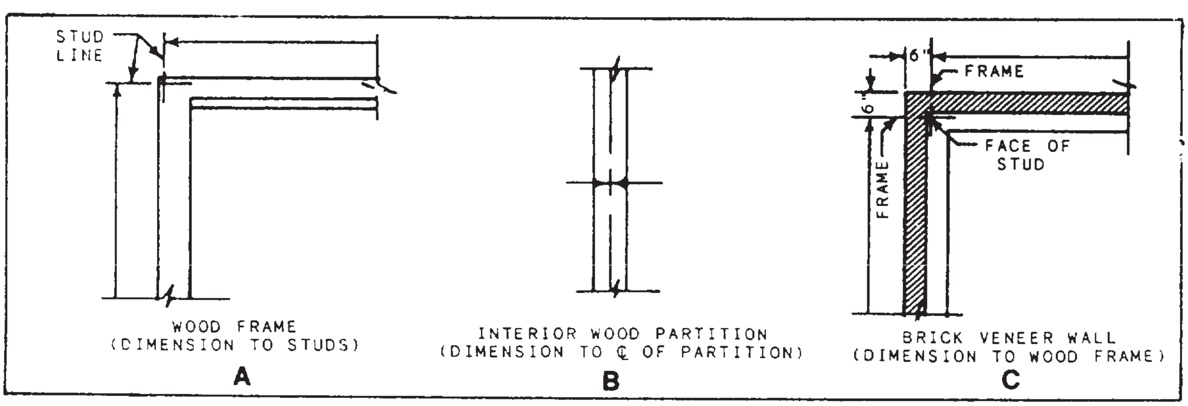


Figure 10-14.-Dimensioning wood-frame and veneer construction.

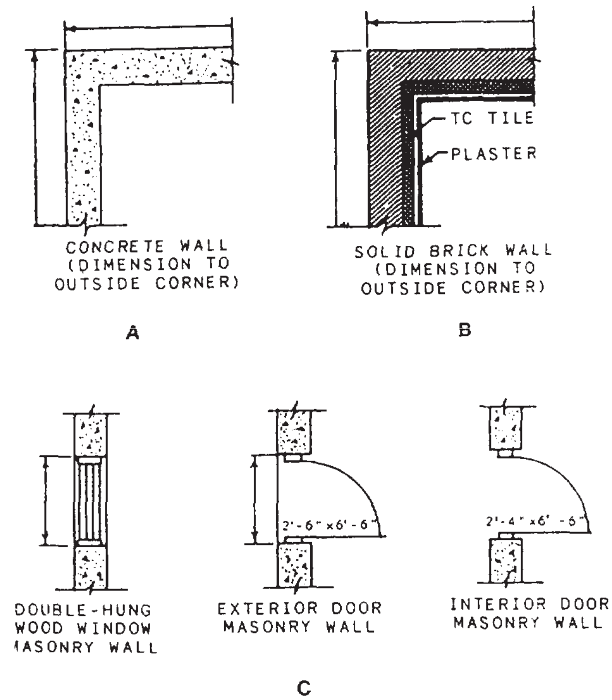


Figure 10-15.-Dimensioning concrete-masonry construction; window and door openings.

outside face of the studs to the center line of the partition (fig. 10-14, view B). In some cases, partitions are measured from the outside face of the studs to the face of the interior stud walls. The important thing is to be consistent. You must take extra care to see that all of the partition measurements are referenced from the same exterior wall. In wood frame with veneer construction, dimensioning is the same as wood frame without veneer (fig. 10-14, view C). The only difference is in the overall dimension showing the total size of the house when the veneer is added. In concrete-masonry constructions, the dimensions are all given to the face of the walls and not to the center lines, as shown in figure 10-15, views A and B.

2. In wood frame construction, doors and windows are dimensioned to their center lines. This is not the case in concrete or masonry construction, as shown in figure 10-13. Notice in this figure that the rough openings of the doors and windows and the distance between the rough openings are dimensioned. This is the correct procedure for concrete or masonry construction. Also see figure 10-15, view C, for dimensioning doors and windows in masonry construction.

3. Throughout your dimensioning of the floor plan, and then again when finished, take time to check your dimensions for legibility and accuracy. Make sure, also, that the cumulative total of all short dimensions add up to their corresponding overall dimension.

Elevations

ELEVATIONS are orthographic projections showing the finished interior and exterior appearance of the structure. Interior elevations are required for important features, such as built-in cabinets and shelves, but it is not uncommon for elevations to be drawn for all interior walls in each room of a building. Cabinet elevations show the cabinet lengths and heights, distance between base cabinets and wall cabinets, shelf arrangements, doors and direction of door swings, and materials used. Interior wall elevations show wall lengths, finished floor-to-ceiling heights, doors, windows, other openings, and types of finish materials used.

Exterior elevations show the types of materials used on the exterior, where the materials are used, the finished grade around the structure, the roof slope, the basement or foundation walls, footings, and all of the vertical dimensions.

Basically, four elevations are needed in a set of drawings to complete the exterior description: the front, the rear, and two sides of a structure, as they would appear projected on vertical planes. A typical elevation is drawn at the same scale as the floor plan, either 1/4 in. = 1 ft or 1/8 in. = 1 ft, but occasionally a smaller scale may be used because of space limitations, or a larger scale, to show more detail.

There are several methods used to identify each elevation as it relates to the floor plan. The method most commonly used by SEABEEs is to label the elevations with the same terminology used in multi-view and orthographic projection; that is, FRONT, REAR, RIGHT-SIDE, and LEFT-SIDE ELEVATIONS (fig. 10-16). On

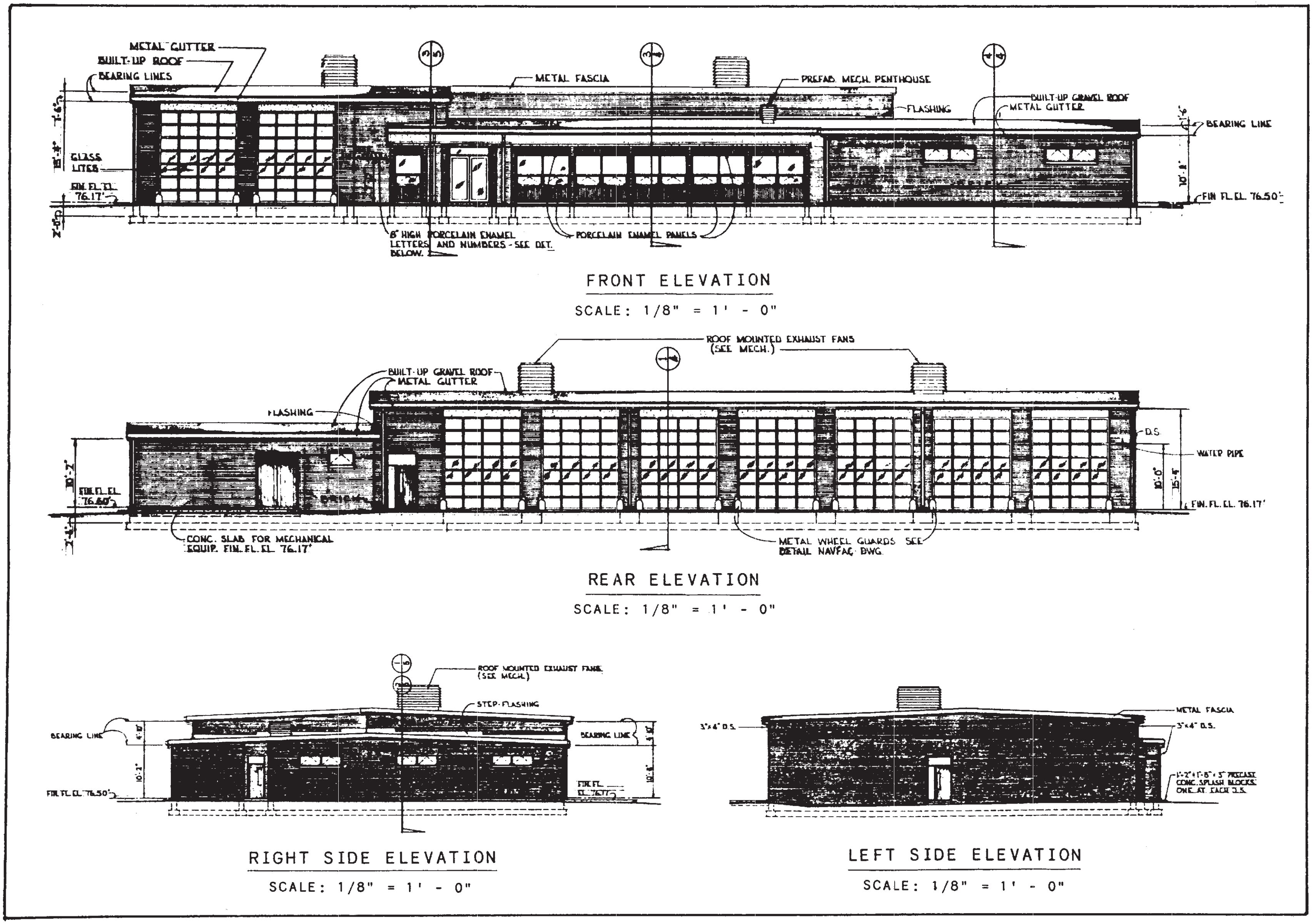


Figure 10-16.—Labeling elevations for the plan shown in figure 10-14.

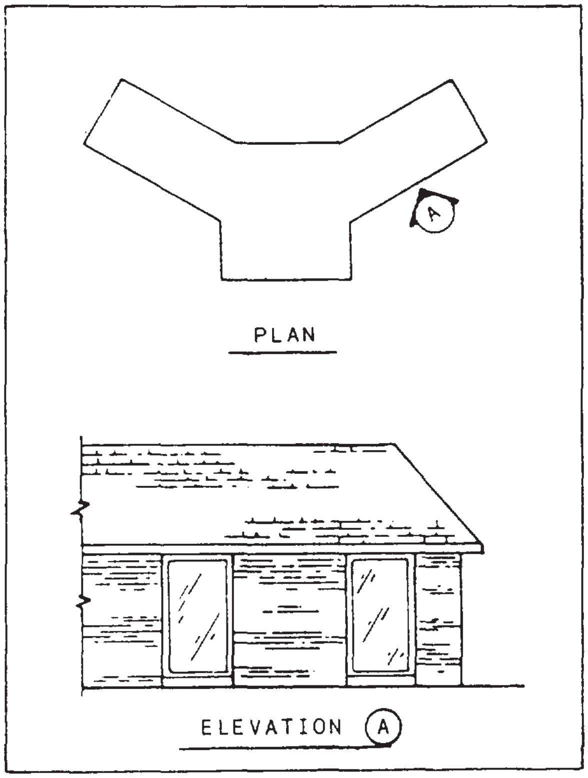


Figure 10-17.-Use of a letter to identify elevation on irregular floor plans.

irregular plans, such as shown in figure 10-17, the elevations may be identified by a letter or a number.

The following basic procedures will serve as a guide in the development and drawing of elevations:

1. Use the same sheet size as that of the floor plan. Determine the overall height and length of the elevation from the floor plan and wall section (predetermined by prior computation or a sketch). We assume that you are using the same scale for elevations as for the floor plan. Block in the views with construction lines placed in a logical order, such as starting with the front view and working around the building. Generally, the front and right-side elevations are next to each other, and the rear (if necessary) and the left-side elevations are shown below. Whenever possible, show all of the elevations on one sheet.

2. Draw the exterior limits of the elevations. The floor plan may be placed underneath the drafting sheet on which the elevations will be drawn. Vertical projections determine and define the length of exterior walls, any breaks or corners along the wall, windows, roof overhang, doors, and other elements, such as chimney location. Horizontal projections from a wall section locate the height of the doors and windows, the cave line, the bottom of fascia, the top and bottom of the footing, and the top of the roof to the space in which the elevation is to be drawn.

3. Repeat this process until all of the elevations are lightly laid out and final changes are incorporated into the exterior design. Darken the drawing, following the same procedures used in the floor plan: from left to right, top to bottom, until completed. You must remember that all of the portions drawn below the grade line are shown with a dark hidden line, and the grade line is the darkest line on the elevation drawing (disregarding the border lines).

4. Add the dimensions. Show only vertical dimensions to include the following: the bottom of the footing, all of the finished floor lines, finished ceiling lines, finished grade, height of features, chimney height, and freestanding walls. Refer to chapter 3 of this book for additional information on drafting format, conventions, and techniques.

