NONRESIDENT
TRAINING
COURSE

April 1995

Engineering Aid 1

NAVEDTRA 14070

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.

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.

COURSE OVERVIEW: In completing this nonresident training course, you will demonstrate a knowledge of the subject matter by correctly answering questions on the following subjects: Technical Administration; Field Astronomy and Triangulation; Soils: Surveying & Exploration/Classification/Field Identification; Mix Design: Concrete & Asphalt; and Soil Stabilization.

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.

1995 Edition Prepared by
EACS Gary L. Davis

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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 illustrations indicated below are included in this edition of *Engineering Aid: Intermediate and Advanced* through the courtesy of the designated company. Permission to use these illustrations is gratefully acknowledged.

SOURCE	TABLES
American Concrete Institute	17-1 through 17-6

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).

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Answer Sheets: All courses include one "scannable" answer sheet for each assignment. These answer sheets are preprinted with your SSN, name, assignment number, and course number. Explanations for completing the answer sheets are on the answer sheet.

Do not use answer sheet reproductions: Use only the original answer sheets that we provide—reproductions will not work with our scanning equipment and cannot be processed.

Follow the instructions for marking your answers on the answer sheet. Be sure that blocks 1, 2, and 3 are filled in correctly. This information is necessary for your course to be properly processed and for you to receive credit for your work.

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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.

ERRATA

Errata are used to correct minor errors or delete obsolete information in a course. Errata may also be used to provide instructions to the student. If a course has an errata, it will be included as the first page(s) after the front cover. Errata for all courses can be accessed and viewed/downloaded at:

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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.

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DSN: 922-1001, Ext. 1826
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If you are a member of the Naval Reserve, you may earn retirement points for successfully completing this course, if authorized under current directives governing retirement of Naval Reserve personnel. For Naval Reserve retirement, this course is evaluated at 8 points. (Refer to *Administrative Procedures for Naval Reservists on Inactive Duty,* BUPERSINST 1001.39, for more information about retirement points.)

<u>Student Comments</u>

Course Title: *Engineering Aid* 1

NAVEDTRA: 14070 **Date**: ____________

<u>We need some information about you</u>:

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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 information will 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

PART I

EA2 INTERMEDIATE

CHAPTER 1

CONSTRUCTION METHODS AND MATERIALS: HEAVY CONSTRUCTION

As a general rule, the term *heavy construction* refers to the type of construction in which large bulks of materials and extra-heavy structural members are used, such as steel, timber, concrete, or a combination of these materials. In the Naval Construction Force, heavy construction includes the construction of bridges, waterfront structures, and steel flame structures.

The Seabee's construction functions, in support of the Navy's and Marine Corps' operating forces, might include the design and construction of these various structures or their rehabilitation; therefore, you, as an EA, should understand the terminology, the basic principles, and the methodology used in the construction of these facilities. Your knowledge of the methods and materials used in heavy construction will greatly assist you in the preparation of engineering drawings (original, modified, or as-built).

This chapter will discuss basic heavy construction methods and materials.

BRIDGE CONSTRUCTION

A bridge is a structure used to carry traffic over a depression or an obstacle, and it generally consists of two principal parts: the lower part, or **substructure;** and the upper part, or **superstructure.** When a bridge is supported only at its two end supports, or **abutments,** it is called a **single-span bridge.** A bridge that has one or more intermediate supports, such as the one shown in figure 1-1, is known as a **multispan bridge.** Although bridges may be either fixed or floating, only fixed bridges will be discussed in this training manual (TRAMAN). The following is a discussion of the components of a fixed bridge.

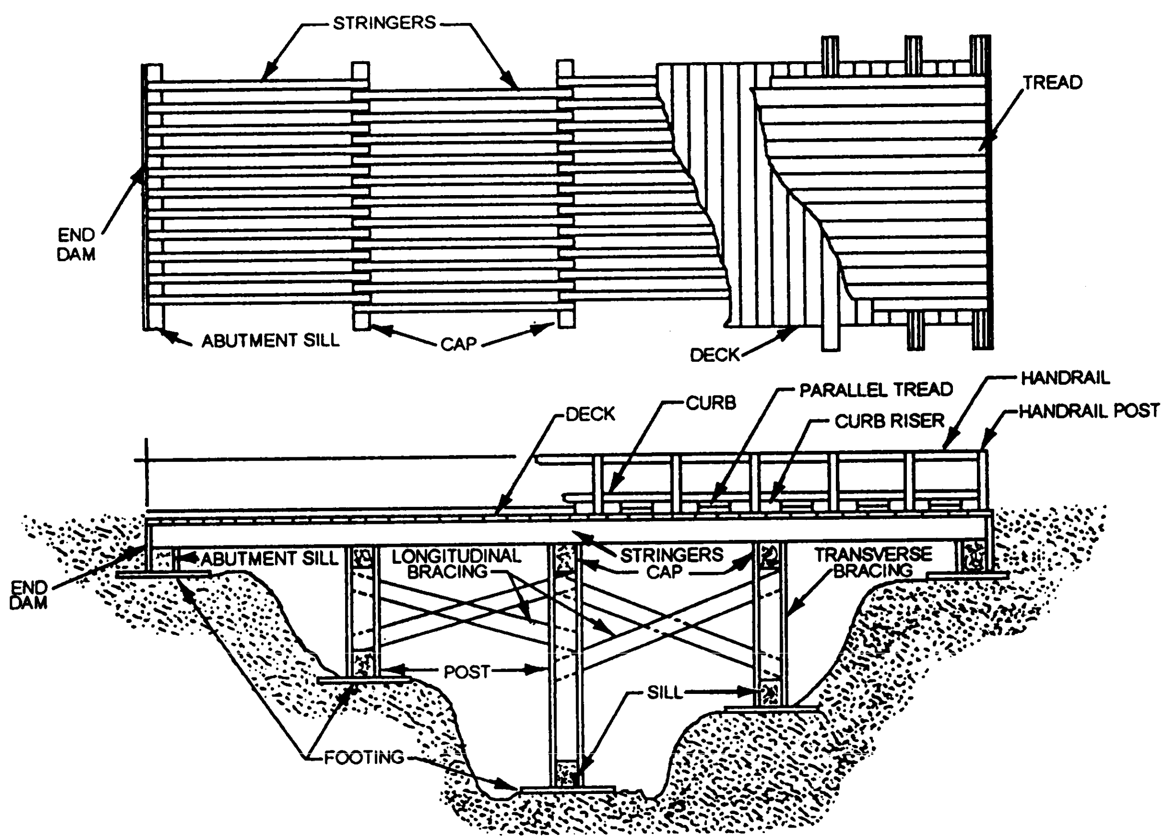


Figure 1-1.—A multispan (trestle-bent) bridge.

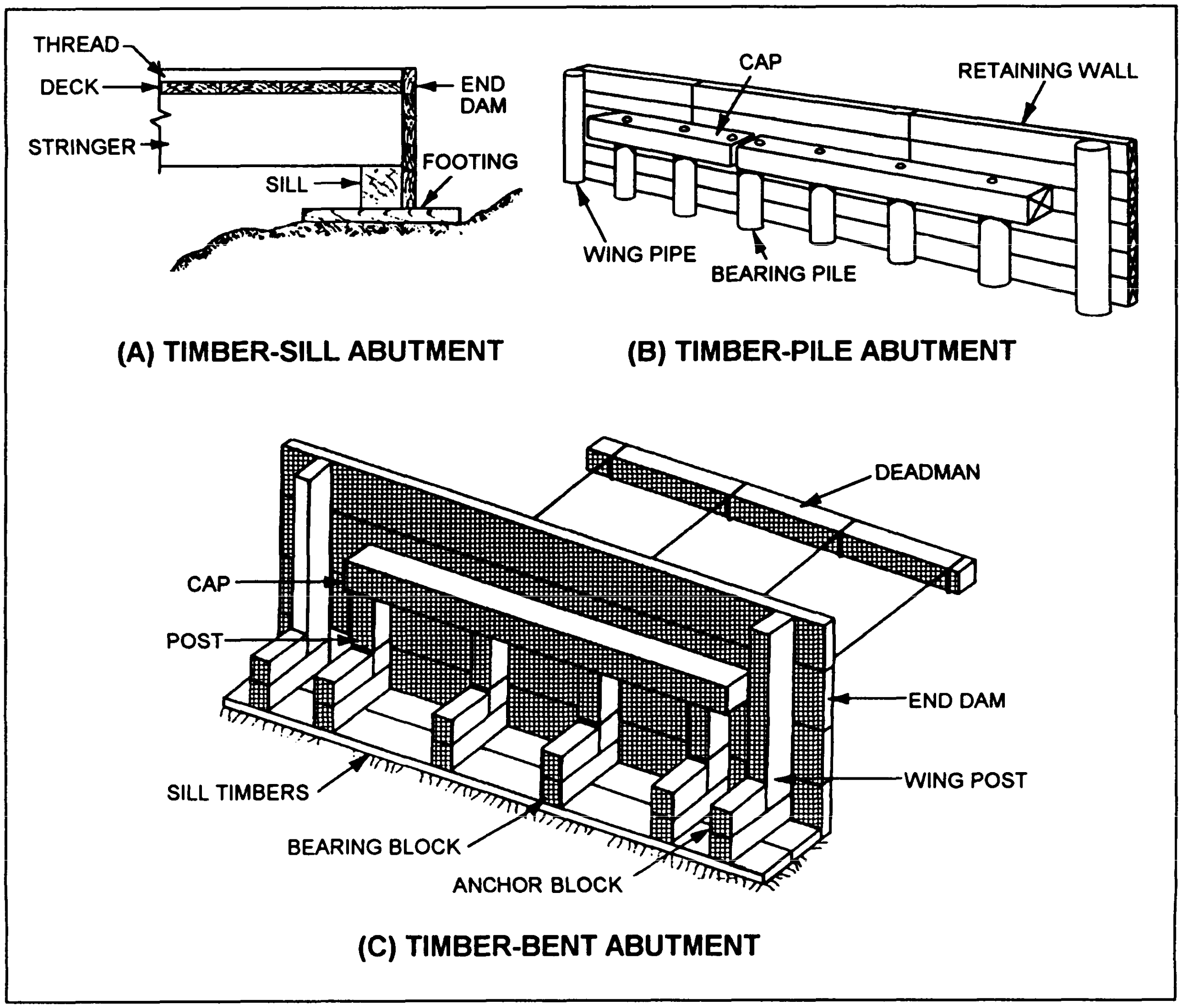


Figure 1-2.—Types of fixed-bridge abutments.

ABUTMENTS

There are different types of fixed bridge abutments. First, let us discuss the **footing-type** abutment. In figure 1-2, views A and C show two types of footing abutments. View A shows a timber-sill abutment, and view C shows a timber-bent abutment. By studying both of these views, you should see that there are three elements that are common to a footing-type abutment. Each type has a footing, a sill, and an end dam.

If you will notice, the timber-sill abutment shown in figure 1-2, view A, is the same footing-type abutment that is shown for the bridge in figure 1-1. In this type of abutment, loads are transmitted from the bridge stringers to the **sill,** which, in turn, distributes the load to the **footing.** The footing then distributes the combined load over a sufficient area to keep the support from sinking into the ground. The **end dam** is a wall of planks that keeps the approach-road backfill from caving in between the stringers. The timber-sill abutment should not be more than 3 feet high. It can be used to support spans up to 25 feet long.

The timber-bent abutment shown in figure 1-2, view C, can be used with timber or steel stringers on bridges with spans up to 30 feet. The **deadman** is used to provide horizontal stability. These abutments do not exceed 6 feet in height.

Other types of fixed-bridge abutments are **pile** abutments and **concrete** abutments. Timber- or steel-pile abutments can support spans of any length, can be used with steel or timber stringers, and can reach a maximum height of 10 feet. A timber-pile abutment is shown in figure 1-2, view B. Concrete abutments are the most permanent type. They may be mass or reinforced concrete, can be used with spans of any length, and can be as high as 20 feet. They may be used with either steel or timber stringers.

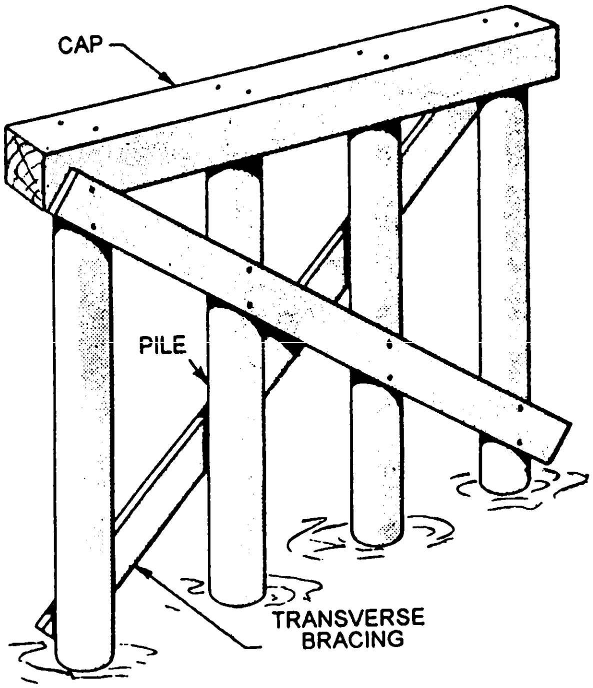


Figure 1-3.—Typical pile bent.

INTERMEDIATE SUPPORTS

Bents and piers provide support for the bridge superstructure at points other than the bank ends. A **bent** consists of a single row of posts or piles, while a **pier** consists of two or more rows of posts or piles. The following text discusses some of the different types of bents and piers.

The pile bent shown in figure 1-3 consists of the bent cap, which provides a bearing surface for the bridge stringers, and the piles, which transmit the load to the soil. The support for the loads may be derived either from column action when the tip of the pile bears on firm stratum, such as rock or hard clay, or from friction between the pile and the soil into which it is driven. In both cases, earth pressure must provide some lateral support, but traverse bracing is often used to brace the bent laterally.

A timber pile bent consists of a single row of piles with a pile cap. It should be braced to the next bent or to an abutment to reduce the unbraced length and to provide stability. This bent will support a combined span length of 50 feet

The trestle bent shown in figure 1-4 is similar to the pile bent except that the posts, taking the place of the piles, transmit the load from the cap to the sill. The sill transmits the load to the footings, and the footings transmit the load to the soil. Timber trestle bents are normally constructed in dry, shallow gaps in which the soil is firm. They are not suitable for use in soft soil or swift or deep streams. The bent can support a combined span length of up to 30 feet and can be 12 feet high.

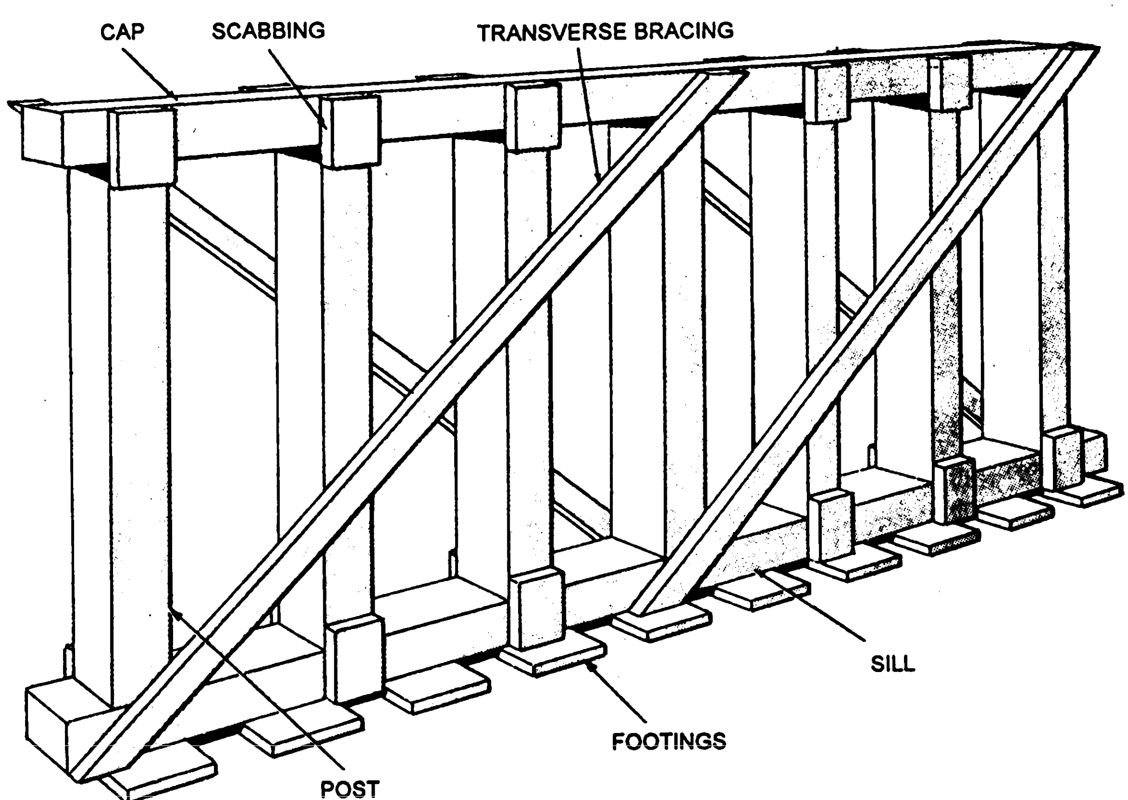


Figure 1-4.—Timber trestle bent.

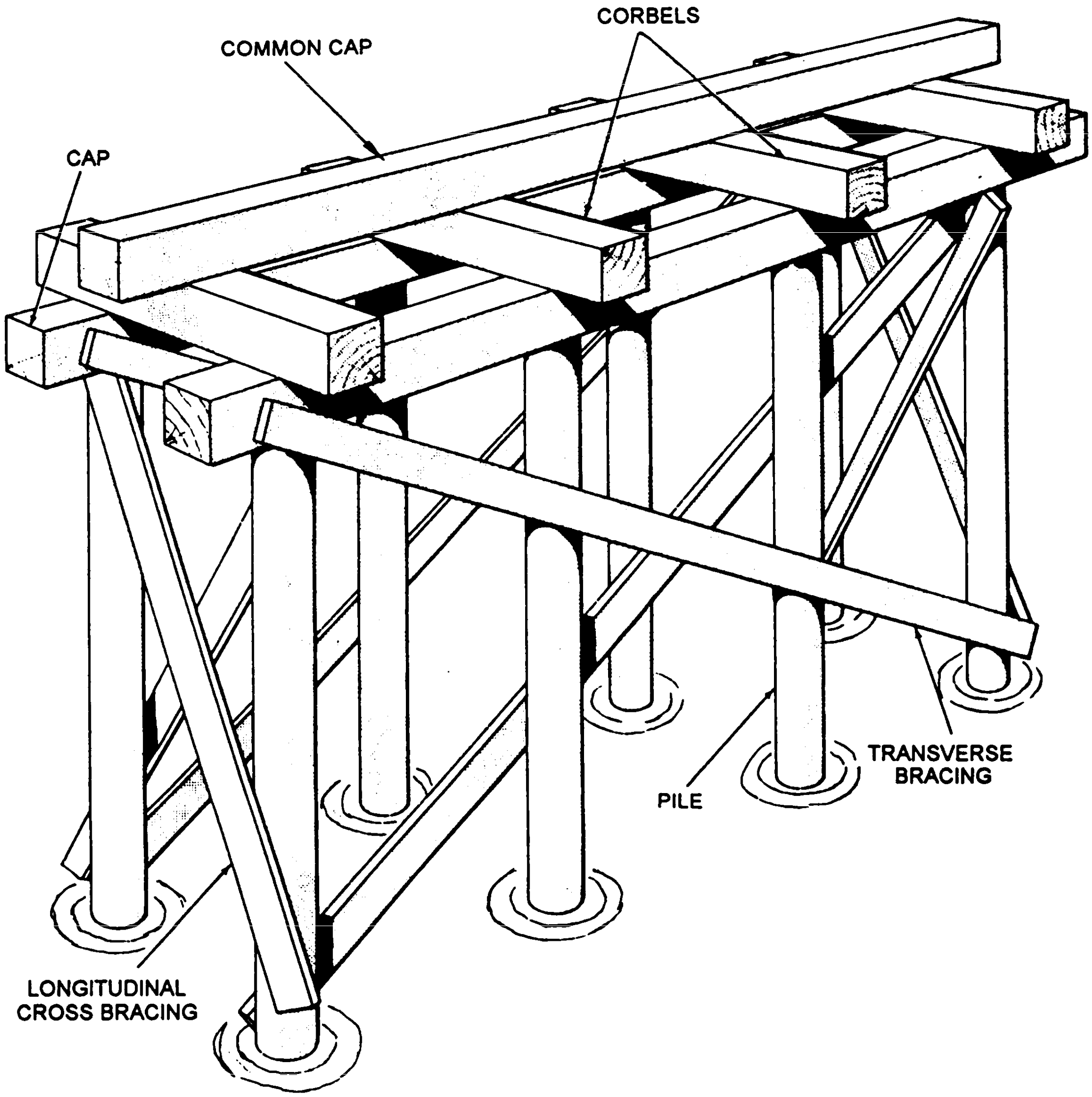


Figure 1-5.—Typical pile pier.

The pile pier (fig. 1-5) is composed of two or more pile bents. In this figure, notice the common cap. The cap transmits the bridge load to the **corbels,** which in turn, transmit the combined load to the individual bent caps. Piers are usually provided with cross bracing that ties the bents together and provides rigidity in the longitudinal direction.

SUPERSTRUCTURE

The superstructure of a bridge consists of the stringers, flooring (decking and treads), curbing, walks, handrails, and other items that form the part of the bridge above the substructure. Figure 1-6 is an illustration of a superstructure.

As seen in the figure, those structural members resting on and spanning the distance between the intermediate supports or abutments are called **stringers.** The stringers are the mainload-carrying members of the superstructure. They receive the load from the flooring and transmit it to the substructure. Although the figure shows both steel and timber stringers, in practice only one type would normally be used.

The flooring system includes the deck; the wearing surface, or tread, that protects the deck; and the curb and handrail system. The plank deck is the simplest to design and construct, and it provides considerable savings in time compared to other types of decks. Plank decking is normally placed perpendicular to the bridge center line (direction of traffic) for ease and speed of construction. A better arrangement, however, is provided if the decking is placed at about a 30- to 60-degree skew to

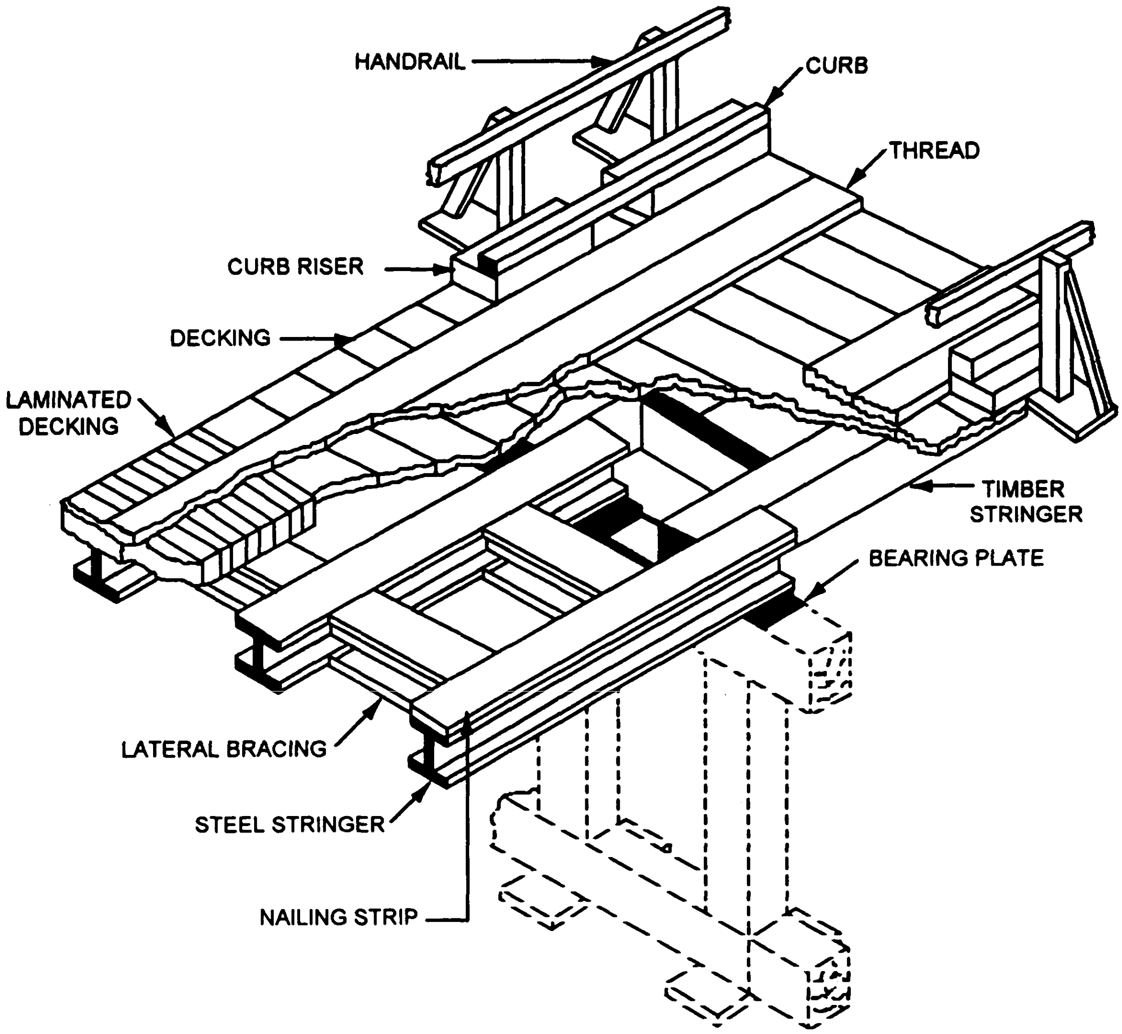


Figure 1-6.—Nomenclature of a fixed highway bridge superstructure.

the center line. A space of approximately one-quarter inch should be provided between the planks to allow for swelling, to provide water drainage, and to permit air circulation. The **minimum** thickness of decking is 3 inches in all cases; however, when the required thickness of plank decking exceeds 6 inches, then a laminated type of decking should be used.

FOUNDATIONS AND PILES

That part of a building or structure located below the surface of the ground is called the **foundation.** Its purpose is to distribute the weight of the building or structure and all live loads over an area of subgrade large enough to prevent settlement and collapse.

A **pile** is a slender structural unit driven into the ground to transmit loads to the underground strata. It transfers loads to the surrounding underground strata by friction along its surface or by direct bearing on the compressed soil at or near the bottom. A **bearing pile** sustains a downward load and may be driven vertically or otherwise; however, when a bearing pile is driven other than vertically, it is known as a **batter pile.** Another type of pile is the sheet pile. It is used to resist lateral soil pressure.

The following discussion is intended to introduce and familiarize you with some of the common types of foundations and piles that you may be required to include in your construction drawings.

FOUNDATIONS

In general, all foundations consist of three essential parts: the **foundation bed,** which consists of the soil or rock upon which the building or structure rests; the **footing,** which is normally widened and rests on the foundation bed; and the **foundation wall,** which rises from the foundation to a location somewhere above the

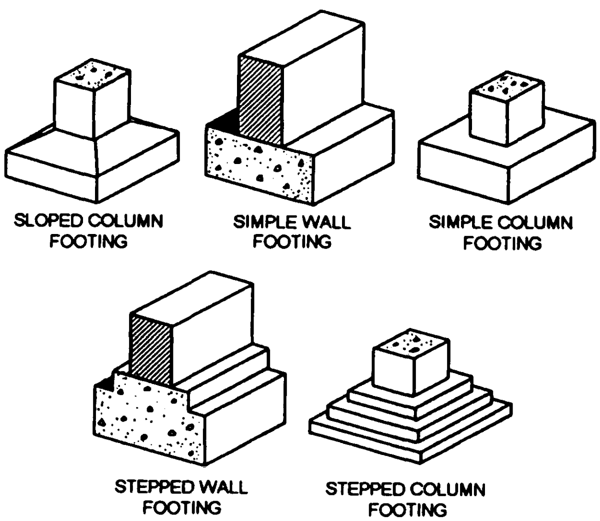


Figure 1-7.—wall and column foundations.

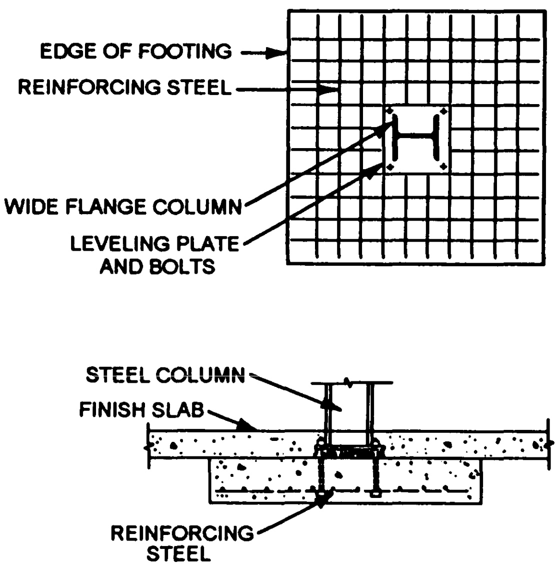


Figure 1-8.—Plan and section of a typical spread footing.

ground. The foundation wall, contrary to its name, may be a column or a pedestal instead of a wall. But, when it is a wall, it forms what is known as a **continuous foundation.** Figure 1-7 shows common types of wall and column foundations.

The continuous foundation is the type of foundation that is most commonly used for small buildings. The size of the footing and the thickness of the foundation wall are specified on the basis of the type of soil at the site. Most building codes also require that the bottom of the footing be horizontal and that any slopes be compensated for by stepping the bottom of the footing.

Another type of foundation is the **grade-beam foundation.** A **grade beam** is a reinforced concrete

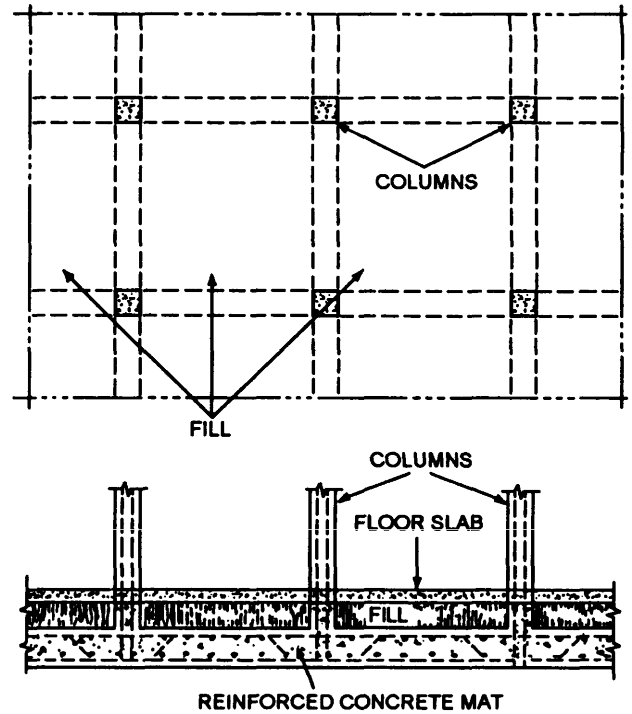


Figure 1-9.—Plan and section of a mat foundation.

beam located at grade level around the entire perimeter of a building, and it is supported by a series of concrete piers extending into undisturbed soil. The building loads are supported by the grade beam, which distributes the load to the piers. The piers then distribute the load to the foundation bed

A **spread foundation,** such as the one shown in figure 1-8, is often required where heavy concentrated loads from columns, girders, or roof trusses are located. This type of foundation may be located under isolated columns or at intervals along a wall where the concentrated loads occur. Spread footings are generally reinforced with steel. They may be flat, stepped, or sloped, such as shown in figure 1-7.

Figure 1-9 shows the plan and section of a typical **mat foundation.** In this type of foundation, a heavily reinforced concrete slab extends under the entire building and distributes the total building load over the entire site. This minimizes problems created by unequal settlement when the subsoil conditions are uneven. The mat foundation is often referred to as a **floating foundation.**

PILE CONSTRUCTION

Piles include many different types and materials. The following text discusses the more common types.

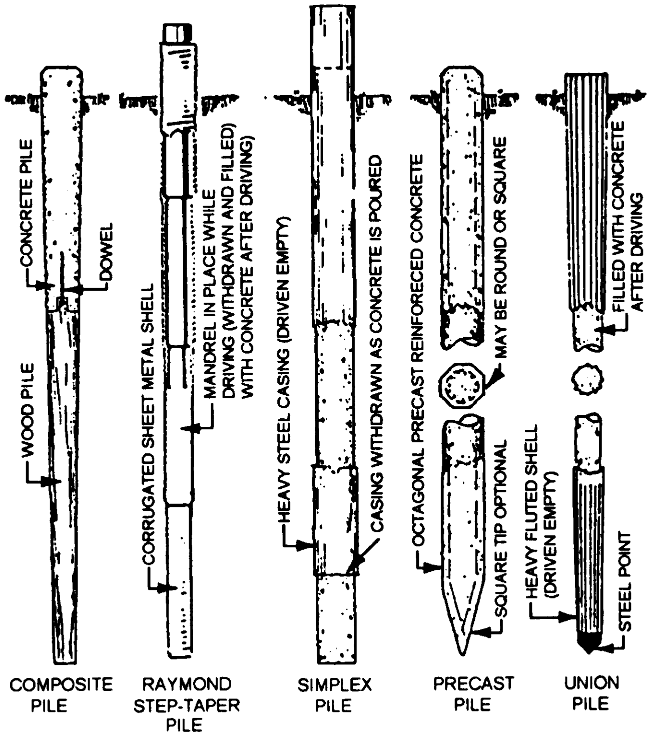


Figure 1-10.—Types of concrete piles.

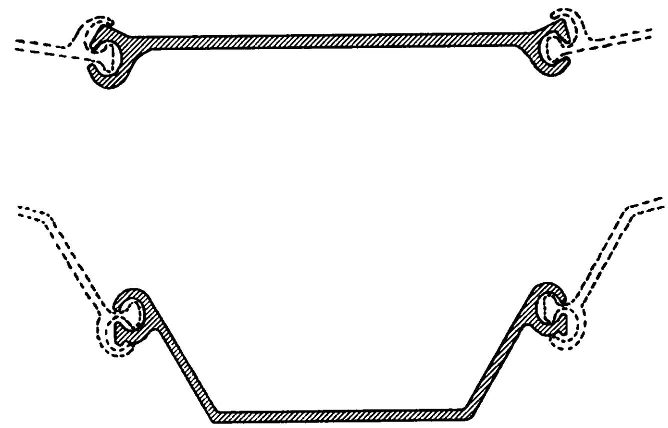


Figure 1-11.—Steel sheetpiling.

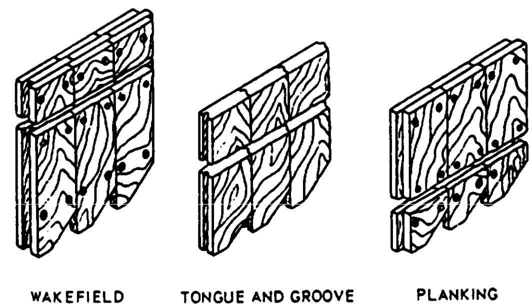


Figure 1-12.—Wood sheet piles.

Bearing Piles

Timber bearing piles are usually straight tree trunks with the limbs and bark removed. These piles, if kept continuously wet, will last for centuries; however, they are used for low design loads because of their vulnerability to damage while they are being driven into the ground. The small end of the pile is called the tip; the larger end is called the butt. Timber piles range from 16 to 90 feet in length with a tip diameter of at least 6 inches. The butt diameter is seldom less than 12 inches.

A steel bearing pile might be an H-pile (having an H-shaped cross section). These piles are usually used for driving to bedrock. A steel pile can also be a pipe pile with a circular cross section. A pipe pile can be either an open-end pile or a closed-end pile, depending on whether the bottom end is open or closed.

Concrete piles, such as those shown in figure 1-10, may be either precast or cast in place. Most precast piles used today are pretensioned and are manufactured in established plants. These piles are made in square, cylindrical, or octagonal shapes. If they are being driven into soft or mucky soil, they are usually tapered. Cast-in-place piles are cast on the jobsite and are classified as shell type or shell-less type. The shell type is formed by driving a hollow steel tube (shell), with a closed end, into the ground and filling it with concrete. The shell-less type is formed by first driving a casing and core to the required depth. The core is removed and the casing is filled with concrete. The casing is then removed, leaving the concrete in contact with the earth.

Sheet Piles

Sheet piles, made of wood, steel, or concrete, are equipped or constructed for edge-joining, so they can be driven edge-to-edge to form a continuous wall or bulkhead. A few common uses of sheet piles are as follows:

1. To resist lateral soil pressure as part of a temporary or permanent structure, such as a retaining wall

2. To construct cofferdams or structures built to exclude water from a construction area

3. To prevent slides and cave-ins in trenches or other excavations

The edges of steel sheetpiling are called **interlocks** (fig. 1-11) because they are shaped for locking the piles together edge-to-edge. The part of the pile between the interlocks is called the **web.**

A wood sheet pile might consist of a single, double, or triple layer of planks, as shown in figure 1-12. Concrete sheet piles are cast with tongue-and-groove edges for edge-joining.

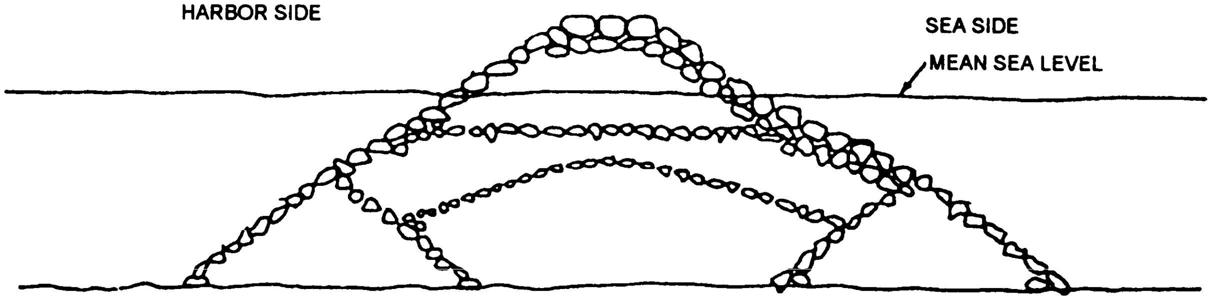


Figure 1-13.—Rubble-mound breakwater or jetty.

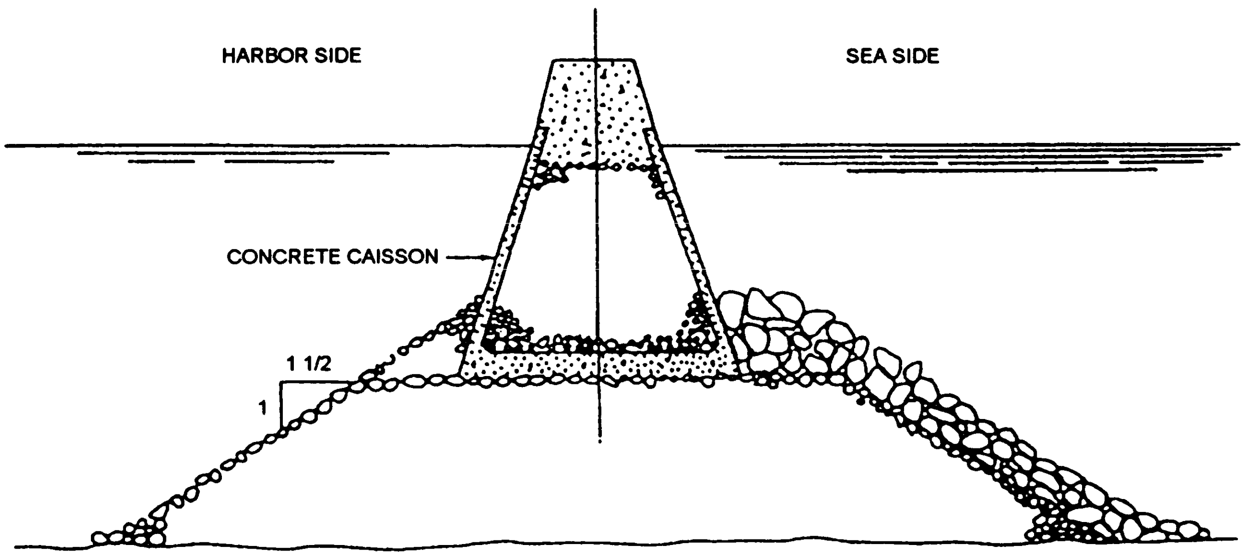


Figure 1-14.—Composite breakwater or jetty.

WATERFRONT STRUCTURES

Waterfront structures may be broadly divided into three types as fpllows: (1) harbor-shelter structures, (2) stable-shoreline structures, and (3) wharfage structures.

HARBOR-SHELTER STRUCTURES

Harbor-shelter structures are offshore structures that are designed to create a sheltered harbor. Various types of these structures are discussed below.

A **breakwater** is an offshore barrier, erected to break the action of the waves and thereby maintain an area of calm water inside the breakwater. A **jetty** is a similar structure, except that its main purpose is to direct the current or tidal flow along the line of a selected channel.

The simplest type of breakwater or jetty is the rubble-mound (also called rock-mound) type shown in figure 1-13. The width of its cap may vary from 15 to

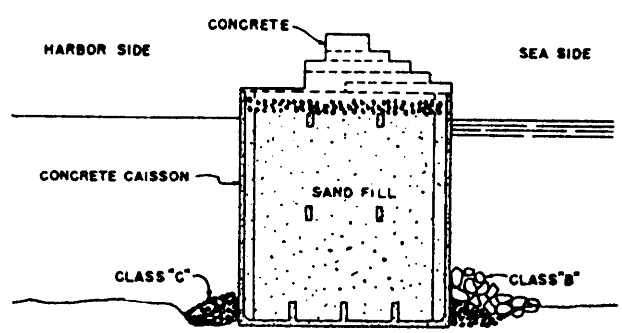


Figure 1-15.—Caisson breakwater or jetty.

70 feet. The width of its base depends on the width of the cap, height of the structure, and the slopes of the inner and outer faces. For a deepwater site or from with an extra-high tide range, a rubble-mound breakwater may be topped with a concrete cap structure, such as shown in figure 1-14. A structure of this type is called a composite breakwater or jetty. In figure 1-14, the cap structure is made of a series of precast concrete

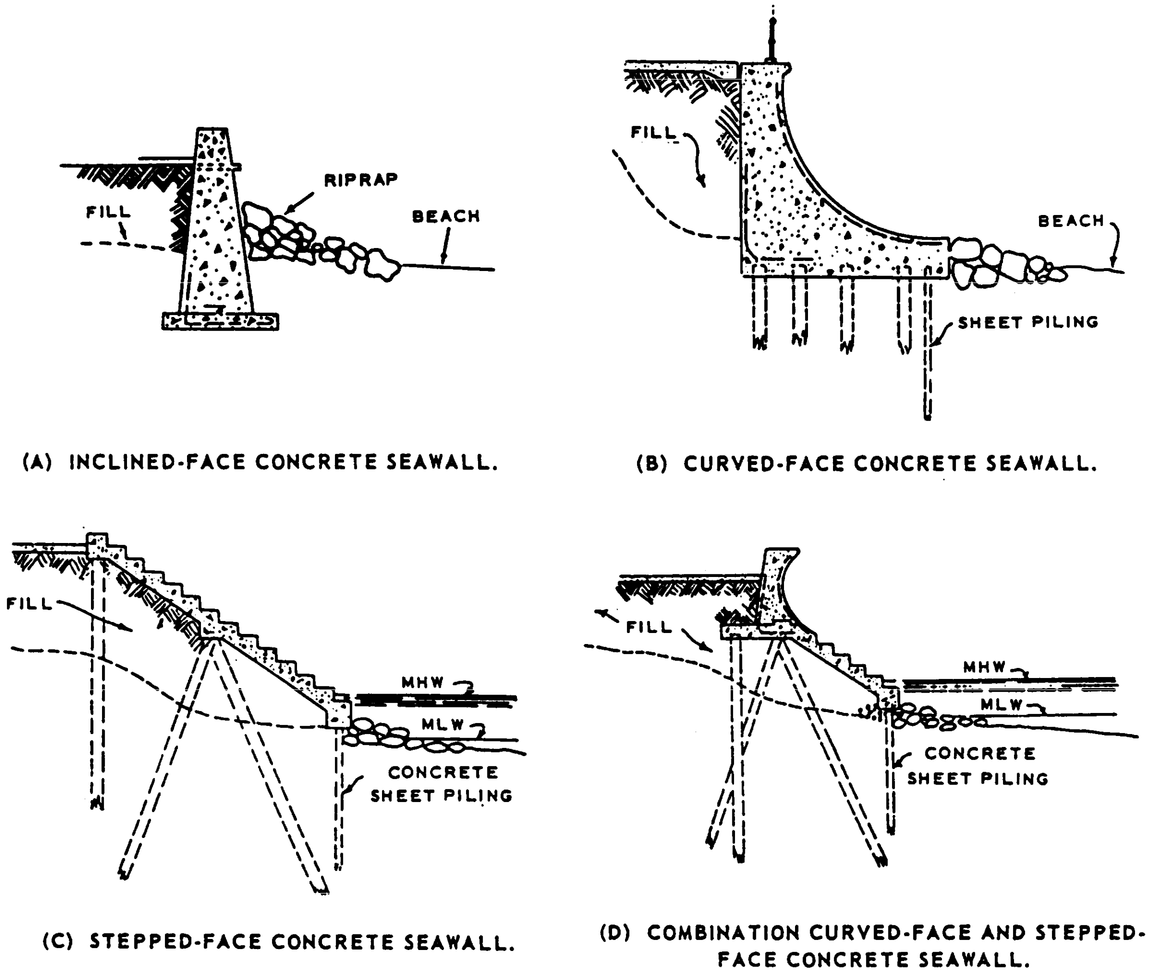


Figure 1-6.—Various types of seawalls.

boxes called **caissons,** each of which is floated over its place of location, and then sunk into position. A monolithic (single-piece) concrete cap is then cast along the tops of the caissons. Sometimes, breakwaters and jetties are built entirely of caissons, as shown in figure 1-15.

A **groin** is a structure similar to a breakwater or jetty, but it has a third purpose. A groin is used in a situation where a shoreline is subject to alongshore erosion, caused by wave or current action parallel or oblique to the shoreline. The groin is run out from the shoreline (usually there is a succession of groins at intervals) to check the alongshore wave action or deflect it away from the shore.

A **mole** is a breakwater that is paved on the top for use as a wharfage structure. To serve this purpose, it must have a vertical face on the inner side, or harborside. A jetty may be similarly constructed and used, but it is still called a jetty.

STABLE-SHORELINE STRUCTURES

These structures are constructed parallel with the shoreline to protect it from erosion or other wave damage.

A **seawall** is a vertical or sloping wall that offers protection to a section of the shoreline against erosion and slippage caused by tide and wave action. A seawall is usually a self-sufficient type of structure, such as a gravity-type retaining wall. Seawalls are classified according to the types of construction. A seawall may be made of riprap or solid concrete. Several types of seawall structures are shown in figure 1-16.

A **bulkhead** has the same general purpose as a seawall; namely, to establish and maintain a stable shoreline. However, while a seawall is self-contained, relatively thick, and is supported by its own weight, the bulkhead is a relatively thin wall. Bulkheads are classified according to types of construction, such as the following:

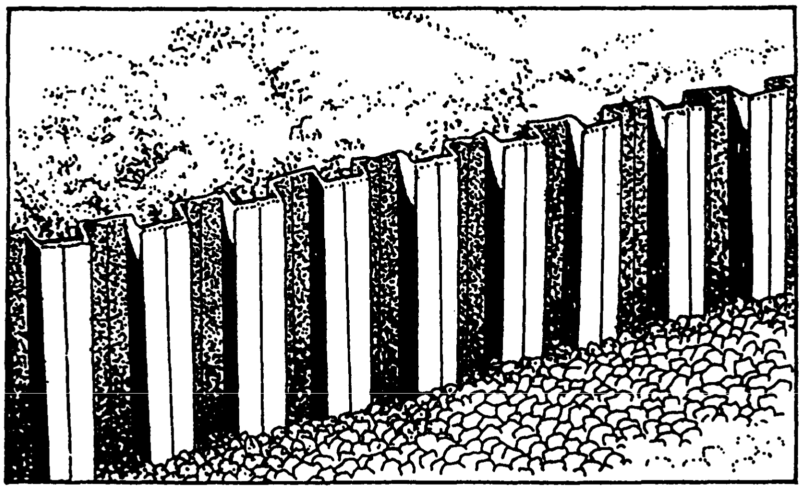


Figure 1-17.—Steel sheet-pile bulkhead.

1. Pile-and-sheathing bulkhead
2. Wood sheet-pile bulkhead
3. Steel sheet-pile bulkhead
4. Concrete sheet-pile bulkhead

Most bulkheads are made of steel sheet piles, such as shown in figure 1-17, and are supported by a series of tie wires or tie rods that are run back to a buried anchorage (or deadman). The outer ends of the tie rods are anchored to a steel wale that runs horizontally along the outer or inner face of the bulkhead. The wale is usually made up of pairs of structural steel channels that are bolted together back to back.

In stable soil above the groundwater level, the anchorage for a bulkhead may consist simply of a buried timber, a concrete deadman, or a row of driven and buried sheet piles. A more substantial anchorage for each tie rod is used below the groundwater level. Two common types of anchorages are shown in figure 1-18. In view A, the anchorage for each tie rod consists of a timber cap, supported by a batter pile, which is bolted to a bearing pile. In view B, the anchorage consists of a reinforced concrete cap, supported by a pair of batter piles. As shown in the figure, tie rods are supported by piles located midway between the anchorage and the bulkhead.

Bulkheads are constructed from working drawings like those shown in figure 1-19. The detail plan for the bulkhead shows that the anchorage consists of a row of sheet piles to which the inner ends of the tie rods are anchored by means of a channel wale.

The section view shows that the anchorage will lie 58 feet behind the bulkhead. This view also suggests the order of construction sequence. First, the shore and bottom will be excavated to the level of the long, sloping dotted line. The sheet piles for the bulkhead and anchorage will then be driven. The intervening dotted lines, at intervals of 19 feet 4 inches, represent supporting piles, which will be driven to hold up the tie rods. The piles will be driven next, and the tie rods then set in place. The wales will be bolted on, and the tie rods will be tightened moderately (they are equipped with turnbuckles for this purpose).

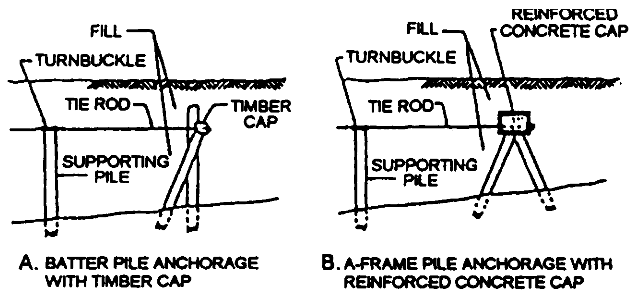


Figure 1-18.—Two types of tie-rod anchorages for bulkheads.

Backfilling to the bulkhead will then begin. The first backfilling operation will consist of filling over the anchorage, out to the sloping dotted line. The turnbuckles on the tie rods will then be set up to bring the bulkhead plumb. Then the remaining fill, out to the bulkhead, will be put in. Finally, outside the bulkhead, the bottom will be dredged to a depth of 30 feet.

To make it possible for ships to come alongside the bulkhead, it will be fitted with a timber cap and batter fender piles, as shown in figure 1-20. These piles, installed at proper intervals, will provide protection against the impact of ships and will protect the hulls of ships from undue abrasion.

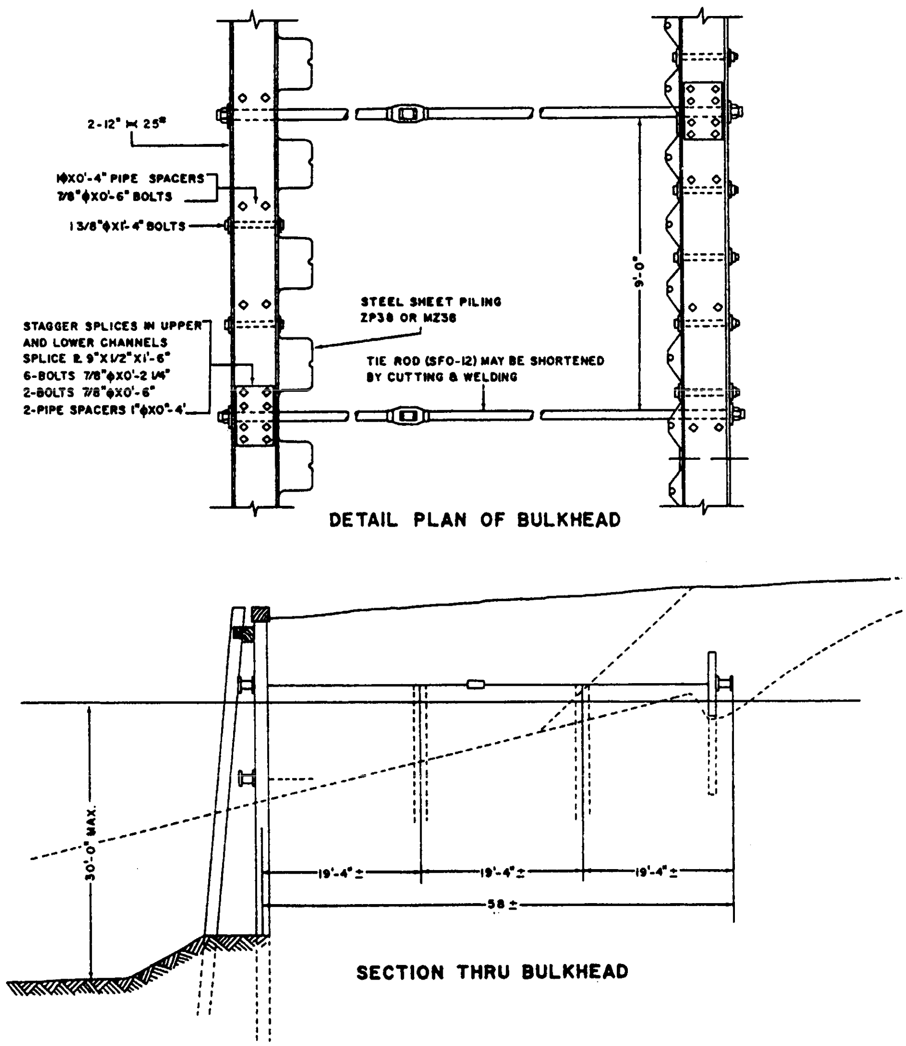


Figure 1-19.—Working drawings for steel sheet-pile bulkhead.

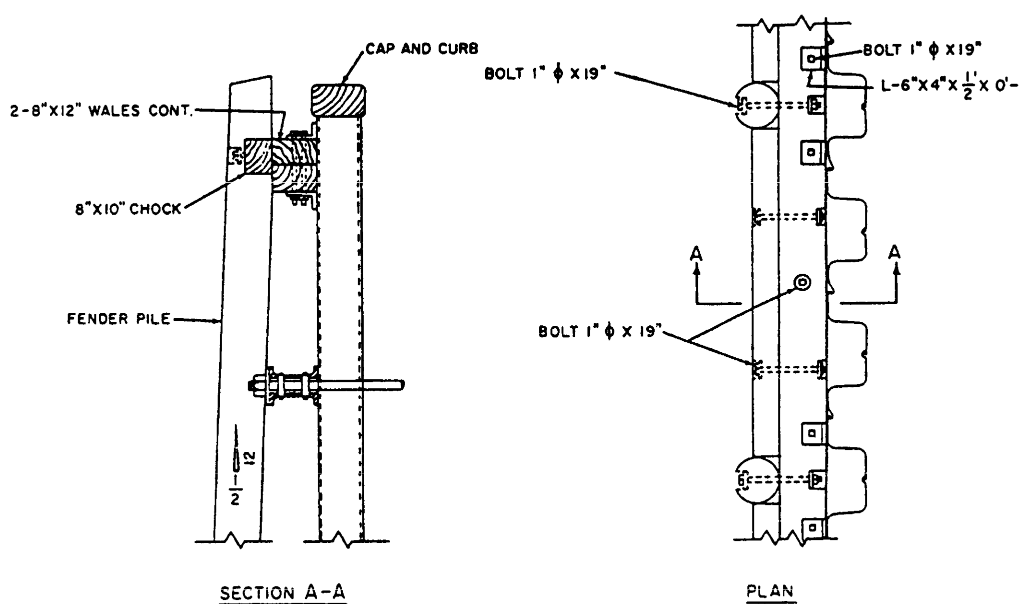


Figure 1-20.—Cap and fender pile for bulkhead.

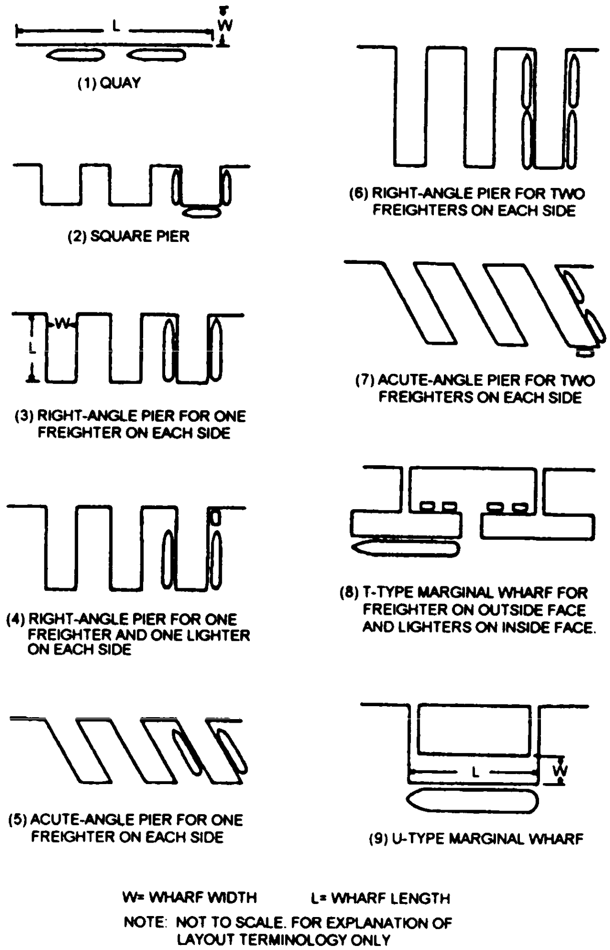


Figure 1-21.—Types of wharfage structures.

WHARFAGE STRUCTURES

Wharfage structures are designed to allow ships to lie alongside for loading and discharge. Figure 1-21 shows various plan views of wharfage structures. Any of these may be constructed of fill material, supported by bulkheads. However, a pier or marginal wharf usually consists of a timber, steel, or concrete superstructure, supported on a substructure of timber-, steel-, or concrete-pile bents.

Working drawings for advanced-base piers are contained in *Facilities Planning Guide,* Volume 1, NAVFAC P-437. Figures 1-22, 1-23, and 1-24 are portions of the advanced-base drawing for a 40-foot timber pier.

Each part of a pier lying between adjacent pile bents is called a bay, and the length of a single bay is equal to the on-center spacing of the bents. In the general plan shown in figure 1-22, you can see that the 40-foot pier consists of one 13-foot outboard bay, one 13-foot inboard bay, and as many 12-foot interior bays as needed to meet the length requirements for the pier.

The cross section shown in figure 1-24 shows that each bent consists of six bearing piles. The bearing piles are braced transversely by diagonal braces. Additional transverse bracing for each bent is provided by a pair of batter piles. The batter angle is specified as 5 in 12. One pile of each pair is driven on either side of the bent, as shown in the general plan. The butts of the batter piles are joined to 12-inch by 12-inch by 14-foot longitudinal batter-pile caps, each of which is bolted to the undersides of two adjacent bearing-pile caps in the positions shown in the part plan. The batter-pile caps are placed 3 feet inboard of the center lines of the outside bearing piles in the bent. They are backed by 6- by 14-inch batter-pile cap blocks, each of which is bolted to a bearing-pile cap. Longitudinal bracing between bents consists of 14-foot lengths of 3 by 10 planks, bolted to the bearing piles.

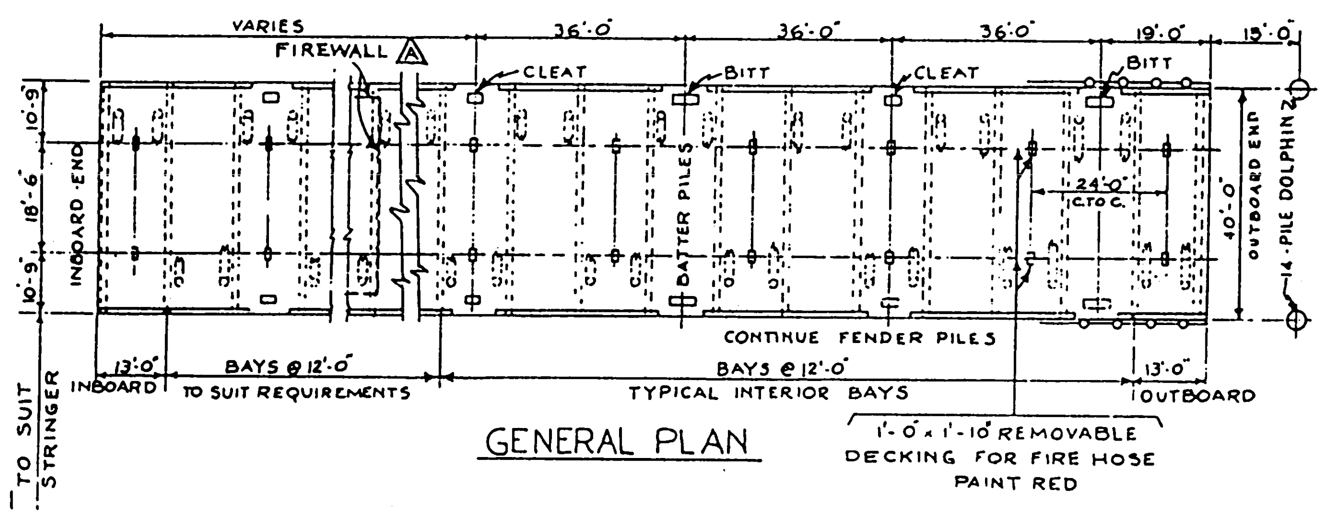


Figure 1-22.—General plan of an advanced-base 40-foot timber pier.

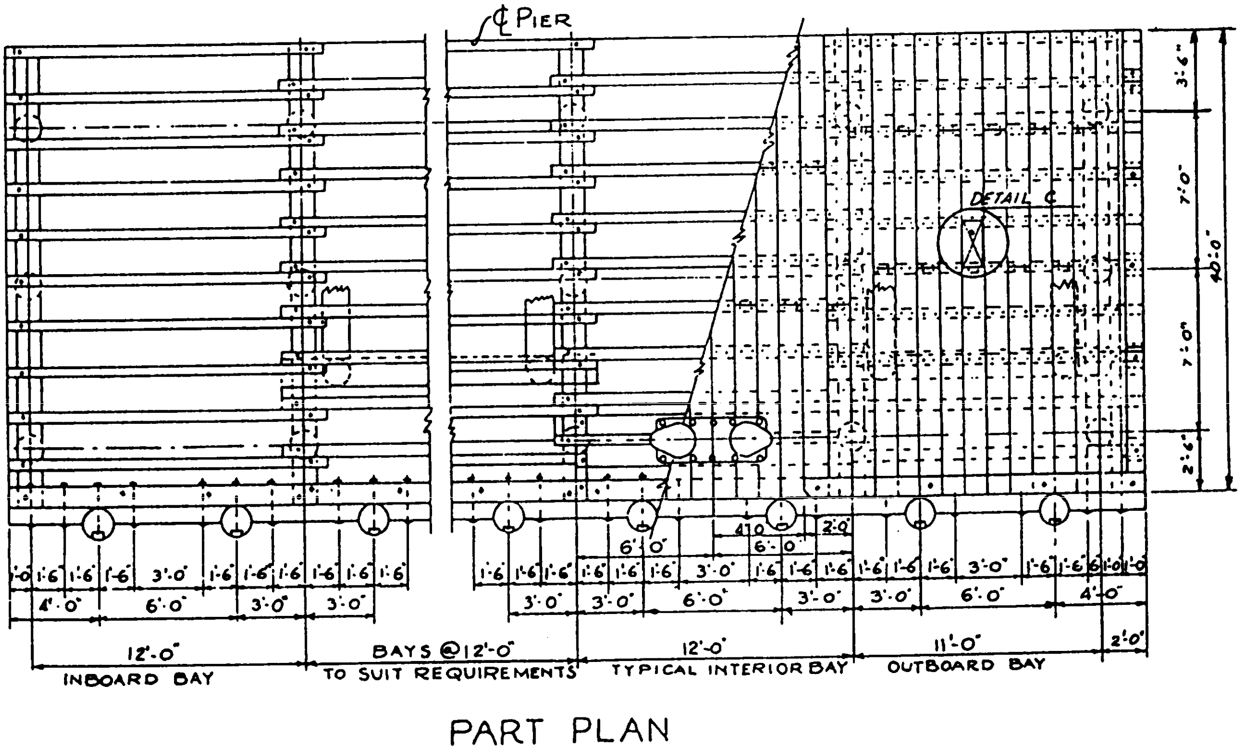


Figure 1-23.—Part plan of an advanced-base timber pier.

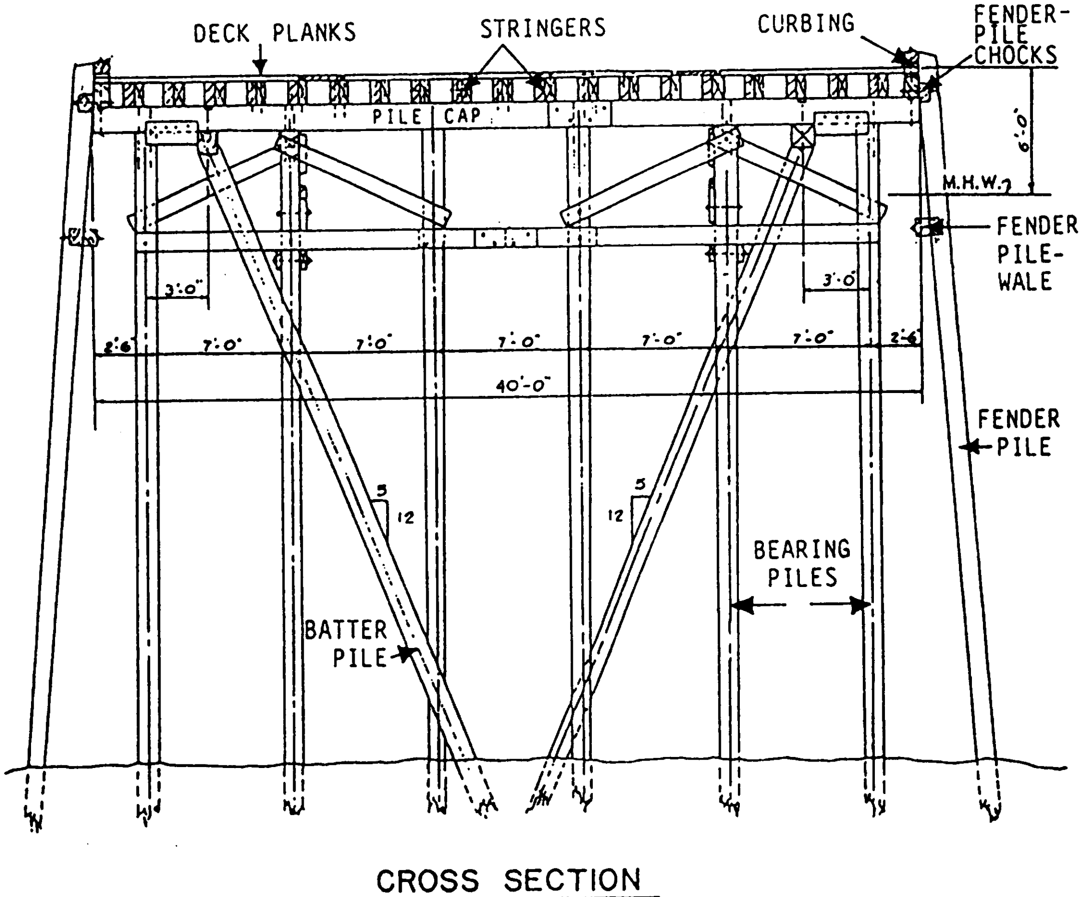


Figure 1-24.—Cross section of an advanced-base timber pier.

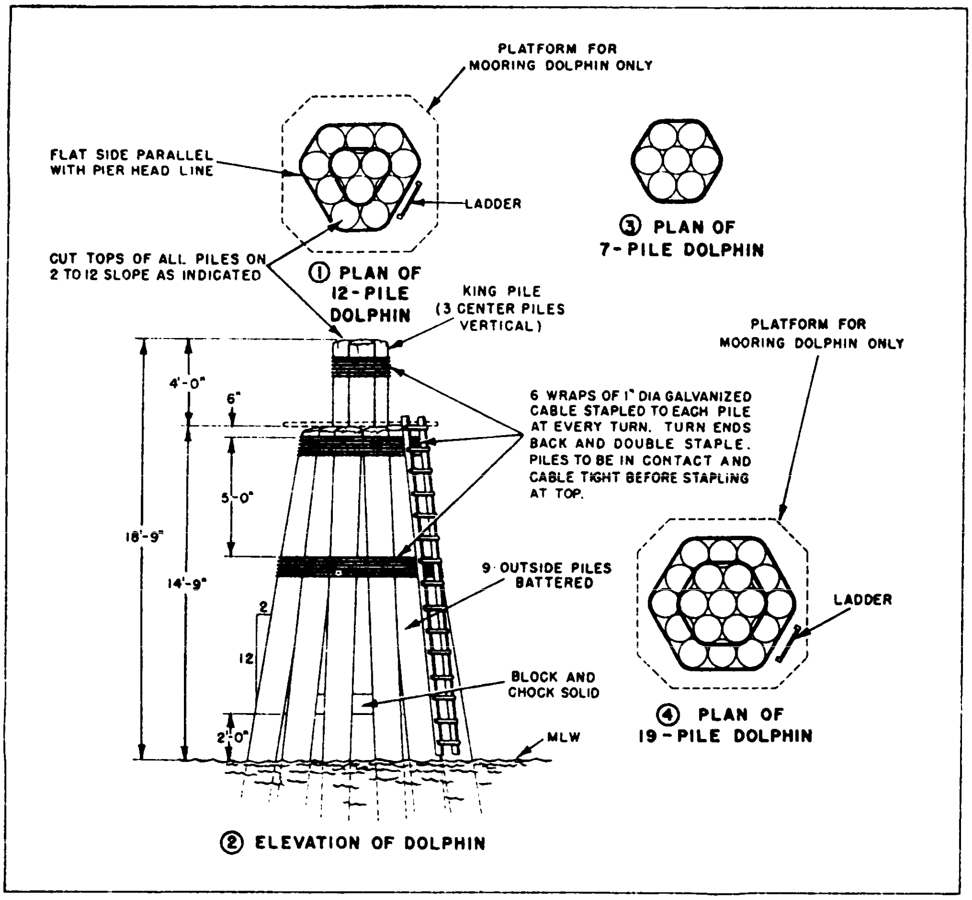


Figure 1-25.—Dolphins.

The superstructure (fig. 1-24) consists of a single layer of 4 by 12 planks laid on 19 inside stringers measuring 6 inches by 14 inches by 14 feet. The inside stringers are fastened to the pile caps with driftbolts. The outside stringers are fastened to the pile caps with bolts. The deck planks are fastened to the stringers with 3/8- by 8-inch spikes. After the deck is laid, 12-foot lengths of 8 by 10 are laid over the outside stringers to form the curbing. The lengths of curbing are distributed as shown in the general plan. The curbing is bolted to the outside stringers.

The pier is equipped with a fender system for protection against shock, caused by contact with vessels coming or lying alongside. Fender piles, spaced as shown in the part plan, are driven along both sides of the pier and bolted to the outside stringers. The heads of these bolts are countersunk below the surfaces of the piles. An 8-by-10 fender wale is bolted to the backs of the fender piles. Lengths of 8-by-10 fender-pile chocks are cut to fit between the piles and bolted to the outside stringers and the fender wales. The spacing for these bolts is shown in the part plan. As shown in the general plan, the fender system also includes two 14-pile dolphins, located 15 feet beyond the end of the pier. A **dolphin** is an isolated cluster of piles, constructed as shown in figure 1-25. A similar cluster attached to a pier is called a **pile cluster.**

TIMBER FASTENERS AND CONNECTORS

From your studies of the EA3 TRAMAN, you should be aware that it is usually unnecessary to call out in working drawings the types of fasteners used for light frame construction. This is not the case, however, for heavy timber construction. As an EA preparing drawings for timber structures, you need to have a working knowledge of timber fasteners and connectors and the manner in which they are used. The following text discusses the more common types.

TIMBER FASTENERS

Bolts used to fasten heavy timbers usually come in 1/2-, 3/4-, and 1-inch diameters and have square heads and nuts. In use, the bolts are fitted with round steel

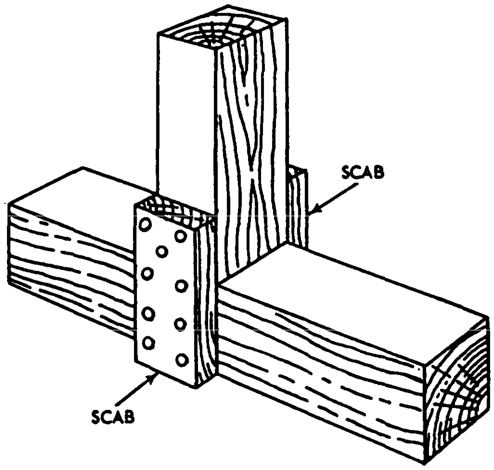


Figure 1-26.—Scabs.

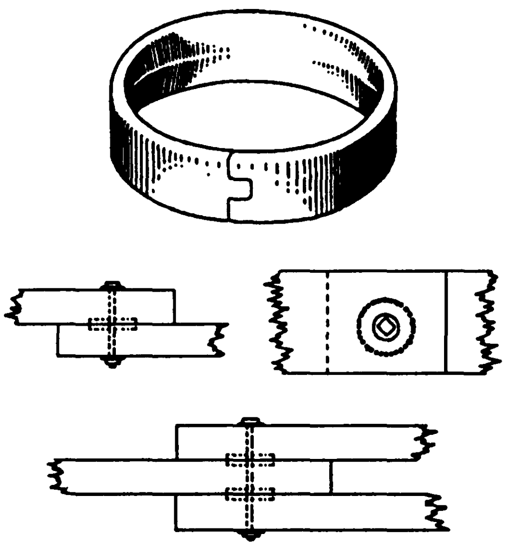


Figure 1-27.—Split ring and split-ring joints.

washers under both the bolt head and the nut. The bolts are then tightened until the washers bite well into the wood to compensate for future shrinkage. Bolts should be spaced a minimum of 9 inches on center and should be no closer than 2 1/2 inches to the edge or 7 inches to the end of the timber.

Driftbolts, also called **driftpins,** are used primarily to prevent timbers from moving laterally in relation to each other, rather than to resist pulling apart. They are used more in dock and trestle work than in trusses and building frames. A driftbolt is a long, threadless rod that is driven through a hole bored through the member and into the abutting member. The hole is bored slightly

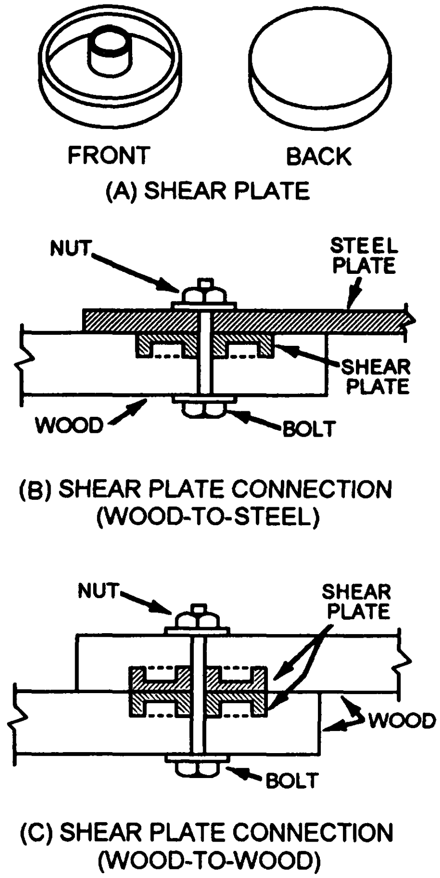


Figure 1-28.—Shear plate and shear-plate joints.

smaller than the bolt diameter and about 3 inches shorter than the bolt length. Driftbolts are from 1/2 to 1 inch in diameter and 18 to 26 inches long.

Butt joints are customarily connected using driftbolts; however, another method of making butt-joint connections is to use a **scab.** A scab is a short length of timber that is spiked or bolted to the adjoining members, as shown in figure 1-26.

TIMBER CONNECTORS

A timber connector is any device used to increase the strength and rigidity of bolted lap joints between heavy timbers. For example, the **split ring** (fig. 1-27) is embedded in a circular groove. These grooves are cut with a special bit in the faces of the timbers that are to be joined. Split rings come in diameters of 2 1/2 and 4 inches. The 2 1/2-inch ring requires a 1/2-inch bolt, and the 4-inch ring uses a 3/4-inch bolt.

Shear plates are shown in figure 1-28. These connectors are intended for wood-to-steel connections, as shown in view B. But when used in pairs, they may

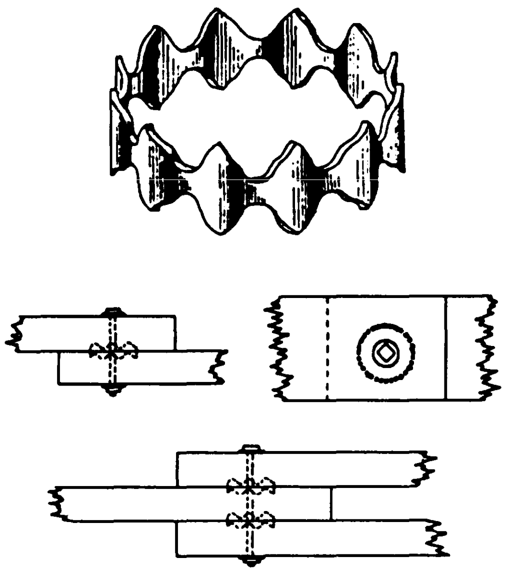


Figure 1-29.—Toothed ring and toothed-ring joints.

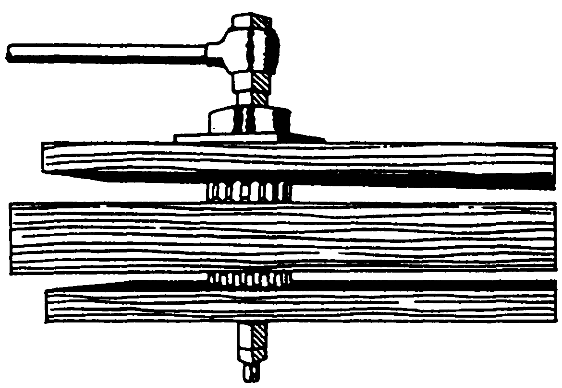


Figure 1-30.—Embedding toothed rings.

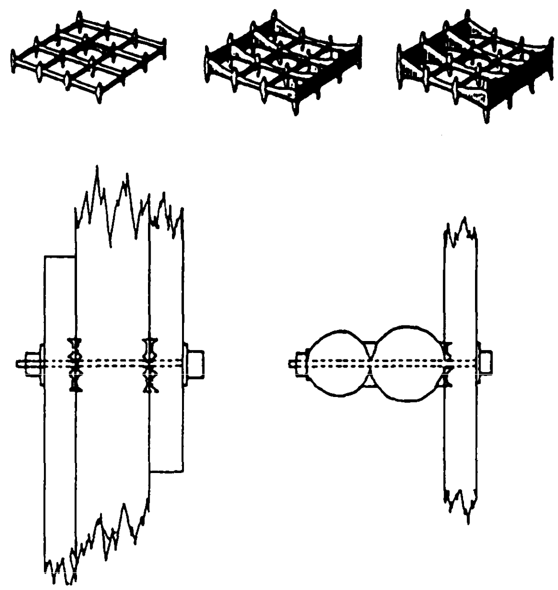


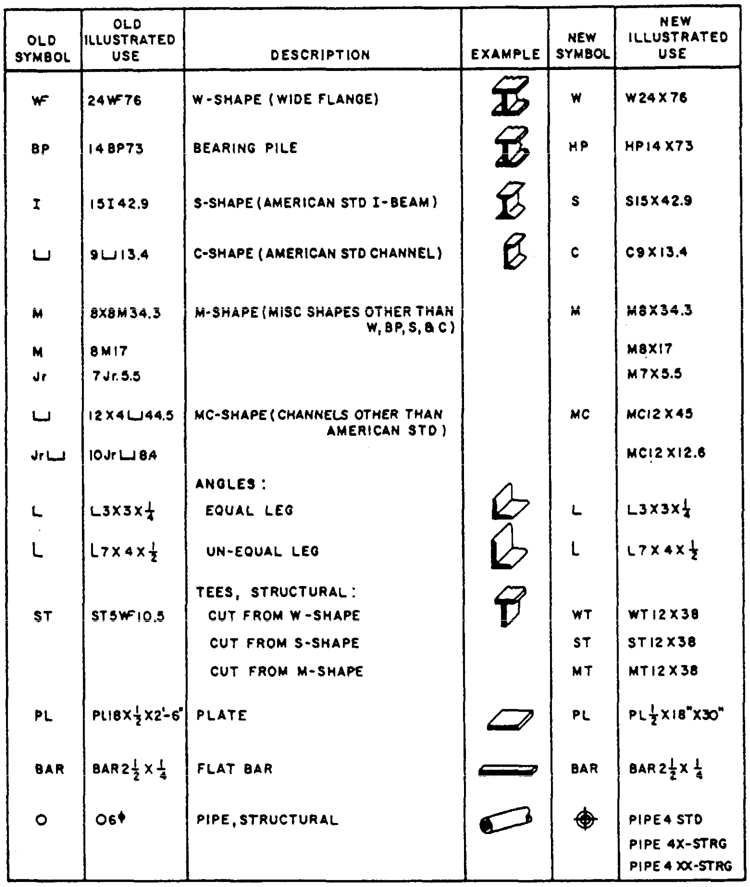
Figure 1-31.—Spike grids and spike-grid joints.

be used for wood-to-wood connections (view C). When making a wood-to-wood connection, the fabricator first cuts a depression into the face of each of the wood members. These depressions are cut to the same depth as the shear plates. Then a shear plate is set into each of the depressions so that the back face of the shear plate is flush with the face of the wood members. Finally, the wood members are slid into place and bolted together. Because the faces are flush, the members easily slide into position, which reduces the labor necessary to make the connection. Shear plates are available in 2 5/8- and 4-inch diameters.

For special applications, **toothed rings** and **spike grids** are sometimes used. The toothed ring connector (fig. 1-29) functions in much the same manner as the split ring but can be embedded without the necessity of cutting grooves in the members. The toothed ring is embedded by the pressure provided from tightening a high-tensile strength bolt, as shown in figure 1-30. The hole for this bolt is drilled slightly larger than the bolt diameter so that the bolt may be extracted after the toothed ring is embedded. The spike grid is used as shown in figure 1-31. A spike grid may be flat (for joining flat surfaces), single-curved (for joining a flat and a curved surface), or double-curved (for joining two curved surfaces). A spike grid is embedded in the same manner as a toothed ring.

STRUCTURAL STEEL

Structural steel is one of the basic materials commonly used in structures, such as industrial and commercial buildings, bridges, and piers. It is produced in a wide range of shapes and grades, which permits great flexibility in its usage. It is relatively inexpensive to manufacture and is the strongest and most versatile material available to the construction industry. This



OLD SYMBOL	OLD ILLUSTRATED USE	DESCRIPTION	EXAMPLE	NEW SYMBOL	NEW ILLUSTRATED USE
WF	24WF76	W-SHAPE (WIDE FLANGE)		W	W24X76
BP	14BP73	BEARING PILE		HP	HP14X73
I	15I42.9	S-SHAPE (AMERICAN STD I-BEAM)		S	S15X42.9
⊔	9⊔13.4	C-SHAPE (AMERICAN STD CHANNEL)		C	C9X13.4
M	8X8M34.3	M-SHAPE (MISC SHAPES OTHER THAN W, BP, S, & C)		M	M8X34.3
M	8M17				M8X17
Jr	7Jr.5.5				M7X5.5
⊔	12X4⊔44.5	MC-SHAPE (CHANNELS OTHER THAN AMERICAN STD)		MC	MC12X45
Jr⊔	10Jr⊔8A				MC12X12.6
		ANGLES:			
L	L3X3X$\frac{1}{4}$	EQUAL LEG		L	L3X3X$\frac{1}{4}$
L	L7X4X$\frac{1}{2}$	UN-EQUAL LEG		L	L7X4X$\frac{1}{2}$
		TEES, STRUCTURAL:			
ST	ST5WF10.5	CUT FROM W-SHAPE		WT	WT12X38
		CUT FROM S-SHAPE		ST	ST12X38
		CUT FROM M-SHAPE		MT	MT12X38
PL	PL18X$\frac{1}{2}$X2'-6"	PLATE		PL	PL$\frac{1}{2}$X18"X30"
BAR	BAR2$\frac{1}{2}$X$\frac{1}{4}$	FLAT BAR		BAR	BAR2$\frac{1}{2}$X$\frac{1}{4}$
O	O6φ	PIPE, STRUCTURAL		⊕	PIPE4 STD PIPE 4X-STRG PIPE 4 XX-STRG

Figure 1-32.—Structural steel shapes and designations.

section describes structural steel shapes, the terminology applied to structural steel members, the use of these members, and the methods by which they are connected.

STRUCTURAL STEEL SHAPES

Structural steel is manufactured in a wide variety of cross-sectional shapes and sizes. Figure 1-32 shows many of these various shapes.

Figure 1-33 shows cross-sectional views of the **W-shape** (wide flange), the **S-shape** (American Standard I-beam), and the **C-shape** (American Standard channel). The W-shape is the most widely used structural member for beams, columns, and other load-bearing applications. As seen in the figure, it has parallel inner and outer flange surfaces that are of constant thickness. This flange design provides greater cross-sectional area in the flanges, which results in greater strength than is provided by the S-shape, which has a slope of approximately 17 degrees on the inner flange surfaces. The C-shape is similar to the S-shape in that its inner flange surface is also sloped approximately 17 degrees. The C-shape is especially useful in locations

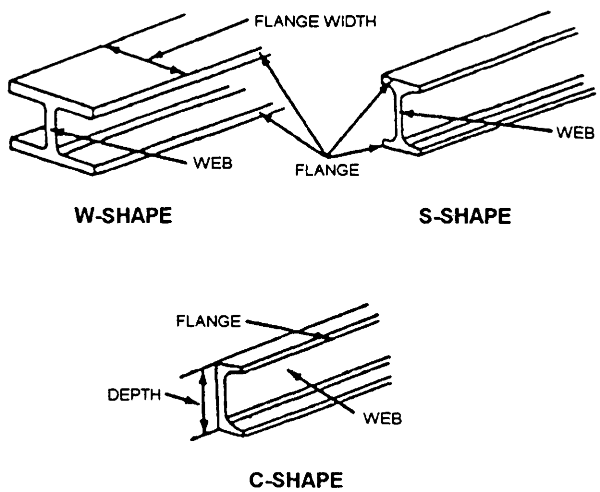


Figure 1-33.—Structural shapes.

where a single flat surface on one side is required. When used alone, the C-shape is not very efficient as a beam or column. However, efficient built-up members maybe constructed of charnels assembled together with other structural shapes and connected by rivets or welds.

The W-, S-, and C-shape structural members are designated by their nominal depth, in inches, along the

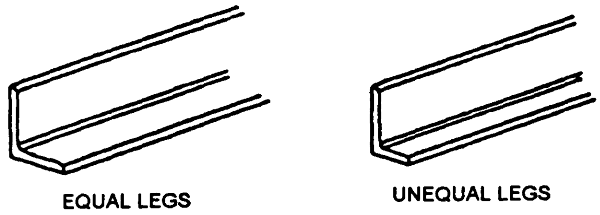


Figure 1-34.—Angles.

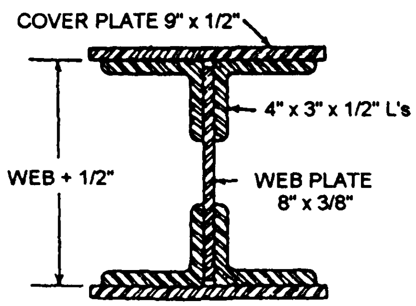


Figure 1-35.—Built-up column section.

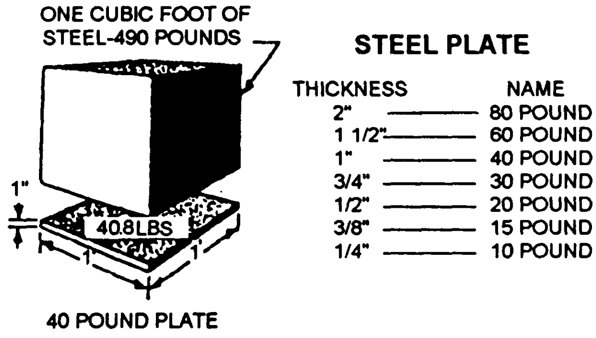


Figure 1-36.—Weight and thickness of steel plate.

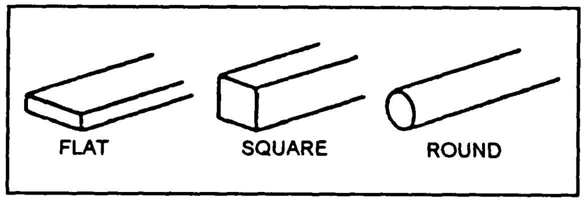


Figure 1-37.—Bars.

web and the weight, in pounds, per foot of length. A W14 x 30, for example, indicates a W-shape that is 14 inches deep along its web and weighs 30 pounds per linear foot. Hence a 20-foot length of this size W-shape would weigh a total of 600 pounds.

The **bearing pile,** HP-shape, is almost identical to the W-shape. The only difference is the thickness of the web and flange. In the bearing pile, the web and flange thickness are equal, whereas the W-shape has unequal web and flange thickness.

An **angle** is a structural shape whose cross section resembles the letter *L*. As pictured in figure 1-34, angles are available with either equal or unequal legs. The dimension and thickness of its legs are used to identify an angle; for example, L6 x 4 x 1/2. The dimension of each leg is measured along the outside of the angle, and for unequal-leg angles, the dimension of the wider leg is always given first, as in the example just cited. The third dimension applies to the thickness of the legs, which always have equal thickness. Angles are used primarily to support, brace, or connect other structural members. They may be used as single members, or they may be used in combinations of two or four to form main members.

Steel **plate** is a structural member that has a width greater than 8 inches and a thickness of 1/4 inch or more. Plates are generally used as connections between other structural members. They may also be used as component parts of built-up structural members, such as the built-up column shown in figure 1-35. Plates cut to specific sizes may be obtained in widths ranging from 8 inches to 120 inches or more and in various thicknesses.

Plates are identified by their thickness, width, and length, all measured in inches; for example, PL 1/2 x 18 x 30. Sometimes, you may also hear plate referred to by its approximate weight per square foot for a specified thickness. As shown in figure 1-36, 1 cubic foot of steel weighs 490 pounds. This weight divided by 12 gives you 40.8 pounds, which is the weight of a steel plate measuring 1 foot square and 1 inch thick. By dropping the fractional portion, a 1-inch plate is called a 40-pound plate; and, with similar reasoning, a 1/2-inch plate is called a 20-pound plate.

The structural shape referred to a **bar** has a width of 8 inches or less and a thickness greater than 3/16 inch. The edges of bars usually are rolled square, like universal mill plates. The dimensions are expressed in a similar manner as that for plates; for instance, bar 6 x 1/2. Bars are available in a variety of cross-sectional shapes-round, hexagonal, octagonal, square, and flat. Three different shapes are shown in figure 1-37. Both squares and rounds are commonly used as bracing members of light structures. Their dimensions, in

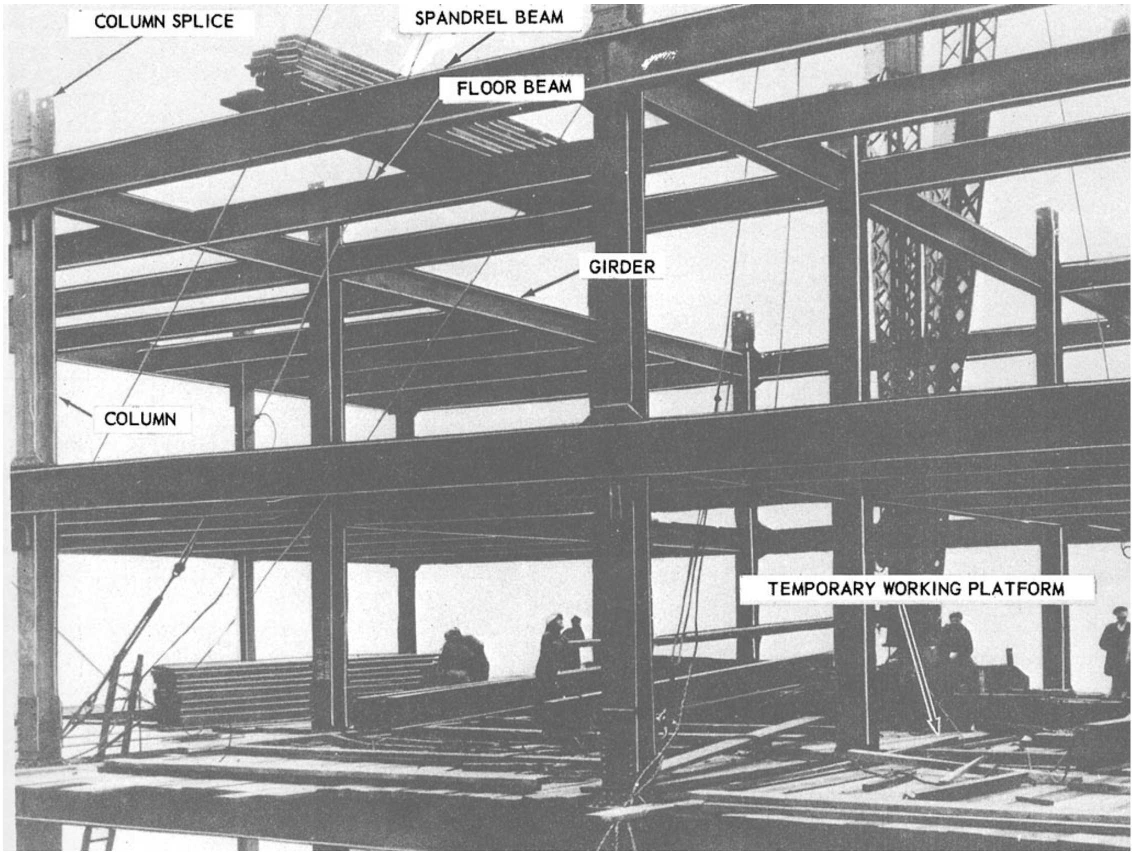


Figure 1-38.—Structural steel skeleton construction.

inches, apply to the side of the square or the diameter of the round.

STEEL FRAME STRUCTURES

The construction of a framework of structural steel involves two principal operations: fabrication and erection. Fabrication involves the processing of raw materials to form the finished members of the structure. Erection includes all rigging, hoisting, or lifting of members to their proper places in the structure and making the finished connections between members.

A wide variety of structures are erected using structural steel. Basically, they can be listed as buildings, bridges, and towers; most other structures are modifications of these three.

Buildings

There are three basic types of steel construction. These may be designated as **wall-bearing construction, skeleton construction,** and **long-span construction.**

In wall-bearing construction, exterior and interior masonry walls are used to support structural members, such as steel beams and joists, which carry the floors and roof. It should be noted that while this section of your TRAMAN discusses steel structures, wall-bearing construction is applicable to nonsteel structures as well. Wall-bearing construction is one of the oldest and most common methods in use. Although modern developments in reinforced concrete masonry make the use of this method feasible for high-rise structures, wall-bearing construction is normally restricted to relatively low structures, such as residences and light industrial buildings.

A tall building with a steel frame, such as shown in figure 1-38, is an example of skeleton construction. In this type of construction, all live and dead loads are carried by the structural-frame skeleton. For this reason, the exterior walls are nonbearing **curtain walls.** Roof and floor loads are transmitted to beams and girders,

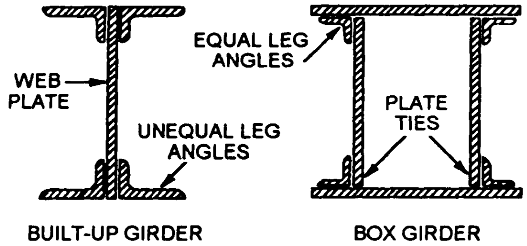


Figure 1-39.—Typical built-up girders.

which are, in turn, supported by columns. The horizontal members or beams that connect the exterior columns are called **spandrel beams.** If you add additional rows of columns and beams, there is no limitation to the area of floor and roof that can be supported using skeleton construction. One limitation on using skeleton construction, however, is the distance between columns.

Oftentimes, large structures, such as aircraft hangars, may require greater distances between supports than can be spanned by the standard structural steel shapes. In this case, one of several methods of long-span steel construction is used. One method uses built-up girders to span the distances between supports. Two types of built-up girders are shown in figure 1-39. As seen in this figure, the built-up girder consists of steel plates and shapes that are combined together to meet the necessary strength. The individual parts of these girders are connected by welding or riveting.