5. Add all notes and pertinent information on exterior materials and finishes, title, scale, window identification marks, and roof pitch. Section symbols (fig. 10-6) may be shown on the elevation to indicate where the sections have been taken (fig. 10-16).

6. Finish up the elevations by adding the material symbols (fig. 10-7). Notice that symbols do not take the place of the material notations; they just supplement them. Go over your elevation checklist for completeness and accuracy of information.

STRUCTURAL DRAWINGS

STRUCTURAL DRAWINGS (sometimes identified with the designating letter *S* on their title blocks) consist of all the drawings that describe the structural members of the building and their relationship to each other. A set of structural drawings includes foundation plans and details, framing plans and details, wall sections, column and beam details, and other plans, sections, details, and schedules necessary to describe the structural components of the building or structure. The general notes in the structural drawings should also include, when applicable, roof, floor, wind, seismic, and other loads, allowable soil pressure or pile bearing capacity, and allowable stresses of all material used in the design.

Foundation Plan

A FOUNDATION PLAN is a top view of the footings or foundation walls, showing their area and their location by distances between center lines and by distances from reference lines or boundary lines. Actually, it is a horizontal section view cut through the walls of the foundation showing beams, girders, piers or columns, and openings, along with dimensions and internal composition.

The foundation plan is used primarily by the building crew who will construct the foundation of the proposed structure. In most SEABEE construction, foundations are built with concrete-masonry units and cast-in-place concrete. Figure 10-18 shows a plan view of a structure as it would look if projected into a horizontal plane that passes through the structure slightly below the level of the top of the foundation wall. The plan shows that the main foundation will consist of 12-in. concrete-masonry unit (CMU) walls measuring 28 ft lengthwise and 22 ft crosswise. In this plan, the CMU walls are identified by the standard symbol for concrete block. Ideally, a specific note should be added to call out the material.

A girder running through the center of the building will be supported at the ends by two 4-by 12-in. concrete pilasters that will butt against the end foundation walls. Intermediate support for the girder will be provided by two 12-by 12-in. concrete piers, each supported on 18- by 18-in. spread footings, 10 in. deep. The dotted lines around the foundation walls indicate that these walls will also rest on spread footings.

You need relative information about the total concept of the structure before you can draw the foundation plan. You must make a careful study of the materials and construction methods used, observe the type of foundation used, and analyze the relative position of the framing and the foundation wall or footing. You must also make reference to all of the applicable wall sections and typical sill details found in your texts and reference materials, such as the Architectural *Graphics Standards* before you start the foundation plan.

In most drafting practices, it is customary to use the ground floor plan to develop the

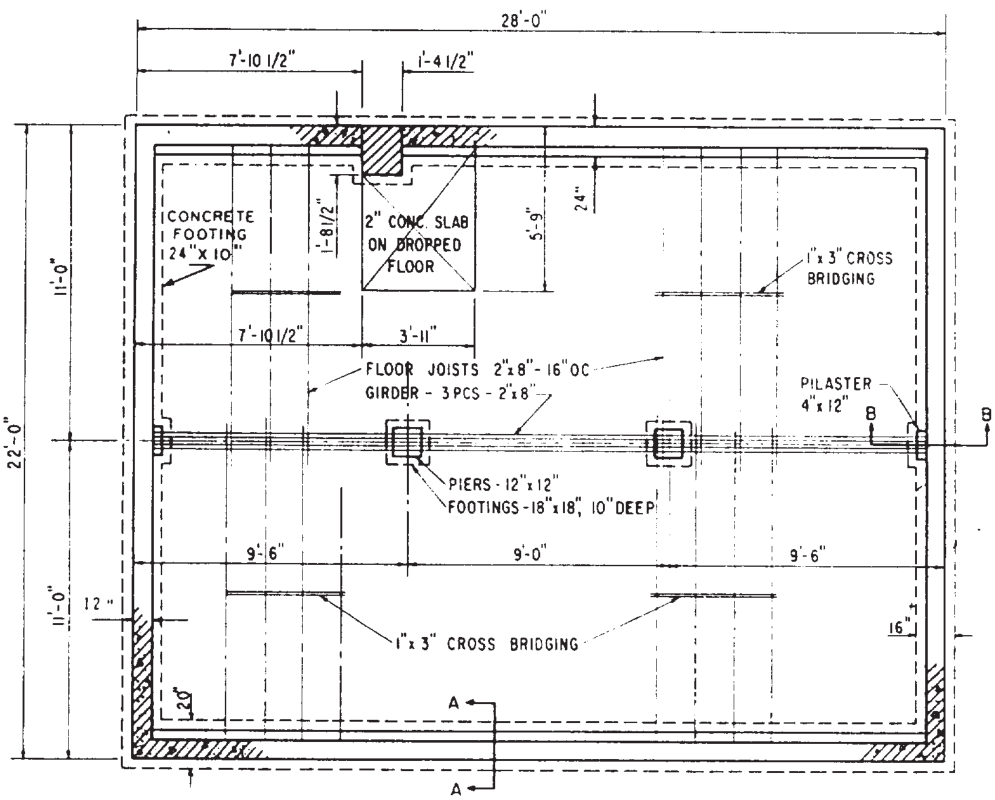


Figure 10-18.-Example of a foundation plan.

foundation plan because the floor plan readily offers the information you need for the foundation plan, such as the general shape of the building, openings, dimensions, and so forth. Some of the basic procedures in the proper development of a foundation plan are outlined below.

1. Prepare and organize your drafting needs. Since the foundation plan is usually drawn at the same scale as the floor plan (1/4 in. = 1 ft), use the same sheet size and layout. A smaller scale (1/8 in. = 1 ft) may be used for the foundation plan when it is necessary to save space and provided that the amount of information given on this plan is limited. From an EA's point of view, drawing the foundation plan at the same scale as the floor plan is easier because you can use the floor plan to trace the outline and other features, thus saving time and effort. Ideally, centering the plan would provide more space for notes and details on footings.

2. Lay out the drafting sheet lightly, beginning with the borders and title block. Tape the original, or preferably a print of the floor plan, under the sheet for the foundation plan if the same scale is being used. Draw the exterior outline of the foundation wall (usually the outside line of the exterior lines of the building), and also locate any retaining walls, steps, porches, and fireplaces. Again, be careful to notice what type of frame construction is used. The extent of using the floor plan in laying out the foundation plan varies among wood-frame, masonry, and steel-frame construction. Study these differences closely. Most often, dimensions are modified on the foundation plan, depending on the materials used. If the foundation is not drawn to the same scale as the floor plan, first determine the size of the foundation plan to be drawn, and lay it out on the sheet. Follow up by transferring all of the dimensions from the floor plan to the foundation plan. Locate other features accurately.

3. Draw the inside wall of the foundation wall once the wall thickness is scaled and the outside foundation line is located. Along the wall, locate other features, such as access doors, vents, and pilasters. Also, draw the foundation for piers, columns, chimney, and retaining wall, if required.

4. Lay out the footings. Check the standards for typical details on different types of footing and the minimum allowable footing size. Now, draw and note any additional structural information required. In wood-frame construction, the structural information for the first-floor construction is commonly shown on the foundation plan. If required, locate and lay in the supporting beam or girder and the size, spacing, and direction of floor joists.

5. Lay out the dimensions. As in all of the EA work, be sure to double-check all of the dimensions to be certain they are correct and complete and that all of the features required are located in the drawing. Apply the principals and correct drafting techniques learned from chapter 3 of this book. Add all of the notes, materials, appropriate plan symbols, and other pertinent information required to complete the plan.

6. Draw in the scale to the plan and the title of the drawing. Go over your foundation-plan checklist, and make sure the entire drawing is darkened in and labeled.

Framing Plan

FRAMING PLANS show the size, number, and location of the structural members (steel or wood) in the building framework. Separate framing plans may be drawn for the floors, the walls, and the roof.

The FLOOR FRAMING PLAN must specify the sizes and spacing of joists, girders, and columns used to support the floor. Detail drawings must be added, if necessary, to show the methods of anchoring joists and girders to the columns and foundation walls or footings.

The floor framing plan is basically a plan view showing the layout of the girders and joists. Figure 10-19 shows the manner of presenting floor framing plans. The unbroken double-line symbol indicates joists. Joist symbols are drawn in the position they will occupy in the completed building. Double framing around openings and beneath bathroom fixtures is shown where used. Bridging is also shown by a double-line symbol that runs perpendicularly to the joist. In the figure, the number of rows of cross bridging is controlled by the span of the joist; the rows should not be placed more than 7 or 8 ft apart. Hence, a 14-ft span may need only one row of bridging, but a 16-ft span needs two rows.

Dimensions need not be given between joists. Such information is given along with notes. For example, "2" by 8" joists @ 2' – 0" O.C." indicates that the joists are to be spaced at intervals of 2 ft 0 in. on center (O.C.). Lengths may not be indicated in framing plans; the overall building dimensions and the dimensions for each bay or distances between columns or posts provide such data. Notes also identify floor openings, bridging, and girts or plates.

The WALL FRAMING PLANS show the location and method of framing openings and ceiling heights so that studs and posts can be cut.

The ROOF FRAMING PLANS show the construction of the rafters used to span the building and support the roof. The size, spacing, roof slope, and all of the details are also shown in the plan. The roof framing plan is drawn in the same manner as the floor framing plan; rafters are shown in the same manner as joists. Figure 10-20 is an example of a roof framing plan for a wood-frame roof.

In a precast or cast-in-place concrete floor and roof framing, a structural plan should indicate, with symbols, the location of bearing walls, beams, and columns, and the direction and size of steel reinforcing bars, the direction of the span, and the size and thickness of required structural members. Figure 10-21 shows an example of a structural roof framing with schedules and general notes included.

When preparing framing plans, follow the procedures outlined below.

1. For wood-frame construction, trace or transfer the dimensions of the location of the exterior stud wall, and lay out the limits of the roof overhang. Next, lay out the roof framing by locating the ridgeboard first and then all of the required intersecting pieces.

2. When the floor framing plans are required, proceed to transfer dimensions of the foundation walls or footings. Lay out supporting girders and joists in their proper spacing. Notice any bearing wails, stairwells, and other openings when you are developing a second-floor framing plan.

3. For concrete framing, take a similar approach. Lay out the dimensions of the bearing walls below the floor (or roof) being framed. Hence, you will need the foundation plan to draw the first-floor framing, and you will need the first-floor plan to draw the second-floor framing. Next, add the locations of the beams and columns and the direction of the span and size of the precast concrete or the reinforcing steel for the poured-in-place concrete.

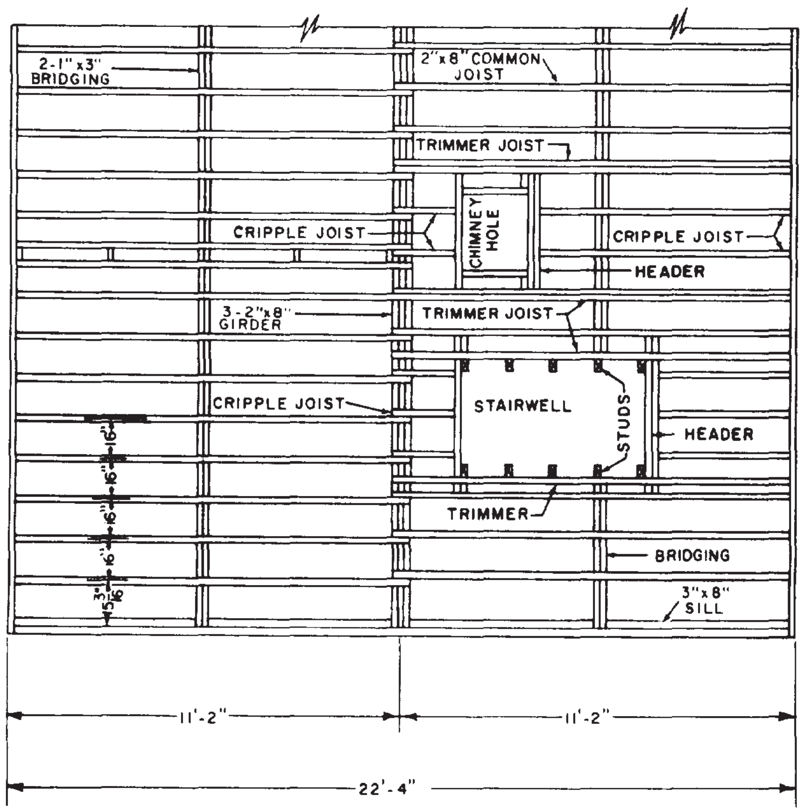


Figure 10-19.-Example of a structural floor framing plan for a wood-frame construction.