Another method, which is usually more economical, is to use a **truss** to span large distances. As you learned in the EA3 TRAMAN, a truss is a framework of structural members consisting of a top chord, bottom chord, and diagonal web members that are usually placed in a triangular arrangement. (See figs. 1-40 and 1-41.) As shown in figure 1-40, trusses can be fabricated to conform to the shape of nearly any roof system.

A third long-span method, although not as versatile as trusses, is the use of **bar joists.** Bar joists are much lighter than trusses and are fabricated in several different types. One type is shown in figure 1-42. Prefabricated bar joists, designed to conform to specific load requirements, are obtainable from commercial companies. Other long-span construction methods involve several different types of framing systems, which include steel arches, cable-hung frames, and other types of systems. These methods are beyond the scope of this TRAMAN.

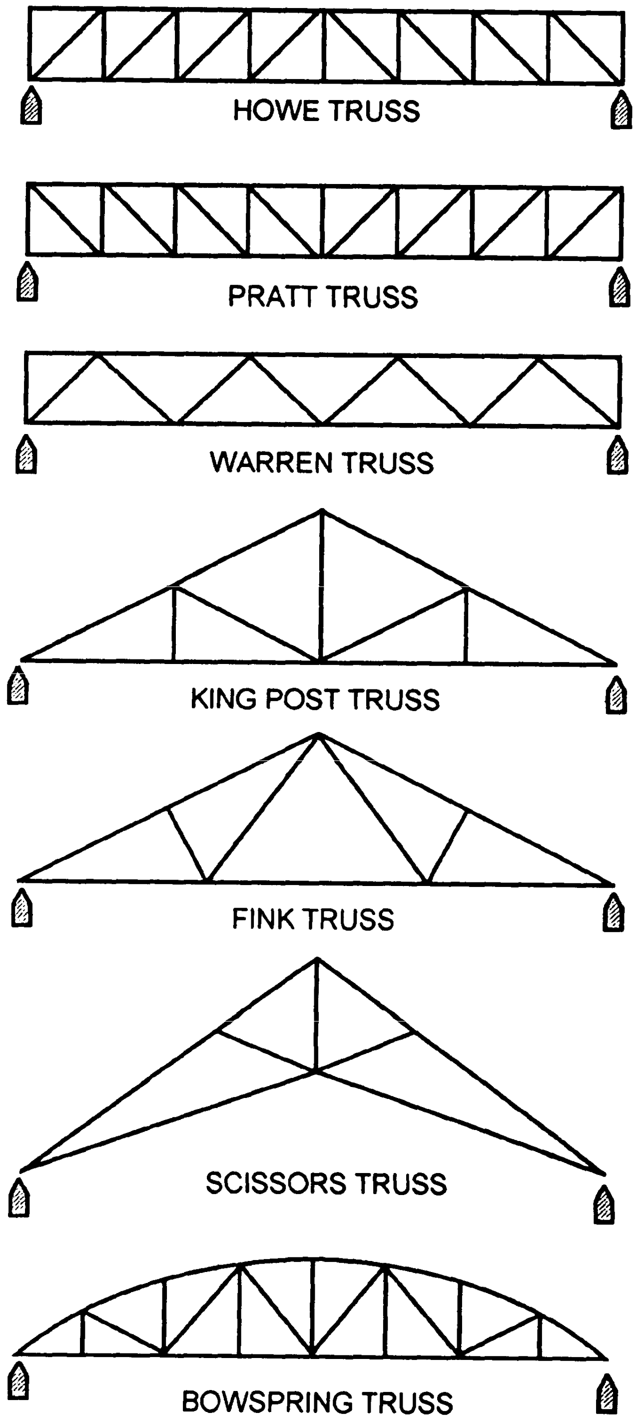


Figure 1-40.—Typical steel trusses.

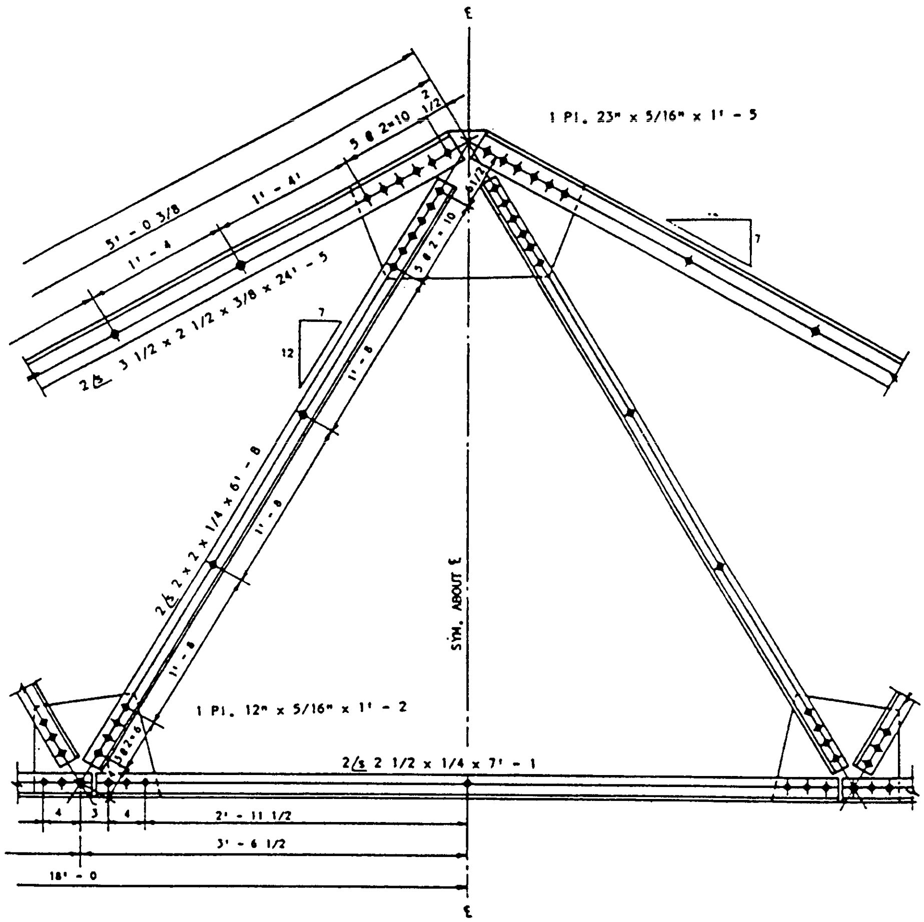


Figure 1-41.—Steel truss fabricated from angle-shaped members.

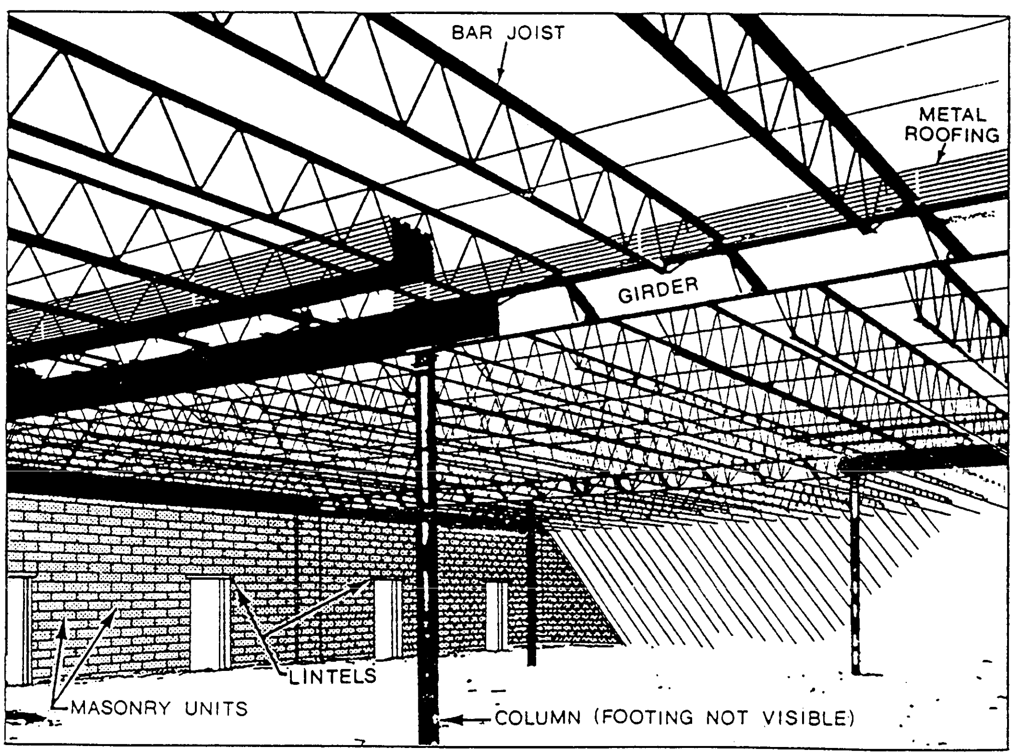


Figure 1-42.—Clear span bar joists.

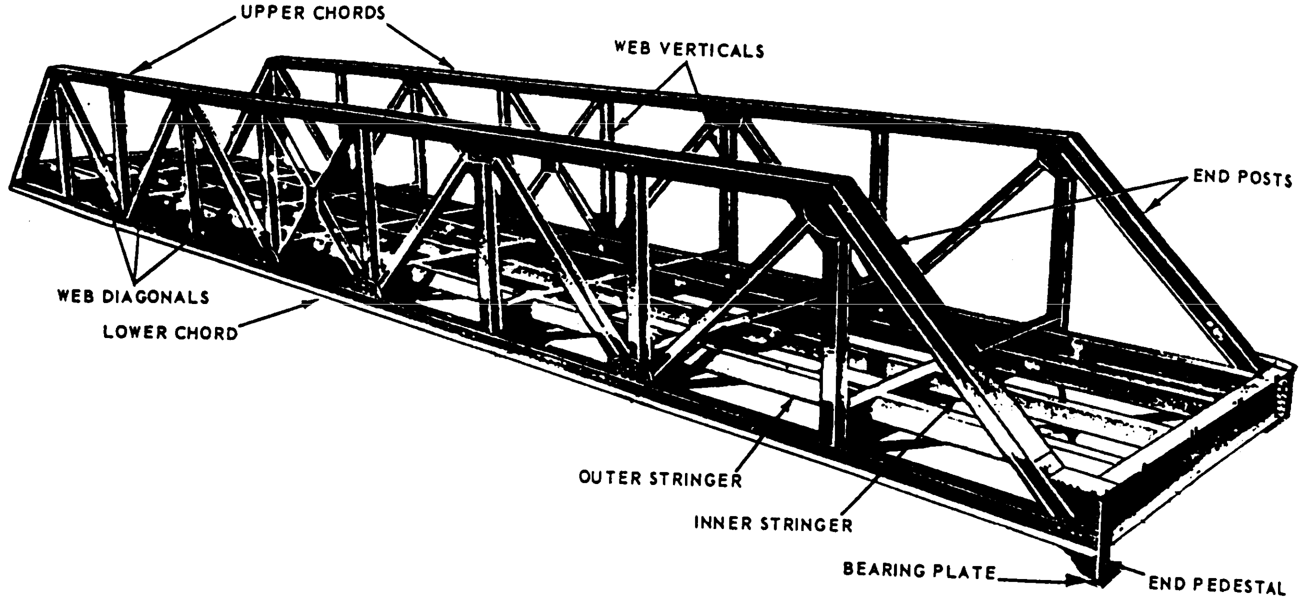


Figure 1-43.—Truss bridge.

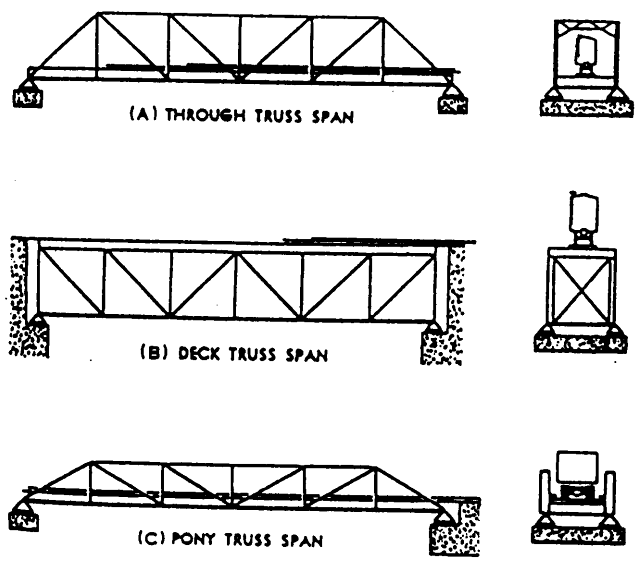


Figure 1-44.—Types of bridge spans.

Bridges

Figure 1-43 shows the structural framework of a single-span truss bridge. As with all bridges, the floor and traffic loads of the truss bridge are carried by the stringers. In the truss bridge, however, the stringers are supported by transverse beams rather than by the bridge abutments (and intermediate supports when needed). As seen in the figure, these transverse beams are supported by the structural framework of the two trusses. Finally, the entire bridge structure plus any traffic loads are transmitted through the **end pedestals** and **bearing plates** to the supporting abutments. As you will note, the nomenclature of the truss members is the same as discussed in the preceding section; however, the

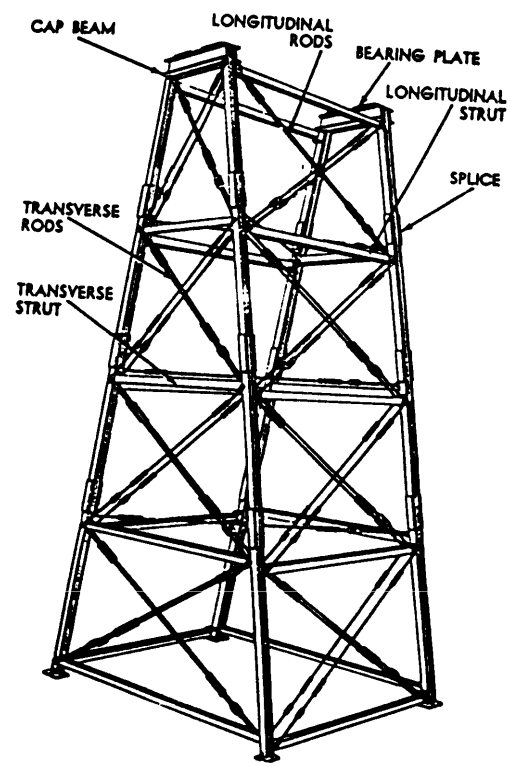


Figure 1-45.—A trestle tower.

diagonal end members, adjacent to the abutments, are normally called **end posts.**

The truss framework and the manner in which the trusses are used may differ depending upon the design of the truss bridge. Figure 1-44 shows three examples. View A shows a **through truss** span. In it, the traverse beams are connected to the bottom chord of the trusses, and the top chords are braced by a lateral bracing system under which traffic passes. In the **deck truss** span, view B, the traverse beams are carried by the top chord

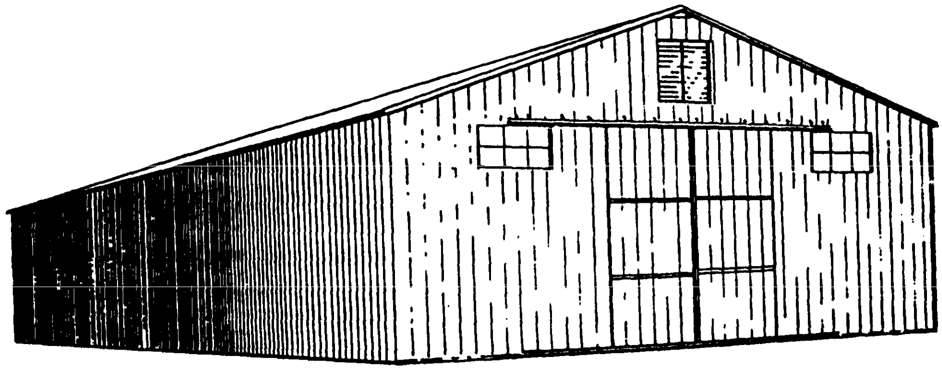


Figure 1-46.—Completed 40' x 100' x 14' preengineered metal building.

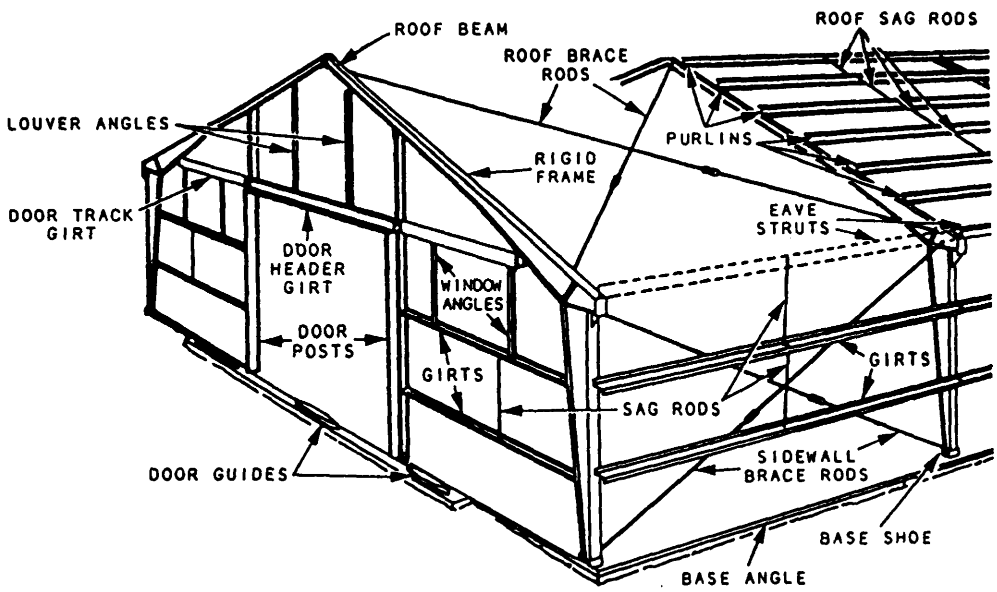


Figure 1-47.—Structural members of a preengineered metal building.

Again, a lateral bracing system is used between the trusses. The **pony truss** span is the same as that discussed in the preceding paragragh. Because of the small depth of the trusses, no top lateral bracing is used.

Towers

Towers are framework structures designed to provide vertical support. They may be used to support another structure, such as a bridge, or they may be used to support a piece of equipment, such as a communication antenna. Since the prime purpose of a tower is to provide vertical support for a load applied at the top, the compression members providing this support are the only ones that require high-structural strength. The rest of the structure is designed to stiffen the vertical members and to prevent bending under load. Primarily, the bracing members are designed to take loads in tension and are based on a series of diagonals. A typical trestle tower used in bridge construction is shown in figure 1-45.

Preengineered Metal Structures

Preengineered metal structures are commonly used in military construction. These structures are usually designed and fabricated by civilian industry to conform with specifications set forth by the military. Rigid frame buildings, steel towers, communications antennas, and steel tanks are some of the most commonly used structures, particularly at overseas advanced bases. Prerengineered structures offer an advantage in that they are factory built and designed to be erected in the shortest amount of time possible. Each structure is shipped as a complete kit, including all the materials and instructions needed to erect it.

Of the preengineered metal structures available, the one that is perhaps most familiar to the Seabees is the preengineered metal building (PEB) shown in figures 1-46 and 1-47. Figure 1-47 shows the nomenclature of the various parts of the PEB. For definition of this nomenclature, erection details, and other important information regarding the PEB, you should refer to the current *Steelworker* TRAMAN.

STRUCTURAL STEEL CONNECTORS

There are four basic connectors used in making structural steel connections. They are **bolts, welds, pins,** and **rivets.** Bolts and welds are the most common connectors used in military construction. Pins are used for connections at the ends of bracing rods and various support members that require freedom of rotation. Commercial prefabricated steel assemblies may be received in the field with riveted conectors. Types and uses of the four basic connectors are discussed in the following text.

Bolts

Bolts are used more than any other type of connectors. They are easy to use and, in contrast to all other types of connectors, require little special equipment. The development of higher strength steels and improved manufacturing processes have resulted in the production of bolts that will produce strong structural steel connections.

Specifications for most bolted structural joints call for the use of high-strength steel bolts tightened to a high tension. The bolts are used in holes slightly larger than the nominal bolt size. Joints that are required to resist shear between connected parts are designated as either **friction-type** or **bearing-type** connectors.

Bolted parts should fit solidly together when they are assembled and should NOT be separated by gaskets or any other type of compressible material. Holes should be a nominal diameter, not more that 1/16 inch in excess of the nominal bolt diameter. When the bolted parts are assembled, all joint surfaces should be free of scale, burrs, dirt, and other foreign material. Contact surfaces with friction-type joints must be free of oil, paint, or other coatings.

Welds

Welding is a highly specialized skill, and welding of load-bearing parts of a structure should be performed only by properly qualified personnel. As an EA, you will not be expected to perform welding operations. However, you should have a general knowledge of the principal welding processes and the different types of welds and their applications, and you should know how welding symbols are used to identify welded connections shown in working drawings.

The two principal welding processes used in structural work are **electric arc** welding and **oxy-MAPP** gas welding. In the electric arc welding process, welding heat, sufficient to fuse the metal together, is developed by an electric arc formed between a suitable **electrode** (welding rod) and the **base metal** (the metal of the parts being welded). In the oxy-MAPP gas welding process, heat is obtained by burning a mixture of MAPP gas and oxygen as it is discharged from a torch designed for this purpose. While electric arc welding is normally used for metals that are 1/8 inch or larger in thickness, oxy-MAPP gas welding is usually restricted to thinner metals.

The principal types of welds and welded joints that are suitable for structural work are shown in figures 1-48 and 1-49.

On drawings, special symbols are used to show the kinds of welds to be used for welded connections. These symbols have been standardized by the American Welding Society (AWS). You should become familiar with the basic welding symbols and with the standard location of all elements of a welding symbol.

The distinction between a **weld symbol** and a welding symbol should be noted. A weld symbol is a basic symbol used to indicate the type of weld. Basic weld symbols are shown at the top of figure 1-50. The supplementary symbols shown in the figure are used when necessary in connection with the basic weld symbols.

A **welding symbol** consists of the following eight elements, or as many of these elements as are required: (1) reference line, (2) arrow, (3) basic weld symbol, (4) dimensions and other data, (5) supplementary symbols, (6) finish symbols, (7) tail, and (8) specification, process, or other reference. These elements of the welding symbol have specific standard locations with respect to each other, as shown in figure 1-50. When a finish symbol is used in a welding symbol, it indicates the method of finish, not the degree of finish. For example, a *C* is used to indicate finish by chipping, an *M* indicates machining, and a *G* indicates grinding.

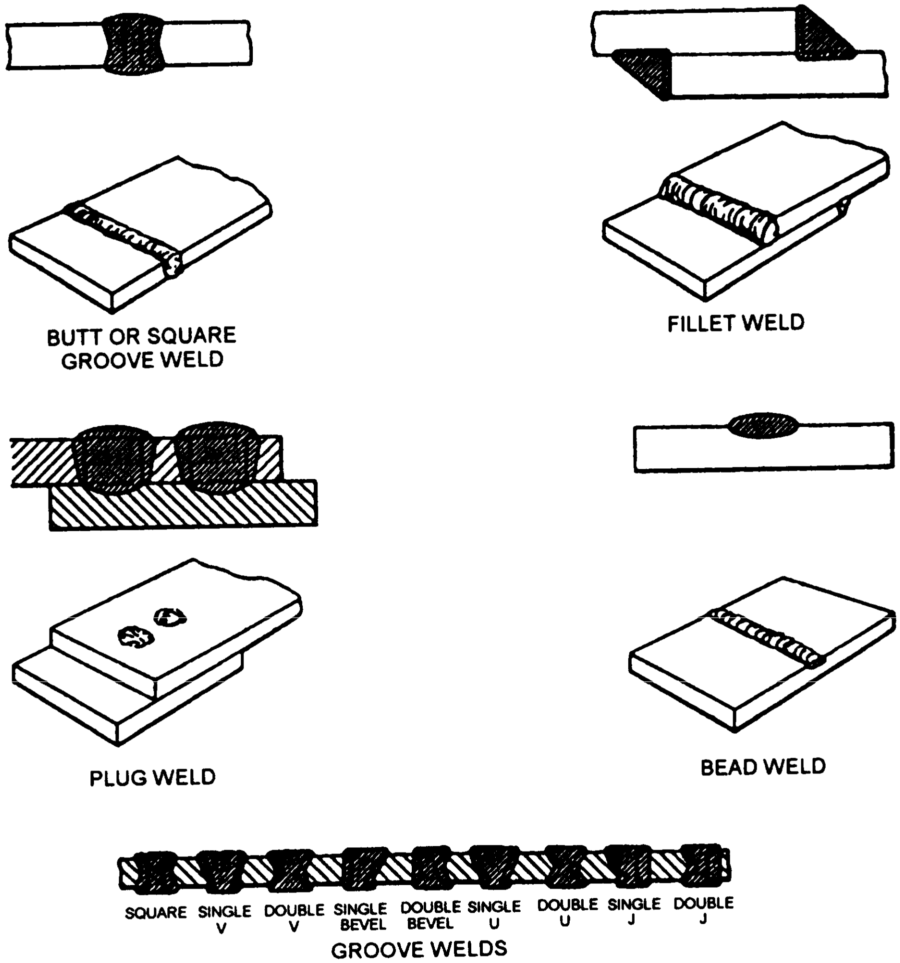


Figure 1-48.—Types or welds.

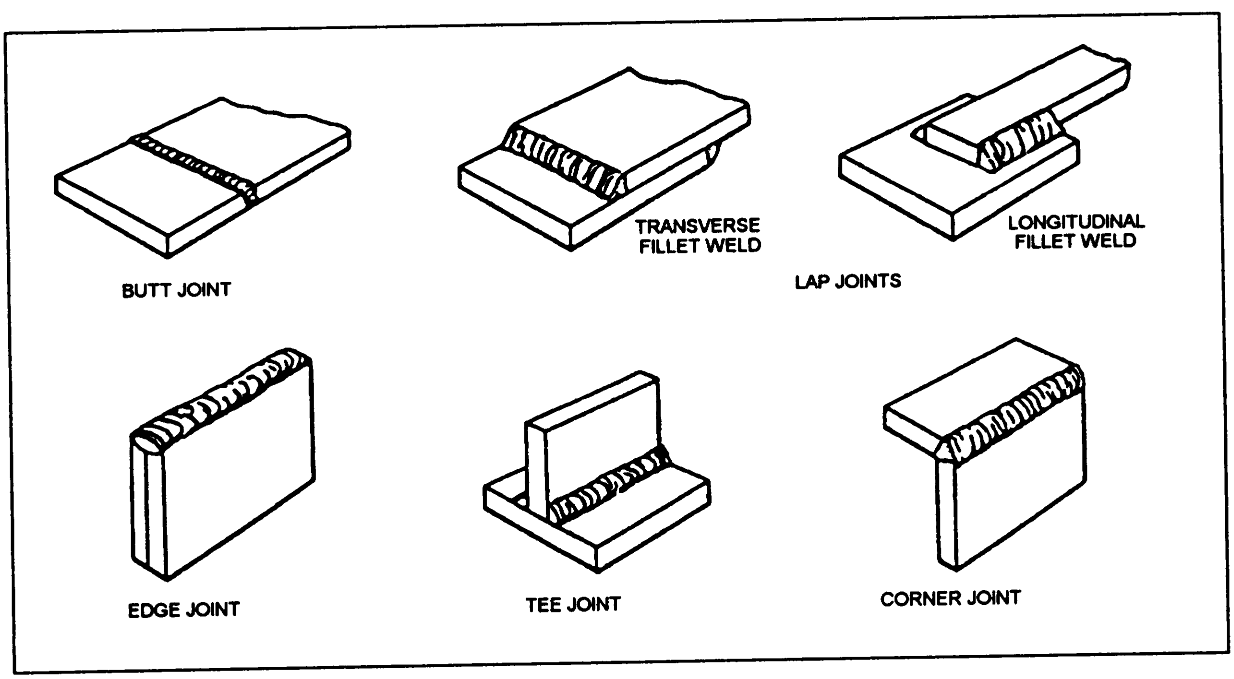


Figure 1-49.—Welded joints.

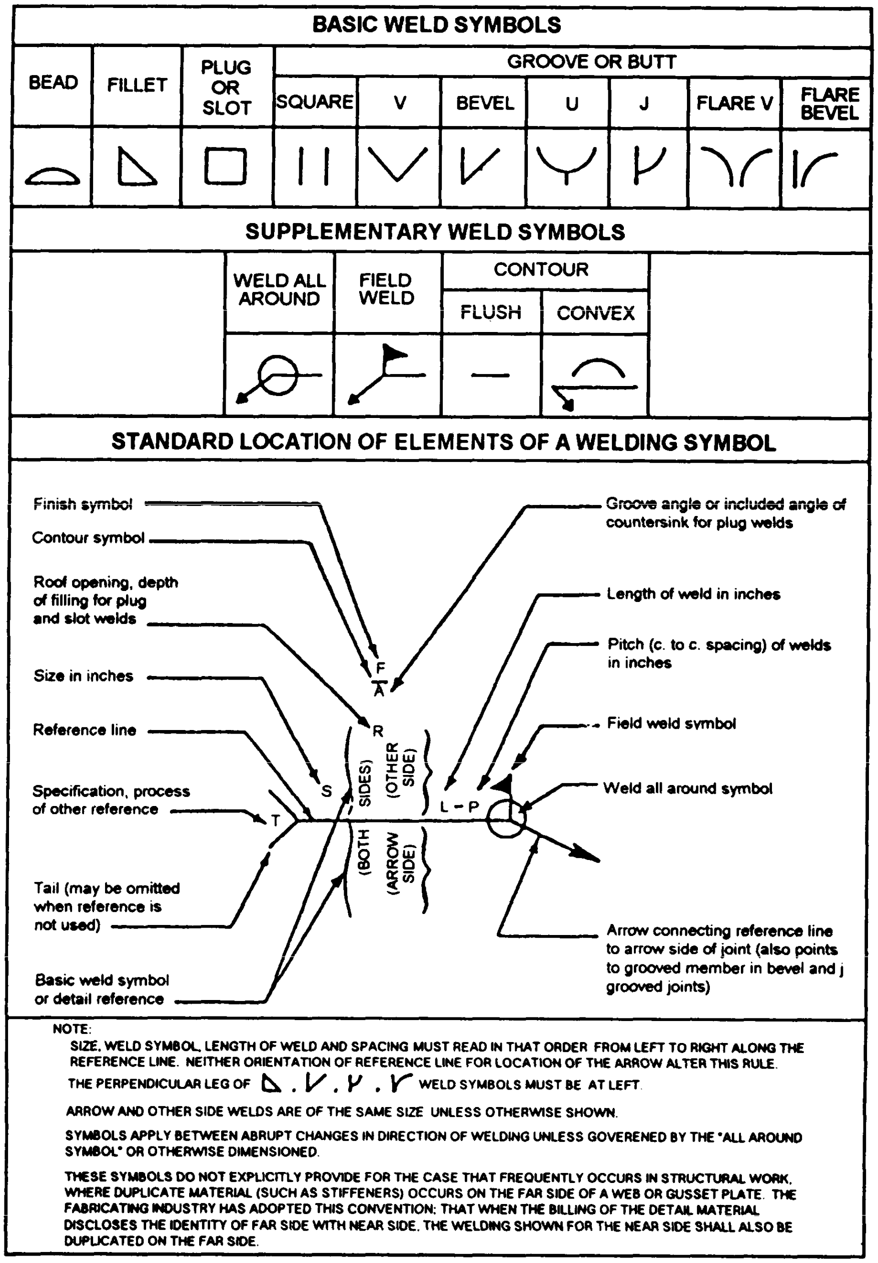


Figure 1-50.—Standard symbols for welded joints.

Figure 1-51 shows the use of a welding symbol. This figure shows a steel-pipe column that is to be welded to a baseplate. The symbol identifies to the welder that the type of weld to be used is a fillet weld, that the weld is to extend completely around the pipe-to-column joint, and that the weld is to be made in-place in the field rather than in a fabrication shop.

A detailed explanation of welding symbols and their usage is contained in *Symbols for Welding and Nondestructive Testing,* ANSI/AWS A2.4-86. Welding terms and definitions are found in *Standard Welding Terms and Definitions,* ANSI/AWS A3.0-89.

Pins

Pins for very large structures are manufactured especially for the type of job and may have diameters of 24 inches or more and be several feet in length. For most types of jobs, however, pins are between 1 1/4 inches and 10 inches in diameter. The two types of pins commonly used are threaded-bridge pins and cotter

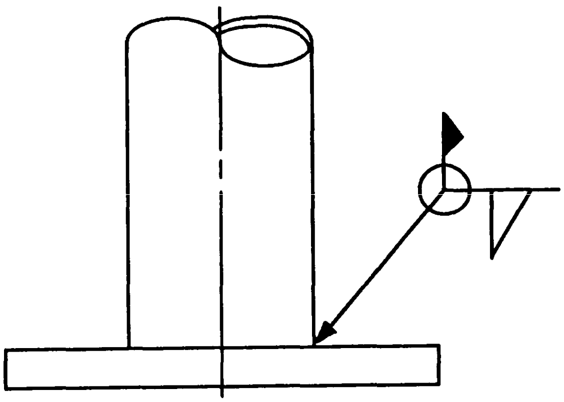


Figure 1-51.—Example of a welding symbol in use.

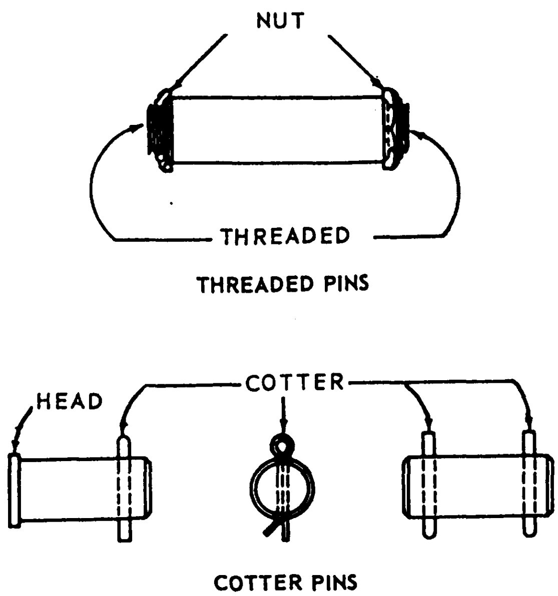


Figure 1-52.—Pins for structural steel connections.

pins. (See fig. 1-52.) **Threaded pins** are held in place after insertion by threaded recessed nuts on both ends of the pin. **Cotter pins** are held in place by small cotters that pass through holes drilled in the pins. Washers and separators, made from lengths of steel pipe, are used to space members longitudinally on pins. Holes for small pins are drilled; larger pinholes are bored.

Rivets

Rivets are manufactured of soft steel in various nominal sizes and lengths. The sizes most often used in structural work are 3/4 inch and 7/8 inch in diameter. The lengths differ according to the thickness of materials to be connected. Rivets are inserted in the rivet

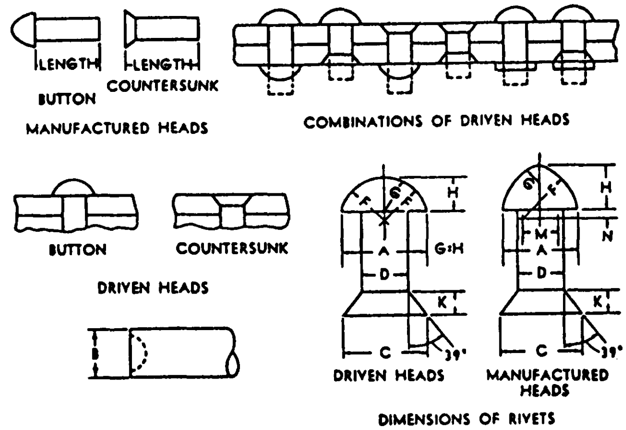


Figure 1-53.—Structural rivets.

holes while the rivet is red hot; consequently, the holes are drilled or punched 1/16 inch larger in diameter than the nominal diameter of the cold rivet.

Rivets are manufactured with one whole head already fixed. The rivet shank is cylindrical and the second head is formed by driving it with a pneumatic hammer. The rivet set, which is inserted in the end of the hammer, has a cavity of the proper shape to form the head of the rivet. Most Structural rivets are two full heads (fig. 1-53). Manufactured heads of rivets may also be obtained in countersunk shape to fit into holes countersunk in the material to be connected. When a driven countersunk head is to be formed, the rivet is driven with a flat-ended rivet set to fill the countersunk cavity in the material.

QUESTIONS

The following questions are strictly for your use in determining how well you understand the topics discussed in this chapter AND IN THE REFERENCES SPECIFICALLY CITED IN THIS CHAPTER. The intent of these questions is to help you learn the topics contained in the chapter and in the references. Remember, when you participate in the advancement examination for EA2, you may be asked questions that are drawn not only from this TRAMAN, but from the cited references as well. Therefore, it is to your benefit to answer the review questions. You do NOT have to submit your answers to these review questions to anyone for grading. Similar review questions will be included at the end of each chapter of this TRAMAN. After answering the questions, you may turn to appendix VI of this book to see how well you performed.

Q1. What are the three principal types of abutments used for fixed bridges?

Q2. Other than the material used, what is the difference between a timber pile bent and a steel pile pier?

Q3. In general, what are the three essential elements that are common to all foundations?

Q4. What type of pile is used to resist lateral loads?

Q5. What is the name of the breakwater that serves a dual function as a wharfage structure?

Q6. Between a W12 x 50 structural steel shape and an S12 x 50 shape, which one provides the greater strength? Why?

Q7. Define wall-bearing construction.

Q8. In a preengineered metal building, what is the primary purpose of the girts?

CHAPTER 2

CONSTRUCTION METHODS AND MATERIALS: ELECTRICAL AND MECHANICAL SYSTEMS

The responsibility for the design of electrical and mechanical systems rests with the engineering officer. However, as an EA assisting the engineering officer, you should be familiar with the methods, materials, and terminology used in the design and construction of these systems. This chapter provides that familiarity.

This chapter expands on the EA3 TRAMAN discussion of exterior electrical distribution systems. You should find it helpful to review chapter 9 of that TRAMAN before beginning the study of the following text.

This chapter also discusses water distribution and sewage collection systems that are exterior to buildings. You will find that some of the materials and terminology used in the design and construction of these systems are the same as those used for building plumbing. Therefore, you also should find it helpful to review chapter 8 of *Engineering Aid 3.*

ELECTRICAL POWER SYSTEM

Overall, an electrical power system includes the electrical lines, or circuits, and all of the associated equipment that are necessary to supply power from a generation point to the users of the supplied power. Generally, the power system is considered to consist of two parts: the **transmission system** and the **distribution system.** Figure 2-1 shows a typical electrical power

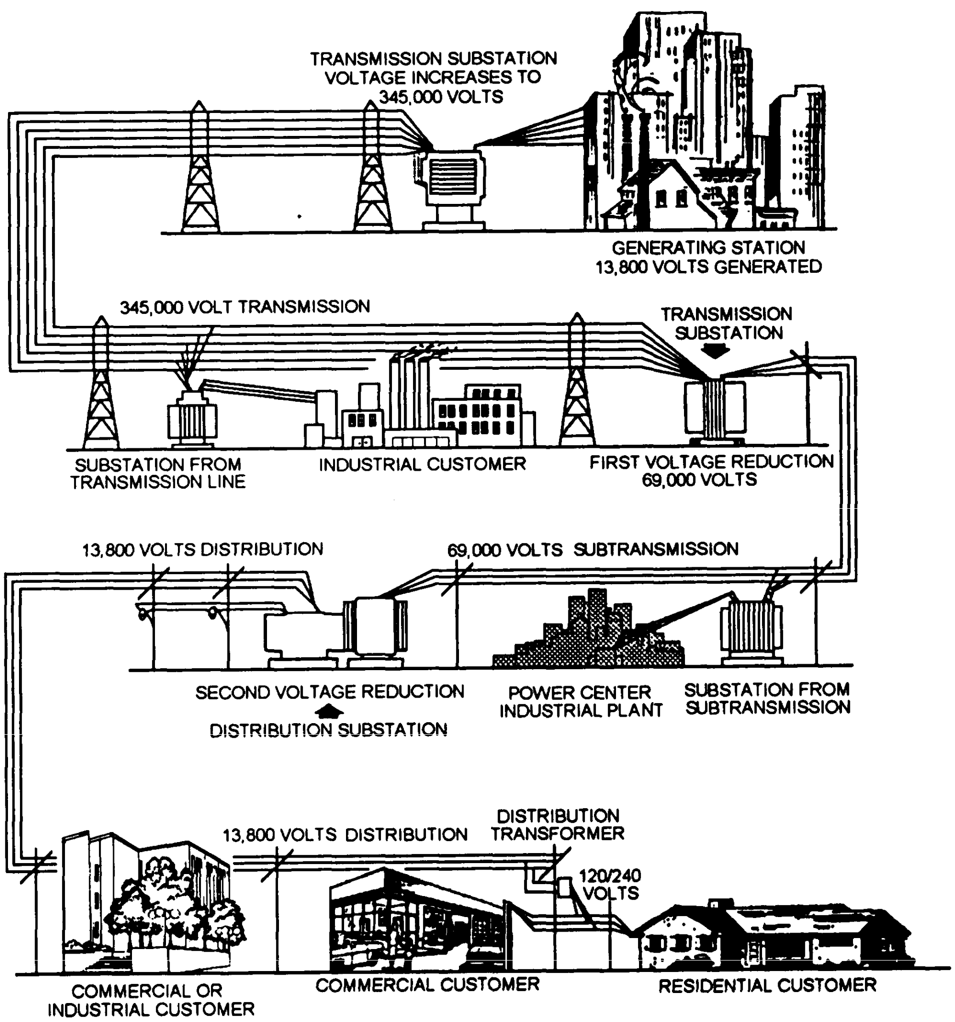


Figure 2-1.—Typical electrical power system.

system that includes both the transmission and distribution systems. To explain the two systems, we will begin with the transmission system.

TRANSMISSION SYSTEM

Refering to figure 2-1, you will see that the starting point for electrical power is its place of generation, or **generating station,** which uses fossil fuels, water pressure, or, in some locations, nuclear energy to drive turbine generators. The energy generated in these stations is generally in the range of 13,200 to 24,000 volts. That voltage is insufficient for economical transmission over long distances. Therefore, the voltage is raised to transmission levels of 138,000 to 765,000 volts at a **transmission substation** located at the generating station. A substation is a facility that contains transformers, switches, and other equipment that is used to raise or lower voltages to transmission or distribution levels and to protect the substation and the transmission lines or distribution feeders against faults.

Sets of conductors that are energized with high voltage and transmit large bulks of power over relatively long distances are known as **transmission lines** or **transmission circuits.** Usually, these circuits are run overhead with structures supporting the conductors, which are attached to insulators. In some locations where it is not practical or permissible to have overhead high-voltage lines, the transmission lines may be run underground. The transmission lines shown in figure 2-1 are overhead and supported by towers.

As shown in the figure, the transmission lines, or circuits, deliver power from the **transmission substation** located at the generating plant to customers located along the route. Where required throughout its length, transmission circuits are equipped with additional transmission substations that lower the voltage to reduced transmission (or subtransmission) levels. The transmission circuits are also equipped with **distribution substations** that reduce the voltage to required distribution levels. It is at the distribution substations that the distribution system begins.

DISTRIBUTION SYSTEM

The distribution system is that portion of the electrical power system that connects the transmission system to the user's equipment. It includes distribution substations, feeder circuits, distribution centers, primary mains, distribution transformers, protective devices, secondary circuits, and services. Figure 2-2 shows the principal elements of a distribution system.

A power distribution system may be either an overhead distribution line or an underground cable

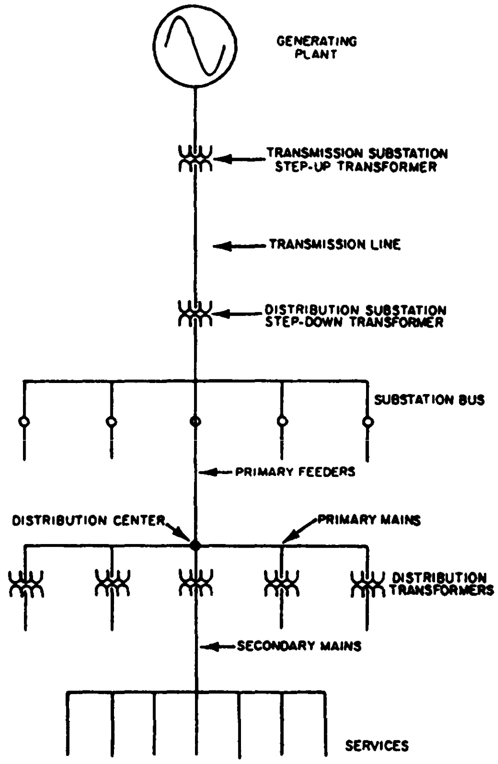


Figure 2-2.—Elements of a power distribution system.

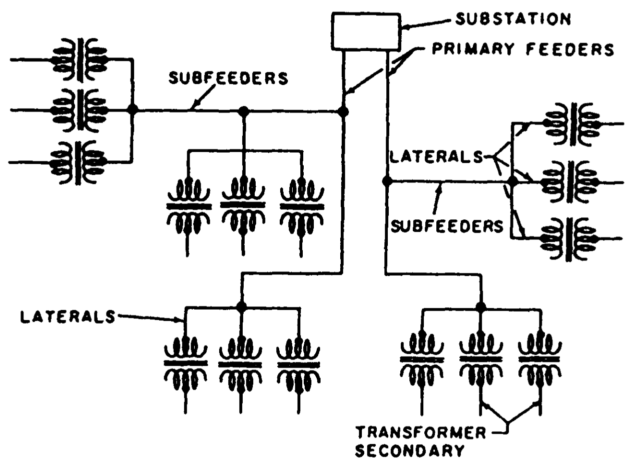


Figure 2-3.—Radial distribution system.

system. Since it is less costly to construct, the overhead system is more common. However, in some instances, such as near an airfield, an underground system may be required. This chapter will discuss mainly the overhead distribution system.

Substations

The distribution substation transforms the transmission voltage to the proper distribution voltage levels and protects the substation and transmission lines against faults occurring in the feeder circuits. At advanced bases, the source of power may be generators

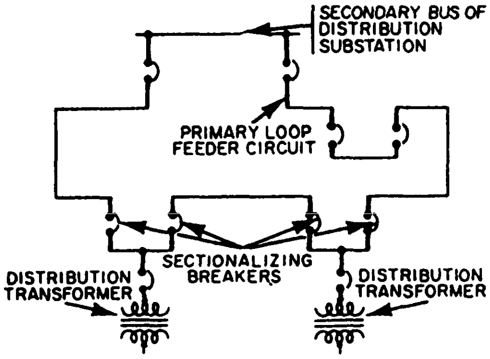


Figure 2-4.—Loop (or ring) distribution system.

connected directly to distribution centers. This eliminates the need for substations because the generator generates a usable voltage.

Primary Feeders

Primary feeders are those conductors in a distribution system that are connected from the distribution substations and that transfer power to the distribution centers (fig. 2-2). They may be arranged as radial, loop, or network systems and may be overhead or underground.

RADIAL DISTRIBUTION SYSTEM.— A schematic example of a radial distribution system is shown in figure 2-3. In this system, primary feeders take power from the distribution substation to the load areas by way of subfeeders and lateral-branch circuits. This is the most common system used because it is the simplest and least expensive to build. It is not the most reliable system, however, because a fault or short circuit in a main feeder may result in a power outage to all the users served by the system.

Service on this type of system can be improved by installing automatic circuit breakers that will reclose the service at predetermined intervals. If the fault continues after a predetermined number of closures, the breaker will be locked out until the fault is cleared and service is restored.

PRIMARY LOOP (OR RING) DISTRIBUTION SYSTEM.— The loop (or ring) distribution system is one that starts at a distribution substation, runs through or around an area serving one or more distribution transformers or load centers, and returns to the same substation. The loop system (fig. 2-4) is more expensive to build than the radial type, but it is more reliable and may be justified in areas where continuity of service is required—at a medical center, for example.

In the loop system, circuit breakers sectionalize the loop on both sides of each distribution transformer connected to the loop. A fault in the primary loop is cleared by the breakers in the loop nearest the fault, and power is supplied the other way around the loop without interruption to most of the connected loads. If a fault occurs in a section adjacent to the distribution substation, the entire load can be fed from one direction over one side of the loop until repairs are made.

NETWORK SYSTEM.— The network system (fig. 2-5) is the most flexible type of primary feeder

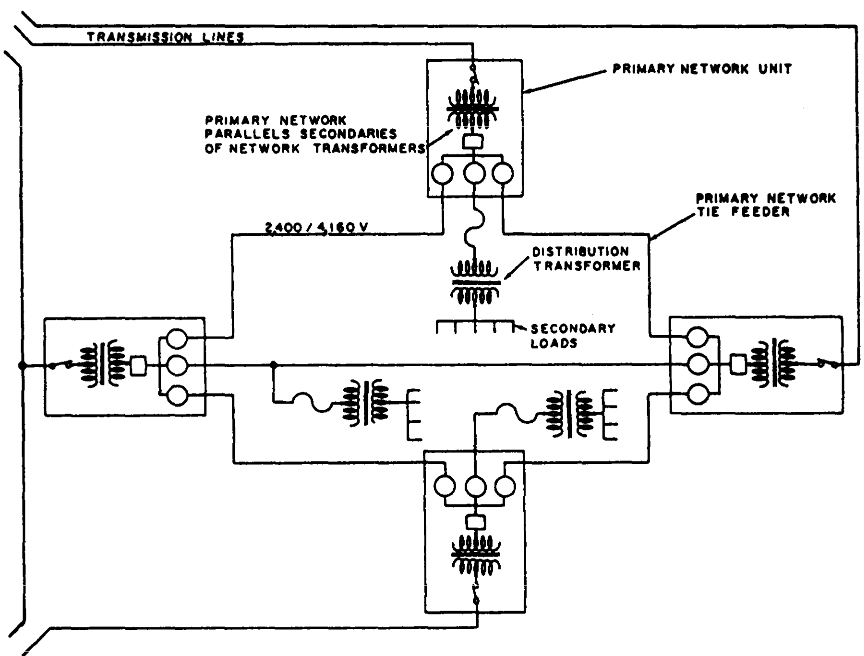


Figure 2-5.—Network distribution system.

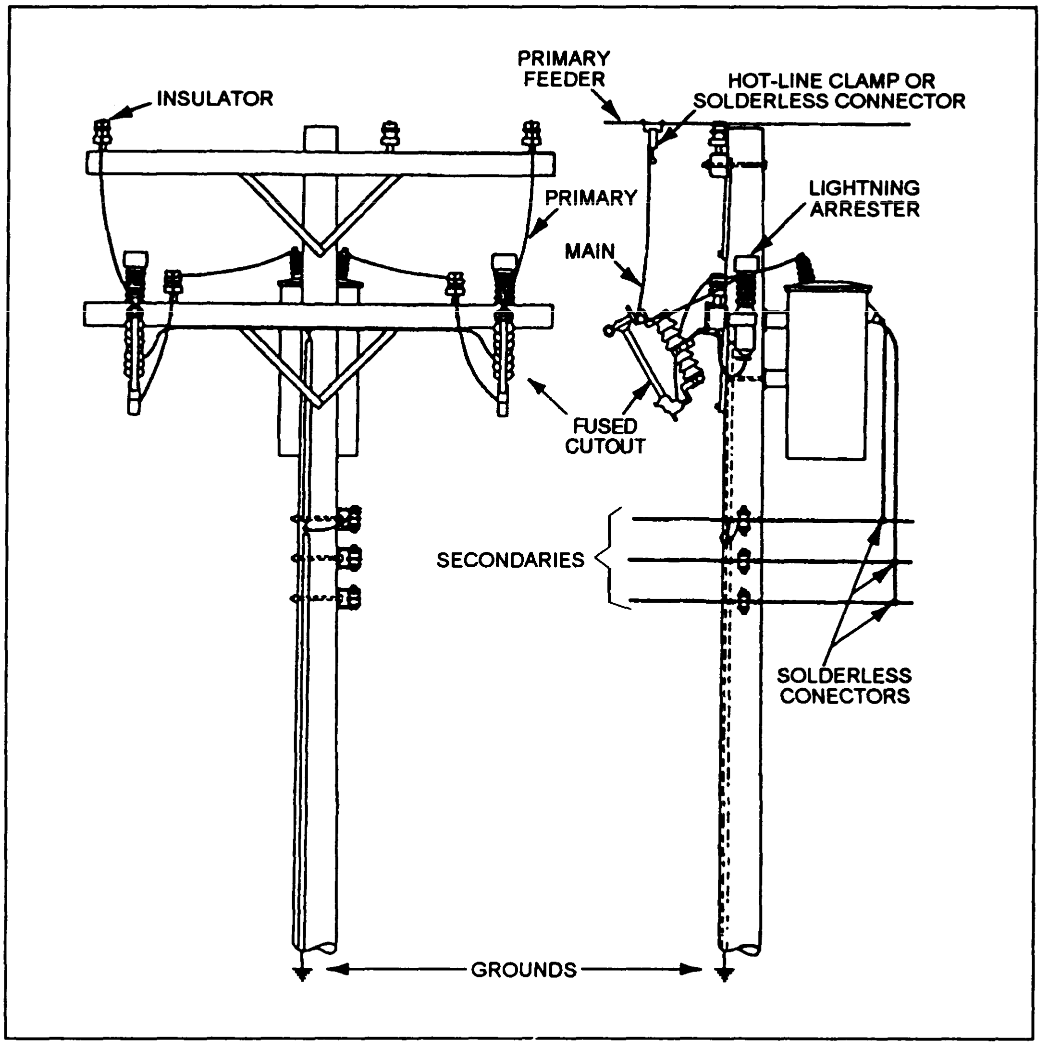


Figure 2-6.—Typical pole-mounted feeders, primary mains, transformers, and secondaries.

system. It provides the best service reliability to the distribution transformers or load centers, particularly when the system is supplied from two or more distribution substations. Power can flow from any substation to any distribution transformer or load center in the network system. The network system is more flexible about load growth than the radial or loop system. Service can readily be extended to additional points of usage with relatively small amounts of new construction. The network system, however, requires large quantities of equipment and is, therefore, more expensive than the radial system.

Primary Mains

Primary mains are connected to the primary feeders. In overhead installations, these mains are always installed below the feeders on a pole. The distribution transformers are connected to the primary mains through fused or automatic cutouts. Figure 2-6 shows the primary main to which the transformer is tapped. The cutouts, one on each primary line, contain the fuses that protect the transformer against overload and short circuits.

Distribution Transformers

Most electrical equipment in the Navy uses 120/208 volts. The primary voltage on Navy shore installations, however, is usually 2,400/4, 160 volts. For this reason, a **distribution transformer** is required to reduce (step down) the high primary voltage to the utilization voltage of 120/208 volts. Figure 2-6 shows one of various different types of transformer arrangements and installations. Regardless of the type of installation or arrangement, transformers must be protected by fuses or circuit breakers and lightning protection.

There are three general types of single-phase distribution transformers. The conventional type (fig. 2-6) requires a lightning arrester and fused cutout on the primary phase conductor feeding it. The self-protected (SP) type has a built-in lightning protector. The completely self-protected (CSP) type has the lightning arrester and current-overload devices connected to the transformer. It requires no separate protective devices.

Secondary Mains

Secondary mains or circuits are the lines that carry the electric power from the secondary side of the transformer through a distribution system to supply the electrical loads. They may or may not be on the same pole with the feeder lines. If on the same pole, they may be either on a crossarm below the feeder lines or, as shown in figure 2-6, on spool racks attached to the side of the pole below the feeder lines. The secondary circuits may have several wires (service drops) connected to various buildings to serve their electrical needs. Where a large load is in demand, a transformer or transformer bank may be located at the building site.

SINGLE PHASE.— Single-phase secondary circuits usually supply current for electrical lighting loads, small electric appliances, and small (1 horsepower and under) single-phase electric motors. The secondaries consist of two hot conductors and one neutral conductor. In overhead construction, these conductors are mounted on the bottom crossarm on a pole or on spools attached to the side of a pole. (See fig. 2-6.) One transformer will feed this circuit if the required load to be served is not too heavy. Where the load is heavy or where several buildings are served, a bank of three transformers may feed the circuit.

The normal voltage of a single-phase circuit is 120 volts from either one of the energized conductors to the neutral or 240 volts across the two energized conductors.

THREE PHASE.— Some facilities, such as motor pools, industrial shops, and water and sewage plants, may have equipment using three-phase motors, which require three-phase power. Transformer banks are installed to supply this power. If a number of buildings in the area require three-phase power, cluster mount may be installed with the three-phase secondaries extending in two or three directions and with service drops extending from the secondary to the buildings.

Service Drops

As you learned in the EA3 TRAMAN, each building requiring electric current must have lead-in conductors, known as **service drops.** These may be two-, three-, or four-wire conductors or a single cable containing the required number of conductors. A service drop may be connected to a secondary main to provide service to a small load. Where a transformer bank services a building requiring a large power load, the secondary becomes the service drop, since it feeds current to one load only.

Most Navy buildings are not metered. However, where it is desired to know how much electricity is being consumed, a meter is installed ahead of the main switch to the building. In this case, the service drop is connected to the meter before it is connected to the mains.

CONTROL AND PROTECTIVE DEVICES

A power-distribution circuit, like any other electrical circuit, requires the use of special devices to provide control and to protect the system from internal or external influences that may damage the circuit or injure personnel.

Distribution Cutouts, Switches, Reclosers, and Circuit Breakers

A distribution cutout is used to protect the distribution system or the equipment connected to it. Distribution cutouts are used with the installation of transformers (fig. 2-6), capacitors, cable circuits, and at sectionalizing points on overhead circuits.

Two types of switches used in power distribution are the air switch and the oil switch. Both devices are used to connect or disconnect a portion of the power distribution system. The air switch is used for the overhead section of the distribution system, and the oil switch is used with underground portions.

Reclosers are for overload protection and are designed to open a circuit in an overload condition and then automatically reclose the circuit. Reclosers come in single-or three-phase models and can either be pole mounted or installed in a substation.

Oil, air, gas, and vacuum circuit breakers are used to switch electric circuits and equipment in and out of the system. They may be operated manually, by remote control, or automatically under predetermined conditions or when electrical failures in the system occur.

Lightning Arresters

The purpose of installing a lightning arrester (fig. 2-6) on primary lines is twofold: first, to provide a point in the circuit at which a lightning impulse can pass to earth, through a ground wire, without injuring line insulators, transformers, or other connected equipment;

and second to prevent any follow-up power current from flowing to ground Lightning arresters must be installed on the primary side of all substations, distribution centers, distribution transformers, and capacitor banks.

CONDUCTOR SUPPORTS

An important element in any overhead electrical distribution system is a structure that is designed to support the weight of the conductors and all equipment mounted on the structure. The structure is also designed to provide required clearances from the ground to the conductors and between conductors. Common types of structures used for this purpose are wood poles, reinforced concrete poles, metal poles, and metal towers. The following text discusses poles.

Types of Poles

Poles used in the Navy can be wood, reinforced concrete, or metal (steel or aluminum). However, concrete and metal poles should be used only when they are more economical or when special considerations warrant their use.

WOODEN POLES.— Wood poles are available in various types, depending upon species of trees available in the area. For example, yellow pine is commonly used in the eastern United States. The length and circumference of poles also vary. Poles are available in 5-foot incremental lengths and with top circumferences varying in 2-inch increments. Therefore, we have poles that measure 30, 35, 40 feet, and so on, in length and 17, 19, 21 inches, and so on in top circumference.

The classification (or **class)** to which a wood pole, of given length and top circumference, belongs is determined from the circumference of the pole measured at a point 6 feet up from the butt. The class determines the strength of the pole, which is the ability of a pole to resist loads applied 2 feet from the top of the pole. Pole classes are numbered from 1 to 10, with 1 being the strongest. A Class 2 pole, for example, will withstand a force of 3,700 pounds and a Class 4 pole will withstand 2,400) pounds of force.

Wood poles are used mostly in distribution systems and light-duty transmission lines. The class of pole used depends on what the pole is used for. In other words, is the pole to be used as a line pole, corner pole, or transformer pole? The length of pole used is determined, in part, by the clearances required for the voltage of the circuits on the poles, the number of circuits, and the location of the pole in relation to streets, railroads, buildings, and so forth. Clearances are also required to provide safe working conditions for linemen working on the lines. All clearances have minimum requirements that are set by the American National Standards Institute (ANSI) and the National Fire Protection Association (NFPA). These requirements are specified in the *National Electrical Safety Code* (NESC), ANSI C2-87, and the most recent edition of the *National Electrical* Code®(NEC®).

Engineers also consider local conditions when determining the length of poles. For example, poles located in densely popular high-traffic areas need to be higher than those located in sparsely populated rural areas. In the Navy, the MINIMUM height of a wooden transformer pole is 35 feet and of all other wood poles, 30 feet. Other guidance regarding the heights and classes of poles is found in *Power Distribution Systems,* MIL-HDBK-1004/2.

CONCRETE POLES.— Concrete poles are preferred where the life of wood poles is shortened by local conditions. Concrete poles may be solid or hollow. Solid concrete poles are made in a trough form with steel reinforcing rods running lengthwise. The hollow type of pole is made by placing the concrete and reinforcing rods into a cylinder of the desired length and taper and then revolving the cylinder in a lathelike machine. The hollow type is lighter than the solid type and, in addition, provides a means for making connections through the pole to underground cables or services. This technique allows wires to be concealed from view and protected from the weather.

The exterior form of concrete poles can be changed to meet almost any need. Gains (cut notches) for crossarms and holes for bolts are cast in the pole. Either metal pole steps are solidly cast into the pole or prethreaded holes for the steps are installed.

Although concrete poles last longer and are stronger than wood poles, they are also expensive to make and install. However, the rising cost of wood poles and their treatment and maintenance plus better landscaping have brought on an increased use of concrete poles.

METAL POLES.— Metal poles used in the Navy are either steel or aluminum. Steel poles are not used in ordinary power-line distribution circuits except for unusual circumstances, such as where there is a high stress or heavy load placed on the pole. Aluminum poles are used for lightweight distribution, such as streetlights.

Guying of Poles

As poles must be strengthened sufficiently to carry heavy conductors and pole-mounted equipment, the

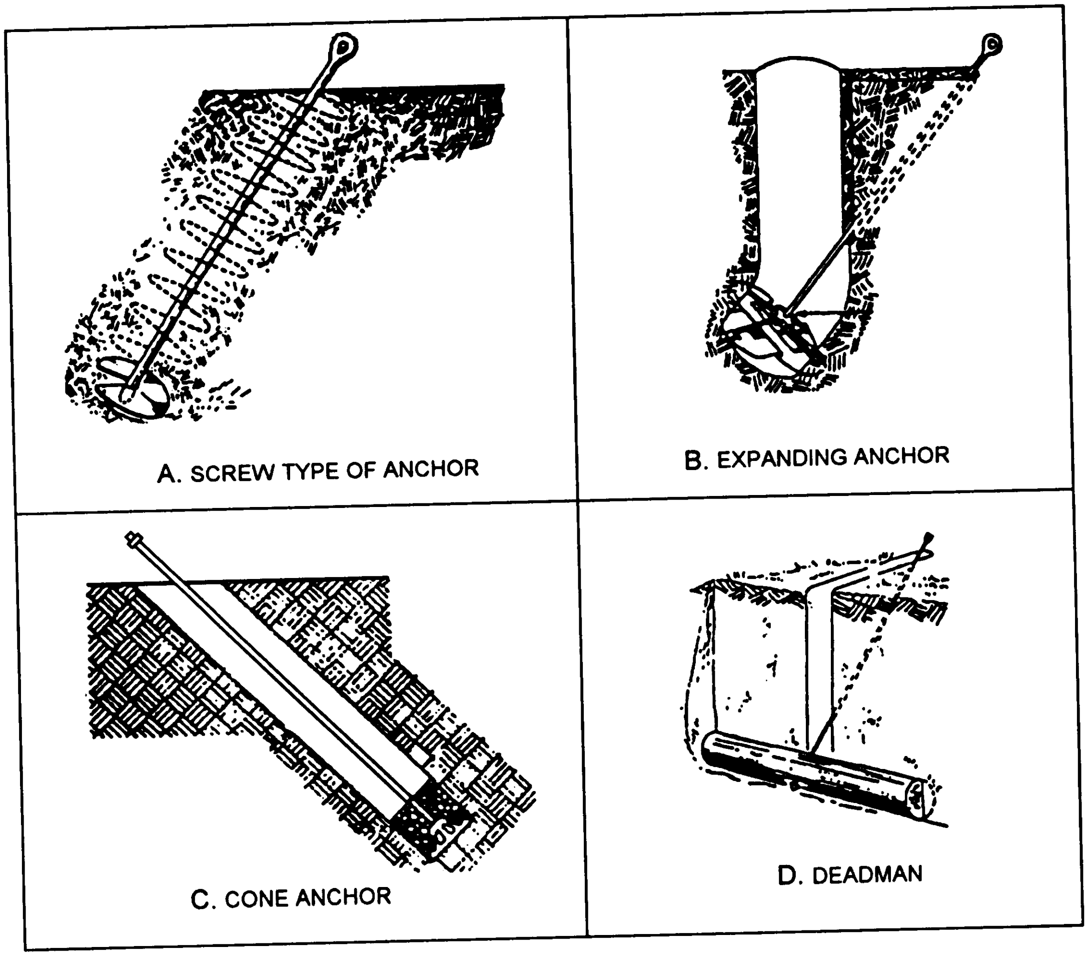


Figure 2-7.—Anchors.

proper anchoring and guying of pole lines is essential. These precautions also help to support poles that are set in sandy or swampy ground, and they counteract added strains caused by the elements, such as high winds, snow, and ice.

Various types of guy anchors have been developed to hold imposed loads securely in varying soil conditions. Some of these types are shown in figure 2-7.

There are many different uses of guys, some of which are shown in figures 2-8 through 2-13. Each usage has its own terminology as follows:

1. DOWN GUYS. The most common type of guy is the down guy. With this type of guy, the wire is run from the top of the pole to an anchor in the ground. Some common uses of the down guys areas follows:

a. SIDE GUY. A side guy (fig. 2-8) is used to reinforce a pole line against an unbalanced side pull of the conductors. Such pulls are developed at curves, angles, or sharp turns in the line.

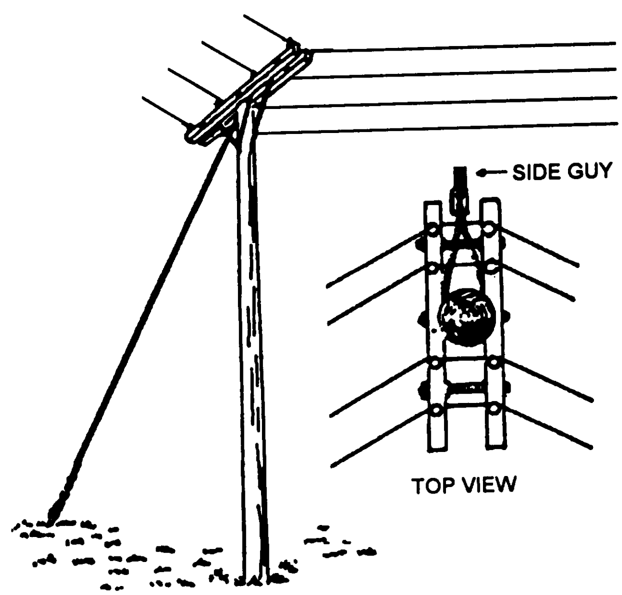


Figure 2-8.—Side guy.

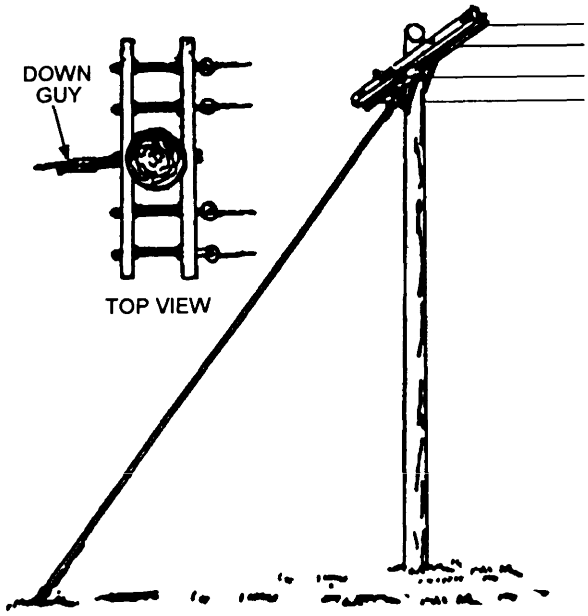


Figure 2-9.—Terminal down guy.

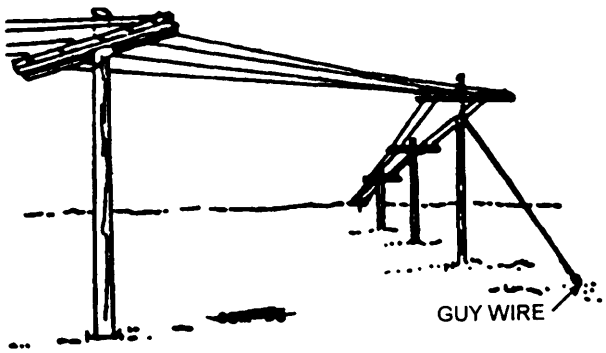


Figure 2-10.—Corner guy.

b. TERMINAL DOWN GUY. As shown in figure 2-9, this type of guy is usually placed at the end of a pole line to counterbalance the pull of the line conductors. The terminal down guy can, at times, be called a **corner guy.**

c. CORNER GUY. The corner guy (fig. 2-10) is used where there is a directional change in the line.

d. LINE GUY. A line guy is installed in a straight pole line where an unusual stress or strain comes from farther down the pole line or where there is a chance the conductors may break and cause excessive damage. Many times, line guys are installed in pairs, as shown in figure 2-11. A line guy is often called a storm guy.

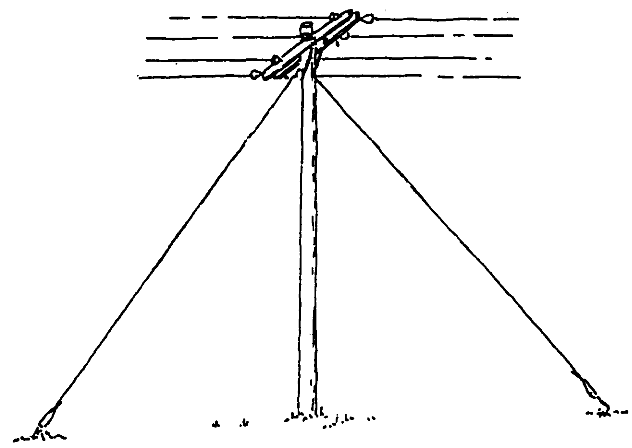


Figure 2-11.—Line guy, or storm guy.

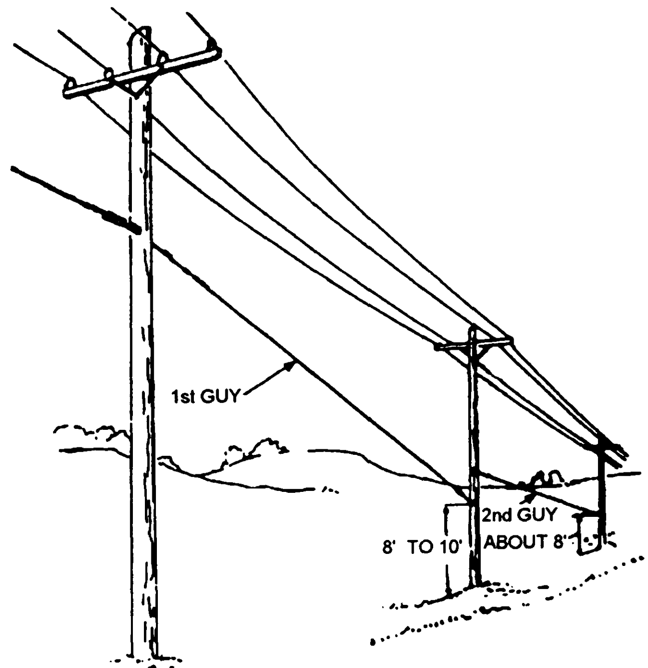


Figure 2-12.—Head guy.

2. HEAD GUY. A head guy runs from one pole to the next pole down the line. It is used to transfer the load supported by one line pole to another, as shown in figure 2-12.

3. PUSH BRACE. A push brace (fig. 2- 13) is used where a pole cannot be guyed and is too small to be self-sustaining. It is used in marshy or sandy soils where anchors cannot be firmly embedded. The upper end of the brace is bolted to the pole.

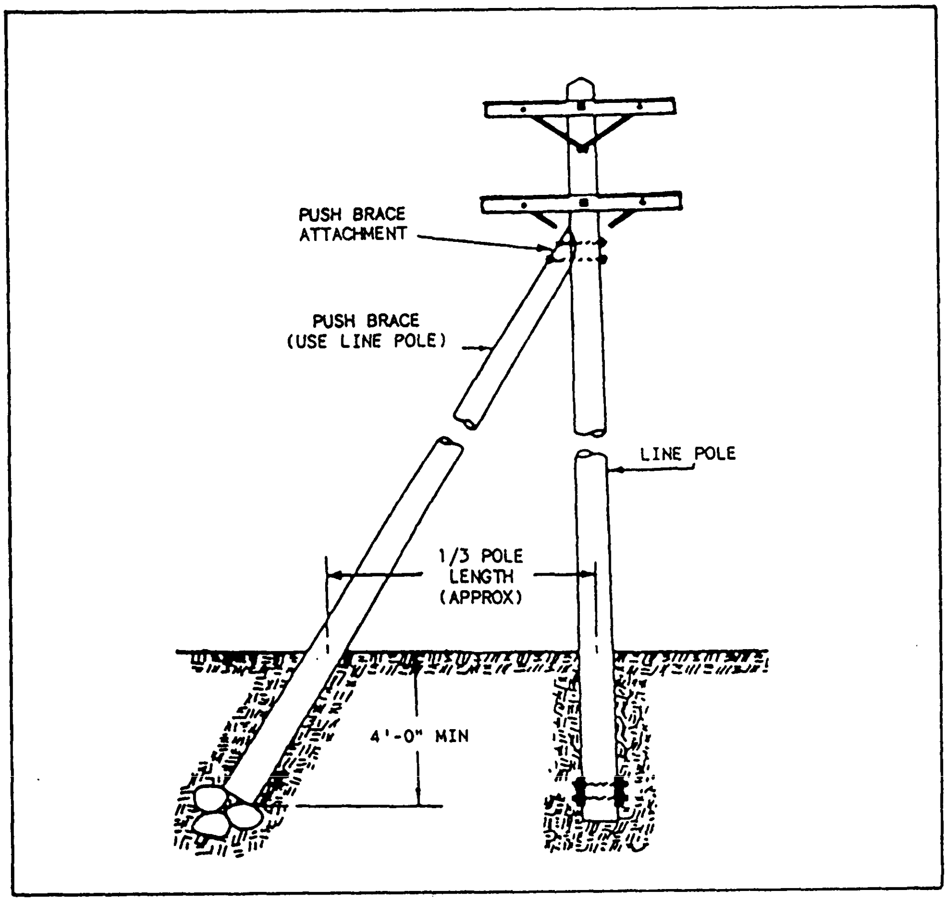


Figure 2-13.—Push brace.

Laying Out of Pole Lines

Pole lines are designed based on materials and construction methods specified in *Overhead Electrical Work,* NAVFAC NFGS-16302. The following paragraphs briefly describe some of the things that are considered when designing and constructing a pole line. As an EA preparing construction drawings or performing surveying operations, you may be directly involved in some of them. The following discussion is intended as familiarization so you will understand why the engineer plans a line the way he does:

1. **Use the shortest possible route.** Most of the time the shortest route is the least expensive. The pole line should be run as straight as possible from one point to another.

2. **Follow highways and roadways as much as possible.** This makes it easy to build the line and to inspect and maintain it. As much as possible, the pole line should be located on the same side of the road, and on the side that is most free of other lines and trees. When trees line the road, it might be better to locate the line a short distance away from the road. That way the trees are preserved, tree trimming is eliminated, there are no outages caused by trees falling into the line, and maintenance of the line is simplified.

3. **Follow the farmer's property or section lines.** This is normally not a major concern in the military. However, the engineer may have to consider bomb ranges and other such areas. If railroad tracks run through the area, it is best to follow them since the path has already been cut.

4. **Route in the direction of possible future loads.** The route of the pole line should go as close to new load centers as possible.

5. **Avoid going over hills, ridges, swamps, and bottom lands.** Hills and ridges are subject to lightning storms. Swamps and bottom lands are subject to

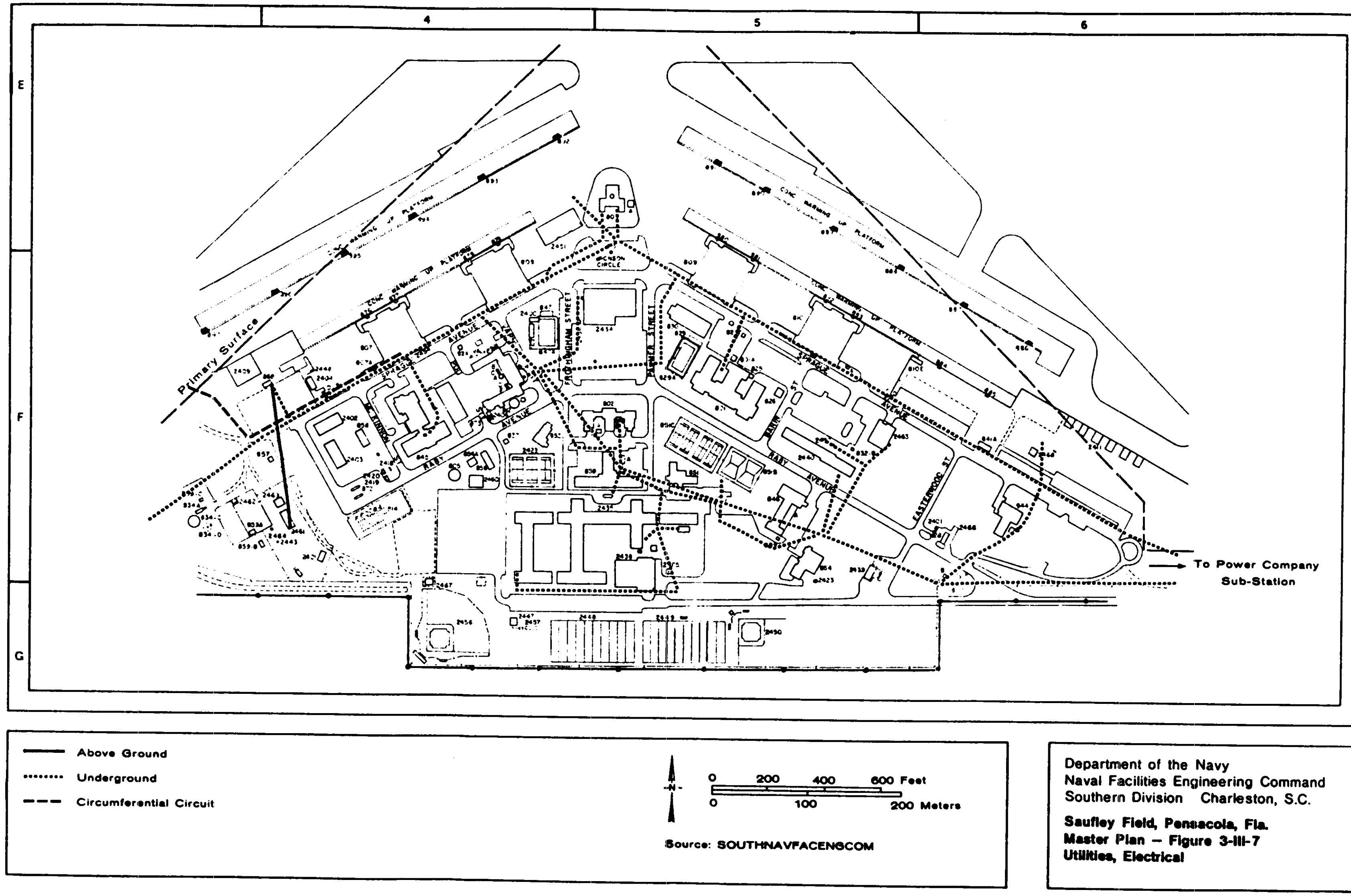


Figure 2-14.—Typical master plan drawing of an electrical distribution system.

flooding. Following these routes also makes it difficult to deliver materials.

6. **Avoid disrupting the environment.** Taking into consideration environmental codes and regulations, the engineer should select routes that cause the least disturbance to the environment. The engineer should also consider aesthetics when reviewing possible routes.

ELECTRICAL DISTRIBUTION DRAWINGS

The following text discusses the types of electrical distribution drawings that you may prepare when you are assisting the engineering officer in a construction battalion or when assigned to the engineering division of a public works department.

Electrical Distribution Plans

The type and extent of information placed on an electrical distribution plan depends on the purpose of the plan. Figure 2-14 is a distribution plan for a Navy activity that is taken from that activity's master plan. As you can see, it shows the routes of the distribution circuits, but it only identifies them as aboveground or belowground. For this plan, you would find a brief narrative description of the circuits located in the text of the master plan.

Obviously, a drawing of the type shown in figure 2-14 is of little use to an engineer or lineman who requires specific information about the distribution system. For this purpose, you should prepare a detailed electrical distribution plan. The detailed plan is drawn using the proper electrical symbols found in ANSI Y32.9. Similar to figure 2-14, the detailed plan shows all buildings and facilities and the routing of the distribution lines. In addition and as applicable to the type of system you are drawing, you also should include the following information:

1. The source of power (power plant, public utility line, substation, or standby generator with electrical data).

2. The number, type, and size of underground conduit or cable ducts and the size, number, voltage, and type of cable.

3. Where cable runs are made without installed ducts, indicate the location, dimensions, and description of splice boxes.

4. Identify and describe all electrical manholes and handholes by location, identification number, type, dimensions, and top and invert elevations.

5. Describe all transformer vaults, either aboveground or belowground, with dimensions, top and invert elevations, numbers, type, and electrical data.

6. Electrical data for all substations.

7. The location and type of all sectionalizing switches.

8. The number, size, type, and voltage of all overhead conductors.

9. The location, identification, material, class, and height of all poles.

10. The number and rating of all pole-mounted transformers.

11. Street-lighting systems, light standards, type, and rating of lights.

12. The number, size, voltage, and type of street-lighting circuits.

13. Note any buildings containing street-lighting transformers and control equipment together with type and rating of transformers.

To simplify the drawing, it is common practice to place much of the above information in appropriate schedules. For example, in an overhead distribution plan, you need only show the location and identification number of the poles on the plan. The material, class, and height of the poles can be placed in a pole schedule that is listed by the pole identification numbers.

Site Plans

Site plans are discussed in the EA3 TRAMAN. As you should recall from your study of that training manual, a site plan furnishes the essential data for laying out a proposed facility. It shows property boundaries, contours, roads, sidewalks, existing and proposed buildings or structures, references, and other significant physical features, such as existing utility lines. For small, uncomplicated buildings, you can often show all proposed electrical and other new utility lines on the same site plan. For the average facility, however, it is common practice to prepare separate utility plans that are included, as applicable, in the plumbing and electrical divisions of a set of project plans.

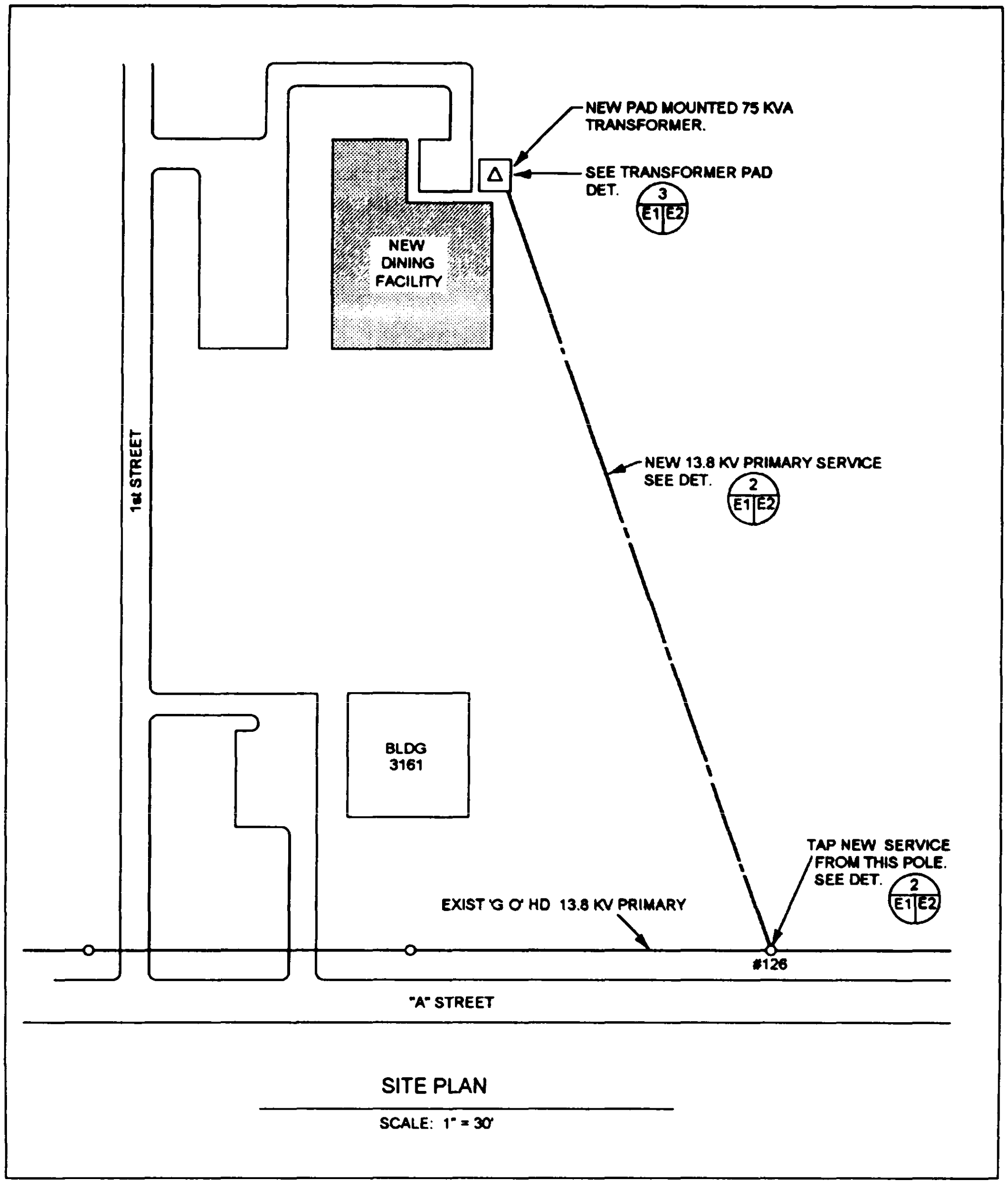


Figure 2-15.—Electrical site plan.

Figure 2-15 shows a simple electrical site plan. This plan shows the routing of a new 13.8-kilovolt (kV) primary service line to a new dining facility. The new service is tapped to an existing 13.8-kV overhead primary feeder, runs down existing pole Number 126, and then runs underground to a new pad-mounted 75-kilovoltampere (kVA) transformer located next to the new facility.

Although a competent Construction Electrician or contractor could install this new service line from only the site plan, as shown in figure 2-15, he would have to prepare additional drawings or sketches to show his workmen the specific details of the construction. Therefore, to provide a better description of the installation, the electrical designer prepares additional electrical details.

Electrical Details

The purpose of details is to leave little doubt about the exact requirements of a construction job. In preparing the details for the installation shown in figure 2-15, the designer chose to begin at the existing pole and work towards the new transformer pad. Figure 2-16 is a detail of the existing pole. This detail leaves little doubt about the requirements at the pole. For example, it shows the existing pole, crossarm, the existing 13.8-kV feeder, and required clearance distances. It also shows that the new circuit taps the existing conductors and then

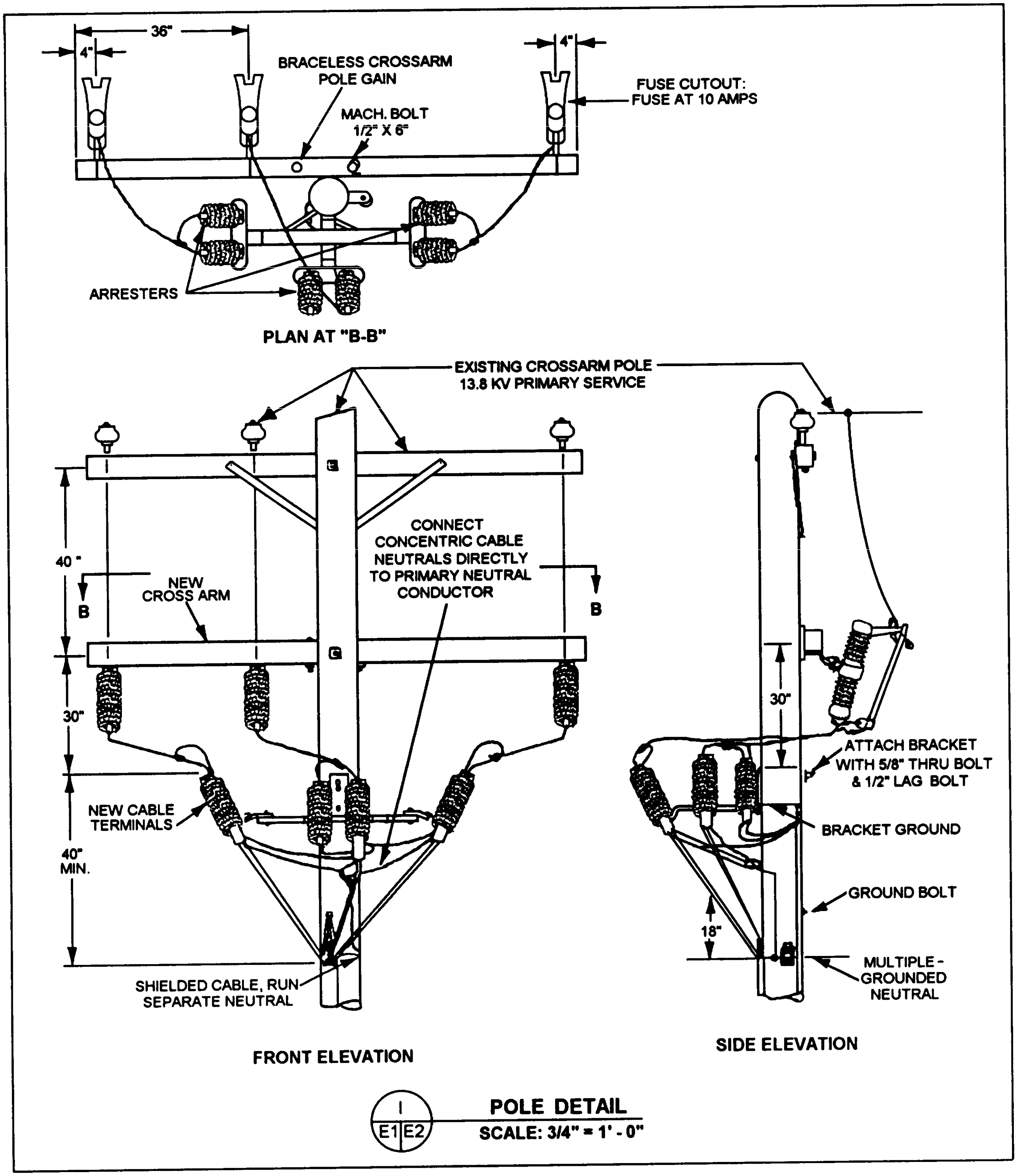


Figure 2-16.—Pole detail for use with the site plan shown in figure 2-15.

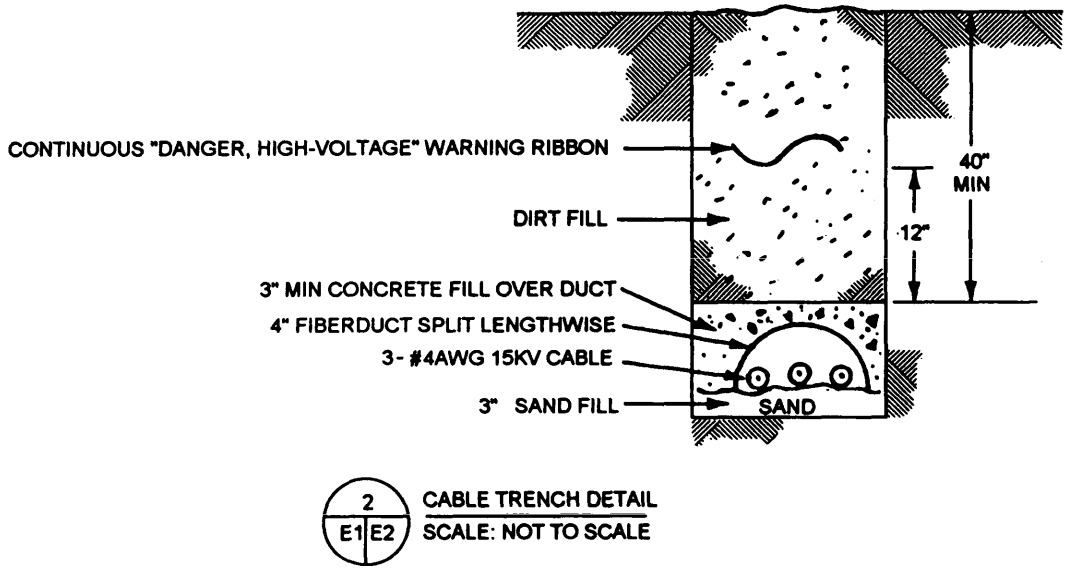


Figure 2-17.—Cable-trench detail for use with the site plan shown in Figure 2-15.

runs to three new 10-ampere fused cutouts before running to the new cable terminals and lightning arresters.

Figure 2-16 also shows that a new three-wire shielded cable is connected to the cable terminators and runs down the pole. From the pole, the cable is then run, as shown in figure 2-17, at a specified distance underground to the new transformer pad. Figure 2-18 is a detail of the pad that the designer included in the working drawings for the circuit installation. As you can see, these details leave little doubt about the job requirements. However, other information, such as specified material requirements for the concrete, cables, conduit, and so forth; specified procedures for backfilling the trench and placing the concrete; and any other information necessary to a fill understanding of the material and installation requirements should also be shown on the drawings or in the project specifications.

The preceding discussions of electrical transmission and distribution systems, distribution plans, and electrical details should leave you in a better position to aid the engineering officer or other design engineers. However, to increase your knowledge and to become even more valuable as an EA, you should further your studies by reading other publications, including the CE TRAMANs and commercial publications, such as *The Lineman's and Cableman's Handbook* by Kurtz and Shoemaker.

Now let us look at some other utility systems that you will be involved with.

WATER SUPPLY AND DISTRIBUTION

A water supply system consists of all the facilities, equipment, and piping that are used to obtain, treat, and transport water for a water distribution system. A distribution system is a combination of connected pipes that carry the supplied water to the users. In this section, we will discuss water distribution so you will be familiar with the elements of a distribution system and types of information that is required on distribution drawings. First,, however, we will discuss water sources and the need for water treatment. Although it is the engineer's responsibility to select a water source for use, to determine the methods of developing the source, and to design the supply and distribution system, you should have a general knowledge of this subject so you, as a technician, will be better able to assist the engineer.

WATER SOURCES AND TREATMENT

While the Navy prefers to obtain potable water from nearby public sources, it is sometimes not possible to do so. The following text briefly discusses the different types of water sources, source selection and develop ment, and the need for water treatment.

Water Sources

For most uses, the principal source of water is rain. This source is classified as **surface water** and **groundwater.**

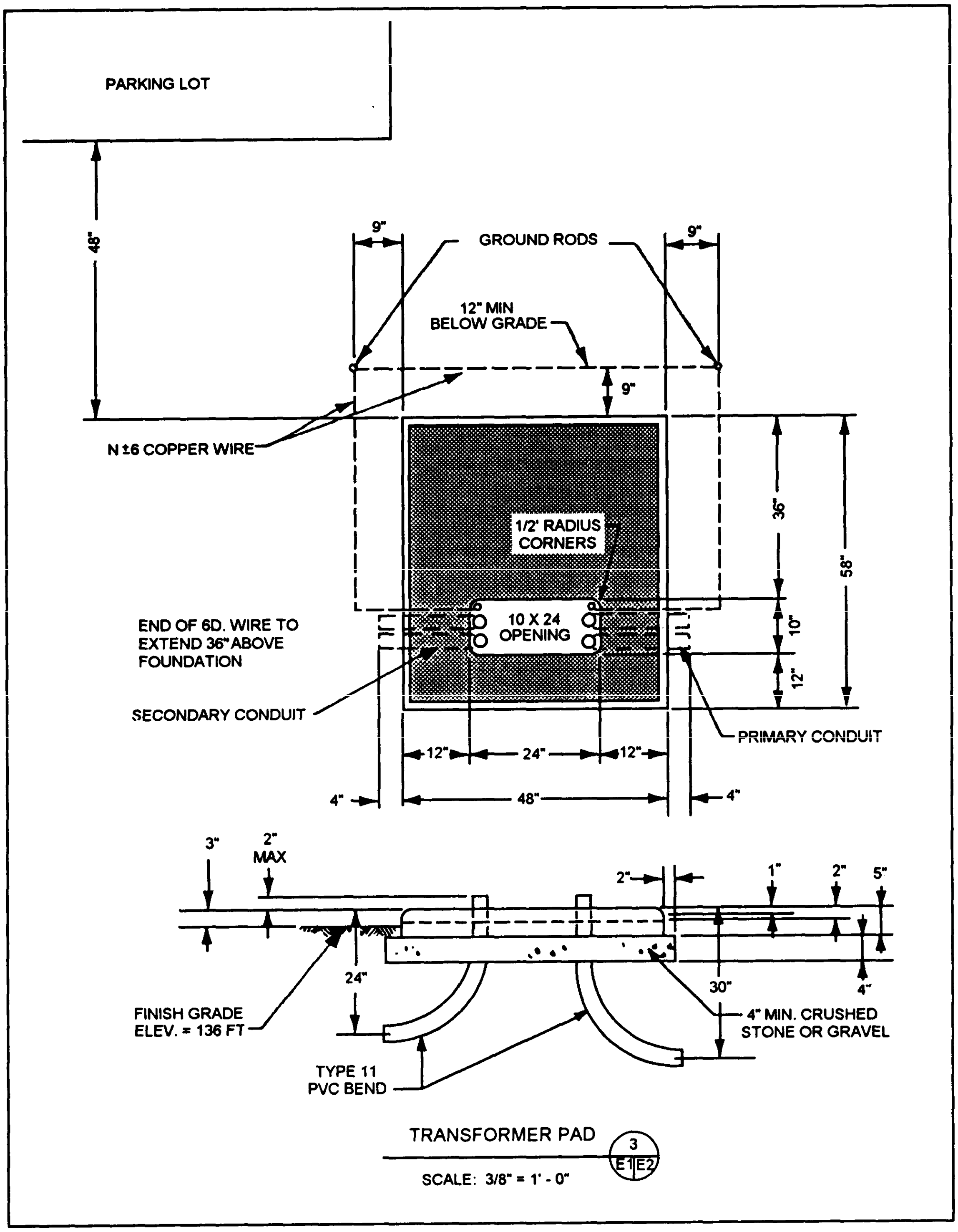


Figure 2-18.—Transformer pad details for use with the site plan shown in figure 2-15.

Surface water is rain that runs off the ground into streams, rivers, and lakes. It is the most common source used for a water supply. The availability of this source, though, depends on the amount of rainfall an area receives. In areas where there is substantial rain, the amount of surface water may be plentiful; but in dry areas or during a drought, the supply may be minimal or significantly reduced.

Groundwater is the water that percolates through the soil and builds up as underground sources. As groundwater seeps through the soil, it collects over an impervious stratum (a layer of earth, usually rock, that the water cannot penetrate) and forms a water level known as the **water table.** The depth of the water table-or the distance from the ground surface to the water level—varies considerably with the amount of rainfall. During droughts, the water table may be lowered, but during a rainy season it will probably rise.

As you should understand from your studies of soil formation, the stratum over which groundwater accumulates is an irregular, rather than a continuously flat, plane. Therefore, unless the water is confined, it flows horizontally over the irregular stratum and is nearer the surface in some places than it is in other places. Where this underground water flows near the surface and the ground area is low, the water may flow out as a spring. Or, it may seep out and create a swampy area. The underground, flowing water also may become entrapped between impervious layers. In this case, enough water pressure may buildup to create an artesian well if the strata is penetrated by drilling or by a natural opening.

In some regions of the world, there is not enough surface water or groundwater available to support the need for water. In these areas alternative sources are necessary. Rain, itself, can be an alternative source. In some locations, large catchment areas are constructed to collect rain and store it for future use. These catchment areas are usually constructed on the side of a mountain or a hill facing the prevailing direction of rainfall. In other areas, snow and ice may be used as alternative sources. Another source, although costly to develop for use, is seawater that has had the salt removed by desalination.

Selection and Development of Water Sources

When selecting a water source for development, the engineer must consider three primary factors: water quantity, water reliability, and water quality.

The quantity factor considers the amount of water that is available at the source and the amount of water that will be required or demanded for use. The amount of water that maybe available at the source depends on variables, such as the amount of precipitation, the size of the drained area, geology, ground surface, evaporation, temperature, topography, and artificial controls. Water demands are estimated using per capita requirements and other controlling factors, such as water requirements for fire protection, industrial use, lawn sprinkling, construction, vehicles, and water delivered to other activities.

The reliability of a water supply is one of the most important factors that the engineer considers when selecting a water source. A reliable water source is one that will supply the required amount of water for as long as needed. To determine the reliability of the water source, the engineer studies data, such as hydrological data, to determine the variations that maybe expected at the water source. Geological data should be studied since geological formations can limit the quantity and flow of water available. Also, legal advice may be necessary when selecting a water source since the laws regulating and controlling water rights may vary considerably from state to state and country to country.

The third primary factor the engineer must consider when selecting a water source is the quality of the water. Practically all water supplies have been exposed to pollution of some kind. Therefore, to ensure that water is potable and palatable, it must be tested to determine the existence of any impurities that could cause disease, odor, foul taste, or bad color. In most cases, the water will require treatment for the removal of these impurities. In water treatment, the water is subjected to various filtration and sedimentation processes, and in nearly all cases is disinfected using chlorine or other disinfecting chemicals.

Once the water source has been selected, development of the source can begin. Developing a water source includes all work that increases the quantity and improves the quality of the water or makes it more readily available for treatment and distribution. In developing a source, the engineer may use the construction of dams, digging or drilling of wells, and other improvements to increase the quantity and quality of the water.

For a more detailed discussion of water source selection, development, and treatment, you should refer to chapter 9 of the UT1 TRAMAN. For NAVFAC guidance, you should refer to *Water Supply System,* MIL-HDBK-1005/7.

Now that you are familiar with water sources, let us move onto water distribution.

DISTRIBUTION SYSTEM ELEMENTS AND ACCESSORIES

The elements of a water distribution system include distribution mains, arterial mains, storage reservoirs, and system accessories. These elements and accessories are described as follows:

1. DISTRIBUTION MAINS. Distribution mains are the pipelines that make up the distribution system. Their function is to carry water from the water source or treatment works to users.

2. ARTERIAL MAINS. Arterial mains are distribution mains of large size. They are interconnected with smaller distribution mains to form a complete gridiron system.

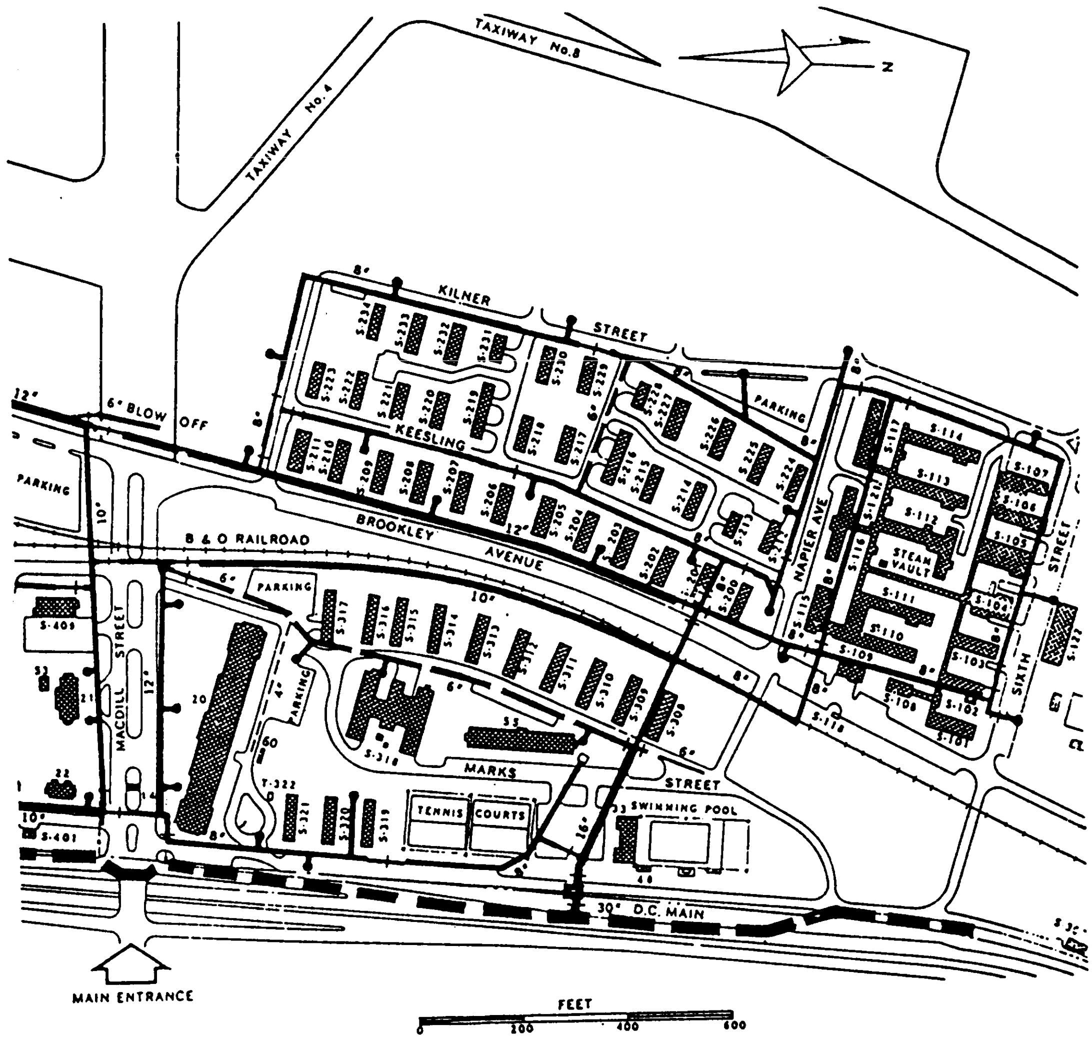


Figure 2-19.—Typical distribution system layout.

3. STORAGE RESERVOIRS. Storage reservoirs are structures used to store water. They also equalize the supply or pressure in the distribution system. A common example of a storage reservoir is an aboveground water storage tank.

4. SYSTEM ACCESSORIES. System accessories include the following:

a. BOOSTER STATIONS. Booster stations are used to increase water pressure from storage tanks or low-pressure mains.

b. VALVES. Valves control the flow of water in the distribution system by isolating areas for repair or by regulating system flow or pressure.

c. HYDRANTS. Hydrants are designed to allow water from the distribution system to be used for fire-fighting purposes.

d. METERS. Meters record the flow of water in a part of the distribution system.

e. SERVICE CONNECTIONS. Service connections are used to connect individual buildings or other plumbing systems to the distribution system mains.

f. BACKFLOW PREVENTERS. A **cross-connection** is any connection between a potable and nonpotable water system through which a contaminating flow can occur. Backflow preventers, such as air gaps and vacuum breakers, are used to prevent flow through potential cross-connections.

DISTRIBUTION SYSTEM LAYOUT

When distribution systems are carefully planned, the pipes are usually laid out in a grid or belt system. A network of large pipes divides the community or base into areas of several blocks each (fig. 2-19). The streets within each area are served by smaller pipes connected to the larger ones. If possible, the network is planned so the whole pipe system consists of loops, and no pipes come to a dead end. In this way, water can flow to any point in the system from two or more directions. This eliminates the need to cut off the water supply for maintenance work or to repair breaks.

Older water systems frequently were expanded without planning and developed into a treelike system. This consists of a single main that decreases in size as it leaves the source and progresses through the area originally served. Smaller pipelines branch off the main and divide again, much like the trunk and branches of a tree. A treelike system is not desirable because the size of the old main limits the expansion of the system needed to meet increasing demands. Also, there are many dead ends in the system where water remains for long periods, causing undesirable tastes and odors in nearby service lines.

MIL-HDBK-1005/7 provides specific guidance to follow when planning the location of mains. In general, mains should be located so they are clear of other structures and should be adjacent and parallel to streets but not within roadways, if possible. Mains also should be separated from other utilities to ensure the safety of potable water and to lessen interference with other utilities during maintenance.

VALVE LOCATIONS

The purpose of installing shutoff valves in water mains at various locations within the distribution system is to allow sections of the system to be taken out of service for repairs or maintenance without significantly curtailing service over large areas. Valves should be installed at intervals not greater than 5,000 feet in long supply lines and 1,500 foot in main distribution loops or feeders. All branch mains connecting to feeder mains or feeder loops should have valves installed as close to the feeders as practical. In this way, branch mains can be taken out of service without interrupting the supply to other locations. In the areas of greatest water demand or when the dependability of the distribution system is particularly important, valve spacing of 500 feet maybe appropriate.

At intersections of distribution mains, the number of valves required is normally one less than the number of radiating mains. The valve omitted from the line is usually the one that principally supplies flow to the intersection As for as practical, shutoff valves should be installed in standardized locations (that is, the northeast comer of intersections or a certain distance from the center line of streets), so they can be easily found in emergencies. All buried small- and medium-sized valves should be installed in valve boxes. For large shutoff valves (about 30 inches in diameter and larger), it may be necessary to surround the valve operator or entire valve within a vault or manhole to allow repair or replacement.

HYDRANT LOCATIONS

Criteria for fire hydrants are found in *Fire Protection for Facilities Engineering, Design, and Construction,* MIL-HDBK-1008A. Street intersections are the preferred locations for fire hydrants because fire hoses can be laid along any of the radiating streets. Hydrants should be located a minimum of 6 feet and a maximum of 7 feet from the edge of paved roadway surfaces. If they are located more than 7 feet from the edge of a road, then ground stabilizing or paving next to the hydrants may be necessary to accommodate fire-fighting equipment.

Hydrants should not be placed closer than 3 feet to any obstruction and never in front of entranceways. In general, hydrants should be at least 50 feet from a building and never closer than 25 feet to a building, except where building walls are blank fire walls.

GENERAL REQUIREMENTS FOR WATER DISTRIBUTION DRAWINGS

The following text provides general information on the contents of water distribution plans and details.

Plans

The MINIMUM information that you should show on a water distribution plan is listed as follows:

1. Locations and lengths of mains

2. Sizes and types of piping materials

3. Locations, sizes, and types of all valves

4. Location of fire hydrants; meter pits; outlets on piers; elevated, ground, or underground water storage reservoirs; water wells; pump houses; and valve boxes, vaults, and manholes

5. Capacities and heads of all water pumps in pump houses, including minimum average and maximum residual pressures at points of connection to municipal water systems

6. Exterior sprinklers or fire mains, including indicator and main shutoff valves

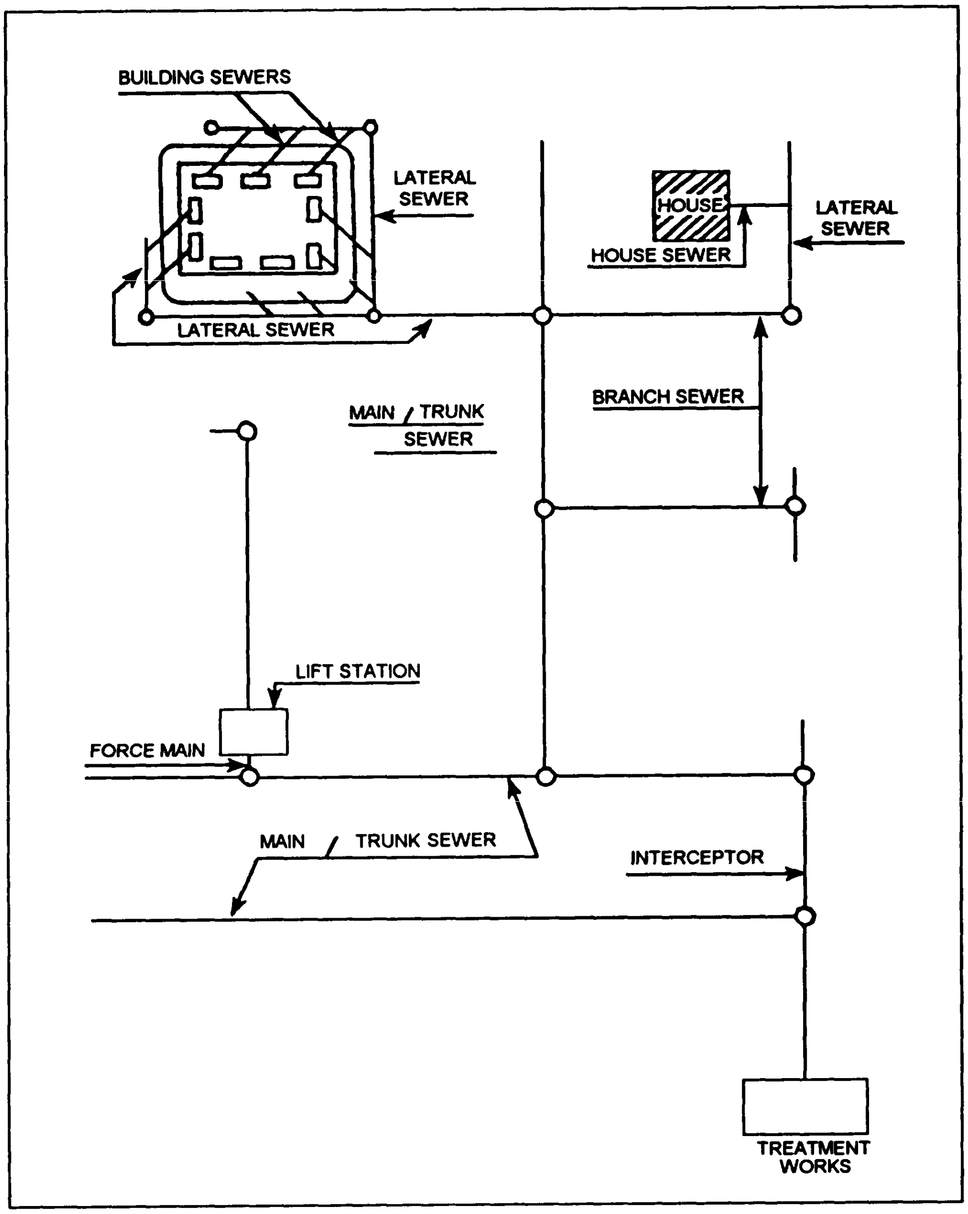


Figure 2-20.—Diagram of a wastewater collection system.

Details

Details that should be included in a set of construction drawings of a water distribution system are varied and numerous. You may, for example, prepare plans, elevations, and details for a new water storage tank. Other examples are as follows: thrust block details, trench details for underground piping, details for aboveground pipe supports, and plans and details for valve boxes, vaults, and so forth. The design engineer will determine the details to be shown.

WASTEWATER SYSTEMS

In addition to drawings of electrical and water distribution systems, you may be required to prepare detailed drawings of wastewater systems. This section provides a brief overview of these systems so you will be familiar with the elements and structures used in wastewater systems and the general content requirements for wastewater system drawings.

SYSTEM ELEMENTS AND STRUCTURES

A wastewater system (fig. 2-20) consists of the collection of sewer pipes and pumps that are designed

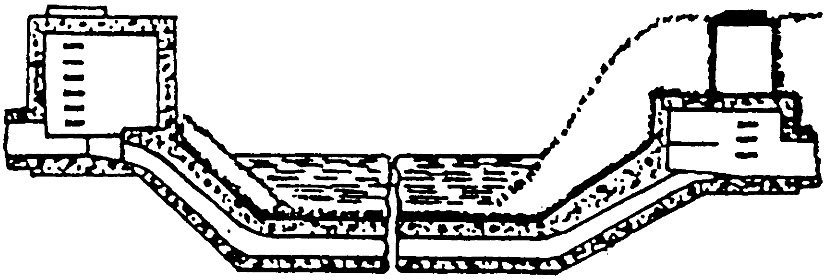


Figure 2-21.—An inverted siphon.

to convey domestic and industrial wastes and to transport them to a wastewater treatment plant. The purpose of these systems is to safeguard public health by preventing disease-producing bacteria, viruses, and parasites getting into groundwater or drinking water systems. A description of the various elements and structures used in a wastewater system is as follows:

1. SANITARY SEWER. A sanitary sewer system carries mostly domestic wastes but may carry some industrial waste. These systems are NEVER designed to carry storm water or groundwater. (To convey storm water, groundwater, or other surface water to disposal points, a **storm sewer** system is designed and constructed separately from the sanitary sewer system.) Sanitary sewer system piping includes the following:

a. BUILDING, OR HOUSE, SEWER. A service-connection pipe that connects an individual building to the wastewater system. These pipes are 4 inches or larger in diameter and are commonly concrete, cast iron, or plastic. The building, or house, sewer is the smallest pipe in a wastewater collection system. All other pipes must be a MINIMUM of 8 inches in diameter.

b. LATERAL SEWER. Piping that receives discharge from house sewers.

c. SUBMAIN, OR BRANCH, SEWER. A pipe that receives waste from two or more lateral sewers.

d. MAIN, OR TRUNK, SEWER. A pipe that takes discharge from two or more submains or from a submain plus laterals.

e. INTERCEPTING SEWER. One that receives wastewater from more than one main, or trunk sewer.

f. RELIEF SEWER. A sewer built to relieve an existing sewer that has an inadequate capacity.

2. LIFT STATION. Most piping in a wastewater system consists of gravity pipes that are designed to flow by gravity action at a rate of not less that 2 feet per second. Where gravity flow is not practical or possible, a lift station, such as the one shown in figure 2-20, is constructed to pump wastewater to a higher level. From the lift station, the wastewater is pumped through a pipe, called a **force main, to** higher elevation gravity pipes. Unlike gravity piping, force mains always flow complete] y filled and under pressure.

3. INVERTED SIPHON. Another sewer pipe designed to flow full and under pressure is the inverted siphon. These pipes dip below the designed gradient of the gravity pipes and are used to avoid obstacles, such as open-cut railways, subways, and streams. An example of an inverted siphon is shown in figure 2-21. The inverted siphon may have one, two, or more pipes and is designed to flow at a rate of at least 3 feet per second to keep the pipe(s) clear of settleable solids. It should have manholes constructed at both ends for maintenance.

4. MANHOLE. A manhole is a concrete or masonry structure used for inspection and maintenance of sewer lines. Examples of manholes are shown in figure 2-22. The bottom portion of a manhole is usually cylindrical and has an inside diameter of at least 4 feet. The upper portion usually tapers to the street or ground surface and is fitted with a cast-iron cover. For proper sewage flow, the bottom of the manhole slopes toward a built-in charnel that has a depth of three fourths of the diameter of the sewer pipe. For sewers up to approximate] y 60 inches in diameter, manholes are usually spaced 300 to 400 feet apart. They are also required at all locations where sewer lines intersect or where the sewer lines change direction, grade, or pipe size.

DESIGN

Design guidance for wastewater systems is contained in *Domestic Wastewater Control,* MIL-HDBK-1005/8.

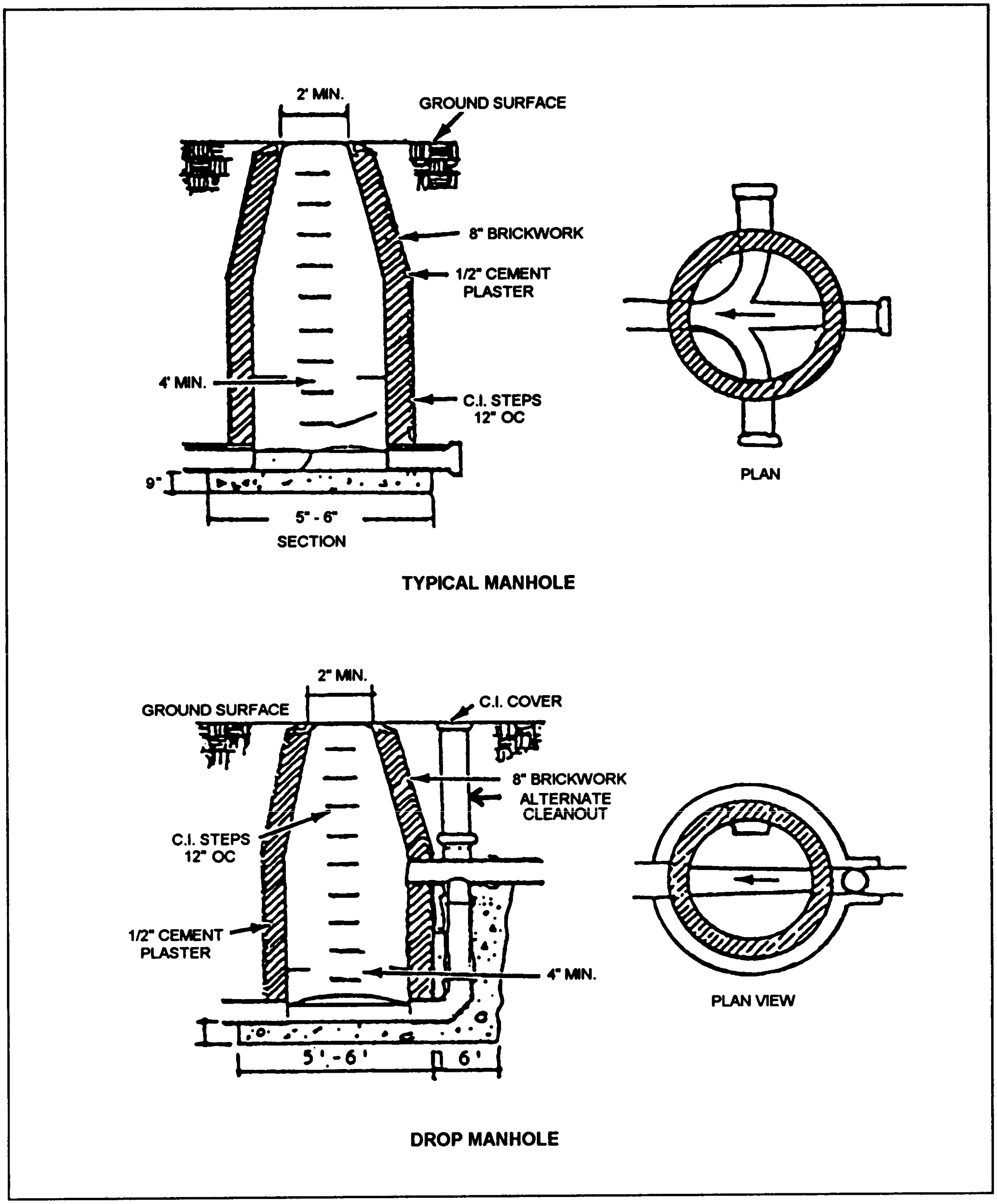


Figure 2-22.—Types of manholes

When designing a wastewater system, the design engineer begins by first determining the types and quantities of sewage to rehandled. This is accomplished through a careful study of the area to be served. The design engineer bases his design on the average daily use of water per person in the area to be served. A typical value is 100 gallons per person per day. But, the use of water is not constant. Use is greater in the summer than in the winter and greater during the morning and evening than it is in the middle of the day or at night. Therefore, the average daily flow (based on the average utilization) is multiplied by a peak flow factor to obtain the design flow.

Typical peak flow factors range from 4 to 6 for small areas down to 1.5 to 2.5 for larger areas. An allowance for unavoidable infiltration of surface and subsurface water into the lines is sometimes added to the peak flow to obtain the design flow. A typical infiltration allowance is 500 gallons per inch of pipe diameter per mile of sewer per day. From the types of sewage and the estimated design flow, the engineer can then tentative] y select the types, sizes, slopes, and distances below grade of the piping to be used for the system.

Then preliminary drawings of the system are prepared. The preliminary drawings should include both plans and profiles of the proposed wastewater system and all buildings, roads, waterways, utilities, geology, and so forth, that may affect the design. As an EA, you may be called upon to assist in the preparation of the preliminary plans. When existing topographic maps of sufficient detail are available, they may be used in selecting the routing of the proposed system. However, when existing maps are not available or to ensure sufficient detail, you may be required to conduct topographic and preliminary route surveying upon which the routing will be based. The procedures for these surveys are explained in chapters 8 through 10 of this manual.

Upon acceptance of the preliminary designs, final design may begin. During this phase, adjustments to the preliminary design should be made as necessary, based upon additional surveys, soil analysis, or other design factors. The final designs should include a general map of the area that shows the locations of all sewer lines and structures. They also should include detailed plans and profiles of the sewers showing ground elevations, pipe sizes and slopes, and the locations of any appurtenances and structures, such as manholes and lift stations. Construction plans and details are also included for those appurtenances and structures.

QUESTIONS

Q1. Name the two systems that comprise an overall power system.

Q2. What system of arranging primary feeders is the least reliable but the most commonly used?

Q3. What is the purpose of a distribution transformer?

Q4. In relation to the primary mains, where on a power distribution pole should the secondaris be located?

Q5. Under what circumstances are concrete power distribution poles authorized for use on a Navy installation?

Q6. On a drawing of an overhead electrical distribution system what information should you show for the overhead conductors?

Q7. Define water table.

Q8. What three primary factors must an engineer consider when selecting a water source?

Q9. When, if ever, is it permissible to install a water line and a sanitary sewer line in the same trench?

Q10. In a waste water system, what is the purpose of a lift station?

CHAPTER 3

HORIZONTAL CONSTRUCTION

The construction of roads and airfields, or portions of roads and airfields, is often tasked to the Seabees for accomplishment. As an Engineering Aid, you can expect involvement in projects of this type. This involvement may include assisting the engineering officer in the design of these facilities or in the surveying operations required before, or during, construction. Whatever your involvement is, you must be familiar with the terminology, methods, and materials of road and airfield construction. This chapter will provide that familiarity.

ROADS

A military road is defined as any route used by the military for transportation of any type. This includes everything from a superhighway to a simple path through the jungle. The type of road required depends mainly upon the missions of the units that use it. In forward combat zones, the requirements are usually met by the most expedient road; that is, one that will get the job done with no attempt for permanency. In the rear zones, however, the requirements usually call for some degree of permanency and relatively high construction standards.

NOMENCLATURE

When assigned to the engineering division, you may help prepare the working plans for the construction of roads and airfields; for example, a two-lane, earth, gravel, or paved-surface road. Figures 3-1 and 3-2 show the basic parts of a road. The following paragraphs give

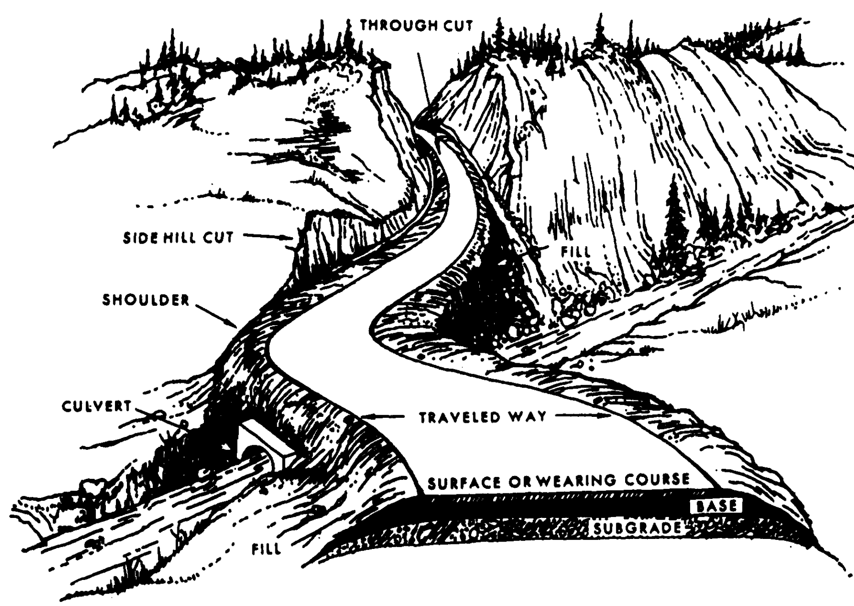


Figure 3-1.-Perspective of road showing road nomenclature.

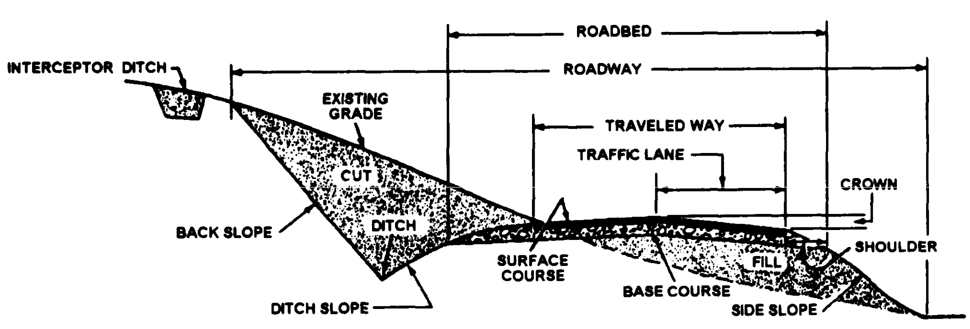


Figure 3-2.—Typical cross section showing road nomenclature.

definitions of some terms that you are likely to use when preparing the working plans for a road:

1. CUT. Has two connotations: (1) an excavation through which the road passes and (2) the vertical distance the final grade is below the existing grade.

2. **FINAL, OR FINISHED, GRADE.** The elevation to which the road surface is built.

3. **SURFACE.** That portion of the road that comes into direct contact with traffic.

4. **EXISTING GRADE.** The undisturbed earth before construction begins.

5. **FILL.** Has two connotations: (1) earth that has been piled up to make the road and (2) the vertical distance the final grade is above the existing grade.

6. **SUBGRADE.** The foundation of a road which can be either undisturbed earth (for a cut) or material placed on top of the existing grade.

7. **BASE.** Select material (crushed stone, gravel, etc.) placed in a layer over the subgrade for the purpose of distributing the load to the subgrade.

8. **TRAFFIC LANE.** That portion of the road surface over which a single line of traffic traveling in the same direction will pass.

9. **TRAVELED WAY.** That portion of the roadway upon which all vehicles travel (both lanes for a two-lane road).

10. **SHOULDERS.** The additional width immediate y adjacent to each side of the traveled way.

11. **ROADBED.** The entire width (including the traveled way and the shoulders) upon which a vehicle may stand or travel.

12. **ROADWAY.** The entire width that lies within the limits of earthwork construction.

13. **ROADWAY DITCH.** The excavation, or channel, adjacent and parallel to the roadbed.

14. **DITCH SLOPE.** The slope that extends from the outside edge of the shoulder to the bottom of the ditch. (Sometimes called **front slope** or **side slope.)**

15. **BACK SLOPE.** The slope from the top of the cut to the bottom of the ditch (Sometimes called **cut slope.)**

16. **FILL SLOPE.** The slope from the outside edge of the shoulder to the toe of the fill. (Also, sometimes called **front slope** or **side slope.)**

17. **TOE OF SLOPE.** The extremity of the fill (where the existing grade intercepts the fill).

18. **INTERCEPTOR DITCH.** A ditch cut to intercept the water table or any subsurface drainage. Also, a ditch cut along the top of fills to intercept surface drainage.

19. **WIDTH OF CLEARED AREA.** The width of the entire area that is cleared for the roadway.

20. **SLOPE RATIO.** A measure of the relative steepness of the slope, expressed as the ratio of the horizontal distance to the vertical distance.

21. **CENTER LINE.** The exact center, or middle, of the roadbed.

22. **BLANKET COURSE.** A 1- or 2-inch layer of sand or screening spread upon the subgrade to prevent mixing of base and subgrade.

23. **CROWN.** The difference in elevation between the center line and the edge of the traveled way.

24. **SUPERELEVATION.** The difference in elevation between the outside and inside edge of the traveled way in a horizontal curve.

25. **STATION.** A horizontal distance generally measured in intervals of 100 feet along the centerline.

26. **STATION NUMBER.** The total distance from the beginning of construction to a particular point (for example, 4 +58 is equal to 458 feet).

SURVEY

When it is decided that a road is needed through a particular area, the first and logical step is to determine a route for it to follow. This mute may be chosen by the use of maps, aerial photographs, aerial reconnaissance, ground vehicle reconnaissance, walk-through reconnaissance, or by any combination of these. Once the route is chosen, a surveying crew makes the preliminary survey. This survey consists of a series of traverse lines connecting a series of traverse stations.

A survey party will stake in each of the traverse stations and determine the bearing and distance of the connecting traverse lines. From this information, an Engineering Aid will draw the **points of intersection** (PI) and the connecting lines. Then an engineer will compute the horizontal curves at each point of intersection, and an Engineering Aid will draw the curves and mark the stationing. This drawing is the proposed center line.

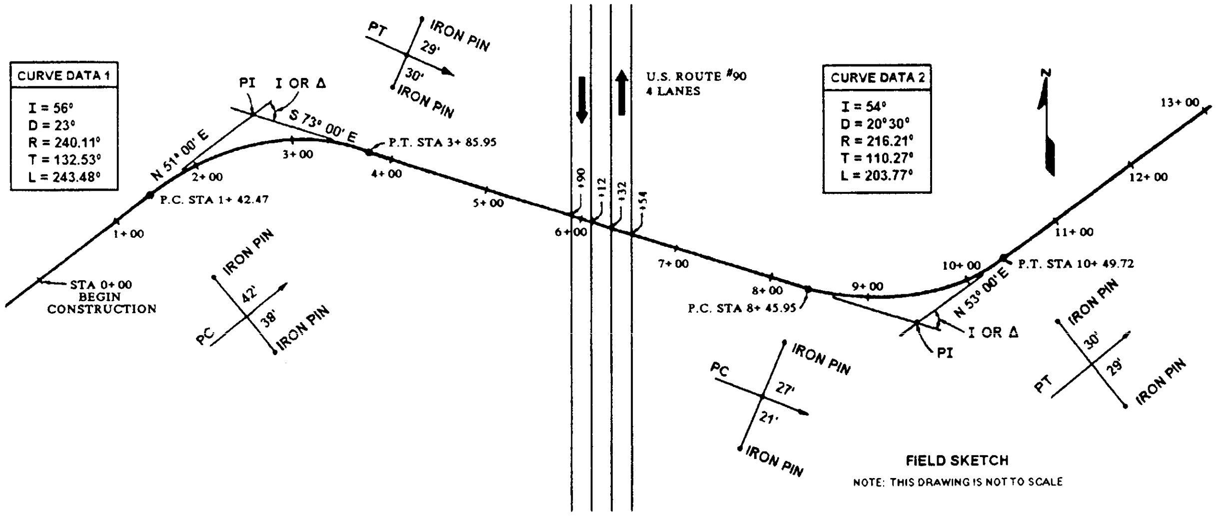


Figure 3-3.—The road plan.

The drawing of the proposed center line is then given to a final location party, which stakes in the center line and curves. With the approval of the engineer, the party chief may make changes in alignment of the center line, but the changes must be recorded.

Once the final location is determined, all information and changes pertinent to the location are used to prepare a second and final drawing, showing the final center-line location, construction limits, all curves and curve data, station marks, control points, natural and man-made terrain features, trees, buildings, and anything else that is helpful in construction. This drawing, known as a **road plan** (fig. 3-3), is a "bird's-eye view" of the road and shows what you should see from a position directly above. The road plan is drawn on the upper portion of plan-and-profile paper, using any scale desired. The bottom portion of the plan-and-profile paper, which, as you know, is composed of grid lines, is reserved for drawing the road profile.

ROAD PLAN

The road plan, or plan view, shows the actual location and length of the road measured along the center line. The length is determined by station points, which are set at full station (full stations are 100 feet or 100 meters apart), half station, or one-tenth station intervals. Odd-station points are set at major breaks in the terrain. Referring to figure 3-3, you see the manner in which the beginning station (0 + 00) is shown, and you also see the manner in which the full stations and the partial stations are shown. Recalling your study of the EA3 TRAMAN, you know, then, that the distance from the beginning station to the last full station shown (13 + 00) is 1,300 feet.

All man-made and natural objects, such as trees, buildings, fences, wells, and so on, are also plotted on the plan if they are in the right-of-way or construction limits. (Right-of-way is the land acquired for the road construction.) Identification and location of these objects are taken from the surveyor's notebook Their location is determined by a station number and distance from the center line. All measurements and distances are made perpendicular to the center line of the particular station unless otherwise noted.

Horizontal Curves

The road center line consists of straight lines and curves. The straight lines are called tangents, and the curves are called horizontal curves. These curves are used to change the horizontal direction of the road. All information necessary to draw a curve should be furnished by the engineer or taken from the surveyor's notebook. The necessary information is known as curve data. Below is the data for curve No. 1 in figure 3-3 and an explanation of the terms.

Δ = 56°00'

D = 23°00'

R = 240.11'

T = 132.53'

L = 243.48'

1. The symbol **Δ** (Delta), or the symbol I, represents the **intersecting angle,** which is the deflection angle made by the tangents where they intersect.

2. D is the **degree of curvature,** or **degree of curve.** It is the angle subtended by a 100-foot arc or chord (to be discussed in chapter 11 of this TRAMAN).

3. R is the **radius** of the curve, or arc. The radius is always perpendicular to the curve tangents at the **point of curvature (PC)** and the **point of tangency** (PT).

4. T is the **tangent distance,** which is measured from the PI to the PC and the PT. The PC is the beginning of the curve, and the PT is the end of the curve.

5. L is the **length of the curve** measured in feet along the curve from the PC to the PT.

A horizontal curve is generally selected to fit the terrain. Therefore, some of the curve data will be known. The following formulas show definite relationships between elements and allow the unknown quantities to be computed:

1. To find the radius (R), or degree of curvature (D), use the following formula:

$$R = \frac{5729.58}{D}$$

2. To find the tangent distance (T), compute as follows:

$$T = R \tan \frac{\Delta}{2}$$

3. To find the length of curve (L), use the following formula:

$$L = 100\frac{\Delta}{D} \text{ (D and } \Delta \text{ in degrees)}$$

The PC and PT are designated on the plan by a partial radius drawn at each point and a small circle on the center line. The station numbers of PC and PT are noted as shown in figure 3-3. The length of the curve (L) is added to the PC station to obtain the station of the PT. The curve data is noted on the inside of the curve it pertains to and is usually between the partial radii.

Since most horizontal curves have superelevation (that is, the outside edge of the traveled way is higher than the inside edge), there must be a transition distance in which the shape of the road surface changes from a normal crown to a superelevated curve. The transition length is generally 150 feet and starts 75 feet before the PC is reached. The same is true in leaving curves. The transition begins 75 feet before the PT and ends 75 feet beyond. The beginning and end of the superelevation are noted on the plan.

Control Points

A control point maybe a PT, PC, PI, or a point on tangent (POT). Since these control points may be destroyed during construction, you must reference them to other points. In the field, a common practice that you should use is to drive iron pins or other reference stakes at right angles to the control point on each side of the center line, and then measure and record the distance from the pins to the control point. If room allows, these reference points should be drawn on the road plan opposite the control points, as shown in figure 3-3. If not, you should show the control points and references on a separate sheet, called a reference sheet.

ROAD PROFILE

The procedure used to plot road profiles is discussed in chapter 7 of the EA3 TRAMAN. From your study of that TRAMAN, you know that a profile is the representation of something in outline. When applied to roads, this means that a profile is a longitudinal-section view of the earth along the centerline, and it is always viewed perpendicular to the centerline.

As you know, profile-leveling procedures are used to determine the ground elevations at each of the station points along the center line. These elevations are recorded in the surveyor's notebook, which is used by the draftsman to prepare the profile drawing. Generally, the profile is drawn on the bottom portion of plan-and-profile paper, directly below the road plan. An example of a road profile is shown in figure 3-4.

A road grade line is also drawn on the lower portion of the plan-and-profile paper and is represented by a heavy solid line, as shown in figure 3-4. Like the profile, the grade line is a longitudinal section taken along the center line and shows the elevations to which the road is built. The grade line is normally the center-line elevations of the finished surface but may be the center-line elevations of the subgrade. If the subgrade was used, make a special note of it.

The grade lines are a series of straight lines that are connected, where necessary, by curves (called vertical

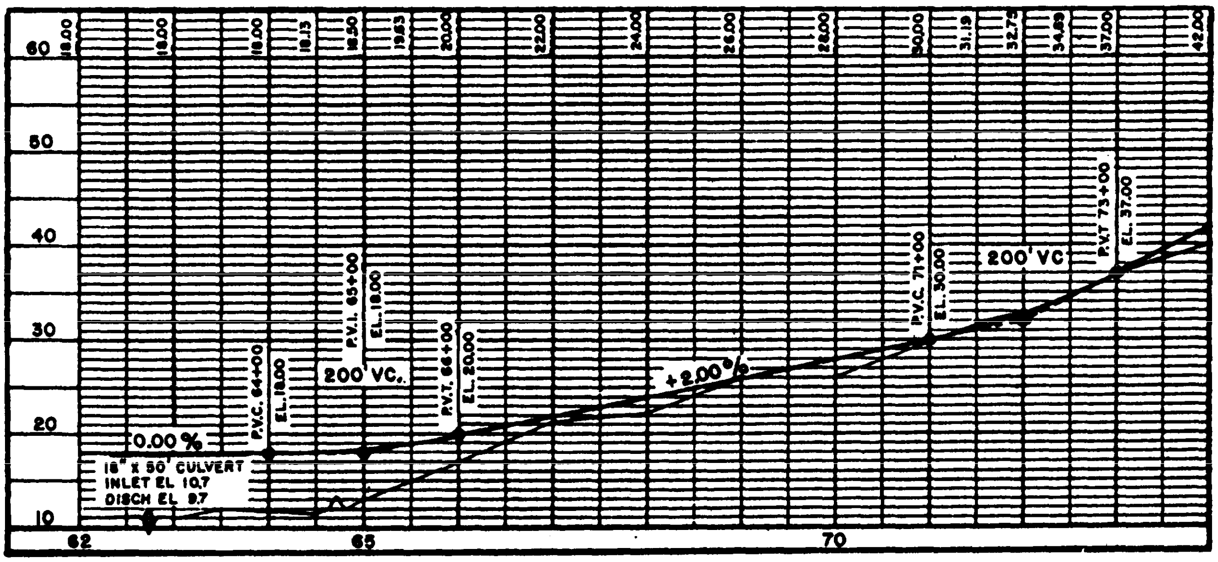


Figure 3-4.-Road profile.

curves), which will be discussed shortly. The grade lines may be level or sloped. If the lines slope upward, the grade is positive; if downward, the grade is negative. The slopes are in reference to the direction of increasing stations. The amount of slope is lettered above the grade line and is usually indicated as the percent of slope. In figure 3-4, the slope from station 66 + 00 to 71 + 00 is +2.00 percent. This means the center-line grade rises 2 feet in 100 feet horizontal distance. If the slope is -1.50 percent, the grade would fall 1.50 feet in 100 feet horizontal distance.

At vertical curves, the straight lines are tangents that intersect at a point called the **point of vertical intersection** (PVI). This point is comparable to the PI of horizontal curves.

Vertical Curves

If the road is to offer safe, comfortable driving conditions, the PVI should not break sharply. The length of the curve depends upon the steepness of the intersecting grades. In most cases, a vertical curve is symmetrical in that its length is the same on both sides of the PVI. Unlike the length of a horizontal curve, the length of a vertical curve is the horizontal distance from beginning to end of the curve, rather than the distance along the curve. The station on which the curve begins and ends is called the **point of vertical curvature** (PVC) and **point of vertical tangency** (PVT), respectively. Unlike horizontal curves, vertical curves are parabolic; they have no constant radius. Therefore, the curves are plotted, usually in 50-foot lengths, by computing the offsets from the two tangents. A vertical curve at the crest or top of a hill is called a summit **curve, or oververtical;** one at the bottom of a hill or a dip is called a **sag curve,** or **undervertical.**

Drawing the Grade Lines

You should use the same horizontal and vertical scale to draw the grade line as to draw the profile. 'Ibis allows the amount of cut or fill for a particular point to be measured. If the grade line is higher than the profile, fill is required; if lower, cut is required.

The profile and grade-line drawings also show the relative locations of drainage structures, such as box culverts and pipe. You use only the vertical scale to draw these structures. You can plot the heights of the structures accurately, using the vertical scale. However, because of the exaggerated difference between the vertical and horizontal scales, you cannot draw the width of the structures to scale. Therefore, you should draw the width of the structures just wide enough to indicate the type of structure. You should show a box culvert as a high, narrow rectangle and a round pipe as a high, narrow ellipse.

ROAD DIMENSIONS

The type of dimensioning used for road plans is a variation of the standard dimensioning. In road dimensioning, numerical values for elevations, cuts, fills, and stations are considered dimensions also. Most road dimensions appear on the profile and grade-line

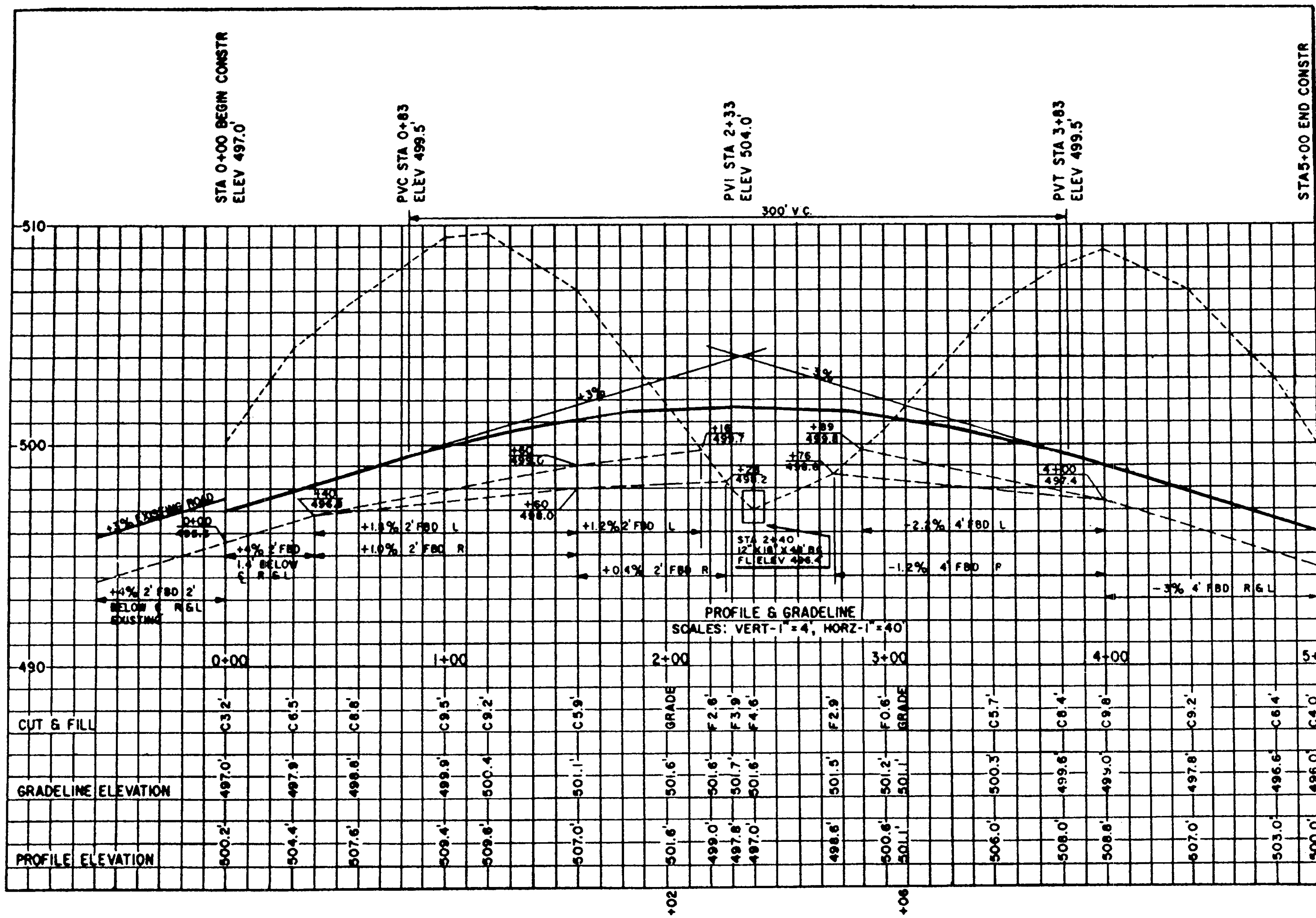


Figure 3-5.—Profile and grade line.

drawing. Refer to the example in figure 3-5, and read the following explanation:

1. **STATION NUMBERS.** The station numbers are lettered horizontally below the profile and grade line and are centered on the appropriate vertical grid line.

2. **ELEVATIONS.** At the bottom of the sheet, the profile and grade-line elevations for each station are lettered vertically. The grade-line elevations are lettered just above the profile elevations. Any station numbers other than full stations are noted as plus stations, vertically, just outside the bottom border.

3. **CUTS AND FILLS.** Above the profile and grade-line elevations are lettered the cuts and fills. They are also in a vertical position. The grade points, or points where the profile crosses the grade line, are also noted in this row. They are designated by the word *GRADE* lettered vertically above the grade-point station.

4. **DITCHES.** The procedure for dimensioning ditches has two steps as follows:

a. First, draw extension lines from the ends of a ditch or any point in the ditch where the ditch grade changes. These lines should be extended downward, and dimension lines (with heavy arrowheads) should be drawn between them. These extension and dimension lines should be drawn heavier than normal so they may be distinguished from grid lines.

b. Next, above the dimension line, letter the information necessary to describe the ditch. If the lettering is crowded, you may also use the space below the line. You should furnish the following information: percent of grade of the ditch, depth relative to center line, type of ditch, and width of ditch. Give the elevation and station at the ends of the ditches and at changes of grade.

5. **VERTICAL CURVES.** Each vertical curve on the grade line is also dimensioned. Draw extension lines upward from the PVC and PVT. Then draw a dimension line between the extension lines and letter the length of the curve above. Letter the station and elevation of the PVC, PVI, and PVT vertically over these points and above the dimension line.

6. **CORRELATION WITH PLAN.** All points on the profile and grade line coincide with center-line points on the plan. For example, you should show the beginning and ending of construction on the plan view and also on the profile and grade line. Also, note the elevations at these points.

7. **DRAINAGE STRUCTURES.** Dimension all drainage structures, such as pipes and culverts, by notes. Note the station number, size of opening, length of pipe, and flow-line elevation.

8. **TITLE.** In this example, the title, "PROFILE AND GRADE LINE is lettered below the ditch dimensions. Below this are noted the horizontal and vertical scales.

SEQUENCE OF CONSTRUCTION

In constructing a road, the construction crews should follow a specific sequence. First, they clear the area through which the road must pass of trees, stumps, brush, boulders, and other debris. The width of the clearing varies greatly but is always at least 12 feet greater than the roadway width; that is, the crew should clear at least 6 feet behind the construction limit on both sides of the road.

The next step is the grading operations and the laying of cross-drain pipes, or culverts. The grading operations are carried on by the Equipment Operators until the subgrade is completed. In fill areas, the grading is brought up in layers and compacted. In cuts, the excavation is carried on until the subgrade elevation is reached, and then the earth is compacted. Throughout this step of the road construction, workers place the culverts when and where required. These culverts are placed in their appropriate positions and at the required slopes according to the roadway plans.

After the subgrade is completed, Equipment Operators place abase course on the subgrade. The base course material can be gravel, sand, crushed stone, or more expensive and permanent materials. Finally, the Equipment Operators place a surface course over the base. This material can be sand, asphalt, blacktop, concrete, or similar materials.

In some cases, traffic may be allowed to travel over the subgrade itself. In others, traffic may require only a gravel or stone surface. A high-speed road, however, requires abase and a hard, durable surface.

SECTIONS

As you should recall from your study of the EA3 TRAMAN, a section is a view of an object that has been cut by a plane that is perpendicular to the line of sight. For road sections, the line of sight is perpendicular to the roadway center line.

Sections are used for a variety of purposes during the various phases of road design and construction. One purpose is to define what the materials and design

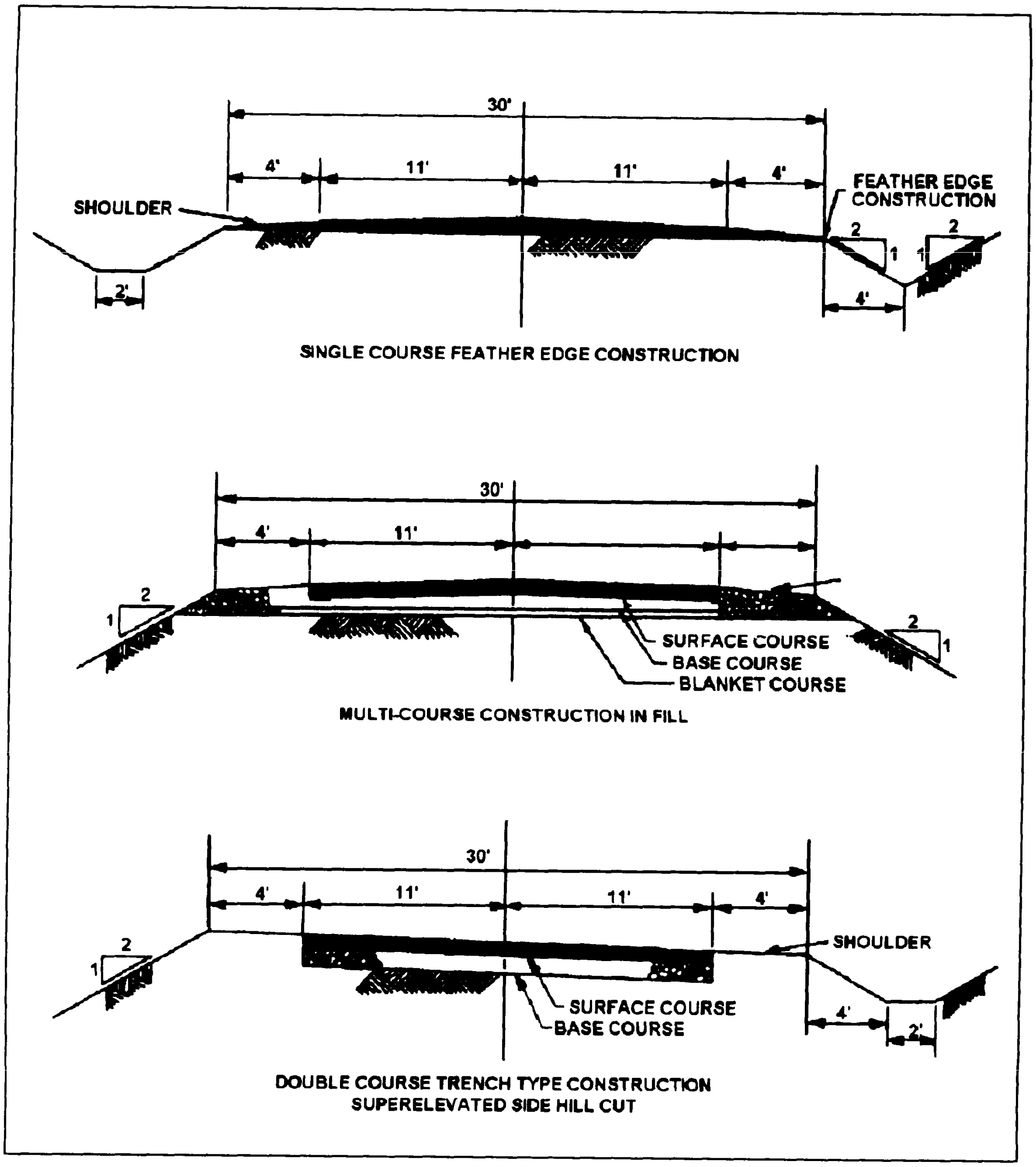


Figure 3-6.—Typical section.

configuration of the completed road should be. You will also use sections for staking out roads, for determining earthwork requirements, and for determining how closely the completed road conforms to its original design.

Typical Section

In the construction of a road, certain conditions or requirements must be met. One requirement is that the shape and features of the road be as uniform as possible. This and other requirements are stipulated in the typical section for the road. (See fig. 3-6.)

The typical section of a road shows exactly what the road should look like after it is constructed. It includes the type and thickness of the base and surface materials, the crown, superelevation, ditch slope, cut slope, fill slope, and all horizontal widths of components, such as surface, shoulders, and ditches. Since slight deviations will occur during construction, a tolerance in construction is allowed. However, the shape and construction of the road should conform as closely as possible to the typical section. (For general provisions and design criteria, refer to NAVFAC DM-5.5.)

Typical sections are prepared for both straight and curved portions of the road. The typical section for a curved portion of a road differs from the straight portion in that the shape of the roadbed is different. In a typical

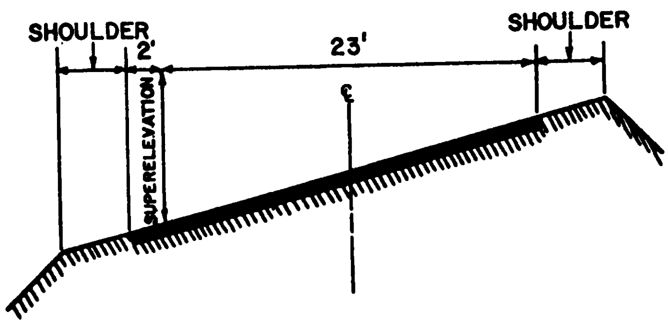


Figure 3-7.-Curve section.

section for a curve, the pavement is a plane surface instead of crowned and is usually superelevated to account for centrifugal force encountered in curves. The outside shoulder slope is the same as the superelevated pavement slope, but the inside shoulder slope is either the same or greater slope. (Inside shoulder refers to the shoulder closest to the center of the arc, or curve.)

Most curves are also widened on the inside to allow for the "curve straightening" effect of long wheelbase vehicles. The back wheels of the trailer in a tractor-trailer rig do not follow in the tracks of the tractor wheels. They run closer to the inside edge on the inside lane and closer to the centerline on the outside lane. This presents a safety hazard when two vehicles meet in curves. Curve widening partially eliminates this hazard.

Figure 3-7 is a superelevated section showing curve widening. Specific guidance for curve widening is contained in NAVFAC DM-5.5.

Preliminary Cross Section

Preliminary cross sections are sectional views of the existing terrain taken at each station point along the center line of the route the road is to take. These sections are usually taken after the roadway has been cleared but may be taken before. If the sections are taken before, the thickness of the sod to be stripped off is normally deducted from the elevations. The preliminary cross section shows the elevations of the natural, or original, ground. These sections, when superimposed on the desired finished roadbed sections, are used for studying various alignments of the road and for preliminary earthwork estimating. Figure 3-8 shows typical preliminary cross sections.

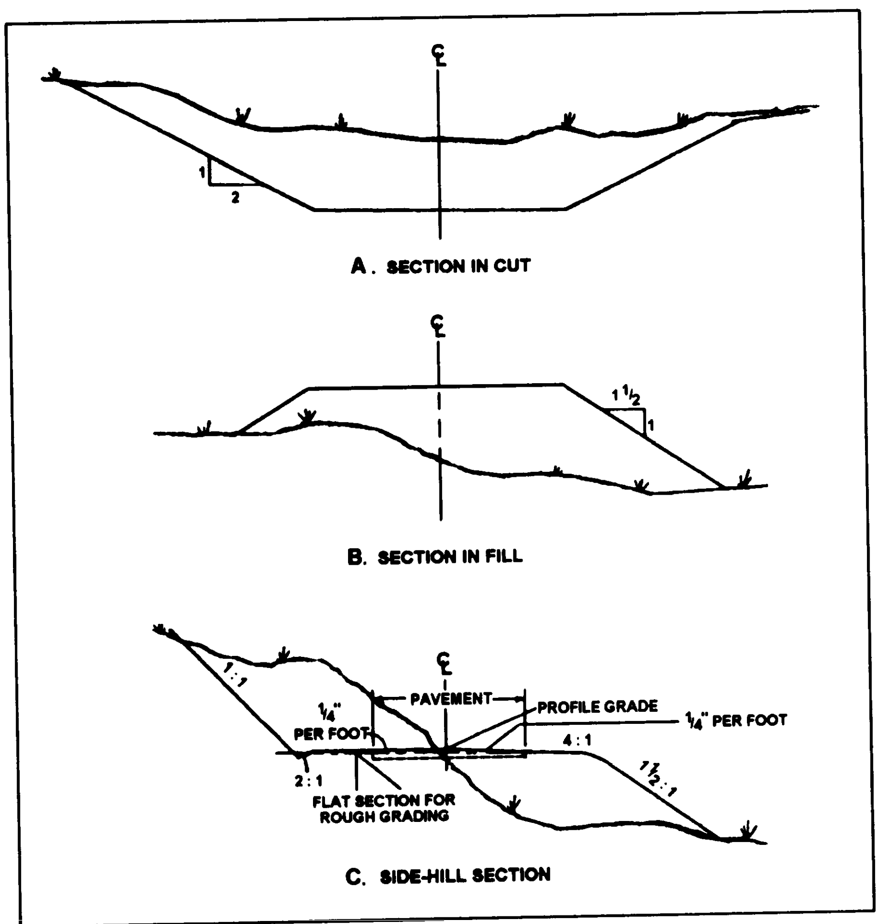


Figure 3-8.—Preliminary cross sections.

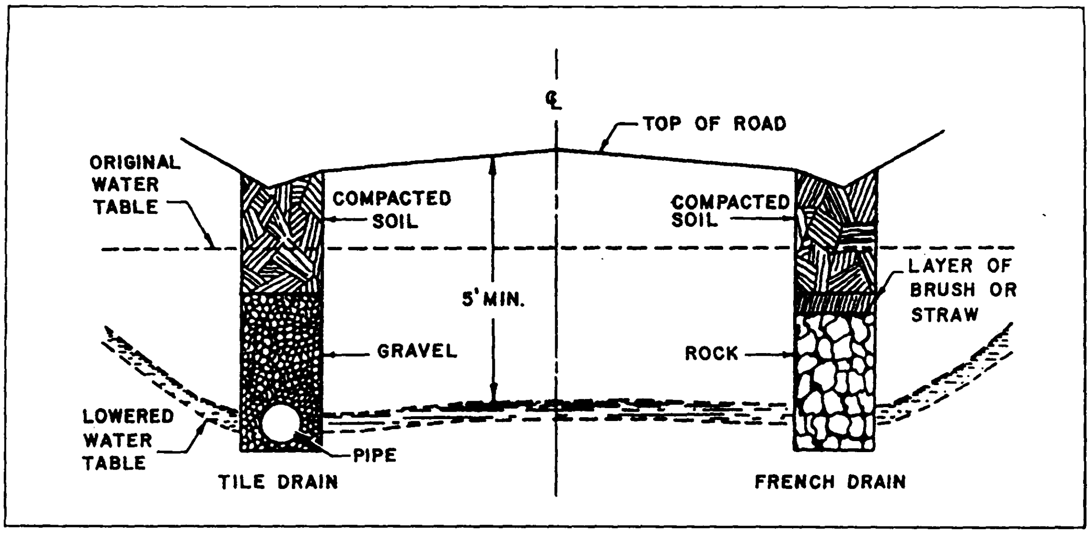


Figure 3-9.-Subsurface drainage.

Final Cross Section

When the final vertical and horizontal alignments of the road are fairly well fixed, final design is commenced. During this phase, final construction drawings are prepared and construction may begin. Before actual construction starts, **final cross sections** are prepared. From these final cross sections, slope stakes are set as described in the EA3 TRAMAN. Final cross sections are taken at each station along the center line of the road. They show the actual shape of the road, the horizontal width of components and their distances from the center line, the finish elevations, and the extremities of the cut and fill. They also show the slopes of the roadbed surface, ditches, and shoulders. The term *final cross section* is also applied to the **as-built** sections that are taken after the road is completed.

The procedures used to plot cross sections are discussed in chapter 14 of the EA3 TRAMAN. You should review that chapter if you are unsure of the procedures.

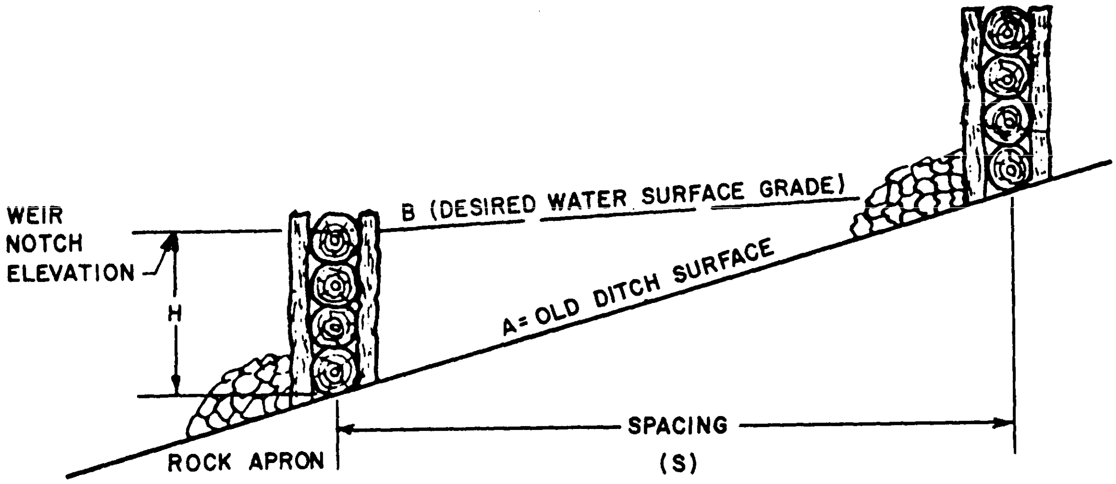
DRAINAGE

Drainage is a major problem in the location, construction, and design of roads. A route should never be located where the drainage presents a problem that cannot be handled or would be too costly to handle. A route may have to be relocated because there is not enough material available to build a particular type of road. It may also have to be relocated because of a swamp or underground spring, high flood waters that can cover the road, or flash floods that can completely wash out the road. These are some of the reasons for planning alternate routes. During construction, the problem of drainage is mainly one of preventing standing puddles on the roadway. This problem is solved by slanting the worked surface of the road so that water can run off quickly or by cutting ditches, called bleeders, so that the water maybe carried away as it accumulates.

Subsurface drainage problems are solved by raising the grade line of the road or lowering the water table. In either case, the distance between the water table and the top of the subgrade should be as great as possible. There are several ways of lowering the water table. In one way, deep, open ditches are set back beyond the roadway limits. These ditches intercept the water table, allowing groundwater to seep through the sides. The water then flows along the bottom and out the end of each ditch

In another way of lowering the water table, a deep trench is dug exactly where the finished roadway ditch would be. The trench is then backfilled to a designated depth with rocks or large gravel of varying size, with the larger size at the bottom. The rocks are capped with a layer of branches or straw and the remainder of the trench backfilled with soil and compacted This trench is called a **french drain** (fig. 3-9). A tile drain, also shown in figure 3-9, is the same as a french drain except that a perforated pipe or tile is placed in the bottom of the trench. The trench is then backfilled with gravel to the desired depth. The minimum pipe grade is 0.3 percent with the maximum varying to meet conditions.

Surface drainage involves water from direct precipitation, surface runoff, rivers, and streams. (Surface runoff is rainfall that is not absorbed by the soil but runs off a surface in sheets or rivulets.) Rainfall has an immediate effect upon a roadway. Obviously, rainwater would be a safety hazard or cause weak spots on the roadway if it were allowed to stand. Water that



$$S = \frac{100\ H}{A\text{-}B}$$

Where H = height of checkdam in feet, measured from bottom of weir notch to bottom of ditch.

A = % grade of existing ditch.
B = desired % grade of proposed water surface.
(H can vary from 1 to 3 feet. A is usually known
B should be between 0.5% and 4%– desirably, 2%).

Figure 3-10.-Check dams.

falls upon the surface, or traveled way, is drained by crowning the surface; that is, constructing the traveled way so that the middle is higher than the edges.

The traveled way in curves is drained by superelevating the surface; that is, constructing the traveled way so that the inside edge of the curve is lower than the outside edge.

The water that drains from the surface continues over the shoulders. The shoulders always have a slope greater than, or at least equal to, the surface slope. This slightly increases the speed of the draining water and therefore increases the rate of drainage. The water then flows from the shoulder down the side of the fall, if in a fill section of a roadway. If the section is in a cut, the water flows into a roadway ditch. Roadway ditches are not normally in a fill section.

Roadway Ditches

The functioning of a roadway ditch is the most important factor in roadway drainage. If this ditch, which runs alongside the roadway, becomes obstructed or is inadequate for the volume of water, then the roadbed becomes flooded. Not only can this block traffic, but it can also wash away surface and shoulder material.

There are several factors to consider in determining the size and type of roadway ditches, such as volume of water to be carried, the slope of the backslope, soil types, the "lay of the land," and the maximum and minimum ditch grades.

The slopes of the surface, shoulders, and backslopes affect the volume. A steep slope increases the rate of runoff, thereby causing a greater instantaneous volume of water in the ditch. On the other hand, a lesser slope decreases the rate of runoff but exposes more surface area on the backslope, which increases the amount of runoff.

The choice of slopes to be used is governed by other factors, however. The foremost factors are whether the additional excavation is needed in the roadway construction and the type of soil. A lesser slope would be required if the cut is in sand instead of clay or rock. The usual cut slope, or backslope, is 1 1/2:1 (1 1/2 foot horizontal, 1 foot vertical). This slope maybe decreased for sandy soil or greatly increased for rock cuts. The usual ditch slope, from the shoulder to the bottom of the ditch, is 3:1. All these soil types have different amounts of runoff. The runoff from a sandy soil is small, but from a clay soil or solid rock it is large.

An important design factor is the ditch grade itself. The minimum grade is 0.5 percent, and the desirable maximum grade is 4 percent. A grade greater than 4 percent would cause excessive erosion due to the greater velocity of the water. In this case, low dams of wood or stones, called check dams (fig. 3-10), are built across

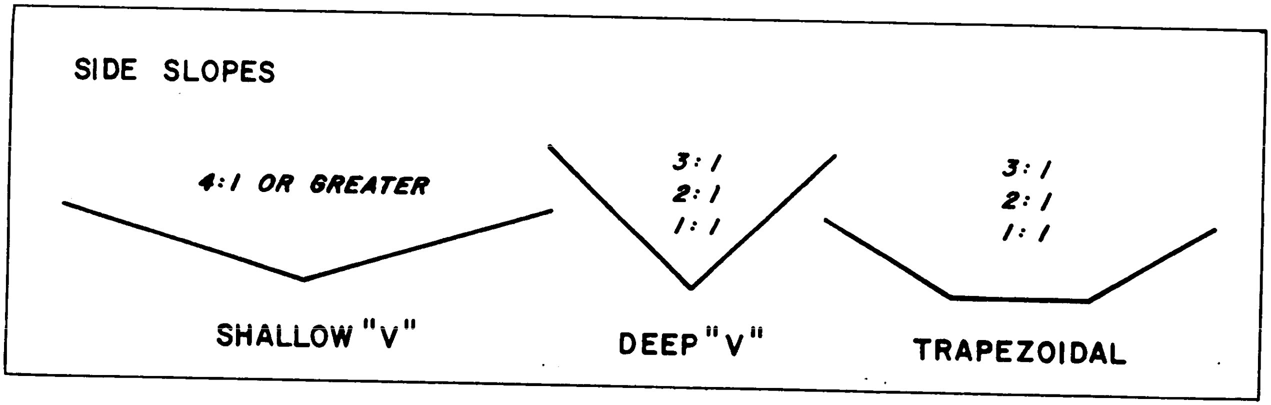


Figure 3-11.—Types of ditches

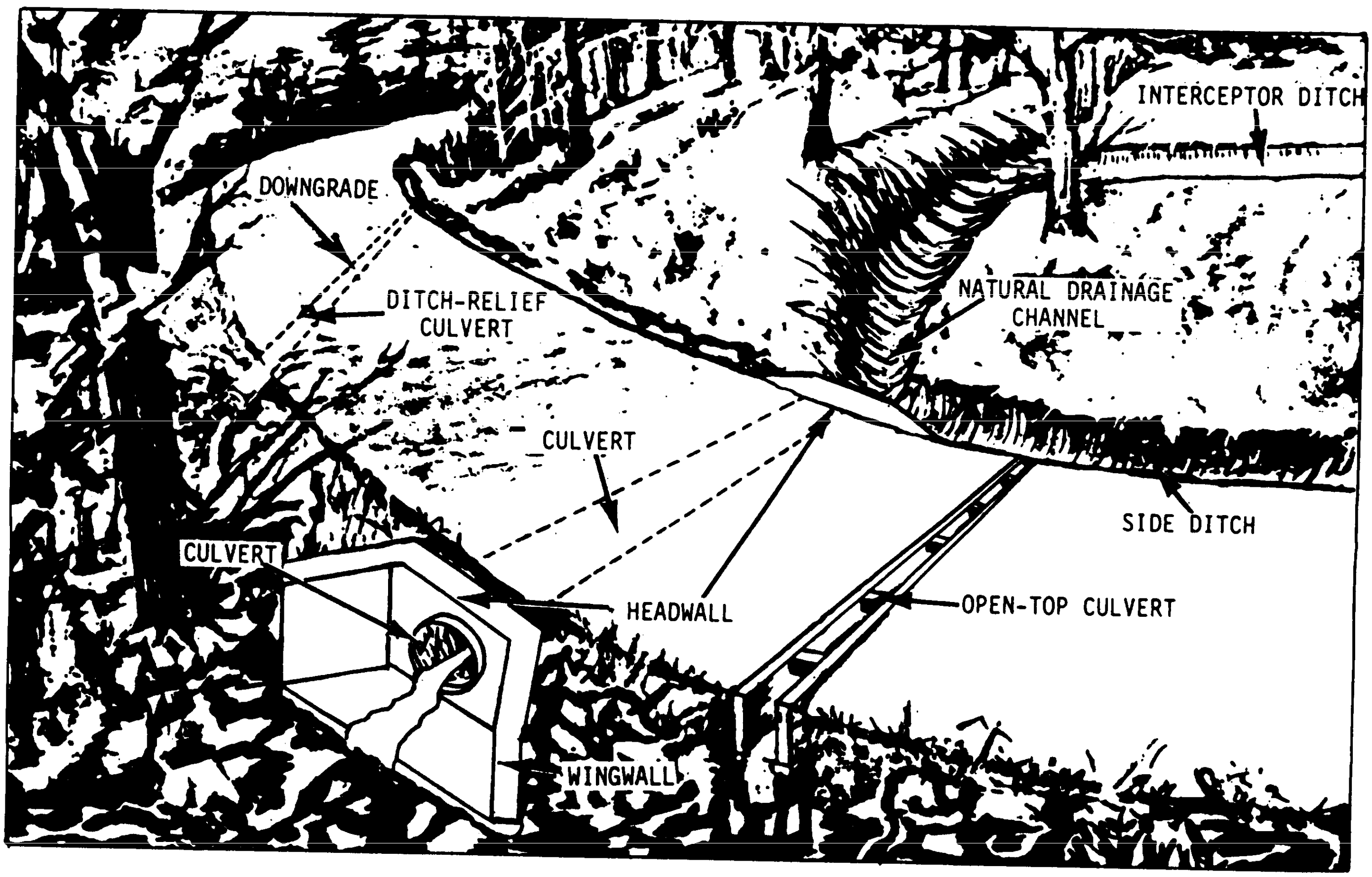


Figure 3-12.—Drainage systems.

the bottom of the ditch to slow down the water. In general, a moderate velocity is desirable because it prevents excessive erosion and can offset the pending effect of slower moving water.

One factor involving the volume of water that cannot be controlled is the rainfall itself. The more intense the rainfall and the longer the duration, the greater the volume of water the ditch has to carry. Talking to local residents and observing high-water marks along streams are helpful to the engineer in determining the heaviest rainfall to expect in a particular area.

The engineer must consider not only the factors involving the volume of water but also the design of the ditch itself. Two common types of ditches are the V-bottom and the flat bottom, or trapezoidal, ditch. Examples of these ditches are shown in figure 3-11. Under similar conditions, water flows faster in a V-bottom ditch than in a trapezoidal ditch. The side slope for a shallow V-bottom ditch is 4:1 or greater. For

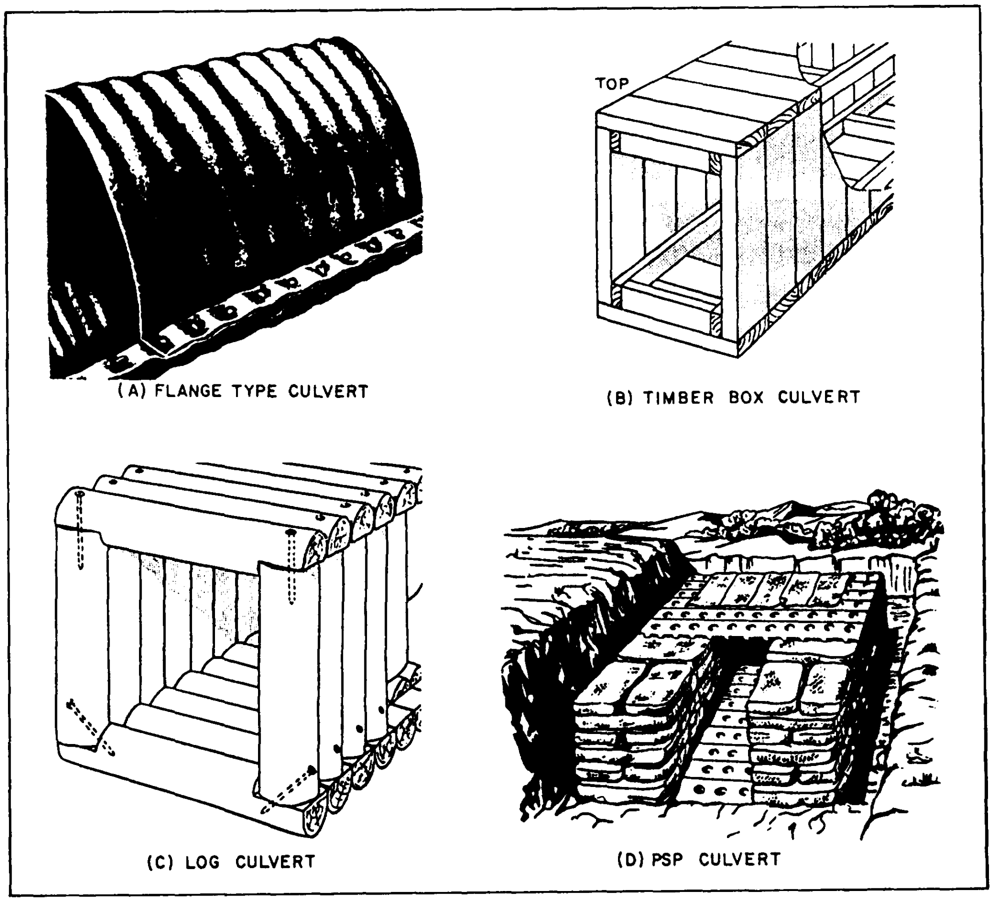


Figure 3-13.-Types of culverts.

a deep V-bottom ditch, the side slope is 3:1, 2:1, or 1:1. The side slope for a trapezoidal ditch is 3:1,2:1, or 1:1. The flat bottom is generally 2 feet wide but can range from 1 foot to 6 feet or more.

Interceptor Ditches

The volume of water draining into a roadway ditch can be decreased by the use of shallow ditches that extend around the top of the cut and intercept the water draining from the original ground toward the roadway. An interceptor ditch shown in figure 3-12 is dug 2 or 3 feet behind the backslope limits. Its size depends on the original ground slope, runoff area, type of soil and vegetation, and other factors related to runoff volume.

Diversion Ditches

As it leaves the cut, water from the roadway ditches cannot be allowed to pond in the ditches or against the roadway fill. Therefore, diversion ditches are dug to carry the water away from the roadway to natural drains. These drains can be rivers, streams, gullies, sinkholes, natural depressions, or hollows.

Culverts

Sometimes it is necessary to have the water flow from one side of the road to the other or have the road cross a small stream. You do this with cross drains. They are called culverts if they are 10 feet or less in width. Over 10 feet wide, they are called bridges. Culverts are made of many materials, such as corrugated metal, reinforced concrete, concrete pipe, timber, logs, and even open-ended oil drums. The type of material selected is dependent upon various factors including, in part, the type and life expectancy of the road.

For permanent roads and highways with concrete or asphalt paving, the most durable of materials, such as reinforced concrete or concrete pipe, should be used. Concrete pipe is one of the strongest and most durable materials used in making culverts. The shell thickness and length depend on the pipe diameter. (The larger the diameter, the thicker the shell and longer the section.) Pipe diameters are nominal inside dimensions. For semipermanent and temporary roads, the design engineer may choose to use materials such as those shown in figure 3-13.

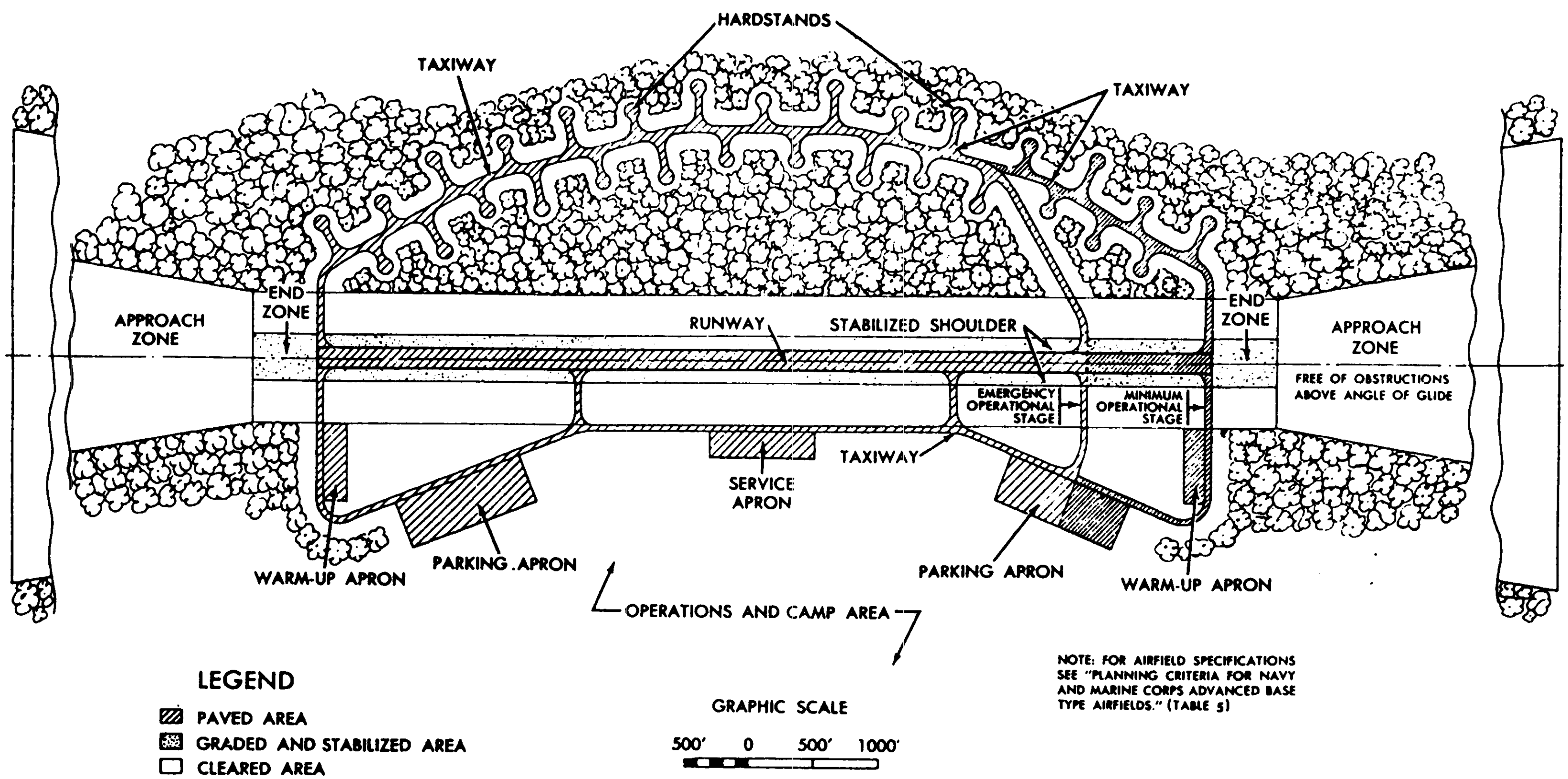


Figure 3-14.—Plan view of an advanced-base airfield.

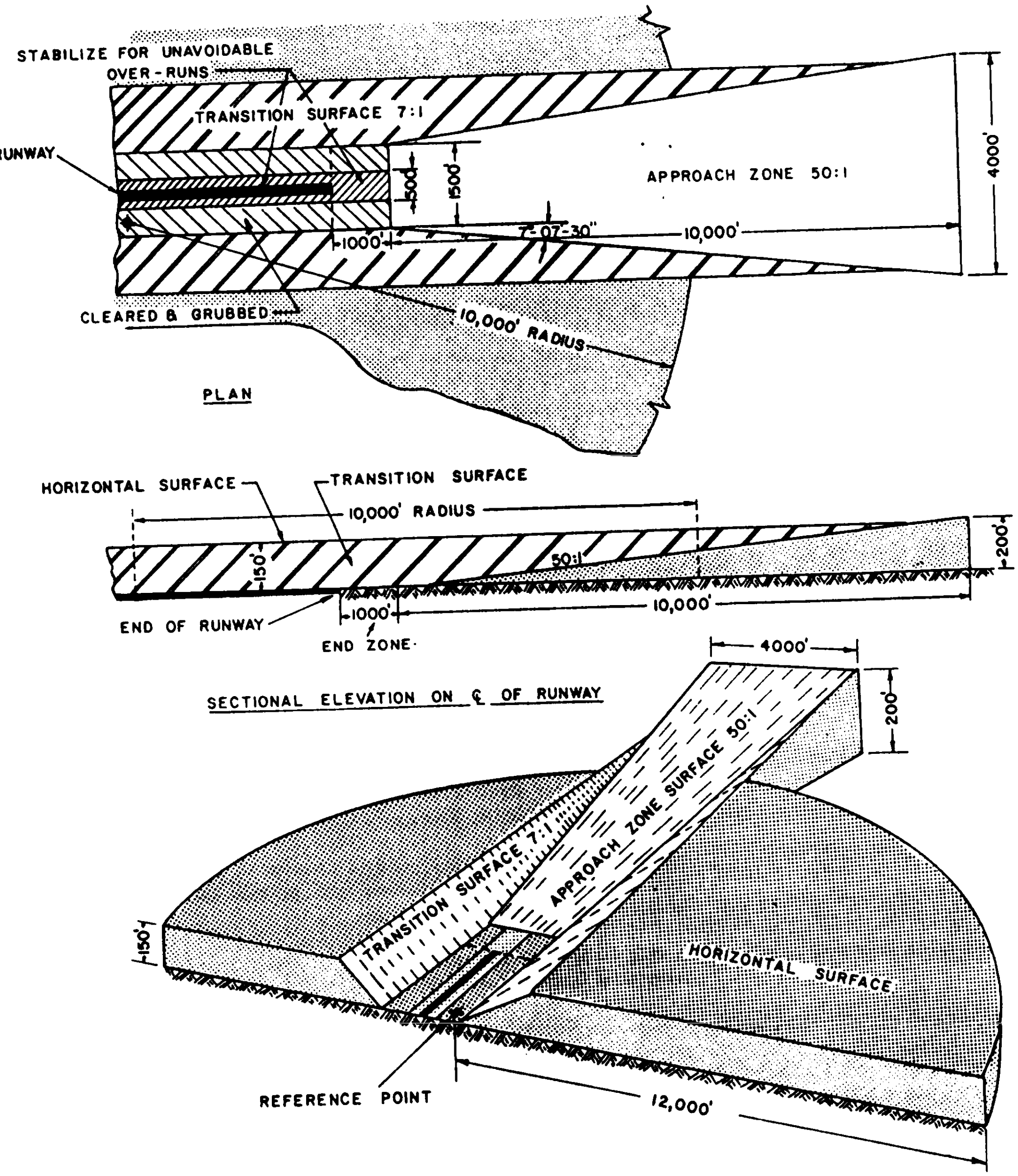


Figure 3-15.-Runway approach zone.

AIRFIELDS

Road construction and airfield construction have much in common, such as construction methods, equipment used, and sequence of operations. Each road or airfield requires a subgrade, base course, and surface course. The methods of cutting and falling, grading and compacting, and surfacing are all similar. As with roads, the responsibility for designing and laying out lies with the same person-the engineering officer. Again, as previously said for roads, you can expect involvement when airfield projects occur.

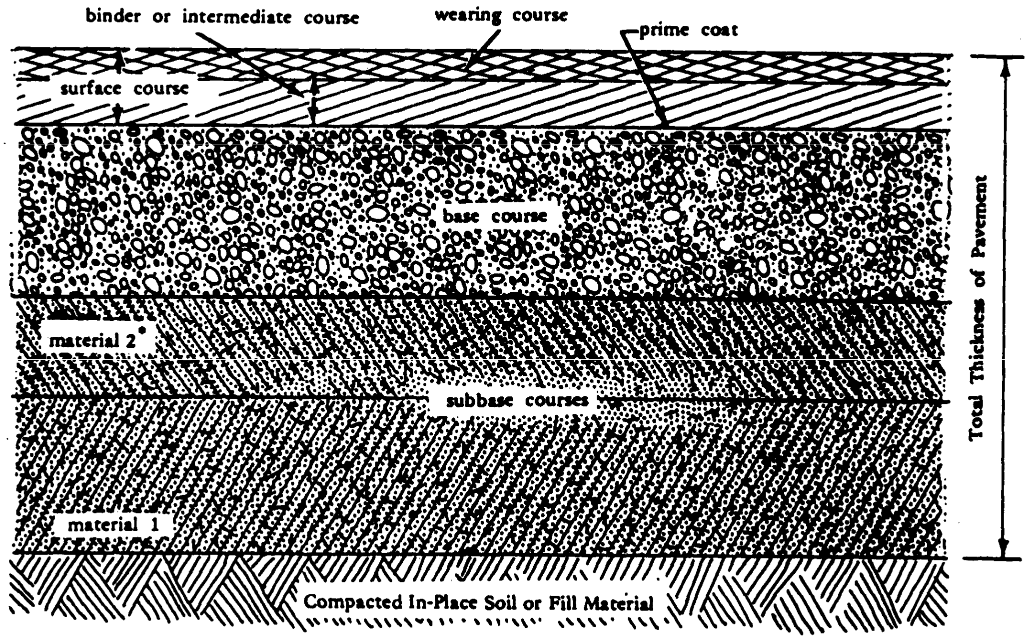
In this section, you will be introduced to airfields and airfield terminology. More information on airfields will be discussed in a later chapter of this TRAMAN.

AIRFIELD TERMINOLOGY

Figure 3-14 is a plan view of a small advanced-base airfield. Afield of this type is constructed for operational use in a combat area. It contains a minimum of servicing facilities and is not intended for permanent occupancy. Some of the terms shown in the figure are defined as follows:

APPROACH ZONE. A trapezoidal area established at each end of a runway. The approach zone must be free of obstructions on the plane of a specific glide angle. (See fig. 3-15.)

APRON. A stabilized, paved or metal-plank surface area, designed for the temporary parking of aircraft



*Material 2 is of a higher quality than material 1.

PAVEMENT	Combination of subbase, base, and surface constructed on subgrade
SURFACE COURSE	A hot mixed bituminous concrete designed as a structural member with weather and abrasion resisting properties. May consist of wearing and intermediate courses.
PRIME COAT	Application of a low viscosity liquid bitumen to the surface of the base course. The prime penetrates into the base and helps bind it to the overlying bituminous course
SEAL COAT	A thin bituminous surface treatment containing aggregate used to waterproof and improve the texture of the surface course
COMPACTED SUBGRADE	Upper part of the subgrade which is compacted to a density greater than the soil below
TACK COAT	A light application of liquid or emulsified bitumen on an existing paved surface to provide a bond with the superimposed bituminous course
SUBGRADE	Natural in-place soil, or fill material

Figure 3-16.—Typical flexible pavement and terminology.

other than at hardstands. Aprons are classified as service, **warm-up,** and **parking.**

END ZONE. A cleared and graded area that extends beyond each end of the runway. The dimensions of the end zone depend upon the safety clearances specified by the design criteria for advanced-base airfields. (See fig. 3-15.)

GLIDE ANGLE. The angle between the flight path of an airplane during a glide for landing or takeoff and a horizontal plane fixed relative to the runway. The glide angle is measured from the outer edge of the end zone. (See fig. 3-15.)

HARDSTAND. A stabilized, paved, or metal-plank-surfaced parking area of sufficient size and strenght tp accomodate a limited number of aircraft. Handstands are usually dispersed over the ground area beyond the safety clearance zones of a landing strip. They provide protection for aircraft on the field by dispersal, concealment, and revetment

LANDING AREA. The paved portion, or runaway, of the landing field. The landing area should have unobstructed approaches and should be suitable for the safe landing and takeoff of aircraft under ordinary weather conditions.

LANDING STRIP. Includes the landing area, end zones, shoulders, and cleared areas.

REVETMENT. A protective pen usually made by excavating into the side of a hill or by constructing earth, timber, sandbag, or masonry traverse around the hardstands. Such pens provide protection against bomb fragments from high-altitude bombing but provide little protection against ground strafing. They may actually draw this type of fire if they are not well concealed.

RUNWAY. That portion of the landing strip, usually paved, that is used for the landing and takeoff of aircraft.

SHOULDER. The graded and stabilized area adjacent to the runway or taxiway. Although it is made capable of supporting aircraft and auxiliary equipment (such as crash trucks) in emergencies, its principal function is to facilitate surface drainage.

TAXIWAY. A specially prepared area over which aircraft may taxi to and from the landing area.

TRANSITION SURFACE. A sloping plane surface (about 1 foot rise to 7 feet run) at the edge of a landing strip. Its function is to provide lateral safety clearances for planes that accidental] y run off the strip. (See fig. 3-15.)

PLANNING AN AIRFIELD

Planning for aviation facilities requires special consideration of the type of aircraft to be accommodated; physical conditions of the site, including weather conditions, terrain, soil, and availability y of construction materials; safety factors, such as approach zone obstructions and traffic control; the provision for expansion; and defense. Under wartime conditions, tactical considerations are also required. All of these factors affect the number, orientation, and dimensions of runways, taxiways, aprons, hardstands, hangars, and other facilities.