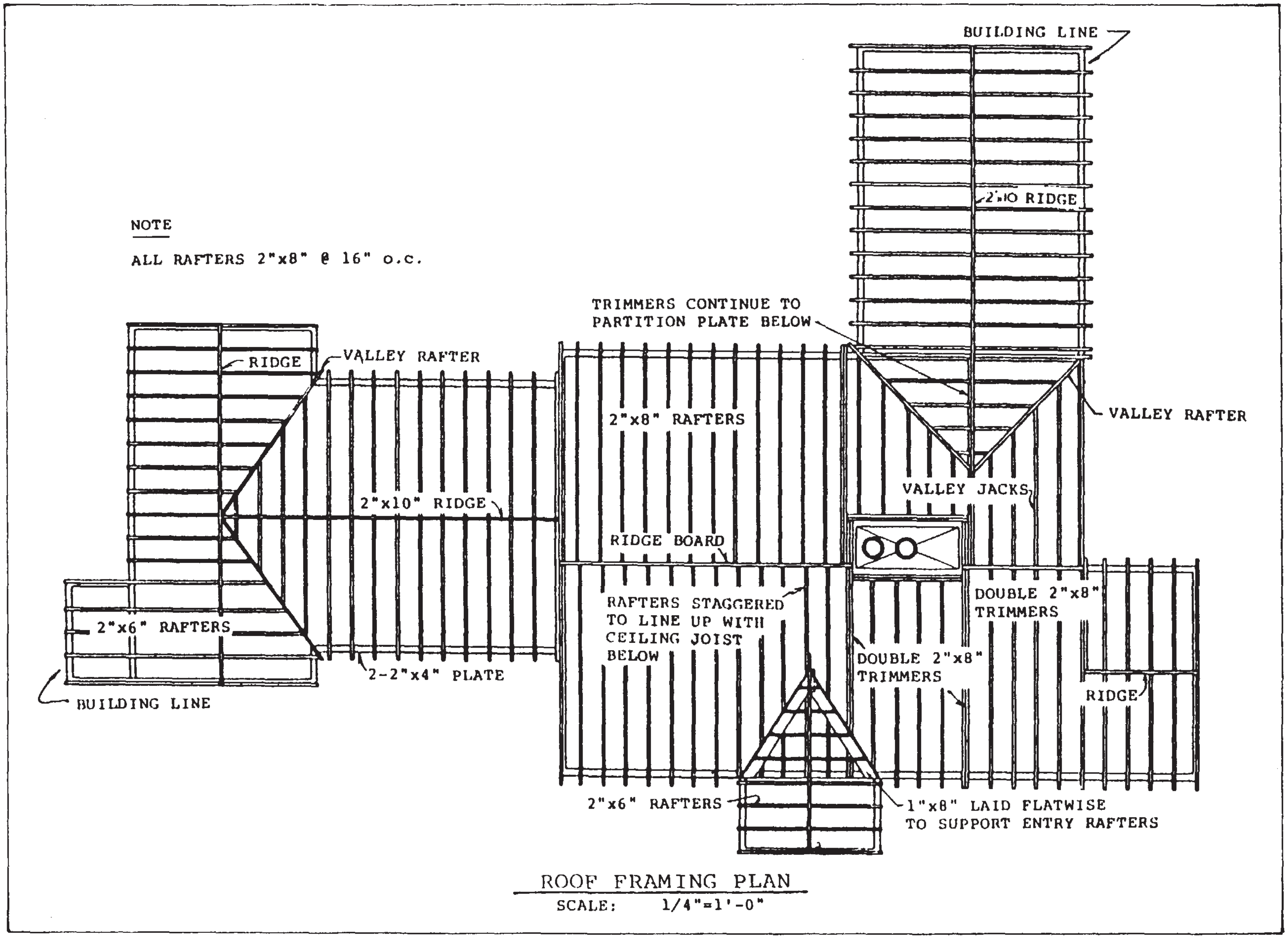


Figure 10-20.—Typical structural roof framing plan for a wood-frame construction.

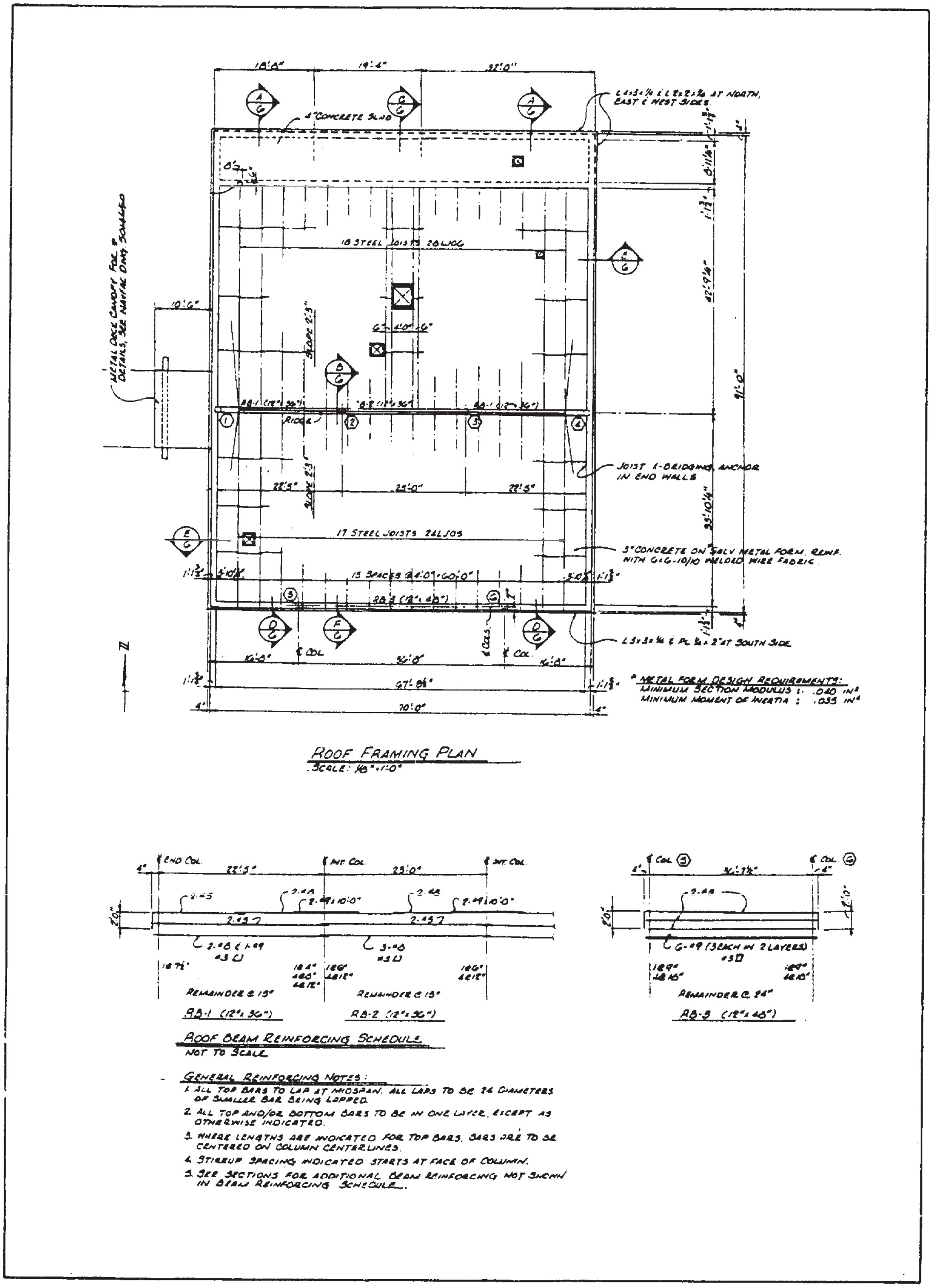


Figure 10-21.-Example of a structural roof framing plan for a precast or a cast-in-place concrete construction.

4. For steel framing, trace off or transfer the dimensions of all of the bearing walls, columns, and beams below the floor (or roof) being framed. Lay out the steel framing, using the grid system (a common setup used in steel framing).

5. Lay out guidelines for dimensions, notes, and labels. Darken in all of the framing and fill in the notes and dimensions. Draw in the section and detail marks. Go over your structural plans checklist and check the dimensions against those traced from the floor plan.

MECHANICAL DRAWINGS

Refer to chapter 8 of this book to review the basic functions of the components associated with the mechanical systems and the methods used in the development of a mechanical plan. This section will focus on the procedures applicable in drawing plumbing plans for residential and commercial buildings.

In some residences and commercial structures, a separate mechanical plan is drawn to show fixtures, water supply and waste disposal lines, equipment, and other supply and disposal sources. In drawing a plumbing plan, the following procedures apply:

1. Trace the floor plan, showing all exterior and interior walls, major appliances, and plumbing fixtures. Orient your drawing so that enough space is left for fixture schedules, legends, details, or other related information. Note that the outline of the building is drawn in thin but visible lines.

2. Draw the water-supply line from the source into the house, and then, one by one, to all of the fixtures. Use the appropriate line thickness and symbols for drawing valves, fittings, and pipe sizes. Next, draw the disposal system. Start the layout with the house or building drain from just outside the building. Also, locate the waste and vent stack at this time.

3. Add a symbol legend, drawing title, notes, and scales, and fill in the title block. Go over and double-check the dimensions and the checklist.

As you can readily tell from figure 8-27 in chapter 8, plumbing plans alone can become extremely difficult to read and fully comprehend. For this reason, it is general practice to prepare and include riser diagrams, such as those shown in chapter 8, figures 8-24 through 8-26. These isometric drawings are much easier to understand and are invaluable to those responsible for preparing material estimates and to the craftsmen (UTs) responsible for installing plumbing systems.

As alluded to in chapter 8, the mechanical division of a set of construction drawings will include, in addition to plumbing plans and details, drawings for any heating, ventilation, and air-conditioning systems that a building might contain. Frequently, the drawing sheets in the mechanical division are identified by the designating letter *M* in the title block. However, remember that in the order of drawings, these sheets containing heating, ventilation, and air-conditioning drawings will precede those for plumbing.

ELECTRICAL DRAWINGS

The electrical systems and plans, as described in chapter 9, consist of the basic functions of the components associated with electrical distribution and interior wiring and the methods used in the development of an electrical plan. This section, however, emphasizes the procedures used in preparing an electrical drawing or plan. It is important for an EA not only to understand the symbols and drafting methods used here, but also to learn a great deal about how the system works, the safety of the system, and the minimum requirements of local and national codes included in the drawing. The drawing sheets in the electrical division of construction drawings are frequently identified by the letter *E* in their title blocks.

In drawing the electrical plan, follow the same approach used in the mechanical drawing, such as using the correct line thickness and proper orientation. To the fullest extent possible, be sure, also, to use the standard electrical symbols discussed previously in the text.

1. After the floor plan is traced, locate the meter and service panel, noting the voltage rating and the amperage. Locate all of the convenience outlets, ceiling and wall fixtures, and other electrical devices required with the appropriate symbols.

2. Locate all of the switches; connect the switches to the fixtures or convenience outlets,

using a template or a french curve. The curved lines may be solid or dashed, and should be included in the symbols list. Add the circuits, the circuit numbers, and the circuit notations.

3. Next, add a symbol legend and a fixture legend (if required). Place the drawing title, note the scale, and fill in the title block. Again, go over your drawing for completeness and accuracy.

SECTIONS

As necessary, SECTIONS are used in each of the main divisions of construction drawings to show the types of construction required, the types of materials used, their locations, and the method of assembling the building parts. Although they may be used in each of the divisions, the most common sections are generally located in the architectural and structural divisions.