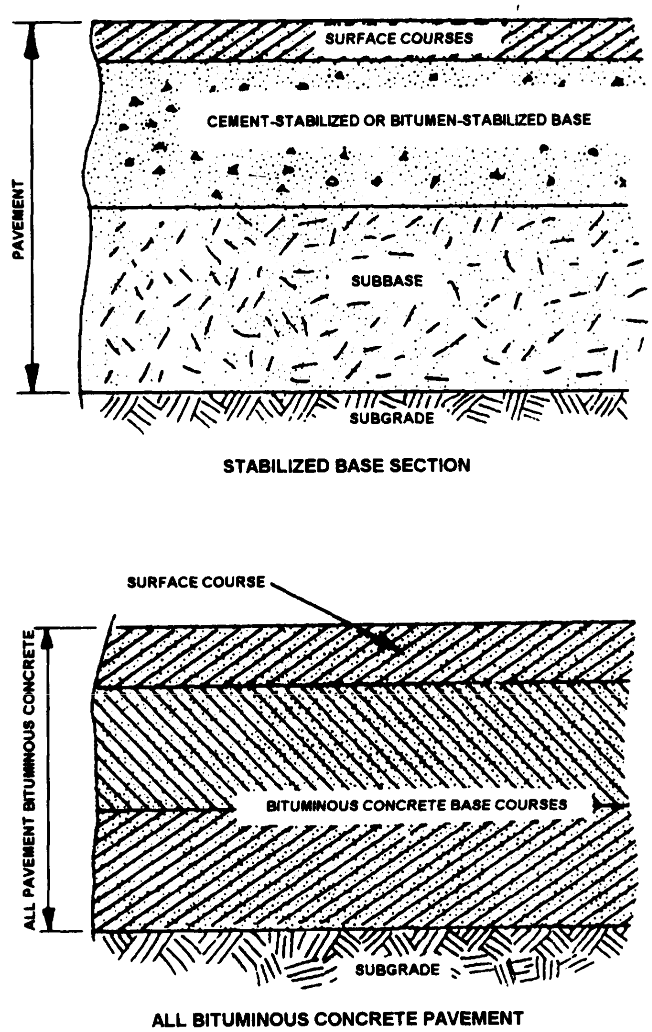


Figure 3-17.-Typical pavements using stabilized layers.

SUBBASE AND BASE COURSE

Pavements (including the surface and underlying courses) may be divided into two classes—rigid and flexible. The wearing surface of a rigid pavement is constructed of portland cement concrete. Its flexural strength enables it to act as abeam and allows it to bridge over minor irregularities in the base or subgrade upon which it rests. All other pavements are classified as flexible. Any distortion or displacement in the subgrade of a flexible pavement is reflected in the base course and upward into the surface course. These courses tend to conform to the same shape under traffic. Flexible pavements are used almost exclusively in the theater of operations for road and airfield construction since they adapt to nearly all situations and can be built by any construction battalion unit in the Naval Construction Force (NCF).

FLEXIBLE PAVEMENT STRUCTURE

A typical flexible pavement is constructed as shown in figure 3-16, which also defines the parts or layers of pavement. All layers shown in the figure are not present in every flexible pavement. For example, a two-layer structure consists of a compacted subgrade and a base course only. Figure 3-17 shows a typical flexible pavement using stabilized layers. (The word *pavement,* when used by itself, refers only to the leveling, binder, and surface course, whereas *flexible pavement* refers to the entire pavement structure from the subgrade up.) The use of flexible pavements on airfields must be limited to paved areas not subjected to detrimental effects of jet fuel spillage and jet blast. In fact, their use is prohibited in areas where these effects are severe.

Flexible pavements are generally satisfactory for runway interiors, taxiways, shoulders, and overruns. Rigid pavements or special types of flexible pavement, such as tar rubber, should be specified in certain critical operational areas.

MATERIALS

Select materials will normally be locally available coarse-grained soils, although fine-grained soils maybe used in certain cases. Lime rock, coral, shell, ashes, cinders, caliche, disintegrated granite, and other such materials should be considered when they are economical.

Subbase

Subbase materials may consist of naturally occurring coarse-grained soils or blended and processed soils. Materials, such as lime rock, coral, shell, ashes, cinders, caliche, and disintegrated granite, maybe used as subbases when they meet area specifications or project specifications. Materials stabilized with commercial admixes may be economical as subbases in certain instances. Portland cement, cutback asphalt, emulsified asphalt, and tar are commonly used for this purpose.

Base Course

A wide variety of gravels, sands, gravelly and sandy soils, and other natural materials such as lime rock, corals, shells, and some caliches can be used alone or blended to provide satisfactory base courses. In some instances, natural materials will require crushing or removal of the oversize fraction to maintain gradation limits. Other natural materials may be controlled by mixing crushed and pit-run materials to form a satisfactory base course material.

Many natural deposits of sandy and gravelly materials also make satisfactory base materials. Gravel deposits vary widely in the relative proportions of coarse and fine material and in the character of the rock fragments. Satisfactory base materials often can be produced by blending materials from two or more deposits. Abase course made from sandy and gravel] y material has a high-bearing value and can be used to support heavy loads. However, uncrushed, clean washed gravel is not satisfactory for a base course because the fine material, which acts as the binder and fills the void between coarser aggregate, has been washed away.

Sand and clay in a natural mixture maybe found in alluvial deposits varying in thickness from 1 to 20 feet. Often there are great variations in the proportions of sand and clay from the top to the bottom of a pit. Deposits of partially disintegrated rock consisting of fragments of rock, clay, and mica flakes should not be confused with sand-clay soil. Mistaking such material for sand-clay is often a cause of base course failure because of reduced stability caused by the mica content. With proper proportioning and construction methods, satisfactory results can be obtained with sand-clay soil. It is excellent in construction where a higher type of surface is to be added later.

Processed materials are prepared by crushing and screening rock, gravel, or slag. A properly graded crushed-rock base produced from sound, durable rock particles makes the highest quality of any base material. Crushed rock may be produced from almost any type of rock that is hard enough to require drilling, blasting, and crushing. Existing quarries, ledge rock, cobbles and gravel, talus deposits, coarse mine tailings, and similar hard, durable rock fragments are the usual sources of processed materials. Materials that crumble on exposure to air or water should not be used. Nor should processed materials be used when gravel or sand-clay is available, except when studies show that the use of processed materials will save time and effort when they are made necessary by project requirements. Bases made from processed materials can be divided into three general types-stabilized, coarse graded, and macadam. A stabilized base is one in which all material ranging from coarse to fine is intimately mixed either before or as the material is laid into place. A coarse-graded base is composed of crushed rock, gravel, or slag. This base may be used to advantage when it is necessary to produce crushed rock, gravel, or slag on site or when commercial aggregates are available. A macadam base is one where a coarse, crushed aggregate is placed in a relatively thin layer and rolled into place; then fine aggregate or screenings are placed on the surface of the coarse-aggregate layer and rolled and broomed into the coarse rock until it is thoroughly keyed in place. Water may be used in the compacting and keying process. When water is used, the base is a water-bound macadam. The crushed rock used for macadam bases should consist of clean, angular, durable particles free of clay, organic matter, and other objectional material or coating. Any hard, durable crushed aggregate can be used, provided the coarse aggregate is primarily one size and the fine aggregate will key into the coarse aggregate.

Other Materials

In a theater of operations where deposits of natural sand and gravel and sources of crushed rock are not available, base courses are developed from materials that normally would not be considered. These include coral, caliche, tuff, rubble, lime rock, shells, cinders, iron ore, and other select materials. Some of these are primarily soft rock and are crushed or degraded under construction traffic to produce composite base materials. Others develop a cementing action, which results in a satisfactory base. The following text describes the characteristics and usage of some of these materials:

1. **CORAL.** Uncompacted and poorly drained coral often results in an excessive moisture content and loss of stability. The bonding properties of coral, which are its greatest asset as a construction material, vary with the amount of volcanic impurities, the proportion of fine and coarse material, age, length of exposure to the elements, climate, traffic, sprinkling, and method of compaction. Proper moisture control, drainage, and compaction are essential to obtain satisfactory results.

2 **CALICHE.** A variable material that consists of sand, silt, or even gravel, that when saturated with water, compacted, and allowed to settle, can be made into high-quality base courses, especially caliches that are cemented with lime, iron oxide, or salt. Caliches vary, however, in content (limestone, silt, and clay) and in degree of cementation; therefore, it is important that caliche of good uniform quality be obtained from deposits and that it be compacted at optimum moisture.

3. **TUFF.** A porous rock usually stratified, formed by consolidation of volcanic ashes, dust, and so forth, and other cementitious materials of volcanic origin, may be used for base courses. Tuff bases are constructed the same as other base courses except that after the tuff is dumped and spread, the oversize pieces are broken and the base compacted with sheepsfoot rollers. The surface is then graded, compacted, and finished.

4. **RUBBLE.** It may be advantageous to use the debris or rubble of destroyed buildings in constructing base courses. If so, jagged pieces of metal and similar objects are removed.

Bituminous Base

Bituminous mixtures are frequently used as base courses beneath high-type bituminous pavements, particularly for rear-area Wields which carry heavy traffic. Such base courses may be used to advantage when locally available aggregates are relatively soft and otherwise of relatively poor quality, when mixing plant and bituminous materials are readily available, and when a relatively thick surface course is required for the traffic. In general, a bituminous base course may be considered equal on an inch-for-inch basis to other types of high-quality base courses. When a bituminous base course is used, it will be placed in lifts not exceeding 3 1/2 inches in thickness. If a bituminous base is used the binder course may be omitted, and the surface course may be laid directly on the base course.

QUESTIONS

Q1. What is the correct nomenclature for each of the items labeled in figure 3-18?

Q2. What feature is normally provided in a horizontal curve to counteract the effect of centrifugal force?

Q3. What type of section is used to set slope stakes and to show as-built conditions?

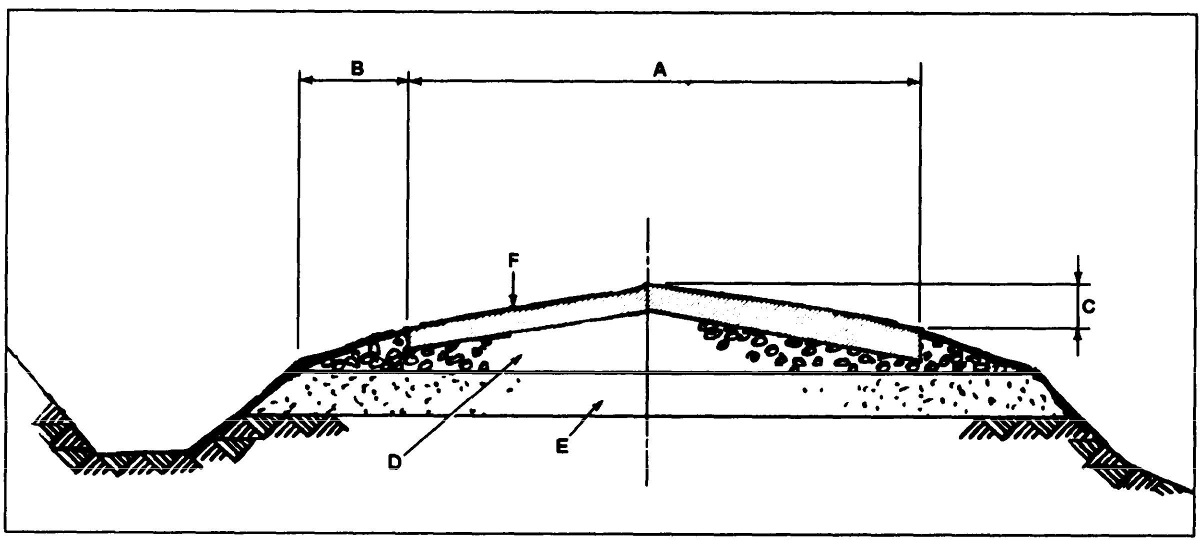


Figure 3-18.-Typical section.

CHAPTER 4

PROJECT DRAWINGS

As you learned in chapter 10 of the EA3 TRAMAN, a construction drawing maybe one of several different types depending upon its intended use; and, in practice, more than one type may be used during the design and construction of a new facility or structure. For instance, a **presentation drawing** (often based on a NAVFAC **definitive design)** maybe prepared to "sell" an idea or concept for anew facility. Them, after the design phase is completed, the facility is constructed using one or more sets of **shop drawings** and, of course, a set of **project** (or **working) drawings.** Shop drawings, as you recall, are those drawings, diagrams, or other-related data that are used to illustrate a material, product, or system; for example, a shop drawing might be an assembly drawing, prepared by a manufacturer, to describe the proper steps in assembling a set of commercially purchased cabinets. Project drawings are those drawings that describe to construction crews the construction of a complete facility or structure. These drawings are most often supplemented with shop drawings and project specifications (discussed in chapter 5 of this TRAMAN).

Our discussions in this chapter center on project drawings as they pertain mostly to building construction. In the EA3 TRAMAN, you learned that NAVFAC project drawings are divided into the following categories or divisions: civil, architectural, structural, mechanical, electrical, and fire protection. Our discussions will include a brief review of the information you learned in the EA3 TRAMAN concerning these divisions. We also will expand on the EA3 TRAMAN information by including a discussion of heating, ventilating, and air-conditioning systems and drawings; riser diagrams for plumbing; and electrical wiring diagrams and schedules. In addition, you will be provided with information and tips that you can use when checking and editing project drawings.

For NAVFAC policy regarding project drawing sizes, formats, and conventions, you should refer to *Policy and Procedures for Project Drawing and Specification Preparation,* MIL-HDBK-1006/1 and to the various Department of Defense (DOD) standards, military standards, and American National Standards Institute (ANSI) standards referred to in MIL-HDBK-1006/1.

PROJECT DRAWING DIVISIONS

The following paragraphs briefly describe the contents of the drawing categories or divisions mentioned above.

CIVIL DIVISION

The drawings contained in the civil division are those that describe the existing conditions and planned development of a project site. As applicable to any particular project, the division typically includes drawings that describe, at a minimum, the following information:

1. Project location (shown on regional and vicinity maps)

2. Soil boring logs and profiles.

3. Existing site conditions to include terrain contours, buildings or structures, utilities, drainage, and other physical features on or near the project site. For small projects, this information can be shown in the site (plot) plan; however, for large or complex construction projects, it is often shown in a separate existing conditions plan.

4. Planned demolition of existing buildings, structures, utilities, or other physical features that must be demolished as a part of the project. Dependent upon the complexity of the project, you may show this in the site plan or in a separate demolition plan.

5. Planned grading for surface drainage (shown by contours or a combination of contours and spot elevations) and the planned grading and paving of driveways, access roads, and parking areas. For grading and paving, you should show plans, profiles, cross sections, and paving details as necessary to describe the new construction fully. Also show details for any curbs, gutters, sidewalks, and so forth. Again, dependent upon the complexity of the project, you may show all of this in the site plan or in a separate grading and paving plan.

6. Proposed site plan showing property boundaries, construction limits, and exactly defined locations and finished floor elevations of new buildings or structures. Each building or structure should be located using a minimum of two location dimensions.

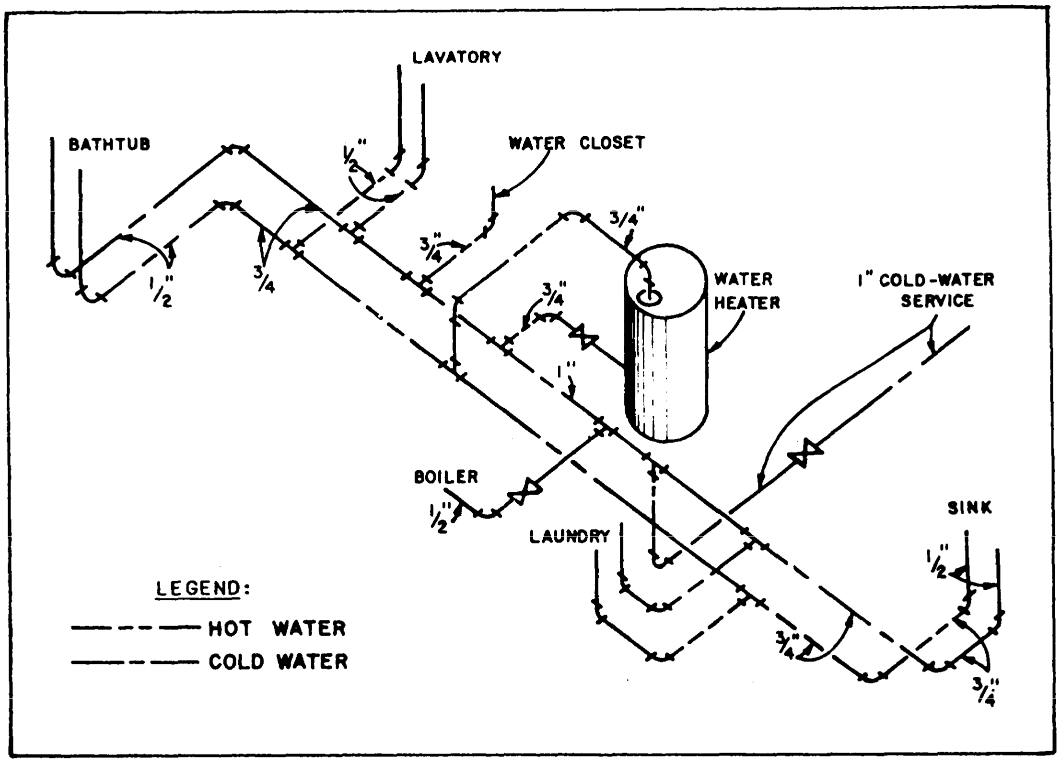


Figure 4-1.—Hot- and cold-water riser diagram.

Show the location and direction of all new utilities, unless separate utility site plans are included in other divisions, such as the mechanical, plumbing, or electrical divisions. That is sometimes done for large, complex projects.

ARCHITECTURAL DIVIS1ON

The architectural division includes drawings, such as floor and roof plans, interior and exterior elevations, millwork, door and window schedules, finish schedules, special architectural treatments, and nonstructural sections and details. For a discussion of these drawings, you should review chapter 10 of the EA3 TRAMAN.

STRUCTURAL DIVISION

The structural division is comprised of all of the drawings that fully describe the structural composition and integrity of a building or structure. Included in the division are the foundation plan and details; floor, wall, and roof framing plans and details; reinforcing plans and details; beam and column details; and other such structural plans and details. In a set of drawings, the first sheet in the structural division also should include, when applicable, roof, floor, wind, seismic, and other loads, allowable soil bearing capacity, and allowable stresses of all materials, such as concrete and reinforcing steel. Again, you should review chapter 10 of the EA3 TRAMAN.

MECHANICAL DIVISION

The mechanical division includes the plans, details, and schedules that describe the heating, ventilating, and air-conditioning (HVAC) systems equipment and installation requirements. We'll discuss more about these systems later in this chapter.

The mechanical division also includes plumbing drawings that show the fixtures, water supply and waste disposal piping, and related equipment that are to be installed in a building. The drawings include plumbing plans, riser diagrams, details, and fixture schedules. Remember, that in the order of drawings, plumbing drawings always follow the HVAC drawings.

As you recall from your study of chapters 8 and 10 of the EA3 TRAMAN, a plumbing plan (or layout) is a plan view of the fixtures, lines, and fittings to be installed in a building. For an uncomplicated building containing, let's say, one water closet and one lavatory, you can easily prepare a plumbing plan that can be clearly interpreted by the planners and estimators, inspectors, or other users of the drawing. For such a building, the plumbing plan might well be all that is

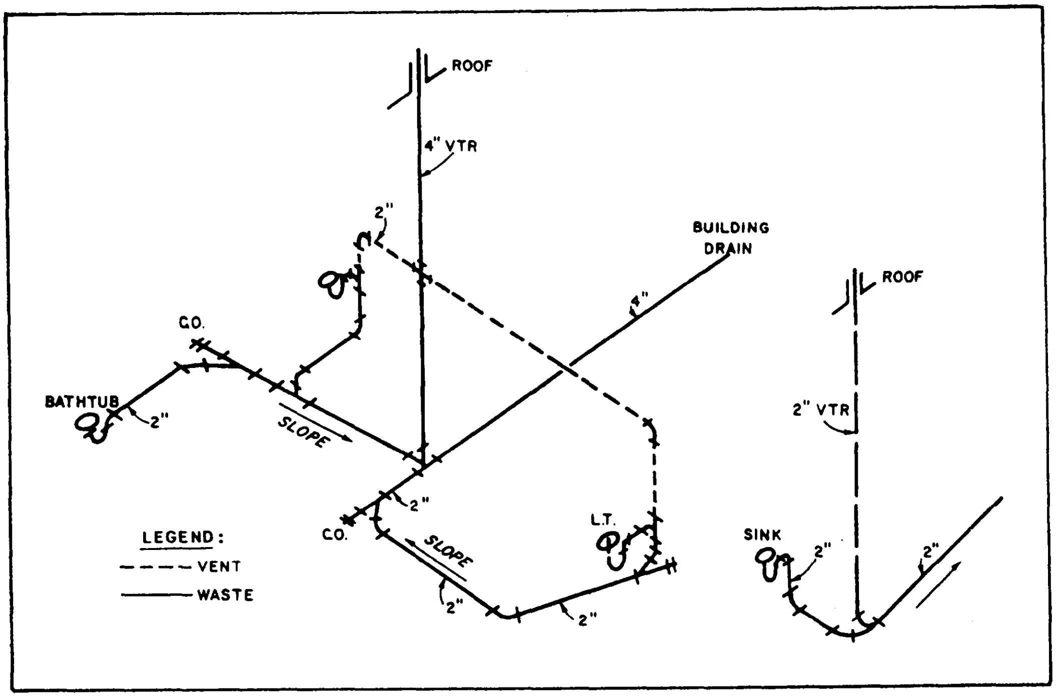


Figure 4-2.—Riser diagram for waste and soil piping.

needed to install the plumbing system. As the complexity of the building plumbing increases, however, your ability to describe the plumbing layout accurately and clearly using only a plumbing plan diminishes. This can easily lead to misinterpretations by the users of the plan. In such cases as this, it is common practice to supplement the plumbing plan with riser diagrams.

The most commonly used type of riser diagram for plumbing is the isometric riser diagram. As you see in the examples shown in figures 4-1 and 4-2, the isometric riser diagram provides a three-dimensional representation of the plumbing system. Although a riser diagram is usually not drawn to scale, it should be correctly proportioned. In other words, a long run of piping in the plumbing plan should be shown as a long run of piping in the riser diagram. Conversely, short runs should be shown as short runs. Make sure, too, that you use proper symbols (from MIL-STD-17B) for the piping and fittings. This makes it easy for someone familiar with the symbols to read and interpret the drawing. A glance at figure 4-1 tells you, for example, that the plumbing system contains three gate valves and that all of the fittings are screw-type fittings. Be sure that the pipe sizes are properly labeled, especially where changes in pipe size occur. Label all fixture connections to identify to what fixture the piping connects. In figure 4-1, the fixtures are spelled out; however, it is also common practice to label the fixtures using an alphanumeric coding, keyed to a fixture schedule.

Another type of riser diagram, though less often used in construction drawings, is the orthographic riser diagram that shows the plumbing system in elevation. When used, it is normally reserved for buildings that are two or more stories in height. Also, since you probably cannot clearly describe an entire plumbing system for a building in a single elevation, more than one orthographic riser diagram is necessary for the building. Examples of these diagrams can be found in *Architectural Graphic Standards,* by Ramsey and Sleeper.

ELECTRICAL DIVISION

Included in the electrical section are power and lighting plans, electrical diagrams, details, and schedules. Chapters 9 and 10 of the EA3 TRAMAN provide a discussion of interior wiring materials and the drawing of electrical plans.

Electrical single-line block diagrams are drawings that show electrical components and their related connections in a diagrammatic form. The diagrams, seldom drawn to scale, use standard symbols to represent individual pieces of electrical equipment and lines to represent the conductors or wires connecting the equipment.

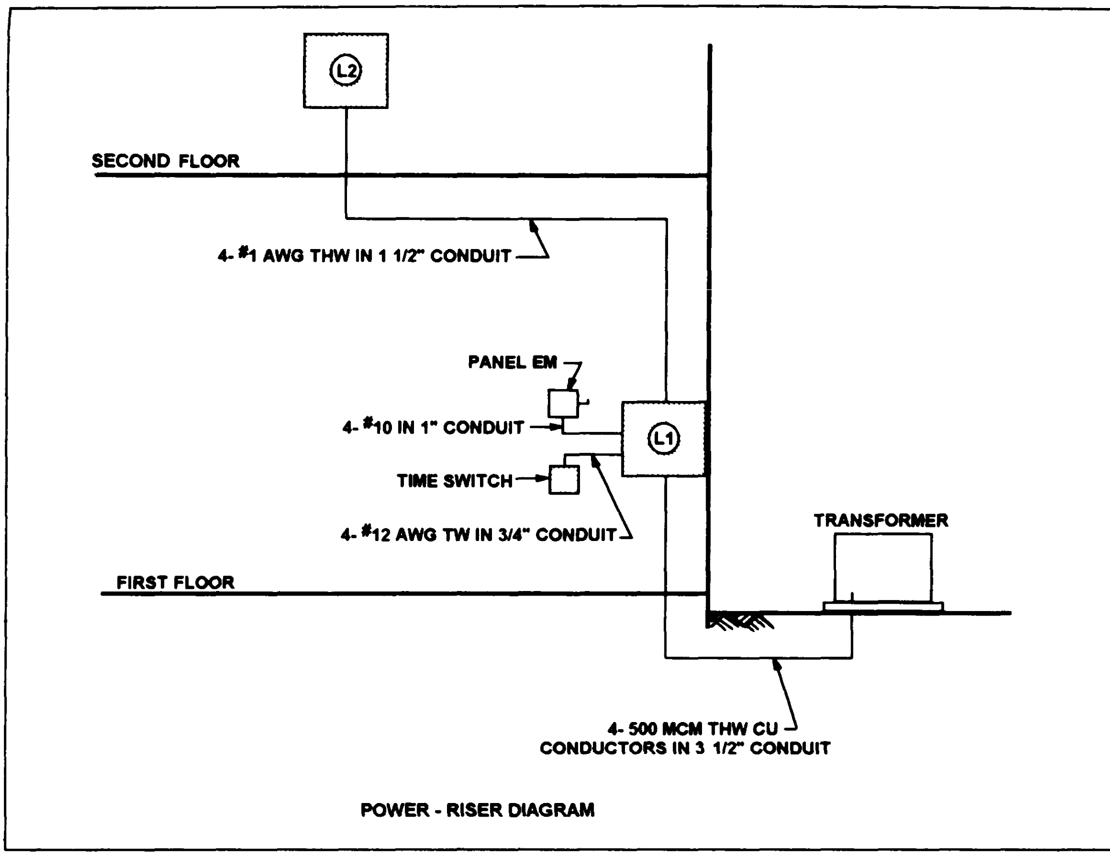


Figure 4-3.—Example of a power-riser diagram.

A simple example is the power-riser diagram shown in figure 4-3. In this example, you see the manner in which two electrical panels *(L1* and *L2)* are planned for installation in a two-story building. As you see, notes are used to identify each piece of equipment and to indicate the number, size, and type of conductors in each conduit. A panelboard schedule for each of the panels should also be included in the drawings to indicate the components, such as fuses or circuit breakers, contained in the each panelboard.

A schematic wiring diagram is similar to the single-line block diagram; however, it provides more detailed information and the actual number of wires used in each circuit is shown. Complete schematic wiring diagrams are usually used for unique and complicated systems, such as control circuits. An example of a schematic diagram is shown in figure 4-4.

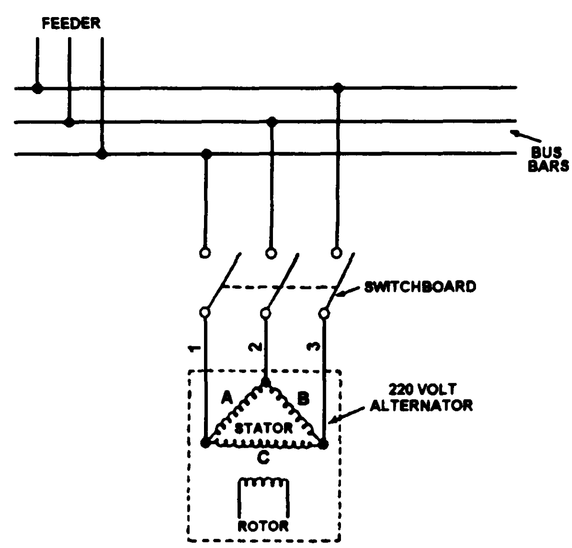


Figure 4-4.—Example of a schematic diagram

FIRE PROTECTION DIVISION

This division includes the plans, details, and schedules that describe the fire protection systems that are to be installed in the building. These systems can include, as applicable, wet-pipe or dry-pipe sprinkler systems, monitoring equipment, and alarms. A discussion of these systems is beyond the scope of this TRAMAN.

HVAC SYSTEMS AND DRAWINGS

Although it's the engineers responsibility to design heating, ventilating, and air-conditioning systems, the drafter who prepares drawings of the systems should have a basic understanding of the operating principles of each. Those principles, and a typical heating and air conditioning layout for a building, are discussed in the

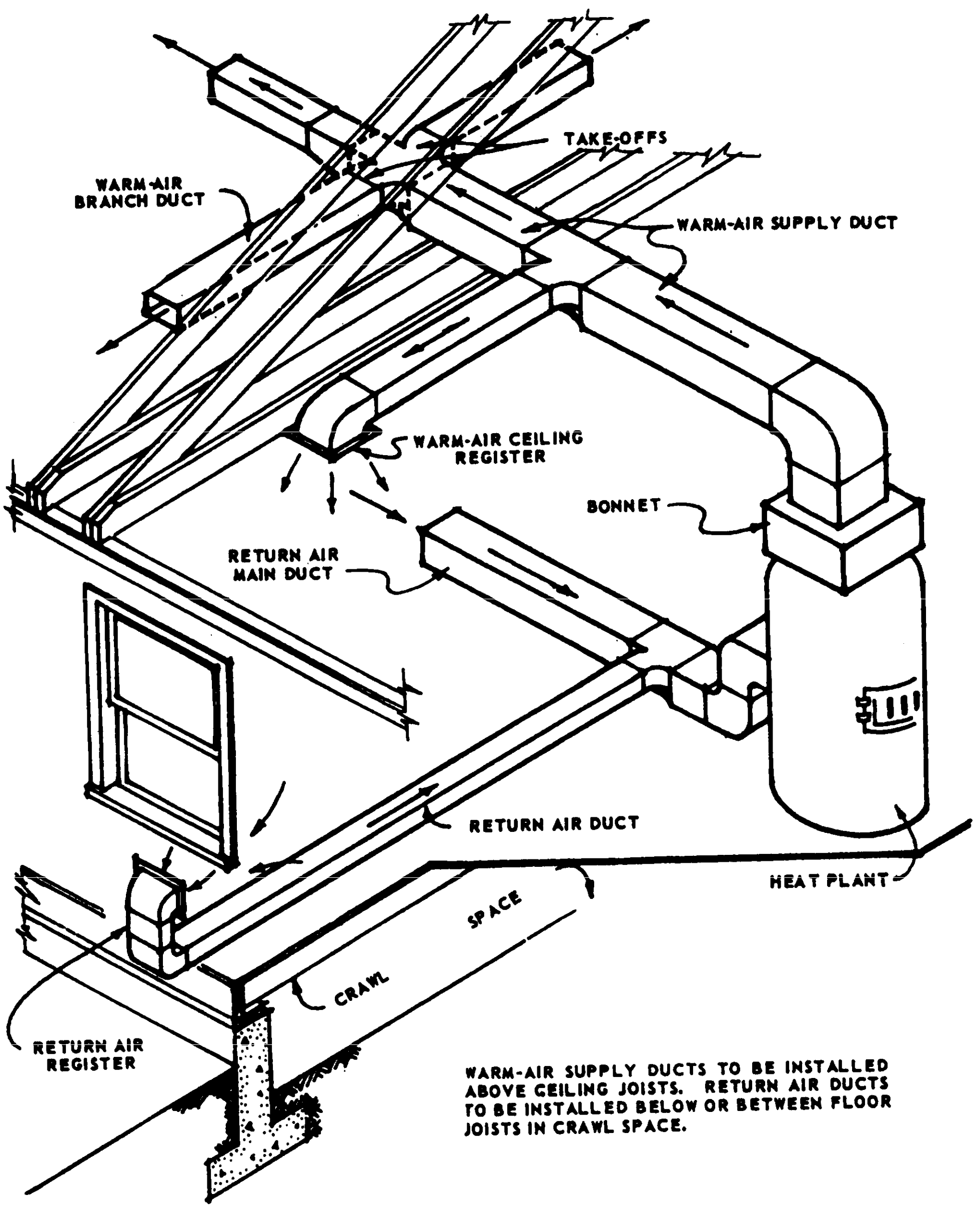


Figure 4-5.—Forced-air heating system.

following paragraphs. For a discussion of heating principles (including theory, measurement of heat, and heat transfer) and a discussion of the principles of refriger-ation and air conditioning, you should read chapters 9 and 10 of *Utilitiesman 3,* NAVEDTRA 12532.

HEATING SYSTEM

The purpose of designing and installing a heating system in a building is to provide proper heat distribution to the various rooms or zones within the building. This can be done by means of various types of heating systems.

Warm-Air Furnace Systems

A warm-air furnace can be any type of heating device that circulates warmed air to locations where it is needed. One type, the **wall heater,** draws in cold air near the floor, passes the air over a heating unit, and then exhausts the warmed air to heat the surrounding area Another type is the **gravity warm-air furnace.** It is a direct-fired furnace that transfers heat by convection In other words, warmed air circulating through the furnace rises through ductwork to the areas to be heated and then, as the air cools, it descends to the furmace to be reheated Since the installation of this type of system requires abasement and large, unsightly ductwork, it is seldom used in new construction.

A more commonly used type of warm-air furnace is the forced-air furnace (fig. 4-5). In this type, an oil or gas burner heats the fins of a heat exchanger. The heat exchanger warms the cool air passing over it. The warmed air is then forced, by fan, through relatively small **supply ducts** to the areas to be heated. The air is then returned through **return ducts** to the furnace for reheating. Outside air can be supplied to the return ducts for a continual supply of fresh air.

Forced-air furnaces are controlled by two thermostats: a room thermostat to control the burner and another thermostat to control the blower. Most of these furnaces have filters that eliminate any solid particles in the air before it is heated. These furnaces are also frequently equipped with humidifiers to replace moisture that has been removed from the heated air.

Ducts for forced-air furnace systems can be round, square, or rectangular in shape and can be fabricated from tin-plated steel, fiberglass, or more commonly, galvanized sheet metal using methods discussed in chapter 11 of *Steelworker 3 &* 2, NAVEDTRA 10653-G. Insulation for the ducts usually consist of 1/2-inch to 2-inch-thick fiberglass or rock-wool blankets wrapped around the ducts.

Supply and return outlets may be located in walls, ceilings, or floors. The cover for the outlet may be a decorative grill that covers the end of the duct opening, or it can be a **register** that can be adjusted to vary the amount of airflow. **Diffusers** are used to direct the flow of air. They can be either adjustable or nonadjustable and can also include a register. Supply outlets carrying only hot air are best located in or near the floor. That way, the hot air is introduced to the coolest part of the room, and the cold air is returned through return outlets located near or in the ceiling. When the ducts are used also for supplying cooled air, then the opposite location arrangement is best. A small building, such as a residence, may have a single return air grill located in a central hallway. In this case, doors leading to the hall are undercut by about 1 or 2 inches.

For a more thorough discussion of warm-airheating systems and equipment, you should read chapter 9 of *Utilitiesman 2,* NAVEDTRA 10662.

Steam-Heating Systems

Steam-heating systems consist of a boiler, a piping system, and radiators or connectors. The boiler is fired by oil, gas, coal, or electricity. Although there are many variations and combinations of steam-heating systems, they are all basically either **one-pipe** or **two-pipe** systems.

The one-pipe system uses the same pipe to convey the steam to the radiator and to return the condensate to the boils. When the unit is started, the steam pushes air out of the system through thermostatically controlled air wolves at the radiators. When the air has been expelled and steam reaches the valve, the valve closes automatically. As the steam gives up heat through the radiators, it condenses and runs back to the boiler through the bottom of the supply piping. In the one-pipe system, the mains must be large and sloped to allow the condensate to flow back to the boiler without interfering with the flow of steam.

In a two-pipe system, the steam flows into one end of the radiator and out the opposite end through a thermostatically controlled **drip trap** that is set to open automatically when the temperature drops below 180°F. When enough condensate has collected in the radiator to cool it, the drip trap opens, allowing the condensate to flow into return lines where it is carried to a collecting tank.

A **radiator** used in a steam- (or hot water) heating system usually consists of a series of interconnected, vertical cast-iron sections. As the steam flows through the radiator, the surface of the sections radiates heat to the surrounding walls, objects, and the surrounding air. As the surrounding air is heated, it rises towards the ceiling, setting into motion a convection current that transfers heat throughout the room.

Convectors usually consist of iron or copper pipes surrounded by metal fins and are most often placed near the floor. Openings at the top and bottom of the convector unit allow circulation of air over the fins. That movement of air over the fins transfers heat to the surrounding area. Small connectors placed around the base of the wall are termed *baseboard heaters.*

For a more thorough discussion of steam-heating systems and equipment, you should read chapter 7 of *Utilitiesman 2,* NAVEDTRA 10662

Water-Heating Systems

A water-heating system includes a boiler, a piping system, radiators or connectors (discussed **above),** and a water-circulating pump that is used to force the water to the radiators or connectors and back to the boiler. For water heating, three types of piping systems are used.

The **one-pipe** system (fig. 4-6) consists of a single supply main that carries hot water to each radiator in turn. To overcome a loss of water temperature at each successive radiator, you must balance the size of the piping or the orifice at the radiator.

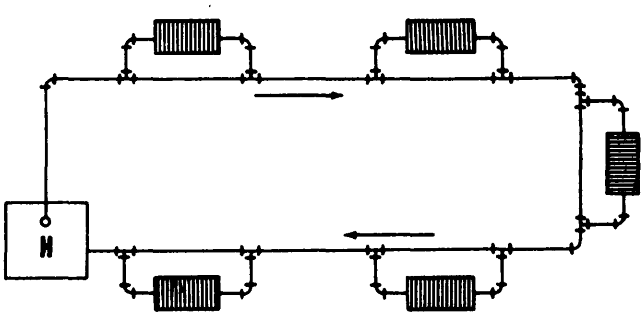


Figure 4-6.—One-pipe water-heating system.

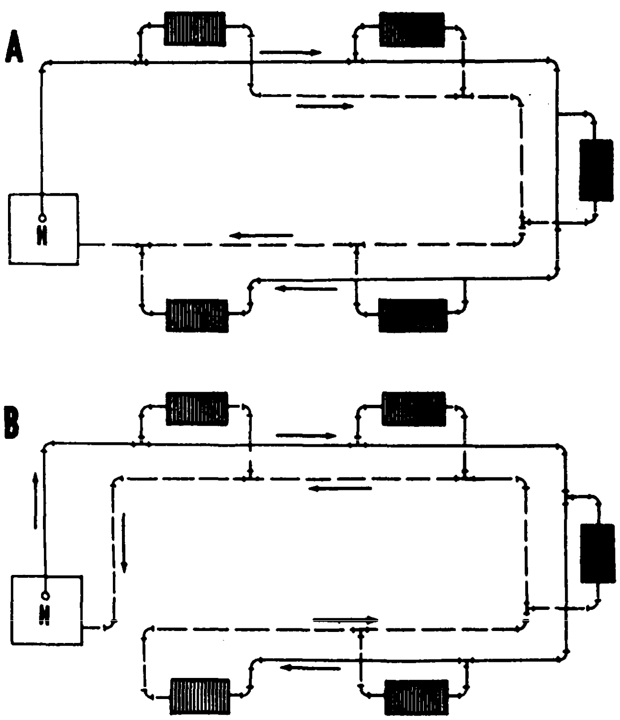


Figure 4-7.—Two-pipe water-heating system: A. direct return; B. reverse return.

A **two-pipe** system is shown in figure 4-7. In this system, the supply main carries hot water, and the cooled water is returned through a separate return pipe.

For a more thorough discussion of hot-water heating systems and equipment, you should read chapter 10 of *Utilitiesman 2,* NAVEDTRA 10662.

Unit Heaters

Unit heaters are either gas-fired units or they consist of coils of tubing that circulate hot water or steam. A built-in fan behind the unit or coils blows the heated air throughout the area it is heating. When used, unit heaters are usually suspended from ceilings or are mounted high on walls in large, open areas of garages, shops, and similar facilities.

Radiant-Heating Systems

When you are in a cold room, your sensation of chill is due more to the loss of your body heat to the surrounding surfaces than to the temperature of the air. To compensate for this condition, a radiant-heating (or panel-heating) system warms the surrounding surfaces so that you are more comfortable at a lower air temperature. This type of heating system consists of hot-air pipes, hot-water pipes, or electric coils that are embedded in walls, floors, or ceilings.

VENTILATING SYSTEMS

Most ventilating systems take advantage of the natural environment. The ventilating system is designed to use the natural forces of wind and interior-exterior temperature differences to cause circulation and maintain a continuous freshening of the internal air. In general, air is permitted to enter through openings at or near floor level and allowed to escape through openings high on the walls or in ceilings and roof.

In mechanical ventilation, air circulation is induced by mechanical means-usually by fans-that may be combined with supply and exhaust duct systems.

AIR-CONDITIONING SYSTEMS

Providing complete "comfort conditioning" for a building involves more than simply controlling temperature. It also includes providing balanced humidity; fresh and clean air that is free of odors, dirt, dust, and lint particles; and controlled air motion. **Air conditioning** is the process that provides and controls all of those conditions.

The cooling and warming of the air is usually referred to as winter and summer air conditioning. Winter and summer air conditioning is done by installing both cooling and heating equipment in the air-conditioning system. Of course, single units for heating and cooling may be used separately.

Heating equipment for winter air conditioning is most often automatic. Heating coils, usually built into the air-conditioning unit, give up heat from the water or steam that passes through them from a heating unit. Heat may also be generated within an air-conditioning unit directly by a gas-heating unit or by an electric heater. No matter what type of heat is used, the goal is to heat the air.

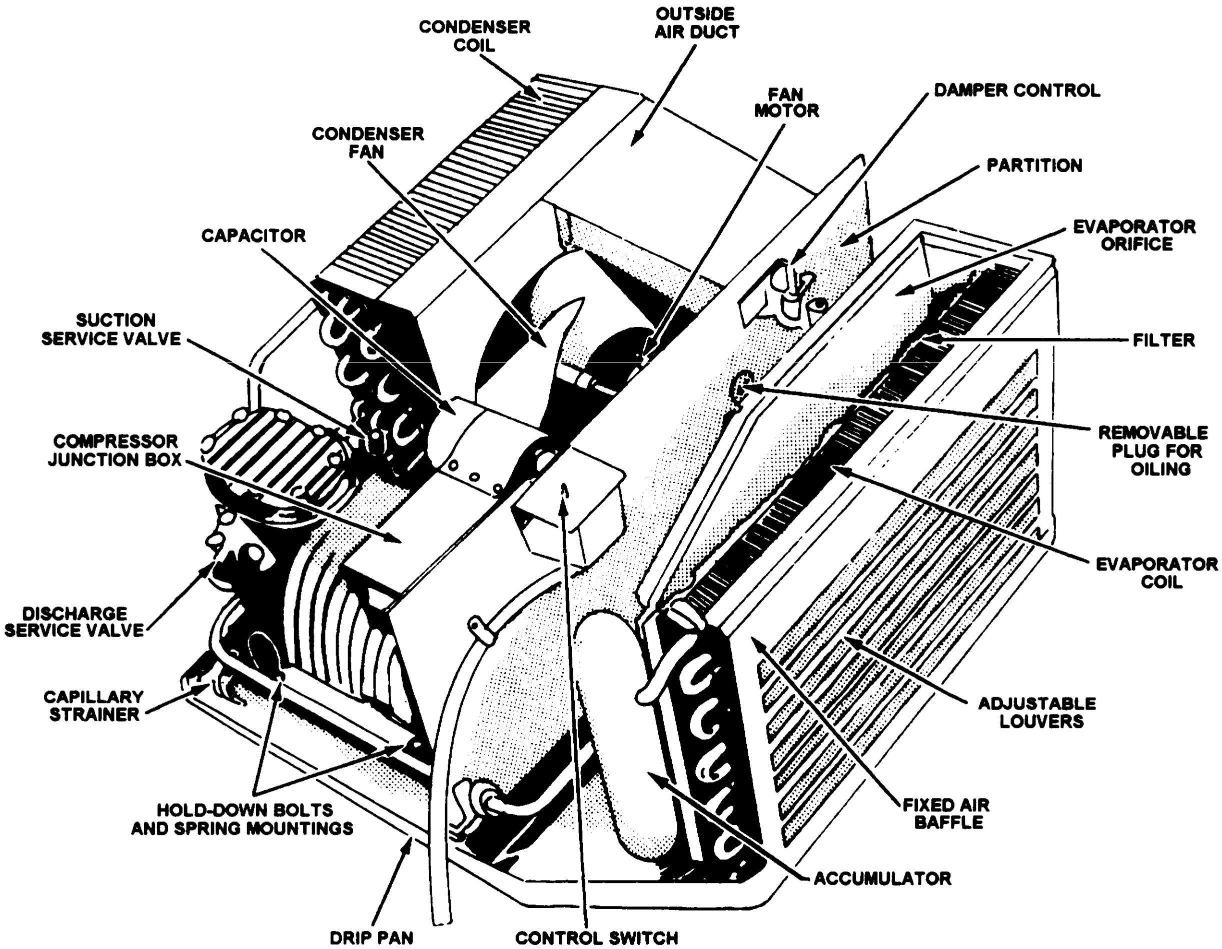


Figure 4-8.—Window air conditioner.

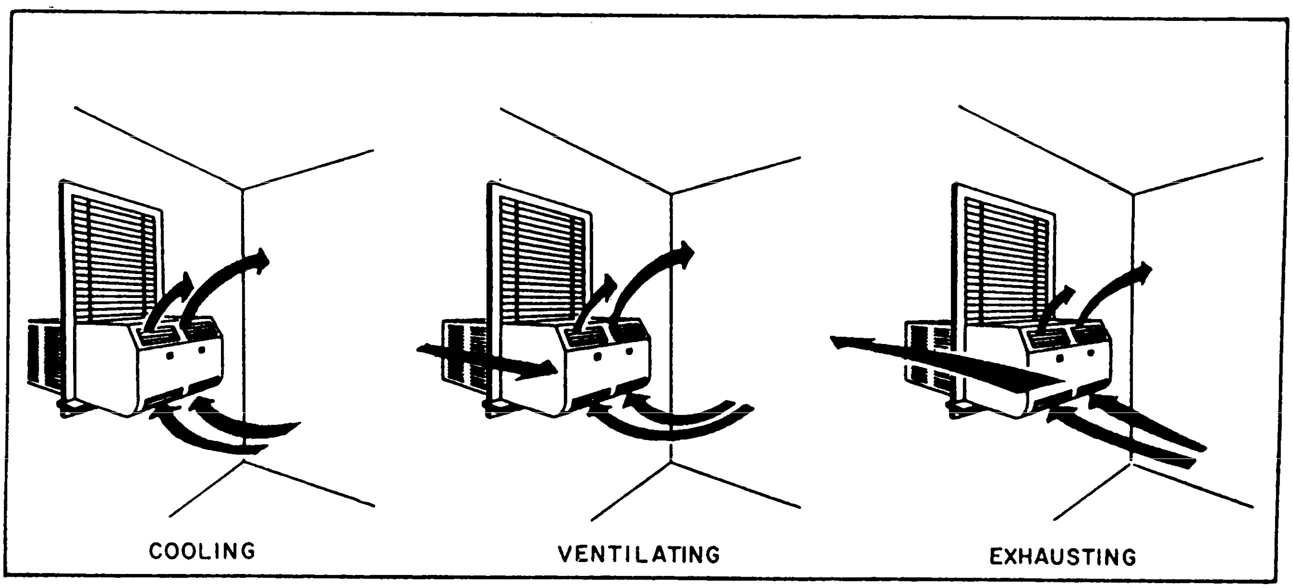


Figure 4-9.—Window air conditioners, showing airflow patterns for cooling, ventilating, and exhausting.

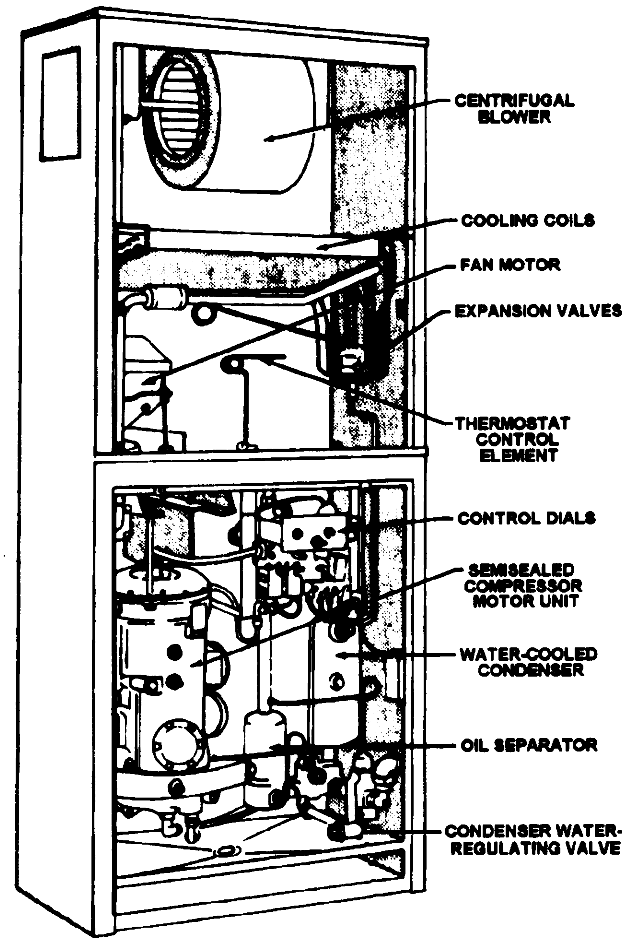


Figure 4-10.-FIoor-mounted air-conditioning unit (shown with cover panels removed).

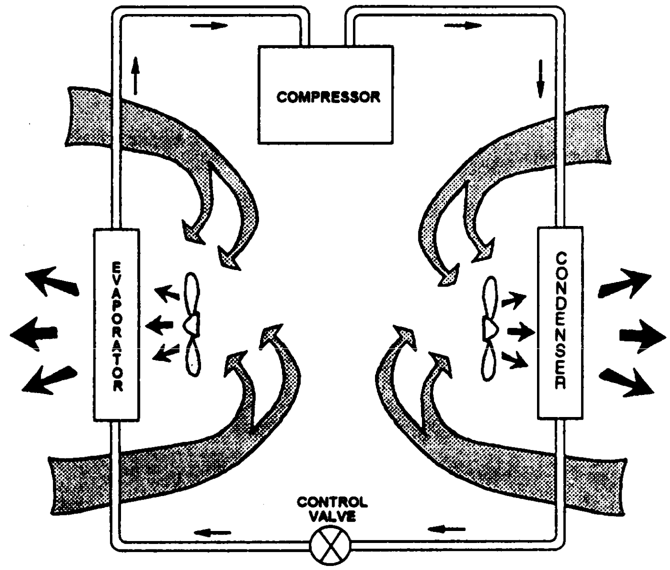


Figure 4-11.-Refrigerating cycle of a package type air-conditioning unit.

Cooling equipment for air conditioning must be of a type that will satisfactorily cool the air for a particular space that is being air conditioned. One method used to cool air in air-conditioning units is to evaporate water. A discussion of this method, called *evaporative cooling,* can be found in chapter 10 of the UT3 TRAMAN. Another method, and one of the most important, is **mechanical refrigeration.** In this method, the air that is to be conditioned and cooled is blown through cooling coils having a temperature of about 50°F. This not only cools, but dehumidifies the air. A discussion of this method can also be found in chapter 10 of the UT3 TRAMAN.

There are various types of air-conditioning units and systems. A few of the common types are discussed below.

Self-Contained (Package) Units

Self-contained refrigerative air-conditioning units are either window units (figs. 4-8 and 4-9) or larger floor-mounted units (fig. 4-10). Both types of units contain a complete system of refrigeration components.

The window units need not be installed in windows. They also can be installed in transoms, or they can be framed into outside walls. The use of outside walls is important for proper performance. When the unit is operating, the compressor (fig. 4-11) forces a high--pressure (high-temperature) refrigerant gas to the condenser. The condenser fan draws in and blows outside air over the condenser coils. This movement of the relatively cooler outside air over the hot condenser coils changes the gas to a liquid, giving off heat that is exhausted to the outside. The liquid then passes through a control device that regulates the flow of the liquid to the evaporator. In the evaporator, the liquid changes to a low-pressure (low-temperature) gas that is circulated through the evaporator coils. The inside or room air is then circulated by an evaporator fan over the cold evaporator coils. This action removes heat from the air and returns the cooled air back to the room.

A variation of this type of unit is the **heat pump.** In a heat pump, the roles of the condenser and the evaporator can be reversed so that the unit draws in and heats outside air and expels cold inside air. In this way, the unit functions as a heating unit, rather than a cooling unit.

Cooling Coils

Most forced-air furnaces are designed for the addition of a cooling coil. The coil is placed on the output side of the furnace and uses a forced-air furnace blower to circulate the air over the cooling coils. The addition of a dehumidifier reduces moisture in the air. The cooling unit, placed in any convenient location outside the building, produces chilled water that is circulated through the cooling coils near the air-conditioned space. The air to be conditioned is then blown over the cooling coils and is cooled by the chilled water absorbing the heat from the air. The warmed water is then returned to the unit.

Fan-Coil Units

You have probably seen fan-coil units in a school or motel room. These units contain a fan, coil, falter, condensate drain, and sometimes, an outside-air inlet. A central unit furnishes air to the unit, and duct coils heat or cool the air. The amount of air moving over the coils and the temperature of the coils can be manually or thermostatically controlled. A piping system provides hot or cold water to each unit.

HEATING AND AIR-CONDITIONING LAYOUT

Figure 4-12 (a foldout at the end of this chapter) shows a heating and air-conditioning layout for a hospital. You can see that the air- conditioning plant consists of four separate self- contained units, three of which are located in the mechanical equipment room, and one on the porch of the ward. Note the cooling towers, that have not as yet been mentioned. In a water-cooled air-conditioning system, cold water is run over the coils of the condenser (rather than air being blown over the coils). The purpose of the cooling tower is to cool the water. Water is sprayed at the top of the tower, and as it falls through the redwood louvers, it is cooled by the air. Sometimes, large blowers force air through the water, making the cooling tower more efficient. You can read more about cold-water air-conditioning systems in the UT2 TRAMAN.

In figure 4-12, you can see the line of air-conditioning ducts running from each of the air-conditioning units. Note that the section dimensions of each length of specified size are noted on the drawing. Notice, too, that these dimensions decrease as distance away from the unit increases.

You should notice, also, that some spaces are heated by radiators, rather than the air-conditioning system. These spaces (all the toilets, for example) may contain odors or gases that would make it inadvisable to connect them with the air-conditioning duct system. On each of the radiators, the heating capacity, in British thermal units (BTUs), is inscribed. In each space not connected to the air-conditioning system, you can see an exhaust fan (for ventilation) shown. On each fan, the air capacity, in cubic feet per minute (CFM), is noted.

In each air-conditioned room, you see a circle (or more than one circle) on the duct. This indicates an outlet for the conditioned air. In this case, the outlets are diffusers, and the capacity of each diffuser, in CFM, is inscribed. Note that this capacity varies directly with the size of the space serviced by the outlet.

Steam lines from the boiler in the mechanical equipment room to the air-conditioning units and radiators appear as solid lines. Small diagonal lines on these indicate that they are low-pressure steam lines. Returns appear as dashed lines.

In the upper left corner, a detail shows the valve arrangement on the steam and condensate return lines to each of the air conditioners. Referring to the mechanical symbols specified in MIL-STD-17B, the detail indicates that in the steam line, the steam headed for the unit passes agate valve, then a strainer, and then an electrically operated modulating valve. This last reduces the pressure to that for which the unit coils are designed.

The steam condensate leaving the unit first passes a gate valve, then a strainer, then a union, and then a steam trap. This trap is a device that performs two functions: (1) it provides a receptacle in which steam condenses into water and (2) it contains an automatic valve system that periodically releases this water into the rest of the return lines.

Beyond the steam trap, there is another union, next comes a check valve, and finally a gate valve. A check valve, as you know from the EA3 TRAMAN, is a one-way valve. It permits passage in one direction and prevents backup in the opposite direction.

CHECKING AND EDITING CONSTRUCTION DRAWINGS

Every drawing prepared in the drafting room must be checked and edited. As a capable EA2, you maybe delegated the job of doing so. When **checking** a drawing, you are inspecting it to make sure that it accurately conveys the information contained in the data source. That source may be survey field notes, sketches, written data, another drawing, or any combination of these. Any error or omission of information in these sources will result in inaccuracies in the drawing; therefore, the first check is to make sure that the source accurately provides everything needed to make the drawing. “Editing” means that you are inspecting the drawing to make sure that the procedures and conventions prescribed in relevant NAVFAC publications and military standards are followed. It might be said that editing begins as soon as drawings begin-meaning that you must constantly edit drawings to ensure that proper procedures and conventions are followed at the time the drawings are made.

When checking and editing a detail drawing, the checker ALWAYS uses a print of the drawing, rather than the original. That way, any corrections that need to be made can be marked with a colored pencil or pen on the print without disturbing or destroying the original. The detail drafter then uses the marked-up print to make corrections to the original drawing. After all of the corrections have been made, the checker compares a print of the corrected drawing with the originally marked-up print.

For a thorough job of checking and editing, you should first make an overall check with the following questions in mind:

1. Does the drawing reproduce well? Any poorly defined or weak line work and lettering must be corrected.

2. Does the size and format of the drawing conform to the MIL-HDBK-1006/1 requirements for Naval Facilities Engineering Command (NAVFACENG-COM) drawings? As specified in that publication, the project drawings should be prepared on flat C-, D-, or F-size paper. It also specifies that a vertical title block format is mandatory for D-size drawings and optional for F-size. Examples of both horizontal and vertical format title blocks can be found in MIL-HDBK-1006/1.

3. For a set of drawings, is a different drawing number assigned to each sheet and are all of the drawing numbers correct? Is the set of drawings arranged in the correct order as specified in MIL-HDBK-1006/1. That is, are they arranged as follows:

a. Title sheet and index of drawings (only for projects containing 60 or more drawings).

b. Plot and vicinity plans (including civil and utility plans). This sheet should include an index for small projects.

c. Landscape and irrigation.

d. Architectural.

e. Structural.

f. Mechanical (heating, ventilating, and air conditioning).

g. Plumbing.

h. Electrical.

i. Fire protection.

If the overall check is satisfactory, proceed with more detailed questions, such as the following:

1. Is the method of projection appropriate?

2. Are the views shown the minimum number required to show all the data?

3. Are sectional views constructed correctly and is the section lining correct?

4. Are line conventions and symbols consistent with the requirements of appropriate and current standards? Are all symbols (especially nonstandard ones) explained in a legend?

5. Are proper scales used for the drawing and are the scales shown? Appropriate scales for construction drawings are as follows:

a. Floor plans and elevations: 1/4", 3/16", 1/8", or 1/16" = 1´ – O".

b. Architectural details: 3/4", 1 1/2", or 3" = 1´ – 0´.

c. Molding sections and similar details: full scale or half scale.

d. Mechanical and electrical details: 3/8", 1/2", 3/4", or 1" = 1´ – 0´.

e. Structural details: 3/8", 1/2", 3/4", or 1" = 1´ – 0´.

f. Structural erection drawings (such as structural floor and roof framing plans): 1/8" or 1/16" = 1´ - 0".

g. Site (plot) plans: 1" = 10´, 20´, 30´, 40´, 50´, 60´, 100´, or 200´.

h. Utility plans: 1" = 20´, 30´, 40´, or 50´.

6. Are graphic scales shown as required by NAVFACENGCOM (MIL-HDBK-1006/1)?

7. Do the dimensions agree with those shown in the data source? Does the sum of partial dimensions equal the overall dimensions?

8. Are all of the required dimensions shown? Are there superfluous dimensions that are not needed?

9. Are all necessary explanatory notes given? Are all general notes in their proper location on the drawing?

10. Are terms and abbreviations consistent with military standards? Are the abbreviations (especially unusual ones) explained in a legend?

In addition to all of the above, you also should be constantly alert to misspellings and the improper use of phases and statements. Oftentimes, phases and statements that are used in common practice are not acceptable for use in project drawings. Listed below are some of the most common errors found in project drawings. (A correction follows each incorrect phrase or grouping of phrases.)

1. Incorrect: "As instructed by the architect."

   Correct: "As directed" (Note, however, that you should avoid using this type of language since it indicates uncertainty as to what the requirements are.)

2. Incorrect: "As approved by the architect."

   Correct: "As approved."

3. Incorrect: "By the Navy."
   "By others."

   Correct: "By the Government."

4. Incorrect: "By the electrical contractor."
   "By the plumber."
   "By the plumbing contractor."

   Correct: (Usually no statement is necessary since the government recognizes only the prime contractor.)

5. Incorrect: "12 gauge zinc-coated steel flashing."
   "copper flashing."

   Correct: "Metal flashing." (Metals are referred to only as metal and not as a particular kind or gauge. Type and weight should be covered in the project specifications.)

6. Incorrect: "Formica."

   Correct: "Laminated plastic." (Proprietary or brand names are not permitted.)

QUESTIONS

Q1. Into what drawing divisions should you place drawings that &scribe each of the following types of information?

a. Number and size of treads and risers in a stairway

b. Bearing and distance of property lines

c. Equipment for HVAC systems

d. Steel reinforcing requirements for beams and columns

Q2. In which of the following ways does a forced-air furnace differ from a gravity warm-air furnance?

a. It uses a fan for circulation of the heated air

b. It requires smaller ductwork

c. It can be equipped with cooling coils

d. All of the above

Q3. In what primary way does a heat pump differ from a window air-conditioning unit?

Q4. "Effective temperature" is the net effect of three factors that affect human health and comfort What are those three factors?

Q5. What NAFACENGCOM publication provides basic guidance and policy for the preparation of project drawings?

Q6. When using the international system of units, what SI unit (meter, millimeter, or centimeter) should you NOT use for project drawings ?

Q7. What title block format must you use when preparing NAVFACENGCOM project drawings on 22- by 34-inch tracing paper?

Q8. For a large set of project drawings, what letter should you place near the title block to designate those sheets of drawings that are in the plumbing division?

Q9. When is it permissible for you *to reuse a NAVFAC drawing number?*

Q10. What is the primary reason that you should always check line weights when checking and editing drawings?

FIGURE REMOVED

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Figure 4-12.—Heating and air-conditioning layout.

CHAPTER 5

SPECIFICATIONS/MATERIAL ESTIMATING/ADVANCED BASE PLANNING

As an Engineering Aid assigned to either a construction battalion or a Public Works Department, you may be required to assist in the preparation of specifications for a construction project. You will, most certainly, use construction specifications in your day-to-day job, especially when surveying or testing materials. This chapter briefly discusses the organization and content of construction specifications.

In addition, EAs frequently are involved in estimating material requirements for a project and assisting in the planning of advanced bases. This chapter introduces you to those topics.

SPECIFICATIONS

Because many aspects of construction cannot be shown graphically, even the best prepared construction drawings are most often not entirely adequate in revealing all the aspects of a construction project; for instance, how can anyone show on a drawing the quality of workmanship required for the installation of doors and windows or who is responsible for supplying the materials, except by extensive hand-lettered notes? The standard procedure then is to supplement construction drawings with detailed written instructions. These written instructions, called **specifications** (or more commonly specs), define and limit the materials and fabrication according to the intent of the engineer or the designer.

Usually, it is the design engineer's responsibility to prepare project specifications. As an EA, you maybe required to help the engineer in doing this. You also will be required to read, interpret, and use specifications in your work performance as a surveyor or soils technician. To help the engineer in writing specs, you need to be familiar with the various types of reference specifications that are used in preparing project specs. These reference specifications include various federal, military, and nongovernmental specifications. When assisting the engineer in preparing specifications or when using specifications, you also need to be familiar with the general format and terminology used in specifications. This section provides that familiarity.

NAVFAC SPECIFICATIONS

NAVFAC specifications are prepared by the Naval Facilities Engineering Command (NAVFACENGCOM), which sets forth standards for all construction work performed under its jurisdiction. This includes work performed by the Seabees. There are three types of NAVFAC specifications. These types are discussed as follows:

1. **NAVFACENGCOM GUIDE SPECIFICATIONS (NFGS).** NAVFACENGCOM guide specifications are the primary basis for preparing specifications for construction projects. These specifications define and establish minimum criteria for construction, materials, and workmanship and must be used as guidance in the preparation of project specifications. Each of these guide specifications (of which there are more than 300) has been written to encompass a wide variety of different materials, construction methods, and circumstances, and must be tailored to suit the work actually required by the specific project. To better explain this, let's look at figure 5-1, which is a page taken from a NAVFACENGCOM guide specification. In this figure, you can see that there are two paragraphs numbered 3.2.1. This indicates that the spec writer must choose the paragraph that best suits the particular project for which he is writing the specification. The capital letters *I* and *J* in the right-hand margin next to those paragraphs refer to footnotes (contained elsewhere in the same guide specification) that the spec writer must follow when selecting the best paragraph. Additionally, you can see that some of the information in figure 5-1 is enclosed in brackets ([ ]). This indicates other choices that the spec writer must make. Guide specifications, also, should be modified and edited to reflect the latest proven technology, materials, and methods.

2. **EFD REGIONAL GUIDE SPECIFICATIONS.** These specifications are used in the same way as the NAVFACENGCOM guide specifications but are used only in an area that is under the jurisdiction of one of the engineering field divisions (EFDs) of the Naval Facilities Engineering Command. When the spec writer is given a choice between using an EFD regional guide specification or a NAVFACENGCOM guide

NFGS-07310 (August 1993)

PART 3 - EXECUTION

3.1 SURFACES AND CONDITIONS: Do not apply shingle roofing on surfaces that are unsuitable or that will prevent a satisfactory application. Ensure that roof deck is smooth, clean, dry, and without loose knots. Cover knotholes and cracks with sheet metal nailed securely to the sheathing. Properly flash and secure vents and other roof projections and drive projecting nails firmly home.

3.2 APPLICATION: The manufacturer's written instructions shall be followed for applications not listed in this specification and in cases of conflict with this specification.

3.2.1 Underlayment (for Roof Slopes 4 Inches Per Foot and Greater): (I)
Apply underlayment consisting of one layer of No. 15 asphalt-saturated felt to the roof deck. Lay felt parallel to roof eaves continuing from eaves to ridge, using 2-inch head laps, 6-inch laps from both sides over all hips and ridges, and 4-inch end laps in the field of the roof. Nail felt sufficiently to hold until shingles are applied. Turn underlayment up vertical surfaces not less than 4 inches.

** OR **

3.2.1 Underlayment (for Roof Slopes [Between 2 Inches and 4 (I)
Inches Per Foot] [4 Inches Per Foot and Greater]): Apply underlayment (J)
consisting of two layers of No. 15 asphalt-saturated felt to the roof deck. Provide a 19-inch wide strip of felt as a starter sheet to maintain the specified number of layers throughout the roof. Lay felt parallel to roof eaves continuing from eaves to ridge, using 19-inch head laps for 6-inch laps from both sides over all hips and ridges, and 12-inch end laps in the field of the roof. Nail felt sufficiently to hold until shingles are applied. Confine nailing to the upper 17 inches of each felt. Turn underlayment up vertical surfaces not less than 4 inches.

3.2.2 Metal Drip Edges: Provide metal drip edges as specified in Section 07600, "Flashing and Sheet Metal," applied directly on the wood deck at the eaves and over the underlayment at the rakes. Extend back from the edge of the deck not more than 3 inches and secure with fasteners spaced not more than 10 inches on center along the inner edge.

[3.2.3 Eaves Flashing (for Roof Slopes 4 Inches Per Foot and (K)
Greater): Provide eaves flashing strips consisting of 55-pound or heavier smooth-surface roll roofing. The flashing strips shall overhang the metal drip edge 1/4 to 3/8 inch and extend up the slope far enough to cover a point 12 inches inside the interior face of the exterior wall. Where overhangs require flashings wider than 36 inches, locate the laps outside the exterior wall face. The laps shall be at least 2 inches wide and cemented. End laps shall be 12 inches and cemented.]

4

Figure 5-1.—Sample page from a NAVFACENGCOM guide specification.

specification with the same identification number, the writer must use the one that has the most recent date. This is because there can only be one valid guide specification for a particular area at any one time.

3. **STANDARD SPECIFICATIONS.** These specifications are written for a small group of specialized structures that must have uniform construction to meet rigid operational requirements. NAVFAC standard specifications contain references to federal, military, other command and bureau, and association specifications. NAVFAC standard specifications are referenced or copied in project specifications. When it is necessary to modify requirements of a standard specification, it must be referenced and exceptions taken.

EXAMPLE: "The magazine shall be Arch, Type I, conforming to Specifications S-M8E, except that all concrete shall be Class F- 1."

OTHER SPECIFICATIONS

The following specifications establish requirements mainly in terms of performance. Referencing these documents in project specifications assures the procurement of economical facility components and services while considerably reducing the verbiage required to state such requirements.

1. **FEDERAL AND MILITARY SPECIFICATIONS. Federal specifications** cover the characteristics of materials and supplies used jointly by the Navy and other government agencies. These specifications do not cover installation or workmanship for a particular project but specify the technical requirements and tests for materials, products, or services. The engineering technical library should contain all of the commonly used federal specifications pertinent to Seabee construction. Military specifications are those specifications that have been developed by the Department of Defense. Like federal specifications, they also cover the characteristics of materials. They are identified by "DOD" or "MIL" preceding the first letter and serial number.

2. **TECHNICAL SOCIETY AND TRADE ASSOCIATION SPECIFICATIONS. Technical society specifications—** for example, those published by the American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), Underwriter's Laboratories (UL), and American Iron and Steel Institute (AISI)—should be referenced in project specifications when applicable. **Trade association specifications** contain the requirements among the companies within a given industry.

3. **MANUFACTURER'S SPECIFICATIONS.** These specifications contain a manufacturer's precise description for the manner and process for making, constructing or compounding, and using any items the manufacturer produces. They should not be referenced or copied verbatim in project specifications but maybe used to aid in preparing project specifications.

PROJECT SPECIFICATIONS

Construction drawings are supplemented by written **project specifications.** Project specifications give detailed information regarding materials and methods of work for a particular construction project. They cover various factors relating to the project, such as general conditions, scope of work, quality of materials, standards of workmanship, and protection of finished work.

The drawings, together with the project specifications, define the project in detail and show exactly how it is to be constructed. Usually, any set of drawings for an important project is accompanied by a set of project specifications. The drawings and project specifications are inseparable. The drawings indicate what the project specifications do not cover; the project specifications indicate what the drawings do not portray, or they further clarify details that are not covered amply by the drawings and notes on the drawings. When you are preparing project specification, it is important that the specifications and drawings be closely coordinated so that discrepancies and ambiguities are minimized. Whenever there is conflicting information between the drawings and project specs, the specifications take precedence over the drawings.

Organization of Specifications

For consistency, the Construction Standards Institute (CSI) organized the format of specifications into 16 basic divisions. These divisions, used throughout the military and civilian construction industry, are listed in order as follows:

1. **General Requirements.** Includes information that is of a general nature to the project, such as inspection requirements and environmental protection.

2. **Site Work.** Includes work performed on the site, such as grading, excavation, compaction, drainage, site utilities, and paving.

3. **Concrete.** Precast and cast-in-place concrete, formwork, and concrete reinforcing.

4. **Masonry.** Concrete masonry units, brick, stone, and mortar.

5. **Metals.** Includes such items as structural steel, open-web steel joists, metal stud and joist systems, ornamental metal work, grills, and louvers. (Sheet-metal work is usually included in Division 7.)

6. **Wood and Plastics.** Wood and wood framing, rough and finish carpentry, foamed plastics, fiber-glass reinforced plastics, and laminated plastics.

7. **Thermal and Moisture Protection.** Includes such items as waterproofing, dampproofing, insulation, roofing materials, sheet metal and flashing, caulking, and sealants.

8. **Doors and Windows.** Doors, windows, finish hardware, glass and glazing, storefront systems, and similar items.

9. **Finishes.** Includes such items as floor and wall coverings, painting, lathe, plaster, and tile.

10. **Specialties.** Prefabricated products and devices, such as chalkboards, moveable partitions, fire-fighting devices, flagpoles, signs, and toilet accessories.

11. **Equipment.** Includes such items as medical equipment, laboratory equipment, food service equipment, kitchen and bath cabinetwork and counter tops.

12. **Furnishings.** Prefabricated cabinets, blinds, drapery, carpeting, furniture, and seating.

13. **Special Construction.** Such items as prefabricated structures, integrated ceiling systems, and swimming pools.

14. **Conveying Systems.** Dumbwaiters, elevators, moving stairs, material-handling systems, and other similar conveying systems.

15. **Mechanical Systems.** Plumbing, heating, air conditioning, fire-protection systems, and refrigeration systems.

16. **Electrical Systems.** Electrical service and distribution systems, electrical power equipment, electric heating and cooling systems, lighting, and other electrical items.

Each of the above divisions is further divided into sections. You can find a discussion of the required sections of Division 1 in *Policy and Procedures for Project Drawing and Specification Preparation,* MIL-HDBK-1006/1. The Division 1 sections, sometimes referred to as "boilerplate", are generally common to all projects that are accomplished under a construction contract.

Divisions 2 through 16 contain the technical sections that pertain to the specific project for which the spec writer has prepared the specification. These technical sections follow the CSI-recommended three-part section format. The first part, **General,** includes requirements of a general nature. Part 2, **Products,** addresses the products or quality of materials and equipment to be included in the work. The third part, **Execution,** provides detailed requirements for performance of the work.

Guidance

Usually, the engineer or spec writer prepares each section of a specification based on the appropriate guide specification listed in the most recent edition of *Engineering and Design Criteria for Navy Facilities,* MIL-BUL-34. This military bulletin (issued quarterly by the Naval Construction Battalion Center, Port Hueneme, California) lists current NAVFACENGCOM guide specifications, standard specifications and drawings, definitive drawings, NAVFAC design manuals, and military handbooks that are used as design criteria.

As discussed earlier, when writing the specifications for a project, you must modify the guide specification you are using to fit the project. Portions of guide specifications that concern work that is not included in the project will be deleted. When portions of the required work are not included in a guide specification, then you must prepare a suitable section to cover the work, using language and form similar to the guide specification. Do not combine work covered by various guide specifications into one section unless the work is minor in nature. Do NOT reference the guide specification in the project specifications. You must use the guide spec only as a manuscript that can be edited and incorporated into the project specs.

The preceding discussion provides only a brief overview of construction specifications. For additional guidance regarding specification preparation, you should refer to MIL-HDBK-1006/1.

MATERIAL ESTIMATING

A **material estimate** is a listing and description of the various materials required to construct a given project. An **estimator** is one who evaluates the requirements of a construction task and determines the quantities of materials needed to accomplish that task As an EA2, you maybe called upon to assist in preparing material estimates, especially for bulk materials, such as fill materials, concrete, and asphaltic paving materials. To be a **good** estimator, you must have sound and thorough construction knowledge and experience, and you must be familiar with the techniques and pitfalls of material estimating. It is beyond the scope of this book to give you the construction knowledge and experience you will need; however, this section does introduce you to some of the techniques and pitfalls that you will use or encounter when estimating material requirements.

USE OF DRAWINGS AND SPECIFICATIONS

Construction drawings are the main basis for defining required construction activities and for measuring quantities of material. Accurate estimating requires a thorough examination of the drawings. All notes and references should be read carefully, and all details and reference drawings should be examined. The orientation of sectional views should be checked carefully. Dimensions shown on drawings or computed figures shown from those drawings should be used in preference to those obtained by scaling distances. An overall dimension shown on a drawing should be checked to see if it tallies with the sum of the partial lengths. If scaling is unavoidable, the graphic scale must be checked for possible expansion or shrinkage at a rate different from that of other parts of the drawing. The revision block should be checked for changes made to the drawings. The construction plan, the specification, and the drawing must be verified to see if they are, in fact, all talking about the same project. When there are inconsistencies between general drawings and details, details should be followed unless they are obviously wrong. When there are inconsistencies between drawings and specifications, the specifications should be followed.

The estimator must first study the specifications and then use them with the drawings when preparing quantity estimates. The estimator should become thoroughly familiar with all the requirements stated in the specifications. Most estimators will have to read the specifications more than once to fix these requirements in their minds. If the estimator makes notes while reading the specifications, these notes will prove helpful when the drawings are examined. In the notes, the estimator should list items of work or materials that are unusual or unfamilar. These notes should also contain reminders for use during examination of the drawings. A list of activities and materials that are described or mentioned in the specifications will be helpful in checking quantity estimates.

The *Seabee Planner's and Estimator Handbook,* NAVFAC P-405, is a publication that has been prepared specifically for the Seabee estimator. Whenever possible, the tables and the diagrams contained in the P-405 are based on the Seabees' experience. Where suitable information was not available, construction experience was adjusted to represent production under the range of conditions encountered in Seabee construction. Using the P-405 will save you time in preparing estimates and, when understood and used properly, will give accurate results.

Need for Accuracy

Quantity estimates are used as a basis for purchasing materials, for determining equipment, and for determining manpower requirements. They are also used in scheduling material deliveries, equipment, and manpower. Because of this widespread use, accuracy in preparing quantity estimates is very important, especially since an error in quantity tends to multiply itself; for example, consider that a certain concrete slab is to measure 100 feet by 800 feet. If the estimator misreads the dimension for the 800-foot side as 300 feet, the computed area of the slab will be 30,000 square feet, when it should actually be 80,000 square feet. Since this area will be the basis for ordering materials, there will be a shortage of concrete ingredients, lumber, reinforcing materials, and everything else involved in mixing and pouring the concrete. This includes equipment time, manpower, and man-hours.

Checking Estimates

Quantity estimates should be checked in a manner that will eliminate as many errors as possible. One of the best ways to check your quantity estimate is to have another person make an independent estimate and then to compare the two estimates after both are completed. Any differences should be checked to see which estimate is right. A less effective way of checking is for another person to take your quantity estimate and check all measurements, recordings, computations, extensions, and copy work.

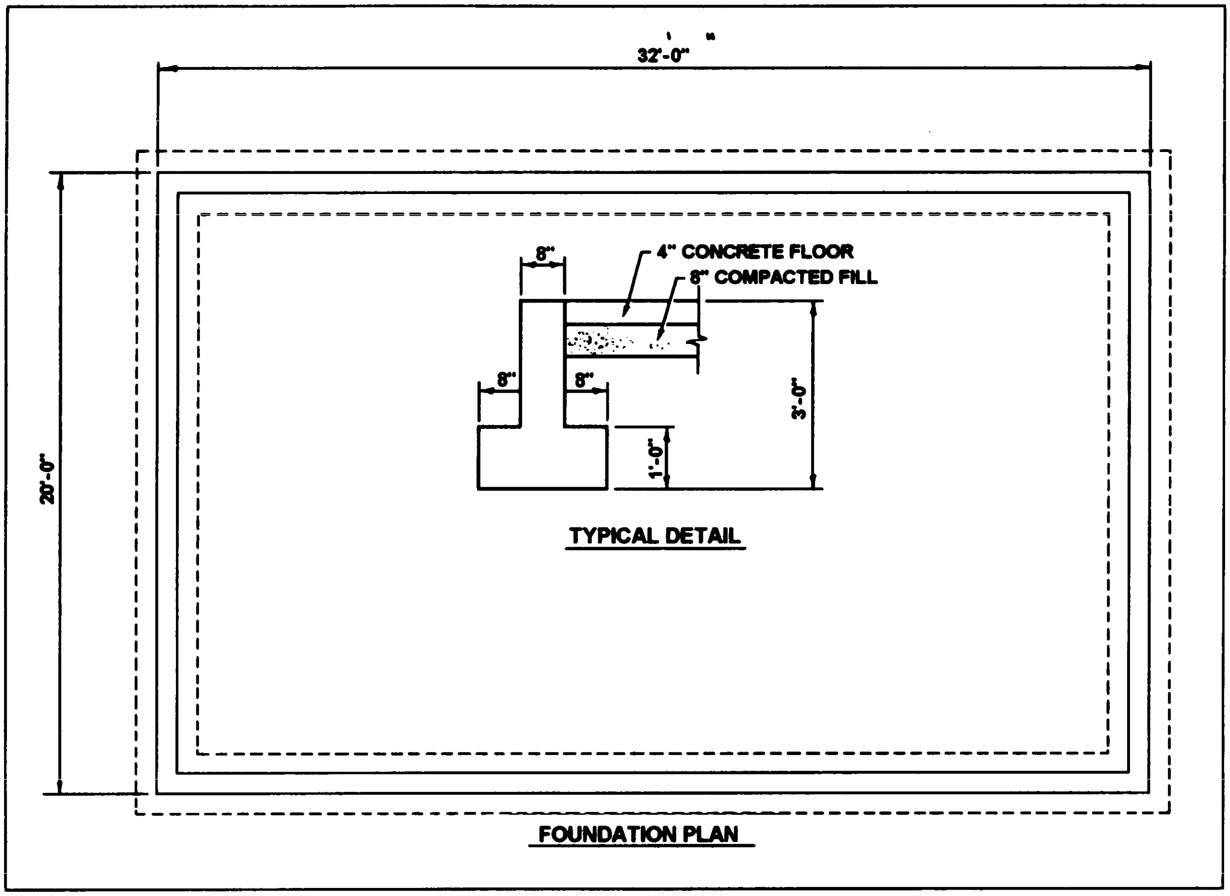

Figure 5-2.—Foundation plan and detail.

Sources of Error

Failure to read all the notes on a drawing or failure to examine reference drawings results in many omissions; for example, an estimator may overlook a note that states "symmetrical about ℄" and thus compute only half of the required quantity.

Errors in scaling obviously mean erroneous quantities. Great care should be taken in scaling drawings so that correct measurements are recorded Some common scaling errors are using the wrong scale and failing to note that a detail being scaled is drawn to a scale different from that of the rest of the drawing. Remember that some drawings are not drawn to scale. These, of course, cannot be scaled for dimensions.

Sometimes a wrong interpretation of a section of the specifications can cause errors in the estimate. If the estimator has any doubt concerning the meaning of any portion of the specification, he should request an explanation of that portion.

Omissions are usually the result of careless examination of the drawings. Thoroughness in examining drawings and specifications will usually eliminate errors of omission. Checklists should be used to assure that all activities or materials have been included in the estimate. If drawings are revised after takeoff, new issues must be compared with the copy used for takeoff and appropriate revisions made in the estimate.

Construction materials are subject to waste and loss through handling, cutting to fit, theft, normal breakage, and storage loss. Failure to make proper allowance for waste and loss results in erroneous estimates.

Other sources of error are copying errors, inadvertent figure transpositions, and computational and arithmetic errors.

ESTIMATING BULK MATERIAL REQUIREMENTS

All material estimates, including those for bulk materials, are used as a basis for material procurement and as a check to determine if sufficient materials are available to constructor complete a project. In general, the term *bulk material* refers to concrete, bituminous paving materials, and mineral products, such as sand, gravel, or rock. A few examples of estimating these materials are described below.

Concrete

Estimating the amount of concrete required for a project consists of determining the volume (in cubic yards or, in many locations outside the United States, in cubic meters) of the spaces that will be occupied by the concrete. As an example, let's look at figure 5-2. This figure shows the foundation plan and a typical foundation detail for a small 20 foot by 32 foot building. As shown in the detail, the foundation is continuous and the floor is a 4-inch-thick concrete slab. Our task is to determine the amount of concrete that will be required for the foundation and slab. Since in any concrete job a certain amount of concrete will be unavoidably lost during placement, we will include a 10-percent waste factor. You can find this waste factor listed in the P-405.

Although we could proceed in various ways to estimate the amount of concrete that is required, an easy method is tabulated as follows:

Foundation wall:

(32.00 ft x .67 ft x 2 fi) x 2 = 85.76 cu ft

(18.67 ft x .67 ft x 2 ft) x 2 = 50.04 cu ft

Footing:

(33.33 ft x 2 ft x 1 ft) x 2 = 133.032 cu ft

(17.33 ft x 2 ft x 1 ft) x 2 = 69.32 cu ft

Slab:

18.67 ft x 30.67 ft x .33 ft = 188.96 cu ft

527.40 cu ft

x 1.10 (10% waste)

580.14 cu ft

= 21 cu yd

From the above tabulation, you can see that separate estimates were prepared for the foundation wall, footing, and slab. You can also see that both the foundation wall and the footing were further subdivided based on the length and width of the building; for example, the foundation wall consists of two walls measuring 32 feet long and two measuring 18 feet 8 inches long (allowing for overlap at the foundation corners). Then, the separate estimates were added together, the waste factor was applied, and the final cubic feet of concrete was converted to cubic yards.

Now let's see how much compacted fill will be required for this job. For this example, we will assume that the project specifications call for sand to be used as the fill material.

Figure 5-2 shows that the fill material is to be 8 inches thick after compaction. Therefore, the volume of the compacted fill is 383.65 cubic feet. However, from your knowledge of soils, you know that compacted sand occupies less volume than loose sand. Since the sand for this project will be delivered to the jobsite in a loose condition, a compaction factor must be applied. NAVFAC P-405 lists compaction factors for various materials. For sand, the compaction factor listed is 1.17. So, the total amount of sand required for this project is 383.65 x 1.17=448.87 cubic feet, or 16.6 cubic yards. Again, however, we know that a certain amount of sand will be wasted. So, let's increase the total by 10 percent. Now we need approximately 18 cubic yards of sand for the job.

Bituminous Paving

Although not always, most bituminous paving projects that are accomplished by the Seabees use hot-mixed bituminous concrete that is purchased from a central plant. In this case, the job of estimating consists of determining the compacted volume, in cubic feet, of the pavement. This volume is then multiplied by the unit weight of the mix, in pounds per cubic foot (pcf), and the final result is converted to tons of mix required. An equation for determining the required tons of mix can be expressed as follows:

$$\text{Tons of mix} = \frac{L \times W \times T \times UW}{12 \times 2000}$$

Where:

L = Length of paved area in feet

W = Width of paved area in feet

T = Compacted thickness of the pavement in inches

UW = Unit weight of the mix in pounds per cubic foot

To illustrate the use of this formula, let's assume that we are estimating a 2-inch-thick hot-mix bituminous pavement on a 150-foot by 600-foot parking lot. The unit weight (which usually ranges from 140 to 160 pcf) should be determined from laboratory testing when possible; however, when the unit weight is not known, an estimated weight of 160 pcf maybe used. In this example, let's assume a unit weight of 147 pcf. From this, we can estimate the tons of plant mix required by substitution into the above formula as follows:

$$\frac{600 \times 150 \times 2 \times 147}{12 \times 2000} = 1{,}102.5 \textit{ tons.}$$

Then if we include a loss factor of, let's say 5 percent, we will need 1,158 tons of plant mix for this parking lot.

Now, let's assume that this same parking lot is to be laid over a compacted-soil subbase. In this case, we will need a prime coat also. The prime coat is a low-viscosity liquid bitumen that is sprayed on the subbase. It provides a seal and promotes adhesion between the subbase and the pavement. To estimate the amount of bitumen required for the prime coat, multiply the area to be treated by the rate of application The estimate should include enough bitumen for an additional width of 1 foot on each side of the pavement. A formula for estimating the number of gallons of primer needed is as follows:

$$Gallons = \frac{L \times W \times AR}{9}$$

Where:

L = Length of paved area in feet

W = Width of paved area in feet

AR = Application rate of bitumens in gallons per square yard

So, if the project specs for the parking lot we have been discussing call for an application rate of 0.3 gallons of prime coat per square yard of surface and if we assume a 5 percent loss factor, how many gallons of primer will be required? You can try this one on your own.

ADVANCED BASE PLANNING

During World War II when bases were constructed across the island chains of the Pacific Ocean, it became apparent that significant savings in both time and material could be realized if units of materials, equipment, and personnel required to perform specific functions were standardized. This was the beginning of the Advanced Base Functional Components (ABFC) System that is still in use today. In this section we will briefly discuss the ABFC System and the *Facilities Planning Guide,* NAVFAC P437.

ADVANCED BASE FUNCTIONAL COMPONENTS SYSTEM

A thorough discussion of the Advanced Base Functional Components System may be found in the *Naval Construction Force (NCF) Manual,* NAVFAC P-315, and in volume II of the *Facilities Planning Guide,* NAVFAC P-437. Briefly, however, the overall ABFC System comprises a preplanned collection of individual functional **components,** each of which is designed and organized to perform a specific function at an advanced base. These functional components are given code numbers and names to indicate their function; for example, Component P-26 is a Seabee Team, and Component N-24A is a 750-man tent camp.

By using the ABFC System, planners for logistics, facilities, and construction can readily identify the equipment, facilities, materials, construction effort, and other pertinent information that is needed for each component. The basic document that identifies all of this data is the NAVFAC P-437.

NAVFAC P-437

The *Facilities Planning Guide,* NAVFAC P-437, is the basic tool that you should consult when tasked to assist in planning the construction of an advanced base. This document identifies the structures and supporting utilities of the Navy ABFC System. It was developed to make preengineered facility designs and corresponding material lists available to planners at all levels. While these designs relate primarily to expected needs at advanced bases and to the Navy ABFC System, they can also be used to satisfy peacetime requirements. Facilities, logistic, and construction planners will each find the information required to select and document the material necessary to construct facilities.

NAVFAC P437 consists of two volumes. Although it may seem unusual to do so, let's first discuss volume II.

Volume II

Volume II of the P-437 is organized into three parts. **Part 1 (Components)** contains data displays foreachof the ABFC components and is indexed by code number. These data displays list and describe the **facilities** that make up each ABFC component. Figure 5-3 is an

COMPONENT P17 OCT 22 82

FACILITY	DESCRIPTION	FACILITY CAPACITY	QTY	COMPONENT CAPACITY	WEIGHT SHORT TON	CUBE MEAS TON	DOLLAR VALUE	CONST EFFORT MANHOURS
851 10A	ROAD WITH DRAINAGE 1 MILE	14000 SY	1	14000 SY	38.8	76.3	16,206	3,330
				TOTAL NORTH (TEMPERATE)	139.5	263.1	321,810	5,517
				TOTAL TROPICAL (BASIC)	122.2	220.4	274,418	5,477

COMPONENT P17

CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA CONNECTED	POWER KVA DEMAND	WATER GPD	SEWER GPD	FUEL GAL/30DAYS HEATING DSL	FUEL GAL/30DAYS HEATING MOGAS	FUEL GAL/30DAYS PWR GEN DSL
INIT	0	.6	25	14	3,600	3,600	25,608	1,101	2,000

SKILLS MANHOURS	EA	BU	UT	CE	SW	EO	CM	MS
	104	158	493	594	329	2,298	0	1,541

COMPONENT P25

NAVAL MOBILE CONSTRUCTION BATTALION

PROVIDES PERSONNEL,ADMINISTRATION,SUBSISTANCE,
EQUIPMENT,AND MINIMAL HOUSING REQUIRED FOR THE
MOBILIZATION OF ONE MOBILE CONSTRUCTION BATTALION.

SITE PLAN 6027643 MAJOR REV 11 12 78

FACILITY	DESCRIPTION	FACILITY CAPACITY	QTY	COMPONENT CAPACITY	WEIGHT SHORT TON	CUBE MEAS TON	DOLLAR VALUE	CONST EFFORT MANHOURS
123 10A	MOGAS STORAGE-DISPENSING FACILITY	1 OL	1	1 OL	5.4	23.5	48,832	208
123 10F	DIESEL STOR-DSPNSG FACIL 200000 GAL	1 OL	1	1 OL	8.7	35.9	86,106	484
143 45E	ARMORY SEMITRAILER	210 SF	1	210 SF	7.6	82.2	14,061	175
214 20H	A CO AUTO VEHICLE SHOP	4000 SF	1	4000 SF	5.1	11.1	23,450	158
215 10A	WEAPONS REPAIR SEMITRAILER	210 SF	1	210 SF	4.5	78.7	12,475	48
218 20A	A COMPANY CONSTRUCTION EQUIP SHOP	4000 SF	1	4000 SF	5.1	11.0	23,257	136
219 10J	B C AND D COMPANY SHOPS MINIMAL	5872 SF	1	5872 SF	3.4	12.1	29,163	92
219 10H	CENTRAL TOOL ROOM (MINIMUM)	4000 SF	1	4000 SF	1.7	5.3	10,631	46
441 10S	WAREHOUSE GENERAL STORAGE MIN	4000 SF	3	12000 SF	3.9	12.0	24,910	120
530 10B	MEDICAL/FIRST AID INITIAL	936 SF	2	1872 SF	5.8	12.6	8,345	110
540 10J	DENTAL CLINIC SEMI-TRAILER MOUNTED	2 OU	1	2 OU	10.1	104.7	93,197	17
610 10PS	SPECIAL SERVICES/POST OFFICE	936 SF	1	936 SF	.6	2.5	3,173	33
610 10V	OFFICE ADMINISTRATIVE MINIMAL	936 SF	10	9360 SF	6.0	25.0	31,727	200
722 10AH	GALLEY MESS FIELD W/CNTNR REFR-FRZR	800 MN	1	800 MN	62.8	267.3	237,143	1,027
722 10BH	BAKERY PLANT FIELD PORTABLE	1500 MN	1	1500 MN	2.9	6.5	4,238	61
723 60BX	EXCHANGE-BARBER SHOP	936 SF	1	936 SF	.6	2.5	3,173	20
723 61A	SHOWER TRAILER 24-SHOWER HEAD GED	1 EA	6	6 EA	13.8	42.6	84,600	102
725 10V	TROOP HSG EMERG W/OUT WASHROOMS	3744 SF	2	7488 SF	8.2	28.0	27,119	320
725 10W	TROOP HSG EMERG W/O SHOWERS ENLIST	8424 SF	6	50544 SF	60.6	201.6	185,554	2,424
725 10VD	QUARTERS F/AIR DET	5632 SF	1	5632 SF	4.5	17.4	30,372	88
730 40H	LAUNDRY TRAILER-MOUNTED	280 SF	1	280 SF	9.9	55.0	92,721	40
811 10AU	ELECTRIC POWER PLANT DIESEL 2-200KW	400 KW	1	400 KW	11.9	15.7	111,911	106
812 30PC	ELECTRICAL DISTRIBUTION LINE-EXPED	2000 LF	1	2000 LF	30.8	38.8	222,253	2,270
831 30A	LEACH FIELD	1 EA	3	3 EA	1.2	5.7	1,561	396
841 10H	WATER TREATMENT FACILITY 1500 GPH	30 KG	2	60 KG	11.0	19.0	33,825	82
841 40E	WATER STORAGE POTABLE	30000 GA	2	60000 GA	6.0	10.6	32,860	134
842 10J	WATER DISTRIBUTION LINE POTABLE	7640 LF	1	7640 LF	15.1	27.7	41,460	480
851 10B	ROAD UNSTABILIZED W/DRAINAGE	33066 SY	1	33066 SY	4.9	14.2	6,142	777
872 10B	SECURITY FENCING	1980 LF	4	7920 LF	29.2	68.4	30,315	4,216
872 20D	BUNKER COMMAND POST	1 EA	3	3 EA	36.9	44.1	17,681	2,652
				TOTAL NORTH (TEMPERATE)	378.2	1,279.7	1,582,045	17,018
				TOTAL TROPICAL (BASIC)	365.4	1,238.5	1,500,341	16,688

COMPONENT P25

CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA CONNECTED	POWER KVA DEMAND	WATER GPD	SEWER GPD	FUEL GAL/30DAYS HEATING DSL	FUEL GAL/30DAYS HEATING MOGAS	FUEL GAL/30DAYS PWR GEN DSL
INIT	0	150.0	360	244	40,383	33,980	85,820	2,864	1,340

SKILLS MANHOURS	EA	BU	UT	CE	SW	EO	CM	MS
	181	2,457	1,724	2,197	457	4,041	0	5,981

COMPONENT P26

SEABEE TEAM

PROVIDES PERSONNEL AND EQUIPMENT REQUIRED
TO ESTABLISH AND DEPLOY A SEABEE TEAM.

SITE PLAN NONE MAJOR REV 04 11 74

FACILITY	DESCRIPTION	FACILITY CAPACITY	QTY	COMPONENT CAPACITY	WEIGHT SHORT TON	CUBE MEAS TON	DOLLAR VALUE	CONST EFFORT MANHOURS
143 77A	STORAGE OPERATIONAL	107 SF	1	107 SF	1.1	21.4	10,000	4
219 10H	SHOP SEABEE TEAM	936 SF	1	936 SF	.7	2.8	3,920	22
722 10AG	GALLEY-MESS SEABEE TEAM	13 MN	1	13 MN	3.6	20.9	30,317	40
723 20A	SHOWER/WR 100 MAN 16X32 TENT	512 SF	1	512 SF	5.1	34.3	12,224	428
723 20J	LATRINE	336 SF	1	336 SF	2.7	5.8	1,336	123
725 10R	QUARTERS-TROOP HOUSING	936 SF	1	936 SF	.7	2.9	3,651	35
811 10CF	ELECTRIC GEN STA 2-30KW 60HZ	60 KW	1	60 KW	5.3	8.5	38,981	77
841 10U	WATER TREATMENT FACILITIES	30 KG	1	30 KG	1.2	3.3	9,889	13
				TOTAL NORTH (TEMPERATE)	20.3	108.9	110,318	742
				TOTAL TROPICAL (BASIC)	19.8	107.0	108,076	726

PAGE 46 P26

Figure 5-3.—Typical data display for a component.

FACILITY 123 10E — PLANNING FACTOR VH/100,MIN 2 — OCT 22 82

FUEL STORAGE AND DISPENSING FACILITY

NAVFAC DRAWING NUMBER NETWORK — MAJOR REV. 02 10 78

ASSEMBLY	DESCRIPTION	ZONE	QTY.	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
20010	TANK FUEL PILLOW 3000 GALLON		1	719.1	25.8	3,917.63	4
20135	FUEL LINE W/APPURTENANCES		1	1,154.7	18.6	2,180.89	72
20234	PUMP FUEL OIL ROTARY 20 GPM		1	243.0	4.2	588.41	24
20307	NOZZLE DISPENSING STAND		2	355.7	47.9	1,576.60	16

	SHORT TON	MEAS TON	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
TOTAL NORTH (TEMPERATE)	1.2	2.4	2,472.5	96.5	8,263.53	116
TOTAL TROPICAL (BASIC)	1.2	2.4	2,472.5	96.5	8,263.53	116

FACILITY 123 10E — PRIMARY UNIT OF MEASURE 2 OL — SECONDARY UNIT OF MEASURE 20 GM

CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA CONNECTED	POWER KVA DEMAND	VOLTS	PHASE	WATER TOT. GPD	WATER PEAK GPM	SEWER GPD	RECOV. CODE
INIT	3	.05	1	1	208	3	0	0	0	A

FUEL (GAL/30DAYS) HEATING DSL	MOGAS	PWR GEN DSL	EA	BU	UT	CE	SW	EO	CM	MS
0	0	0	0	0	101	13	0	2	0	0

(EA through MS: S K I L L S M A N H O U R S)

NOTES -THIS FACILITY RECEIVES MOGAS OR DIESEL FUEL FROM TANK TRUCKS OR TRAILERS.

WHEN THIS FACILITY IS USED TO STORE AND DISPENSE DIESEL FUEL,DIESEL FUEL SHOULD BE FILTERED PRIOR TO DELIVERY TO THIS FACILITY.

ELECTRICAL LOAD F/PUMP: 3/4 HP,208 V,60 HZ,3-PHASE

FACILITY 123 10F — PLANNING FACTOR NA

DIESEL OIL STORAGE AND DISPENSING 200000 GAL

NAVFAC DRAWING NUMBER NETWORK — MAJOR REV. 03 11 77

ASSEMBLY	DESCRIPTION	ZONE	QTY.	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
20002	TANK FUEL PILLOW 50000 GAL		4	7,698.4	547.2	51,124.44	352
20124	HOSE MANF F/200000 GAL TANK ARR		1	642.2	55.8	1,954.19	2
20204	FUEL TRANSFER ASSEMBLY 350 GPM		1	3,774.9	470.3	13,670.99	44
20305	FUEL DISPENSING ASSY PORTABLE		1	1,619.1	53.2	6,457.53	36
20307	NOZZLE DISPENSING STAND		1	177.8	23.9	788.30	8
20506	FUEL FILTER AND METER ASSY 600 GPM		1	3,478.8	284.3	12,110.31	42

	SHORT TON	MEAS TON	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
TOTAL NORTH (TEMPERATE)	8.7	35.9	17,391.2	1,434.7	86,105.76	484
TOTAL TROPICAL (BASIC)	8.7	35.9	17,391.2	1,434.7	86,105.76	484

FACILITY 123 10F — PRIMARY UNIT OF MEASURE 1 OL — SECONDARY UNIT OF MEASURE 350 GM

CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA CONNECTED	POWER KVA DEMAND	VOLTS	PHASE	WATER TOT. GPD	WATER PEAK GPM	SEWER GPD	RECOV. CODE
TEMP	6	1.28	17	8	208	3	0	0	0	A

FUEL (GAL/30DAYS) HEATING DSL	MOGAS	PWR GEN DSL	EA	BU	UT	CE	SW	EO	CM	MS
0	490	0	8	8	108	0	20	324	0	16

(EA through MS: S K I L L S M A N H O U R S)

FACILITY 123 10G — PLANNING FACTOR VH/100 OL,2MIN

FUEL STORAGE-DISPENSING STATION 100BBL

NAVFAC DRAWING NUMBER NONE — MAJOR REV. 08 06 75

ASSEMBLY	DESCRIPTION	ZONE	QTY.	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
12037	FOUNDATION F/BOLTED TANKS		1	1,516.1	27.3	89.74	28
12702	STABILIZED SURFACE 200SY		1	564.0	22.0	55.87	2
20008	OVERFLOW 2N F/100-250-500 BBL TANKS		1	105.6	1.1	53.35	10
20236	PUMP CNTFGL FUEL OIL 75 GPM		1	253.0	2.6	384.81	24
20507	FILTER-SEPARATOR LIQ FUEL 50 GPM		2	930.2	48.0	541.12	18
20623	PIPING LIQ FL F/100BBL STOR DSPNSG		1	1,660.0	28.1	5,162.01	174
20705	TANK FUEL OIL 1250 GAL P-1 PONTOON		1	4,277.6	211.4	2,404.69	53
30303	PERIMETER LIGHTING 4-250W HPS		1	1,152.8	112.6	1,568.83	17
31001	ELEC SERVICE ENTRANCE ASSY 1AWG		1	611.0	11.6	358.71	21
35000	FLOAT LEVEL CONTROL		1	120.5	2.2	605.67	26
42001	TANK STEEL 100BBL		1	3,264.0	114.0	3,062.00	104

	SHORT TON	MEAS TON	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
TOTAL NORTH (TEMPERATE)	7.2	14.5	14,454.8	580.9	14,286.80	477
TOTAL TROPICAL (BASIC)	7.2	14.5	14,454.8	580.9	14,286.80	477

FACILITY 123 10G — PRIMARY UNIT OF MEASURE 1 OL — SECONDARY UNIT OF MEASURE 75 GM

CONST STD	LAPSED DAYS	LAND ACRES	POWER KVA CONNECTED	POWER KVA DEMAND	VOLTS	PHASE	WATER TOT. GPD	WATER PEAK GPM	SEWER GPD	RECOV. CODE
TEMP	10	.03	1	1	208	3	0	0	0	C

PAGE 6 — 123 10G

Figure 5-4.—Typical data display for a facility.

example of one of the data displays that you can find in part 1.

As you can see, figure 5-3 is for Component P-25. The name of this component is Naval Mobile Construction Battalion. The specific function, or purpose, of this component is shown directly below the component name. Listed below the function are all of the facilities that comprise Component P-25. For each facility, you find the single-facility capacity, total quantity, and total facility capacity required for the component; for example, there is a total of two water-storage facilities (Facility Number 841 40E) required for the complete component. Each of these storage facilities has a capacity of 30,000 gallons, and the total water-storage capacity for the component is 60,000 gallons. Also listed for each facility is the weight, cube, dollar value, and estimated construction effort for the total quantity of each facility. At the bottom of figure 5-3, you find additional information concerning the complete component. This includes a breakdown, by Seabee rating, of the estimated direct-labor man-hours that are needed to construct the component.

Part 2 (Facilities) includes a data display for each of the ABFC facilities. This part, indexed by facility number, is used to identify the **assemblies** that are required for each facility. For our discussion, let's stay with the requirements for the P-25 Component and look at the data display for Facility Number 123 10F. This data display, found in part 2, is shown in figure 5-4.

At the top of this data display (fig. 5-4) is the facility number and nomenclature of the facility. Below this, you see a listing, by assembly number, of all of the assemblies that are needed for one complete facility. This listing includes the description, quantity, weight, cubic feet, dollar value, and the estimated construction effort required for each assembly. Below the listing of assemblies, you also find other information regarding the complete facility; for example, you can see that Facility 123 10F requires a land area of 1.28 acres, that a 30-day supply of gasoline (MOGAS) will be needed, and that the estimated EA direct labor required to install this facility is 8 man-hours.

Part 3 (Assemblies) is indexed by assembly number and contains data displays that list all of the materials required for each assembly. For an example, let's look at the data display for Assembly Number 20002 that is required for Facility 123 10F. This data display, which you could find in part 3, is shown in figure 5-5. On this display, you see the national stock number (NSN), description, unit of issue, quantity, weight, cubic feet, and dollar value for each line item of material that is required for one complete assembly. Also, on this data display, you can find the estimated number of man-hours and the recommended size of crew needed to assemble and install one of these assemblies.

Volume I

Refer again to figures 5-3,5-4, and 5-5. In each of these figures, you see reference to a drawing. It is for these drawings that you use volume I of the P-437. Volume I contains reproducible engineering drawings and is organized as follows:

Part 1 (Component Site Plans) is indexed by component designation and includes typical site plans for the ABFC components. When a component does not have a site plan, the word *None* appears on the data display for the component.

Part 2 (Facility Drawings and Networks) is indexed by facility number and contains detailed construction drawings of the ABFC facilities. Also included in part 2 are construction networks. A network is a diagram that is used to guide and manage a construction project. It includes information, such as the sequence of construction activities, start and finish dates of each construction activity, duration of each activity, and other information that is of use to the crew leaders, supervisors, and managers of a project. The *Seabee Planner's and Estimator Handbook,* NAVFAC P-405, provides detailed guidance on reading and preparing construction networks.

Part 3 (Assembly Drawings) contains working drawings of the ABFC assemblies. It is indexed by assembly number.

The above is only a brief overview of Advanced Base Functional Components. For more information, you should refer to the NAVFAC P-437, volume II.

QUESTIONS

Q1. What type of guide specifications is mandatory for use when preparing project specifications for a nonspecialized structure?

Q2. When there is conflicting information between the drawings and the specifications, which takes precedence?

Q3. Into how many divisions are project specifications divided?

OCT 22 82

ASSEMBLY 20002 ZONE 20002

COG	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9C	4710-00-273-1041	PIPE CULV NESTABLE 16 GA AL 12N X 2FT	EA	4	26.40	2.1600	51.04
9C	4710-00-630-9445	PIPE STL BI STD WT 2N NPT	FT	20	75.00	.7800	25.60
9C	4720-00-878-6887	HOSE ASSY RBR FUEL-XFR 4N X 10 FT FEM X MALE QDISC	EA	3	171.00	7.5000	628.74
9C	4730-00-068-0393	REDUCER QUICK DISCONNECT CAM-LOCKING TYPE 4N	EA	1	10.00	.3000	95.72
	3	FEMALE X 6N MALE					
9C	4730-00-068-9286	COUPLING HALF QDISC CAM-LOCKING TYPE FEMALE X	EA	2	16.00	.4000	51.58
	6	INTERNAL PIPE THREAD 4N					
9C	4730-00-196-2079	NIPPLE PP STL BI 4 X 4N NPT	EA	1	3.15	.0600	2.31
9C	4730-01-078-0234	REDUCER,QDISC,CAM-LOCKING TYPE,6N FEMALEX4N MALE	EA	1	12.00	.4000	84.47
9C	4820-00-469-7825	VALVE GATE QIK-OPNG BRS 2N NPT	EA	1	11.00	.2000	74.69
9Z	5330-00-899-4509	GASKET-COUPLING HALF QDISC CAM-LOCKING TYPE 4N	EA	3	.06	.0102	.96
2C	5430-00-182-6181	TANK, FABRIC, COLLAPSIBLE, 50000 GAL,FUEL STORAGE,	EA	1	1,600.00	125.0000	11,786.00
	1	NYLON CLOTH, MATERIAL IMPREGNATED AND COATED					
	1	INSIDE AND OUTSIDE WITH POLYURETHANE, 5.67FT HIGH,					
	1	65FT LONG, 24FT WIDE FILLED					
	ASSEMBLY 20002			TOTAL	1,924.61	136.8102	12,781.11

FUEL (GAL/30DAYS) HEATING DSL	MOGAS	PWR GEN DSL	SKILLS MANHOURS EA	BU	UT	CE	SW	EO	CN	NS	CONST EFFORT MANHOURS
0	0	0	2	0	2	0	0	81	0	3	88

NOTE - CREW SIZE: 2 EA, 1 UT, 4 EO, 3 CN

ASSEMBLY 20004 ZONE 20004

TANK FUEL PILLOW 10000 GALLON

NAVFAC DRAWING NUMBER 6002630 MAJOR REVISION DATE 02 09 82

COG	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9C	4710-00-273-1041	PIPE CULV NESTABLE 16 GA AL 12N X 2FT	EA	4	26.40	2.1600	51.04
9C	4710-00-630-9445	PIPE STL BI STD WT 2N NPT	FT	20	75.00	.7800	25.60
9C	4720-00-878-6887	HOSE ASSY RBR FUEL-XFR 4N X 10 FT FEM X MALE QDISC	EA	3	171.00	7.5000	628.74
9C	4730-00-068-9286	COUPLING HALF QDISC CAM-LOCKING TYPE FEMALE X	EA	2	16.00	.4000	51.58
	6	INTERNAL PIPE THREAD 4N					
9C	4730-00-196-2079	NIPPLE PP STL BI 4 X 4N NPT	EA	1	3.15	.0600	2.31
9C	4820-00-469-7825	VALVE GATE QIK-OPNG BRS 2N NPT	EA	1	11.00	.2000	74.69
9Z	5330-00-899-4509	GASKET-COUPLING HALF QDISC CAM-LOCKING TYPE 4N	EA	3	.06	.0102	.96
2C	5430-00-052-3412	TANK, FABRIC, COLLAPSIBLE, 10000 GAL, PETRO ONLY,	EA	1	387.00	24.7400	6,121.00
	2	20.5FT X 20.5FT X 4FT HIGH FILLED, ELASTOMERIC-					
	2	COATED FABRIC, 4 INCH QUICK-DISCONNECT FILLER/DIS-					
	2	CHARGE ASSEMBLY					
	ASSEMBLY 20004			TOTAL	689.61	35.8502	6,955.92

FUEL (GAL/30DAYS) HEATING DSL	MOGAS	PWR GEN DSL	SKILLS MANHOURS EA	BU	UT	CE	SW	EO	CN	NS	CONST EFFORT MANHOURS
0	0	0	2	0	2	0	0	31	0	3	38

NOTE - CREW SIZE: 2 EA, 1 UT, 3 EO, 3 CN

ASSEMBLY 20005 ZONE 20005

MANIFOLD AND HOSE FOR 10000 GALLON TANKS

PROVIDES NECESSARY MANIFOLDS AND HOSE FOR CROSS-
CONNECTING FOUR 10000 GALLON PILLOW TANKS.

NAVFAC DRAWING NUMBER NONE MAJOR REVISION DATE 02 09 82

COG	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9C	3835-00-986-2328	MANIFOLD ASSEMBLY,CROSS,FOUR WAY,VALVED,FUEL-XFR	EA	3	31.02	3.4800	2,400.00
	8	ONE 4N MALE X THREE 4N FEM QDISC CONNS					
9C	4720-00-817-8373	HOSE ASSY RBR FUEL-XFR 4N X 50 FT FEM X MALE QDISC	EA	2	220.00	18.0000	331.36
9C	4720-00-985-1234	HOSE ASSY RBR FUEL-XFR 4N X 50 FT FEM X MALE QDISC	EA	6	2,130.00	54.0000	3,036.84
9C	4730-00-935-1613	ADAPTER QDISC CAM-LOCKING TYPE MALE X MALE 4X4N	EA	2	16.00	.4000	71.20
9C	4820-00-999-3680	VALVE FILLING FUEL F/FABRIC TANK 4N	EA	4	140.00	6.0000	1,908.60
	ASSEMBLY 20005			TOTAL	2,537.02	79.8800	7,748.00

FUEL (GAL/30DAYS) HEATING DSL	MOGAS	PWR GEN DSL	SKILLS MANHOURS EA	BU	UT	CE	SW	EO	CN	NS	CONST EFFORT MANHOURS
0	0	0	0	0	8	0	0	0	0	0	8

NOTE - CREW SIZE: 2 UT

ASSEMBLY 20007 ZONE 20007

OVERFLOW 4 INCH FOR 1,000-3,000 BBL TANKS

NAVFAC DRAWING NUMBER 6002572 MAJOR REVISION DATE 01 30 73

COG	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9C	4710-00-203-0186	TUBE STL PTD-FNSH 4N X 20FT GRV	LG	2	148.00	7.0000	52.32
9C	4730-00-142-1590	COUPLING CLAMP F/GRV PP MI 4N W/RBR GSKT	EA	4	36.00	.6000	15.04
9C	4730-00-202-7212	COUPLING PP STL UNCTD 4N GRV X MPT	EA	3	17.10	.3600	18.63
9C	4730-00-273-8322	ELBOW PP MI UNCTD 900 4N GRV	EA	2	19.00	.4440	8.98
9Z	5305-00-071-2508	SCREW CAP 0.25-20X1.5N UNC HEX HD CD PL STL	HD	1	4.00	.0400	2.55
9Q	5310-00-761-6882	NUT 0.25-20 UNC HEX CD PL STL	HD	1	.01	.0001	.53
9Z	5310-00-809-3078	WASHER FL 0.31N ID 0.73N OA DIA RND CD PL STL	HD	2	1.16	.0116	.90
9Z	5340-00-246-5126	HANGER PP MI HINGED RING 4N PP W/3/4N ROD SKT	EA	4	6.00	.2000	22.36
9Z	9510-00-189-1553	STEEL BAR HRL FLT .25X1	FT	2	1.70	.0044	.68
9Z	9515-00-204-3866	STEEL STRIP HRL .1875X4	FT	2	5.10	.0132	1.76
9Z	9520-00-954-5666	STEEL ANGLE 3X3X1-4	FT	2	9.80	.0214	2.42
	ASSEMBLY 20007			TOTAL	245.87	8.6947	126.17

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Figure 5-5.—Typical data display for an assembly.

Q4. *As a surveyor, you have been tasked to stake out a sanitary sewer line for a project. In which division of the specifications should you find the gradient requirements for the sewer piping?*

Q5. *Referring to the above question, in what part of the specification division should you find the gradient requirements?*

Q6. *What estimating publication has been prepared specifically for Seabee construction?*

Q7. *You have been tasked to prepare the concrete estimate for a 150-foot long retaining wall that has atypical cross section as shown in figure 5-6. Including a lo-percent waste factor, how many cubic meters of concrete will be required?*

Q8. *When detaining how many sheets of plywood will be required as forming material for the retaining wall shown in figure 5-6, what waste factor (according to NAVFACP-405) should you use if the plywood is to be used twice?*

Q9. *What is the basic planning tool that you should use when assisting in the planning of an advanced base?*

Q10. *Where in the Facilities Planning Guide, NAVFAC P-437, will you find recommended crew sizes?*

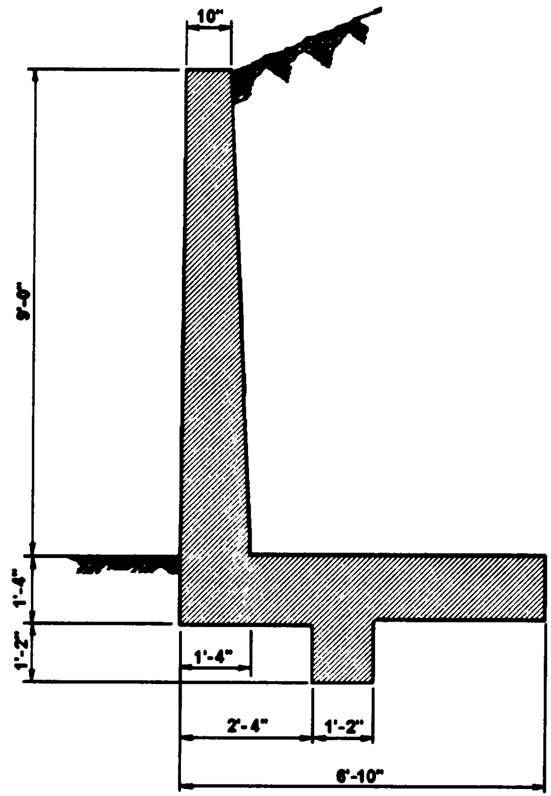


Figure 5-6.—Typical retaining wall.

CHAPTER 6

CARE AND ADJUSTMENT OF SURVEYING EQUIPMENT

To a great extent, the accuracy and quality of your surveys will depend upon how well you take care of your surveying equipment; therefore, the first part of this chapter reviews the proper instrument handling, stowing, and maintenance practices that you studied in the EA3 TRAMAN. While to some readers this review may seem redundant, taking care of your equipment properly cannot be overemphasized.

In this chapter we also discuss instrument adjustment and repair. As used in this chapter, the term ***adjustment*** means bringing the various fixed parts of an instrument into proper relationship with one another. It is different from the ordinary operations of leveling the instrument, aligning the telescope, and so forth.

CARE OF INSTRUMENTS

As you know, every instrument is accompanied by a user's manual that tells you not only the proper operation and components of the instrument but also its proper care and maintenance. Study this user's manual thoroughly before you even attempt to use the instrument. Some suggestions for the care and maintenance of surveying equipment are discussed in the following paragraphs.

HANDLING, CARRYING, AND STOWING

Always exercise care in handling instruments, such as the transit, level, theodolite, or plane table. When removing an instrument from its carrying case, NEVER grasp the telescope. Wrenching the telescope in this manner could damage a number of delicate parts. When you set up an instrument, make sure that it is securely fastened to the tripod head. In tightening the various clamp screws, leveling screws, and adjustment screws, bring them only to a firm bearing. Overtightening these screws may strip the threads, twist off the screw, bend the connecting part, or place undue stresses in the instrument. NEVER leave an instrument unattended while it is set upon a street, near construction work or in any other place where it can be damaged.

When you carry an instrument mounted on a tripod, place the instrument and tripod on one shoulder with the tripod legs pointing forward and held together by your hand and forearm. If you are walking along a sidehill, you should always carry the instrument on the downhill shoulder. This leaves the uphill arm and hand free to catch yourself should you trip or stumble. Before climbing over a fence, you should first place the instrument on the other side with the tripod legs well spread. Also, when carrying an instrument, you should ensure that all clamp screws are only lightly clamped so that the parts will move if the instrument is struck. Avoid carrying the instrument on your shoulder through doorways or beneath low-hanging branches; instead, you should carry it under your arm with the head of the instrument to the front.

Every transit, theodolite, or level comes equipped with a carrying box or case. The instrument and its accessories can be stowed in the case in a manner that ensures a minimum of motion during transportation. The instrument should ALWAYS be stowed in the carrying case when it is not in use.

Bags are provided for carrying stakes and hubs. These are usually canvas bags equipped with a shoulder strap and closely resemble a newsboy's bag. A newsboy's bag, in fact, makes an excellent carrying bag for stakes and hubs. So does a Navy seabag, equipped with a shoulder strap.

Various types of leather or canvas bags and sheaths, such as chaining-pin quivers, plumb-bob sheaths, and sheaths for Abney and Locke levels, are provided for various items of equipment. Most of these can be attached to the belt. Leather pouches, also usually attachable to the belt, are available for carrying small tools, marking equipment, turning-point pins, and the like. In time you will learn various conveniences, such as carrying your supply of surveyor's tacks stuck in a rubber ball or in a piece of softwood attached to your belt.

CLEANING AND LUBRICATION

All surveying instruments, equipment, or tools must be thoroughly cleaned immediately after you have used them; for example, after each use, you must dust off the transit or theodolite and wipe it dry before placing it back in its case. Remove all dust with a soft brush before wiping dirty components with a clean cloth. When the instrument becomes wet, you should remove it from its carrying case and dry it thoroughly at room temperature once you get home. NEVER leave a wet instrument stored in the carrying case.

NEVER rub the lenses of a telescope with your fingers or with a rough cloth. Clean chamois leather or a lint-free soft cloth is suitable for this purpose. Occasionally, you may clean the lenses with a soft cloth that is dampened with a mixture of equal parts of water and alcohol.

You should always remove mud and dirt from tripods, range poles, leveling rods, and so forth, immediately after each use. This is very important, especially when the surveying gear is made of a material that is susceptible to rust action or decay.

When lubricating instruments, you must use the right lubricant that is recommended for the climatic condition in your area; for instance, it is recommended that graphite be used to lubricate the moving parts of a transit when the transit is to be used in sub-zero temperatures; however, in warmer climates you should use alight film of oil (preferably watch oil).

Consult the manufacturer's manual or your senior EA whenever you are in doubt before doing anything to an instrument.

INSTRUMENT ADJUSTMENTS AND REPAIRS

Making minor adjustments and minor repairs to surveying instruments are among the responsibilities of EA personnel. Minor adjustments and minor repairs are those that can generally be done in the field using simple tools. Major adjustments and major repairs are those generally done in the factory. If the defect in the instrument cannot be corrected by minor adjustment or minor repair, do not attempt to disassemble it; instead, make necessary arrangements for sending the instrument to the manufacturer. Most surveying instruments are precision instruments for which major adjustments and recalibration require special skills and tools that can be provided only by the instrument company or its subsidiaries.

INSTRUMENT ADJUSTMENTS

As stated previously, adjustment, as used in this chapter, means the process of bringing the various parts of an instrument into proper relationship with one another. The ability to make these adjustments is an important qualification of any surveyor. To make proper adjustments, the surveyor should have the following knowledge:

1. They must be familiar with the principles upon which the adjustments are based.

2. they must know the methods or tests used to determine if an instrument is out of adjustment.

3. They must know the procedure for making adjustments and the correct sequence by which adjustments must be made.

4. They must be able to tell what effect the adjustment of one part will have on other parts of the instrument.

5. They must understand the effect of each adjustment upon the instrument when it is actually used for measurement.

Generally, instrument adjustments involve the level tubes, the telescope, and the reticle; for example, if one or both of the plate-level bubbles of an engineer's transit are centered when the plate is, in fact, not level, the instrument is out of adjustment. An optical instrument equipped with vertical and horizontal cross hairs is out of adjustment if the point of intersection between the cross hairs does not coincide with the optical axis. If the reflected bubble on a Locke or Abney level is centered when the optical axis is other than horizontal, the instrument is out of adjustment.

The process of adjustment chiefly involves the steps that are necessary to bring a bubble to center when it should be at center or to bring a cross-hair point of intersection into coincidence with the optical axis. Instrument manufacturers publish handbooks containing recommended adjustment procedures. These are usually small pamphlets, obtainable free of charge.

The following discussion is intended to give you an idea of general instrument adjustment procedures. For adjusting your particular instruments, however, you should follow the appropriate manufacturer's instructions.

General Adjustment Procedures

Instruments should be carefully checked periodically to determine whether or not they need adjustment. There is an adage that an instrument should be checked frequently but adjusted rarely. The basis for this adage is the fact that modern quality instruments get out of adjustment much less frequently than is generally believed; consequently, a need for adjustment is frequently caused by a previous improper adjustment that was not really required but resulted from errors in checking.

Before assuming that adjustment is necessary, you must positively ascertain that an apparent maladjustment actually exists. The following procedures apply, in general, to all tripod-mounted optical instruments that you may use in surveying:

1. Check the instrument on a cloudy day, if possible.

2. Ascertain that the tripod shoes are tight and that the instrument is screwed all the way down on the tripod.

3. Set the tripod up on firm ground in the shade, but in a good light, where a sight of at least 200 feet can be taken in opposite directions.

4. Spread the tripod feet well apart and place them so that the plate is approximatel y level. Press the shoes in firmly, or set them in cracks or chipped depressions if on a hardened surface. (Avoid setting up on asphalt pavement in warm weather.)

5. After the tripod feet are set, release and then retighten the wing nuts. The purpose of this is to release any possible residual friction that, if not released, might cause an eventual shift in the legs.

6. Level the instrument with particular care. After leveling, loosen all level screws slightly (again to release residual friction) and relevel. Tighten all screws with equal firmness but avoid overtightening. Too much tightness will eventually deform the centers, causing both friction and play.

7. Carry out all checks in the order prescribed for the instrument. Do NOT make an adjustment unless the same check, repeated at least three times, indicates the same amount of error every time.

8. Remember that most tests show an error that is **double** the actual displacement error in the instrument.

Be especially watchful for **creep;** that is, a change in position caused by settlement or by temperature change in the instrument. To detect any possible creep, you should allow every set bubble or setline of sight to stand for a few seconds and ensure that no movement occurs during the interval.

Before an adjustment is made, consider whether or not the error discovered will have a material effect on field results. Make adjustments in a prescribed order. After making an adjustment, retighten the adjusting parts firmly but not too tightly. Then repeat the original check and readjust if necessary. After making all the contemplated adjustments, repeat the entire round of checks in the prescribed order. This will indicate whether or not an adjustment has been disturbed by a subsequent adjustment.

In the following sections, we will discuss the field tests and adjustments that you need to know how to perform for the engineer's level and the transit. While the principles of performing the adjustments are nearly the same for one manufacturer's level or transit as compared to those produced by another manufacturer, there are some differences in detail. For this reason, when preparing to perform an adjustment to an instrument, you should first consult the operator's manual for that instrument.

When a high degree of accuracy is required for surveying results, the level or transit used must be in perfect adjustment. In this event, you must perform the tests described in the following sections and make any necessary adjustments to the instrument. When results of lower accuracy can be tolerated, however, you can usually compensate for the maladjustment of a part until a proper adjustment can be made. Therefore, at the end of each of the following instrument-adjustment discussions, a method of compensating for the maladjustment is noted. You should keep in mind, however, that if you frequently check your instruments and keep them in good adjustment, these compensations should seldom be necessary.

Engineer's Level Adjustments

Regardless of how well an engineer's level is manufactured, you should perform certain checks and field adjustment at regular intervals; for example, you should test the instrument every day before starting work. You also should check it for proper adjustment anytime the level is bumped or jolted. The parts of the level that you will check are the level tube and the cress hairs. For the latter, be sure that parallax is removed and that the cross hairs and objective are sharply focused. To do this, use a well-defined object at least 250 feet away. When parallax is present, the image is not exactly in the plane of the cross hairs, and the objective focusing must be refined. Since this condition can occur each time the objective lens is focused, you must make a parallax check each time you observe a new object.

When adjusting the engineer's level, it is important that you accomplish the tests and adjustments in a prescribed sequence. The reason for this is that one adjustment may depend upon, or alter, another adjustment. The following paragraphs describe, in proper sequence, the test and adjustment procedures that you should follow when checking and adjusting the engineer's level.

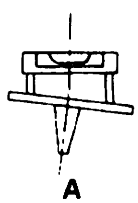


Figure 6-1.—Adjusting the level tube.

ADJUSTING THE LEVEL TUBE.— The vertical axis of rotation of the instrument is the basis for all adjustments to the engineer's level. When the instrument is set up and leveled the vertical axis of rotation and the longitudinal axis of the level tube should be perpendicular to one another. If they are not perpendicular, then the vertical axis cannot be made truly vertical. Adjustment of the level tube makes the axis of the level tube perpendicular to the vertical axis. To check and adjust the level tube, you should follow the procedures below:

1. Setup the instrument and approximately level the bubble over each pair of opposite leveling screws. Then carefully center the bubble over one pair of screws, as shown in view A, figure 6-1.

2. Rotate the instrument 180°. If the bubble remains centered, then the level tube is in proper adjustment. If the bubble does NOT remain centered note the movement of the bubble away from center (view B, fig. 6-1).

3. Bring the bubble half the distance back to the center of the tube by turning the capstan nuts at one end of the tube (view C, fig. 6-1).

4. Relevel with the leveling screws (view D, fig. 6-1) and rotate the instrument again. Repeat Step 3 above if the bubble does not remain at the center of the tube.

5. Check the final adjustment by noting that the bubble remains in the center of the tube during the entire revolution about the vertical axis.

NOTE: When the level tube is out of adjustment, you can compensate for it by releveling the instrument before each sighting.

ADJUSTING THE HORIZONTAL CROSS HAIR.— For the horizontal cross hair to lie in a truly horizontal plane when the instrument is leveled, the horizontal cross hair must be perpendicular to the vertical axis. To make the horizontal cross hair (fig. 6-2) lie in a plane perpendicular to the vertical axis, you should perform the following steps:

1. With the instrument carefully leveled, sight one end of the horizontal cross hair on a well-defined point at least 250 feet away. Turn the telescope slowly about the vertical axis, using the slow motion screw. If the cross hairs are in adjustment, the horizontal cross hair will stay on the point through its entire length.

2. If it does not stay on the point, loosen two adjacent reticle capstan screws and rotate the reticle by lightly tapping two opposite screws.

3. Sight on the point again. If the horizontal cross hair does not stay on the point through its entire length, rotate the ring again.

4. Repeat this process until the condition is satisfied.

NOTE: To compensate for the above maladjustment, you should use only that part of the horizontal cross hair that is closest to the vertical hair for all sightings.

ADJUSTING THE LINE OF SIGHT.— For a perfectly adjusted level, the line of sight is parallel to the axis of the level tube. When the level meets this condition, the line of sight will generate a truly horizontal plane when the instrument is rotated. When

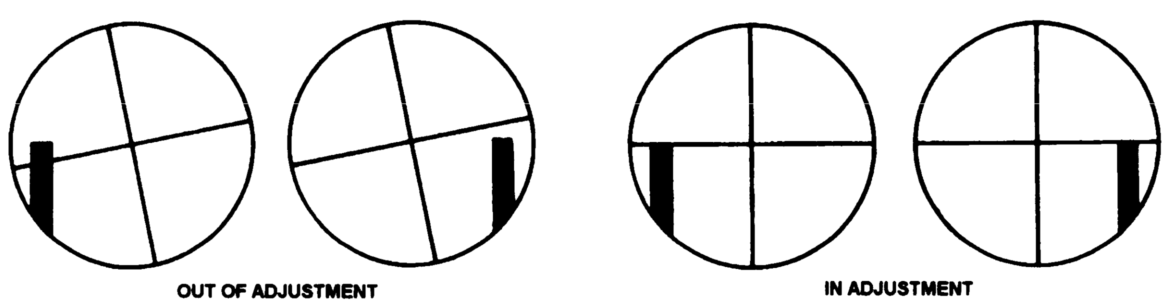


Figure 6-2.—Adjusting the horizontal cross hair.

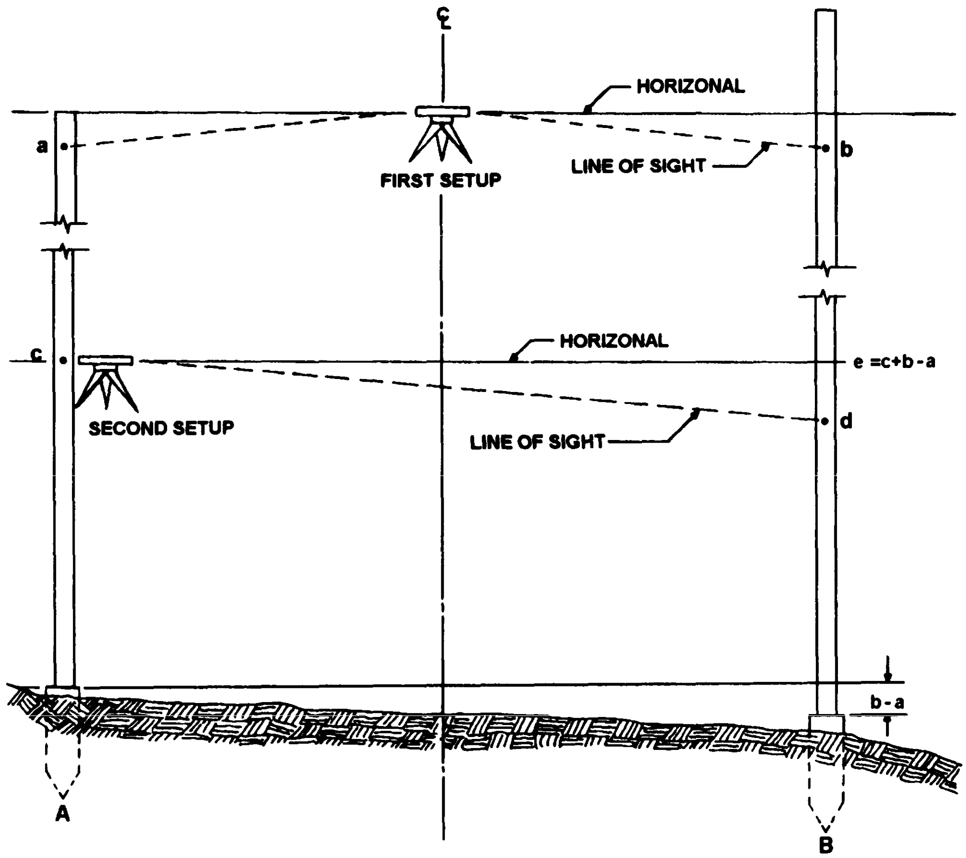


Figure 6-3.—Two-peg test method.

the line of sight is not parallel to the axis of the level tube, then you must adjust the line of sight. The method used for adjustment is known as the *two-peg test* (fig. 6-3). This method requires you to do the following steps:

1. Setup and level the instrument (first setup, fig. 6-3). Drive stake (peg) A about 150 feet away, then drive stake *B* at the same distance in the opposite direction.

2. Take a rod reading a on stake *A* and a rod reading *b* on stake *B*. With the instrument exactly halfway between the two stakes, *b-a* is the true difference in elevation between the stakes.

3. Move the instrument close to stake *A* (second setup, fig. 6-3) so that the eyepiece is within a half inch from the rod. Then, by sighting through the objective-lens end of the telescope, take a rod reading c on stake *A*. Next, take a rod reading *d* on stake *B* in the normal manner. If the instrument is in adjustment, *d-c* will equal *b-a*.

4. If the instrument is out of adjustment, calculate what the correct rod reading e should be on the farther rod *B* ($e = c + b - a$). Set the rod reading *e* with a target for accurate reading. Move the horizontal cross hair to the correct reading (on target) by loosening the correct vertical screw and tightening the opposite screw.

5. Check the horizontal cross hair adjustment again. The ring may have rotated during this adjustment.

6. Rerun the peg test to check the adjustment.

NOTE: The compensation for the above maladjustment is careful balancing of your backlights and foresights.

Transit Adjustments

You must be capable of performing six commonly performed tests and adjustments of the transit. All tests and adjustments of the transit are made with the instrument mounted on its tripod and setup in the shade. You must make these tests periodically and in the sequence in which they are discussed in the following paragraphs. When one of the tests indicates that an adjustment is necessary, you must make this adjustment and then you must repeat all previous tests before proceeding with the next test.

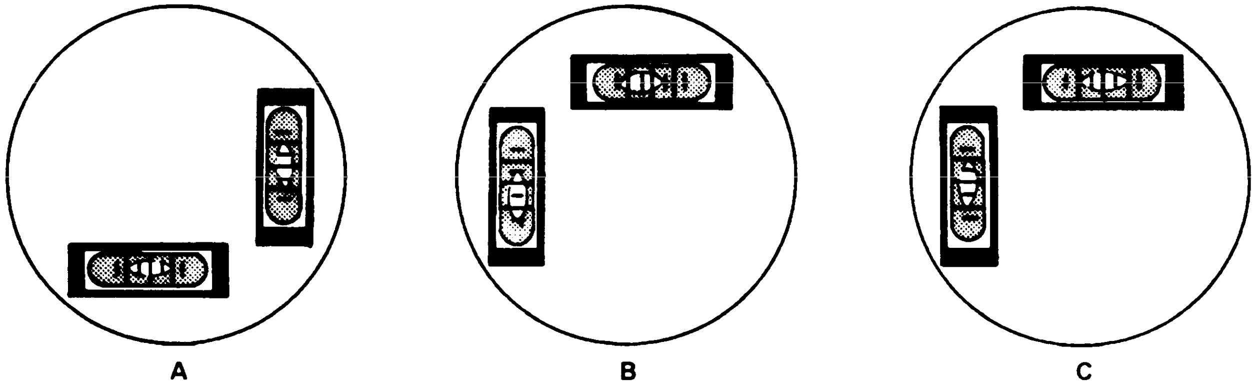


Figure 6-4.—Adjusting the plate bubbles.

ADJUSTING THE PLATE BUBBLES.— The purpose of adjusting the plate bubbles is to make the axis of the plate-level tubes perpendicular to the vertical axis (fig. 6-4). This ensures that when the instrument is set up and leveled, the vertical axis is truly vertical. When this condition is met, horizontal angles are measured in a truly horizontal plane and vertical angle do not incur index error because of an inclined vertical axis.

You should make the plate-bubble test every time you set up the instrument for use and always before making any other tests and adjustments of the transit. Make this test and adjustment using the following steps:

1. Rotate the instrument about the vertical axis and bring each level tube parallel to a set of opposite leveling screws. Bring both bubbles to the center of their tubes by turning the leveling screws (view A, fig. 6-4).

2. Rotate the instrument 180° about its vertical axis. If the bubbles remain centered, no adjustment is necessary. If the bubbles do not remain centered, note the amount of distance that the bubbles move from their center (view B, fig. 6-4) and proceed with Steps 3 through 5.

3. Bring each bubble half the distance back to the center of its tube by turning the capstan screws at the end of each tube.

4. Relevel the instrument using the leveling screws and rotate the instrument again. Make a similar correction if the bubbles do not remain in the center of the tubes.

5. Check the final adjustment by noting that the bubbles remain in the center of the tubes during the entire revolution about the vertical axis (view C, fig. 6-4).

NOTE: You can compensate for out-of-adjustment plate levels by leveling the instrument, rotating it 180° in azimuth, and bringing the bubbles halfway back using the leveling screws.

ADJUSTING THE VERTICAL CROSS HAIR.— In a perfectly adjusted transit, the vertical cross hair should lie in a plane that is perpendicular to the horizontal axis. In this way, any point on the hair may be used when measuring horizontal angles or running lines.

To make the vertical cross hair lie in a plane perpendicular to the horizontal axis (fig. 6-5), you should follow the procedure below:

1. See that parallax is eliminated. Sight the vertical cross hair on a well-defined point; and with all motions clamped, move the telescope slightly up and down on its horizontal axis, using the vertical slow motion tangent screw. If the instrument is in adjustment, the vertical hair will appear to stay on the point through its entire length.

2. If it does not stay on the point, loosen the two capstan screws holding the cross hairs and slightly rotate the ring by tapping the screws lightly.

3. Sight again on the point. If the vertical cross hair does not stay on the point through its entire length as the telescope is moved up and down, rotate the ring again.

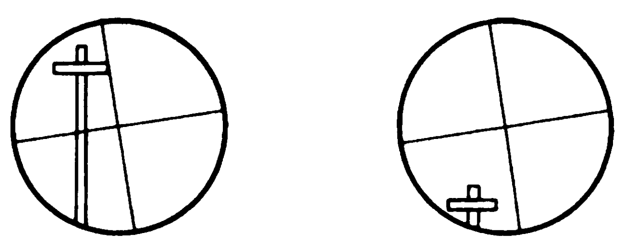


Figure 6-5.—Adjusting the vertical cross hair.

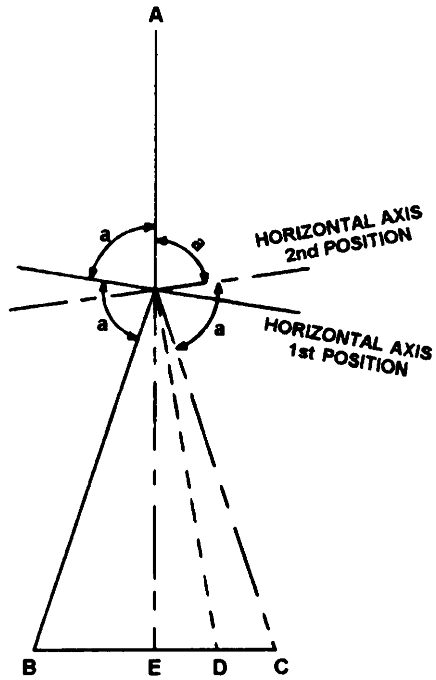


Figure 6-6.—Adjusting the line of sight.

4. Repeat this process until the condition is connected.

NOTE: To compensate for the above maladjustment, use only that part of the vertical hair that is closest to the horizontal cross hair.

ADJUSTING THE LINE OF SIGHT.— In a perfectly adjusted telescope, the line of sight should be perpendicular to the horizontal axis at its intersection with the vertical axis. To make the line of sight perpendicular to the horizontal axis (fig. 6-6), you should proceed as follows:

1. Sight on a point, A, at a distance of not less than 200 feet with the telescope normal; clamp both plates.

2. Plunge the telescope and set another point, *B,* on the ground at a distance from the instrument equal to the first distance and at about the same elevation as point A.

3. Unclamp the upper motion, rotate the instrument about its vertical axis, sight on the first point (telescope inverted), and clamp the upper motion.

4. Plunge the telescope and observe the second point. If the instrument is in adjustment, the point over which it is set will be on a straight line, *AE,* and point *B* will fall at position *E.* If the instrument is not in adjustment, the intersection of the cross hairs (point *C)* will fall to one side of the second point, *B.*

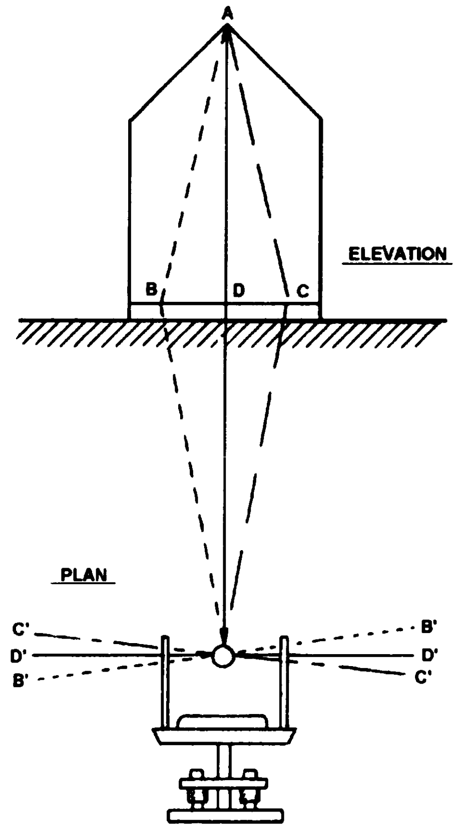


Figure 6-7.—Adjusting the horizontal axis.

5. Measure the distance *BC* and place a point, *D,* one fourth of this distance back toward the original point, *B.*

6. Move the cross-hair reticle horizontally by loosening the screws on one side of the telescope tube and tightening the opposite screw until the vertical cross hair appears to have moved from *C* to the corrected position, *D.*

7. Repeat this operation from number 1 above, until no error is observed.

8. Repeat the test described for adjusting the vertical cross hair, since the vertical cross hair may have rotated during this adjustment.

NOTE: You can compensate for the above maladjustment by double centering (discussed in the EA3 TRAMAN).

ADJUSTING THE HORIZONTAL AXIS.— When you plunge the telescope, the line of sight should generate a truly vertical plane. For this to occur, the horizontal axis of the telescope must be perpendicular to the vertical axis. To make the horizontal axis of the telescope perpendicular to the vertical axis (fig. 6-7), you should perform the following steps:

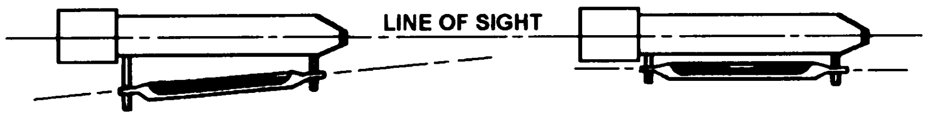


Figure 6-8.—Adjusting the telescope level.

1. Sight the vertical cross hair on some high point, *A,* at least 30° above the horizontal and at a distance of 200 feet, such as the tip of a church steeple or other well-defined object, and clamp the plates.

2. Depress the telescope and mark a second point, *B,* at about the same level as the telescope.

3. Plunge the telescope, unclamp the lower plate, and rotate the instrument about its vertical axis.

4. Sight on the first point, A.

5. Clamp the lower plate and depress the telescope. If the vertical cross hair intersects the second or lower point, *B,* the horizontal axis is in adjustment. In this case, point *B* is coincident with point *D* in both direct and reverse positions of the telescope.

6. If not, mark the new point, *C,* on this line and note the distance, *BC,* between this point and the original point.

7. Mark point *D* exactly midway of the distance *BC. CD* is the amount of correction to be made.

8. Adjust the horizontal axis by turning the small capstan screw in the adjustable bearing at one end of the horizontal axis until point *C* appears to have moved to point *D.*

9. Repeat this test until the vertical cross hair passes through the high and low points in the direct and inverted position of the telescope.

10. Check all previous adjustments.

NOTE: When you cannot immediately correct the above condition, you can compensate by repeating any survey procedure with the telescope reversed and then use the average of the results.

ADJUSTING THE TELESCOPE LEVEL.— To be able to use a transit for direct leveling and to measure vertical angles without index error, you must ensure that the axis of the telescope level is parallel to the line of sight. To adjust the telescope level of the transit, use the same two-peg method that we discussed previously for the engineer's level. The only difference is that you must level the telescope carefully before each reading. After computing the reading that should be made on the far rod (fig. 6-3), you set the horizontal cross hair on the computed reading using the vertical slow motion screw. Then you move one end of the spirit level vertically by means of the adjusting nuts until the bubble is centered in the tube (fig. 6-8).

NOTE: As with the engineer's level, you should compensate for the above maladjustment by careful balancing of all backlights and foresights.

ADJUSTING THE VERTICAL CIRCLE VERNIER.— For vertical angles to be measured without index error caused by displacement of the vertical circle vernier, the vernier should read zero when the plate bubbles and telescope bubbles are properly leveled. To make the vertical circle vernier read zero when the instrument is leveled (fig. 6-9), you should perform the following steps:

1. With the plate bubbles leveled, bring the telescope bubble to the center of the tube and read the vernier of the vertical circle.

2. If the vernier does not read zero, loosen the capstan screws holding the vernier and move the index until it reads zero on the vertical circle.

3. lighten the screws and read the vernier with all the bubbles in the center of their tubes to make sure that

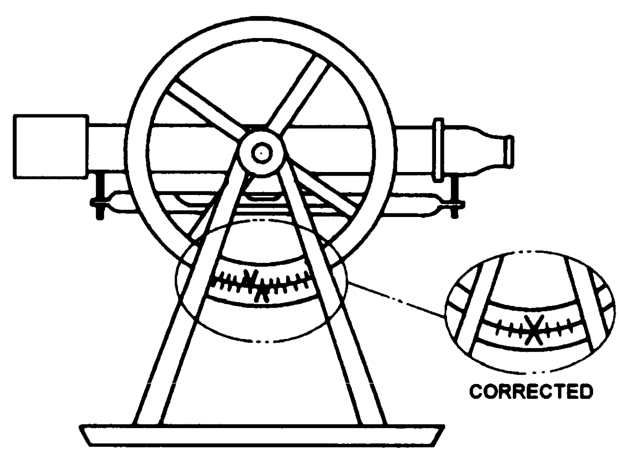


Figure 6-9.—Adjusting the vertical circle vernier.

the vernier still reads zero and has not moved during the operation.

NOTE: To compensate for the above maladjustment, you should read all vertical angles direct and reversed; then use the average of the result.

This concludes our discussion of instrument adjustment. As a reminder, you should always check your surveying instruments frequently for proper adjustment and then make those adjustments either immediately or as soon as practicable. Do not put it off or you may quickly forget to do it until it is too late. Also, be sure to check the manufacturer's instructions before making the adjustments described above or when you need to adjust other instruments, such as the automatic level, alidade, or hand level.

MINOR REPAIRS AND REPLACEMENT PROCEDURES

As stated earlier in this chapter, minor repairs to surveying instruments and equipment are those that can be done in the field with the use of simple tools. Major repairs are done by instrument specialists who are generally employed by the manufacturers of the instruments. You should never attempt to make a major repair yourself.

Repair It or Replace It?

Whether or not you or someone else in the battalion should attempt the repair of a damaged item of equipment depends on the nature of the damage and the character of the item. A broken tape, for example, can easily be spliced (explained in the EA3 TRAMAN). On the other hand, whether or not you should attempt to straighten a bent compass needle depends on the type of compass —for an ordinary pocket compass, perhaps yes; for the compass on a transit, perhaps no. Many types of damage to such articles as range poles, tripod legs, and the like may be repaired in the battalion or PWD shops. Minor damage to instruments maybe repaired occasionally in the battalion machine shop. However, major repairs to instruments, when they are economically worthwhile at all, should be done by manufacturers or their authorized representatives or by competent Navy instrument repairmen.

When in the judgment of the senior EA or the engineering of!icer concerned an instrument is beyond economical repair, it must be surveyed (properly disposed of) by standard survey procedures. Then a replacement instrument must be ordered fkom the Navy supply system. Expendable items are procured in the same manner.

Navy Supply System

Each individual item of equipment or supply that is available through the Navy supply system is identified by a stock number and listed and described in a stock catalog. Identification of the items that may be drawn from supply by a battalion and the maximum number of each item a battalion may have are set forth in an allowance list. When the number of items available in a battalion falls short of the allowance (because of expenditure, wear, casualty, loss, or some other type of attrition), the shortage must be replaced.

Some items, such as range poles, chaining pins, bull-points, turning-point pins, targets, stake bags, equipment boxes, and the like, may be replaced by using the battalion or PWD shops personnel expertise. Most items, however, are replaced from supply; that is, they are ordered from the nearest available naval supply depot.

To replenish an item, you must order by stock number and follow a prescribed procedure. To learn the correct procedures, you should get in touch with one of the supply petty officers in the battalion or study the chapters on the Navy supply system in Military Requirements for Petty Officer Third Class, NAVEDTRA 12044, and *Military Requirements for Petty Officer Second Class,* NAVEDTRA 12045.

NMCB Surveyor's Kit

Every NMCB is properly outfitted with adequate surveying supplies and equipment. These necessary items are listed in the NMCB *Table of Allowance* (TOA) and are contained in Surveyor Kit #80010. For this reason, no attempt will be made to list all the equipment and supplies currently carried in the standard surveyor kit. Normally, four complete kits will be carried in the battalion allowance. They are available for check-out to the surveyor section supervisor or the senior EA. It is the responsibility of each survey party chief to make sure that the kit assigned to the crew is complete. The kits are required to be inventoried during turnover and at twice-monthly intervals throughout deployment. The purpose of these inventories is to ensure 100-percent accountability of the items contained in the kit and to ensure that all of those items are in a proper state of good repair. Remember, if you have custody of the kit, you can be held financially accountable for items missing or damaged through negligence.

Most consumable items contained in the kit, such as pencils, pencil leads, lumber crayon, and surveyor's flaggings, are stocked in the battalion supply department for kit replenishment. Additional supplies and equipment are also stocked in the engineering office surveyor's linker to supplement the kits.

QUESTIONS

Q1. According to your textbook, the vertical axis is the basis of all adjustments made to the engineer's level. What is the basis for adjustments to the transit?

Q2. You should never attempt to adjust an instrument until the same test, repeated how many times, shows the same amount of error?

Q3. What is the purpose of adjusting the line of sight of a level or a transit?

Q4. Why is it necessary for the vertical cross hair of a transit to be perpendicular to the horizontal axis of the instrument?

Q5. As you have learned when apart, such as a level tube or a cross hair, is out of adjustment, there is a method of compensating for the maladjustment. When should you use these compensating methods?

CHAPTER 7

INDIRECT LEVELING/LEVEL AND TRAVERSE COMPUTATIONS

As you know, leveling is the surveying operation that determines the difference in elevation between points on the earth's surface. This operation is divided into two major categories: **direct** leveling and **indirect** leveling. From your study of the EA3 TRAMAN, you should, by now, be familiar with the methods and procedures used in direct leveling. In this chapter you will be introduced to the theory and basic procedures used in indirect leveling.

You also learned in the EA3 TRAMAN that perfect closure in level nets and traverses is seldom, if ever, obtained. There is nearly always a certain amount of linear or angular error. When this error exceeds a prescribed amount, then the level net or traverse must be rerun. However, when the error is within the specified allowable limits, then certain adjustments can be made. In this chapter you will study those adjustments and the calculations needed to make the adjustments.

Also discussed in this chapter are various methods that you can use to determine the area of traverses.

INDIRECT LEVELING

Indirect methods of leveling include **barometric leveling** and **trigonometric leveling.** A discussion of these methods is discussed in the following paragraphs.

BAROMETRIC LEVELING

Barometric leveling makes use of the fact that differences in elevation are proportional to differences in the atmospheric pressure. Therefore, when you read the atmospheric pressure with a barometer at various points on the earth's surface, you have a measurement of the relative elevation of these points. A **mercurial barometer, aneroid barometer,** or **sensitive altimeter** may be used for this purpose. However, the mercurial barometer is too cumbersome to take out into the field. Barometric leveling is used mostly in reconnaissance surveys where differences in elevations are large; for example, in mountainous regions. Elevations determined by barometric leveling probably are several feet in error even after they are corrected for the effects of temperature and humidity. These errors are caused by the day-to-day pressure fluctuations, even by fluctuations from hour to hour in 1 day. Barometric observations are, therefore, usually taken at a fixed station during the same period that observations are made on a second barometer that is carried from point to point in the field. The use of two barometers enables you to correct for atmospheric disturbances that could not be readily detected if only one barometer were used. This method is not normally used in construction surveying, except when a construction surveyor may need to run his own preliminary topographic control.

Barometric or altimeter surveys are run by one of three methods: the **single-base,** the **two-base,** and the **leapfrog.** The single-base method requires a minimum number of observers and less equipment. However, the method needs a series of corrections and is neither as practical nor as accurate as the other two. The two-base method is generally accepted as the standard method for accuracy and is the one most widely used. It requires fewer corrections than the single-base method. The leapfrog method uses the same type of corrections as the single-base, but the altimeters are always in close relationship to each other and are operating under reasonably similar atmospheric conditions. The results of the leapfrog method are more accurate than the single-base method and compare favorably with the two-base method.

The two-base method will be described here only to give you an idea of how this system works. There are several factors and limitations that must be observed in barometric leveling, which are beyond the scope of this training manual. For actual barometric leveling, you should consult the instruction manual that goes with the instrument. The theory of two-base barometric leveling is explained below.

In the two-base method, you need at least three altimeters, one at each lower and upper base where elevations are known initially and one or more altimeters roving where elevations are needed between the upper and lower base elevations. Obviously, for this operation, points of unknown elevations to be determined must lie in heights within the range of the elevations of the lower and upper base stations. The readings of the altimeters at the unknown elevations are taken at the same instant that both the upper and the lower base altimeters are read. When there is no radio

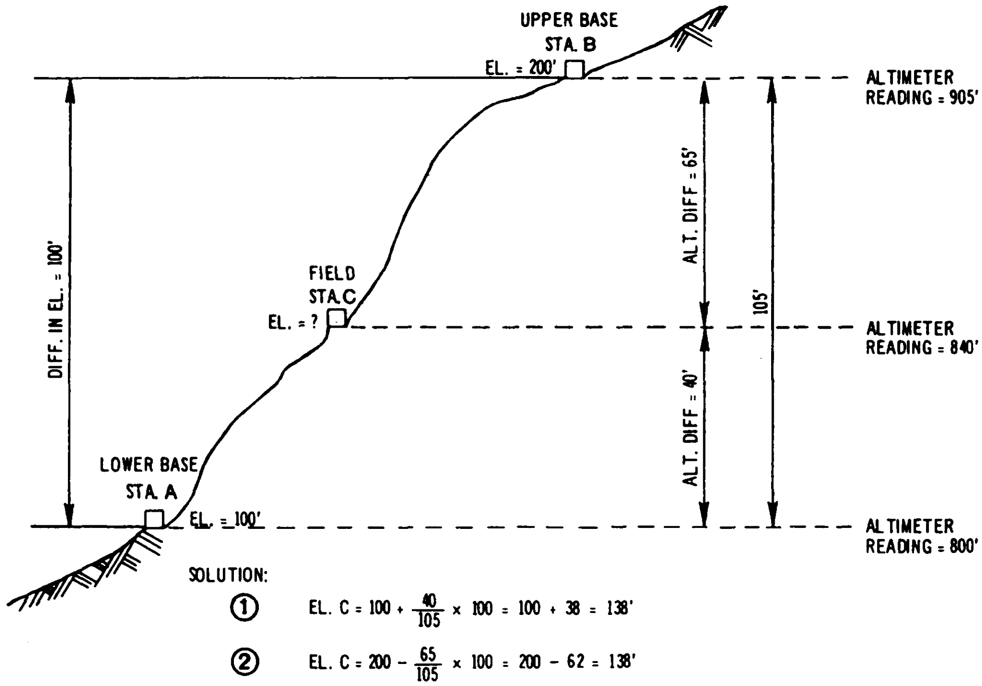


Figure 7-1.—Diagram of a two-base altimeter survey.

communication, a timepiece is needed for each altimeter. These timepieces are synchronized, and the altimeter readings are taken at prearranged intervals.

Figure 7-1 shows a diagram of the two-base method when three altimeters are used. This figure shows the known elevations of the lower (Sta. A) and upper (Sta. B) base stations. Altimeter readings at each of the base stations and at field station C are also shown. The difference in elevation is computed by direct proportion, using either the lower base or the upper base as reference. For example, to find the differences in elevation between Sta. A and Sta. C, we proceed as follows:

$$\frac{\textit{Diff. El. AC}}{100} = \frac{40}{105}$$

$$\textit{Diff. El. AC} = \frac{40 \times 100}{105} = 38\,ft$$

Then this result is added to the elevation of Sta. A, as shown in solution No. 1, figure 7-1. If we use the upper base as a reference, you compute the difference in elevation by using the same method; but to compute from Sta. B, subtract the result, as shown in solution No. 2, figure 7-1.

For a more accurate result, altimeter surveys should be made on days when there is not much variation in barometric pressure. Windy days when detached clouds are traveling rapidly should be avoided because alternating sunlight and shade over the survey area can cause fluctuations in the altimeter reading. Steady barometric pressures generally occur on days with gentle winds and an overcast sky. The recommended time for observations is 2 to 4 hours after sunrise and 2 to 4 hours before sunset. Midday observation must be avoided if possible. Remember, you must shade the instrument at all times, and you must avoid jarring the instrument suddenly during its transfer from one station to another.

TRIGONOMETRIC LEVELING

When you know the vertical angle and either the horizontal or slope distance between two points, you can apply the fundamentals of trigonometry to calculate the difference in elevation between the points. That is the basic principle of trigonometric leveling. This method of indirect leveling is particularly adaptable to rough, uneven terrain where direct leveling methods are impracticable or too time consuming. As in any survey, the equipment that you will use in trigonometric leveling depends on the precision required. For most trigonometric-leveling surveys of ordinary precision, angles are measured with a transit, or alidade, and distances are measured either with a tape or by stadia, which you will study in chapter 8. On reconnaissance surveys the vertical angles may be measured with a clinometer, and distances maybe obtained by pacing.

The method used in trigonometric leveling is described in the following paragraphs:

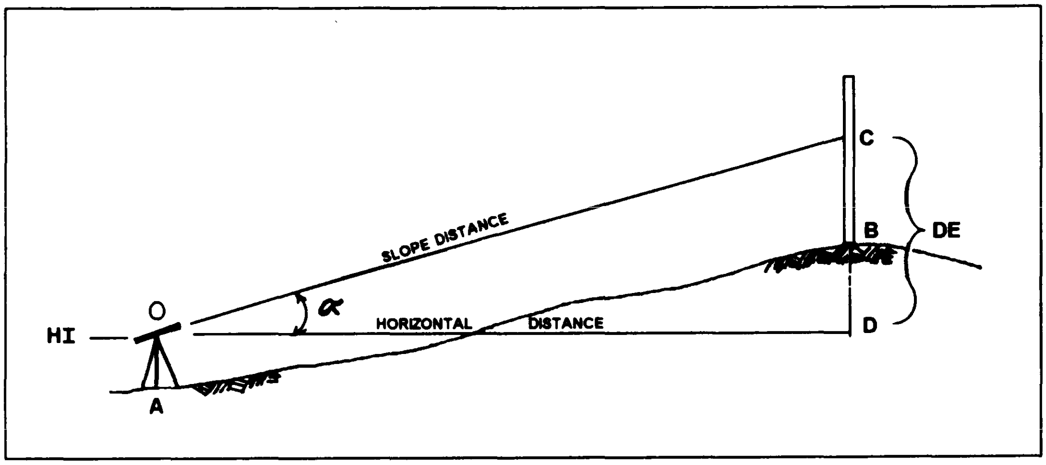


Figure 7-2.—Difference in elevation in trigonometry leveling.

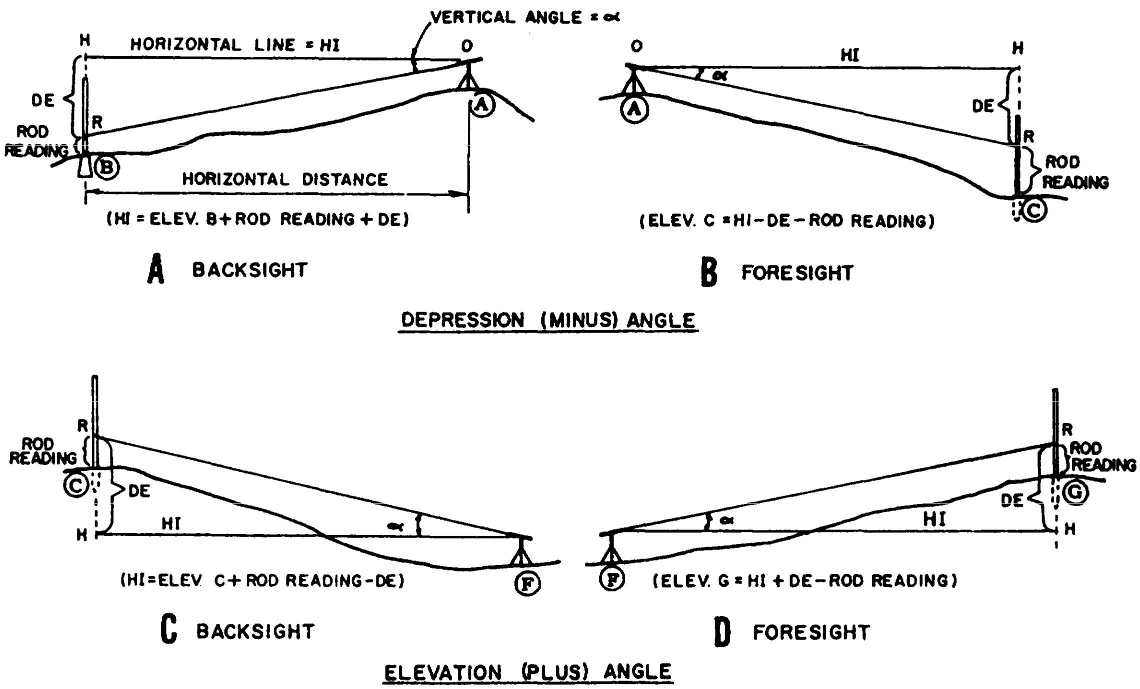


Figure 7-3.—Lines of indirect levels.

In figure 7-2, a transit is setup and leveled at A. The rodman holds a rod on B. The instrumentman trains the telescope on C, which is an easily read value (usually a full foot) on the rod. With the telescope trained on C, the vertical angle (a) is read. Then either the horizontal distance or the slope distance between the instrument and rod is determined. Now one side and one angle of a right triangle (OCD) are known. From your knowledge of trigonometry, you know that the other sides and angle can be computed. However, in trigonometric leveling, you are concerned only with determining the length of the side opposite the measured angle (side CD). The length of this side is the **difference in elevation (DE).** As-you can see in figure 7-2, the DE is the distance between the height of instrument (HI) and the intersection of your line of sight with the rod (point C). Computing the DE consists of multiplying the measured distance by the proper trigonometric function of the measured angle (sine, when slope distance (OC) is measured; tangent, when horizontal distance (OD) is measured).

The following paragraphs discuss typical situations that you will encounter in trigonometric leveling. You will see in each of these situations the reamer in which the computed DE is applied to determine the HI and required elevations.

1. DEPRESSION ANGLE BACKSIGHT (fig. 7-3, view A). The rod is on point B below the instrumerit. The measured vertical angle (a) is a depression (minus)

angle. To compute the HI, the rod reading RB and the DE are added to the elevation of B, or

$$HI = RB + DE + Elev.\ B.$$

2. DEPRESSION ANGLE FORESIGHT (fig, 7-3, view B). The rod is below the instrument, and the vertical angle is minus. The elevation at C equals the HI minus the DE and minus the rod reading RC, or

$$Elev.\ C = HI - DE - RC.$$

3. ELEVATION ANGLE BACKSIGHT (fig. 7-3, view C). The rod is above the instrument, and the vertical angle is plus. The HI at F equals the elevation at C plus the rod reading (RC) and minus the DE, or

$$HI = Elev.\ C + RC - DE.$$

4. ELEVATION ANGLE FORESIGHT (fig. 7-3, view D). The rod is above the instrument and the angle is plus. The elevation of G equals the HI plus the DE and minus the rod reading (RG), or

$$Elev.\ G = HI + DE - RG.$$

As mentioned earlier in this section, the horizontal or slope distances used for calculating the DE may be obtained using various methods. For each method, there are requirements and limitations that must be adhered to. These requirements and limitations are discussed as follows:

1. Measured distances obtained by horizontal chaining should be corrected for standard error, temperature, and sag before you compute the DE. These corrections are discussed in chapter 12 of the EA3 TRAMAN. Under ordinary circumstances in the Seabees, corrections for earth curvature and refraction are not necessary. However, methods to perform these corrections can be found in commercial publications, such as *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail.

2. Measured distances obtained by slope chaining also should be corrected as discussed above. In addition, you must convert the slope distance to a horizontal distance before computing the DE. As an aid in computations, tables have been developed that provide the following data:

a. Inclination corrections for 100-foot tape

b. Differences in elevation forgiven horizontal distances and gradients from 0° to 45°

c. Differences in elevation for given slope distances and gradients from 0° to 45°

d. Horizontal distances for given slope distances and gradients from 0° to 45°

3. When using stadia, you should refer to the stadia procedures and formulas described in chapter 8 of this TRAMAN. With practice, stadia provides a rapid means of determining the horizontal distances and elevations.

4. Electronic distance-measuring devices measure the straight-line horizontal or slope distance between instruments. When you use the same setup for slopes, replace the electronic equipment with a theodolite and either a target or a rod to measure the vertical angle. The measured vertical angle can be used to convert the measured slope distance to DE by multiplying by the sine of the vertical angle.

LEVEL AND TRAVERSE COMPUTATIONS

In this section we provide information on procedures used in making level and traverse computations. We also discuss methods of differential leveling, including steps to follow in checking level notes. Coverage includes information on adjusting intermediate bench marks as well as a level net. In addition, we describe several methods of plotting horizontal control that may be used in determining the bearing of the traverses. These methods include plotting angles by protractor and scale, plotting angles from tangents, and plotting by coordinates. We point out some of the common types of mistakes that the EA may encounter in making or checking computations, and we provide some information about locating mistakes.

PRELIMINARIES TO COMPUTATIONS

Before computations are started, a close check on the field data for completeness and accuracy is required. This includes checking the field notes to ensure that they accurately reflect what was actually measured; for example, a deflection-angle note 79°01'R must be checked to be sure that the angle actually measured 79°01' (by ascertaining that the sum of the angle and the closing angle is 360° or within allowable differences) and to ensure that the angle was actually turned to the right.

A field measurement may itself require transformation (called **reduction)** before it can be applied as a value in computations; for example, field notes may show plate readings for two-, four-, or

LEVEL CIRCUIT FROM B.M. 35 TO B.M. 19

Leveler EA2 M.T. Todd; Rodman EA3 C.L. Miller; B & B Dumpy Level 31057

Sta.	B.S. +	H.I.	F.S. −	Elev.	Sights B.S.	Sights F.S.	Remarks
							April 3, 1984 (3 hours) Cloudy, moderate.
B.M. 35	6.659	139.822		133.163	220		Concrete monument
⊙ 16	4.968	139.819	4.971	134.851	250	220	Peg
⊙ 17	4.508	136.875	7.452	132.367	310	250	"
⊙ 18	1.412	132.430	5.857	131.018	100	310	"
T.P. 1	7.073	138.242	1.261	131.169	190	100	Turning Point
B.M. 19			1.785	136.457		190	Concrete monument
	24.620		21.326	133.163	1070	1070	Actual elevation of ⊡ 19 = 136.442 ft.
			24.620	3.294		1070	Permissible error = 0.05 $\sqrt{2140/5280}$ = 0.032 ft
			3.294	Check		2140	Actual error of closure = 0.015 ft.

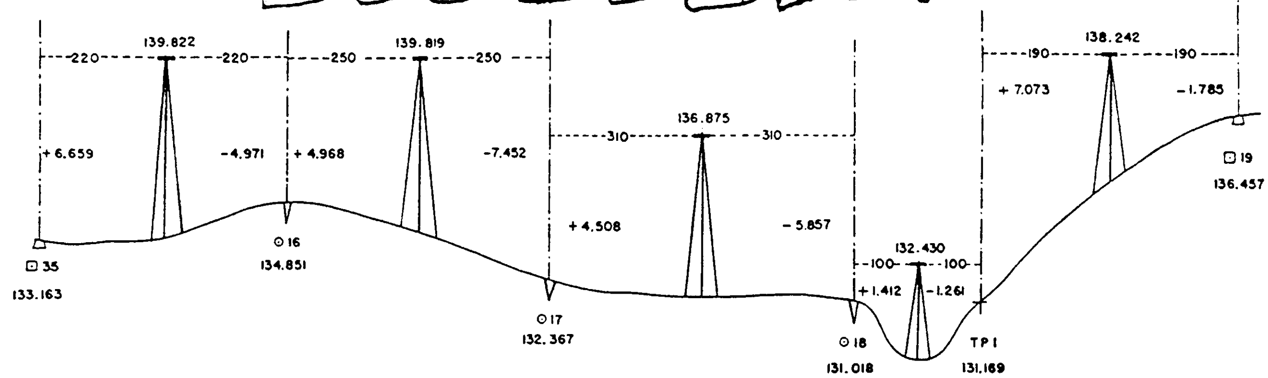


Figure 7-4.—Differential-level circuit and notes for differential leveling.

six-time angles. Each of these must be reduced to the mean angle, as explained in the EA3 TRAMAN. For another example: field notes may show a succession of chained slope distances. Unless the order of precision of the survey permits slope corrections to be ignored, each of these slope distances must be reduced to the corresponding horizontal distance.

In a closed traverse you must attain a ratio of linear error of closure and a ratio of angular error of closure that are within the maximums specified for, or implied from, the nature of the survey.

An error that is within the maximum allowable is eliminated by adjustment. "Adjustment" means the equal distribution of a sum total of allowable error over the separate values that contribute to the total. Suppose, for example, that for a triangular closed traverse with interior angles about equal in size, the sum of the measured interior angles comes to 179°57′. The angular error of closure is 03′. Because there are three interior angles about equal in size, 01′ would be added to the measured value of each angle.

LEVEL COMPUTATIONS

In making level computations, be sure to check the notes for a level run by verifying the beginning bench mark (BM); that is, by determining that the correct BM was used and its correct elevation was duly recorded.

Then check the arithmetical accuracy with which you added backlights and subtracted foresights. The difference between the sum of the foresights taken on BMs or turning points (TPs) and the sum of the backlights taken on BMs or TPs should equal the difference in elevation between the initial BM or TP and the final BM or TP. This fact is shown in figure 7-4.

You must remember that this checks the arithmetic only. It does not indicate anything about how accurately you made the vertical distance measurements.

Adjusting Intermediate Bench Mark Elevations

Level lines that begin and end on points that have fixed elevations, such as benchmarks, are often called level circuits. When leveling is accomplished between two previously established bench marks or over a loop that closes back on the starting point, the elevation determined for the final bench mark is seldom equal to its previously established elevation. The difference between these two elevations for the same bench mark is known as the **error of closure.** The REMARKS column of figure 7-4 indicates that the actual elevation of BM 19 is known to be

136.442 ft. The elevation found through differential leveling was 136.457 ft. The error of closure of the level circuit is 136.457 – 136.442 = 0.015 ft.

Assume that errors have occurred progressively along the line over which the leveling was accomplished. You make adjustments for these errors by distributing them proportionally along the line as shown by the following example. If you refer to figure 7-4, you will notice that the total distance between BM 35 and BM 19, over which the line of levels was run, is 2,140 ft. The elevation on the closing BM 19 is found to be 0.015 ft greater than its known elevation. You must therefore adjust the elevations found for the intermediate BMs 16, 17, and 18.

The amount of correction is calculated as follows:

$$\text{Correction} = \begin{matrix}\text{Error}\\ \text{of}\\ \text{Closure}\end{matrix} \times \frac{\text{distance between the starting and intermediate BM}}{\text{distance between the starting and closing BM}}$$

BM 16 is 440 ft from the starting BM. The total length distance between the starting and closing BMs is 2,140 ft. The error of closure is 0.015 ft. By substituting these values into the above formula, the correction is as follows:

$$\text{Correction} = 0.015 \times \frac{440}{2{,}140} = 0.003$$

Since the observed elevation of the closing BM is greater than its known elevation, the adjustments are subtracted from the intermediate BMs. Therefore, for BM 16, the adjusted elevation is 134.851 – 0.003 = 134.848. The adjustments for intermediate BMs 17 and 18 are made in a similar manner.

Calculating the Allowable Error

The error of closure that can be allowed depends on the precision required (first, second, or third order). The allowable error of closure in leveling is expressed in terms of a coefficient times the square root of the horizontal length of the actual route over which the leveling was accomplished

Most differential leveling (plane surveying) is third-order work. In third-order leveling, the closure is usually made on surveys of higher accuracy without doubling back to the benchmark at the original starting point of the level circuit. The length of the level circuit, therefore, is the actual distance leveled. For third-order leveling, the allowable error is

$$0.05\,ft\ \sqrt{\text{length of the level circuit in miles.}}$$

Refer again to figure 7-4. By adding the sight distances in the sixth and seventh columns of the figure, you will find that the length of the level circuit is 2,140 ft (or 0.405 miles). The allowable error of closure, then, is

$$0.05\,ft\ \sqrt{0.405} = 0.032\,ft.$$

Since the actual error is only 0.015 ft, the results are sufficiently accurate for third-order precision.

First- and second-order levels usually close on themselves; that is, the leveling party runs a line of levels from an old BM or station to the new BM or station, and then doubles back to the old BM for closure. The actual distance leveled is twice the length of the level circuit.

For second-order leveling, the allowable error is

$$0.035\,ft\ \sqrt{\text{length of the level circuit in miles.}}$$

First-order leveling is even more precise. The allowable error cannot be greater than

$$0.017\,ft\ \sqrt{\text{length of the level circuit in miles.}}$$

Adjusting Level Nets

When a level survey system covers a large area, you, in turn, adjust the interconnecting network in the whole system. Adjustment of an interconnecting network of level circuits consists of adjusting, in turn, each separate figure in the net, with the adjusted values for each circuit used in the adjustment of adjacent circuits. This process is repeated for as many cycles as necessary to balance the values for the whole net. Within each circuit the error of closure is normally distributed to the various sides in proportion to their lengths. Figure 7-5 represents a level net made up of circuits BCDEB, AEDA, and EABE.

Along each side of the circuit is shown the length of the side in miles and the observed difference in elevation in feet between terminal BMs. The difference in elevation (plus or minus) is in the direction indicated by the arrows. Within each circuit is shown its total length (L) and the error of closure (E_c) that is determined by summing up the differences in elevation in a clockwise direction. Figure 7-6 shows the computations required to balance the net. The circuits, sides, distances (expressed in miles and in percentages of the total), and differences in elevation (DE) are listed.

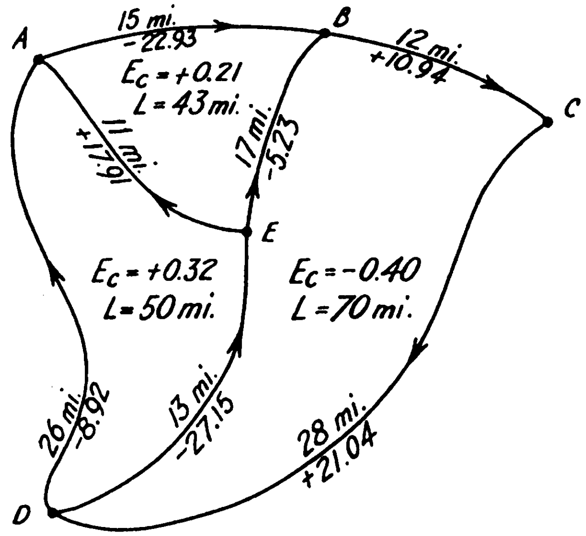


Figure 7-5.–Adjustmmt of level nets.

For circuit BCDEB, the error of closure is –0.40 ft. This is distributed among the lines in proportion to their lengths. Thus, for the line BC, the correction is

$$0.40 \times \frac{12}{70} = +0.07\,ft.$$

(Notice that the sign is opposite to that of the error of closure.) The correction of +0.07 ft is entered on the first line of the column headed CORR and is added to the difference in elevation (10.94 + 0.07 = +11.01). That sum is entered on the first line under the heading CORR DE (corrected difference in elevation). The same procedure is followed for the remaining lines CD, DE, and EB of circuit BCDEB.

The sum of the corrections must have the opposite sign and be equal to the error of closure. The algebraic sum of the corrected differences in elevation must equal zero. The lines in circuit AEDA are corrected in the same manner as BCDEB, except that the corrected value of ED (+27.08 instead of +27.15) is used. The lines of EABE are corrected using the corrected value of EA (+17.97 instead of +17.91) and BE (+5.13 instead of +5.23). In the column Cycle II, the procedure of Cycle I is repeated. You should always list the latest corrected value from previously adjusted circuits before computing the new error of closure. The cycles are continued until the corrections become zero. The sequence in which the circuits are taken is immaterial as long as they are repeated in the same order for each cycle. Computations may be based on corrections rather than differences in elevation.

TRAVERSE COMPUTATIONS

Traverse operations are conducted for mapping; for large construction projects, such as a military post or an

Circuit side	Distance		Cycle I			Cycle II			Cycle III			Cycle IV		
	Mi	%	DE	Corr	Corr DE	DE	Corr	Corr DE	DE	Corr	Corr DE	DE	Corr	Corr DE
BCDEB														
BC	12	17	+10.94	+0.07	+11.01	+11.01	−0.02	+10.99	+10.99	−0.01	+10.98	+10.98	0	+10.98
CD	28	40	+21.04	+0.16	+21.20	+21.20	−0.05	+21.15	+21.15	−0.01	+21.14	+21.14	−0.01	+21.13
DE	13	19	−27.15	+0.07	−27.08	−27.02	−0.03	−27.05	−27.03	−0.01	−27.04	−27.03	0	−27.03
EB	17	24	−5.23	+0.10	−5.13	−5.06	−0.03	−5.09	−5.07	−0.01	−5.08	−5.08	0	−5.08
Total	70	100	−0.40	+0.40	0	+0.13	−0.13	0	+0.04	−0.04	0	+0.01	−0.01	0
AEDA														
AE	11	22	−17.91	−0.06	−17.97	−17.93	−0.01	−17.94	−17.93	0	−17.93	−17.93	------	-------
ED	13	26	+27.08	−0.06	+27.02	+27.05	−0.02	+27.03	+27.04	−0.01	+27.03	+27.03	------	-------
DA	26	52	−8.92	−0.13	−9.05	−9.05	−0.04	−9.09	−9.09	−0.01	−9.10	−9.10	------	-------
Total	50	100	+0.25	−0.25	0	+0.07	−0.07	0	+0.02	−0.02	0	0	------	-------
EABE														
EA	11	26	+17.97	−0.04	+17.93	+17.94	−0.01	+17.93	+17.93	0	+17.93	+17.93	------	-------
AB	15	35	−22.93	−0.06	−22.99	−22.99	−0.01	−23.00	−23.00	−0.01	−23.01	−23.01	------	-------
BE	17	39	+5.13	−0.07	+5.06	+5.09	−0.02	+5.07	+5.08	0	+5.08	+5.08	------	-------
Total	43	100	+0.17	−0.17	0	+0.04	−0.04	0	+0.01	−0.01	0	0	------	-------

Figure 7-6.—Computations required to balance the level net.

air base; for road railroad, and pipeline alignment; for the control of hydrographic surveys; and for many other projects. A traverse is always classified as either a closed traverse or an open traverse. A closed traverse starts and ends at the same point or at points whose relative horizontal positions are known. An open traverse ends at the station whose relative position is not previously known and, unlike a closed traverse, provides no check against mistakes and large errors. In the EA3 TRAMAN, you studied field procedures for laying out traverses. In this chapter you will study computations that are necessary for adjusting and determining the areas of traverses.

Checking and Reducing Angles

Begin traverse computations by checking to make sure that all the required angles (including closing angles) were turned and that the notes correctly indicate their sizes. For deflection angles, check to make sure that angles marked *L* or *R* were actually turned and have been turned in those directions. Check your sketches and be sure they agree with your field notes. Next, you reduce repeated angles to mean angles using the procedures that you learned in the EA3 TRAMAN.

Checking and Reducing Distances

Check to make sure that all required linear distances have been chained. Reduce slope distances when needed. If you broke chain on the slopes, you check to make sure that the sums of break distances were correctly added.

Finally, you should apply standard error, tension, and temperature corrections if needed.

Adjusting Angles

From your study of the EA3 TRAMAN, you should recall the following three conditions for a closed traverse: (1) the theoretical or geometrical sum of the interior angles is 180° x $(n - 2)$, n being the number of angles measured; (2) the sum of the exterior angles is 180° x $(n + 2)$, where n = number of angles measured; and (3) the difference between the sum of the right deflection angles and the sum of the left deflection angles is 360°. Any discrepancy between one of these sums and the actual sum of the angles as turned or measured constitutes the **angular error of closure.**

You adjust the angles in a closed traverse by distributing an angular error of closure that is within the allowable maximum equally among the angles.

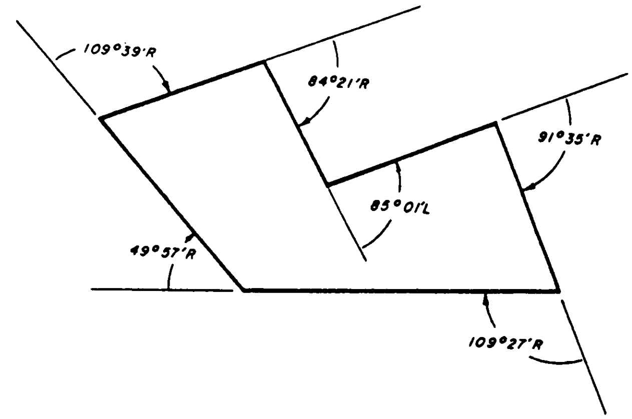


Figure 7-7.—Closed traverse by deflection-angle method.

Figure 7-7 shows a traverse in which one of the deflection angles was turned to the lefft, all others to the right. The sum of the right deflection angles is 444°59'. Then, by subtracting the left deflection angle (85°01'), you find that the angular error of closure is 02', which is an average of 20" per deflection angle. This average angular error of closure is then **added** to each right deflection angle and **subtracted** from each left deflection angle. After applying this adjustment to each deflection angle in this example, you find, then, that the sum of the adjusted angles to the right equals 445°00'40" and that the sum of the left angles (of which there is only one) is 85°00'40". The difference between these values is 360°00'00", as it should be.

Remember that in adjusting the angles in a deflection-angle traverse, you apply the adjustments to right and left angles in opposite direction.

Adjusting for Linear Error of Closure

The procedure for distributing a linear error of closure (one within the allowable maximum, of course) over the directions and distances in a closed traverse is called balancing or closing the traverse. Before you can understand how to do this, you must have a knowledge of latitude and departure.

LATITUDE AND DEPARTURE.— Latitude and **departure** are values that are employed in the method of locating a point horizontally by its plane coordinates. In the plane coordinate system, a point of origin is arbitrarily y selected for convenience. The location of a point is given in terms of its distance north or south and its distance east or west of the point of origin. The plane coordinate system will be explained later in this chapter.

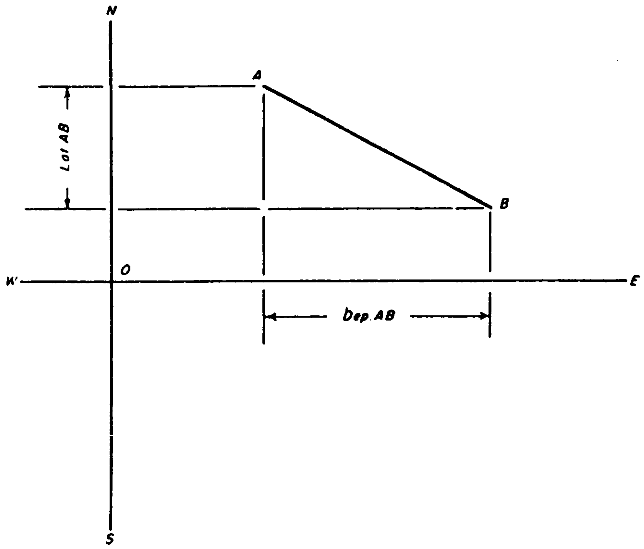


Figure 7-8.—Latitude and departure.

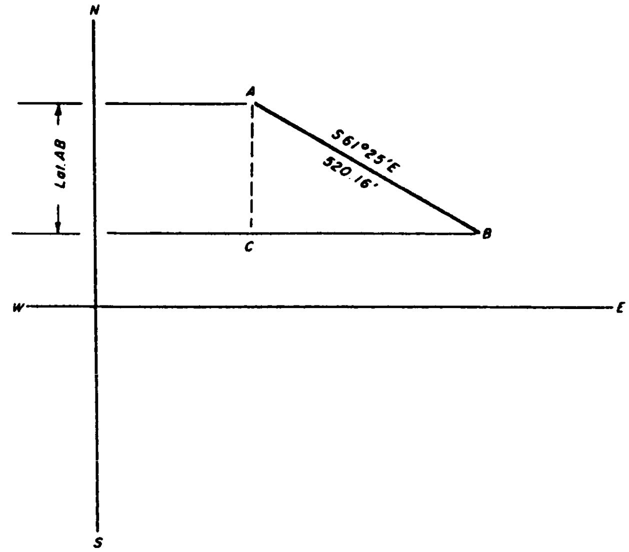


Figure 7-9.—Latitude equals length of traverse line times twine of angle of bearing.

The latitude of a traverse line means the length of the line as projected on the north-to-south meridian running through the point of origin. The departure of a traverse line means the length of the line as projected on the east-to-west parallel running through the point of origin. To understand this, you should examine figure 7-8. The point of origin is at *O*. The line *NS* is the meridian through the point of origin; the line *EW* is the parallel through the point of origin. The latitude of *AB* is the length of *AB* as projected on *NS;* the departure of *AB* is the length of *AB* as projected on *EW*. You can see that for a traverse line running due north and south, the latitude would equal the length of the line and the departure would be zero. For a line running due east and west the departure would equal the length of the line and the latitude would be zero.

Now, for a line running other than north to south or east to west, you can determine the latitude or departure by simple triangle solution. Figure 7-9 shows a traverse line 520.16 feet long bearing S61°25'E. To determine the latitude, you solve the triangle ABC for the length of the side AC. From the bearing, you know that the size of angle CAB (the angle of bearing) is 61°25'. The triangle is a right triangle; therefore

$$AC = 520.16 \cos 61°25' = 248.86\, ft.$$

The latitude of a traverse line, then, equals the product of the length of the line times the **cosine** of the angle of bearing.

To determine the departure, you solve the triangle for the length of the side *CB* shown in figure 7-10.

$$CB = 520.16 \sin 61°25' = 456.76\, ft.$$

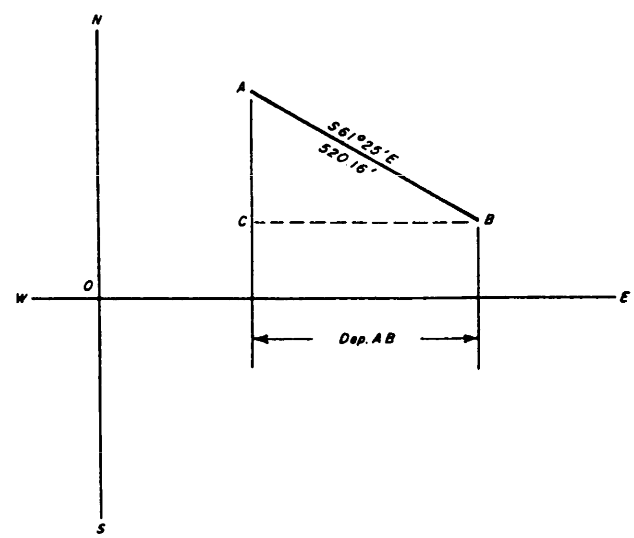


Figure 7-10.—Departure equals length of traverse line times sine of angle of bearing.

The departure of a traverse line, then, equals the length of the line times the sine of the angle of bearing.

The latitude of a traverse line is designated north or south and the departure is designated east or west following the compass direction of the bearing of the line. A line bearing northeast, for example, has a north latitude and east departure. In computations, north latitudes are designated plus and south latitudes minus; east departures are designated plus and west departures minus.

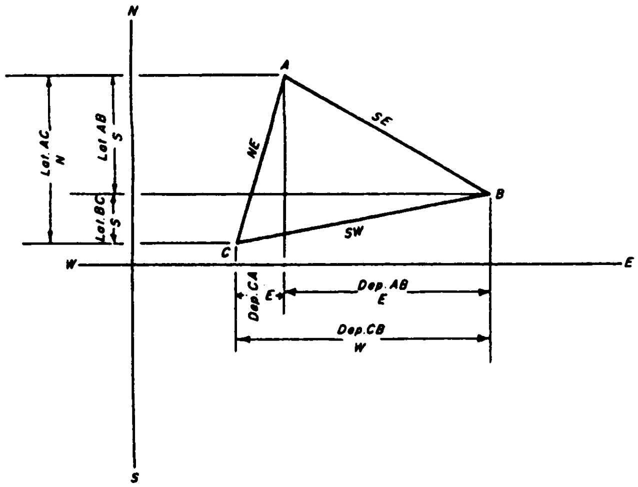


Figure 7-11.—Graphic solution of a closed traverse by latitude and departure.

Figure 7-11 is a graphic demonstration of the fact that, in a closed traverse, the algebraic sum of the plus and minus latitudes is zero; and the algebraic sum of the plus and minus departures is zero. The plus latitude of CA is equal in length to the sum of the two minus latitudes of AB and BC; the minus departure of BC is equal in length to the sum of the two plus departures of CA and AB.

LINEAR ERROR OF CLOSURE.— In practice, as you will learn, the sum of the north latitudes usually differs from the sum of the south latitudes. The difference is called the error of closure in latitude. Similarly, the sum of the east departures usually differs from the sum of the west departures. The difference is called error of closure in departure.

From the error of closure in latitude and the error of closure in departure, you can determine the linear error of closure. This is the horizontal linear distance between the location of the end of the last traverse line (as computed from the measured angles and distances) and the actual point of beginning of the closed traverse.

For example, you come up with an error of closure in latitude of 5.23 feet and an error of closure in departure of 3.18 feet. These two linear intervals form the sides of a right triangle. The length of the hypotenuse of this triangle constitutes the linear error of closure in the traverse. By the Pythagorean theorem, the length of the hypotenuse equals approximately 6.12 feet. Suppose the total length of the traverse was 12,000.00 feet. Then your ratio of linear error of closure would be 6.12:12,000.00, which approximately equates to 1:2,000.

CLOSING A TRAVERSE.— You **close** or **balance** a traverse by distributing the linear error of closure (one within the allowable maximum, of course) over the traverse. There are several methods of doing this, but the one most generally applied is based on the so-called **compass rule.** By this rule you adjust the latitude and departure of each traverse line as follows:

1. Correction in latitude equals the linear error of closure in latitude times the length of the traverse line divided by the total length of traverse.

2. Correction in departure equals the linear error of closure in departure times the length of the traverse line divided by the total length of traverse.

Figure 7-12 shows a closed traverse with bearings and distances notes. Figure 7-13 shows the computation of the latitudes and departures for this traverse entered on the type of form that is commonly used for this purpose. As you can see, the error in latitude is +0.33 foot, and the error in departure is +2.24 feet. The linear error of closure, then, is

$$\sqrt{(0.33^2 + 2.24^2)} = 2.26 ft.$$

The total length of the traverse is 2614.85 feet; therefore, the ratio of error of closure is 2.26:2614.85, or about 1:1157.

We will assume that this ratio is within the allowable maximum. Proceed now to adjust the latitudes and departures by the compass rule. Set down the latitudes and departures on a form like the one shown in figure 7-14 with the error of closure in latitude at the foot of the latitudes column and the error of closure in departure at the foot of the departures column.

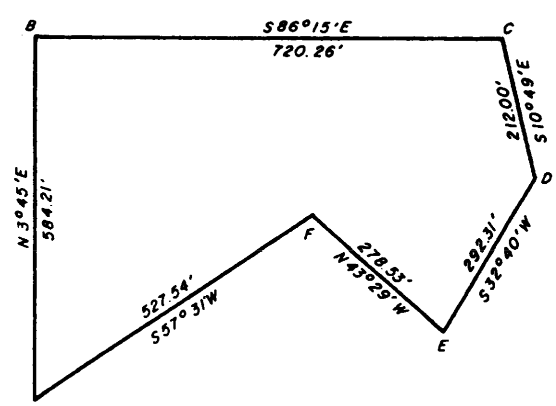


Figure 7-12.—Closed traverse by bearings and distances.

COMP. BY EAY DATE 11 OCT.

STATION	BEARING	DISTANCE	FUNCTION COSINE	FUNCTION SINE	LATITUDE NORTH	LATITUDE SOUTH	DEPARTURE EAST	DEPARTURE WEST
A								
	N 3° 45′ E	584.21	.99786	.06540	582.95		38.20	
B								
	S 86° 15′ E	720.26	.06540	.99786		47.10	718.72	
C								
	S 10° 49′ E	212.00	.98223	.18767		208.23	39.77	
D								
	S 32° 40′ W	292.31	.84182	.53975		246.07		157.77
E								
	N 43° 29′ W	278.53	.72557	.68814	202.09			191.67
F								
	S 57° 31′ W	527.54	.53705	.84335		283.31		445.01
A								
	TOTAL	2614.85		TOTALS	785.04	784.71	796.69	794.45
					−784.71	−	794.45	
					+ .33		2.24	

Figure 7-13.—Form for computing latitudes and departures.