All properly prepared sections are important to those responsible for constructing a building. Perhaps the most important of all are WALL SECTIONS, such as those shown in figure 10-22. These sections, commonly drawn at a scale of 3/4 in. = 1 ft, and normally located in the structural division, provide a wealth of information that is necessary to understand the structural

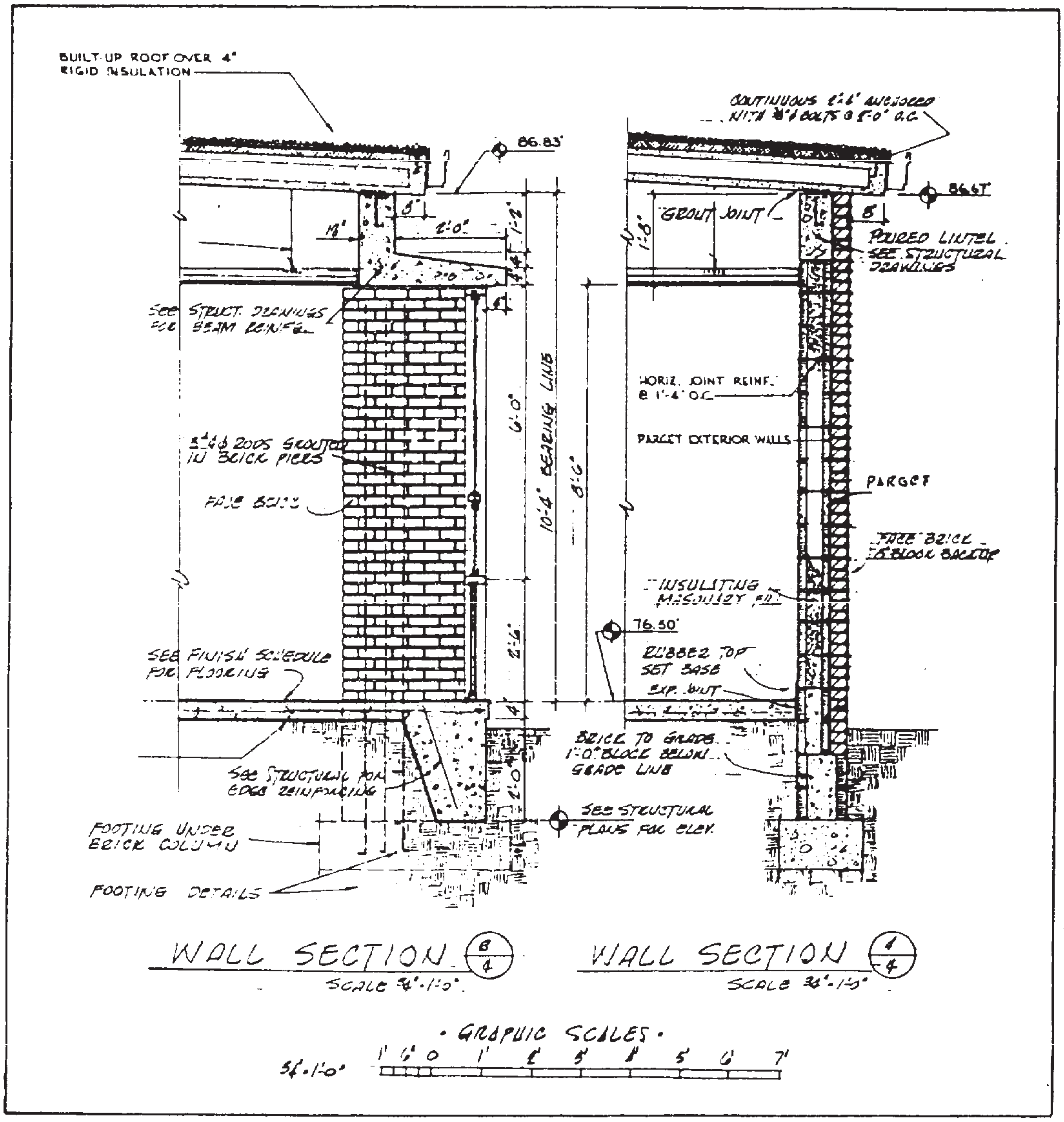


Figure 10-22.-Examples of wall sections.

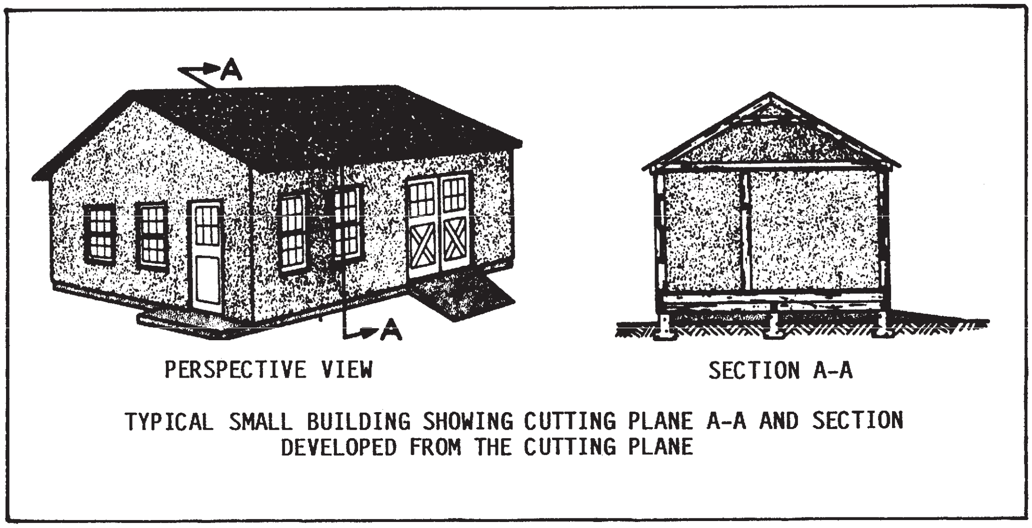


Figure 10-23.—Development of a sectional view.

arrangement, construction methods, and material composition of the walls of the building.

When a cutting plane is passed through the narrow width of a building, as shown in figure 10-23, a TRANSVERSE, or CROSSSECTION, is developed. Similarly, passing the cutting plane through the length of a building results in a LONGITUDINAL SECTION. These section, usually located in the architectural division, are used to clarify the building design and total construction process. Another example of a building section is shown in figure 10-24, view A. Often, transverse and longitudinal sections are drawn at the same scale as the floor plan. To show as much construction information as possible, it is not uncommon for staggered (offset) cutting planes to be used in developing these sections.

If the time and effort were spent to draw a separate section for each and every wall and part of a building, it would soon become apparent that many of these sections are completely identical. To reduce the time and effort required for drafting and to simplify the construction drawings, it is common practice to use typical sections where exact duplications would otherwise occur. An example of a typical section is shown in figure 10-24, view B.

For best results and to save time, you should make a sketch of the section before beginning the actual drawing. Always have your sketch checked by your leading petty officer or another experienced EA to make sure that your work is compatible with their concept of the design of the building.

When more than one section is placed on the drafting sheet, arrange the sections so that the first one is through the front of the building, the other sections, excluding the last, move progressively through the interior, and the last one is through the back. This way, when the sections are finished, they give the user an orderly construction "tour" through the building. The following procedures will guide you in the development of a section:

1. After having selected the appropriate scale, lay out the first section lightly. Next, lay out all the other sections, allowing enough space between them for notes and dimensions. Align the sections so that the same elevation is maintained and the sections relate to one another, as shown in figure 10-22. Again, maintain enough clearance for subtitles and scale and enough room for your title block.

2. Lay out the guidelines for the material labels, leaders, and vertical dimensions.

3. Darken the section drawings, using a system such as starting at the top of the sheet and working down, then starting at the left and

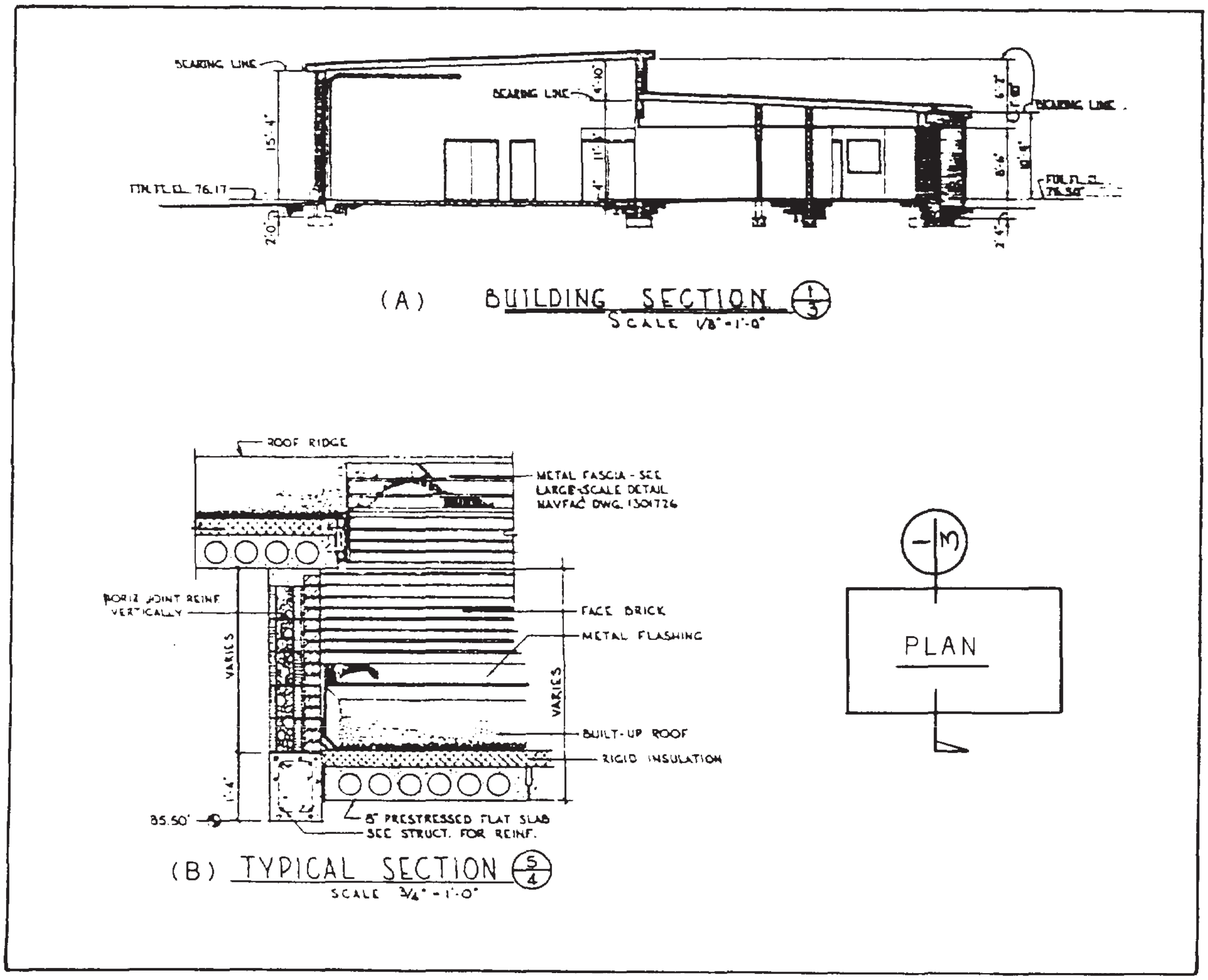


Figure 10-24.-Types of sections.

working to the right until completed. Next, put in all of the labels, notes, and dimensions. You may add detail markings, if any, at this time.

4. Add material symbols. Some EAs prefer to place the symbols at the back of the sheet rather than in the front for neatness and fast access for erasure when a minor change or revision affects them. Place the title and scale below to complete the section drawing. Remember to go over your section checklist for accuracy and completeness.