LINE	LATITUDE	DEPARTURE	LAT. CORRECTION	DEP. CORRECTION	ADJ. LATITUDE	ADJ. DEPARTURE
AB	+582.95	+ 38.20	−0.07	−0.50	+582.88	+ 37.70
BC	− 47.10	+718.72	−0.09	−0.62	− 47.19	+718.10
CD	−208.23	+ 39.77	−0.03	−0.18	−208.26	+ 39.59
DE	−246.07	−157.77	−0.04	−0.25	−246.11	−158.02
EF	+202.09	−191.67	−0.03	−0.24	+202.06	−191.91
FA	−283.31	−445.01	−0.07	−0.45	−283.38	−445.46
	+0.33	+2.24	−0.33	−2.24	0.00	0.00

Figure 7-14.—Form for adjusting latitudes and departures.

Next, you use the compass rule to determine the latitude correction and departure correction for each line. For All, the latitude correction equals

$$0.33 \times \frac{584.21}{2614.85} = 0.07\,ft.$$

The error of closure in latitude is plus; therefore, the correction is minus.

Note that the sum of the applied latitude corrections equals the error of closure in latitude and the sum of the applied departure corrections equals the error of closure

Distance.	15°. Lat.	15°. Dep.	15¼°. Lat.	15¼°. Dep.	15½°. Lat.	15½°. Dep.	15¾°. Lat.	15¾°. Dep.	Distance.
1	0.97	0.26	0.96	0.26	0.96	0.27	0.96	0.27	1
2	1.93	0.52	1.93	0.53	1.93	0.53	1.92	0.54	2
3	2.90	0.78	2.89	0.79	2.89	0.80	2.89	0.81	3
4	3.86	1.04	3.86	1.05	3.85	1.07	3.85	1.09	4
5	4.83	1.29	4.82	1.32	4.82	1.34	4.81	1.36	5
6	5.80	1.55	5.79	1.58	5.78	1.60	5.77	1.63	6
7	6.76	1.81	6.75	1.84	6.75	1.87	6.74	1.90	7
8	7.73	2.07	7.72	2.10	7.71	2.14	7.70	2.17	8
9	8.69	2.33	8.68	2.37	8.67	2.41	8.66	2.44	9
10	9.66	2.59	9.65	2.63	9.64	2.67	9.62	2.71	10
11	10.63	2.85	10.61	2.89	10.60	2.94	10.59	2.99	11
12	11.59	3.11	11.58	3.16	11.56	3.21	11.55	3.26	12
13	12.56	3.36	12.54	3.42	12.53	3.47	12.51	3.53	13
14	13.52	3.62	13.51	3.68	13.49	3.74	13.47	3.80	14
15	14.49	3.88	14.47	3.95	14.45	4.01	14.44	4.07	15
16	15.45	4.14	15.44	4.21	15.42	4.28	15.40	4.34	16
17	16.42	4.40	16.40	4.47	16.38	4.54	16.36	4.61	17
18	17.39	4.66	17.37	4.73	17.35	4.81	17.32	4.89	18
19	18.35	4.92	18.33	5.00	18.31	5.08	18.29	5.16	19
20	19.32	5.18	19.30	5.26	19.27	5.34	19.25	5.43	20
21	20.28	5.44	20.26	5.52	20.24	5.61	20.21	5.70	21
22	21.25	5.69	21.23	5.79	21.20	5.88	21.17	5.97	22
23	22.22	5.95	22.19	6.05	22.16	6.15	22.14	6.24	23
24	23.18	6.21	23.15	6.31	23.13	6.41	23.10	6.51	24
25	24.15	6.47	24.12	6.58	24.09	6.68	24.06	6.79	25
26	25.11	6.73	25.08	6.84	25.05	6.95	25.02	7.06	26
27	26.08	6.99	26.05	7.10	26.02	7.22	25.99	7.33	27
28	27.05	7.25	27.01	7.36	26.98	7.48	26.95	7.60	28
29	28.01	7.51	27.98	7.63	27.95	7.75	27.91	7.87	29
30	28.98	7.76	28.94	7.89	28.91	8.02	28.87	8.14	30
31	29.94	8.02	29.91	8.15	29.87	8.28	29.84	8.41	31
32	30.91	8.28	30.87	8.42	30.84	8.55	30.80	8.69	32
33	31.88	8.54	31.84	8.68	31.80	8.82	31.76	8.96	33
34	32.84	8.80	32.80	8.94	32.76	9.09	32.72	9.23	34
35	33.81	9.06	33.77	9.21	33.73	9.35	33.69	9.50	35
36	34.77	9.32	34.73	9.47	34.69	9.62	34.65	9.77	36
37	35.74	9.58	35.70	9.73	35.65	9.89	35.61	10.04	37
38	36.71	9.84	36.66	10.00	36.62	10.16	36.57	10.31	38
39	37.67	10.09	37.63	10.26	37.58	10.42	37.54	10.59	39
40	38.64	10.35	38.59	10.52	38.55	10.69	38.50	10.86	40
41	39.60	10.61	39.56	10.78	39.51	10.96	39.46	11.13	41
42	40.57	10.87	40.52	11.05	40.47	11.22	40.42	11.40	42
43	41.53	11.13	41.49	11.31	41.44	11.49	41.39	11.67	43
44	42.50	11.39	42.45	11.57	42.40	11.76	42.35	11.94	44
45	43.47	11.65	43.42	11.84	43.36	12.03	43.31	12.21	45
46	44.43	11.91	44.38	12.10	44.33	12.29	44.27	12.49	46
47	45.40	12.16	45.35	12.36	45.29	12.56	45.24	12.76	47
48	46.36	12.42	46.31	12.63	46.25	12.83	46.20	13.03	48
49	47.33	12.68	47.27	12.89	47.22	13.09	47.16	13.30	49
50	48.30	12.94	48.24	13.15	48.18	13.36	48.12	13.57	50
Distance.	75°. Dep.	75°. Lat.	74¾°. Dep.	74¾°. Lat.	74½°. Dep.	74½°. Lat.	74¼°. Dep.	74¼°. Lat.	Distance.

Distance.	15°. Lat.	15°. Dep.	15¼°. Lat.	15¼°. Dep.	15½°. Lat.	15½°. Dep.	15¾°. Lat.	15¾°. Dep.	Distance.
51	49.26	13.20	49.20	13.41	49.15	13.63	49.09	13.84	51
52	50.23	13.46	50.17	13.68	50.11	13.90	50.05	14.11	52
53	51.19	13.72	51.13	13.94	51.07	14.16	51.01	14.39	53
54	52.16	13.98	52.10	14.20	52.04	14.43	51.97	14.66	54
55	53.13	14.24	53.06	14.47	53.00	14.70	52.94	14.93	55
56	54.09	14.49	54.03	14.73	53.96	14.97	53.90	15.20	56
57	55.06	14.75	54.99	14.99	54.93	15.23	54.86	15.47	57
58	56.02	15.01	55.96	15.26	55.89	15.50	55.82	15.74	58
59	56.99	15.27	56.92	15.52	56.85	15.77	56.78	16.01	59
60	57.96	15.53	57.89	15.78	57.82	16.03	57.75	16.29	60
61	58.92	15.79	58.85	16.04	58.78	16.30	58.71	16.56	61
62	59.89	16.05	59.82	16.31	59.75	16.57	59.67	16.83	62
63	60.85	16.31	60.78	16.57	60.71	16.84	60.63	17.10	63
64	61.82	16.56	61.75	16.83	61.67	17.10	61.00	17.37	64
65	62.79	16.82	62.71	17.10	62.64	17.37	62.56	17.64	65
66	63.75	17.08	63.68	17.36	63.60	17.64	63.52	17.92	66
67	64.72	17.34	64.64	17.62	64.56	17.90	64.48	18.19	67
68	65.68	17.60	65.61	17.89	65.53	18.17	65.45	18.46	68
69	66.65	17.86	66.57	18.15	66.49	18.44	66.41	18.73	69
70	67.61	18.12	67.54	18.41	67.45	18.71	67.37	19.00	70
71	68.58	18.38	68.50	18.68	68.42	18.97	68.33	19.27	71
72	69.55	18.63	69.46	18.94	69.38	19.24	69.30	19.54	72
73	70.51	18.89	70.43	19.20	70.35	19.51	70.26	19.82	73
74	71.48	19.15	71.39	19.46	71.31	19.78	71.22	20.09	74
75	72.44	19.41	72.36	19.73	72.27	20.04	72.18	20.36	75
76	73.41	19.67	73.32	19.99	73.24	20.31	73.15	20.63	76
77	74.38	19.93	74.29	20.25	74.20	20.58	74.11	20.90	77
78	75.34	20.19	75.25	20.52	75.16	20.84	75.07	21.17	78
79	76.31	20.45	76.22	20.78	76.13	21.11	76.03	21.44	79
80	77.27	20.71	77.18	21.04	77.09	21.38	77.00	21.72	80
81	78.24	20.96	78.15	21.31	78.05	21.65	77.96	21.99	81
82	79.21	21.22	79.11	21.57	79.02	21.91	78.92	22.26	82
83	80.17	21.48	80.08	21.83	79.98	22.18	79.88	22.53	83
84	81.14	21.74	81.04	22.09	80.94	22.45	80.85	22.80	84
85	82.10	22.00	82.01	22.36	81.91	22.72	81.81	23.07	85
86	83.07	22.26	82.97	22.62	82.87	22.98	82.77	23.34	86
87	84.04	22.52	83.94	22.88	83.84	23.25	83.73	23.62	87
88	85.00	22.78	84.90	23.15	84.80	23.52	84.70	23.89	88
89	85.97	23.03	85.87	23.41	85.76	23.78	85.66	24.16	89
90	86.93	23.29	86.83	23.67	86.73	24.05	86.62	24.43	90
91	87.90	23.55	87.80	23.94	87.69	24.32	87.58	24.70	91
92	88.87	23.81	88.76	24.20	88.65	24.59	88.55	24.97	92
93	89.83	24.07	89.73	24.46	89.62	24.85	89.51	25.24	93
94	90.80	24.33	90.69	24.72	90.58	25.12	90.47	25.52	94
95	91.76	24.59	91.65	24.99	91.54	25.39	91.43	25.79	95
96	92.73	24.85	92.62	25.25	92.51	25.65	92.40	26.06	96
97	93.69	25.11	93.58	25.51	93.47	25.92	93.36	26.33	97
98	94.66	25.36	94.55	25.78	94.44	26.19	94.32	26.60	98
99	95.63	25.62	95.51	26.04	95.40	26.46	95.28	26.87	99
100	96.59	25.88	96.48	26.30	96.36	26.72	96.25	27.14	100
Distance.	75°. Dep.	75°. Lat.	74¾°. Dep.	74¾°. Lat.	74½°. Dep.	74½°. Lat.	74¼°. Dep.	74¼°. Lat.	Distance.

Figure 7-15.—Sample pages from traverse table.

in departure. The corrections, however, are opposite in sign to the error of closure.

Traverse Tables/Adjusting Bearings and Distances

In computing latitudes and departures, your arithmetical calculations can be greatly expedited by the use of a traverse table, in which latitudes and departures for any bearing and distance can be determined mostly by looking for them in the table.

Figure 7-15 shows sample pages from a table that gives angle-of-bearing values to the nearest quarter-degree (15'). More precise tables give angular values to the nearest 01'.

Under each of the bearing values at the head of the page, a double column gives latitudes and departures for distances of from 1 to 100 feet. For a particular traverse line, you determine the latitudes and departures by breaking down the distance, moving decimal points, and adding up results as in the following example:

Suppose you want to determine the latitude and departure for a traverse line 725.32 feet long, bearing N15°30'E. To get the latitude, do it as follows. In the latitude column under 15 1/2°, lookup the latitude for 70 feet. You read 67.45 feet. If the latitude for 70 feet is 67.45 feet, the latitude for 700 feet is 674.50 feet. Note this in your notes.

Next, you look up the latitude for 25 feet under the same 15 1/2° latitude column, which is 24.09 feet. The latitude for 725 feet, then, is 674.50+ 24.09= 698.59 feet.

Finally, for the 0.32 foot, look up the latitude for 32 feet, which is 30.84 feet. If the latitude for 32 feet is 30.84 feet, the latitude for 0.32 foot must be 0.3084 fret, which rounds off at 0.31 foot. The numerical value of the latitude then is 698.59 + 0.31 = 698.90 feet. Because the line *AB* bears northeast, the latitude is positive.

You get the departure in the same way by using the departure column.

Finally, you enter the adjusted latitudes and adjusted departures in the last two columns. Determine the values in each case by applying the correction to the original latitude or departure. Note that the negative latitudes now equal the positive latitudes and the negative departures equal the positive departures. This indicates that the errors of closure have been entirely distributed.

With the adjusted latitudes and departures, you can now adjust the original bearings and distances by the method called **inversing.** Inversing simply means computing the bearing and length of a traverse line from the latitude and departure. Again the process is one of simple triangle solution. Figure 7-16 shows traverse line AB with the adjusted latitude and departure noted. To determine the adjusted angle of bearing, you solve the triangle *AA'B* for angle *A'AB* as follows:

$$\tan A'AB = \frac{37.70}{583.88} = 0.06468$$

$$A'AB - 3°42'$$

The adjusted bearing of *AB,* then, is N3°42'E. For the adjusted distance, solve the triangle for AB as follows:

The adjusted length of AB, then, is 584.22 feet.

$$AB = \frac{37.70}{\sin 3°42'} = \frac{37.70}{0.06453} = 584.22\,feet$$

Plane Coordinates

The location of a point by **plane coordinates** means to describe the location of the point in terms of its distance north or south and east or west from a point of origin.

Figure 7-17 shows how coordinate distances are measured on an axis (called the Y axis) running north to south through the point of origin. East to west coordinates are measured on an X axis running east to west through the point of origin. Values on the Y axis north of the point of origin are plus; values south of the point of origin are minus. Values on the X axis east of the point of origin are plus; values west of the point of origin are minus.

PLANE COORDINATES FROM LATITUDE AND DEPARTURE.— Figure 7-17 also shows the relationship between the plane coordinates of the end stations on a traverse line and the latitude and departure of the line. You can see that the difference between the *Y* coordinate of *A* and the *Y* coordinate of *B* (which is 200.00 feet) equals the latitude of *AB*. Also, you can see that the difference between the X coordinate of *A* and the *X* coordinate of *B* (which is 600.00 feet) equals the departure of *AB*. Therefore, if you know the coordinates of one of the stations in a traverse, you can determine the coordinates of the others from the latitudes and

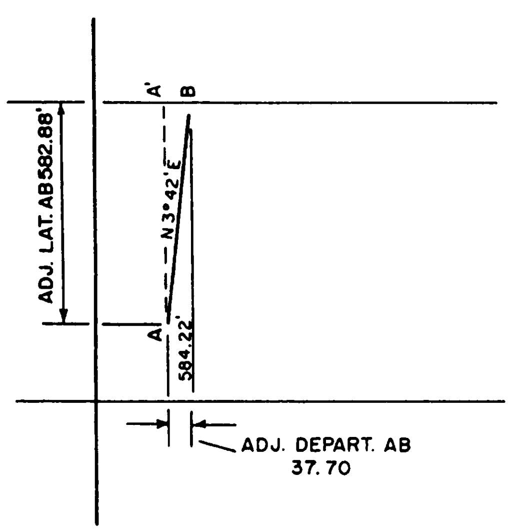


Figure 7-16.—Adjusted bearing and distance from adjusted latitude and departure.

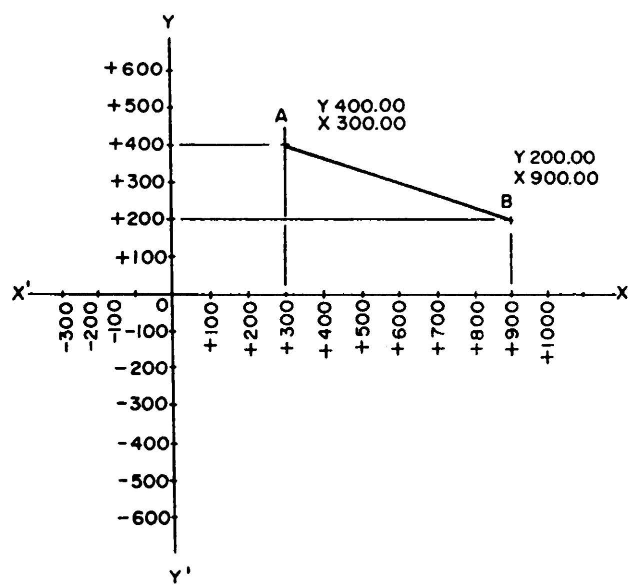


Figure 7-17.—Location by plane coordinates.

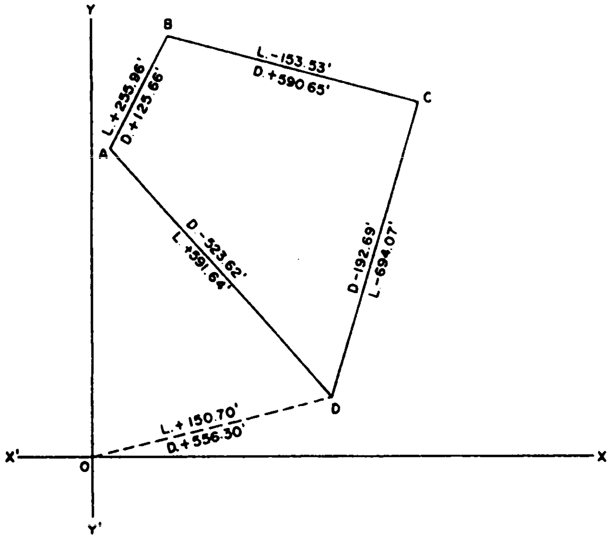


Figure 7-18.—Closed traverse with adjusted latitudes and departures.

departures. Figure 7-18 shows a closed traverse with adjusted latitudes and departures notes. You want to assign plane coordinates to the traverse stations. To avoid the necessity of working with negative coordinates, you select as point of origin a point *O* that is west of the most westerly traverse station and south of the most southerly traverse station.

You determine the bearing and length of dotted line *OD* and compute from these values the latitude and departure of *OD*. You can see that the *Y* coordinate of station *D* must equal the latitude of *OD,* or 150.70 feet Also the *X* coordinate of *D* must equal the departure of *OD* or 556.30 feet.

The *Y* coordinate of station *A* equals the *Y* coordinate of *D* plus the latitude of *AD* or

150.70 + 591.64 = 742.34 *ft.*

The *X* coordinate of station *A* equals the *X* coordinate of *D* minus the departure of *AD* or

556.30 – 523.62 = 32.68 *ft.*

The *Y* coordinate of station *B* equals the *Y* coordinate of station *A* plus the latitude of *AB* or

742.34 + 255.96 = 998.30 *ft.*

The *X* coordinate of station *B* equals the *X* coordinate of station *A* plus the departure of *AB* or

32.68 + 125.66 = 158.34 *ft.*

The *Y* coordinate of station *C* equals the *Y* coordinate of station *B* minus the latitude of *C* or

998.30 – 153.53 = 844.77 *ft.*

The *X* coordinate of station *C* equals the *X* coordinate of station *B* plus the departure of *BC* or

158.34 + 590.65 = 748.99 *ft.*

The *Y* coordinate of station *D* equals the *Y* coordinate of station C minus the latitude of *CD* or

844.77 – 694.07 = 150.70 *ft.*

The *X* coordinate of station *D* equals the *X* coordinate of station *C* minus the departure of *CD* or

748.99 – 192.69 = 556.30 *ft.*

These are the same coordinates you originally computed for station *D,* a fact that serves as a check on your accuracy.

You enter these values on a form that is similar to the one shown in figure 7-19. In actual practice, however, you will use a wider form on which all values and computations from the original station through bearing and distance, latitude and departure, and coordinates can be entered.

LATITUDE AND DEPARTURE FROM PLANE COORDINATES.— The numerical values of latitude and departure of a traverse line are easily computed from the coordinates of the end stations of the line. For traverse line *AB,* for example, the numerical value of latitude equals the difference between the *Y* coordinate of *A* and the *Y* coordinate of *B,* while the numerical value of departure equals the difference between the *X* coordinate of *A* and the *X* coordinate of *B.*

To determine whether a latitude or departure computed this way is positive or negative, the best method is to examine a sketch of the traverse to determine the compass direction of the bearing of the line in question. If the line bears northeast, the latitude is positive, or north, and the departure is positive, or east. If the line bears southwest, both latitude and departure are negative.

Computing Areas

Various methods are used in computing areas. Some of the common methods with which the EA should be familiar are discussed below.

STATION	LATITUDE		DEPARTURE		COORDINATES	
	NORTH	SOUTH	EAST	WEST	Y	X
A					742.34	32.68
	255.96		125.66			
B					998.30	158.34
		153.53	590.65			
C					844.77	748.99
		694.07		192.69		
D					150.70	556.30
	591.64			523.62		

Figure 7-19.—Form for computing coordinates

AREA BY DOUBLE MERIDIAN DISTANCE.— The **meridian distance** of a traverse line is equal to the length of a line running east to west from the midpoint of the traverse line to a reference meridian. The reference meridian is the meridian that passes through the most **westerly** traverse station.

In figure 7-20, the dotted lines indicate the meridian distances of the traverse lines to which they extend from the reference meridians. You can see that the meridian distance of the initial line *AB* equals one half of the departure of *AB*. The meridian distance of the next line *BC* equals the meridian distance of *AB*, plus one half of the departure of *AB*, plus one half of the departure of *BC*.

You can also see that the meridian distance of *CD* equals the meridian distance of *BC*, plus one half of the departure of *BC*, **minus** one half of the departure of *DC*. Similarly, the meridian distance of *AD* equals the meridian distance of *DC*, **minus** one half of the departure of *DC*, **minus** one half of the departure of *AD*.

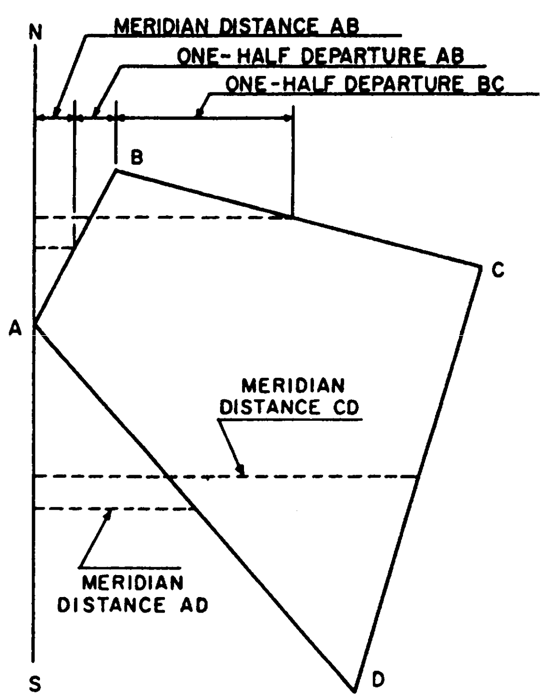


Figure 7-20.—Meridian distances.

You should now be able to understand the basis for the following rules for determining meridian distance:

1. For the initial traverse line in a closed traverse, the meridian distance equals one half of the departure.

2. For each subsequent traverse line, the meridian distance equals the meridian distance of the preceding line, plus one half of the departure of the preceding line, plus one half of the departure of the line itself. However, it is the **algebraic** sum that results—meaning that plus departures are added but minus departures are subtracted.

COURSE	LATITUDE +	LATITUDE −	DEPARTURE +	DEPARTURE −	DMD	DOUBLE AREA +	DOUBLE AREA −
AB	+255.96		+125.66		+125.66	+32163.93	
BC		−153.53	+590.65		+841.97		−129267.65
CD		−694.07		−192.69	+1239.93		−860598.21
DA	+591.64			−523.62	+523.62	+30979454	
						341958.47	989865.86
							341958.47
						2	647907.39
							323953.69
			AREA = 323,953.69 SQ. FT. = 7.44 ACRES				

Figure7-21.—Area from double meridian distances.

For convenience, it is customary to use **double meridian distance** (DMD) rather than meridian distance in calculations. When the meridian distance of the initial traverse line in a closed traverse equals one half of the departure of the line, the DMD of this line equals its departure. Again, from the rule for meridian distance of the next line, the DMD of that line equals the DMD of the preceding line, plus the departure of the preceding line, plus the departure of the line itself.

It can be shown geometrically that the area contained within a straight-sided closed traverse equals the sum of the areas obtained by multiplying the meridian distance of each traverse line by the latitude of that line. Again the result is the algebraic sum. If you multiply a positive meridian distance (when the reference meridian runs through the most westerly station, all meridian distances are positive) by a plus or north latitude, you get a plus result that you add. If you multiply a positive meridian distance by a minus or south latitude, however, you get a minus result that you subtract.

Therefore, if you multiply for each traverse line the double meridian distance by latitude instead of meridian distance by latitude, the sum of the results will equal twice the area, or the double area. To get the area, you simply divide the double area by 2.

Figure 7-21 shows entries for the computations of the DMD of the area of the traverse we have been working on. Because *AB* is the initial traverse line, the DMD of *AB* equals the departure. The DMD of *BC* equals the DMD of *AB* (125.66), plus the departure of AB (125.66), plus the departure of *BC* (590.65), or 841.97 feet. The DMD of *CD* equals the DMD of *BC* (841.97), plus the departure of *BC* (590.65), plus the departure of *CD* (which is **minus** 192.69, and therefore is subtracted), or 1239.93 feet. The DMD of *DA* equals the DMD of *CD* (1239.93), plus the departure of CD (–192.69), plus the departure of DA (–523.62), or 523.62 feet. Note that the DMD of this last traverse line equals the departure of the line, but with an opposite sign. This fact serves as a check on the computations.

The double area for *AB* equals the DMD times the latitude or

125.66 x 255.96 = 32,163 .93square feet.

The double area for *BC* equals 841.97 (the DMD) times **minus** 153.53 (the latitude), or **minus** 129,267.65 square feet. The double area of *CD* is

1,239.93 x (-694.07) = –860,598.21 *square feet.*

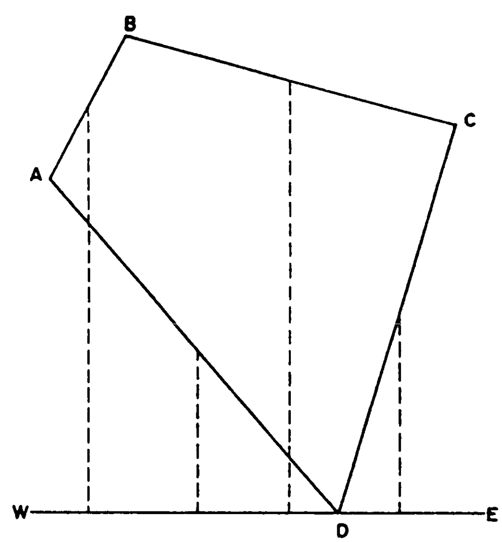


Figure 7-22.—Parallel distances.

COURSE	LATITUDE +	LATITUDE −	DEPARTURE +	DEPARTURE −	DPD	DOUBLE AREA +	DOUBLE AREA −
DA	+591.64			-523.62	+591.64		-309794.54
AB	+255.96		+125.66		+1439.24	+180854.90	
BC		-153.53	+590.65		+1541.67	+910587.38	
CD		-694.07		-192.69	+694.07		-133740.35
						+1091442.28	-443534.89
						-443534.89	
					2)	647907.39	
						323953.69	
			AREA = 323,	953.69 SQ.	FT. = 7.44	ACRES	

Figure 7-23.—Area from double parallel distances.

The double area of *DA* is

523.62 x 591.64 = 309,794.54 *square feet.*

The difference between the sum of the minus double areas and the sum of the plus double areas is the double area which is 647,907.39 square feet. The area is one half of this, or 323,953.69 square feet. Land area is generally expressed in acres. There are 43,560 square feet in 1 acre; therefore, the area in acres is

$$\frac{323953.69}{43560} = 7.44\ A.$$

AREA BY DOUBLE PARALLEL DISTANCE.— You can check the accuracy of the area computation of a DMD by computing the same area from **double parallel distances** (DPD).

As shown in figure 7-22, the parallel distance of a traverse line is the north-to-south distance from the midpoint of the line to a reference parallel. The reference parallel is the parallel passing through the most **southerly** traverse station.

You can see that the solution for parallel distance is the same as the one used for meridian distance, except that to compute parallel distance you use latitude instead of departure. The parallel distance of the initial traverse line (which is *DA* in this case) equals one half of the latitude. The parallel distance of the next line, *AB,* equals the parallel distance of the preceding line, *DA,* plus one half of the latitude of the preceding line *DA,* plus one half of the latitude of line *AB* itself.

It follows from the above that the DPD of the initial traverse line *DA* equals the latitude of the line. The DPD of the next line, *AB,* equals the DPD of the preceding line, *DA,* plus the latitude of the preceding line, *DA,* plus the latitude of the line *AB* itself. The solution for area is the same as for area by meridian distance except that, for the double area of each traverse line, you multiply the DPD by the departure instead of multiplying the DMD by the latitude.

Figure 7-23 shows entries for the computation of the area of DPD for the traverse we are working on. Note that the result is identical with that obtained by the computation of the DMD.

AREA FROM COORDINATES.— Before we explain the method of computing area from coordinates, let us set coordinates for the stations of the traverse we are working on. To avoid using negative coordinates, we will measure *Y* coordinates from an *X* axis passing through the most southerly station and *X* coordinates from a *Y* axis passing through the most westerly station, as shown in figure 7-24.

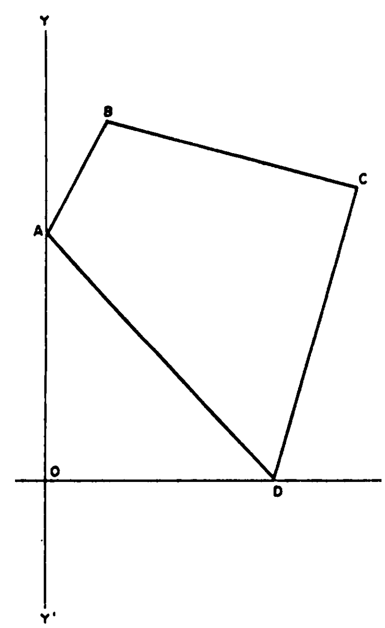


Figure 7-24.—Computations of a closed traverse by coordinate method.

STATION	LATITUDE +	LATITUDE −	DEPARTURE +	DEPARTURE −	COORDINATES Y	COORDINATES X
A					591.64	0
	+255.96		+125.66			
B					847.60	125.66
		−153.53	+590.65			
C					694.07	716.31
		−694.07		−192.69		
D					0	523.62
	+591.64			−523.62		
A					591.64	0

Figure 7-25.—Coordinate entries for computation of figure 7-24.

STATION	COORDINATES Y	COORDINATES X
A	591.64	0
B	847.60	125.66
C	694.07	716.31
D	0	523.62
A	591.64	0

$$591.64 \times 125.66 = 74{,}345.48$$

$$847.60 \times 716.31 = 607{,}144.35$$

$$694.07 \times 523.62 = 363{,}428.93$$

$$0 \times 0 = 0$$

$$\Sigma \rightarrow 1{,}044{,}918.76$$

Figure 7-26.—First step for tabulated computation of figure 7-24.

Figure 7-25 shows the coordinate entries. You can see that the *Y* coordinate of *A* equals the latitude of *DA,* or 591.64 feet, while the *X* coordinate of *A* is zero. The *Y* coordinate of *B* equals the *Y* coordinate of A plus the latitude of *AB* or 591.64 + 255.96 = 847.60 feet.

The *X* coordinate of *B* equals the departure of *AB,* or 125.66 feet. The *Y* coordinate of *C* equals the *Y* coordinate of *B* ***minus*** the latitude of *BC* or 847.60 – 153.53 = 694.07 feet.

The *X* coordinate of *C* equals the *X* coordinate of *B* plus the departure of *BC* or 125.66 + 590.65 = 716.31 feel.

The *Y* coordinate of *D* obviously is zero; however, it computes as the *Y* coordinate of *C* minus the latitude of *CD* of 694.07 – 694.07, which serves as a check. The *X* coordinate of *D* equals the *X* coordinate of *C* minus the departure of *CD* or 716.31 – 192.69 = 523.62 feet. 'This is the same as the departure of *DA,* but with an opposite sign—a fact which serves as another check.

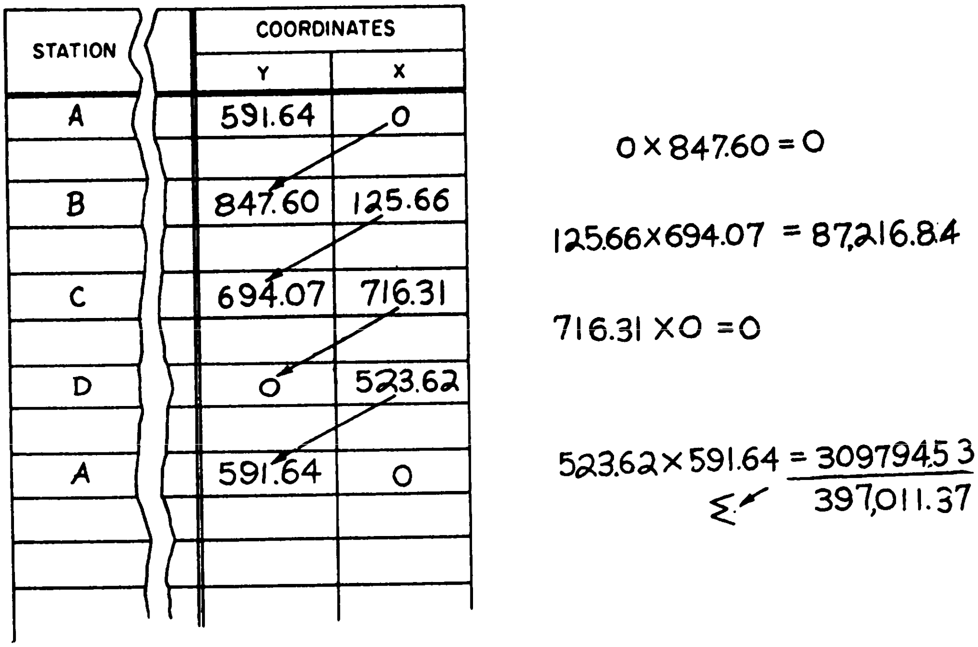


Figure 7-27.—Second step for tabulated computation of figure 7-24.

Figures 7-26 and 7-27 show the method of determining the double area from the coordinates. First, multiply pairs of diagonally opposite *X* and *Y* coordinates, as shown in figure 7-26, and determine the sum of the products. Then, multiply pairs diagonally in the opposite direction, as shown in figure 7-27, and determine the sum of the products. The difference between the sums (shown in fig. 7-26) is the double area or 1,044,918.76 – 397,011.37 = 647,907.39 square feet

The symbol shown beside the sum of the coordinate products is the capital Greek letter **(Σ)** sigma In this case, it simply means sum.

AREA BY TRAPEZOIDAL FORMULA.— It is often necessary to compute the area of an irregular figure, one or more of whose sides do not forma straight line. For illustration purpose, let us assume that figure 7-28 is a parcel of land in which the south, east, and west boundaries are straight lines per pendicular to each other, but the north boundary is a meandering shoreline.

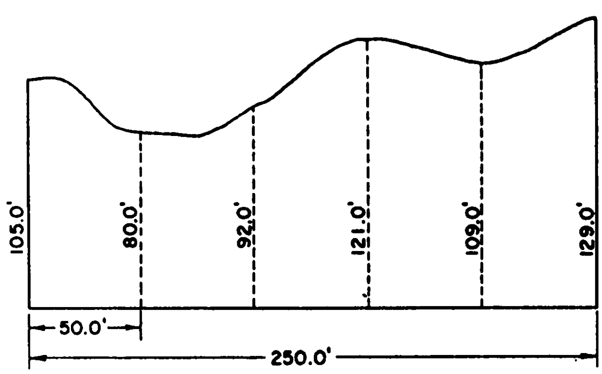


Figure 7-28.—Area of irregular figure by trapezoidal rule.

To determine the area of this figure, first lay off conveniently equal intervals (in this case, 50.0-foot intervals) from the west boundary and erect perpendiculars as shown. Measure the perpendiculars. Call the equal interval d and the perpendiculars (beginning with the west boundary and ending with the east boundary) h_1 through h_6.

Now, you can see that for any segment lying between two perpendiculars, the approximate area, by the rule for determining the area of a trapezoid, equals the product of d times the average between the perpendiculars. For the most westerly segment, for example, the area is

$$d\left(\frac{h_1 + h_2}{2}\right).$$

The total area equals the sum of the areas of the segments; therefore, since d is a factor common to each segment, the formula for the total area may be expressed as follows:

$$A = d\left(\frac{h_1 + h_2}{2} + \frac{h_2 + h_3}{2} + \frac{h_3 + h_4}{2} + \frac{h_4 + h_5}{2} + \frac{h_5 + h_6}{2}\right).$$

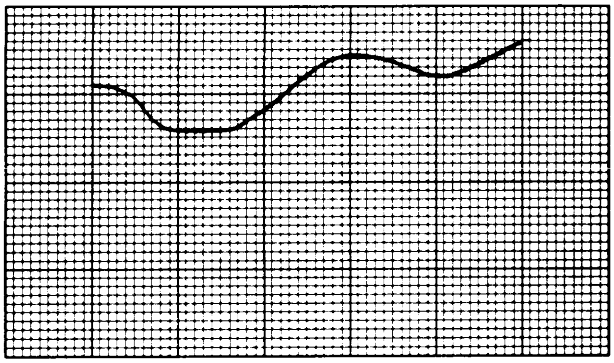


Figure 7-29.—Computing area by counting the squares.

However, this works out to

$$A = d\left(\frac{h_1 + 2h_2 + 2h_3 + 2h_4 + 2h_5 + 2h_6}{2}\right).$$

And this, in turn, reduces to

$$A = d\left(\frac{h_1 + h_6}{2} + h_2 + h_3 + h_4 + h_5\right).$$

Substituting in the formula the data from figure 7-26, you have

$$A = 50\left(\frac{105 + 129}{2} + 80 + 92 + 121 + 109\right).$$

If you work this out, you will find that the result is 25,950 square feet or approximately 0.6 acre.

AREA BY COUNTING THE SQUARES.— Another method of computing the area of an irregular figure is to plot the figure on a sheet of graph paper (plotting is explained later in this chapter). Then you determine the area by counting the squares within the figure outline and multiplying the result by the area represented by each square.

Figure 7-29 shows the same figure shown in figure 7-28 but plotted to scale on a sheet of graph paper on which each of the small squares is 5 feet x 5 feet or 25 square feet. When you count the squares within the outline, you will find that they total 1,038 squares which means

1,038 x 25 = 25,950 *square feet.*

AREA BY PLANIMETER.— A **planimeter** is a mechanical device that you can use to compute the area of an irregular figure after tracing the perimeter of a scale drawing of the figure with the tracing point on the planimeter. The most commonly used instrument is called the polar planimeter.

Figure 7-30 shows a polar planimeter. Its parts include an anchor point, *P;* a tracing point, *T,* with a guide, *G;* a vernier, *V;* and a roller, *R.* An adjustable arm, *A,* is graduated to permit adjustment to conform to the scale of the drawing. This adjustment provides a direct ratio between the area traced by the tracing point and the revolutions of the roller. As the tracing point is moved over the paper, the drum, *D,* and the disk *F,* revolve. The disk records the revolutions of the roller in units and

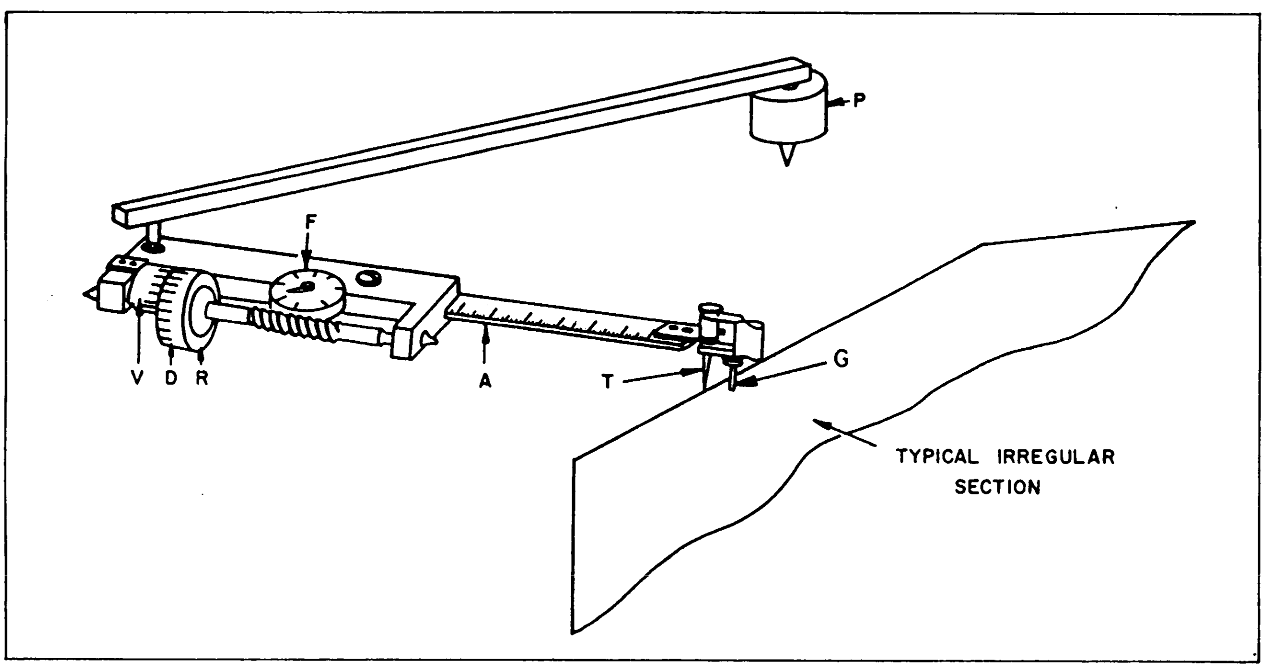


Figure 7-30.—Polar planimeter.

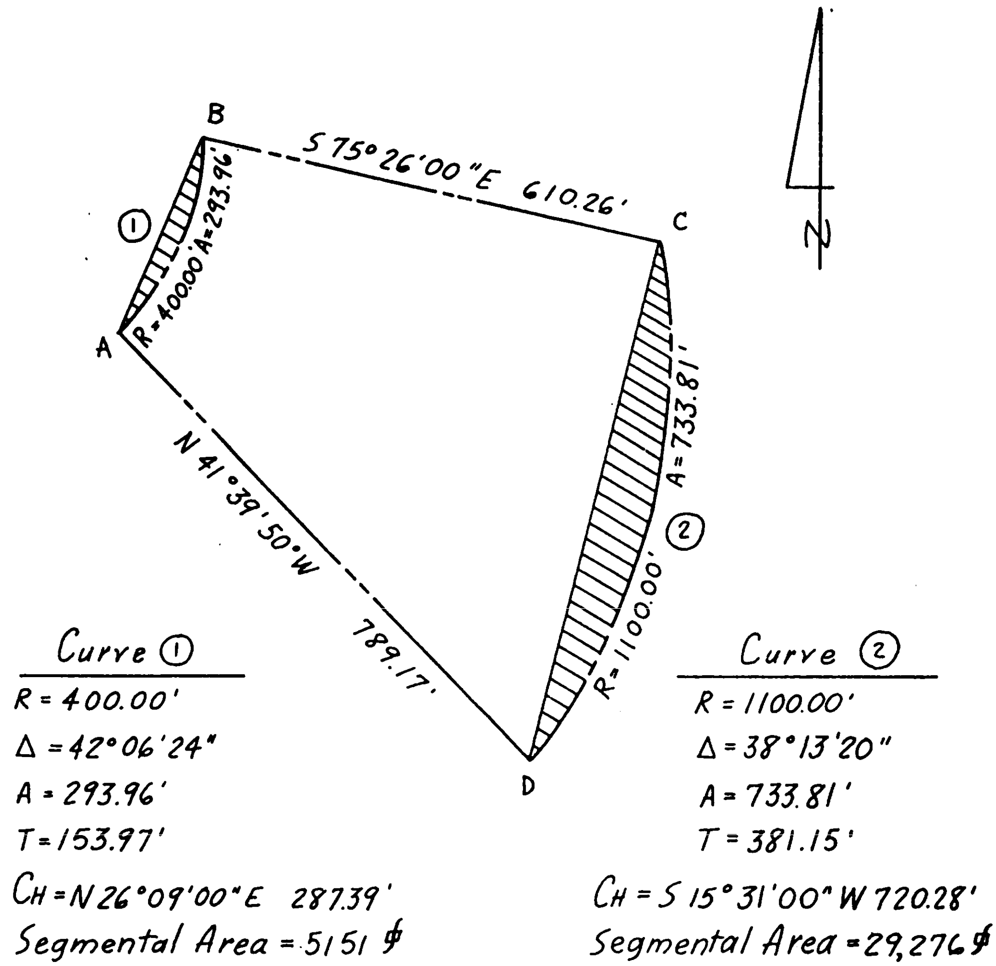


Figure 7-31.—Area within straight-line and curved-line boundaries (curved segments).

tenths; the drum, in hundredths; and the vernier, in thousandths.

Specific instructions for using the polar planimeter are found in the instruction booklet that is provided with the instrument. With minimal practice, you will find that the planimeter is a simple instrument to operate. You should remember, though, that the accuracy obtained with the planimeter depends mostly on the skill of the operator in accurately tracing the boundary lines of the figure with the tracing point of the planimeter.

If the instruction booklet has been lost, do not worry. The planimeter can still be used. Simply determine how many revolutions of the roller it takes to trace a figure of known area (drawn to the same scale as the figure you wish to determine the area of). Then trace the figure you are working with and read the number of revolutions taken to trace the unknown area. You now know three values as follows: (1) the area of the figure of known size, (2) the number of revolutions taken to trace the figure of known size, and (3) the number of revolutions taken to trace the figure of unknown size. B y ratio and proportion, you can then determine the unknown area.

PARCELS THAT INCLUDE CURVES.— Not all parcels of land are bounded entirely by straight lines. You may have to compute the area of a construction site that is bounded in part by the center lines or edges of curved roads or the right-of-way lines of curved roads.

Figure 7-31 shows a construction site with a shape similar to the traverse you have been studying in previous examples. In this site, however, the traverse lines *AB* and *CD* are the chords of circular curves, and the boundary lines *AB* and *CD* are the arcs intercepted by the chords. The following sections explain the method of determining the area lying within the straight-line and curved-line boundaries.

The data for each of the curves is inscribed on figure 7-31; that is, the radius *R,* the central angle **Δ,** the arc length *A* (to be discussed in chapter 11 of this

STATION	BEARING	DIST	FUNCTION		LAT.	DEP.	COORDINATES	
			COS	SIN	N+; S-	E+; W-	NORTH	EAST
A							740.33	31.68
Chord #1	N26°09'00"E	287.39	89764	44072	+257.97	+126.66		
B							998.30	158.34
	S75°26'00"E	610.26	25151	96786	-153.49	+590.65		
C							844.81	748.99
Chord #2	S15°31'00"W	720.28	96355	26752	-694.03	-192.69		
D							150.78	556.30
	N41°39'50"W	789.17	74705	66477	+589.55	-524.62		
A							740.33	31.68
							Σ↘ 1,339,	685.1
							Σ↙ -690,	171.7
							2A = 649,	513.4
							A = 324,	757
					less segmental area #1		-5,	151
					plus segmental area #2		+29,	276
							348,	882 □'
							or 8.	0092 Ac.

Figure 7-32.—Computation of area which includes curve segments.

TRAMAN), the tangent length T and the chord bearing and distance C_H.

The crosshatched areas lying between the chord and arc are called segmental areas. To determine the area of this parcel, you must (1) determine the area lying within the straight-line and chord (also straight-line) boundaries, (2) determine the segmental areas, (3) subtract the segmental area for Curve 1 from the straight-line boundary area and (4) add the segmental area for Curve 2 to the straight-line boundary area.

The method of determining a segmental area was explained in the EA3 TRAMAN. The straight-line area may be determined by the coordinate method, as explained in this chapter. For figure 7-31, the segmental area for Curve 1 works out to be 5,151 square feet; for Curve 2, it is 29,276 square feet.

Figure 7-32 shows atypical computation sheet for the area problem shown in figure 7-31. Included with the station letter designations in the station column are designations (Chord #1 and Chord #2) showing the bearings and distances that constitute the chords of Curves 1 and 2. The remainder of the upper part of the form shows the process (with which you are now familiar) of determining latitudes and departures from the bearings and distances, coordinates from the latitudes and departures, double areas from cross multiplication of coordinates, double areas from the difference between the sums of north and sums of east coordinates, and areas from half of the double areas. As you can see in figure 7-32, the area within the straight-line boundaries is 324,757 square feet. From this area, segmental area No. 1 is subtracted. Then segmental area No. 2 is added.

To obtain the area of the parcel as bounded by the arcs of the curves, you must add or subtract the segmental areas depending on whether the particular area in question lies inside or outside of the actual curved boundary. In figure 7-31, you can see that the segmental area for Curve 1 lies outside and must be subtracted from the straight-line area, while that for Curve 2 lies inside and must be added. With the segmental areas accounted for, the area comes to 348,882 square feet or 8.01 acres.

The second method of determining a curved-boundary area makes use of the external areas rather than the segmental areas of the curves, as shown in figure 7-33. The straight-line figure is defined by the tangents of the curves, rather than by the chords. This method may be used as an alternative to the chord method or to check the result obtained by the chord method.

The computation sheet shown in figure 7-34 follows the same pattern as the one shown in figure 7-32. However, there are two more straight-line boundaries,

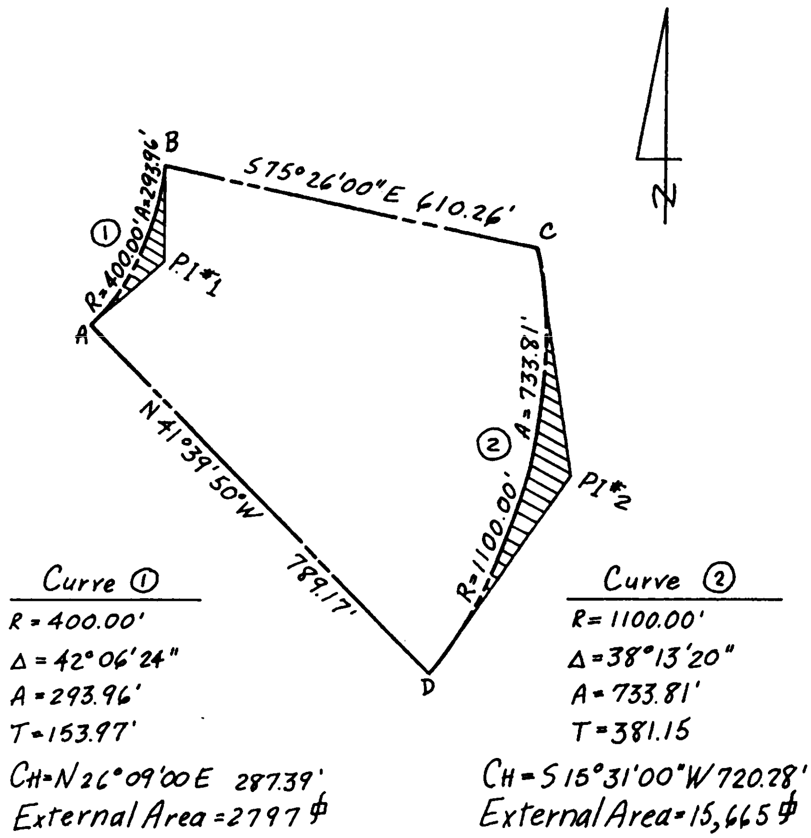


Figure 7-33.—Area within the curve and its tangents.

STATION	BEARING	DIST.	FUNCTION COS	FUNCTION SIN	LAT N+;S−	DEP E+;W−	COORDINATES NORTH	COORDINATES EAST
A							740.33	31.68
tangent	N 47°12'12" E	153.97	67940	73377	+104.61	+112.98		
P.I. #1							844.94	144.66
tangent	N 5°05'48" E	153.97	99605	08884	+153.36	+13.68		
B							998.30	158.34
C							844.81	748.99
tangent	S 3°35'40" E	381.15	99803	06269	−380.40	+23.89		
P.I. #2							464.41	772.88
tangent	S 34°37'40" W	381.15	82286	56824	−313.63	−216.58		
D							150.78	556.30
A							740.33	31.68

① ②

Δ/2 = 21°03'12" Δ/2 = 19°06'40" Σ↘ 1,904,665.4

Σ↙ −1,181,167.9

CHB = N26°09'00"E CHB = S15°31'00" W 2A = 723,497.5

+Δ/2 = +21°03'12" +Δ/2 = +19°06'40" A = 361,749

tan B = N47°12'12"E tan B = S34°37'40"W plus external area #1 = + 2,797

less external area #2 = −15,665

CHB = N26°09'00"E Δ/2 = 19°06'40" 348,881 #

− Δ/2 = −21°03'12" −CHB = −15°31'00 or 8.0092 Ac.

tan B = N 5°05'48"E tan B = S 3°35'40"E

Figure 7-34.—Computation of area which includes external area of curves.

in this case, because each curve has two tangents rather than a single long chord.

The coordinates of *A, B, C,* and *D* are the same as in the first example, but the coordinates of the points of intersection (PIs) must be established from the latitudes and departures of the tangents. The computations for determining the tangent bearings are shown in the lower left of figure 7-34. When you have only the chord bearing, you can compute the tangent bearing by adding or subtracting one half of delta **(Δ)** as correct. The angle between the tangent and the chord equals **Δ/2.**

After setting coordinates on the PIs, you cross-multiply, accumulate the products, subtract the smaller from the larger, and divide by 2, as before, to get the area of the straight-line figure running around the tangents. You then add or subtract each external area as appropriate. In figure 7-33, you can see that the external area for Curve 1 is inside the parcel boundary and must be added, while that of Curve 2 is outside and must be subtracted. The area comes to 348,881 square feet, which is an acceptable check on the area obtained by using segmental areas.

Plotting Horizontal Control

Computations for horizontal control become greatly clarified when you can see a **plot** (that is, a graphic representation to scale) of the traverse on which you are working. A glance at the plot of a closed traverse, for instance, tells you whether you should add or subtract the departure or the latitude of a traverse line in computing the departure or latitude of an adjacent line or in computing the coordinates of a station.

For linear distances that are given in feet and decimals of feet, you use the correct scale on an engineer's scale for laying off linear distances on a plot. For plotting traverses, there are three common methods: by protractor and scale, by tangents, and by coordinates.

PLOTTING ANGLES BY PROTRACTOR AND SCALE.— For the traverse on which you have been working, the adjusted bearings and distances are as follows:

Traverse Line	Bearing	Distance
AB	N26°09'E	285.14 feet
BC	S75°26'E	610.26 feet
CD	S15°31'W	720.28 feet
DA	N41°31'W	789.96 feet

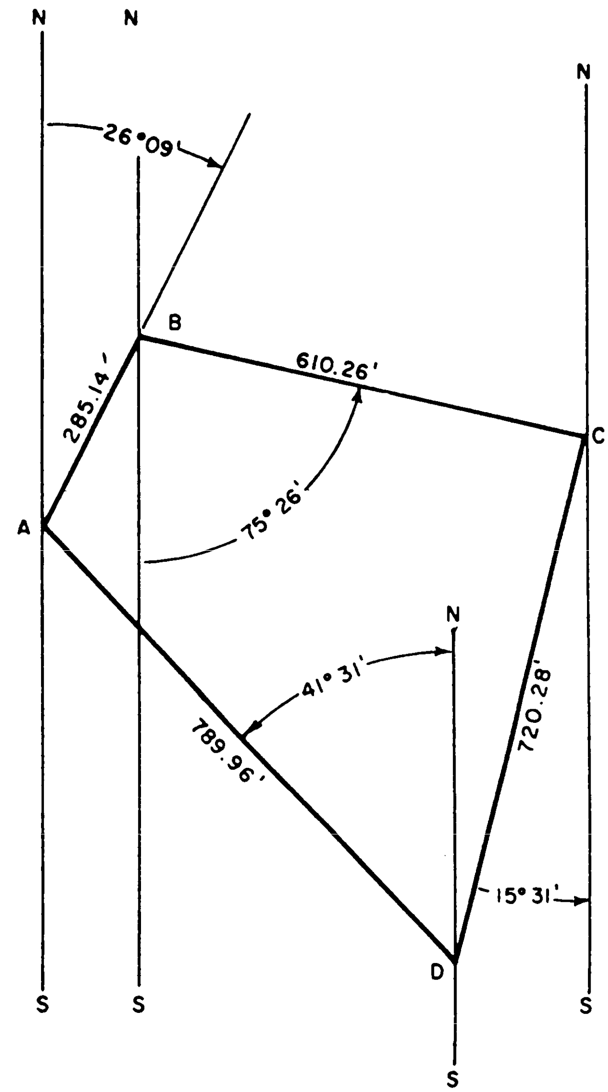


Figure 7-35.—Traverse plotted by protractor-and-scale method.

Figure 7-35 shows the method of how to plot this traverse with a scale and protractor. First select a scale that will make the plot fit on the size of your paper. Select a convenient point on the paper for stations A and draw a light line *NS,* representing the meridian through the station.

AB bears N26°9'E. Set the protractor with the central hole on *A* and the *00* line at *NS,* and lay off 26°09'E. You will have to estimate the minutes as best you can. Draw a line in this direction from A, and on the line measure off the length of *AB* (285. 14 feet) to scale.

This locates station *B* on the plot. Draw a light line *NS* through *B* parallel to *NS* through A, and representing the meridian through station *B. BC* bears S75°26'E. Set the protractor with the central hole on B and the 00 line on *NS,* lay off 75°26' from the S leg of *NS* to the *E,* and measure off the length of *BC* (610.26 feet) to scale to

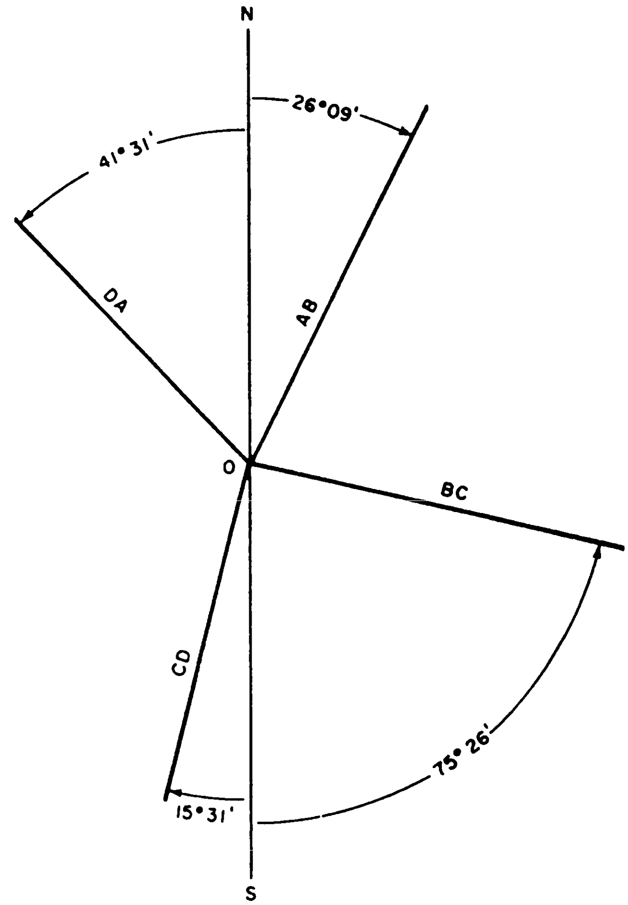


Figure 7-36.—Plotting traverse lines by parallel method from a single meridian.

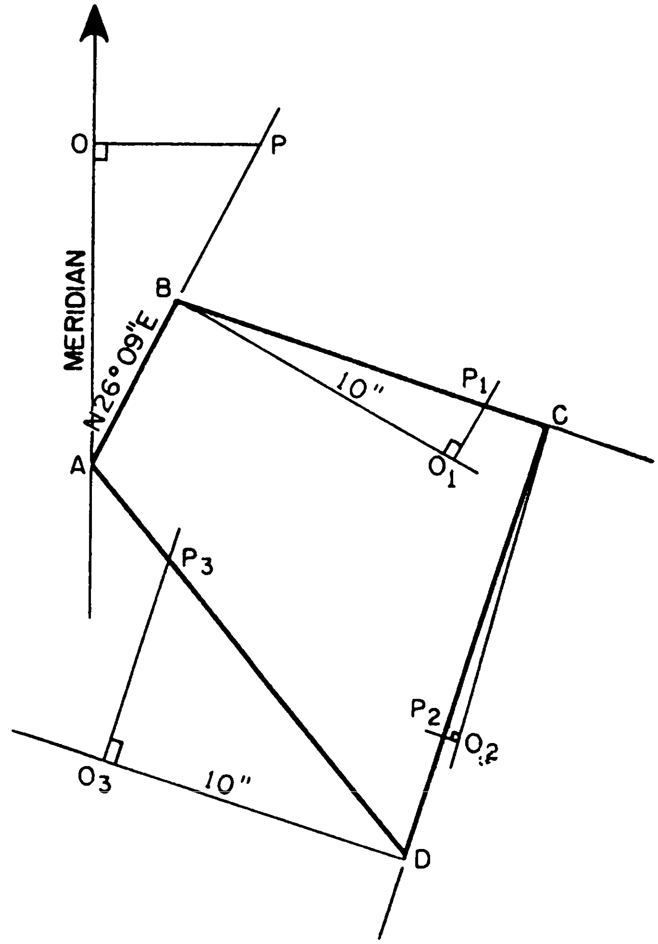


Figure 7-37.—Plotting by tangent-offset method from deflection angles larger than 45°.

locate *C.* Proceed to locate *D* in the same manner. This procedure leaves you with a number of light meridian lines through stations on the plot. A procedure that eliminates these lines is shown in figure 7-36. Here you draw a single meridian *NS,* well clear of the area of the paper on which you intend to plot the traverse. From a convenient point *O,* you layoff each of the traverse lines in the proper direction. You can then transfer these directions to the plot by one of the methods for drawing parallel lines.

PLOTTING ANGLES FROM TANGENTS.— Sometimes instead of having bearing angles to plot from, you might want to plot the traverse from deflection angles turned in the field. The deflection angles for the traverse you are working on are as follows:

AB to *BC*	78°25'R
BC to *CD*	90°57'R
CD to *DA*	122°58'R
DA to *AB*	67°40'R

You could plot from these angles by protractor. Lay off one of the traverse lines to scale; then lay off the direction of the next line by turning the deflection angle to the right of the firt line extension by protractor and soon.

However, the fact that you can read a protractor directly to only the nearest 30 minutes presents a problem. When you plot from bearings, your error in estimation of minutes applies only to a single traverse line. When you plot from deflection angles, however, the error carries on cumulatively all the way around. For this reason, you should use the tangent method when you are plotting deflection angles.

Figure 7-37 shows the procedure of plotting deflection angles larger than 45°. The direction of the starting line is called the meridian, following a conventional procedure, that the north side of the figure being plotted is situated toward the top of the drawing paper. In doing this, you might have to plot the appropriate traverse to a small scale using a protractor and an engineer's scale, just to have a general idea of where to start. Make sure that the figure will fit proportionately on the paper of the desired size. Starting at point A, you draw the meridian line lightly. Then you lay off *AO,* 10 inches (or any convenient round-figure length) along the referenced meridian. Now, from *O* you draw a line OP perpendicular to *AO.* Draw a light line *OP* as shown. In a trigonometric table, look for the natural tangent of the bearing angle 26°90', which equals to 0.49098. Find the distance *OP* as follows:

$OP = AO$ tan 26°09' = 4.9098, or 4.91 inches.

You know that *OP* is equal to 4.91 inches. Draw *AP* extended; then you lay off the distance *AB* to scale along *AP.* Remember that unless you are plotting a closed traverse, it is always advantageous to start your offsets from the referenced meridian. The reason is that, after you have plotted three or more lines, you can always use this referenced meridian line for checking the bearing of the last line plotted to find any discrepancy. The bearing angle, used as a check should also be found by the same method (tangent-offset method).

Now to plot the directions of lines from deflection angles larger than 45°, you have to use the complementary angle (90° minus the deflection angle). To plot the direction of line *BC* in figure 7-37, draw a light perpendicular line towards the right from point B. Measure off again a convenient round-figured length, say 10 inches, representing BO_1. The complement of the deflection angle of *BC* is 90° – 78°25' = 11°35'.

The natural tangent value of 11°35' is equal to 0.20497. From O_1 draw O_1P_1 perpendicular to BO_1. Solving for O_1P_1, you will have

$O_1P_1 = BO_1$ tan 11°35' = 2.0497, or 2.05 *inches.*

Now lay off the distance O_1P_1. Draw a line from B through P_1 extended; lay off the distance *BC* to scale along this line. The remaining sides, *CD* and *DA,* are plotted the same way. Make sure that the angles used for your computations are the correct ones. A rough sketch of your next line will always help to avoid major mistakes.

When the deflection angle is less than 45°, the procedure of plotting by tangent is as shown in figure 7-38. Here you measure off a convenient round-figure length (say 500.00 feet) on the extension of the initial traverse line to locate point *O,* and from *O,* draw *OP* perpendicular to *AO.* The angle between *BO* and *BC* is,

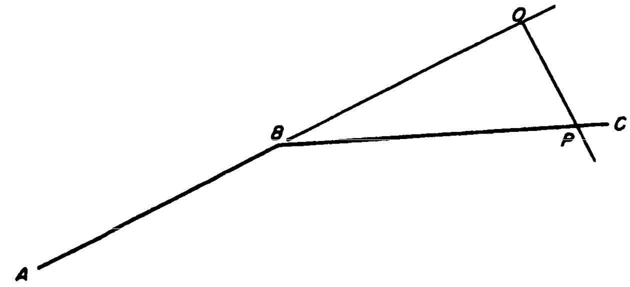


Figure7-38.—Plotting by tangent-offset method from deflection angle smaller than 45°.

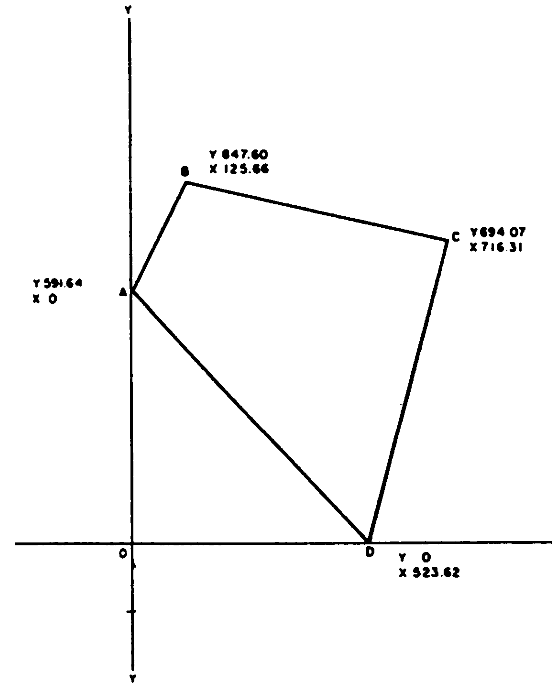


Figure 7-39.—Plotting by coordnates.

in this case, the deflection angle. Assume that this is 23°21'. The formula for the length of *OP* is

$OP = BO$ tan 23°21' = 500 x 0.43170= 215.85 *feet.*

PLOTTING BY COORDINATES.— A common and accurate method of plotting by coordinates is shown in figure 7-39. Here you simply locate each station by its coordinates and have no angular measurements to bother about. To plot station *B,* for instance, you would layoff from *O* on the *Y* axis a distance equal to the *Y* coordinate of *B* (847.60 feet). Draw a light line from this point perpendicular to the *Y* axis, and measure off on this line a distance equal to the *X* coordinate of *B* (125.66 feet). The remaining points are plotted in the same way.

Mistakes in Computations

An involved computation, such as determining an area by DMDs, involves a large number of calculations that present the possibility of a large number of errors. Some of the most common types of mistakes are discussed below in the hope that, if you know what they are, you may be able to avoid them.

MISTAKES WITH SIGNS.— You must be extremely careful to give a value (such as a latitude or departure) its correct sign in the first place and to apply the sign correctly in addition, subtraction, multiplication, and division. The matter of signs is such a fertile field for mistakes that a good idea is never to write a value without including the sign. The practice of omitting plus signs is a correct procedure, but it is safer to write in the plus signs. Then, if you find a value without a sign, you know that you forgot to put the sign in and that it might just as possibly be a minus as a plus.

WRONG COLUMN.— A WRONG COLUMN mistake may be an entry made in a wrong column or a reading taken from a wrong column. To avoid such mistakes, make both entries and readings with deliberation; that is, without undue haste and always with close attention to the column in which it should be entered or read.

WRONG QUADRANT.— When you mistake the quadrant in which a line lies, you get a bearing that may have the correct angular value but that has the wrong compass direction. The usual mistake of this kind is to set down the compass direction of the back bearing rather than of the front bearing.

A common cause of this mistake is viewing the direction of a line from the wrong station. In figure 740, the direction of *AB* is northeast but the direction of *BA* is southwest. *AB* and *BA* are, however, the same traverse line. But if you are determining the direction of *AB,* that direction is northeast. But if you are determining the direction of *BA,* that direction is precisely the opposite, or southwest. To minimize direction error, you may place arrows on the diagram showing the direction of the line.

WRONG AZIMUTH.— The same consideration applies to azimuths. Suppose that the bearing of *AB* in figure 7-40 is N46°E. Then the azimuth of *AB* is (measured from north) 46°. *BA* is the same traverse line; but the azimuth of *BA* is definitely not 46°, but 226°.

LEAVING OUT A TRAVERSE LINE.— A common source of mistakes is leaving out (commonly called **dropping)** a traverse line, either in the field notes or in computations. If you get an outsized angular and linear error of closure, you check first to make sure that you have not dropped one of the traverse lines.

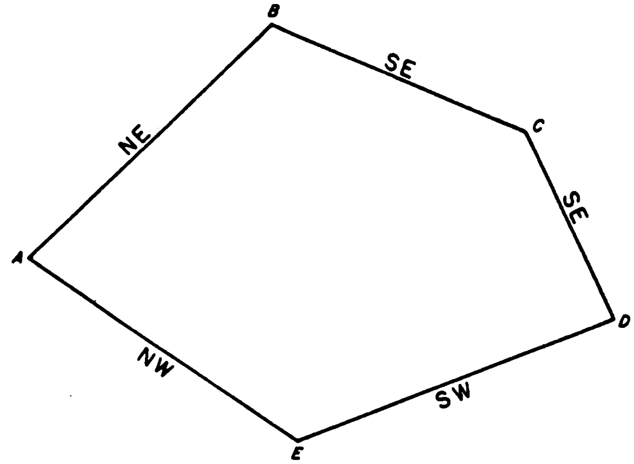


Figure 7-40.—Proper compass direction of a closed traverse.

WRONG DECIMAL PLACE.— The incorrect placement of a decimal point is a common mistake. Suppose, for example, you are determining an approximate double area by multiplying a DMD of +841.97 feet by latitude of –153.53 feet If you were to mistakenly use a value of –1535.3 instead of the correct –153.53, you obviously will not arrive at the correct result.

Locating Mistakes

If you cannot locate and correct a particular mistake, you must rerun the whole traverse to find it. However, this can often be avoided if you know a few tricks for locating mistakes.

OUTSIZED ANGULAR ERROR OF CLOSURE.— The size of an outsized angular error of closure may be a clue to the location of the particular mistake. Suppose, for example, that for a six-sided closed traverse, you measure interior angles as follows:

90°18'
118°48'
154°42'
147°18'
101°12'
612°18'

The interior angles in a six-sided closed traverse should add up to 720°00'. The difference between 720°00' and 612°18' is 107°42'. This large difference suggests that you dropped an angle measuring about

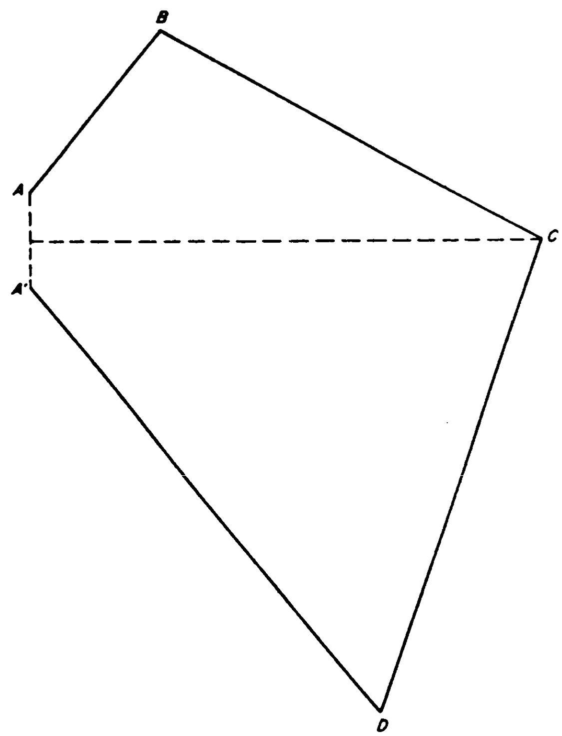


Figure 7-41.—Gaphical method to locate angular mistake in a closed traverse (see angle C).

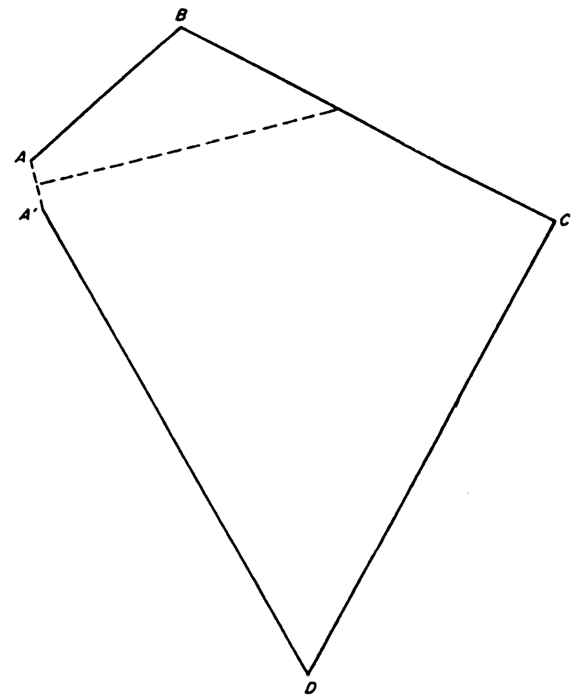


Figure 7-42.—Graphical method to locate angular mistake in a closed traverse (see angle A).

107°42' along the way. You should look for an angle of about this size in the traverse.

Suppose that in a four-sided traverse, the difference between the sum of the R-deflection angles and the sum of the L-deflection angles comes to 180°. For a four-sided traverse, this difference should be 360°. The larger difference suggests that you have given one of the angles a wrong direction. Look for an angle measuring about half the error of closure (in this case, measuring half of 180°, or 90°), and see whether you may have given this angle the wrong direction.

If you have not dropped an angle, a large interior-angle error of closure probably means a large mistake in measuring or in recording the measuring of one of the angles. You may be able to locate the doubtful angle by plotting the traverse from the measured angles. 'Then draw in the line of the linear error of closure and erect a perpendicular bisector from this line. The bisector may point to the dubious angle.

For example: In figure 7-41, all the bearings are correct except the bearing of *CD,* which should be S15°31'W for closure, but inadvertently you made a mistake and have S05°31'W. Because of this error, the traverse fails to close by the length of the dotted line *AA'*. A perpendicular bisector from *AA'* points directly at the faulty angle *C*.

If a perpendicular bisector from the line of linear error of closure does not point at any angle, the faulty angle may lie at the point of the beginning of the traverse. In figure 7-42, the bearings of all lines are correct for closure except that of the initial line *AB*. Line *AB* should be N29°09'E for closure but was plotted N16°09'E. A perpendicular from *AA'* does not point at any angle in the traverse.

OUTSIZED LATITUDE AND/OR DEPARTURE ERROR OF CLOSURE.— When both the latitudes and departures fail to close by large amounts, there is probably a mistake in an angle or a distance. When one closure is satisfactory and the other is not, a computational mistake is probably the cause of the outsized closure error.

OUTSIZED LINEAR ERROR OF CLOSURE.— When an angular error of closure is within allowable limits and there is an outsized linear error of closure, you should check for mistakes as follows:

1. Ascertain that you have not dropped a traverse line.

2. Ascertain that each latitude and departure is in the correct column.

3. Make sure that, in computing latitudes and departures, you have not accidently used cosine instead of sine or vice versa. The latitude of a traverse line equals the product of the length times the cosine of the bearing; the departure equals the product of the length times the sine of the bearing.

4. Make sure that you have given each bearing the proper compass direction; that is, the direction of the front bearing, **NOT** that of the back bearing.

5. Make sure that you copied all bearings and distances correctly.

6. Make sure that you copied all cosines and sines correctly.

7. Make sure that you made no arithmetical errors.

If none of these procedures serves to identify the mistake, you will have to rerun the traverse. If you must do this, examine the direction of the line of linear error of closure on the plot. Often, the traverse line that contains the mistake is parallel to this line. If there is a line that is parallel, you should start your rerun with this one.

QUESTIONS

Q1. What are the two principal methods of indirect leveling?

Q2. Refering to figure 7-43, you have determined the slope distance from BM31 to point A to be 404.163 meters. If you disregard corrections for standard error, temperature, and sag, what is (a) the horizontal distance from BM31 to point A and(b) the elevation at point A?

Q3. Refer to figure 7-44. What is the error of closure? Is this error of closure satisfactory for third-order leveling?

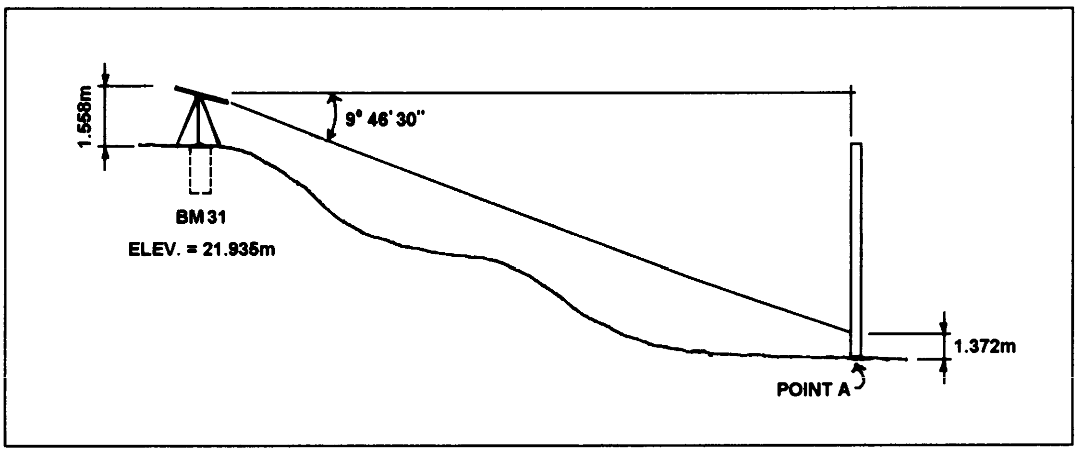


Figure 7-43.—Trigonometric leveling scenario for question Q2.

CAMP COVINGTON, GUAM
LEVEL CIRCUIT FROM
B.M. 35 TO B.M. 19

GURLEY
LEVEL
#31057

◻ ∮ ⊼ - EA2 HARRIS
Ø - EA3 CHAPMAN
30 JUNE 1990
WARM, OVERCAST

STA	B.S. (+)	H.I.	F.S. (−)	ELEV.	DIST B.S.	DIST F.S.	REMARKS
⊙35	6.35			100.02	220		CONCRETE MONUMENT B.M.
⊙16	4.66		4.67		250	220	PEG
⊙17	4.20		7.15		310	250	PEG
⊙18	1.11		5.55		400	310	PEG
T.P.#1	6.77		0.98		190	400	ROCK OUTCROP T.P.
⊡19			1.48			190	CONCRETE MONUMENT B.M. = 103.20

Figure 7-44.—Field notes for a differential-level circuit.

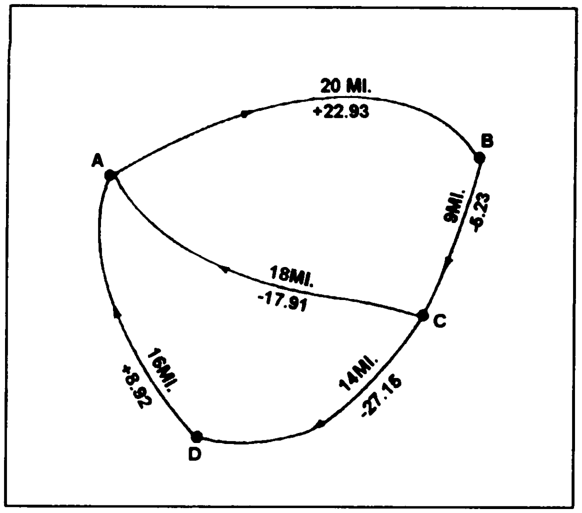


Figure 7-45.—Level net for use in answering question Q4.

Q4. *Refer to the level circuit ABCA shown in figure 7-45. What is (a) the error of closure in the circuit, and (b) the corrected difference in elevation (cycle I) for line AB?*

Q5. *What is the latitude of a 300-foot traverse line running due east and west?*

Q6. *Assume that you are working with a traverse that has a total length of 2,541.35 feet, an error of closure in latitude of –1.73 feet, and an error of closure in departure of +2.01 feet. What is the ratio of error of closure?*

Q7. *Compute the bearing of traverse line AB when the coordinates of station A and B are follows:*

Station A: X = 627.42, Y= 326.87

Station B: X = 864.81, Y= 542.50

Q8. *Refer to figure 7-46. What is the approximate area contained within the traverse?*

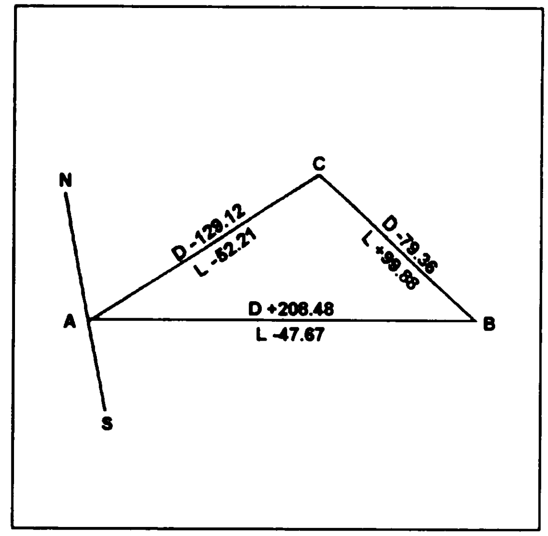


Figure 7-46.—Closed traverse for use with question Q8.

CHAPTER 8

TOPOGRAPHIC SURVEYING AND MAPPING

Topography refers to the characteristics of the land surface. These characteristics include **relief, natural features,** and **artificial** (or **man-made)** features. Relief is the conjuration of the earth's surface and includes such features as hills, valleys, plains, summits, depressions, and other natural features, such as trees, streams, and lakes. Man-made features are highways, bridges, dams, wharfs, buildings, and so forth.

A graphic representation of the topography of an area is called a **topographic map.** A topographic map is simply a drawing that shows the natural and artificial features of an area. A **topographic survey** is a survey conducted to obtain the data needed for the preparation of a topographic map. This data consists of the horizontal and vertical locations of the features to be shown on the map.

In this chapter and the following chapter, you will study methods and procedures used to perform topographic surveying and to prepare topographic maps.

TOPOGRAPHIC SURVEYING

The fieldwork in a topographic survey consists principally of (1) the establishment of a basic framework of horizontally and vertically located control points (called instrument points or stations) and (2) the determination of the horizontal and vertical locations of details in the vicinity of each instrument point. We will begin our discussions with topographic control.

TOPOGRAPHIC CONTROL

Topographic control consists of two parts: (1) horizontal control, which locates the horizontally fixed position of specified control points, and (2) vertical control, in which the elevations of specified bench marks are established. This control provides the framework from which topographic details, such as roads, buildings, rivers, and the elevation of ground points, are located.

Horizontal Control

Locating primary and secondary horizontal control points or stations may be accomplished by traversing, by triangulation (discussed in part 2 of this TRAMAN), or by the combined use of both methods. On an important, large-area survey, there may be both primary control, in which a number of widely separated primary control points are located with a high degree of precision; and secondary control, in which stations are located with less precision within the framework of the primary control points.

The routing of a primary traverse should be considered carefully. It should follow routes that will produce conveniently located stations. Such routes might run along roads, ridges, valleys, edges of wooded areas, public land lines, or near the perimeter of tracts of land. This latter route is of particular importance for small areas. When all the details in the area can be conveniently located from stations on the primary traverse, you do not need secondary traverses. However, the size or character of the terrain or both usually make secondary traverses necessary. Consider, for example, the situation shown in figure 8-1. This figure shows a tract bounded on three sides by highways and on the fourth side by a fence. For simplification, the figure shows only the items to be discussed. An actual complete plan would include a title, date, scale, north arrow, and so forth.

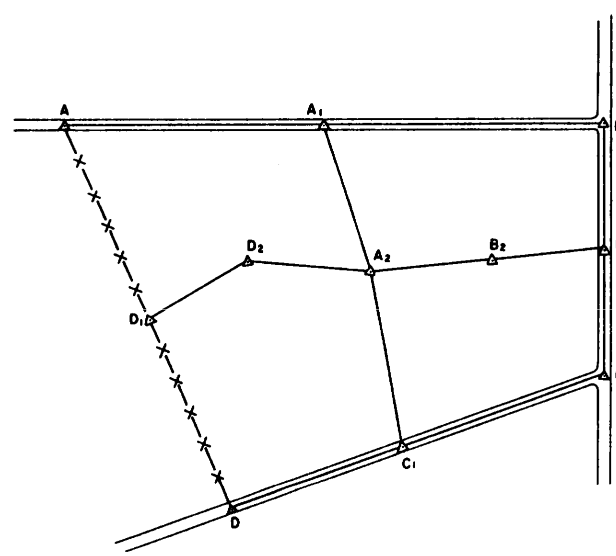


Figure 8-1.-Primary traverse and secondary traverse.

The primary traverse *ABCD* runs around the perimeter of the tract. Were this tract sufficiently small and level, then details within the whole tract could be located from only the primary control points; that is, from stations A, A_1, B, B_1, C, C_1, D, and D_1. In this case, however, the size (or perhaps the character) of the terrain made it necessary to establish additional control points within the perimeter of the tract, such as D_2, A_2, and B_2. These stations were established by running traverse lines (called crossties) across the area from one primary traverse station to another. It should be noted that, since each secondary traverse closes on a primary control point, errors cannot accumulate any farther than the distance between the primary stations.

Field notes for the survey sketched in figure 8-1 must contain (1) notes showing the horizontal locations of the stations and (2) level notes for determining the elevations of the stations.

Vertical Control

In topographic surveying, bench marks serve as starting and closing points for the leveling operations when you are locating details. Although for some surveys the datum may be assumed, it is preferable that all elevations be tied to bench marks which are referred to the sea-level datum. In many areas, particularly in the United States, series of permanent and precisely established bench marks are available. As a surveyor, you must make every feasible effort to tie in your surveys to these bench marks to ensure proper location and identification. Often, the established horizontal control marks are used as the bench marks because the level routes generally follow the traverse lines.

Vertical control is usually carried out by direct leveling; however, trigonometric leveling may be used for a limited area or in rough terrain. When you establish the primary vertical control to use in a topographic survey for an intermediate-scale map, four degrees of precision are used as follows:

1. **0.05 foot $\sqrt{\text{distance in miles}}$.** This order is used as the standard for surveys in flat regions when the contour interval is 1 foot or less. It is also used on surveys that require the determination of the gradient of streams or to establish the grades for proposed drainage and irrigation systems.

2. **0.1 foot $\sqrt{\text{distance in miles}}$.** This order is used in a survey when the contour interval of the map is 2 feet.

3. **0.3 foot $\sqrt{\text{distance in miles}}$.** This order is used for a contour interval of 5 feet.

4. **0.5 foot $\sqrt{\text{distance in miles}}$.** This order is used for a contour interval of 10 feet and may be done by stadia leveling, a method that is very advantageous in hilly terrain. Stadia will be discussed later in this chapter.

You use the third or fourth orders of precision for a large-scale map that generally has a contour interval of 1 or 2 feet. For an extensive survey of a large area, use the third order; for surveys of a smaller area, use the fourth order.

Once the topographic control has been established, your next major step in a topographic survey is to locate the details horizontally and vertically in the vicinity of each control point or station. These details consist of (1) all natural or artificial features that will appear on the map and (2) enough ground points and spot elevations to make the drawing of contour lines possible.

The methods and the instruments used in topographic surveys depend upon the purpose of the survey, the degree of precision needed, the nature of the terrain to be covered, the map scale, and the contour interval. For a high degree of accuracy, you should locate azimuths with a theodolite or transit. Measure horizontal distances with the chain or the electronic distance measurement (EDM) device. Determine elevations with a level.

The following sections discuss two methods that are commonly used to locate topographic details. A third method (topography by plane table) is discussed in the next chapter of this TRAMAN.

LOCATING DETAILS BY TRANSIT AND TAPE

In the EA3 TRAMAN you studied the procedures used to tie in and locate points, using a transit and tape. These same procedures are used for tying in and locating topographic details. Determine the vertical location (or elevation) of the detail points, using direct or trigonometric leveling procedures. Horizontally locate the details either by directions or distances or a combination of both. Use a method, or a combination of methods, that requires the least time in a particular situation. Directly measure the dimensions of structures, such as buildings, with tapes. When details are numerous, assign each one a number in the sketch and key the detail to a legend of some kind to avoid overcrowding. For directions, use azimuths instead of deflection angles to minimize confusion. Locate details as follows:

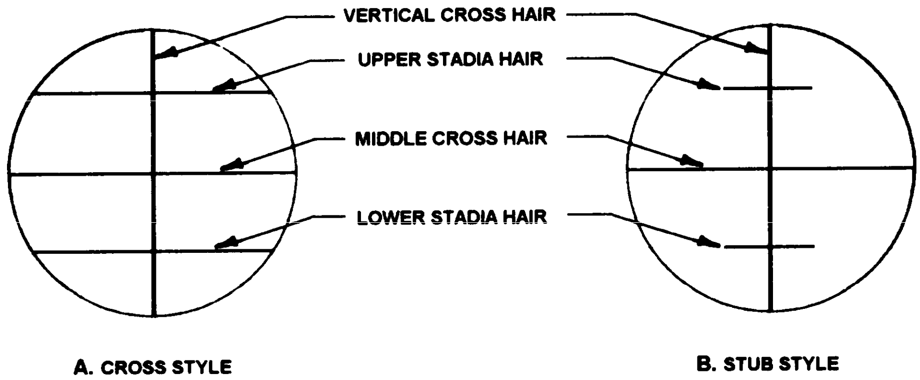


Figure 8-2.-Stadia hairs.

1. measure the angle and distance from transit stations
2. measure angles from two transit stations
3. measure distances from two known points
4. measure an angle from one station and distance from another station
5. measure swing offsets and range ties

As you can well imagine, detailing by transit and tape is a time-consuming process that requires chaining many distances and taking many level shots. This is necessary when a high degree of accuracy is required. However, for lower-precision (third and fourth order) surveys, a less time-consuming method is to locate the details by transit and stadia.

LOCATING DETAILS BY TRANSIT AND STADIA

As an EA, most of the topographic surveying that you will do is of a lower degree of accuracy that is well suited to the transit and stadia method. When you are using this method, horizontal distances and differences in elevation are indirectly determined by using subtended intervals and angles observed with a transit on a leveling rod or stadia board To explain the meaning of this, we will first discuss the principles of stadia and then look at field procedures that are used in stadia work.

Stadia Equipment Terms, and Principles

The following discussion will familiarize you with the equipment, terminology, and principles used in stadia surveying. Although this discussion of stadia surveying is included in this chapter on topography, you should be aware that stadia can be used in any situation in which it is desired to obtain horizontal distances and differences in elevation indirectly. The results, though, are of a lower order of precision than is obtainable by taping, EDM, or differential leveling. However, the results are adequate for many purposes, such as lower-order trigonometric leveling.

A thorough understanding of stadia is highly important to any surveyor. You should supplement the knowledge that you gain from the following discussion by reading other books, such as *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail.

STADIA RODS.— Where sight distances do not exceed 200 feet, a conventional rod, such as a Philadelphia rod, is adequate for stadia work. For longer distances, however, you should use a stadia rod. Stadia rods usually have large geometric designs on them so that they may be read at distances of 1,000 to 1,500 feet or even farther. Some rods do not have any numerals on them. From the geometric pattern on the rod, you can observe intervals of a tenth of a foot and sometimes a hundredth of a foot.

Stadia rods generally are 10 to 15 feet long, 3 to 5 inches wide, and about 3/4 inch thick. They may be made in one piece or in sections for ease in carrying them. Some stadia rods are flexible and maybe rolled up when not in use. Flexible rods are merely graduated oilcloth ribbons, tacked to a board.

Some examples of stadia rods are shown in chapter 11 of the EA3 TRAMAN.

STADIA HAIRS.— The telescope of transits (as well as theodolites, plane-table alidades, and many levels) is equipped with two hairs, called **stadia hairs,** that are in addition to the regular vertical and horizontal cross hairs. Figure 8-2 shows two types of stadia hairs as viewed through a telescope. As shown in this figure, one stadia hair is located above and the other an equal distance below the horizontal (or middle) cross hair. On most equipment, the stadia hairs are not adjustable and remain equally spaced.

STADIA INTERVAL.— As you look at a stadia rod through a transit telescope, the stadia hairs seem to intercept an interval on the rod. The distance on the rod between the apparent positions of the two stadia hairs is the **stadia interval** or **stadia reading.**

Usually, you determine stadia intervals by sighting the lower stadia hair at a convenient foot mark and then observing the position of the upper stadia hair; for example, the lower hair might be sighted on the 2.00 foot mark and the upper hair might be in line with 6.37. By subtracting, we have the stadia reading (6.37 -2.00 = 4.37).

It may happen that the stadia reading is more than the length of the rod. By using the middle hair, you may observe a half-interval and multiply it by 2 to get the stadia reading.

STADIA CONSTANT.— Light rays that pass through the lens (objective) of a telescope come together at a point called the **principal focus** of the lens. Then these light rays continue in straight-line paths, as shown in figure 8-3.

The distance between the principal focus and the center of the lens is called the **focal** ***length(f)*** of the lens. For any particular lens, the focal length does not change. If you divide the focal length by the distance between the stadia hairs *(i),* you get a number known as the **stadia constant** *(k).* Sometimes the stadia constant is called the stadia factor or stadia interval factor.

A convenient value to use for the stadia constant is 100. Stadia hairs usually are spaced so that the interval between them will make the stadia constant equal to 100.

STADIA DISTANCE.— The distance from the principal focus to the stadia rod is called the **stadia distance.** As shown in figure 8-3, this distance *(d)* is equal to the stadia constant ***(k)*** times the stadia reading *(s).*

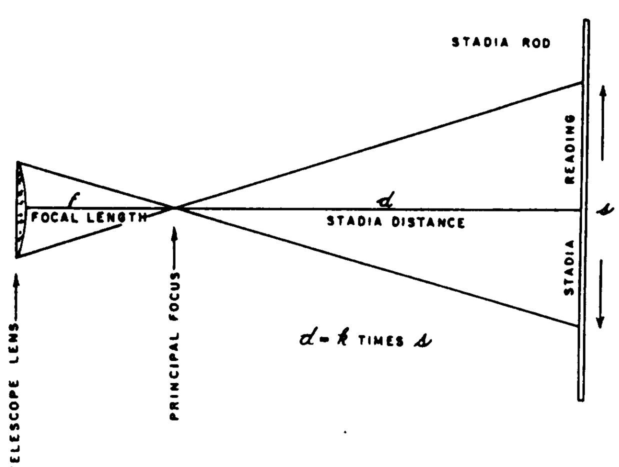


Figure 8-3.—Light rays converge at principal focus of a lens.

INSTRUMENT CONSTANT.— The distance from the center of the instrument to the principal focus is the **instrument constant.** Usually, this constant is determined by the manufacturer of the instrument. You should find it stated on the inside of the instrument box.

Externally focusing telescopes are manufactured so that the instrument constant may be considered equal to 1. For internally focusing telescopes, though, the objective in the telescope is so near the center of the instrument that the instrument constant may be considered as zero. This, as you will learn in the following discussion of stadia reduction formulas, is a distinct advantage of internally focusing telescopes. Most modem instruments are equipped with internally focusing telescopes.

STADIA REDUCTION FORMULAS.— In stadia work we are concerned with finding two values as follows: (1) the horizontal distance from the center of the instrument to the stadia rod and (2) the vertical distance, or difference in elevation, between the center of the instrument and middle-hair reading on the rod. To obtain these values, you must use **stadia reduction formulas.**

Stadia Formula for Horizontal Sights.— For a horizontal sight, the distance that we need to determine is the horizontal distance between the center of the instrument and the stadia rod. This distance is found by adding the stadia distance to the instrument constant as follows:

Write *ks* for the stadia distance and $(f + c)$ for the instrument constant. Then the formula for computing horizontal distances when the sights are horizontal becomes the following:

$$h = ks + (f + c).$$

Where:

h = horizontal distance from the center of the instrument to a vertical stadia rod

k = stadia constant, usually 100

s = stadia interval

$f + c$ = instrument constant (zero for internally focusing telescopes; approximately 1 foot for externally focusing telescopes)

f = focal lengths of the lens

c = distance from the center of the instrument to the center of the lens

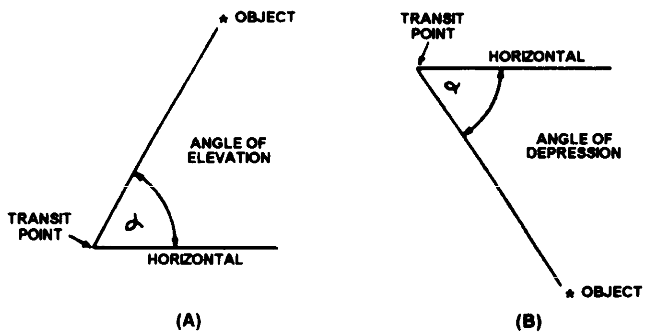


Figure 8-4.-(A) Angle of elevation and (B) angle of depression.