DETAILS

DETAILS are large-scale drawings of the construction assemblies and installation that were not clearly shown in the sections. These enlarged drawings show the user how the various parts of the structure are to be connected and placed. The construction of specific types of foundations, doors, windows, cornices, and so forth, are customarily shown in detail drawings located within their applicable main division of the construction drawings. Details are usually

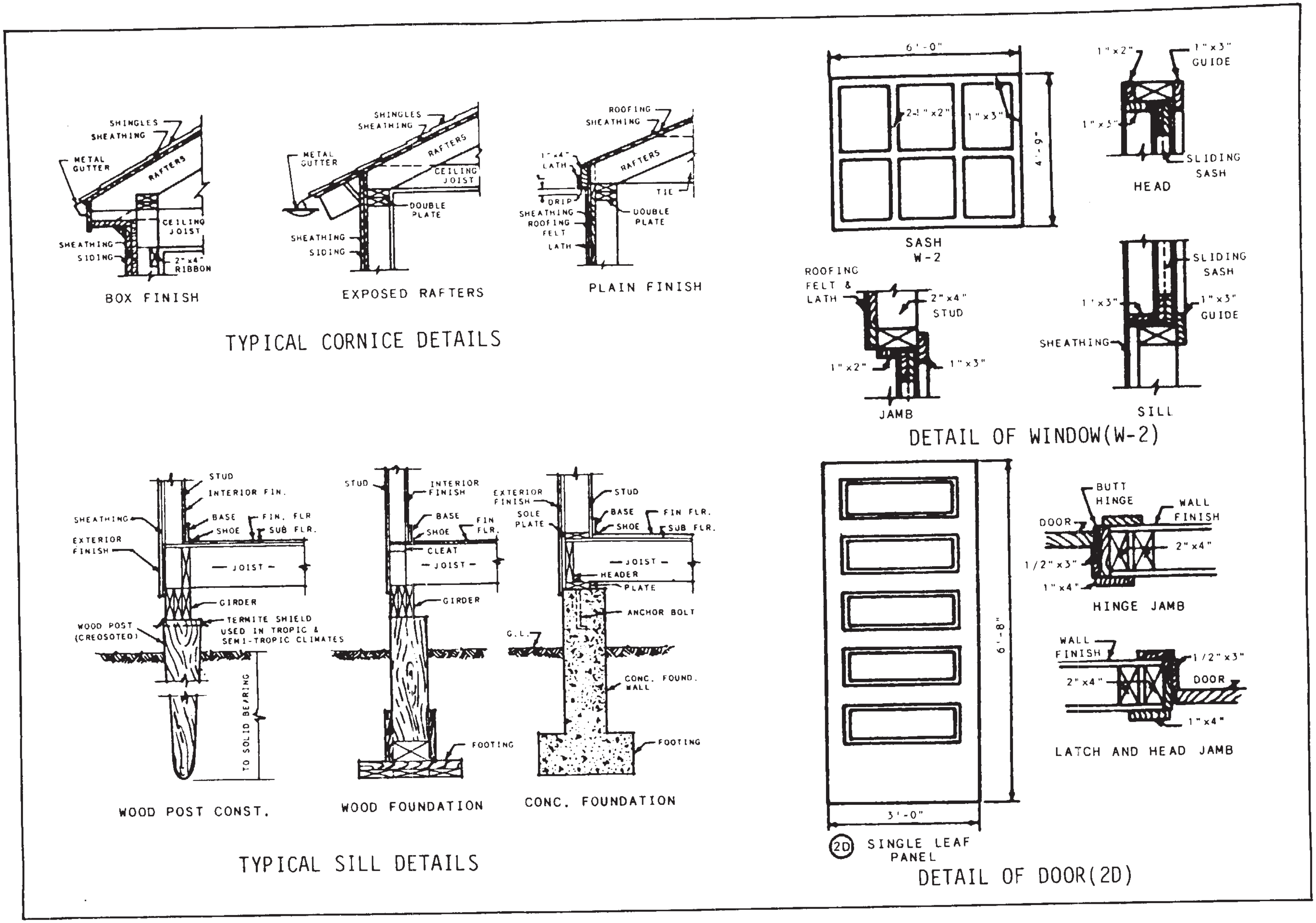


Figure 10-25.—Examples of detail groupings.

grouped (fig. 10-25) so that references may be made more easily from the general drawing.

The scale selected for details depends on how large it needs to be drawn to clearly explain the required information. Details are usually drawn at a larger scale than the sections, generally 1 in., 1 1/2 in., or 3 in. = 1 ft.

Details commonly used for installation of items such as doorframes and window frames, fireproofing, and material connections are readily available in the *Graphic Standards* and Sweet's catalogs. These typical details, however, are to be adapted to the particular building being drawn. You may avoid the use of "typical" details when different conditions actually exist. It is important for an EA to understand construction well enough to make an accurate detail drawing.

Selecting the particular sheet to draw the detail is important. Details that relate to the drawing are placed on that sheet; if space is limited, all other details should be placed with the section or schedules or on a separate sheet set aside for details. Likewise, door details should be placed on the sheet with the floor plans, on the sheet with the door schedule, on a sheet with sections, or on a sheet set aside for details.

The following procedures are given to guide you in the development and drawing of details:

1. Lay out the details on the particular sheet. Draw extension lines, dimensions lines, and guidelines for all of the dimensions lightly.

2. Darken in the details, one at a time, using a system similar to that used in drawing sections. Add labels, notes, and dimensions. Remember to show all of the sizes and thicknesses of materials required.

3. Add material symbols and place title and scale below the detail to complete the drawing.

SCHEDULES

SCHEDULES are tabular or graphic arrangements of extensive information or notes related to construction materials. The use of schedules presents a quick and easy way for planners, estimators, contractors, and suppliers to share similar data, hence reducing construction errors and saving time. In the SEABEEs, the success of the planners and estimators (P&E) in accurately preparing takeoff, of the supply department (S-4) in properly ordering construction materials, and of the construction crew (line companies and detachments) in installing the materials in their proper locations depends greatly upon the efficiency with which the relative information is conveyed on the drawing (plans).

The material information most commonly placed in schedules relates to doors, windows, room finishes, lintels, and other structural elements. The information required on a DOOR SCHEDULE varies from a bare minimum (for small jobs) to extensive (for large projects). A door schedule may include the following: door number, quantity, mark or code number, type, size, material description, lintel, and remarks.

An example of a tabular door schedule is shown in figure 10-26. Doors are commonly

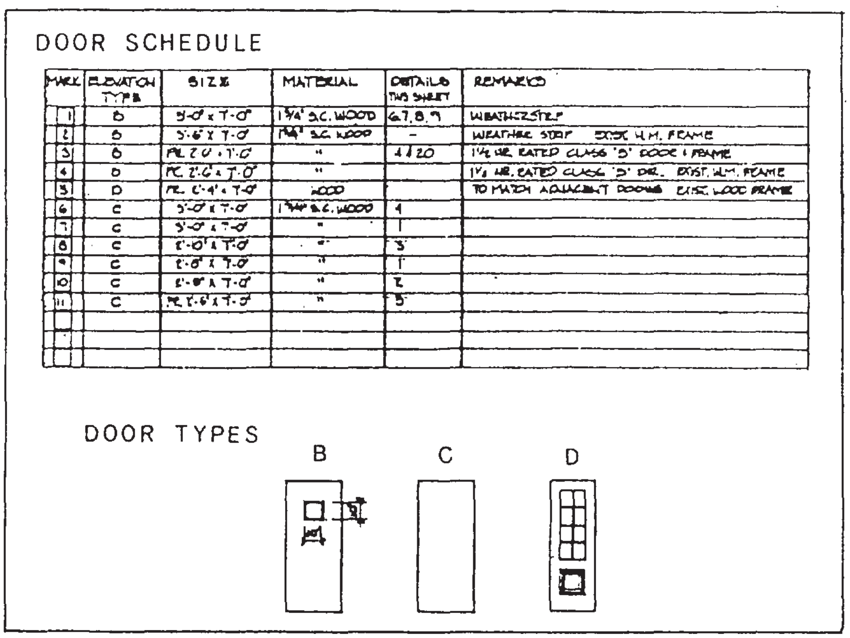


Figure 10-26.-Example of a door schedule.

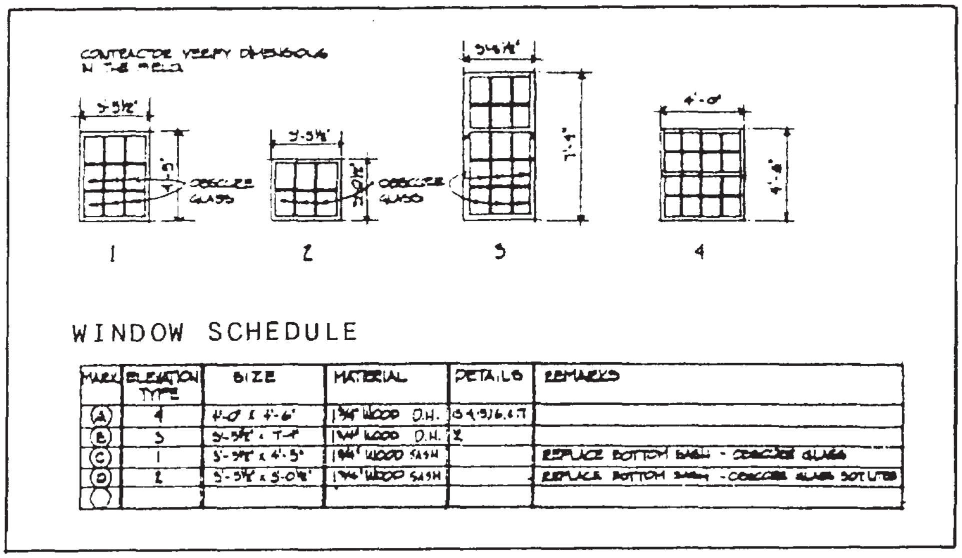


Figure 10-27.-Example of a window schedule.

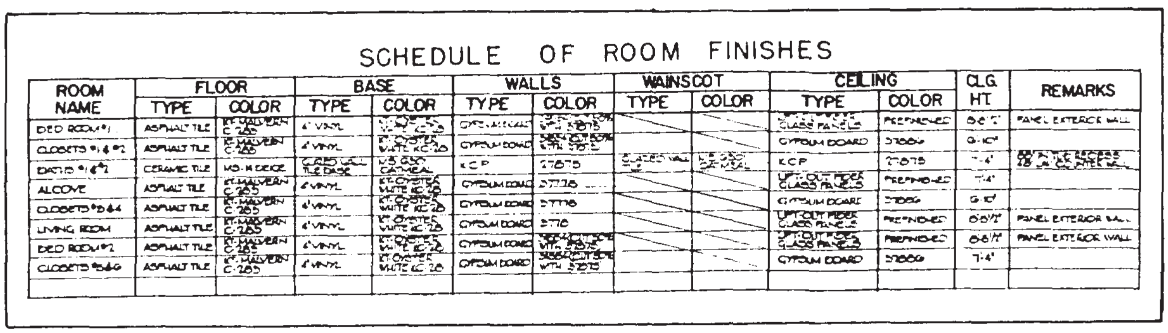


Figure 10-28.-Example of a material finish schedule.

marked with a number or numbers and letters. Letter *D* is a common designation used for doors (sometimes enclosed in a circle or other shape). A WINDOW SCHEDULE (fig. 10-27) provides an organized presentation of the significant window characteristics. Information often includes the following: mark, window type, size, required opening size, material type, lintels, and remarks. Windows are often marked with letters or letters with numbers. Letter *W* is used most commonly for window schedules. A MATERIAL FINISH SCHEDULE (fig. 10-28) may include the following: room number, material finish for floors, walls, base, and remarks. Where several rooms in a row have identical finish, a common practice is to use the ditto mark (´´) or initials DO.

It is essential that you take care when making changes in the material finish used in a particular room, as changes you make will greatly affect other rooms below it. Errors are less likely to occur and revisions will be easier to handle when each space in the schedule is lettered individually. Remember, whenever possible, place all of the schedules on the same sheet as their respective drawings on the building.

BILL OF MATERIALS

A BILL OF MATERIALS (BM) is a tabular statement of material requirements for a given project. It contains information, such as stock numbers, unit of issue, quantity, line item number, description, vendor, and cost. Sometimes the bill of materials will be submitted on material estimate sheets or material takeoff sheets, but all will contain similar information. Actually, a bill of materials is a grouped compilation based on takeoffs and estimates of all of the material needed to complete a structure. The takeoff sheet usually is an actual tally and checkoff of the items shown, noted, or specified on the construction drawings and specifications.

In most cases, each NAVFACENGCOM drawing contains a separate BM; however, sometimes an in-house project prepared by local commands may contain a BM incorporated within the set of drawings. Figure 10-29 shows an example of a completed BM.

BILL OF MATERIAL
11ND-CBC-4013/2 (2-75)
0900-LL-P81-3020

PROJECT: INTERIM WATER SYSTEM REINDEER STATION (CANTONMENT AREA) — SHIP APRIL 19- — BM NO. DIW 112

AUTHORITY — PAGE OF — ACCOUNTING DATA — ROS

ROUT IDENT	M&S	SERV & REQNR	DEMD	SERV & SUPP ADDRESS	SIG	FUND CODE		PROJECT	PRI	RDD	JOB ORDER
P96	2	N62583	N	YIW112	A	TN	W	ZM9	05	094	4K6404

DOC IDENT	FSC	STOCK NUMBER NIIN	UNIT OF ISSUE	QUANTITY	DOCUMENT NUMBER DATE SERIAL	COG	ADV	L/I	CNT FLAG	DESCRIPTION/SPECIFICATION/VENDORS	UNIT COST	TOTAL COST	LOCATION	QTY/DATE RECD	QTY/DATE ISSUED
AOE			SH	69	40817903			1		PLYWOOD, 3/4"X4'X8' BB EXTERIOR TYPE. SUGGESTED VENDOR: THOMPSON LUMBER CO.	12.00	828.00			
			BF	30	7904			2		LUMBER, SOFTWOOD, 1"X6"X12' STANDARD CONSTRUCTION GRADE 2 OR BETTER. SUGGESTED VENDOR: THOMPSON LUMBER CO.	.18	5.40			
			BF	2422	7905			3		LUMBER, SOFTWOOD. 2"X4"X16' STANDARD CONSTRUCTION GRADE 2 OR BETTER. SUGGESTED VENDOR: THOMPSON LUMBER CO.	.28	678.16			
			BF	144	7906			4		LUMBER, SOFTWOOD, 2"X6"X16' STANDARD CONSTRUCTION GRADE 2 OR BETTER. SUGGESTED VENDOR: THOMPSON LUMBER CO.	.28	40.32			
			BF	1173	7907			5		LUMBER, SOFTWOOD, 4"X 4"X 16' STANDARD CONSTRUCTION GRADE 2 OR BETTER. SUGGESTED VENDOR: THOMPSON LUMBER CO.	.33	387.09			

SUBMITTED BY	DATE	APPROVED BY	DATE	TARGET APPROVED BY	DATE	BM TOTAL LINE ITEMS	PAGE TOTAL $	BM TOTAL $
E.B. JASON	20 MAR	T. J. ABERNATHY	3-25-				1938.97	

Figure 10-29.-Example of a bill of materials prepared locally.

CHAPTER 11

ELEMENTS OF SURVEYING AND SURVEYING EQUIPMENT

This chapter provides an overview of surveying in general with emphasis on the principles and procedures of basic surveying and the use of various surveying equipments, instruments, and accessories. As an EA, you should realize that accuracy in surveying is essential because other factors affecting sound decisions in engineering practice are dependent upon the results of your survey.

Surveying is a science that deals with the determination of the relative positions of points on or near the earth's surface. These points may be needed to locate or lay out roads, airfields, and structures of all kinds; they may be needed for cultural, hydrographic, or terrain features for mapping; and, in the military, these points may be targets for artillery and mortar fires. The relative horizontal positions of these points are determined from distances and directions measured in the field, while their vertical positions are computed from the differences in elevations, which are measured directly or indirectly from an established point of reference or datum.

The earliest applications of surveying were for the purpose of establishing the boundaries of land. Although many surveyors are still preoccupied with establishing or subdividing boundaries of landed properties, the purposes of surveys have branched out to many areas that parallel the advancement of various engineering fields and other areas of civilization. Surveyors may be called upon in court to substantiate definite locations of various objects, such as those involving major traffic accidents, maritime disasters, or even murder cases, in which direction and distance have a bearing.

Surveying continues to play an extremely important role in many branches of engineering. The results of today's surveys are being used to map the earth above and below; for navigational charts for use in the air, on land, and at sea; and for other major survey operations for related tasks in geology, forestry, archeology, and landscape architecture. As a surveyor in the Naval Construction Force, you will be required to submit survey results before, during, and after planning and construction of advanced base structures, bridges, roads, drainage works, pipelines, and other types of conventional ground systems. In addition, an EA assigned to an oceanographic unit may be involved in hydrography to a great extent, establishing an offshore triangulation network, depth sounding, and mapping.

Again, though these surveys are for various purposes, still the basic operations are the same—they involve measurements and computations or, basically, fieldwork and office work.

CLASSIFICATION OF SURVEYING

Generally, surveying is divided into two major categories: plane and geodetic surveying.

PLANE SURVEYING

PLANE SURVEYING is a process of surveying in which the portion of the earth being surveyed is considered a plane. The term is used to designate survey work in which the distances or areas involved are small enough that the curvature of the earth can be disregarded without significant error. In general, the term *plane surveying* is applied to surveys of land areas and boundaries (land surveying) in which the areas are of limited extent. For small areas, precise results may be obtained with plane surveying methods, but the accuracy and precision of such results will decrease as the area surveyed increases in size. To make computations in plane surveying, you will use formulas of plane trigonometry, algebra, and analytical geometry.

A great number of surveys are of the plane surveying type. Surveys for the location and construction of highways and roads, canals, landing fields, and railroads are classified under plane surveying. When it is realized that an arc of 10 mi is only 0.04 greater that its subtended chord; that a plane surface tangent to the spherical arc has departed only about 8 in. at 1 mi from the point of tangency; and that the sum of the angles of a spherical triangle is only 1 sec greater than the sum of the angles of a plane triangle for a triangle having an area of approximately 75 sq mi on the earth's surface, it is just reasonable that the errors caused by the earth's curvature be considered only in precise surveys of large areas.

In this training manual, we will discuss primarily the methods used in plane surveying rather than those used in geodetic surveying.

GEODETIC SURVEYING

GEODETIC SURVEYING is a process of surveying in which the shape and size of the earth are considered. This type of survey is suited for large areas and long lines and is used to find the precise location of basic points needed for establishing control for other surveys. In geodetic surveys, the stations are normally long distances apart, and more precise instruments and surveying methods are required for this type of surveying than for plane surveying.

The shape of the earth is thought of as a spheroid, although in a technical sense, it is not really a spheroid. In 1924, the convention of the International Geodetic and Geophysical Union adopted 41,852,960 ft as the diameter of the earth at the equator and 41,711,940 ft as the diameter at its polar axis. The equatorial diameter was computed on the assumption that the flattening of the earth caused by gravitational attraction is exactly 1/297. Therefore, distances measured on or near the surface of the earth are not along straight lines or planes, but on a curved surface. Hence, in the computation of distances in geodetic surveys, allowances are made for the earth's minor and major diameters from which a spheroid of reference is developed. The position of each geodetic station is related to this spheroid. The positions are expressed as latitudes (angles north or south of the Equator) and longitudes (angles east or west of a prime meridian) or as northings and castings on a rectangular grid.

The methods used in geodetic surveying are beyond the scope of this training manual.

TYPES OF SURVEYS

Generally, surveys can be classified by names descriptive of their functions. Functionally, surveys are classed as construction, topographic, route, and special. Special surveys, such as photogrammetry, hydrography, and property surveys, are conducted either with special equipment or for a special purpose. Some of the types of surveys that you may perform as an EA are discussed in the following paragraphs.

CONSTRUCTION SURVEYS

CONSTRUCTION SURVEYS (sometimes called engineering surveys) are conducted to obtain data essential for planning, estimating, locating, and layout for the various phases of construction activities or projects. This type of survey includes reconnaissance, preliminary, location, and layout surveys.

The objectives of engineering or construction surveying include the following:

1. The obtaining of reconnaissance information and preliminary data required by engineers for selecting suitable routes and sites and for preparing structural designs
2. The defining of selected locations by establishing a system of reference points
3. The guidance of construction forces by setting stakes or otherwise marking lines, grades, and principal points and by giving technical assistance
4. The measuring of construction items in place for the purpose of preparing progress reports
5. The dimensioning of structures for preparation of as-built plans

All of the above objectives are called engineering surveys by the American Society of Civil Engineers (ASCE), and the term *construction surveys* is applied to the last three objectives only, The Army Corps of Engineers, on the other hand, generally applies the term *construction surveying* to all of the objectives listed above.

Engineering and/or construction surveys, then, form part of a series of activities leading to the construction of a man-made structure. The term *structure* is usually confined to something that is built of structural members, such as a building or a bridge. It is used here in a broader sense, however, to include all man-made features, such as graded areas; sewer, power, and water lines; roads and highways; and waterfront structures.

Construction surveys normally cover areas considered small enough to use the plane surveying methods and techniques.

TOPOGRAPHIC SURVEYS

The purpose of a TOPOGRAPHIC SURVEY is to gather survey data about the natural and man-made features of the land, as well as its elevations. From this information a three-dimensional map may be prepared. You may prepare the topographic map in the office after collecting the field data or prepare it right away in the field by plane table. The work usually consists of the following:

1. Establishing horizontal and vertical control that will serve as the framework of the survey
2. Determining enough horizontal location and elevation (usually called side shots) of ground points to provide enough data for plotting when the map is prepared
3. Locating natural and man-made features that may be required by the purpose of the survey
4. Computing distances, angles, and elevations
5. Drawing the topographic map

Topographic surveys are commonly identified with horizontal and/or vertical control of third- and lower-order accuracies.

ROUTE SURVEYS

The term *route survey* refers to surveys necessary for the location and construction of lines of transportation or communication that continue across country for some distance, such as highways, railroads, open-conduit systems, pipelines, and power lines. Generally, the preliminary survey for this work takes the form of a topographic survey. In the final stage, the work may consist of the following:

1. Locating the center line, usually marked by stakes at 100-ft intervals called stations
2. Determining elevations along and across the center line for plotting profile and cross sections
3. Plotting the profile and cross sections and fixing the grades
4. Computing the volumes of earthwork and preparing a mass diagram
5. Staking out the extremities for cuts and fills
6. Determining drainage areas to be used in the design of ditches and culverts
7. Laying out structures, such as bridges and culverts
8. Locating right-of-way boundaries, as well as staking out fence lines, if necessary

SPECIAL SURVEYS

As mentioned earlier in this chapter, SPECIAL SURVEYS are conducted for a specific purpose and with a special type of surveying equipment and methods. A brief discussion of some of the special surveys familiar to you follows.

Land Surveys

LAND SURVEYS (sometimes called cadastral or property surveys) are conducted to establish the exact location, boundaries, or subdivision of a tract of land in any specified area. This type of survey requires professional registration in all states. Presently, land surveys generally consist of the following chores:

1. Establishing markers or monuments to define and thereby preserve the boundaries of land belonging to a private concern, a corporation, or the government.
2. Relocating markers or monuments legally established by original surveys. This requires examining previous survey records and retracing what was done. When some markers or monuments are missing, they are reestablished following recognized procedures, using whatever information is available.
3. Rerunning old land survey lines to determine their lengths and directions. As a result of the high cost of land, old lines are remeasured to get more precise measurements.
4. Subdividing landed estates into parcels of predetermined sizes and shapes.
5. Calculating areas, distances, and directions and preparing the land map to portray the survey data so that it can be used as a permanent record.
6. Writing a technical description for deeds.

Control Surveys

CONTROL SURVEYS provide "basic control" or horizontal and vertical positions of points to which supplementary surveys are adjusted. These types of surveys (sometimes termed *geodetic surveys)* are conducted to provide geographic positions and plane coordinates of triangulation and traverse stations and the elevations of bench marks. These control points are further used as references for hydrographic surveys of the coastal waters; for topographic control; and for the control of many state, city, and private surveys.

Horizontal and vertical controls generated by land (geodetic) surveys provide coordinated position data for all surveyors. It is therefore necessary that these types of surveys use first-order and second-order accuracies.

Hydrographic Surveys

HYDROGRAPHIC SURVEYS are made to acquire data required to chart and/or map shorelines and bottom depths of streams, rivers, lakes, reservoirs, and other larger bodies of water. This type of survey is also of general importance to navigation and to development of water resources for flood control, irrigation, electrical power, and water supply.

As in other special surveys, several different types of electronic and radio-acoustical instruments are used in hydrographic surveys. These special devices are commonly used in determining water depths and location of objects on the bottom by a method called taking SOUNDINGS. Soundings are taken by measuring the time required for sound to travel downward and be reflected back to a receiver aboard a vessel.

TYPES OF SURVEYING OPERATIONS

The practice of surveying actually boils down to fieldwork and office work. The FIELDWORK consists of taking measurements, collecting engineering data, and testing materials. The OFFICE WORK includes taking care of the computation and drawing the necessary information for the purpose of the survey.

FIELDWORK

FIELDWORK is of primary importance in all types of surveys. To be a skilled surveyor, you must spend a certain amount of time in the field to acquire needed experience. The study of this training manual will enable you to understand the underlying theory of surveying, the instruments and their uses, and the surveying methods. However, a high degree of proficiency in actual surveying, as in other professions, depends largely upon the duration, extent, and variation of your actual experience.

You should develop the habit of STUDYING the problem thoroughly before going into the field, You should know exactly what is to be done; how you will do it; why you prefer a certain approach over other possible solutions; and what instruments and materials you will need to accomplish the project.

It is essential that you develop SPEED and CONSISTENT ACCURACY in all your fieldwork. This means that you will need practice in handling the instruments, taking observations and keeping field notes, and planning systematic moves.

It is important that you also develop the habit of CORRECTNESS. You should not accept any measurement as correct without verification. Verification, as much as possible, should be different from the original method used in measurement. The precision of measurement must be consistent with the accepted standard for a particular purpose of the survey.