The instrument constant is the same for all readings. Suppose that you are using an externally focusing instrument with an instrument constant of 1.0. If the stadia interval is 1 foot, then the horizontal distance is as follows:

$$h = (100)(1) + 1 = 101 \text{ feet.}$$

If the stadia interval is 2 feet, the horizontal distance is as follows:

$$h = (100)(2) + 1 = 201 \text{ feet.}$$

Now suppose that you are using an internally focusing instrument. In this case, the instrument constant is zero and can be disregarded. This is the advantage of an internally focusing telescope. So, if the stadia interval is 1 foot, the horizontal distance is simply the stadia distance which is 100 feet. For a stadia reading of 2 feet, the horizontal distance is 200 feet.

Horizontal distance usually is stated to the nearest foot. Occasionally on short distances (under 300 feet), it maybe specified that tenths of a foot be used.

Stadia Formulas for Inclined Sights.— -Most often the sights needed in stadia work are not horizontal. It may be necessary to incline the telescope upward or downward at a vertical angle. This vertical angle (α) may be either an angle of elevation or an angle of depression, as shown in figure 8-4. If the line of sight is elevated above the horizontal, you speak of it as an **angle of elevation.** If the line of sight is depressed below the horizontal, the vertical angle is an **angle of depression.**

In either case, you find the horizontal and vertical distances by using the following formulas:

$$h = ks \cos^2 \alpha + (f + c) \cos \alpha$$

$$v = 1/2ks \sin 2\alpha + (f + c) \sin \alpha$$

These two expressions are called the stadia formulas for inclined sights in which

h = horizontal distance

v = vertical distance

h = stadia distance

a = vertical angle

$f + c$ = instrument constant

Refer to figure 8-5 for clarification of the terms in the stadia formulas for inclined sights.

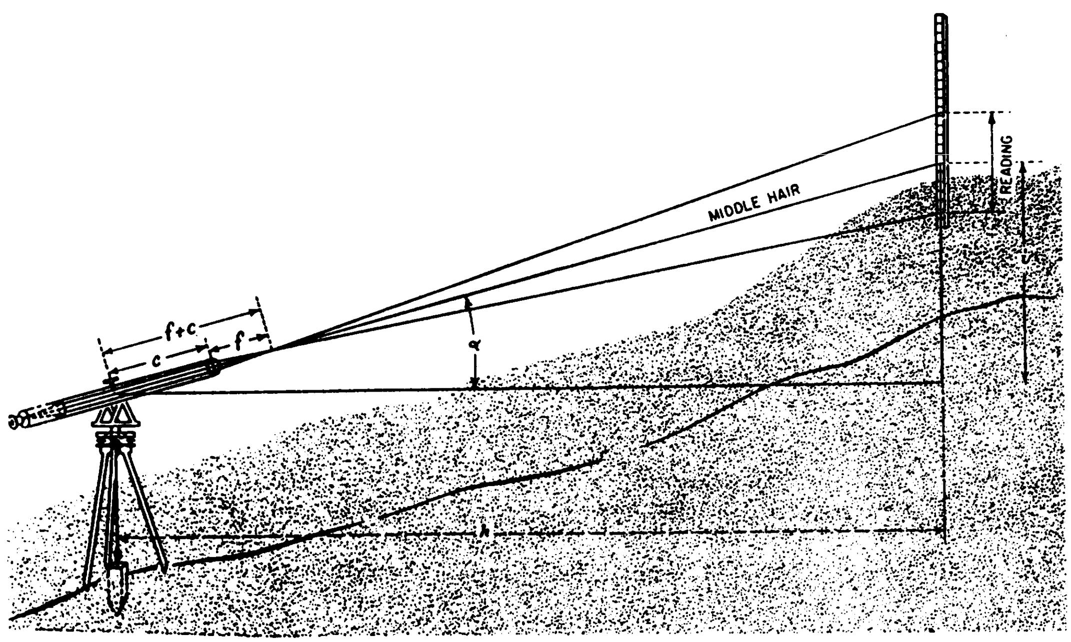


Figure 8-5.-Stadia Interval—inclined sight.

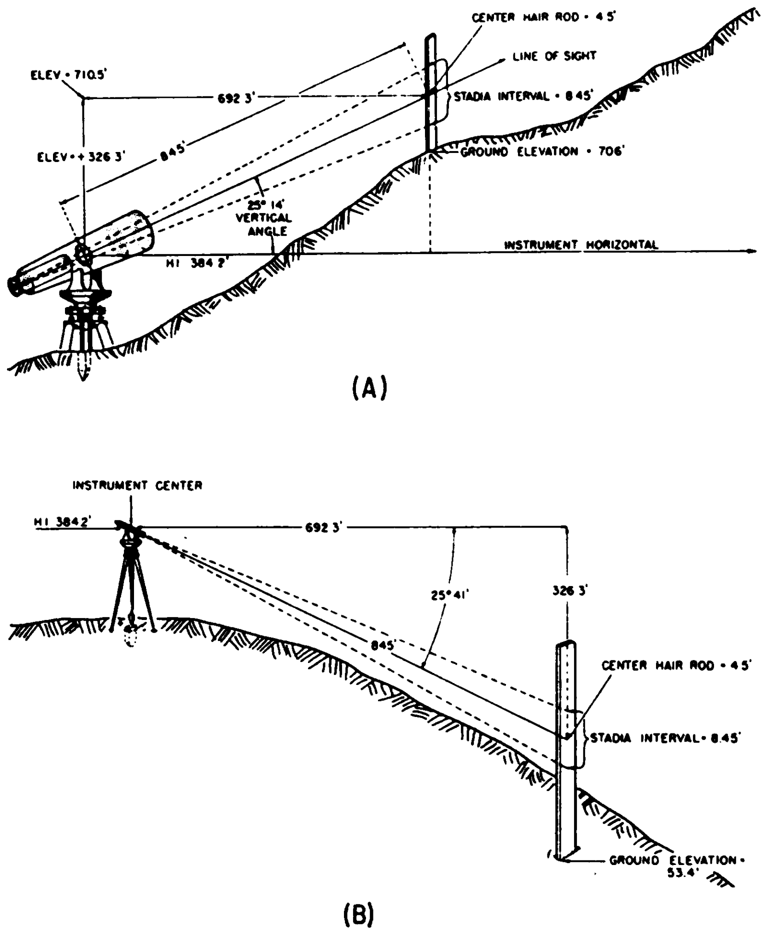


Figure 8-6.—Ground elevations: (A) Telescope raised and (B) telescope depressed.

DISTANCE AND ELEVATION FOR INCLINED SIGHTS.— The following example will describe the use of the stadia reduction formulas for inclined sights. Assume you have a stadia interval of 8.45 and an angle of elevation of 25°14′, as shown in figure 8-6, view A. Let the instrument constant be 1.0.

Substituting the known values in the stadia formula for the horizontal distance, you have

$$h = ks\cos^2\alpha + (f + c)\cos\alpha$$

$$h = 100\ (8.45)\ (0.90458)^2 + (1)\ (0.90458) = 692.34$$

The horizontal distance is 692 feet.

Substituting the known values in the formula for the vertical distance, you have

$$v = 1/2\, ks \sin 2\alpha + (f + c)\sin\alpha$$

$$v = 50\ (8.45)\ (0.77125) + (1)\ (0.42631)$$

$$v = 326.28.$$

The vertical distance to the middle-hair reading on the rod is 326.28 feet.

To find the elevation of the ground at the base of the rod, subtract the center-hair rod reading from this vertical distance and add the height of instrument (HI). (See fig. 8-6, view A). If the HI is 384.20 feet and the center-hair rod reading is 4.50 feet, then the ground elevation is

$$326.28 - 4.5 + 384.20 = 705.98 \text{ feet}$$

If the angle of inclination were depressed, then you would have to add the center-hair rod reading to the vertical distance and subtract this sum from the HI. As you see from figure 8-6, view B, the ground elevation would be

$$384.2 - (326.28 + 4.5) = 53.42 \text{ feet.}$$

STADIA TABLES.— You may save time in finding the horizontal distance and the vertical distance (difference in elevation between two points) by using the stadia reduction tables in appendix II. Here the values of 100 $\cos^2\alpha$ and 1/2(100) sin 2α are already computed at 2-minute intervals for angles up to 30°. You need to multiply the values in the table by the stadia reading, then add the value of the instrument constant given at the bottom of the page.

To find the values from the stadia table, for the example that we have been discussing, read under 25° and opposite 14′. Under Hor. Dist. you find that

$$100 \cos^2 25°14' = 81.83.$$

Under Diff. Elev. you see that

$$1/2\ (100)\ \sin 2\ (25°14') = 38.56.$$

The values of the term containing the instrument constant are given at the bottom of the page.

For

$$(f + c) = C = 1.00.$$

You find

$$(f + c) \cos \alpha = 0.90.$$

Therefore

$$(f + c) \sin \alpha = 0.43.$$

Using these values in the formulas, you have

$$h = 8.45\ (81.83) + 0.90$$

$$h = 692.4 \text{ or } 692 \text{ feet.}$$

and

$$v = 8.45\ (38.56) + 0.43$$

$$v = 326.23 \text{ or } 326 \text{ feet.}$$

APPROXIMATE FORMS OF STADIA FORMULAS.— Because of the errors common in stadia surveying, it has been found that approximate stadia formulas are precise enough for most stadia work If you will refer again to figures 8-5 and 8-6, you will notice that it is customary to hold the stadia rod plumb rather than inclined at right angles to the line of sight. Failure to hold the rod plumb introduces an error causing the observed readings to be longer than the true readings. Another error inherent in stadia surveying is caused by the unequal refraction of light rays in the layers of air close to the earth's surface. The refraction error is smallest when the day is cloudy or during the early morning or late afternoon hours on a sunny day. Unequal refraction, also, causes the observed readings to be longer than the true readings.

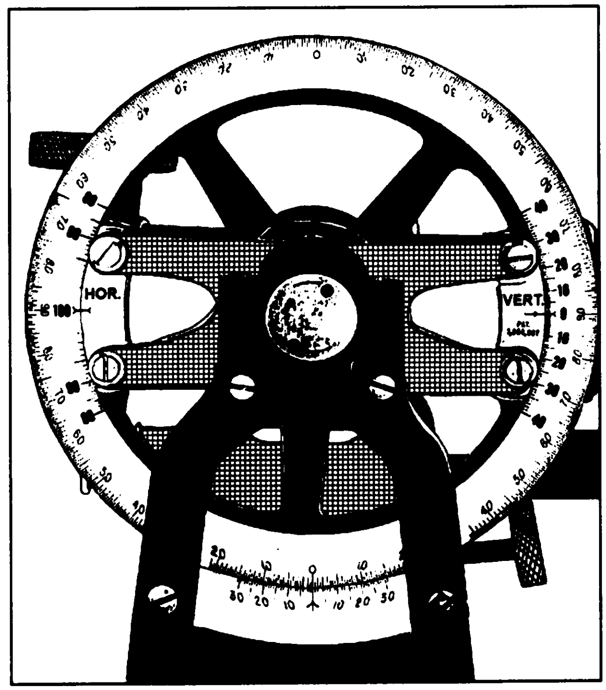


Figure 8-7.-Stadia arc (multiplier type).

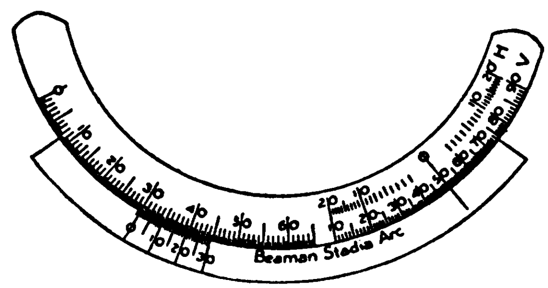


Figure 8-8.-Stadia arc (horizontal scale subtraction type).

To compensate for these errors, topographers often regard the instrument constant as zero in stadia surveying of ordinary precision, even if the instrument has an externally focusing telescope. In this way, the last terms in the stadia formulas for inclined sights vanish; that is, become zero. Then the **approximate expressions for horizontal and vertical distance** are

$$h = ks \cos^2\alpha$$

$$v = 1/2ks \sin 2\alpha.$$

BEAMAN STADIA ARC.— The Beaman stadia arc is a specially graduated arc on the vertical scale of the transit (fig. 8-7) or on the plane-table alidade (fig. 8-8). The Beaman arc on the transit is also known as the **stadia circle.** These arcs are used to determine distances and differences in elevation by stadia without using vertical angles and without using tables or diagrams. A stadia arc has no vernier, but readings are indicated by index marks.

The stadia arc shown in figure 8-7 is the **multiplier** stadia arc (the vertical index is at zero); that is, the observed stadia interval is multiplied by the **Hor** stadia arc reading to get the horizontal distance; or the stadia interval is multiplied by the Vert stadia arc reading to obtain the vertical distance from the center of the instrument to the point sighted on the rod This vertical distance, combined with the HI and the rod reading, will give the difference in elevation between the instrument station and the point where the rod is held

The stadia arc, as shown is figure 8-8, is called the horizontal scale **subtraction** stadia arc (the vertical index is at 50). The use of the Beaman stadia arc to obtain a horizontal distance and difference in elevation is explained in the following sections.

Horizontal Distance (Subtraction Scale).— The **H** scale gives you a percentage that you can apply to an inclined stadia shot with the alidade to get the corresponding horizontal distance from the slope distance. Suppose that with the telescope inclined (that is, at a vertical angle other than 0°), you read an interval of 2.45 feet on the stadia rod. The slope distance, then

$$2.45 \times 100 = 245 \text{ feet.}$$

What is the corresponding horizontal distance? You read the graduation indicated by the Beaman arc indicator on the H scale, and find that the reading is 5. This means that the horizontal distance is 5 percent less than the slope distance, or

245 feet – (0.05 x 245 feet), or

245 – 12.25 = 232.8 feet.

Difference in Elevation (Vertical Index at 50).— The **V** scale on the Beaman arc is used to determine the difference in elevation between the elevation of the line of sight through the telescope (that is, the HI) and the elevation of the point you sighted on the level rod Note that when the telescope is horizontal, the **V** scale on the Beaman arc reads 50. This arrangement makes the use of minus values unnecessary when you are sighting with the telescope at a negative vertical angle.

To read the **V** scale, you take the difference between 50 and whatever you read on the scale and apply this difference as follows to determine the difference in elevation.

Suppose that when you made the shot previously described (where you read 5 on the **H** scale), the reading on the **V** scale was 71. In practice, it is the custom to shoot the rod at a point that will give you an even reading on the **V** scale.

Because the reading was 71, the value you will use is

71 –50, or 21%.

This means that the difference in elevation between the HI and the point you sighted on the rod is 21 percent of the slope distance. The slope distance, in this case, was 245.0 feet; therefore, the difference in elevation is

245.0 x 0.21 = 51.45 feet.

Now that you know how to read stadia and compute horizontal and vertical distances using stadia, we will now discuss typical field procedures.

Field Procedures

Figure 8-9 shows two situations that are encountered in transit-stadia work First, let us discuss the common situation in which you desire to determine the difference in elevation between an instrument station of known elevation and a ground point of unknown elevation. This situation is shown in figure 8-9, view A. In this view, the elevation of the instrument station *P* is known and it is desired to determine the difference in elevation between *P* and the rod station P_1. The horizontal center-line height of the instrument (h.i.) above point *P is* equal to *PA*. As you can see, this h.i. is different than the HI that you are accustomed to working with indirect leveling. The rod reading is P_1B.

From your studies, you know that the difference in elevation *(DE)* between *P* and P_1 can be expressed as follows:

$$DE = PA + BC - P_1B$$

$$\text{or, } DE = h.i. + BC - P_1B.$$

Therefore, the ground elevation at P_1 can be expressed as follows:

$$\text{Elev. } P_1 = \text{Elev. } P + (h.i. + BC - P_1B).$$

Now let us sight on the rod such that $P_1B = PA$ = h.i. In this case, the situation occurs in which a similar triangle (PC_1P_1) is formed at the instrument station *P*. From observation of these similar triangles, you can see that the DE= $P_1C_1 = BC$. Therefore, the ground elevation at P_1 *can be* simply expressed as follows:

$$\text{Elev. } P_1 = \text{Elev. } P + BC.$$

This is an important concept to understand when shooting stadia from a station of known elevation As

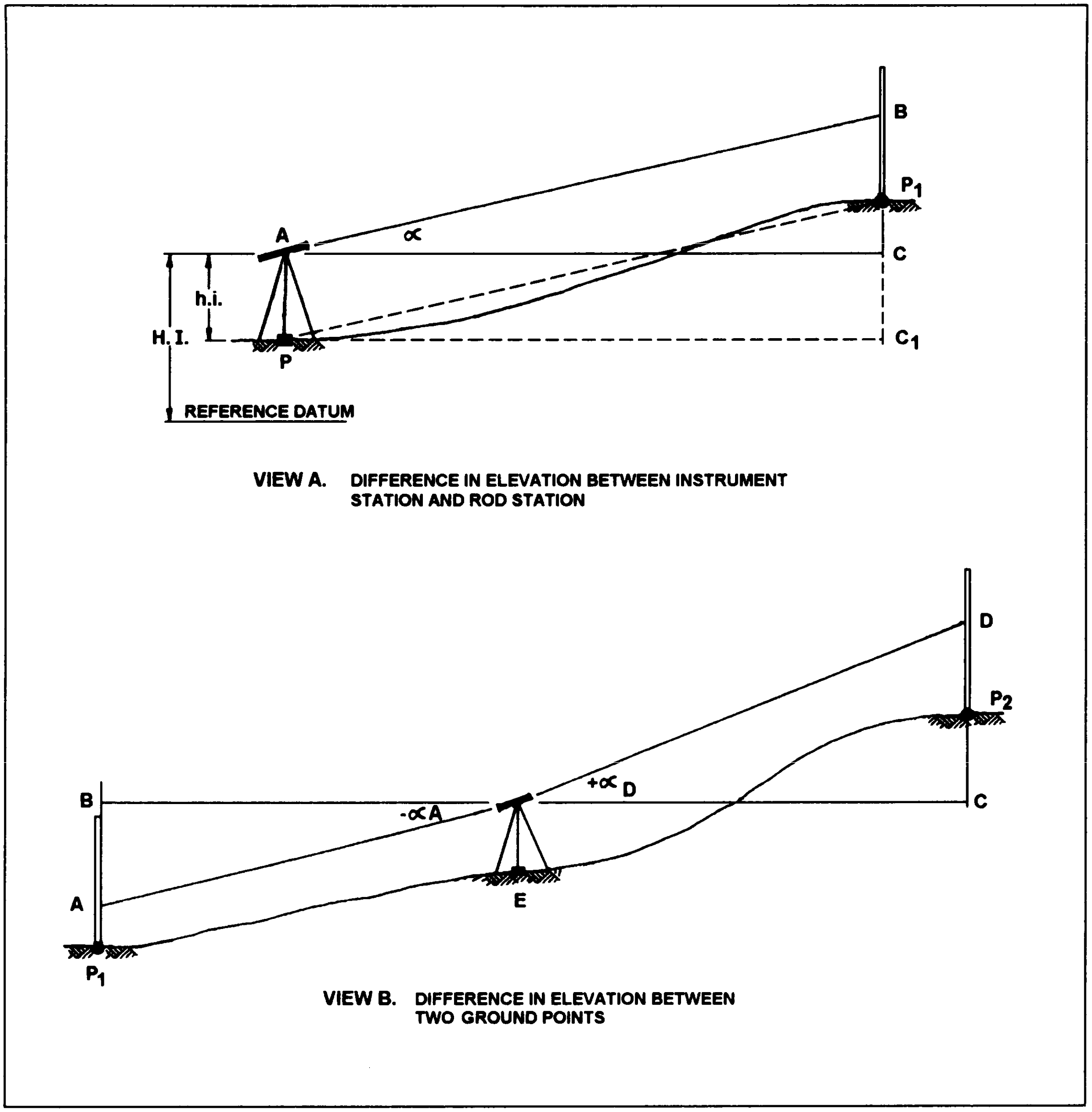


Figure 8-9.-Difference in elevation.

you can see, when the center cross hair is sighted on a rod graduation that is equal to the h.i. before reading the vertical angle, then calculating the difference in elevation is greatly simplified. Obviously, though, if the line of sight is obstructed and you cannot sight on a rod graduation that is equal to the hi., then you must sight on some other graduation.

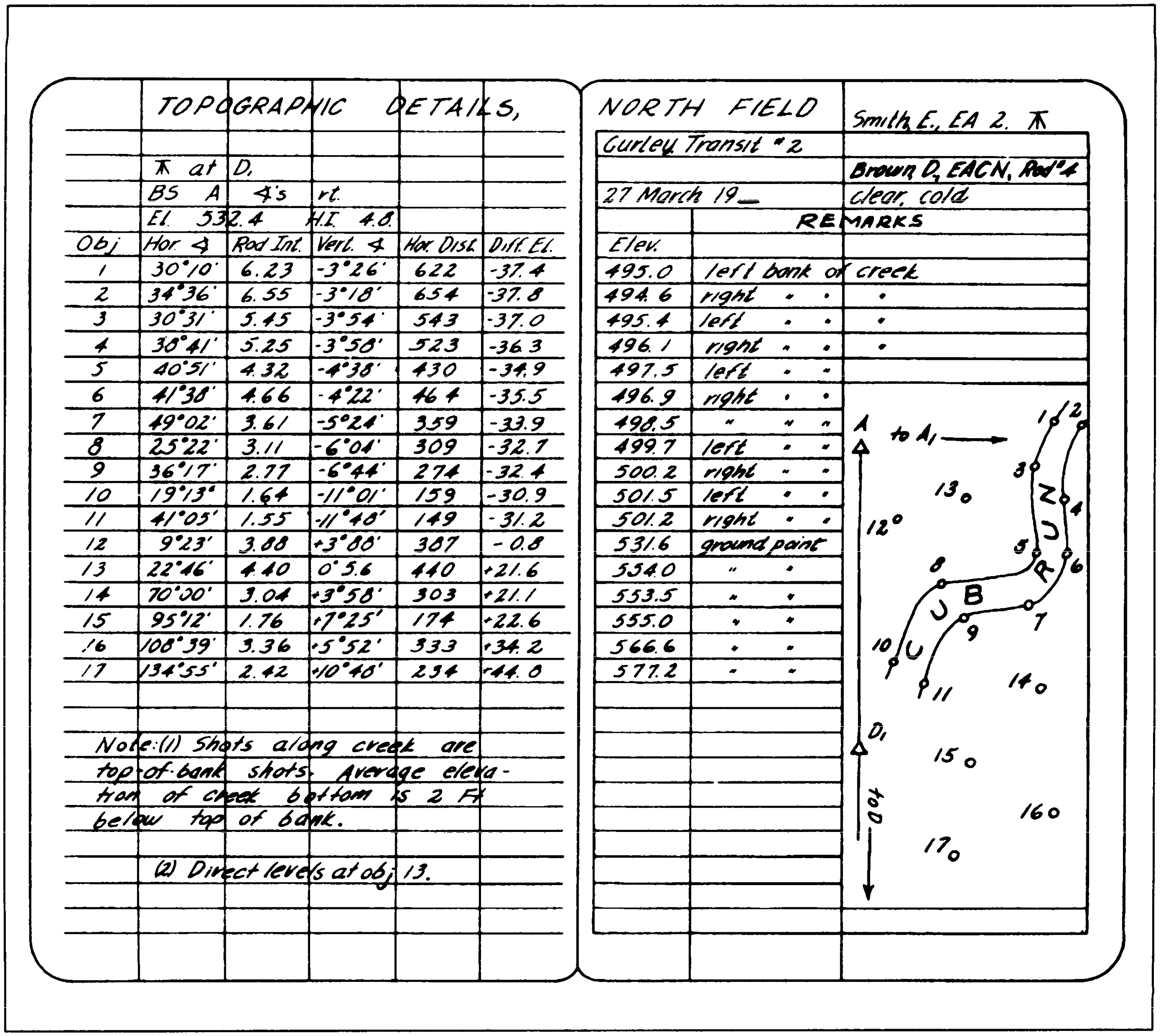
Another, although less frequent, occurrence in topographic work using stadia is shown in figure 8-9, view B. In this situation it is desired to determine the difference in elevation between two points on the ground (P_1 and P_2) from an instrument station (E) that is located between the two points.

For this discussion, let us assume that a backsight is taken on a rod held at P_1 and then a foresight is taken to P_2. Now the difference in elevation *(DE)* between the two points can be written as follows:

$$DE = P_1A + AB + CD - P_2D.$$

In reverse, if a backsight was taken to P_2 with a foresight to P_1, then the expression for *DE* can be written as follows:

$$DE = CD - P_2D - AB - P_1A.$$



TOPOGRAPHIC DETAILS, NORTH FIELD

	⊼ at	D,			
	BS A	∢'s	rt.		
	El. 532.4		H.I. 4.8.		
Obj	Hor. ∢	Rod Int.	Vert. ∢	Hor. Dist.	Diff. El.
1	30°10'	6.23	-3°26'	622	-37.4
2	34°36'	6.55	-3°18'	654	-37.8
3	30°31'	5.45	-3°54'	543	-37.0
4	38°41'	5.25	-3°58'	523	-36.3
5	40°51'	4.32	-4°38'	430	-34.9
6	41°38'	4.66	-4°22'	464	-35.5
7	49°02'	3.61	-5°24'	359	-33.9
8	25°22'	3.11	-6°04'	309	-32.7
9	36°17'	2.77	-6°44'	274	-32.4
10	19°13'	1.64	-11°01'	159	-30.9
11	41°05'	1.55	-11°48'	149	-31.2
12	9°23'	3.88	+3°88'	387	-0.8
13	22°46'	4.40	0°5.6	440	+21.6
14	70°00'	3.04	+3°58'	303	+21.1
15	95°12'	1.76	+7°25'	174	+22.6
16	108°39'	3.36	+5°52'	333	+34.2
17	134°55'	2.42	+10°48'	234	+44.0

Note: (1) Shots along creek are top-of-bank shots. Average elevation of creek bottom is 2 Ft below top of bank.

(2) Direct levels at obj 13.

Smith E., EA 2. ⊼

Gurley Transit #2

Brown D., EACN, Rod #4

27 March 19__

clear, cold

	REMARKS
Elev.	
495.0	left bank of creek
494.6	right " " "
495.4	left " " "
496.1	right " " "
497.5	left " "
496.9	right " "
498.5	" " "
499.7	left " "
500.2	right " "
501.5	left " "
501.2	right " "
531.6	ground point
534.0	" "
553.5	" "
555.0	" "
566.6	" "
577.2	" "

Figure 8-10.-Notes for locating topographical details by transit and stadia.

Now let us see how all that you have learned about transit-stadia topography is used in the field Figure 8-10 shows field notes for locating topographic details by transit and stadia. The details shown by numbers in the sketch on the Remarks side are listed on the data side by numbers in the column headed Obj. At the top of the page on the data side, you see that control point D_1 was used as the instrument station. Immediately below this, you see that from instrument-station D_1, the transit was backsighted to point *A* and that all horizontal angles were measured to the right from the backsight on *A*.

In the third line from the top on the data side, you see that the known elevation of D_1 *is* 532.4 feet and that the vertical distance (hi.) from the point or marker at D_1 to the center of the instrument above D_1 is 4.8 feet. This vertical distance was carefully determined by measurement with a tape or rod held next to the instrument.

Now let us see how each of the objective points was detailed. We will begin with point 1. Remember that in this example, D_1 *is the* instrument station from which all observations are made.

To determine the direction of point 1, train the transit telescope on *A* and match the zeros. Next turn the telescope right to train on point 1 and read the horizontal angle (30°10′).

Minutes	0°		1°		2°		3°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
C=0.75	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
C=1.00	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
C=1.25	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

Figure 8-11.-Horizontal distances and elevations from stadia readings.

For the horizontal distance and elevation of point 1, set a rod on the point, and train the lower stadia hair of the transit telescope on a whole-foot mark on the rod so that the center hair is near the 4.8 graduation. (This is a common practice in stadia work that makes reading the stadia interval easier.) Then read and record the stadia interval (in this case 6.23 feet). Next, rotate the telescope about the horizontal axis until the center hair is on the 4.8 rod graduation. Lock the vertical motion and read and record the vertical angle (-3026'). Be sure to record each vertical angle correctly as plus or minus. While you are reading and recording the vertical angle, the rodman can be moving to the next point. This will help speed up the survey.

From the stadia interval and the vertical angle reading, the horizontal distance (entered in the fifth column of fig. 8-10) and the difference in elevation (in the sixth column) are determined from a stadia reduction table. Figure 8-11 shows the page from a stadia reduction table that applies to the data for point 1 in figure 8-10. For this point, the vertical angle is **–3°26′,** and the stadia interval is 6.23 feet. In the table under 3° and opposite 26′, note that the multiplier for horizontal distance is 99.64, while the one for difference in elevation is 5.98. If the final distance is ignored, the horizontal distance is

$$6.23 \times 99.64 = 620.75 \text{ (or 621 feet).}$$

The difference is elevation is

$$6.23 \times 5.98 = 37.3 \text{ feet.}$$

To these figures, add the corrections for focal distance given at the bottom of the page. For an instrument with a focal distance of 1 foot, add 1 foot to the horizontal difference (making a total horizontal distance of 622 feet) and 0.06 foot to the difference in elevation This makes the difference in elevation round off to 37.4 feet; and since the vertical angle has a negative (-) sign, the difference in elevation is recorded as –37.4 feet.

In the first column on the Remarks side of figure 8-10, enter the elevation of each point, computed as follows. For point 1, the elevation equals the elevation of instrument station D_1 (532.4 feet) minus the difference in elevation (37.4 feet), or 495.0 feet. Subtract the difference in elevation, in this case, because the vertical angle you read for point 1 was negative. For a positive vertical angle (as in the cases of points 12 and 13 through 17 of your notes), add the difference in elevation

The remainder of the points in this example were detailed in a similar reamer except for point 13. When a detail point is at the same, or nearly the same, elevation as the instrument station, the elevation can be determined more readily by direct leveling. 'That was the case for point 13. As seen in the vertical-angle column of the notes, the vertical angle was 0° at a rod reading of 5.6 feet. Therefore the elevation of point 13 is equal to the elevation of the instrument station (532.4 feet) plus the h.i. (4.8 feet) minus the rod reading (5.6 feet), or 531.6 feet.

In the above example, as you recall, the transit was initially backsighted to point *A* and the zeros were matched This was because the azimuth of D_1A was not known. However, if you knew the azimuth of D_1A, you could indicate your directions in azimuths instead of in angles right from D_1A. Suppose, for example, that the azimuth of D_1A was 26°10′. Train the telescope on *A* and set the horizontal limb to read 26°10′. Then when you train on any detail point, read the azimuth of the line from D_1 to the detail point.

TOPOGRAPHIC MAPPING

Now you know how to perform and record a topographic survey, using the transit-tape or tranSit-stadia methods. Next, we will see how the draftsman (who also might be you) prepares a topographic map. To enhance the explanation of topographic mapping, we will also discuss some additional field methods the surveyor uses.

REPRESENTATION OF RELIEF

One of the purposes of a topographic map is to depict relief. In fact, this is the main feature that makes a topographic map different from other types of maps. Before you go any further, refresh your memory on the subject of topographic relief. *Relief* is the term for variance in the vertical configuration of the earth's surface. You have seen how relief can be shown in a plotted profile or cross section. These, however, are views on a vertical plane, but a topographic map is a view on a horizontal plane. On a map of this type, relief may be indicated by the following methods.

A relief model is a three-dimensional relief presentation-a molded or sculptured model, developed in suitable horizontal and vertical scales, of the hills and valleys in the area.

Shading is a pictorial method of showing relief by the use of light and dark areas to suggest the shadows that would be created by parallel rays of light shining across the area at a given angle.

Hachures area pictorial method similar to shading except that the light-and-dark pattern is created by short hachure lines, drawn parallel to the steepest slopes. Relative steepness or flatness is suggested by varying the lengths and weights of the lines.

Contour lines are lines of equal elevation; that is, each contour line on a map is drawn through a succession of points that are all at the same elevation. A contour is the real-life equivalent; that is, a line of equal elevation on the earth's surface.

All of these methods of indicating relief are illustrated in figure 8-12. The contour-line method is the one most commonly used on topographic maps.

CONTOUR LINES

Contour lines indicate a vertical distance above, or below, a datum plane. Contours begin at sea level, normally the zero contour, and each contour line represents an elevation above (or below) sea level. The

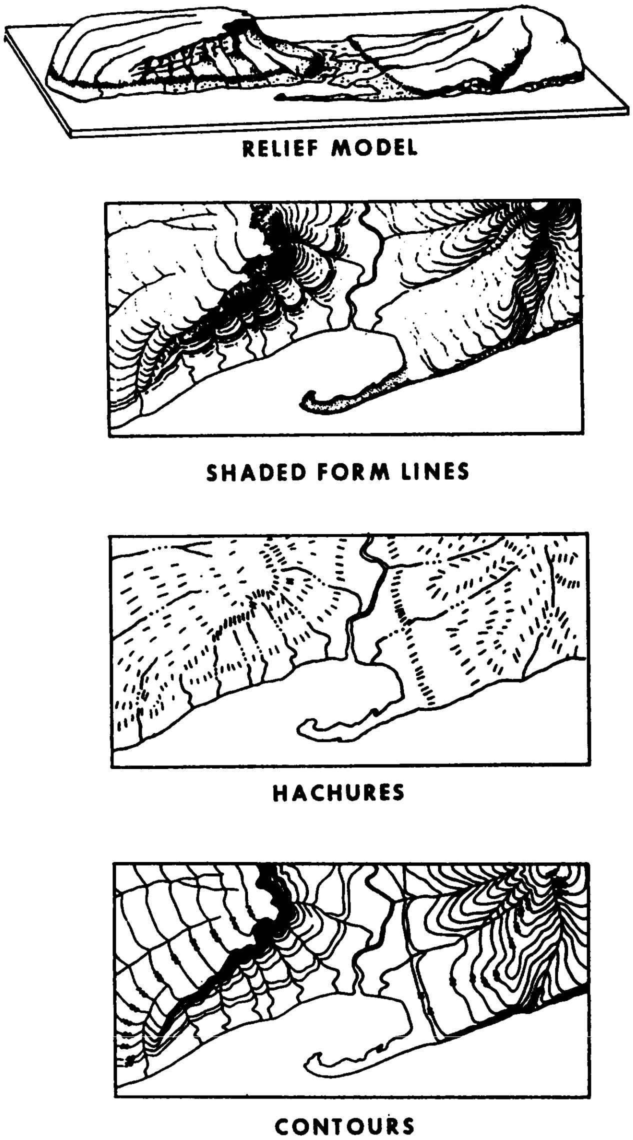


Figure 8-12.-Methods of indicating relief.

vertical distance between adjacent contour lines is known as the contour interval. Starting at zero elevation the topographer draws every fifth contour line with a heavier line. These are known as index contours. At some place along each index contour, the line is broken and its elevation is given. The contour lines falling between index contours are called intermediate contours. They are drawn with a finer line than the index contours and, usually, do not have their elevations given. Examples of index contours and intermediate contours are shown in figure 8-13.

GROUND POINT SYSTEMS

The essential data for showing relief by contour lines consists of the elevation of a sufficient number of ground points in the area. Methods of determining the horizontal and vertical locations of these ground points are called ground point systems. The systems most frequently used are (1) tracing contours, (2) grids, (3) control points, and (4) cross profiles. In practice, combinations of these methods may be used in one survey.

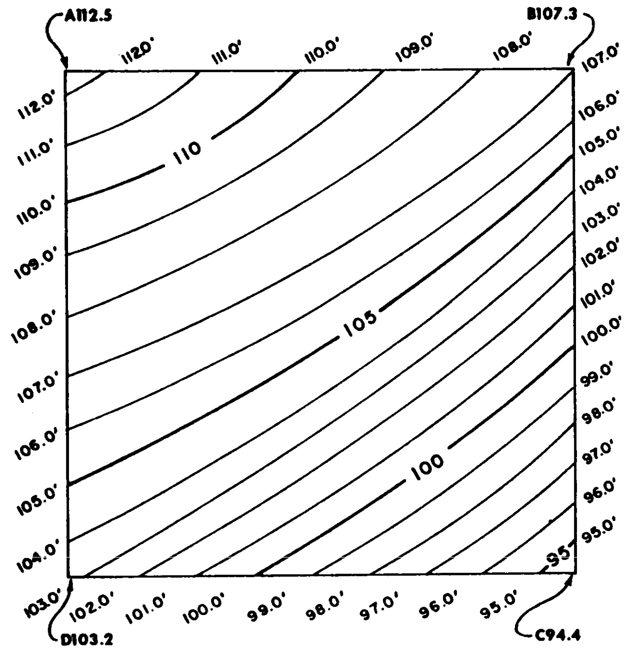


Figure 8-13.—Traverse with contour lines.

Tracing Contours

In the tracing contours system, the ground points located are points on the actual contours. Points on a given contour are plotted on the map, and the contour line is drawn through the plotted points. The method may be illustrated by the following simple example.

Refer again to the traverse shown in figure 8-13. In this figure, assume that the traverse runs around the perimeter of a small field. The elevations at comers *A, B, C,* and *D* are as shown. Obviously the ground slopes downward from AB toward *DC* and from *AD* toward *BC.*

You want to locate contours at a contour interval of 1 fret; that is, you want to plot the 112-foot contour line, the 110-contour line, the 110-foot contour line, and so forth. In this example, we will assume that the required order of precision is low, such as you may encounter in a reconnaissance survey, and because of this you are using a hand level.

You stand at station *A* with a hand level. The elevation of this station is 112.5 feet. Assume that the vertical distance from your eye level to the ground is 5.7 feet. 'Then with the hand level at your eye and with you standing on station *A,* the HI is

112.5 + 5.7= 118.2 feet.

If a level rod is set up anywhere on the 112.0-foot contour, the reading you would get from station *A* would be

118.2 – 112.0= 6.2 feet.

Therefore, to determine the point where the 112.0 foot contour crosses *AB,* you only need to have the rodman back out from point *A* along *AB* until he comes to the point where you read 6.2 feet on the rod. You can determine the point where the 112.0-foot contour crosses *AD* in the same reamer as *AB.* You can measure the distance from *A* to each point and then record the distance from *A* to the 112.0-foot contour on *AB* and *AD.*

When all of the contours have been located on *AB* and *AD,* you can shift to station C and carry out the same procedure to locate the contours along *BC* and *CD.* You have now located all the points where contours at a l-foot interval intersect the traverse lines. If the slope of the ground is uniform (as it is presumed to be in fig. 8-13), you can plot the contour lines by simply drawing lines between points of equal elevation, as shown in that figure. If there were irregularities in the slope, you would send the rodman out along one or more lines laid across the irregular ground, locating the contours on these lines as you located them on the traverse lines.

Grid Coordinate System

In the grid coordinate system, the area is laid out in squares of convenient size, and the elevation of each comer point is determined. While this method lends itself to use on relatively level ground, ridge or valley lines must be located by spot elevations taken along the lines. The locations of the desired contours are then determined on the ridge and valley lines and on the sides of the squares by interpolation. This gives a series of points through which the contour lines may be drawn

Figure 8-14 illustrates this method. Assume that the squares here measure 200.0 feet on each side. Points *a, b,* and *c* are points on a ridge line, also 200.0 feet apart. You need to locate and draw the 260.0-foot contour line. By inspection, you can see that the 260.0-foot contour must cross *AD* since the elevation of *A* is 255.2 feet and the elevation of *D* is 263.3 feet. However, at what point does the 260.0-foot contour cross *AD?* This can be determined by using a proportional equation as follows.

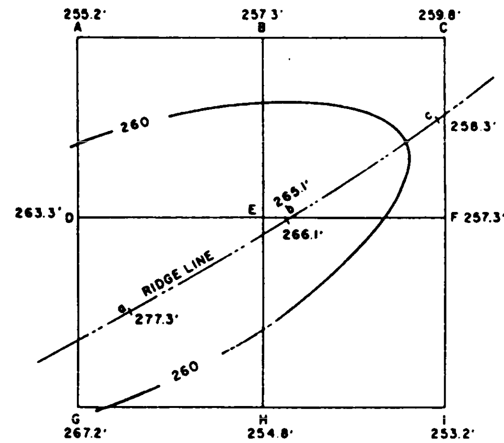


Figure 8-14.-Grid system of ground points

Assume that the slope from *A* to *D* is uniform. The difference in elevation is 8.1 feet (263.3 – 255.2) for 200.0 feet. The difference in elevation between 255.2 and 260.0 feet (elevation of the desired contour) is 4.8 feet. The distance from *A* to the point where the 260.0-foot contour crosses *AD* is the value of x in the proportional equation: 8.1:200 = *4.8:x* or x = 118.5 feet. Lay off 118.5 feet from *A* on *AD* and make a mark.

In the same manner, you locate and mark the points where the 260.0-foot contour crosses *BE,EF, EH,* and *GH.* The 260.0-foot contour crosses the ridge, obviously, between point *b* (elevation 266.1 feet) and point *c* (elevation 258.3 feet). The distance between *b* and *c* is again 200.0 feet. Therefore, you obtain the location of the point of crossing by the same procedure just described.

You now have six plotted points: one on the ridge line between *b* and *c* and the others on *AD, BE, EF, EH,* and *GH.* A line sketched by hand through these points is the 260.0-foot contour line. Note that the line is, in effect, the line that would be formed by a horizontal plane that passed through the ridge at an elevation of 260.0 feet. Note, too, that a contour line changes direction at a ridge summit.

Control Points

This explanation illustrates the fact that any contour line may be located by interpolation on a uniform slope between two points of known elevation a known distance apart. We, also, demonstrated how a ridge line is located in the same manner.

If you locate and plot all the important irregularities in an area (ridges, valleys, and any other points where

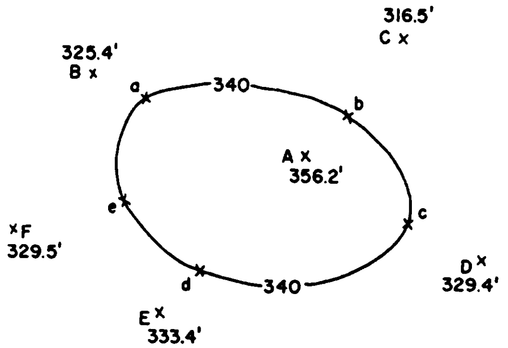


Figure 8-15.-Control-point method of locating contour.

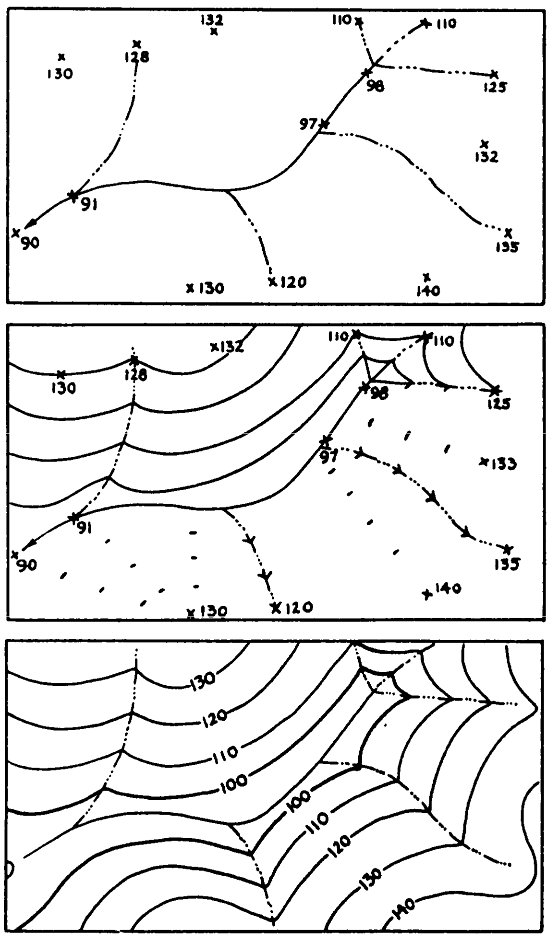


Figure 8-16.-Sketching contours by interpolation between control points of known elevations.

elevation changes radically), you can draw a contour map of the area by interpolating the desired contours between the control points.

A very elementary application of the method is shown in figure 8-15. Point *A* is the summit of a more or less conical hill. A spot elevation is taken here. Spot elevations are also taken at points B, C, *D, E,* and *F,*

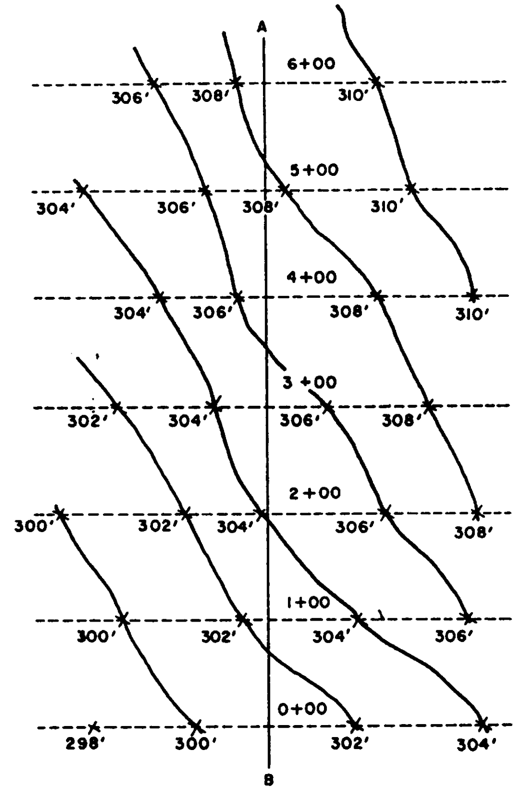


Figure 8-17.-Cross profiles.

which are points at the foot of the hill. It is desired to draw the 340.0-foot contour. Point *a* on the contour line is interpolated on the line from *A* to *B,* point *b is* interpolated on the line from *A* to *C,* point *c* is interpolated on the line from *A* to *D,* and soon.

Figure 8-16 shows a more complicated example in which contours are interpolated and sketched between controlling spot elevations taken along a stream.

Cross Refiles

In the cross-profile system, elevations are taken along selected lines that are at right angles to a traverse line. Shots are taken at regular intervals or at breaks or both in the ground slope. The method is illustrated in figure 8-17. The line *AB* is a traverse along which 100-foot stations are shown. On each of the dotted cross-section lines, contours are located. The particular contour located at a particular station depends on (1) the ground elevations and (2) the specified contour interval. In this instance, it is 2 feet. The method used to locate the contours is the one described earlier for tracing a contour system. When the even-numbered 2-foot interval contours are located on all the cross-profiles lines, the contour lines are drawn through the points of equal elevation.

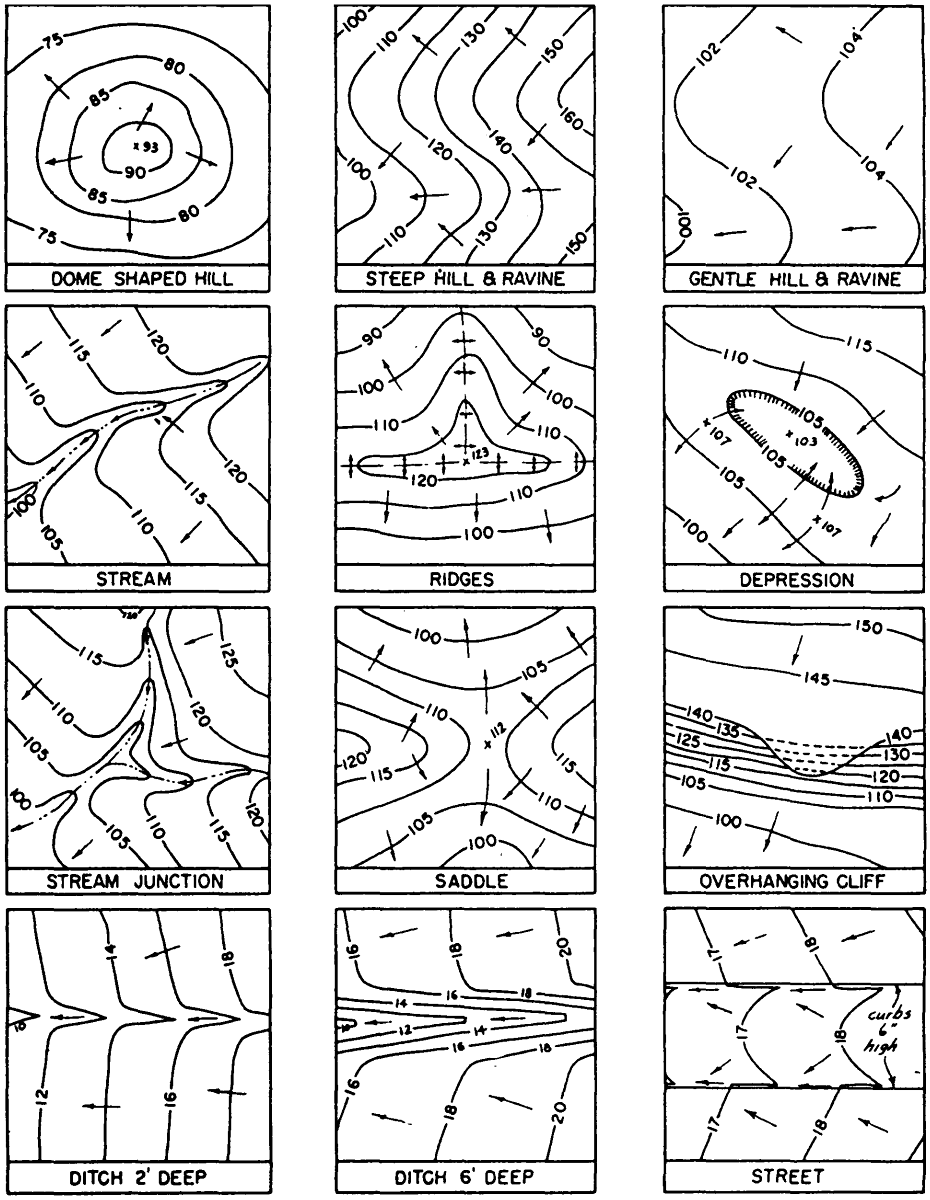


Figure 8-18.-Typical contour formations.

CHARACTERISTICS OF CONTOUR LINES

A contour line is a line of equal elevation; therefore, two different lines must indicate two different elevations. So two different contour lines cannot intersect or otherwise contact each other except at a point where a vertical or overhanging surface, such as a vertical or overhanging face of a cliff, exists on the ground Figure 8-18 shows an overhanging cliff. You can see how the segments of contour lines on this cliff are made as dotted (or hidden) lines. Aside from the exception mentioned, any point where two different contour lines intersect would be a point with two different elevations-an obvious impossibility.

In forming a mental image of the surface configuration from a study of contour lines, it is helpful for you to remember that a contour line is a level line; that is, a line that would be formed by a horizontal plane passing through the earth at the indicated elevation. If you keep this concept of levelness in mind you can usually get the "feel" of the rise and fall of the ground as you study the contour lines on the map.

A contour line must close on itself somewhere—either within or beyond the boundaries of the map. A line

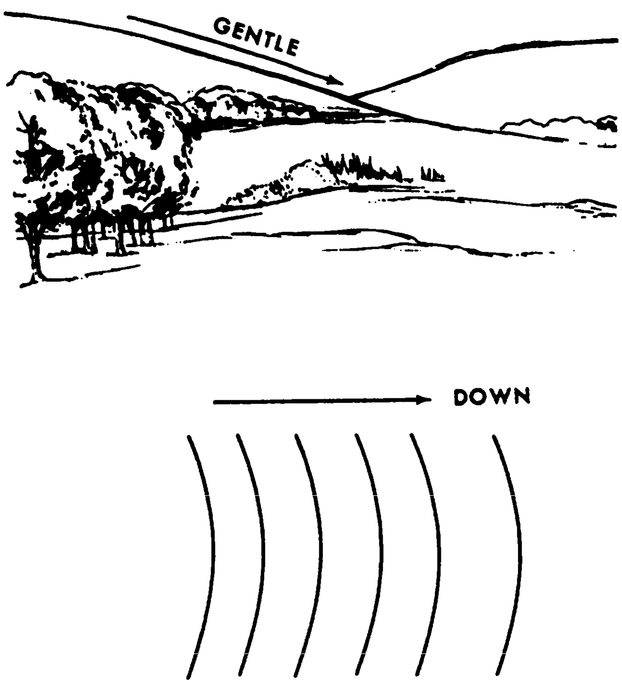


Figure 8-19.-Uniform, gentle slope.

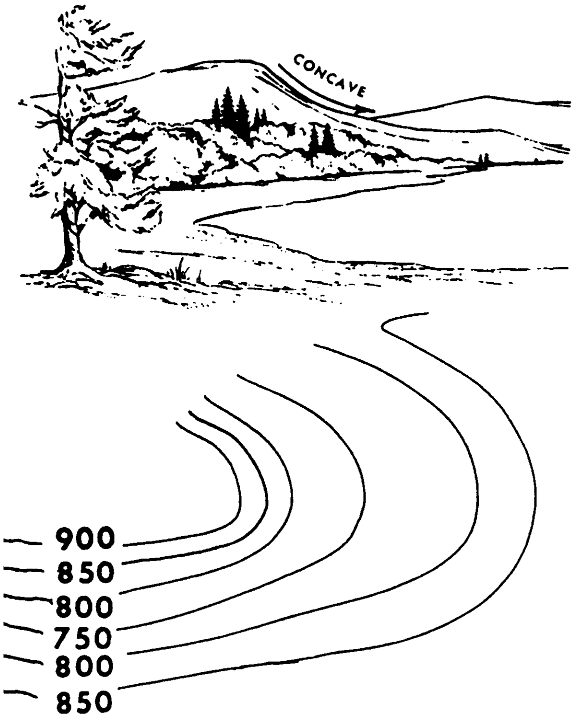


Figure 8-21.-Concave slope.

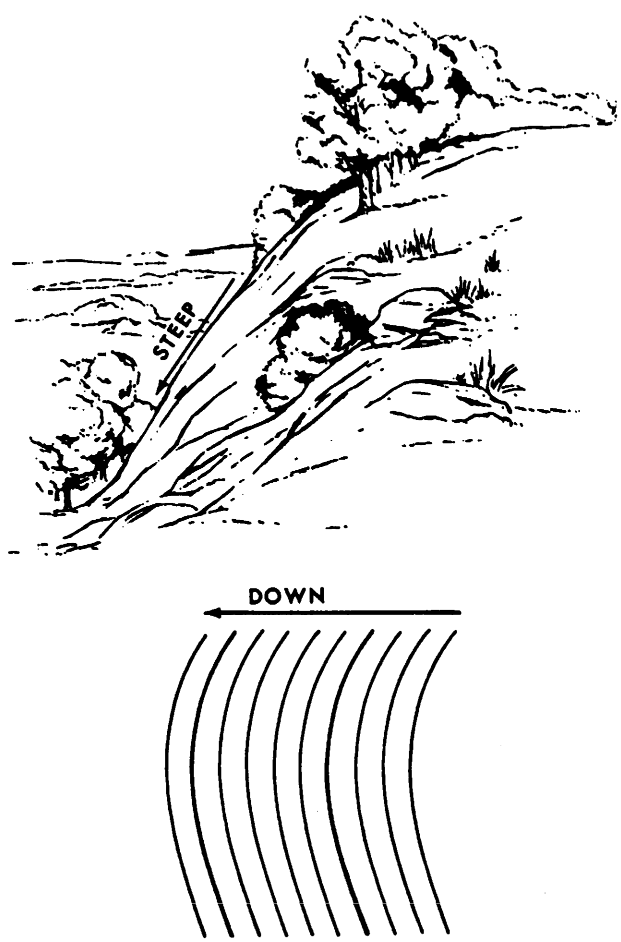


Figure 8-20.-Unifrom, steep slope.

that appears on the map completely closed may indicate either a summit or a depression. If the line indicates a depression, this fact is sometimes shown by a succession of short hachure lines, drawn perpendicular to the inner side of the line. An example of a depression is shown in figure 8-18. A contour line marked in this fashion is called a depression contour.

On a horizontal or level plane surface, the elevation of all points on the surface is the same. Therefore, since different contour lines indicate different elevations, there can be no contour lines on a level surface. On an inclined plane surface, contour lines at a given equal interval will be straight, parallel to each other, and equidistant.

A number of typical contour formations are shown in figure 8-18. For purposes of simplification, horizontal scales are not shown; however, you can see that various intervals are represented. The arrows shown indicate the direction of slope.

Generally, the spacing of the contour lines indicates the nature of the slope. Contour lines (fig. 8-19) that are evenly spaced and wide apart indicate a uniform, gentle slope. Contour lines (fig. 8-20) that are evenly spaced and close together indicate a uniform, steep slope. The closer the contour lines are to each other, the steeper the slope. Contour lines closely spaced at the top and widely spaced at the bottom indicate a concave slope (fig. 8-21).

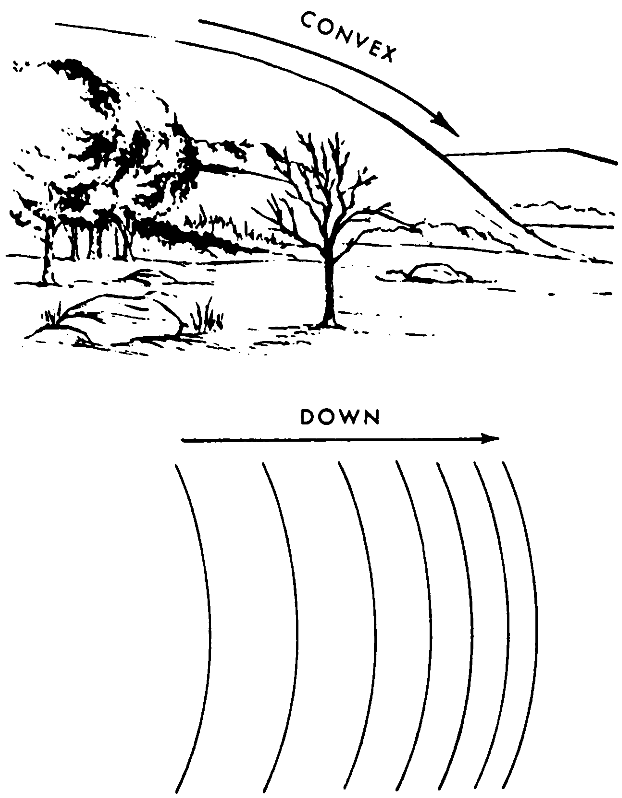


Figure 8-22.-Convex slope

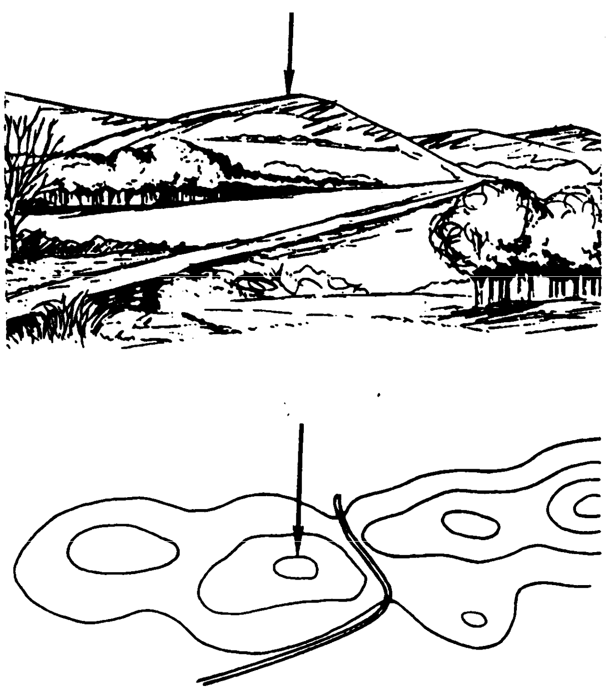


Figure 8-23.-Hill.

Contour lines widely spaced at the bottom indicate a convex slope (fig. 8-22).

A panoramic sketch is a pictorial representation of the terrain in elevation and perspective as seen from one point of observation. This type of map shows the

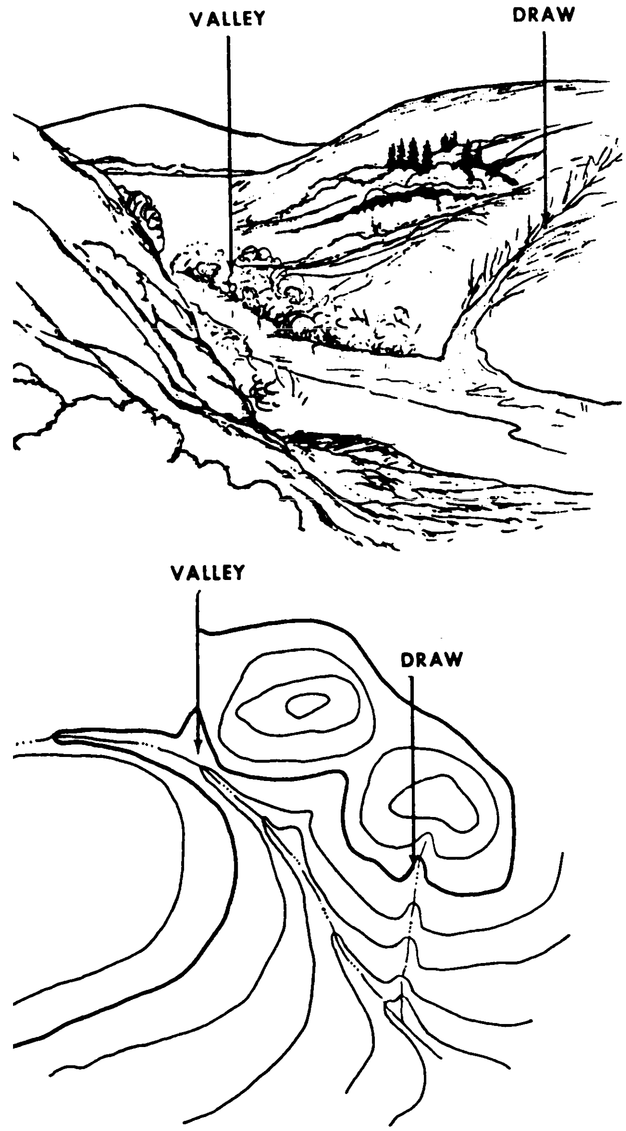


Figure 8-24.-Valley and draw.

horizon, which is always of military importance, with intervening features, such as crests, woods, structures, roads, and fences. Figures 8-23 through 8-29 show panoramic sketches and maps. Each figure shows a different relief feature and its characteristic contour pattern. Each relief feature illustrated is defined in the following paragraphs.

A hill is a point or small area of high ground (fig. 8-23). When you are on a hilltop, the ground slopes down in all directions.

A stream course that has at least a limited extent of reasonably level ground and is bordered on the sides by higher ground is a valley (fig. 8-24). The valley, generally, has maneuvering room within it. Contours indicating a valley are U-shaped and tend to parallel a major stream before crossing it. The more gradual the

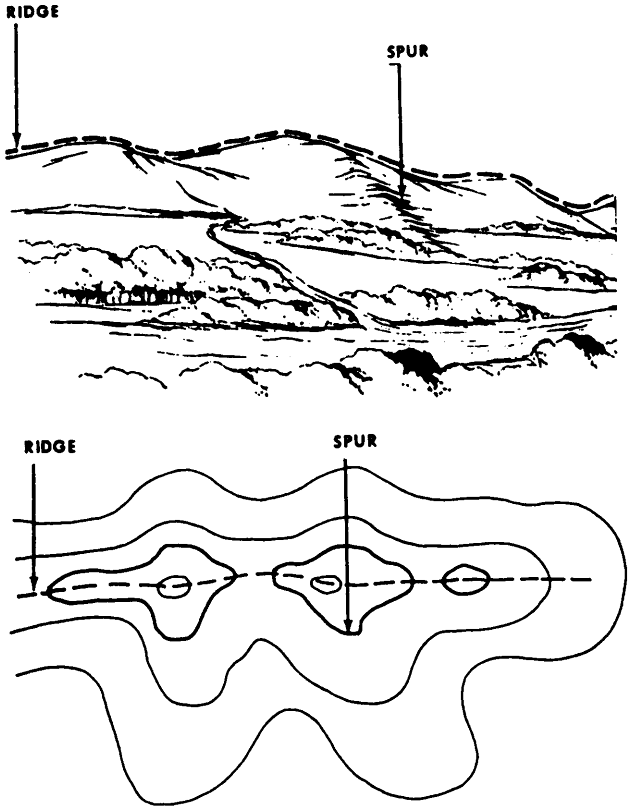


Figure 8-25.-Ridge and spur.

fall of a stream, the farther each contour parallels it. The curve of the contour crossing always points upstream.

A draw is a less-developed stream course where there is essentially no level ground and, therefore, little or no maneuvering room within its sides and towards the head of the draw. Draws occur frequently along the sides of ridges at right angles to the valley between them. Contours indicating a draw are V-shaped with the point of the V toward the head of the draw.

A ridge is a line of high ground that normally has minor variations along its crest (fig. 8-25). The ridge is not simply a line of hills; all points of the ridge crest are appreciably higher than the ground on both sides of the ridge.

A spur is usually a short continuously sloping line of higher ground normally jutting out from the side of a ridge (fig. 8-25). A spur is often formed by two roughly parallel streams that cut draws down the side of the ridge.

A saddle is a dip or low point along the crest of a ridge. A saddle is not necessarily the lower ground between the two hilltops; it maybe simply a dip or break along an otherwise level ridge crest (fig. 8-26).

A depression is a low point or sinkhole, surrounded on all sides by higher ground (fig. 8-27).

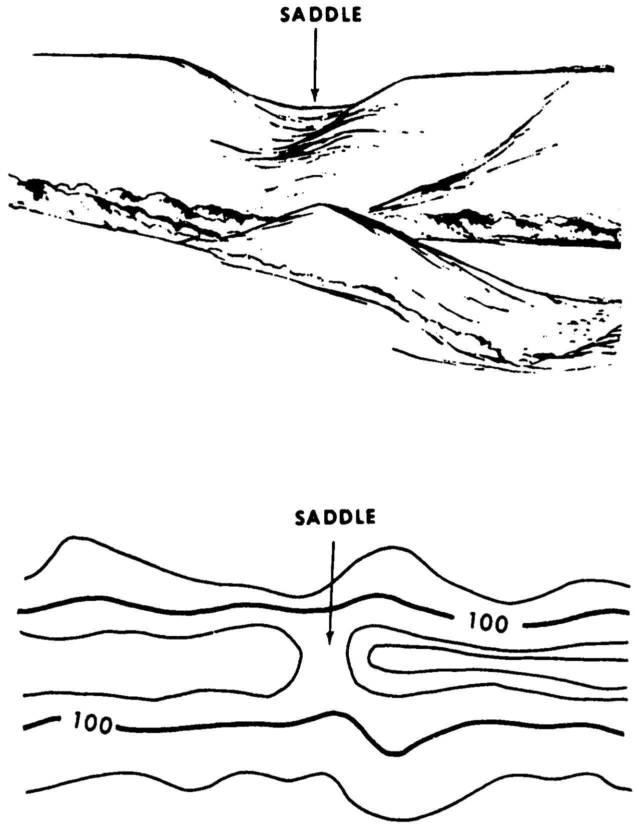


Figure 8-26.-Saddle.

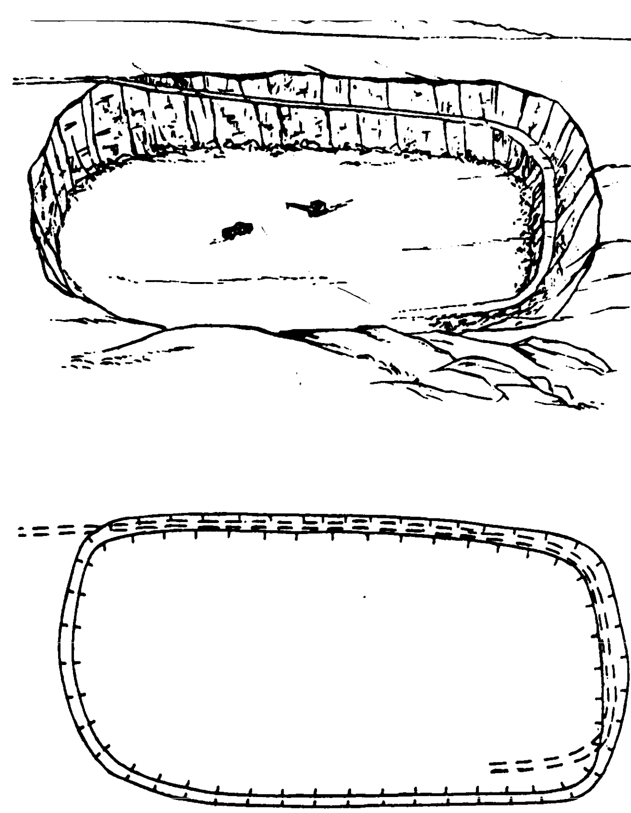


Figure 8-27.-Depression.

Table 8-1.-Recommended Contour Intervals–Topographic Map

TYPES OF TOPOGRAPHIC MAP	NATURE OF TERRAIN	RECOMMENDED CONTOUR INTERVAL IN FT
LARGE SCALE	Flat	0.5 or 1
	Rolling	1 or 2
	Hilly	2 or 5
INTERMEDIATE SCALE	Flat	1, 2, or 5
	Rolling	2 or 5
	Hilly	5 or 10
SMALL SCALE	Flat	2, 5, or 10
	Rolling	10 or 20
	Hilly	20 or 50
	Mountainous	50, 100, or 200

Cuts and fills are man-made features that result when the bed of a road or railroad is graded or leveled off by cutting through high areas and filling in low areas along the right-of-way (fig. 8-28).

A vertical or near vertical slope is a cliff. As described previously, when the slope of an inclined surface increases, the contour lines become closer together. In the case of a cliff, the contour lines can actually join, as shown in figure 8-29. Notice the tick marks shown in this figure. These tick marks always point downgrade.

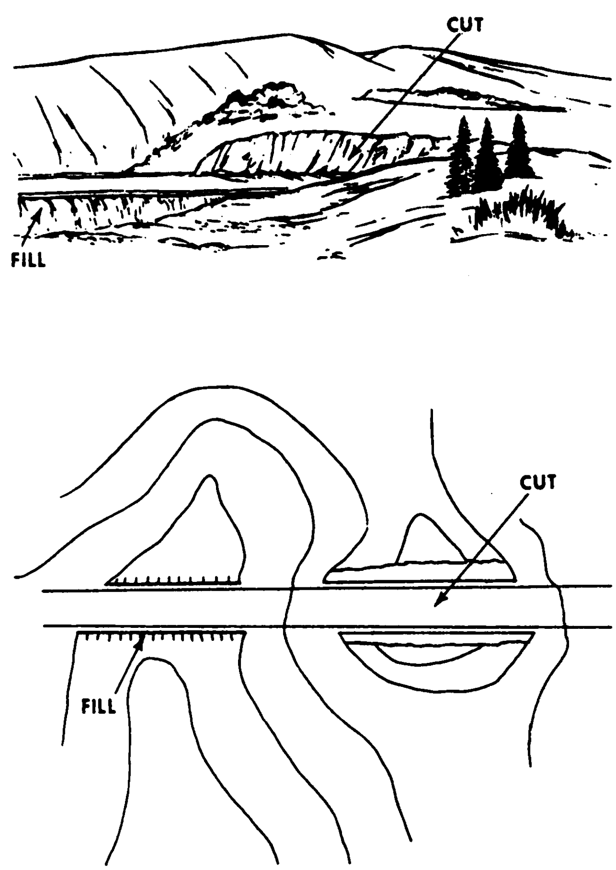


Figure 8-28.-Contour (cut and fill).

MAP SCALES AND CONTOUR INTERVALS

A topographic map is called either large scale, intermediate scale, or small scale by the use of the following criteria:

Large scale: 1 inch= 100 feet or less

Intermediate scale: any scale from 1 inch= 100 feet to 1 inch= 1,000 feet

Small scale: 1 inch= 1,000 feet or more.

The designated contour interval varies with the purpose and scale of the map and the character of the terrain. Table 8-1 shows the recommended contour intervals that you may use to prepare a topographic map.

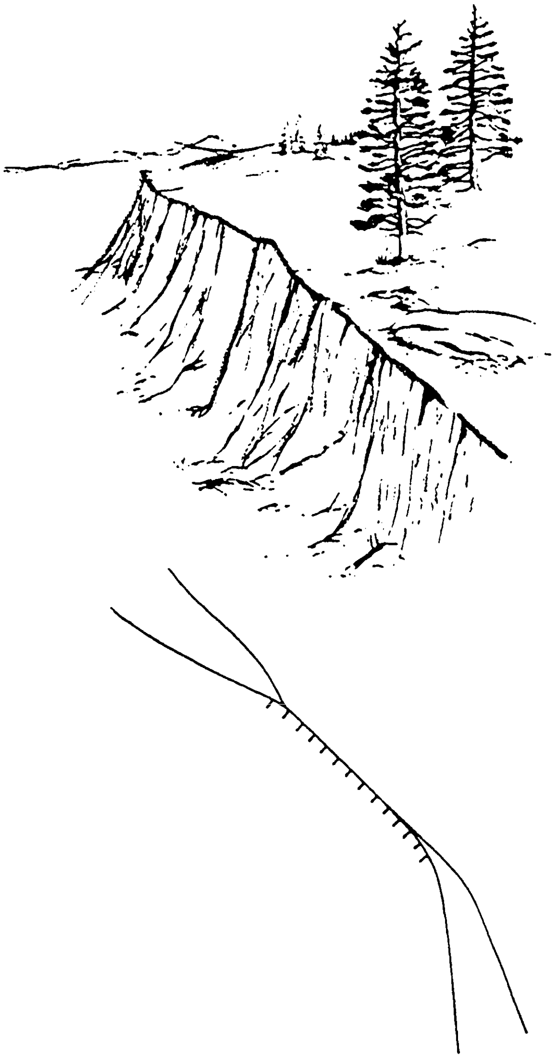


Figure 8-29.—Cliff.

CONTOUR MAP CONSTRUCTION

If EAs can perform ordinary engineering drafting chores, they will not have any difficulty in constructing a topographic map. To some degree, topographers must draw contour lines by estimation. Their knowledge of contour line characteristics and the configuration of the terrain that the contour lines represent will be a great help. Topographers must use their skill and judgment to draw the contour lines so that the lines are the best representation of the actual configuration of the ground surface.

Basically, the construction of a contour map consists of three operations. They are as follows:

1. Plot horizontal control that will serve as the framework of the map.

2. Plot details, including the map location of ground points of known ground elevation. These ground points or contour points will be used as guides for the proper location of the contour lines.

3. Construct contour lines at given contour intervals.

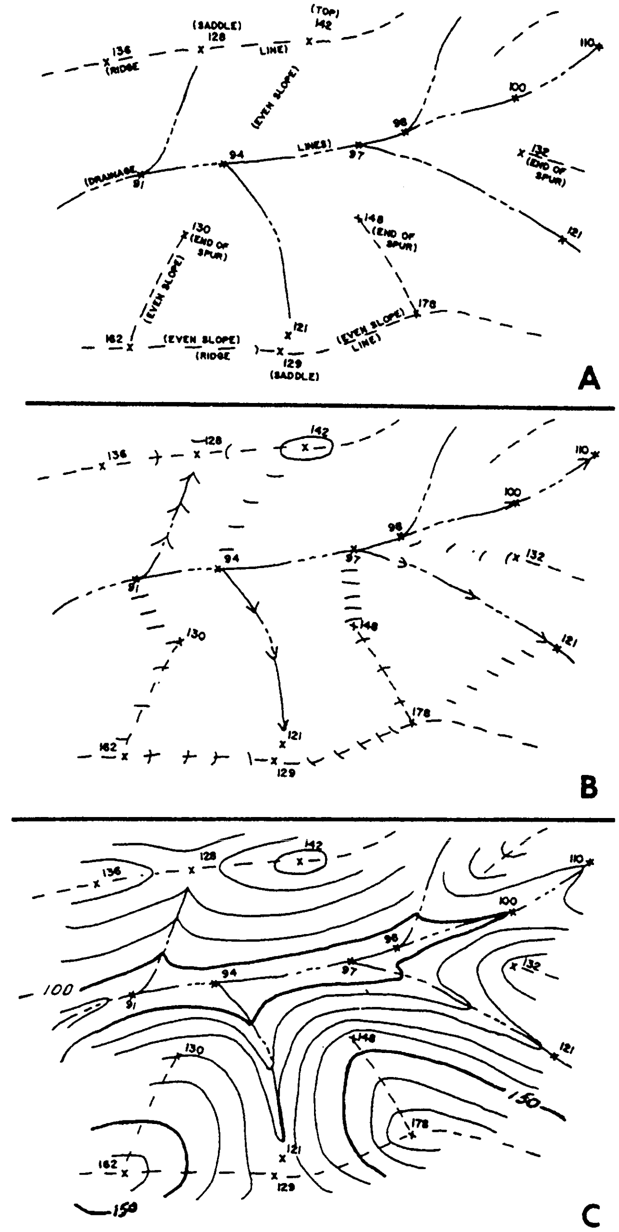


Figure 8-30.—Plotting detail and contouring.

Take special care, in the field, to locate ridge and valley lines because you usually draw these lines first on the map before plotting the actual contour points. (See fig. 8-30, view A.) Since contours ordinarily change direction sharply where they cross these lines and the slopes of ridges and valleys are fairly uniform, these lines aid you in drawing the correct contour lines. After the ridge and valley lines are plotted, space contour crossings (by interpolation) along them before

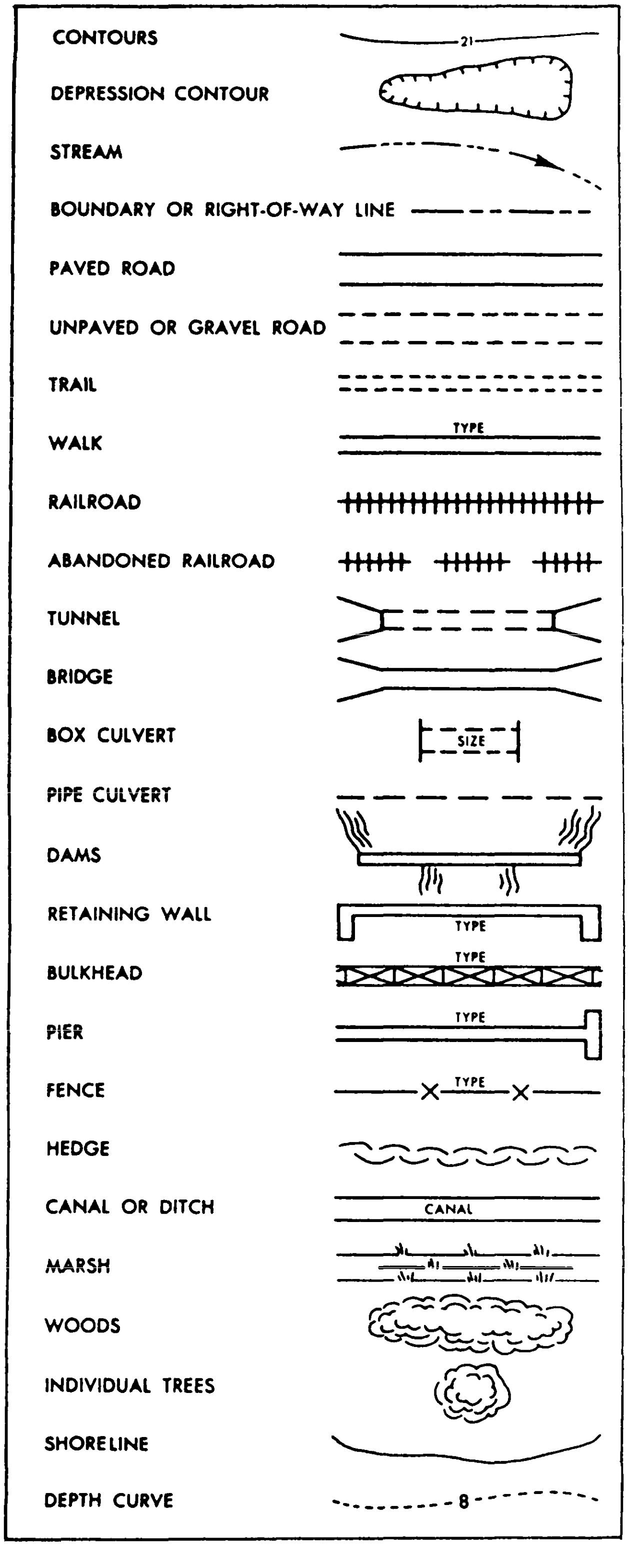


Figure 8-31.-Commonly used map symbols.

making any attempt to interpolate or to draw the complete contour lines. (See fig. 8-30, view B.)

Contour lines can be smoothly drawn freehand with uniform width and with best results if a contour pen is used. Breaks in the lines are provided to leave spaces for the elevations. The numbers that represent these elevations are written this way so that they maybe read from one or two sides of the map. Some authorities prefer that elevations also be written in a way that the highest elevation numbers are arranged from the lowest to the highest uphill. Spot elevations are shown at important points, such as road intersections.

Figure 8-30, view C, shows the completed contour map. For more refined work, the EA must trace the map, using a contour pen on tracing paper or other appropriate medium, to allow reproduction of more copies, if needed.

Often on a large-scale map, you can represent the true shape of features to scale. On small-scale maps, however, you often use symbols for buildings and other features. Center the symbol on the true position, but draw it larger than the scale of the map. Detail of this type is portrayed on the map by means of standardized topographic symbols, such as shown in figure 8-31.

When you are plotting contours, remember that stream and ridge lines have a primary influence on the direction of the contour lines. Also, remember that the slope of the terrain controls the spacing of the contour lines. Contour lines crossing a stream follow the general direction of the stream on both sides, then cross the stream in a fairly sharp V that points upstream. Also, remember that contour lines curve around the nose of ridges in the form of a U pointing downhill and cross ridge lines at approximate y right angles.

INTERPOLATING CONTOUR LINES

In the examples of interpolation previously given, a single contour line was interpolated between two points of known elevation, a known horizontal distance apart, and by mathematical computation. In actual practice, usual] y more than one line must be interpolated between a pair of points; and large numbers of lines must be interpolated between many pairs of points. Mathematical computation for the location of each line would be time-consuming and would be used only in a situation where contour lines had to be located with an unusually high degree of accuracy.

For most ordinary contour-line drawings, one of several rapid methods of interpolation is used. In each case it is assumed that the slope between the two points of known elevation is uniform.

Figure 8-32 shows the use of an engineer's scale to interpolate the contours at 2-foot intervals between *A* and B. The difference in elevation between *A* and *B* is

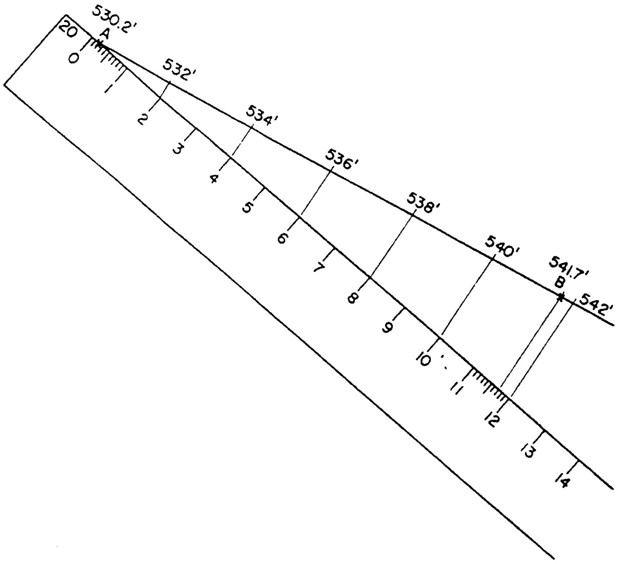


Figure 8-32.—Interpolating contour lines with a scale.

between 11 and 12 feet. Select the scale on the engineer's scale that has 12 graduations for a distance and comes close to matching the distance between *A* and *B* on the map. In figure 8-32, this is the 20 scale. Let the 0 mark on the 20 scale represent 530.0 feet. Then the 0.2 mark on the scale will represent 530.2 feet, the elevation of *A*. Place this mark on *A,* as shown.

If the 0 mark on the scale represents 530.0 feet, then the 11.7 mark represents

530.0 + 11.7, or 541.7 feet,

the elevation of *B*. Place the scale at a convenient angle to the line from *A* to *B,* as shown, and draw a line from the 11.7 mark to *B*. You can now project the desired contour line locations from the scale to the line from *A* to *B* by drawing lines from the appropriate scale graduations (2, 4, 6, and so on) parallel to the line from the 11.7 mark to *B*.

Figure 8-33 shows a graphic method of interpolating contour lines. On a transparent sheet, draw a succession of equidistant parallel lines. Number the lines as shown in the left margin. The 10th line is number 1; the 20th, number 2, and so on. Then the interval between each pair of adjacent lines represents 0.1 feet.

Figure 8-33 shows how you can use this sheet to interpolate contour lines at a 1-foot interval between point *A* and point B. Place the sheet on the map so that the line representing 1.7 feet (elevation of *A* is 500.0 + 1.7, or 501.7 feet) is on *A,* and the line representing 6.2 feet (elevation of *B* is 500.0 + 1.7, or 506.2 feet) is on *B*. You can see how you can then locate the l-foot contours between *A* and *B*.

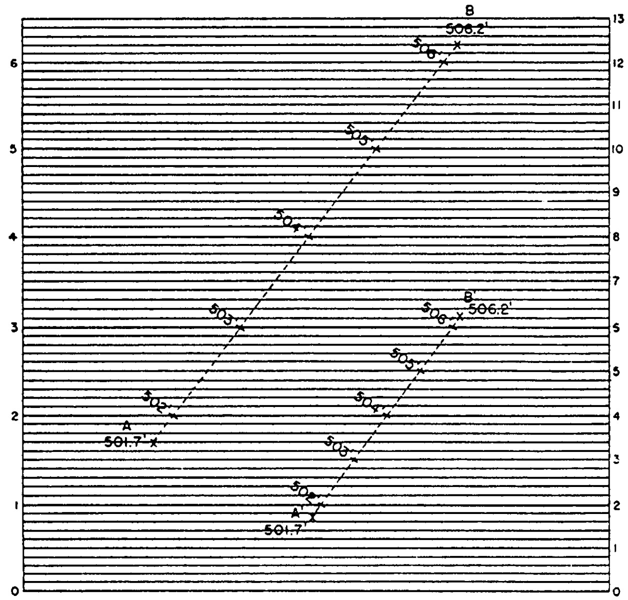


Figure 8-33.—Graphic method of interpolating contour lines.

For a steeper slope, the contour lines would be closer together. If the contour lines were too close, you might find it advisable to give the numbers on the graphic sheet different values, as indicated by the numerals in the right-hand margin. Here the space between each pair of lines represents not 0.1 foot, but 0.2 foot. Points *A´* and B´ have the same elevations as points *A* and B, but the fact that the horizontal distance between them is much shorter shows that the slope between them is much steeper. You can see how the 1-foot contours between *A´* and B´ can be located, using the line values shown in the right margin.

A third method of rapid interpolation involves the use of a rubber band, marked with the correct, equal decimal intervals. The band is stretched to bring the correct graduations on the points.

GENERAL REQUIREMENTS FOR TOPOGRAPHIC MAPS

The scale and contour interval of a map that you are preparing will be specified according to the purpose for which the map will be used. Obviously, a map that will be used for rough design planning of a rural dirt road will be on a smaller scale and have a larger contour interval than one to be used by builders to erect a structure on a small tract in a built-up area.

The extent to which details must be shown may also be specified; if not, it is usually inferred from the purpose of the map. The following guidelines suggest the nature of typical map specifications.

A map should present legibly, clearly, and concisely a summation of all information needed for the use intended, such as planning, design, construction, or record.

Topographic maps for preliminary site planning should preferably have a scale of 1 inch = 200 feet and a contour interval of 5 feet. These maps should show all topographic features and structures with particular attention given to boundary lines, highways, railroads, power lines, graveyards, large buildings or groups of buildings, shorelines, docking facilities, large rock strata, marshlands, and wooded areas. Secondary roads, small isolated buildings, small streams, and similar minor features are generally of less importance.

Topographic maps for detailed design for construction drawings should show all physical features, both natural and artificial, including underground structures. Scales commonly used are 1 inch= 20 feet, 1 inch= 40 feet, and 1 inch = 50 feet. The customary contour interval is 1 foot or 2 feet, depending on the character and extent of the project and the nature of the terrain. Besides contour lines, show any spot elevations required to indicate surface relief.

Additional detail features that are usually required include the following:

1. Plane coordinates for grid systems, grid lines, and identification of the particular system or systems.

2. Directional orientation, usually indicated by the north arrow.

3. Survey control with ties to the grid system, if there is one. This means that the principal instrument stations from which details were located should be indicated in a suitable manner.

4. All property, boundary, or right-of-way lines with identification.

5. Roads and parking areas, including center-line location and elevation, curbs, gutters, and width and type of pavement.

6. Airport runways, taxiways, and apron pavements, including center-line locations with profile elevations and width and type of pavement.

7. Sidewalks and other walkways with widths and elevations.

8. Railroads, including center-line location, top-of-rail elevations, and any turnouts or crossovers.

9. Utilities and drainage facilities, such as gas, power, telephone, water, sanitary sewer and storm sewer lines, including locations of all valve boxes, meter boxes, handholes, manholes, and the invert elevations of sewers and appurtenances.

10. Locations, dimensions, and finished floor (usually first floor) elevations of all structures.

QUESTIONS

Q1. Describe topographic control.

Q2. Assume that you are establishing the primary vertical control for a topographic survey. The terrain is level and the desired contour interval is 1 foot. What is the maximum error closure? Can you use stadia leveling to achieve this error of closure?

Q3. You are detailing a point from a primary control station that has a known elevation of 174.3 feet. Your height instrument (h.i.) above the station is 5.6 feet. After reading a stadia interval of 2.45, you train the center hair of your telescope on the rod to match your h.i. and read a vertical angle of **+6°36'.** *If the stadia constant is 100 and the instrument constant is 1, what is the (A) horizontal distance, (B) difference in elevation and (C) elevation of the detail point? (Use the exact stadia formulas.)*

Q4. Your transit equipped with a stadia arc, is set up at point A (elevation = 245.2 feet) and you are sighting on point B. Your h.i. is 4.3 feet. The line of sight is at 5.8 on the rod and the stadia reading is 6.43. The stadia arc has index marks of H = 0 and V= 50. The stadia arc readings are V = 63 and H = 12. Your stadia constant is 100 and the instrument constant is O. What is (A) the horizontal distance to point B and (B) the elevation of B?

Q5. Define contour interval.

Q6. On a topographic map, when a contour line closes on itself, what is being portrayed?

CHAPTER 9

PLANE-TABLE TOPOGRAPHY AND MAP PROJECTION

In the previous chapter, you studied the procedures used to perform topographic surveying using the transit-tape or transit-stadia methods. As you know, when either of these methods is used, a topographic map is prepared as a separate operation that uses the field notes from the survey to prepare the map. Another method used in topographic surveying and mapping is the plane-table method. This method is preferred by many surveyors since it combines the fieldwork and the office work into one operation that produces a completed, or nearly completed, map in the field. This chapter discusses the basic principles and procedures that you will use when performing plane-able topography.

Another topic discussed in this chapter is map projection. As you will learn, maps can be prepared using various projection methods to portray all or part of the earth's surface on the flat plane of a map or chart. As an EA, you will seldom use most of these methods in drawing maps. However, it is important that you understand the principles of map projection so that you will be able to read and interpret accurately the various types of maps that you will use when plotting control points for surveys or when plotting fire missions as a mortar platoon member in a construction battalion.

PLANE-TABLE TOPOGRAPHY

As mentioned above, the plane-table method of topographic surveying and mapping combines fieldwork (surveying) with office work (drafting) to produce a topographic map. This is so, because when you use plane-table equipment, topographic details are plotted directly on the map in the field. The plane-able method is advantageous in open country and when many irregular lines need to be plotted. It is also advantageous for small-scale mapping. There are, however, some disadvantages. For example, you are required to spend mom time in the field, more equipment (some awkward to handle) must be carried, and you will need mom time to become skilled in using the plane table. Other advantages and disadvantages of the plane-table method are discussed later in this chapter.

A plane-table field party for a large survey should consist of an instrumentman, a note keeper or computer, and one or more rodmen. The instrumentman operates the plane table and alidade, makes the observations, and performs the plotting and sketching. The note keeper reduces stadia readings to horizontal and vertical distances and computes the ground elevations for rod observations. He also carries and positions an umbrella to shade the plane table. The rodman carries a stadia board or Philadelphia rod and holds it vertically at detail points and critical terrain features.

Chapter 11 of the EA3 TRAMAN describes the plane-table equipment and uses. That discussion includes the procedures used to setup and level a plane table and a description of various types of alidades. For plane-table topography, a telescopic alidade, rather than an open-sight alidade, is preferred. Before proceeding further in this chapter, it is strongly recommended that you review pages 11-33 through 11-35 of the EA3 TRAMAN.

LOCATING DETAILS BY PLANE TABLE

We will briefly explain the use of the plane table as follows. Take into the field a sheet of plane-table paper of suitable size and which has the control traverse (fig. 9-1) already plotted to suitable scale. Naturally, you use the same scale as the control traverse to lay off horizontal distances on the map.

Attach the paper to the table. Then set up and carefully level the table so that D_1 on the paper is directly over D_1 on the ground. In this example, D_1 *is* a point of known elevation (532.4 feet). Now the table must be oriented before any detail points can be located. In other words, the table has to be rotated or turned so that the points plotted on the plane-table sheet are in relationship to the corresponding points on the ground. So, with the edge of the alidade blade on D_1 and the telescope trained on *A*, orient the table by rotating it to bring D_1A on the paper in line with the

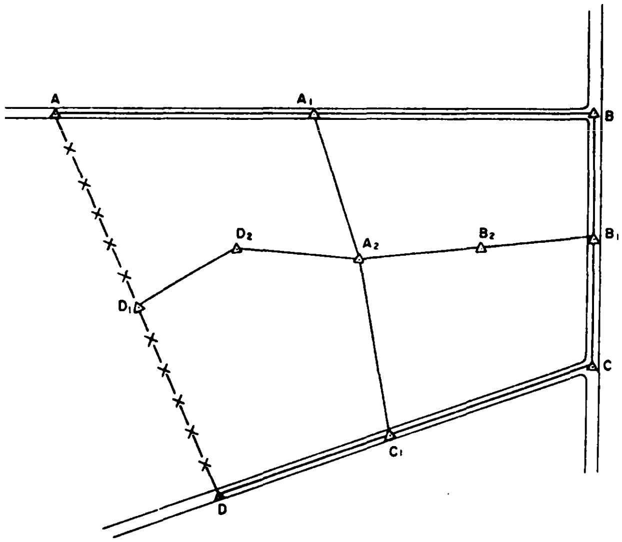


Figure 9-1.—Primary traverse and secondary traverse.

edge of the blade. A more in-depth discussion of orienting the plane table will follow later in this chapter.

Next, carefully measure the vertical distance between the horizontal line of sight through the telescope and the ground level at D_1. Let's say this distance is 4.5 feet. This means that, whenever you sight on a rod, you will line up the horizontal cross hair with the 4.5-foot graduation on the rod.

Figure 9-2 is a sketch of the detail points that we are plotting. Point D_1 and point A in this figure correspond to the same points in figure 9-1. Assuming that your alidade is equipped with a Beaman stadia arc (some alidades are not), plot point 1 of figure 9-2 in the following way. With the edge of the alidade blade exactly on D_1 on the paper, train the telescope on a rod held on point 1, and line up the horizontal cross hair with the 4.5-foot mark on the rod.

You read a rod intercept of 6.23 feet. This means the slope distance is 623.0 feet. On the H-scale of the Beaman arc, you read three-tenths of one percent; you will have to estimate this less than one-percent reading. The horizontal distance, then, is three-tenths of one-percent less than the slope distance, or

623.0 feet - (623.0 x 0.003 feet) = 623.0-1.87.

This rounds off to the nearest foot at 621 feet. Add a focal distance of 1 foot, and the result is 622 feet.

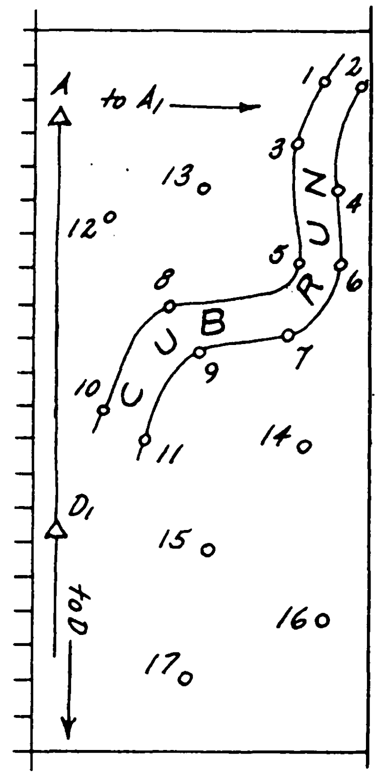


Figure 9-2.-Sketch of topographic detail points.