Fieldwork also includes adjusting the instruments and caring for field equipment. Do not attempt to adjust any instrument unless you understand the workings or functions of its parts. Adjustment of instruments in the early stages of your career requires close supervision from a senior EA.

Collection of Engineering Data

The collection of ENGINEERING DATA is a part of SEABEE surveying. Engineering data is actually any information that is essential for efficient construction. Most of your fieldwork, such as running a traverse, leveling, and determining cuts and fills, may be classified under this category. However, compiling these field measurements and converting them into a common medium that will be of value to the engineer requires skill that can only be attained through long experience. Although the planning and organization will generally be handled by the engineering officer or by a senior EA, the actual collection of engineering data will generally be delegated to you; hence, it is to your advantage to understand the procedures early in your career. This job may take a combination of fieldwork and office work. If the same quality of the desired information can be found from sources other than actual fieldwork, do not hesitate to use them; if necessary, use spot checks to verify certain points, depending upon the source.

Each project requires the study of a different set of engineering data, so it is up to the engineering officer or the senior EAs to devise a workable method of compilation that will suit each particular project. It is essential that the compiled data be complete in all respects as required by the purpose of the project and that the compilation be completed with sufficient lead time. Generally, a separate folder for each project is maintained and labeled.

Some of the engineering data that may be considered for SEABEE projects are as follows:

- Vicinity maps, topographic maps, or aerial photographs of the site

- Geographic factors, accessibility, real estate, and so forth

- Geographic location: latitude and longitude; control points (both horizontal and vertical)

- Tide information

- Weather and climatic conditions: rainfall, wind velocity (including direction and duration), flood, and perhaps typhoon or hurricane seasons

- Current velocity and discharge of a river or stream and perhaps an estimate of the watershed area

- Types of soils and their natural conditions (samples may be collected for testing)

- Availability of construction materials, such as rocks, gravel, sand, borrow pits, and timber, near the site

- Availability and suitability of local labor and existing facilities, such as sources of power, water, and other utilities

- Other factors affecting construction, military operations, and logistics support

Factors Affecting Fieldwork

The surveyor must constantly be alert to the different conditions encountered in the field. Physical factors, such as TERRAIN AND WEATHER CONDITIONS, affect each field survey in varying degrees. Measurements using telescopes can be stopped by fog or mist. Swamps and flood plains under high water can impede taping surveys. Sights over open water or fields of flat, unbroken terrain create ambiguities in measurements using microwave equipment. The lengths of light-wave distance in measurements are reduced in bright sunlight. Generally, reconnaissance will predetermine the conditions and alert the survey party to the best method to use and the rate of progress to expect.

The STATE OF PERSONNEL TECHNICAL READINESS is another factor affecting fieldwork. As you gain experience in handling various surveying instruments, you can shorten survey time and avoid errors that would require resurvey.

The PURPOSE AND TYPE OF SURVEY are primary factors in determining the accuracy requirements. First-order triangulation, which becomes the basis or "control" of future surveys, is made to high-accuracy standards. At the other extreme, cuts and fills for a highway survey carry accuracy standards of a much lower degree. In some construction surveys, normally inaccessible distances must be computed. The distance is computed by means of trigonometry, using the angles and the one distance that can be measured. The measurements must be made to a high degree of precision to maintain accuracy in the computed distance.

So, then, the purpose of the survey determines the accuracy requirements. The required accuracy, in turn, influences the selection of instruments and procedures. For instance, comparatively rough procedures can be used in measuring for earthmoving, but grade and alignment of a highway have to be much more precise, and they, therefore, require more accurate measurements. Each increase in precision also increases the time required to make the measurement, since greater care and more observations will be taken.

Each survey measurement will be in error to the extent that no measurement is ever exact. The errors are classified as systematic and accidental and are explained in the latter part of this text. Besides errors, survey measurements are subject to mistakes or blunders. These arise from misunderstanding of the problem, poor judgment, confusion on the part of the surveyor, or simply from an oversight. By working out a systematic procedure, the surveyor will often detect a mistake when some operation seems out of place. The procedure will be an advantage in setting up the equipment, in making observations, in recording field notes, and in making computations.

Survey speed is not the result of hurrying; it is the result of saving time through the following factors:

1. The skill of the surveyor in handling the instruments
2. The intelligent planning and preparation of the work

3. The process of making only those measurements that are consistent with the accuracy requirements

Experience is of great value, but in the final analysis, it is the exercise of a good, mature, and competent degree of common sense that makes the difference between a good surveyor and an exceptional surveyor.

Field Survey Parties

The size of a field survey party depends upon the survey requirements, the equipment available, the method of survey, and the number of personnel needed for performing the different functions. Four typical field survey parties commonly used in the SEABEEs are briefly described in this section: a level party, a transit party, a stadia party, and a plane table party.

LEVEL PARTY.— The smallest leveling party consists of two persons: an instrumentman and a rodman. This type of organization requires the instrumentman to act as note keeper. The party may need another recorder and one or more extra rodmen to improve the efficiency of the different leveling operations. The addition of the rodmen eliminates the waiting periods while one person moves from point to point, and the addition of a recorder allows the instrumentman to take readings as soon as the rodmen are in position.

When leveling operations are run along with other control surveys, the leveling party may be organized as part of a combined party with personnel assuming dual duties, as required by the work load and as designated by the party chief.

TRANSIT PARTY.— A transit party consists of at least three people: an instrumentman, a head chainman, and a party chief. The party chief is usually the note keeper and may double as rear chainman, or there may be an additional rear chainman. The instrumentman operates the transit; the head chainman measures the horizontal distances; and the party chief directs the survey and keeps the notes.

STADIA PARTY.— A stadia party should consist of three people: an instrumentman, a note keeper, and a rodman. However, two rodmen should be used if there are long distances between observed points so that one can proceed to a new point, while the other is holding the rod on a point being observed. The note keeper records the data called off by the instrumentman and makes the sketches required.

PLANE TABLE PARTY.— The plane table party consists of three people: a topographer or plane table operator, a rodman, and a computer.

The topographer is the chief of the party who sets up, levels, and orients the plane table; makes the necessary readings for the determination of horizontal distances and elevations; plots the details on the plane table sheet as the work proceeds; and directs the other members of the party.

The rodman carries a stadia rod and holds it vertically at detail points and at critical terrain points in the plotting of the map. An inexperienced rodman must be directed by the topographer to each point at which the rod is to be held. An experienced rodman will expedite the work of the party by selecting the proper rod positions and by returning at times to the plane table to draw in special details that he may have noticed.

The computer reduces stadia readings to horizontal and vertical distances and computes the ground elevation for rod observations. He carries and positions the umbrella to shade the plane table and performs other duties as directed by the topographer. At times, the computer may be used as a second rodman, especially when the terrain is relatively flat and computations are mostly for leveling alone.

Field Notes

Field notes are the only record that is left after the field survey party departs the survey site. If these notes are not clear and complete, the field survey was of little value. It is therefore necessary that your field notes contain a complete record of all of the measurements made during the survey and that they include, where necessary, sketches and narrations to clarify the notes. The following guidelines apply.

LETTERING.— All field notes should be lettered legibly. The lettering should be in freehand, vertical or slanted Gothic style, as illustrated in basic drafting. A fairly hard pencil or a mechanical lead holder with a 3H or 4H lead is recommended. Numerals and decimal points should be legible and should permit only one interpretation.

FORMAT.— Notes must be kept in the regular field notebook and not on scraps of paper for later transcription. Separate surveys should be recorded on separate pages or in different books. The front cover of the field notebook should be marked with the name of the project, its general location, the types of measurements recorded, the designation of the survey unit, and other pertinent information. The inside front cover should contain instructions for the return of the notebook, if lost. The right-hand pages should be reserved as an index of the field notes, a list of party personnel and their duties, a list of the instruments used, dates and reasons for any instrument changes during the course of the survey, and a sketch and description of the project.

Throughout the remainder of the notebook, the beginning and ending of each day's work should be clearly indicated. Where pertinent, the weather, including temperature and wind velocities, should also be recorded. To minimize recording errors, someone other than the recorder should check and initial all data entered in the notebook.

RECORDING.— Field note recording takes three general forms: tabulation, sketches, and descriptions. Two, or even all three, forms may be combined, when necessary, to make a complete record.

In TABULATION, the numerical measurements are recorded in columns according to a prescribed plan. Spaces are also reserved to permit necessary computations.

SKETCHES add much to clarify field notes and should be used liberally when applicable. They may be drawn to an approximate scale, or important details may be exaggerated for clarity. A small ruler or triangle is an aid in making sketches. Measurements should be added directly on the sketch or keyed in some way to the tabular data. An important requirement of a sketch is legibility. See that the sketch is drawn clearly and large enough to be understandable.

Tabulation, with or without added sketches, can also be supplemented with DESCRIPTIONS. The description may be only one or two words to clarify t he recorded measurements. It may also be quite a narration if it is to be used at some future time, possibly years later, to locate a survey monument.

ERASURES ARE NOT PERMITTED IN FIELD NOTEBOOKS. Individual numbers or lines recorded incorrectly are to be lined out and the correct values inserted. Pages that are to be rejected are crossed out neatly and referenced to the substituted pages. THIS PROCEDURE IS MANDATORY since the field notebook is the book of record and is often used as legal evidence.

Standard abbreviations, signs, and symbols are used in field notebooks. If there is any doubt as to their meaning, an explanation must be given in the form of notes or legends.

OFFICE WORK

OFFICE WORK in surveying consists of converting the field measurements into a usable format. The conversion of computed, often mathematical, values may be required immediately to continue the work, or it may be delayed until a series of field measurements is completed. Although these operations are performed in the field during lapses between measurements, they can also be considered office work. Such operations are normally done to save time. Special equipment, such as calculators, conversion tables, and some drafting equipment, are used in most office work.

In office work, converting field measurements (also called reducing) involves the process of computing, adjusting, and applying a standard rule to numerical values.

Computation

In any field survey operation, measurements are derived by the application of some form of mathematical computation. It may be simple addition of several full lengths and a partial tape length to record a total linear distance between two points. It maybe the addition or subtraction of differences in elevation to determine the height of instrument or the elevation during leveling. Then again, it maybe checking of angles to ensure that the allowable error is not exceeded.

Office computing converts these distances, elevations, and angles into a more usable form. The finished measurements may end up as a computed volume of dirt to be moved for a highway cut or fill, an area of land needed for a SEABEE construction project, or a new position of a point from which other measurements can be made.

In general, office computing reduces the field notes to either a tabular or graphic form for a permanent record or for continuation of fieldwork.

Adjustment

Some survey processes are not complete until measurements are within usable limits or until corrections have been applied to these measurements to distribute accumulated errors. Small errors that are not apparent in individual measurements can accumulate to a sizeable amount. Adjusting is the process used to distribute these errors among the many points or stations until the effect on each point has been reduced to the degree that all measurements are within usable limits.

For example, assume that 100 measurements were made to the nearest unit for the accuracy required. This requires estimating the nearest one-half unit during measurement. At the end of the course, an error of + 4 units results. Adjusting this means each measurement is reduced 0.04 unit. Since the measurements were read only to the nearest unit, this adjustment would not be measurable at any point, and the adjusted result would be correct.

SIGNIFICANT FIGURES.— The term *significant figures* refers to those digits in a number that have meaning; that is, whose values are definitely known to be exact.

In a measured quantity, the number of significant figures is determined by the accuracy of the measurement. For example, a roughly measured distance of 193 ft has three significant figures. More carefully measured, the same distance, 192.7 ft, has four significant figures. If measured still more accurately, 192.68 ft has five significant figures.

In surveying, the significant figures should reflect the allowable error or tolerance in the measurements. For example, suppose a measurement of 941.26 units is made with a probable error of ± 0.03 unit. The ± 0.03 casts some doubt on the fifth digit which can vary from 3 to 9, but the fourth digit will still remain 2. We can say that 941.26 has five significant figures; and from the allowable error, we know the fifth digit is doubtful. However, if the probable error were ±0.07, the fourth digit could be affected. The number could vary from 941.19 to 941.33, and the fourth digit could be read 1, 2, or 3. The fifth digit in this measurement is meaningless. The number has only four significant figures and should be written as such.

The number of significant figures in a number ending in one or more zeros is unknown unless more information is given. The zeros may have been added to show the location of the decimal point; for example, 73200 may have three, four, or five significant figures, depending on whether the true value is accurate to 100, 10, or 1 unit(s). If the number is written 73200.0, it indicates accuracy is carried to the tenth of a unit and is considered to have six significant figures.

When decimals are used, the number of significant figures is not always the number of digits. A zero may or may not be significant, depending on its position with respect to the decimal and the digits. As mentioned above, zeros may have been added to show the position of the decimal point. Study the following examples:

0.000047 . . . . two significant figures

0.0100470 . . . . six significant figures

0.1000470 . . . . seven significant figures

2.0100470 . . . . eight significant figures

In long computations, the values are carried out to one more digit than required in the result. The number is rounded off to the required numbers of digits as a final step.

ROUNDING OFF NUMBERS.— Rounding off is the process of dropping one or more digits and replacing them with zeros, if necessary, to indicate the number of significant figures. Numbers used in surveying are rounded off according to the following rules:

1. When the digit to be dropped is less than 5, the number is written without the digit or any others that follow it. (Example: 0.054 becomes 0.05.)

2. When the digit is equal to 5, the nearest EVEN number is substituted for the preceding digit. (Examples: 0.055 becomes 0.06; 0.045 becomes 0.04.)

3. When the digit to be dropped is greater than 5, the preceding digit is increased by one. (Example: 0.047 becomes 0.05.)

4. Dropped digits to the left of the decimal point are replaced by zeros.

5. Dropped digits to the right of the decimal points are never replaced.

EXAMPLES:

2738.649	to five significant figures equals	2738.6
792.850	to four significant figures equals	792.8
792.750	to four significant figures equals	792.8
675823.	to four significant figures equals	675800
675863.	to four significant figures equals	675900
4896.3	to four significant figures equals	4896
4896.7	to four significant figures equals	4897

CHECKING COMPUTATIONS.— Most mathematical problems can be solved by more than one method. To check a set of computations, you should use a method that differs from the original method, if possible. An inverse solution, starting with the computed value and solving for the field data, is one possibility. The planimeter and the protractor are also used for approximate checking. A graphical solution can be used, when feasible, especially if it takes less time than a mathematical or logarithmic solution. Each step that cannot be checked by any other method must be recomputed; and, if possible, another EA should recompute the problem. When an error or mistake is found, the computation should be rechecked before the correction is accepted.

Drafting Used In Surveying

The general concept of drafting and the use of drafting instruments were discussed in chapters 2 through 5. By this time, you should be familiar with the use of various drafting instruments and with the elements of mechanical drawing. Drafting used in surveying, except for some freehand sketches, is generally performed by mechanical means; for example, the drawing of lines and surveying symbols is generally done with the aid of a straightedge, spline, template, and so on.

The drawings you make that are directly related to surveying will consist of maps, profiles, cross sections, mass diagrams, and, to some extent, other graphical calculations. Their usefulness depends upon how accurately you plot the points and lines representing the field measurements. It is important that you adhere to the requirements of standard drawing practices. Correctness, neatness, legibility, and well-proportioned drawing arrangement are signs of professionalism.

In drawing a PROPERTY map, for example, the following general information must be included:

1. The length of each line, either indicated on the line itself or in a tabulated form, with the distances keyed to the line designation.
2. The bearing of each line or the angles between lines.
3. The location of the mapped area as referenced to an established coordinate system.
4. The location and kind of each established monument indicating distances from reference marks.
5. The name of each road, stream, landmark, and so on.
6. The names of all property owners, including those whose lots are adjacent to the mapped area.
7. The direction of the true or magnetic meridian, or both.
8. A graphical scale showing the corresponding numerical equivalent.
9. A legend to the symbols shown on the map, if those shown are not standard signs.
10. A title block that distinctly identifies the tract mapped or the owner's name. (It is required to contain the name of the surveyor, the name of the draftsman, and the date of the survey.)

Besides the above information, there are some other items that may be required if the map is to become a public record. When this is the case, consult the local office of the Bureau of Land Management or the local surveyors' society for the correct general information requirements to be included in the map to be drawn.

In drawing maps that will be used as a basis for studies, such as those to be used in roads, structures, or waterfront construction, you are required to include the following general information:

1. Information that will graphically represent the features in the plan, such as streams, lakes, boundaries, roads, fences, and condition and culture of the land.
2. The relief or contour of the land.
3. The graphical scale.
4. The direction of the meridian.
5. The legend to symbols used, if they are not conventional signs.
6. A standard title block with a neat and appropriate title that states the kind or purpose of the map. Again, the surveyor's name and that

of the draftsman, as well as the date of survey, are to be included in the title block.

Maps developed as a basis for studies are so varied in purpose that the above information may be adequate for some but inadequate for others. The Engineering Aid, when in doubt, should consult the senior EA, the engineering officer, or the operations officer as to the information desired in the proposed map. The senior EA or the chief of the field survey party is required to know all these requirements before actual fieldwork is started.

A map with too much information is as bad as a map with too little information on it. It is not surprising to find a map that is so crowded with information and other details that it is hard to comprehend. If this happens, draw the map to a larger scale or reduce the information or details on it. Then, provide separate notes or descriptions for other information that will not fit well and thus will cause the appearance of overcrowding. Studying the features and quality of existing maps developed by NAVFACENGCOM and civilian architects and engineers (A & E) agencies will aid you a great deal in your own map drawing.

Orientation Symbol

Every map you draw has to have an ORIENTATION SYMBOL (sometimes called meridian arrows) on it. The symbol that represents the direction of the meridian is indicated by a needle or feathered arrow pointing north. It must be drawn long enough that it could be transferred accurately to any part of the map. The FULL-HEAD ARROW represents the true meridian; the HALF-HEAD ARROW, the magnetic meridian. If both are drawn, as shown in figure 11-1, the angle between them must be indicated. The general tendency is to draw the symbol in an artistic way; however, the simple design shown in figure 11-1 is adequate for most purposes. If possible, the top of a map must always be oriented north; however, the shape of the mapped area or the most important features of the project may alter this preference.

Kinds of Maps

Maps are classified according to purpose, scale, or type. Maps classified according to purpose include strategic, tactical, and artillery maps; communications, utilities, or soil maps; and maps pertaining to special studies. When maps are classified according to scale, you have large-scale, medium-scale, and small-scale. Some

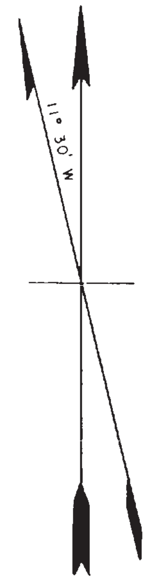


Figure 11-1.-An orientation symbol or meridian arrows.

of the more common types, such as geographic, planimetric, topographic, hydrographic, special-purpose, and photomaps or mosaics, are briefly described in the next several paragraphs.

GEOGRAPHIC MAPS.— A geographic map is a map of a large area, such as that of a state or country, that shows the location of towns, counties, cities, rivers or streams, lakes, roads, and principal civil boundaries, such as county and state lines. Maps showing the general location of the works of people, such as the Railroad Map of the United States, the Irrigation Map of Arizona, and the Panama Canal Zone Map, are classified as geographical maps.

PLANIMETRIC MAPS.— These maps show natural or man-made features in a horizontal plane only. Relief in a measurable form is omitted. A few examples of planimetric maps are property, maps for city layout, site plan, communications, route and distance, and isogonic maps of the magnetic variation lines.

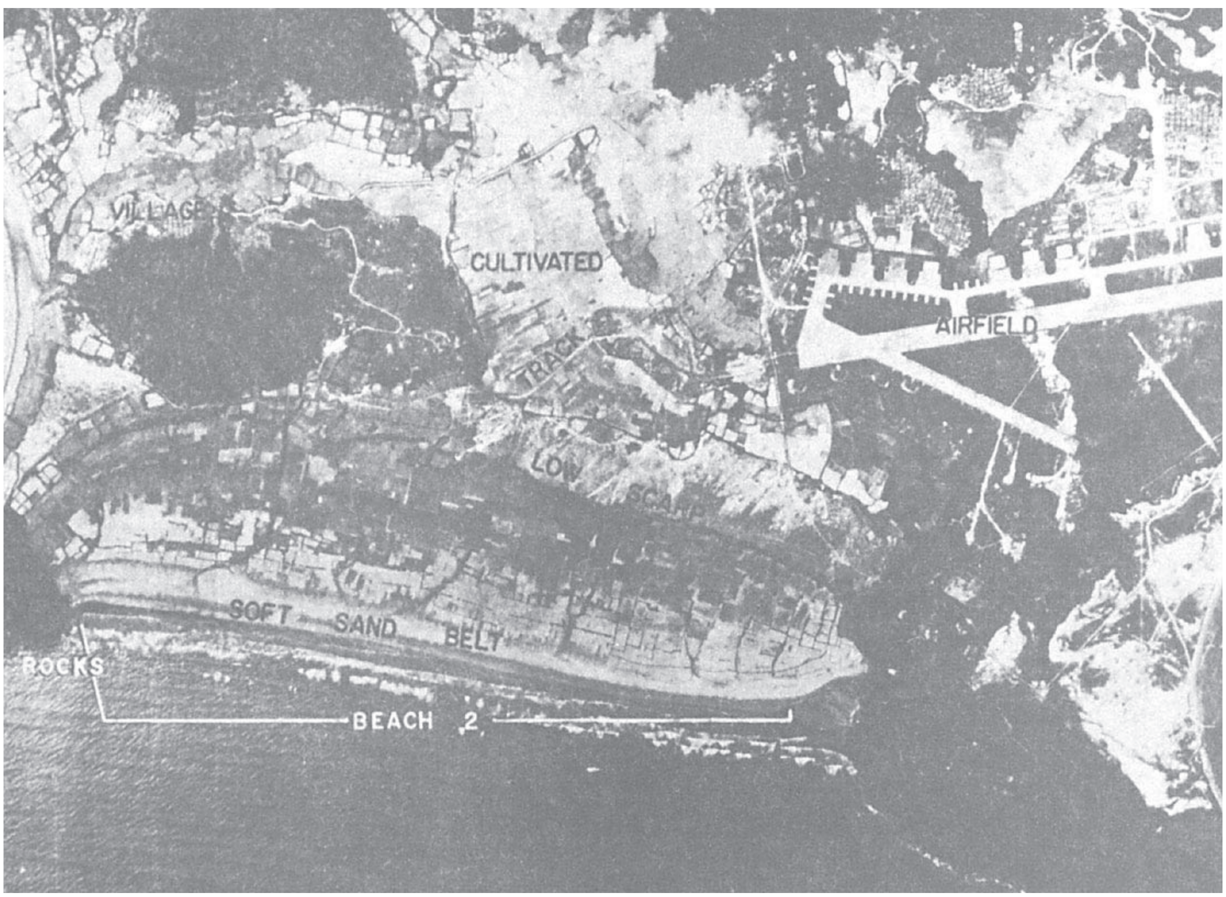
TOPOGRAPHIC MAPS.— Maps that depict the natural and man-made features of the earth's surface in a measurable form, showing both horizontal and vertical positions are called topographical maps. Vertical positions, or relief, are normally represented by contours. A precise topographic map shows surface features so perfectly that it can be used for making an exact three-dimensional model of the area. Such a model is called a RELIEF MAP. Your work in the SEABEEs will generally concern topographic maps for use in construction.

HYDROGRAPHIC MAPS.— A hydrographic map shows the shorelines, the location and depth of soundings, and often the topographic and other features of lands adjacent to the shorelines. It also shows the locations of both horizontal and vertical control in the area.

SPECIAL-PURPOSE MAPS.— These are maps developed for specific purposes. A PRELIMINARY MAP developed from a preliminary survey of a highway, a LOCATION MAP showing the alignment of the located line, and a RIGHT-OF-WAY MAP showing the boundaries of the right-of-way and the adjacent lands all come under the heading of special-purpose maps.

MOSAIC AND OVERLAYS.— The aerial photographic mosaic is constructed from two or more overlapping prints joined so that they form a single picture. Usually, vertical photographs are used and a maplike result is obtained; however, oblique photographs may be used, in which case the result is a panorama. The mosaic has become increasingly useful in cartography and related fields since World War I. Large geographic areas may be represented in this manner with each feature of terrain assuming its natural appearance and approximating its proportionate size. The U.S. Army Topographic Command has a vari-colored map of the entire United States and other countries that was developed from mosaics. The Army calls it a PICTOMAP; this is the type of map that is generally used in a war zone.

Aerial photographs may be converted into line maps by the use of overlays. Usually, these are made by tracing the details from the photograph on transparent paper or vellum and adding such marginal data as desired. This line map may then be reproduced quickly by blueprinting or by lithography. Figure 11-2 shows a vertical aerial



45.735

Figure 11-2.-Example of an aerial photograph.