On the V-scale, you read 44. You know that the value you use is the difference between what you read and 50. In this case, it is 6. Therefore, the difference in elevation is 6 percent of the slope distance, or

623.0 x 0.06 = 37.4 feet.

Then, the elevation of point 1 is the elevation of D_1 minus the difference in elevation, or

532.4 -37.4 = 495.0 feet.

As you know, the difference in elevation was subtracted because the vertical angle was negative.

Finally, with the edge of your alidade blade still on D_1 and your telescope still trained on point 1, you can draw a light line and measure off 622 feet from D_1 along the line to locate point 1. At that distance along the line, mark and label the point and write in the elevation. Many topographers use the decimal point in the elevation to mark the point.

ORIENTATION METHODS

As you learned from the above example, plotting of detail points cannot begin until the plane-table drawing board or table is oriented. Orientation consists of rotating the leveled table around its vertical axis until the plotted information is in exactly the same relationship as the data on the ground. There are several methods of orienting the plane table. Some of these methods are discussed below.

Backlighting

The usual method of orienting the plane table is by backlighting. Using this method, you orient the board by backlighting along an established line for which the direction has previously been plotted. Figure 9-3 illustrates this method.

In figure 9-3, points *a* and *b* are the previously plotted locations of points *A* and *B* on the ground. First, you set up and level the table at point *B*. Then you place the straightedge of the alidade along line *ba* and rotate the table until the alidade is sighted on point *A*. Once the alidade is sighted on *A*, the table is clamped and the orientation is checked by sighting on another visible and previously plotted point. The direction to any other visible point can be plotted as a ray from the plotted position of the occupied station.

Orientation by Compass

For rough mapping at a small scale, you can use a magnetic compass to orient the plane table. If the compass is fixed to the table, you orient by rotating the table about its vertical axis until the established bearing (usually magnetic north) is observed. If the compass is attached to the alidade, you first place the straightedge along a previously drawn line that represents a north-south line. The table is then oriented by rotating it until the compass needle points north.

As you should recall from your study of the EA3 TRAMAN, you know that the earth's magnetic field and local attraction will greatly affect the pointing of the compass needle. For these reasons, you should avoid using the compass to orient the plane table when orientation by backlighting can be accomplished.

Resection

Orienting a plane table by backlighting or by compass requires occupying a station whose position has been plotted. Resection, however, enables you to orient the plane table without setting up at a previously plotted station. This technique uses two or more visible points whose positions are plotted on the plane table. From these plotted points, rays are drawn back toward the occupied but unplotted point.

TWO-POINT METHOD.— The two-point method of resection is used to orient the plane table and establish the position of a station when two previously plotted points cannot be occupied. A description of the two-point method is as follows:

In figure 9-4, *A* and *B* are visible, but inaccessible, control points. Points *a* and *b are* the plotted positions of *A* and *B*. The location of unplotted point C is approximately estimated and marked *c'*. *D* is a selected

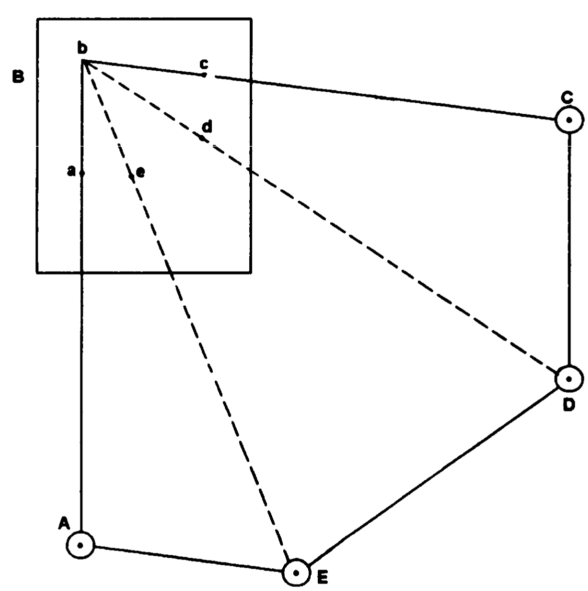


Figure 9-3.-Orientation by backlighting.

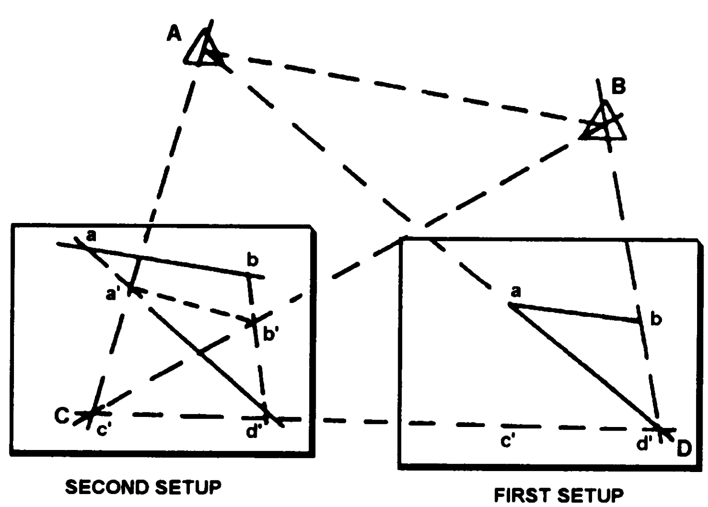


Figure 9-4.—Two-point method of resection.

and marked point when rays from *A* and *B* will give a strong intersection (angle *ADB is* greater than 300).

First set up and level the plane table at point *D* (first setup, fig. 9-4). Using plotted points *a* and *b,* draw resection rays from *A* and *B. These* rays intersect at ***d'*** which is the tentative position of *D.* Draw a ray from d' toward C. Plot c' on this line at the estimated distance from *D* to C.

Next, set up the plane table at ***C*** (second setup, fig. 9-4) and orient by backlighting on *D.* Sight on *A* and draw a ray through c' intersecting line ad' at a'. In a like manner, sight on *B* to establish *b'.* You now have a quadrilateral ***a'b'd'c'*** that is similar to *ABDC.* Since, in these similar quadrilaterals, line ***a'b'*** should always be parallel to line *AB,* the error in orientation is indicated by the angle between *ab* and ***a'b'***.

To correct the orientation, place the alidade on line ***a'b'*** and sight on a distinctive distant point. Then move the alidade to line *ab* and rotate the table to sight on the same distant point. The plane table is now oriented, and resection lines from *A* and *B* through *a* and *b* plot the position of point C.

THREE-POINT METHOD.— The three-point method involves orienting the plane table and plotting a station when three known plotted stations can be seen but not conveniently occupied.

Set up the plane table at the unknown point *P* (fig. 9-5) and approximately orient the table by eye or compass. Draw rays to the known points *A, B,* and *C.* The point *ab* denotes the intersection of the ray to *A* with the ray to *B.* Points *bc* and *ac are* similar in their notation. If the plane table is oriented properly, the

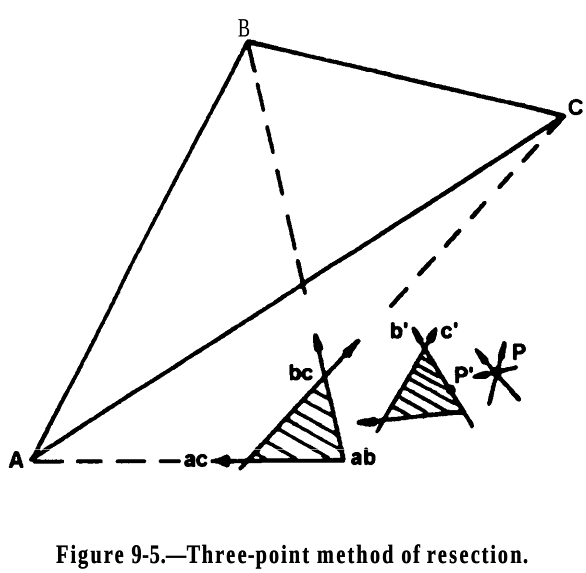


Figure 9-5.—Three-point method of resection.

three rays will intersect at a single point. Usually, however, the first orientation is not accurate, and the rays intersect at three points *(ab, bc,* and *ac)* forming a triangle, known as the triangle of error.

From the geometry involved, the location of the desired point, *P,* must fulfill the following three conditions with respect to the triangle:

1. It will fall to the same side of all three rays; that is, either to the right or to the left of all three rays.

2. It will be proportionately as far from each ray as the distance from the triangle to the respective plotted point.

3. It will be inside the triangle of error if the triangle of error is inside of the main plotted triangle and outside the triangle of error if it is outside the main triangle.

In figure 9-5, notice that the triangle of error is outside the main triangle, and almost twice as far from *B* as from *A,* and about equally as far from C as from *B.* The desired point, *P,* must be about equidistant from the rays to *B,* and to C, and about one half as far from the ray to *A,* and the three measurements must be made to the same side of the respective rays. As drawn, only one location will fulfill all these conditions and that is near P'. This is assumed as the desired location.

The plane table is reoriented using ***P'*** and back-lighting on one of the farther points *(B). The* new rays **(*a'*, *b'*,** and ***c'*)** are drawn. Another (smaller) triangle of error results. This means that the selected position, P', was not quite far enough. Another point, *P,* is selected using the above conditions, the table is reoriented, and the new rays are drawn. If the tri- angle had become larger, a mistake was made and the selected point was on the wrong side of one of the rays. The directions should be rechecked and the point reselected in the proper direction.

The new point, *P,* shows no triangle of error when the rays are drawn. It can be assumed to be the desired location of the point over which the plane table is set. In addition, the orientation is correct. Using a fourth known and plotted point as a check, a ray drawn from that point should also pass through *P.* If not, an error has been made and the process must be repeated.

Normally the second or third try should bring the triangle of error down to a point. If, after the third try, the triangle has not decreased to a point, you should draw a circular arc through one set of intersections *(ab,* ***a'b'*)** and another arc through either of the other sets *(bc,* ***b'c'*,** or *ac,* ***a'c'*)**. *The* intersections of the two arcs will locate the desired point, *P*. This intersection is used to orient the plane table. A check on a fourth location will prove the location.

TRACING-CLOTH METHOD.— Another method you can use to plot the location of an unknown point from three known points is the tracing-cloth method of resection. Figure 9-6 illustrates this method.

In the figure, points *a, b,* and c are the plotted positions of three corresponding known stations *(A, B,* and *C)*. *P* is the point of unknown location over which the plane table is set. To plot the location of *P* you first place a piece of tracing paper (or clear plastic) over the map and select any convenient point on the paper as ***P′***. Then you draw rays from ***P′*** toward the three known stations. Next, you loosen the tracing paper and shift it until the three rays pass through the corresponding plotted points *a, b,* and *c*. The intersection of the rays marks the location of *P,* which can be pricked through the tracing paper to locate the point on the map.

POINT LOCATION

The horizontal location of points can be determined by triangulation using the plane table. Any two points plotted on the plane-table sheet can act as a base for triangulation. A ray drawn from each of these points to some unknown point will form a triangle, with the distance between the two known

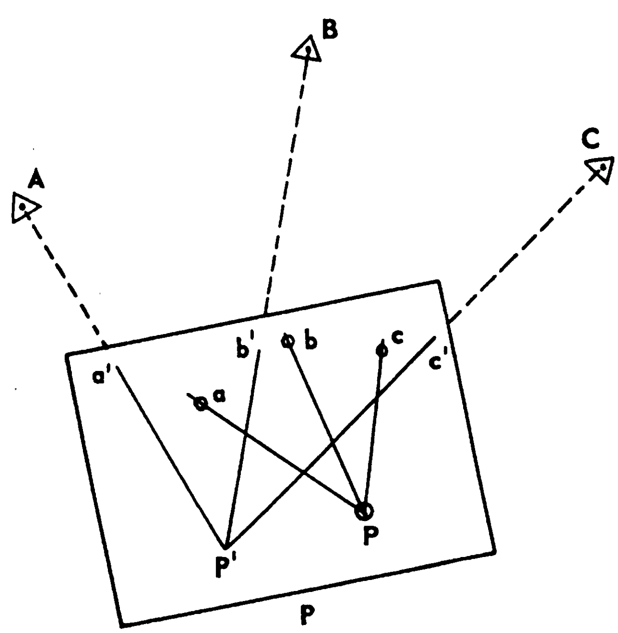


Figure 9-6.-Tracing-cloth method of resection.

plotted points as the third side. The newly plotted position of the third point will be at the intersection of the rays. The rays to the unknown point maybe drawn while occupying the known stations. This is called intersection. The rays also may be drawn while occupying the unknown point, and this is known as resection.

Resection

The methods of resection were explained in the discussion of plane-table orientation. As you know, when using resection methods it is unnecessary to occupy known stations. While resection can be used with two known points, you should use mom than two points to determine the location of a point to a higher degree of precision.

Intersection

Intersection is accomplished by setting up and orienting the plane table at each of two or more known stations in turn. At each station, the alidade is pointed toward the unknown point, and a ray is drawn from the plotted position of the occupied station toward the point being plotted. As such rays are drawn from two or more stations, their point of intersection is the plotted position of the required station. Two points are the minimum requirement to establish a location. For more accuracy, however, you should occupy three or more points.

Radiation

In plane-table surveys when intersection is used, a series of radiating rays are drawn and marked. These rays all radiate from known stations. Points are located by drawing rays from one or more known stations. The intersection of the rays determines the plotted location of the desired points. When drawing rays, be sure to identify clearly the object that each ray is being drawn to. This is important since an object viewed from one direction may appear differently when viewed from another direction. This can lead to rays being drawn to the wrong object which will result in errors in plotting point locations.

Progression

Progression, or plane-table traverse, starts from a known position and uses a continuous series of direction and distances to establish positions. This method of point location is illustrated in figure 9-7.

After you set up and orient the plane table at the first station, you draw the direction to the next point on the survey with a radiating ray. The distance between the occupied station and the new point is measured and plotted along the ray. The new plotted position is now considered a known position and can be occupied and used as the next station on the line. The plane table is setup and oriented over this station and another radiating ray is drawn to the next point. This process continues for the length of the traverse.

Orientation plays an important role in plane-table traverse. Slight errors in direction at each setup can accumulate rapidly and become large in a short time. Long traverses should be avoided except in reconnaissance surveys.

VALUES OF PLANE-TABLE METHOD

Advantages of the plane-table method of topographic surveying are as follows:

1. The map is made directly in the field, thus combining the data collection and drafting into a single operation. The area under survey is visible as a whole, which tends to minimum the overlooking of important data. Errors in measurement maybe easily checked by taking check observations on a prominent point whose position has been plotted on the map. If the edge of the blade does not contact the proper point or points, an error is indicated. An error thus located can be easily corrected on the spot.

2. Since all computation and plotting is performed in the field, the keeping of field notes is not a mandatory requirement in plane-table topography; the decision is left up to your supervisor; however, plane-table field notes are useful as a training device. You should keep this in mind when, later in your career, you are training junior EAs in plane-table work.

3. The graphic solutions of the plane table are much quicker than the same solutions by methods requiring angular measurements, linear measurements, and computations. Thus a great deal more area can be covered in much less time.

4. When the country is open and level, the plane-table topographer has a wider choice in the selection of detail points. He need not be hampered by backsight-foresight requirements. He can locate inaccessible points easily by graphic triangulation or quickly determine the location of a point with reference to one, two, or three points of known location.

5. Irregular lines, such as streams, banks, and contours, can be sketched.

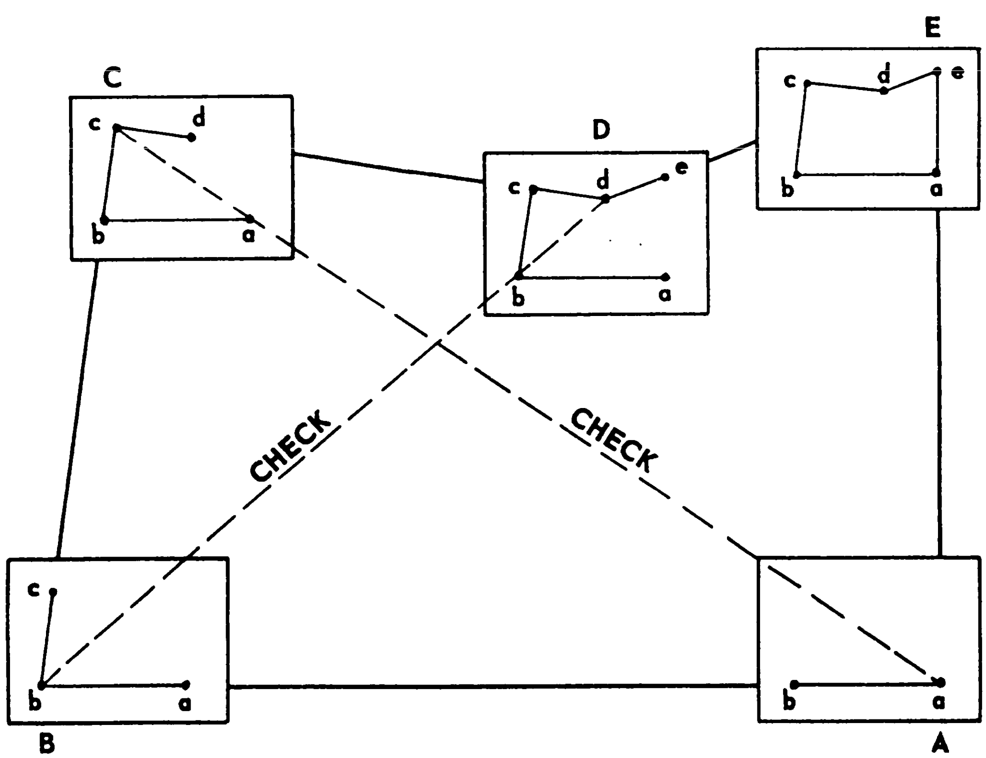


Figure 9-7.-Progression.

6. Fewer points are required for the same precision in locating contours (only 50 to 60 percent of the number on a comparable transit-stadia survey are required to locate contours with the same degree of accuracy).

Disadvantages of the plane table method are as follows:

1. The plane table and its plotting and drawing accessories are more difficult to transport than transit-stadia equipment.

2. Weather not bad enough to rule out transit-stadia will make plane-table work impossible.

3. The use of the plane table is limited to relatively level, open country. It is unsuitable for wooded country.

4. Control must be plotted in advance for precise work on the plane table.

As mentioned above, keeping field notes is not mandated for plane-table topographic work; however, when notes are kept, they should appear as shown in figure 9-8. An explanation of the columns shown in these notes is as follows:

1. OBJ: Self-explanatory.

2. ROD INT (S): Rod or stadia interval.

3. H-SCALE: Reading from the Beaman arc horizontal scale when the stadia interval was taken. (In this example, the stadia arc we are using is a horizontal scale subtraction type: vertical scale index = 50.)

4. CORRECT H DIST: Corrected horizontal distance. This distance is computed as explained in chapter 8 of this TRAMAN.

5. V-SCALE: Reading from the Beaman arc vertical scale when the middle cross hair was sighted on the rod and RC (column 7) was recorded. (Vertical scale index = 50.)

6. PRODUCT ±: Product difference; you compute this by subtracting 50 from the V-scale (column 5) and then multiplying this difference by the stadia interval (column 2). Indicating the correct sign, + or -, is very important.

7. RC: Rod reading when the vertical scale was read and the center cross hair was sighted on the rod. The RC is always negative because it is considered a foresight.

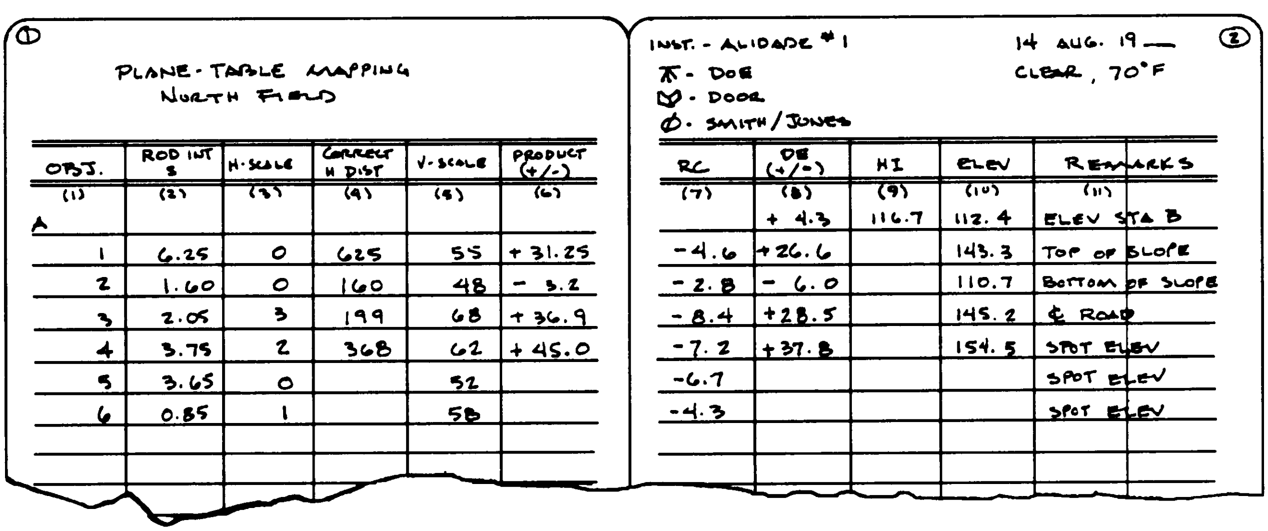
8. DE ±: Algebraic sum of columns 6 and 7.

9. HI: Height of instrument obtained by adding backsight reading to existing elevation.

10. ELEV: Computed elevation; algebraic sum of columns 8 and 9.

11. REMARKS: Self-explanatory.

When other types of alidades are used, you may find it necessary or advantageous to alter the format of your field notes. Remember, too, that before you use any instrument, including the alidade, you should always read and fully understand the operating instructions for the instrument.



①
PLANE-TABLE MAPPING
NORTH FIELD

INST. - ALIDADE #1 14 AUG. 19__ ②
⊼ - DOE CLEAR, 70°F
DOOR
∅ - SMITH/JONES

OBJ. (1)	ROD INT S (2)	H-SCALE (3)	CORRECT H DIST (4)	V-SCALE (5)	PRODUCT (+/-) (6)	RC (7)	DE (+/-) (8)	HI (9)	ELEV (10)	REMARKS (11)
A							+ 4.3	116.7	112.4	ELEV STA B
1	6.25	0	625	55	+ 31.25	-4.6	+26.6		143.3	TOP OF SLOPE
2	1.60	0	160	48	- 3.2	-2.8	- 6.0		110.7	BOTTOM OF SLOPE
3	2.05	3	199	68	+ 36.9	-8.4	+28.5		145.2	℄ ROAD
4	3.75	2	368	62	+ 45.0	-7.2	+37.8		154.5	SPOT ELEV
5	3.65	0		52		-6.7				SPOT ELEV
6	0.85	1		58		-4.3				SPOT ELEV

Figure 9-8.-Plane-table notes.

PLANE-TABLE POINTERS

One of the troublesome problems in operating a plane table is the difficulty of keeping the alidade blade on the plotted position of the occupied point, such as P in figure 9-9. As the alidade is moved to sight a detail, the edge moves off point P. A solution sometimes tried is to use a pin at P and pivot around it, but a progressively larger hole is gouged in the paper with each sight. To eliminate this problem, use two triangles to draw a parallel line with the straightedge of the telescope over pivot point P. The small error produced by the eccentric sight is no greater than that resulting from not being exactly over the ground point, P, or even that caused by the telescope axis not being over the edge of the blade.

Other pointers that may be helpful concerning the use of the plane table are as follows:

1. Use buff or green detail paper to lessen the glare.

2. Plot and ink the traverse in advance of the detailing, showing lengths of traverse lines; coordinates of triangulation stations, if known; and useful signals

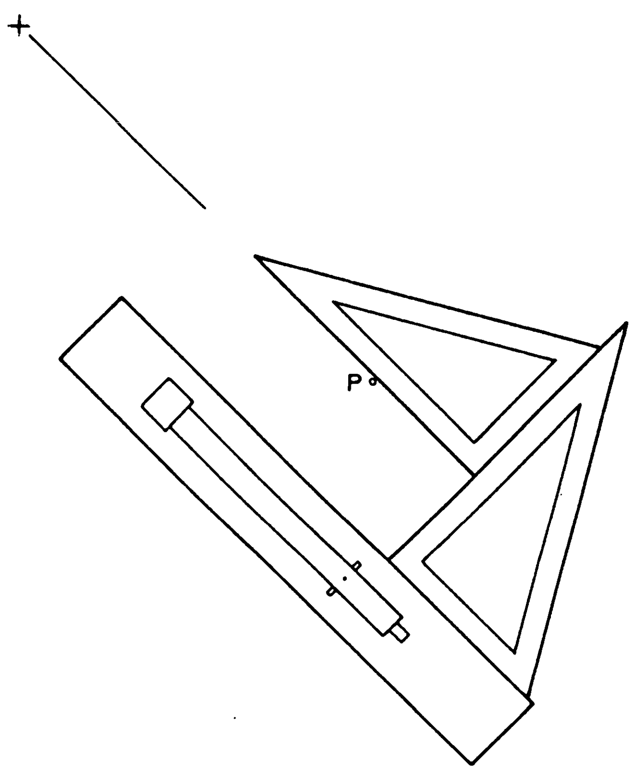


Figure 9-9.—Transfer of pivot point.

3. Have a least one vertical control for each three hubs of a traverse, and show all known elevations.

4. Cover the portion of the map not being used.

5. Setup the table slightly below elbow height.

6. Check the orientation on two or more lines if possible.

7. Check the distance and elevation difference in both directions when setting a new hub.

8. Read the distance first and then the vertical angle; or with a Beaman arc, read the H-scale and then the V-scale.

9. To keep the paper cleaner, lift the forward end of the alidade blade to pivot instead of sliding the blade.

10. Clean the paper frequently to remove graphite.

11. Check the location of hubs by resection and cutting in (sighting and plotting) prominent objects.

12. Draw short lines at the estimated distances on the map to plot points. Do not start the lines at the hub occupied.

13. Identify points by consecutive numbers or names as they are plotted.

14. Have the rodman make independent sketches on long shots for later transference to the plane-table map.

15. Use walkie-talkie sets to enable the rodmen to describe topographic features when the observer cannot identify them because of distance and obstacles.

16. Use the same points to locate details and contours whenever possible.

17. Sketch contours after three points have been plotted. Points on the maps lose their value if they cannot be identified on the ground.

18. Show spot elevations for summits, sags, bridges, road crossings, and all other critical points.

19. Tie a piece of colored cloth on the stadia rod at the required rod reading to speed work in locating contours by the direct method.

20. Use vertical aerial photographs for plane-table sheets. The planimetric details can be checked and contours added.

21. Use a 6H or harder pencil to avoid smudging.

Sources of Error in Plane-Table Work

Sources of error in plane-table operation include the following conditions or procedures:

1. Table not level
2. Orientation disturbed during detailing
3. Sights too long for accurate sketching
4. Poor control
5. Traversing and detailing simultaneously
6. Too few points taken for good sketching

Mistakes in Plane-Table Work

Some typical mistakes made in plane-table work are as follows:

1. Detailing without proper control
2. Table not level
3. Orientation incorrect

DEVELOPMENT OF A TOPOGRAPHIC MAP

In this final section on topography, we will discuss the typical steps leading to the production of a topographic map. In this discussion, you should notice the different operations that are commonly involved and how those operations interplay with one another.

In developing a topographic map, you should first gather all available maps, plans, survey data, and utilities data that pertain to the site and study them carefully. Consider the boundaries of the site in relation to the intended use of the topo map. If the map is to be used for design purposes, certain off-site information will be even more important than on-site details; for example, the location and elevations of utilities and nearby streets are vital. The location of drainage divides above the site and details of outfall swales and ditches below the site are necessary for the design of the storm drainage facilities. Topographic details of an off-site strip of land all around the proposed limits of construction are necessary so that grading can be designed to blend with adjacent areas. Decide what datum and bench marks are to be used; consider previous local surveys, U.S. Coast and Geodetic Survey (USC&GS) monuments, sanitary sewer inverts (not rims—they are frequently adjusted), and assumed datum. Determine whether there is a coordinate system in the area monumented sufficiently for your use; if not, plan to use assumed coordinates. In the latter case, decide on the source of the meridian: adjacent surveys, magnetic, assumed, or shooting the Sun or Polaris (discussed at the EA1 level in Part 2 of this TRAMAN).

Next, perform a reconnaissance survey. Observe the vegetation and decide how many men that you, as party chief, will need to cut brush. Select main control traverse stations at points appropriate for plane-table setups. Decide on the number and location of crossties or secondary traverse lines needed to provide sufficient plane-table stations. Select these points so that plane-table setups will have to be extended only a minimum distance before checking back into control.

The next step is to run the traverse lines; you should check their directions from time to time, where necessary, on long traverses. Checks could be done by astronomical methods (Part 2 of this TRAMAN), by cutoff lines, or by connecting the traverse with established points. Then run the levels, taking elevation on all traverse stations. Close, balance, and coordinate the main traverse. Then adjust the crossties into the main traverse. Balance the levels. Plot the traverse stations by coordinates on the plane-table sheets. Be sure that each sheet overlaps sufficiently. Also, be sure there is sufficient control on each sheet for orientation and for extension of setups (if necessary). Number the traverse stations with the same numbers marked on the guard stakes in the field, and show the elevations.

The plane-table work is the final big step of the fieldwork, but some transit and level work may still need to be done. The location of some details (such as street center lines or buildings) may need to be more precise than the precision obtainable with the plane table; tie in such details to the traverse by transit tape survey. For design purposes, the elevation of some points (such as the inverts of culverts, paved flumes, sewers, and tops of curbs and gutters) may need to be more precise than the precision obtainable with the plane table. Use the level to obtain such elevations. The final step in the production of the topographic map is, of course, tracing the information from the plane-table sheets onto the final drawing.

Random traversing, as previously described, is not the only way of establishing horizontal control. Grids are frequently used. One good way of identifying grid lines is to assign a letter to each line in one set and then run stationing along each line. Another method is described in the paragraphs below.

Referring to figure 9-10, suppose that this site has been chosen (through reconnaissance) for an advanced base with airstrip facilities. As you see in figure 9-10, there is a sheltered water area for a potential harbor; a strip of woodland extending back from the shore; and then a strip of clear, level country where an airstrip could be constructed.

Although topographic data for a map of this area could be obtained by one field party, it would involve extensive time and effort. Therefore, let's assume that three field parties will be used. Two of these parties are transit-level parties since they will use either transits or levels as appropriate to the work performed. The third party is a plane-table party. The plane-table party will work in the clear area and the transit-level parties will operate in the wooded and the water areas.

Basic horizontal control for both the plane-table party and the transit-level parties is the **main base line,** which is run along the edge of the wooded area as shown in figure 9-10. Topographic details in the clearing will be plotted from plane-table stations tied to the main base line. Details in the wooded area and offshore will be plotted from stations on a grid network that is tied to the main base line.

The grid network can be established in the following manner: transit-level party No. 1 runs the main base line from station 0 + 00, located at random. While running the main base line, hubs are set along the line at predetermined intervals; in this case, at every 500-foot station. Transit-level party No. 2 runs a lateral base line from 0 + 00 perpendicular to the main base line and sets hubs at every 500-foot station. From every 500-foot station on the main base line, party No. 1 will run a lateral, perpendicular to the main base line. Likewise, from each station on the lateral base line, party No. 2 will run a longitudinal, perpendicular to the lateral base line (and therefore parallel to the main base line). Hubs are driven at the intersection of each lateral and longitudinal (except in the water area). As you can see in figure 9-10, it is these lateral and longitudinal lines that form the grid net work.

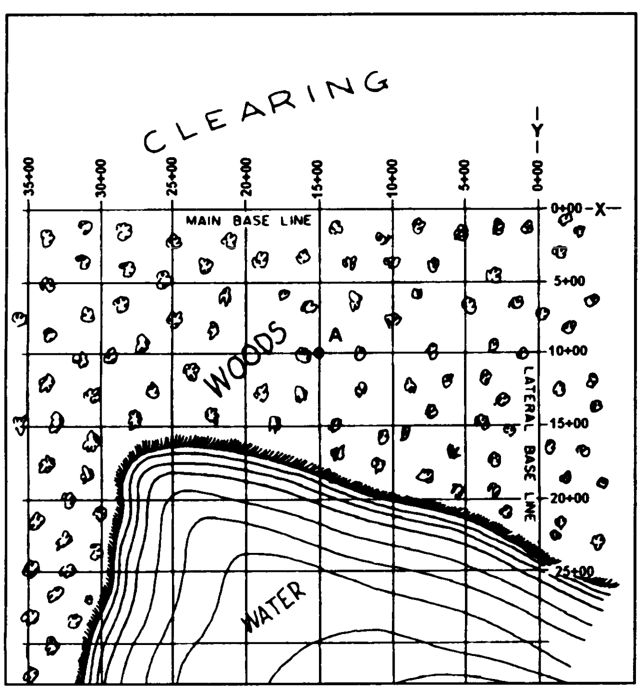


Figure 9-10.—Advanced base site.

From your previous studies you know that points within the grid can be located by coordinates, using the main base line as the X axis and the lateral base line as the Y axis; for example in terms of stations, the X coordinate of point A in figure 9-10 is 15 +00 and the Y coordinate is 10 + 00. For simplicity, these coordinates can be stated in a fractional form as 1500/1000.

With regard to vertical control for a advance base site such as we are discussing, there may be no established bench marks in the immediate area. In this case, a level net may have to be run from an established monument some distance away, perhaps several miles, to establish a bench mark in the area. If this is not possible, then a series of rod readings should be taken over a succession of high and low tides or on the high-water mark wash line along the beach. You may then use the average of these readings as a temporary vertical control datum until a more accurate datum is obtained from tide gauge readings. From a temporary bench mark at or near the beach, a line of levels can be run to station 0 + 00 on the main base line. Temporary elevations of hubs on the main base line and the lateral base line can then be determined.

Finally, the transit-level parties will shoot the detail in the vicinity of each of the intersecting grid lines.

MAP PROJECTION

Now let's discuss map and chart projection. This discussion includes the characteristics and development of various types of projections.

A paper cylinder (without ends) and a paper cone can be cut along the side and flattened out without distortion. For this reason, the two most common basic projection methods are the Mercator, in which the earth's surface is projected onto a cylinder, and the conic, in which the surface is projected onto a cone. A third method is the gnomonic method, in which the earth's surface is projected onto a plane placed tangent to a particular point. For a polar gnomonic chart, this point is one of the earth's geographical poles.

MERCATOR PROJECTION

To grasp the concept of Mercator projection, imagine the earth to be a glass sphere with a strong light at the center. Imagine, also, that the geographical meridians and parallels are inscribed as lines on the sphere at a given interval (for example, every 15 degrees). Now imagine a paper cylinder placed around the sphere, tangent to the equator, as shown in figure 9-11. The shadow images of the meridians will appear on the paper as equally spaced, parallel, vertical lines. The shadow images of the parallels will likewise appear as straight lines running perpendicular to the shadow images of the meridians. The parallels are not actually equally spaced, however; instead, the distance between adjacent parallels will progressively increase as latitude (distance north or south of the equator, the line of tangency) increases.

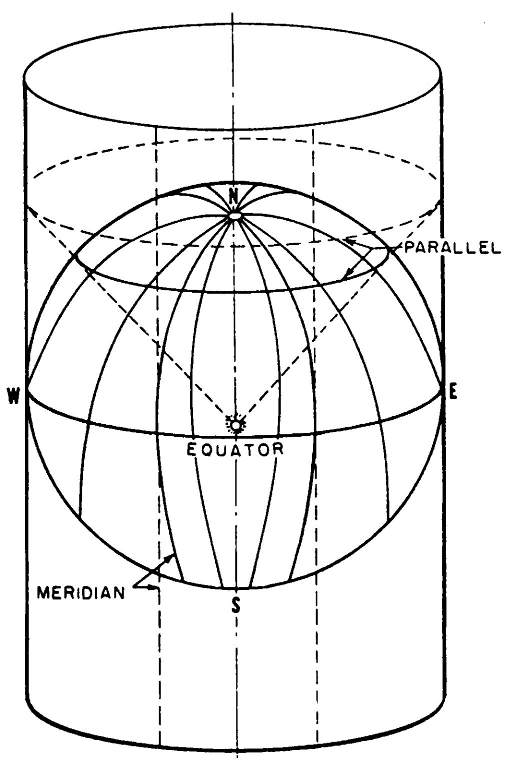


Figure 9-11.—Mercator projection.

You can see that there are two elements of distortion here, each of which progressively increases with latitude. One is the fact that the meridians, which on the earth itself converge at each of the poles, are parallel (and therefore equidistant) for their entire length on the cylinder. The other is the fact that the parallels, which are actually equidistant on the sphere itself, become progressively farther apart as latitude increases.

These two elements produce the familiar distortion that is characteristic of a Mercator map of the world. On such a map the island of Greenland, which has an area of only about 46,740 square miles, is considerably larger in outline than the continental United States, which has an area (excluding Alaska) of about 2,973,776 square miles.

Figure 9-12 shows the meridians and parallels at 15-degree intervals of the earth's surface on a Mercator projection. Note that the parallels extend only to 80 degrees north and south. Because the cylinder has no ends, Mercator projection of regions in latitudes higher than about 80 degrees is impossible. Note, too, that although the distance along a meridian between (for example) 15°N and 30°N and between 60°N and 75°N is the same on the ground, these distances are much different on a Mercator projection. Still another characteristic to note is the fact that a meridian is perpendicular to all parallels it intersects and that all the meridians are parallel to each other.

Transverse Mercator Projection

On a Mercator projection the cylinder is placed tangent to the earth's central parallel, the equator. On

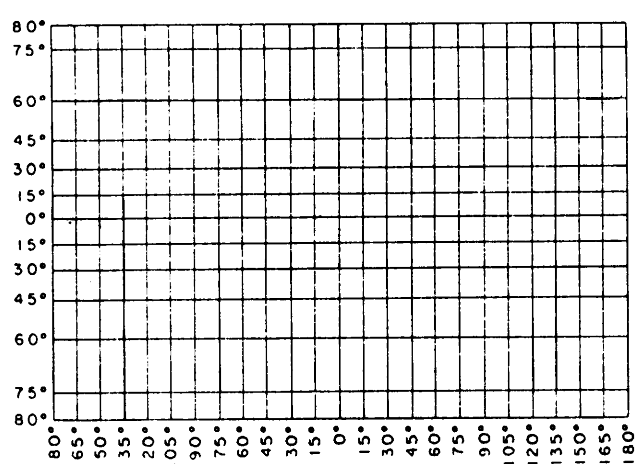


Figure 9-12.—Meridians and parallels on a Mercator projection.

a transverse Mercator projection, the cylinder is rotated 90 degrees from this position to bring it tangent to a meridian. Figure 9-13 shows the appearance of the meridians and parallels on the transverse Mercator world projection when the cylinder is flattened out. In this case, the cylinder was placed tangent to the meridian running through 0-degrees and 180-degrees longitude.

You can see that, in general, a transverse Mercator projection has less distortion than a Mercator projection does. You also can see that, unlike distortion on a Mercator projection, distortion on a transverse Mercator increases with longitude as well as with latitude away from the meridian of tangency. This is indicated by the shaded areas shown in figure 9-13. These areas are the same size on the ground. Since they lie in the same latitude, they would have the same size on a Mercator projection. On the transverse Mercator projection, however, the area in the higher longitude would be larger.

The important thing to note about the transverse Mercator, however, is the fact that in any given area the distortion is about the same in all directions. It is this fact that makes the transverse Mercator the most feasible projection for use with the military grid reference system.

A **rhumb line** is a curve on the surface of a sphere that cuts all meridians at the same angle. A mathematical navigational device, developed to plot the Mercator-projected maps, makes the rhumb line a straight line on the chart, thus preserving the same angle of bearing with respect to the intersected

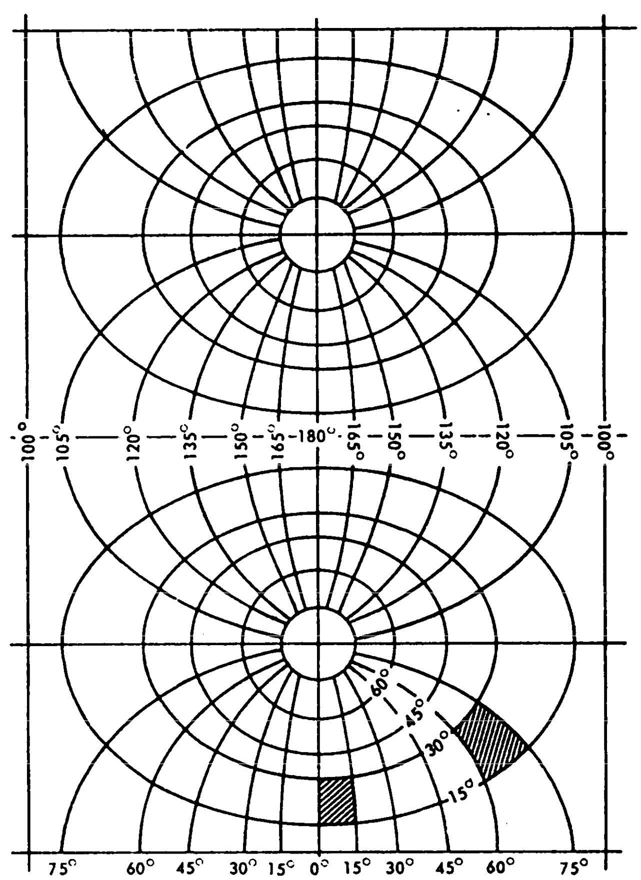


Figure 9-13.—Meridians and parallels on a transverse Mercator projection.

meridians as does the track of a vessel under a true course. On the globe the parallels become shorter toward the poles, and their length is proportionate to the cosine of latitude. In the Mercator projection the parallels are equally long. This means that any parallel is increased by 1/cos θ, or sec θ, where θ is the latitude in degrees. To have the same scale along the parallels as along the meridians, you must increase each degree of latitude by the secant of the latitude. In this mathematical transformation, the tangent cylinder concept was not employed, nor is it ever employed, in the Mercator projection. A Mercator projection table is used to plot the meridional distances. For intensive study on elements of map projection, you may refer to special publications published by the U.S. Coast and Geodetic Survey that deal with this subject.

Universal Transverse Mercator Military Grid

An extensive application of the transverse Mercator projection is in a grid reference system for military maps called the **universal transverse Mercator (UTM) military grid** system. In this system a reference plane grid, like those used in our state grid systems, is imposed on transverse Mercator projections of relatively small areas. The basic

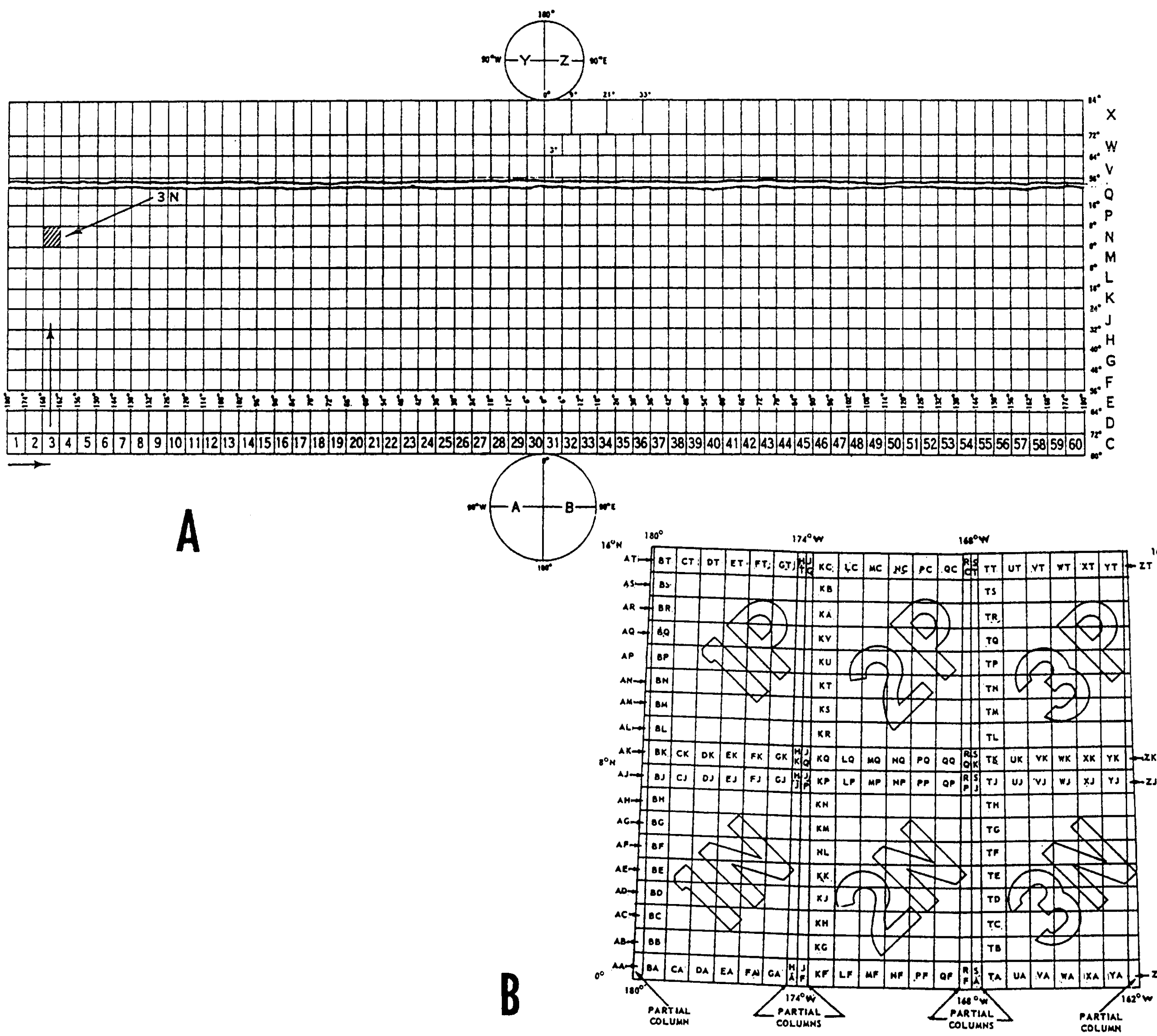


Figure 9-14.—(A) Grid zone designations of the military grid reference system; (B) 100,000-meter-square designations in the UTM military grid system,

Starting at the 180th meridian and progressing eastward by the compass, the earth's surface is divided into a succession of north-south zones, each extending for 6 degrees of longitude. These zones are numbered from 1 through 60. Between latitude 80°S and 84°N, each zone is divided into a succession of east-west rows, each containing 8 degrees of latitude, with the exception of the northernmost row, which contains 12 degrees of latitude. Rows are designated by the letters *C* through *X,* with the letters *I* and *O* omitted. The lettering system begins at the southernmost row and proceeds north. For a particular zone-row area, the designation consists of first, the zone number and next, the row letter, such as 16S, which means row S in zone 16.

The polar regions (that is, the areas above 84°N and below 80°S) have only two zones in each area. These lie on either side of the 0-degrees and 180-degrees meridian. In the North Polar region, the half of the region that contains the west longitudes is zone Y; that containing the east longitudes is zone Z. No numbers are used with these designations. Similarly, in the South Polar region, the half containing the west longitudes is zone A; that containing the east longitudes, zone B.

In the UTM Military Grid System, a particular point on the earth is further identified by the **100,000-meter square** in which it happens to lie. Each of the 6-degree longitude by 8-degree latitude zone-row areas in the system is subdivided into squares measuring 100,000 meters on each side. Each north-south column of 100,000-meter squares is identified by letter as follows. Beginning at the 180th meridian and proceeding eastward, you will find six columns of full squares in each 6-degree zone. Besides the full columns, usually partial columns also run along the zone meridians. The partial columns and full columns in the first three zones are lettered from *A* through Z, again with the letters *I* and *O* omitted. In the next time zones, the lettering systems begins over again.

Observe, for example, figure 9-14, view B. This figure shows the zone-row areas in 1N, 2N, and 3N, and 1P, 2P, and 3P. The zone meridians shown are 180°W, 174°W, 168°W, and 162°W; the zone-row parallels shown are the equator (0° latitude), 8°N, and 16°N. The first 100,000-meter-square column to the east of 180 degrees is the partial column A. Next comes six full columns: B, C, D, E, F, and G. Then comes partial column H, to the west of the zone meridian 174°W. The first column to the east of zone meridian 174°W is partial column J; then comes the full-size columns K, L, M, N, P, and Q, followed by partial column R. To the east of zone meridian 168°W, the first column is partial column S; then comes the six full columns T, U, V, W, X, and Y, and the partial column Z to the west of zone meridian 162°W.

The east-west rows of 100,000-meter squares are designated by the letters *A* through *V,* again with *I* and O omitted. For columns in the odd-numbered zones, the first row of squares north of the equator has the letter designation *A;* for columns in the even-numbered zones, the first row of squares north of the equator has the letter designation *F.* Rows above and below this row are designated alphabetically. The first row south of the equator in the odd-numbered zones, for example, has the letter designation *V,* while the first row south of the equator in the even-numbered zones has the letter designation *E.*

The complete designation for a particular 100,000-meter square consists of the number-letter, zone-row designation plus the two-letter, 100,000-meter-square designation. For example, the designation 1NBA means the first full square east of the 180th meridian and north of the equator (square BA) in zone-row 1N, as shown in figure 9-14, view B.

If you know the latitude and longitude of a certain point on the earth, you can determine the designation of the 100,000-meter square in which the point lies. Take Fort Knox, Kentucky, for example, which lies approximately at latitude **38°00'N,** longitude **86°00'W.**You will find this latitude and longitude in figure 9-15. The point lies in column 16, row S, and 100,000-meter square ES; therefore, the 100,000-meter-square designation for Fort Knox, Kentucky, is 16SES.

The location of a particular point within a 100,000-meter square is given by naming the grid coordinates of the 100-meter square (or, for more precise location, of the 10-meter square) in which the point lies. Within each zone the point of origin for measuring these coordinates is the point of intersection between the zone central meridian and the equator. A **false easting** of 500,000 meters, instead of a value of O meters, is assigned to the **central meridian** to avoid the use of west or negative east-west coordinates. For points in the earth's Southern Hemisphere, the equator is assigned a **false northing** of 10,000,000 meters to avoid the use of south or negative north-south coordinates, and northing values decrease from the equator toward the South Pole. For points in the Northern Hemisphere, the equator has a coordinate value of 0 meters, and northing values increase toward the North Pole.

This procedure results in very large coordinate values when the coordinates are referenced to the

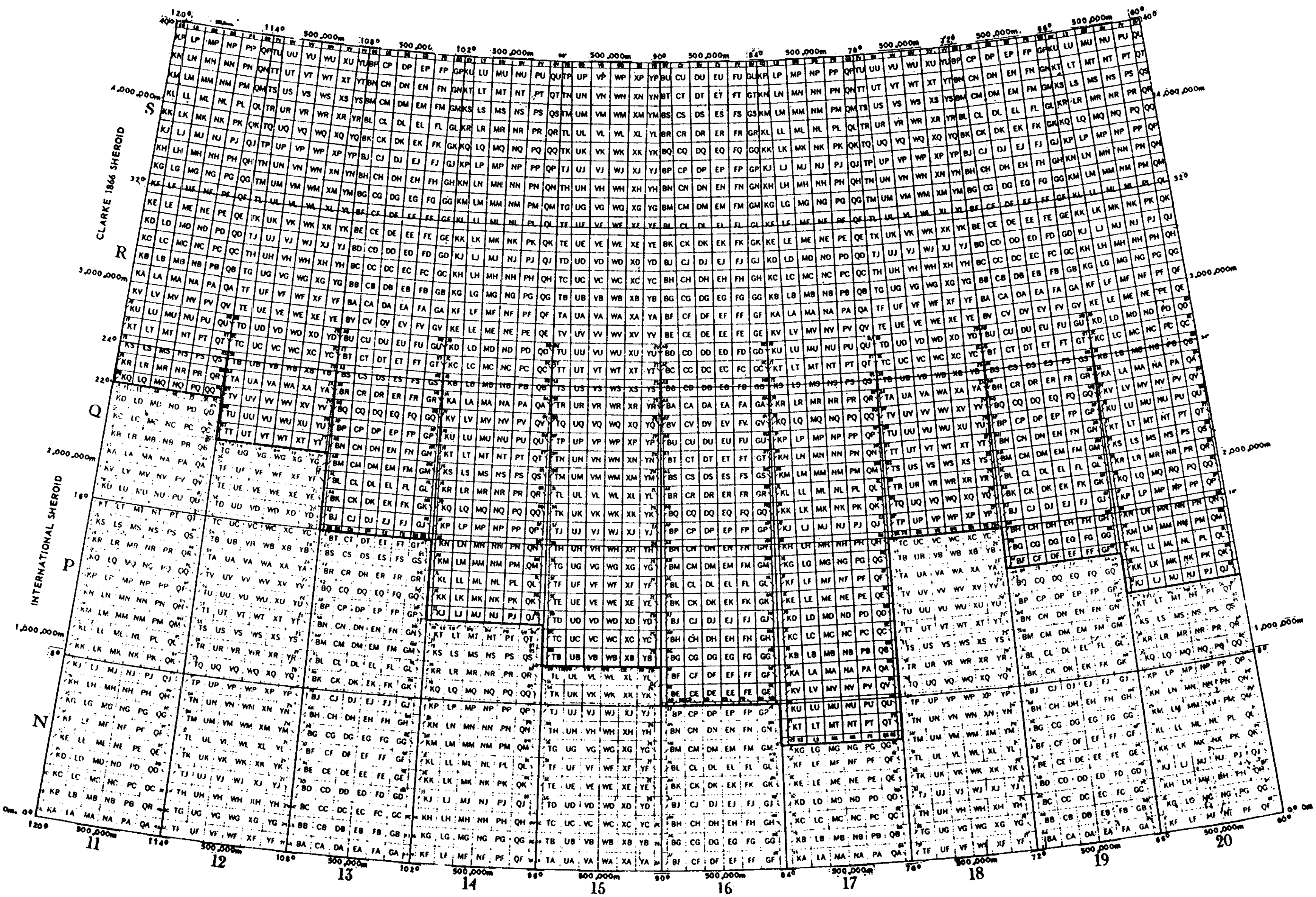


Figure 9-15.—100,000-meter-square identifications for the military grid reference system.

point of origin. For example, for the bullion depository at Fort Knox, Kentucky, the coordinates of the lo-meter square in which the depository is located are casting 590,990 meters, northing 4,193,150 meters; however, since the grid zone-row designation pins the coordinate down to a relatively small area some of the digits of the coordinates are often omitted.

Consider, for example, the part of a map shown in figure 9-16. The grid squares on this map measure 1,000 meters on each side. Note that the casting grid lines are identified by printed coordinates in which only the principal digits are shown, and of these, even the initial number 5 is in small type. The understood value of the number 589 is 589,000 meters. In setting down the coordinate for this line, even the 5 should be omitted and only the 89 written down.

Similarly, in expressing the grid location of a point, some of the digits of the coordinates are often

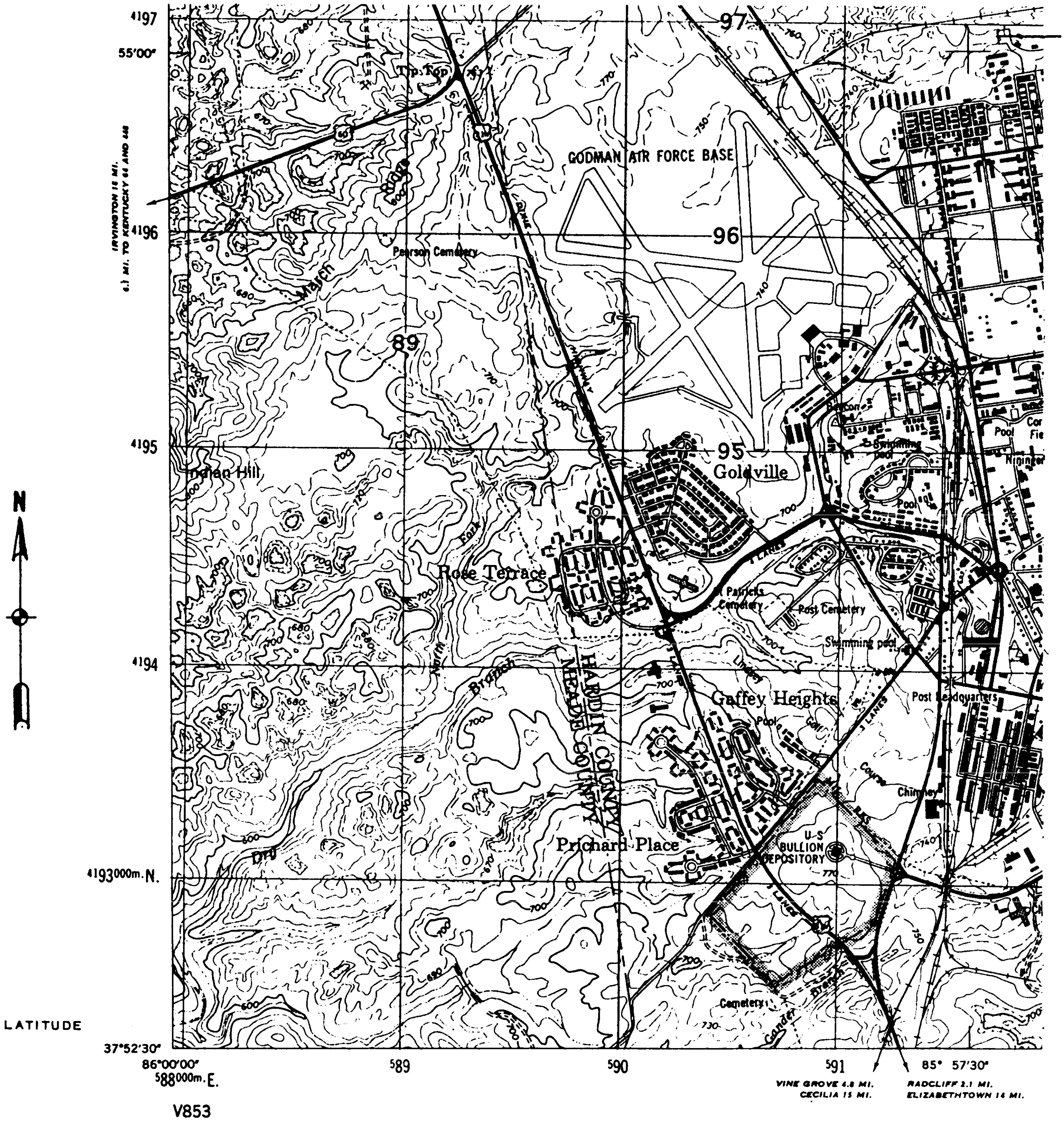


Figure 9-16.-Portion of a military map.

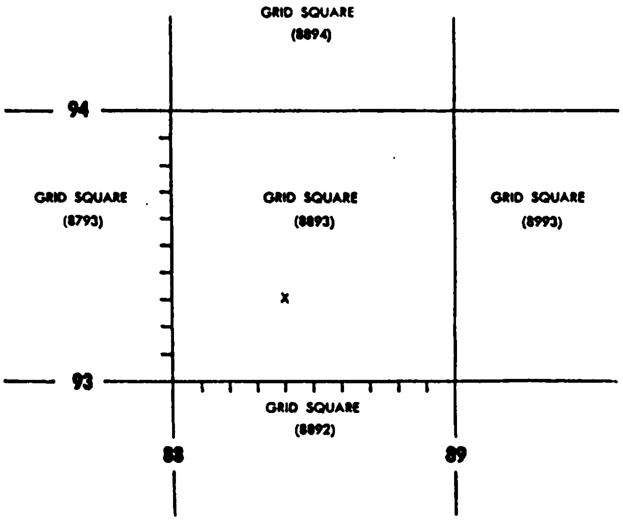


Figure 9-17.-Division of a grid square.

omitted; for example, the grid location of the bullion depository at Fort Knox may be given as 16SES90999315. This means zone-row 16S, 100,000-meter square ES, casting 9099, northing 9315. Actually, the casting is 590,990 and the northing 4,193,150.

If four digits are given in a coordinate element, the coordinates pin a point down to a particular 10-meter square. Consider figure 9-17, for example. For the point X, the two-digit coordinates 8893 would mean that the point is located somewhere within the 1,000-meter-grid square 8893. To pin the location down to a particular 100-meter square within that square, you would have to add another digit to each coordinate element. The X lies four-tenths of 1,000 meters between line 88 and line 89; therefore, the casting of the 100-meter square is 884. By the same reasoning, the northing is 933. The coordinate for the 100-meter square is therefore 884933. To pin the point down to a particular 10-meter square, you should add another pair of digits, these being determined by scale measurement on the map. It follows from all this that the coordinates previously given for the bullion at Fort Knox (909993 15) locate this building with reference to a particular lo-meter square.

Figures 9-18 and 9-19 show the marginal information usually given on a UTM grid military map. Note the reference box, which gives the grid zone-row and 100,000-meter-square designation. The

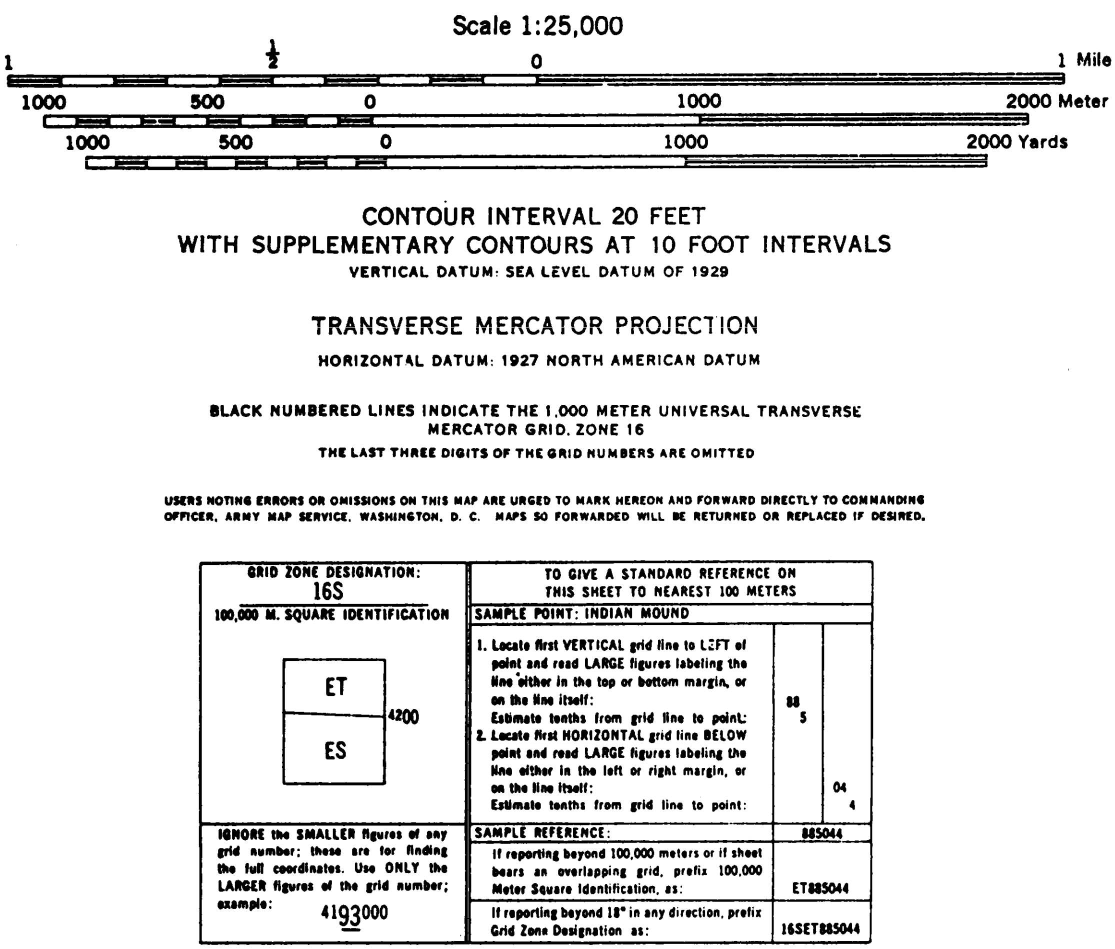


Figure 9-18.-Marginal information on a military map (1).

Prepared by the Army Map Service (TV), Corps of Engineers, U. S. Army, Washington, D. C. Compiled in 1953 from Kentucky, 1:25,000, AMS, Sheet 3859 IV NW, 1946. Planimetric detail revised by photo-planimetric methods from aerial photography dated Feb. 1953. Original map compiled in 1946 by USGS and TVA by photogrammetric (multiplex) methods. Horizontal and vertical control by USC&GS, USGS, and CE. This map complies with the national standard map accuracy requirements. Map field checked, 1953.

LEGEND

ROAD DATA 1953

In developed areas, only through roads are classified

Hard surface, heavy duty road, four or more lanes wide	4 LANES | 6 LANES
Hard surface, heavy duty road: Two lanes wide; Three lanes wide	3 LANES
Hard surface, medium duty road, four or more lanes wide	4 LANES | 6 LANES
Hard surface, medium duty road: Two lanes wide; Three lanes wide	3 LANES
Buildings	
Improved light duty road, street	
Unimproved dirt road	
Trail	
Route markers: Federal; State	87 50
Barns, sheds, greenhouses, stadiums, etc.	
Bench mark, monumented	BM ×792
Bench mark, non-monumented	×431
Spot elevations in feet: Checked; Unchecked	×168 ×168
Light, lighthouse; Windmill, wind pump; Water mill	
Woods or brushwood	GREEN
Vineyard; Orchard	

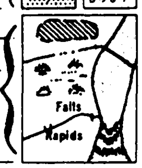
RAILROADS

	Single track	Multiple track
Standard gauge		
Narrow gauge		
In street		
Carline		

BOUNDARIES

National	
State (with monument)	
County	
County subdivision	
Corporate limits	
Military reservation	MIL RES
Other reservation	

Intermittent lake	BLUE
Intermittent stream; Dam	
Marsh or swamp	
Rapids; Falls	
Large rapids; Large falls	



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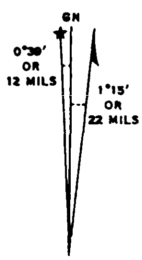
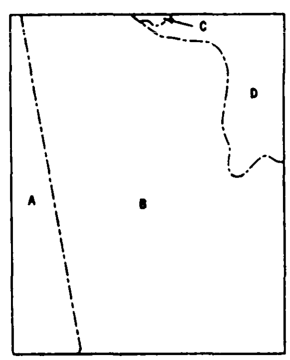


APPROXIMATE MEAN DECLINATION 1950
FOR CENTER OF SHEET
ANNUAL MAGNETIC CHANGE 1' EASTERLY

Use diagram only to obtain numerical values. To determine magnetic north line, connect the pivot point "P" on the south edge of the map with the value of the angle between GRID NORTH and MAGNETIC NORTH, as plotted on the degree scale at the north edge of the map.

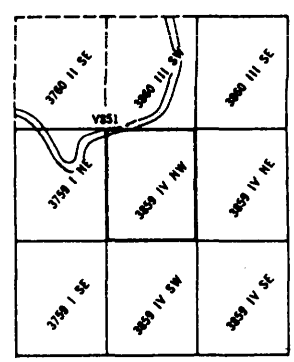
SX 11-61 PRINTED BY ARMY MAP SERVICE CORPS OF ENGINEERS

INDEX TO BOUNDARIES



A. Meade County
B. Hardin County
C. Jefferson County
D. Bullitt County

INDEX TO ADJOINING SHEETS



Sheet 3859 IV NW falls within NJ 16-9, V501, 1:250,000

FORT KNOX, KENTUCKY

Figure 9-19.—Marginal information on a military map (2).

indicate that the map covers parts of both. Note, too, that the direction of grid north (that is, the direction of the north-south grid lines in the map) varies from that of true north by 0°39′E and from the magnetic north by 1°15′W.

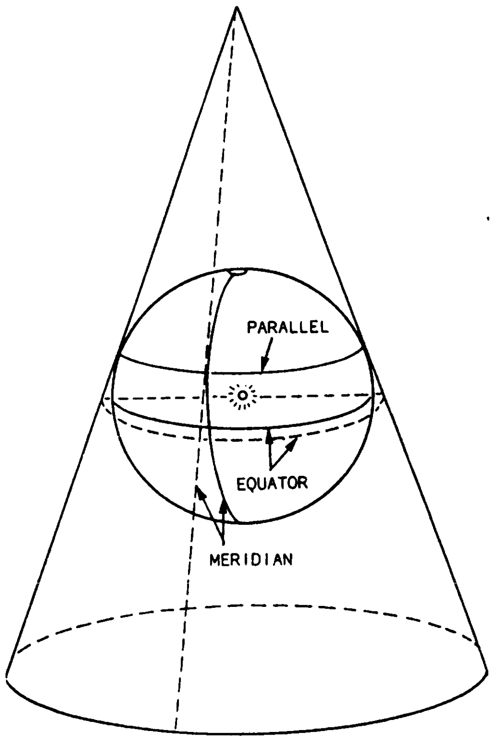


Figure 9-20.-Conic projection.

CONIC PROJECTION

To grasp the concept of conic projection, again imagine the earth as a glass sphere with a light at the center. Instead of a paper cylinder, image a paper cone placed over the Northern Hemisphere tangent to a parallel, as shown in figure 9-20. The North Pole will be projected as a point at the apex of the cone. The meridians will radiate outward from the North Pole as straight lines. The parallels will appear as concentric circles, growing progressively smaller as latitude increases. When the cone is cut along a meridian and flattened out, the meridians and parallels will appear as shown in figure 9-21. In this case, the Northern Hemisphere was projected onto a cone placed tangent to the parallel at 45°N, and the cone was cut along the 180th meridian.

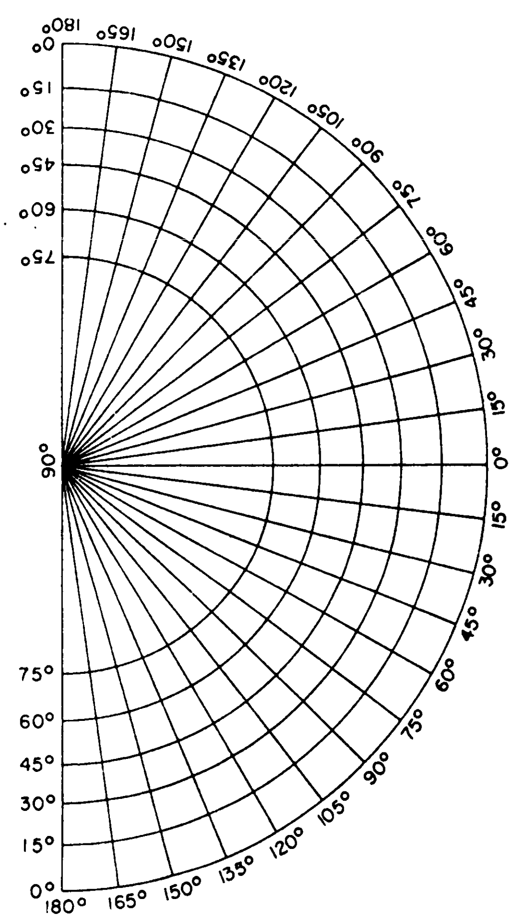


Figure 9-21.—Appearance of meridians and parallels on a conic projection.

GNOMONIC PROJECTION

To grasp the concept of gnomonic projection, again imagine the lighted sphere—this time with a flat-plane paper placed tangent to the North Pole (fig. 9-22). The North Pole will project as a point from which the meridians will radiate outward as straight lines; and the parallels will appear as concentric circles, growing progressively smaller as latitude increases. The difference between this and conic

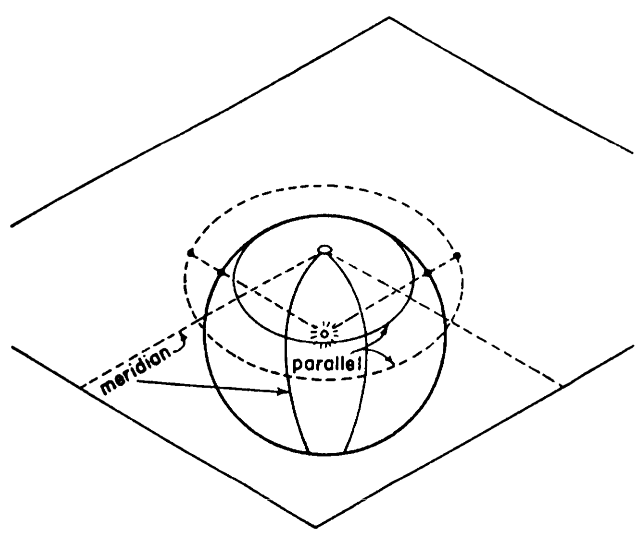


Figure 9-22.-Gnomonic projection.

projection of the polar region is the fact that in the conic projection, the cone is cut and flattened out to form the map or chart, whereas the gnomonic projection will appear as is. On the conic projection, points lying close together on either side of the meridian along which the cone is cut will be widely separated on the map. The gnomonic projection, on the other hand, will give a continuous and contiguous view of the areas. Figure 9-23 shows the appearance of meridians and parallels on a polar gnomonic projection.

CONFORMALITY

According to some authorities, to be **conformal,** a projection must possess both of the following characteristics:

1. It must be a projection on which direction is the same in all parts of the map. Obviously, for this directional conformality, the meridians (which indicate the direction of true north) must be parallel, and the parallels (which indicate true east-west direction) must be parallel to each other and perpendicular to the meridians.

2. It must be a projection on which the distance scale north and south is the same as the distance scale east and west.

Obviously, none of the projections that we have described have both of these characteristics. The only one that has the first characteristic is the Mercator. On this projection the meridians are parallel, and the parallels are parallel to each other and perpendicular to the meridians; therefore, the direction of north or east is the same anywhere on the map. With regard to the second characteristic, however, a distance of 15 degrees (for example) is longer in any part of the map north-south than a distance of 15 degrees east-west (even in the same part).

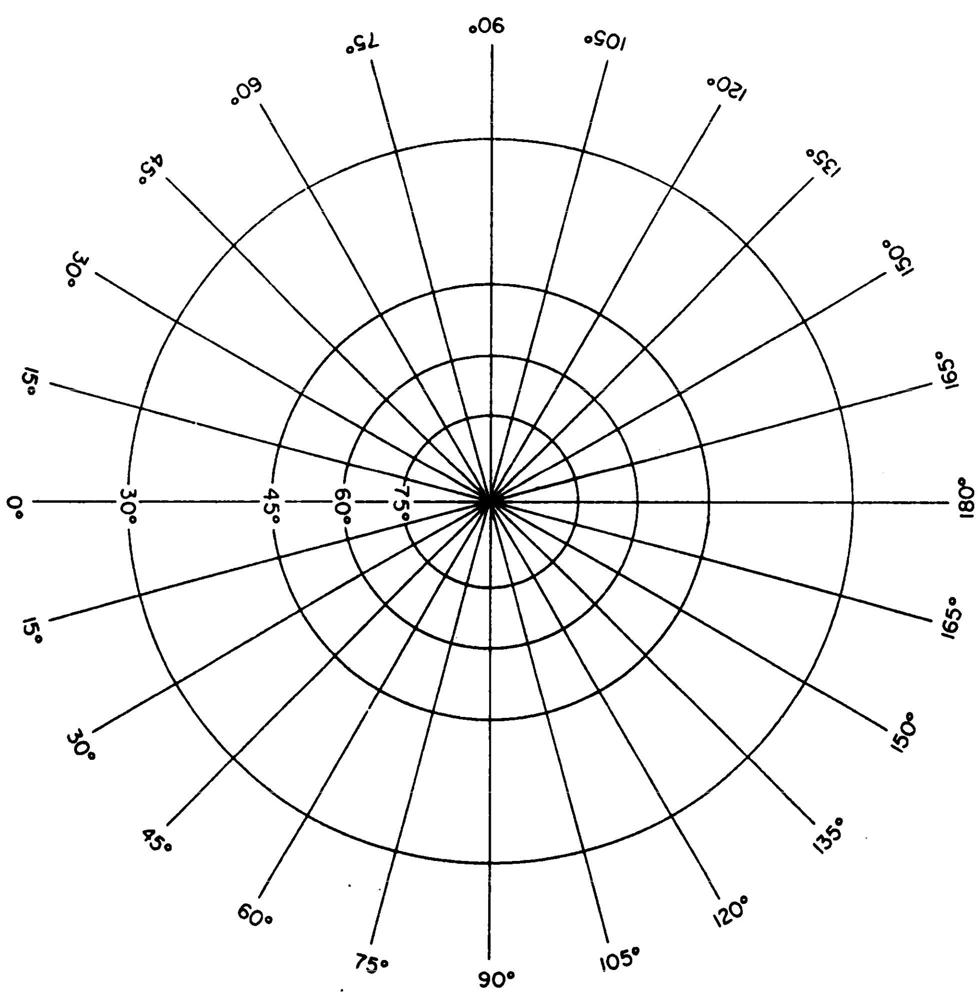


Figure 9-23.-Meridians and parallels on a polar gnomonic projection.

As for the transverse Mercator, the conic, and the gnomonic projections, a glance at the appearance of meridians and parallels on any one of these indicates not only that direction is different in different parts of the map, but that the direction of North (for example) in one part of the map may be precisely opposite to that of north in another. Let's call the two types of conformality we have mentioned **directional** conformality and **distance** conformality. Some authorities hold that directional conformality is all that is required for a conformal projection. A Mercator projection has this type of conformality, and this fact makes that type of projection highly advantageous for navigational charts. A navigator is primarily interested in determining geographical location of his ship; and the principal disadvantage of Mercator projection—the north-south compared to east-west distance distortion (which increases with latitude)–is negligible in navigational practice. This statement applies only to navigation in customary latitudes, however, since Mercator projection of the polar regions (above about 80-degrees latitude) is impossible.

For surveying and other purposes in which distance measurements must be consistent in every direction, Mercator projection presents disadvantages. To understand these, you have only to reflect on the fact that no distance scale could be consistently applied to all parts of a Mercator projection, which means that no square grid system could be superimposed on a Mercator projection; however, the transverse Mercator projection, as it is used in conjunction with the UTM military grid, provides relatively small-area maps that are virtually conformal, both direction-wise and distance-wise.

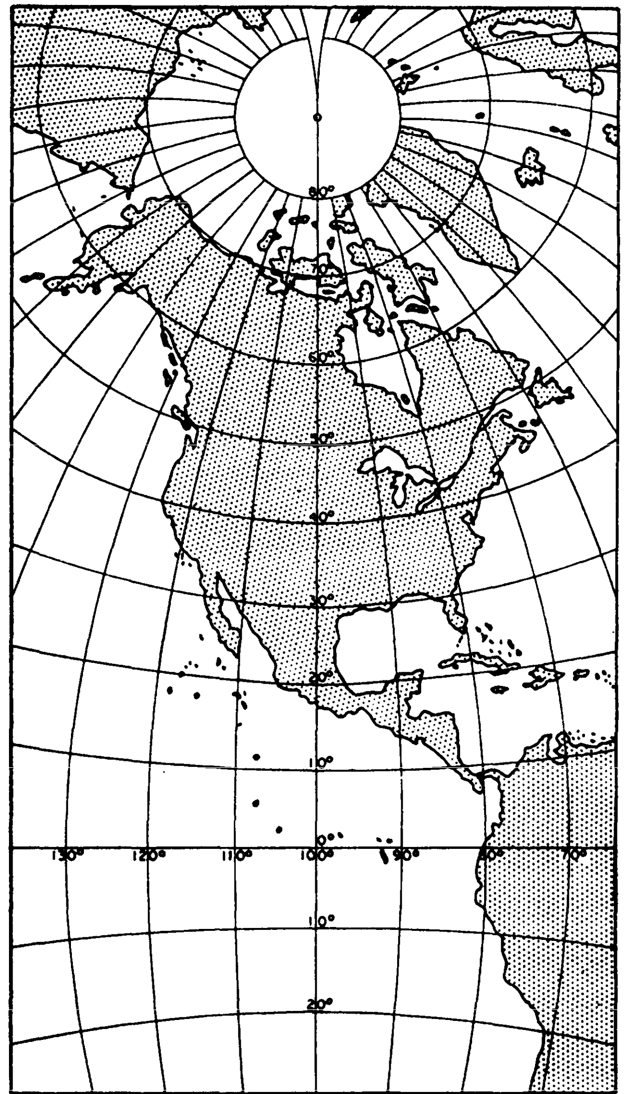


Figure 9-24.—Polyconic projection of North America.

POLYCONIC PROJECTION

In **polyconic projection** a near approach to direction conformality is obtained in relatively small-area maps by projecting the area in question onto more than one cone. A central meridian on the map is straight; all the others are slightly curved and not quite parallel. Similarly, the parallels are slightly curved and not quite parallel; therefore, they are not precisely perpendicular to the meridians. An example of a polyconic map projection is shown in figure 9-24.

Polyconic projection is extensively used for the **quadrangle** maps (familiarly called **quad sheets)** of areas of the United States published by the Geological Survey. For most of the built-up areas of the States, these maps are available on a scale of 1:24,000, showing areas extending for 7°30' of latitude and longitude. An **index map** is available, which gives you the quadrangle divisions and the name of the map that covers a particular area.

That polyconic projection is not conformal distance-wise is indicated by the fact that one of these quad sheets, though it shows an area that is square on the ground, is oblong rather than square. The vertical or latitudinal length of the map is always greater than the horizontal or longitudinal length. The reason is that latitude is measured along a meridian, which is always a great circle, while longitude is measured along a parallel; and every parallel other than the equator is less than a great circle.

An understanding of the concept of the great circle is essential to a thorough understanding of map and

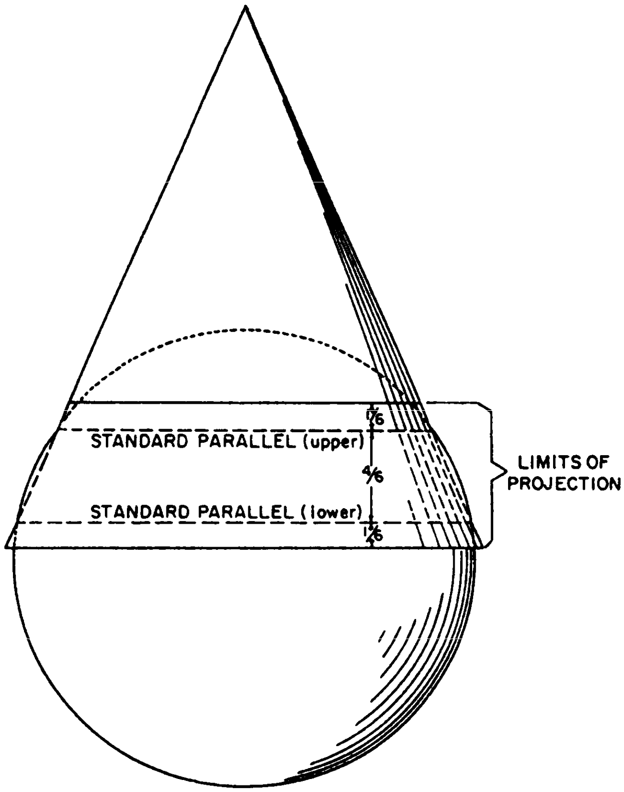


Figure 9-25.-Lambert conformal conic projection.

chart projection. A great circle is any line on the earth's surface (not necessarily a meridian or the equator) that lies in a plane that passes through the earth's center. Any meridian lies in such a plane; so does the equator. But any parallel other than the equator lies in a plane that does not pass through the earth's center; therefore, no parallel other than the equator is a great circle.

Now, 1 minute of arc measured **along a great circle** is equal to 1 nautical mile (6076.115 ft) on the ground. But 1 minute of arc measured along a small circle amounts to less than 1 nautical mile on the ground. Therefore, a minute of latitude always represents a nautical mile on the ground, the reason being that latitude is measured along a meridian and every meridian is a great circle. A minute of longitude at the equator represents a nautical mile on the ground because, in this case, the longitude is measured along the equator, the only parallel that is a great circle. But a minute of longitude in any other latitude represents less than a nautical mile on the ground; and the higher the latitude, the greater the discrepancy.

LAMBERT CONFORMAL CONIC PROJECTION

The **Lambert conformal conic projection** attains such a near approach to both directional and distance conformality as to justify its being called a conformal projection. It is conic, rather than polyconic, because only a single cone is used, as shown in figure 9-25. Instead of being considered tangent to the earth's surface, however, the cone is considered as penetrating the earth along one **standard parallel** and emerging along another. Direction is the same at any point on the map, and the distance scale at a particular point is the same in all

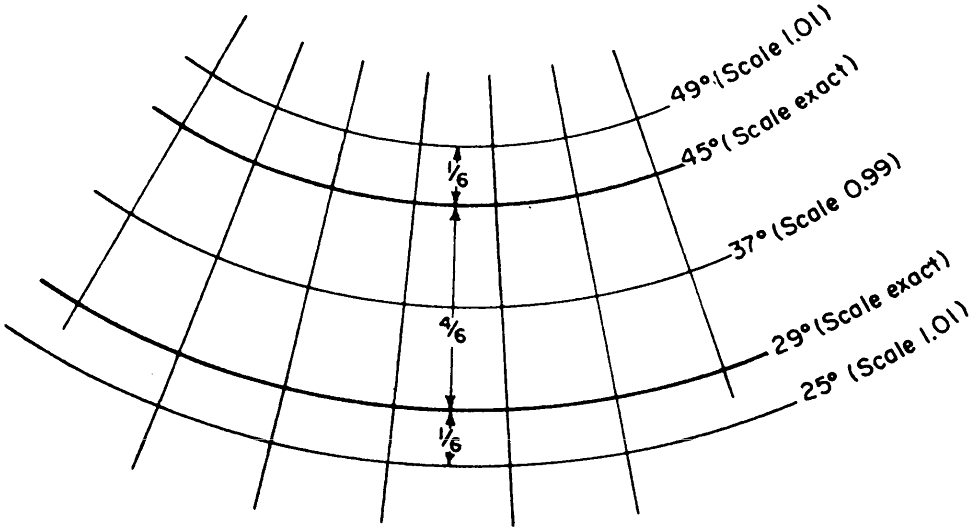


Figure 9-26.-distortion of the Lambert conformal conic projection with the standard parallels at 29 degrees and 45 degrees.

directions. However, the distance scale that applies to the whole map is exact only at the standard parallels, as shown in figure 9-26. Between the parallels the scale is a little too small; beyond them, it is a little too large. The discrepancy is small enough to be ignored in work of ordinary precision or less. For work of higher precision, there are correction factors that may be applied.

The Lambert conformal conic projection is the base for the state coordinate systems devised by the Coast and Geodetic Survey for zones of limited north-south dimension and indefinite east-west dimension. For zones whose greater dimension is north-south, the Coast and Geodetic Survey uses the transverse Mercator projection.

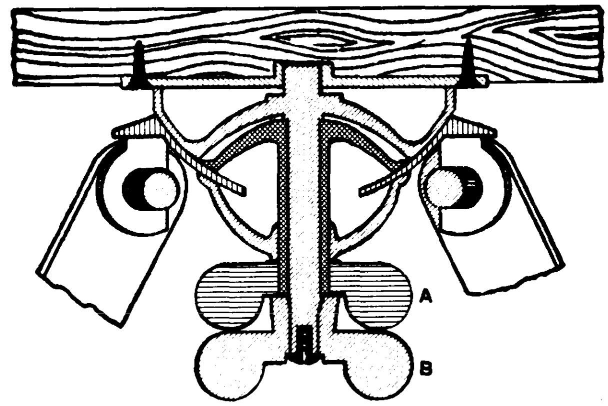


Figure 9-27.-Cross section of a plane-table tripod head.

QUESTIONS

Q1. Which one of the wingnuts, labeled A and B, in figure 9-27 permits a leveled plane table to be rotated in azimuth?

Q2. Assume you are using three-point resection to plot the location of point P and the triangle of error is inside the main triangle formed by the three known points. Where in relation to the triangle of error is point P located?

Q3. What point-location method can you use to run a traverse using a plane table?

Q4. Compute the missing column entries for point 5 in figure 9-8.

Q5. Why is transverse Mercator projection the preferred projection method for use with the military grid reference system ?

Q6. Refer to figure 9-14. What is the complete designation for the first full square east of meridian 168°W and south of the equator?

Q7. Measured along any meridian, what is the approximate distance in statute miles between 16°30'N latitude and 0°30'S latitude ?

er again to figures 8.5 and 8.6, you will If you will ref

CHAPTER 10

ENGINEERING AND LAND SURVEYS

This chapter discusses important factors of engineering surveying and is presented from the viewpoint of the party chief. Included in the discussion are design-data surveys, such as route surveys; and construction surveys that include stakeout and as-built surveys.

Also discussed in this chapter is land surveying which is a special type of surveying performed for the purpose of establishing or reestablishing land boundaries, preparing legal property descriptions, and subdividing tracts of land. Although a complete coverage of land surveying is beyond the scope of this TRAMAN, you will be acquainted with the procedures and some of the legal aspects involved.

ENGINEERING SURVEYS

In the EA3 TRAMAN, you learned that engineering surveys are subdivided into **design-data surveys** and **construction surveys.** A design-data survey is an orderly process of obtaining data that is needed for the planning and design of an engineering project. The activities involved in design-data surveying vary according to the type and complexity of the engineering or construction project; for example, the activities might include simply obtaining topographic data for a proposed building site, or they may include extensive route surveying and soils investigation for a highway. Construction surveying is divided into (1) the **layout,** or **stakeout, survey** and (2) the **as-built survey.** The layout, or stakeout, survey consists of locating and marking (staking) horizontal and vertical control points to guide construction crews, and giving line and grade as needed to establish additional control points and to reestablish disturbed stakes. The as-built survey includes making measurements to verify the locations and dimensions of completed elements of a new structure and to determine the amount of work accomplished up to a given date.

Let's begin the subject of engineering surveys with a discussion of route surveying.

ROUTE SURVEYS

A route survey, as the name implies, is a survey that deals with the route or course that a highway, road, or utility line will follow. While the end product of a route survey for a highway certainly differs from that for a utility line, it may, nevertheless, be said that the purposes of any route survey are to

1. select one or more tentative general routes for the roadway or utility,

2. gather enough information about the general route to make it possible for designers to select the final location of the route, and

3. mark this final location.

Consistent with these purposes, a route survey is usually broken down into reconnaissance, preliminary, and final-location survey phases that satisfy, respectively, each of the purposes given above. Sometimes, however, circumstances may preclude the requirement to perform all three phases; for example, if a new road or utility line is to be constructed on a military installation having well-marked vertical and horizontal control networks and up-to-date topographic maps and utility maps, then perhaps the reconnaissance and preliminary survey phases would not be required. Chapter 14 of the EA3 TRAMAN discusses each phase of route surveying as applied to roads and highways. That discussion is presented in sufficient enough depth to preclude the need to further discuss highway route surveying in this TRAMAN. You should, however, review that discussion and read other publications dealing with the subject of route surveying.

Aside from roads and highways, other uses of route surveys are for aboveground utility lines-most commonly power and communication lines—and for underground utilities, such as power, communication, sewer, water, gas, and fuel lines. The character of the route survey for a utility will vary, of course, with different circumstances; for example, a sanitary sewer, water distribution line, or an electrical distribution line in an urban area will generally follow the streets on which the buildings it serves are located. Also, since these areas will, in all likelihood, have other existing utilities, there should be existing utilities maps that can be used in the design of the new utility line. Consequently, in cases such as this, reconnaissance and preliminary surveys are seldom necessary. On the other hand, a power transmission line or other utility running through open country on a large military installation may require reconnaissance and preliminary surveys in addition to the final-location survey.

For discussion purposes, let's consider route surveys for overhead electrical lines.

Route Surveys for Overhead Electrical Distribution and Transmission Lines

The reconnaissance survey for electrical power lines employs many of the same principles and practices that you studied for highway work; however, the design considerations are different. For a power line, the design engineer considers principles that you studied in chapter 2 of this TRAMAN to select one or more tentative routes over which the line will pass. For convenience, those principles are listed as follows:

1. Select the shortest possible route.
2. Follow the highways and roads as much as possible.
3. Follow the farmer's property or section lines.
4. Route in the direction of possible future loads.
5. Avoid going over hills, ridges, swamps, and bottom lands.
6. Avoid disrupting the environment.

During the reconnaissance phase, you should first study all available maps of the area to gain a general understanding of the landscape. If a portion of the line is off the military installation, determine the ownership of the lands through which the line will pass. That is necessary to obtain permission to run the line. Look for any existing utilities that may already exist in the area. If there are existing utilities, then look for existing utilities maps. Visit the area to examine the terrain and look for any natural or man-made features that may hinder or help the construction. In short, gather all information that the engineer will need to select one or more general routes for the power line.

With the tentative route or routes selected, you are ready to conduct a preliminary survey from which a map is prepared showing the country over which the line will pass. Since the final location is not known, a wide strip of land needs to be mapped. When running the preliminary survey, incorporate all pertinent topographic information into the field notes. Note particularly any existing overhead or underground lines and indicate whether they are power or communications lines. Locate such features as hills, ridges, marshes, streams, forests, roads, railways, power plants, buildings, and adjacent military camps or bases.

When the preliminary mapping is completed, the engineer selects the final route. Again, the engineer considers the principles listed above to select the route.

POLE LINE SURVEYS.— When the route has been selected, a plan and profile are plotted. The plan shows the route the line will follow and the significant topography adjacent to the route. The profile shows the ground elevation along the line and the top elevations of the poles. These elevations are set in accordance with minimum allowable clearances specified in the *National Electrical Safety Code* (NESC), ANSI C2, and the most recent edition of the *National Electrical Code® (NEC®)*.

For distribution lines, poles should be placed on the side of the street that is most free of other lines and trees. Try to keep off the main streets. As much as possible, you should use the same side of the road throughout the length of the line. For straight portions of lines, the usual spacing between poles is about 125 feet (100 feet minimum and 150 feet maximum); however, to make the poles come in line with property lines or fences, the span length may need to be adjusted. The engineer will determine the spans. Along roads, poles should be placed 2 feet from the inside edge of the curb or 2 feet from the edge of the road surface where curbs do not exist. On open roadways or highways, poles should be set 18 inches from the outside of fences.

For transmission lines, poles should be located in high places so that shorter poles can be used and still maintain the proper ground clearance at the middle of the span. Avoid locating poles along the edge of embankments or streams where washouts can be expected. In rolling country, the grading of the line should be considered when determining pole locations. A well-graded line does not have any abrupt changes up or down the line and will appear nearly horizontal regardless of small changes in ground level. Sometimes, by shifting a pole location a few feet, a standard length pole can be used where otherwise an odd-sized pole would be needed. In addition, transmission line poles should be located at least 2 feet from curbs, 3 feet from fire hydrants, 12 feet from the nearest track of a railroad track, and 7 feet from railway sidings.

When you are staking pole locations, the center of each pole is marked with a hub on the line; the hub may be offset. On the guard stake, you put the pole number, the line elevation, and the distance from the top of the hub to the top of the pole obtained from the profile.

TOWER LINE SURVEYS.— High-voltage lines are often supported by broad-based steel towers. For a tower line, construction economy requires that changes in direction be kept at a minimum. That is because a tower located where a line changes direction must withstand a higher stress than one located in a straight direction part of the line. In general, tower construction is cheaper in level country than in broken country; however, the line may be run over broken country to minimize changes in direction, to make the distance shorter, or to follow a line where the cost of obtaining right-of-way is inexpensive. Lines should be located adjacent to existing roads, whenever practical, to provide easier access for construction and future maintenance. When a change in direction in a tower line is unavoidable, it should be made gradually in as small-angular increments as possible. Suppose, for example, a change in direction of 90° is required. Instead of an abrupt change in direction of 90°, towers should be set so as to cause the line to follow a gradual curve in a succession of chords around an arc of 90°.

Route Surveys for Drainage

When man-made structures are erected in a certain area, it is necessary to plan, design, and construct an adequate drainage system. Generally, an underground drainage system is the most desirable way to remove surface water effectively from operating areas. An open drainage system, like a ditch, is economical; however, when not properly maintained, it is unsightly and unsafe. Sometimes, an open drainage system also causes erosion, thus resulting in failures to nearby structures. Flooding caused by an inadequate drainage system is the most prevalent cause leading to the rapid deterioration of roads and airfields. The construction and installation of drainage structures will be discussed later in this chapter. At this point we are mainly interested in drainage systems and types of drainage.

DRAINAGE SYSTEM.—Sanitary sewers carry waste from buildings to points of disposal; **storm** sewers carry surface runoff water to natural water courses or basins. In either case the utility line must have a gradient; that is, a downward slope toward the disposal point, just steep enough to ensure a gravity flow of waste and water through the pipes. This gradient is supplied by the designing engineer.

Natural Drainage.—To understand the controlling considerations affecting the location and other design features of a storm sewer, you must know something about the mechanics of water drainage from the earth's surface.

When rainwater falls on the earth's surface, some of the water is absorbed into the ground. The amount absorbed will vary, of course, according to the physical characteristics of the surface. In sandy soil, for instance, a large amount will be absorbed; on a concrete surface, absorption will be negligible.

Of the water not absorbed into the ground, some evaporates, and some, absorbed through the roots and exuded onto the leaves of plants, dissipates through a process called **transpiration.**

The water that remains after absorption, evaporation, and transpiration is technically known as **runoff.** This term relates to the fact that this water, under the influence of gravity, makes its way (that is, runs off) through natural channels to the lowest point it can attain. To put this in terms of a general scientific principle, water, whenever it can, seeks its own level. The general, final level that unimpeded water on the earth's surface seeks is sea level; and the rivers of the earth, most of which empty into the sea, are the earth's principal drainage channels. However, not all of the earth's runoff reaches the great oceans; some of it is caught in landlocked lakes, ponds, and other nonflowing inland bodies of water.

Let's consider, now, a point high in the mountains somewhere. As rain falls in the area around this point, the runoff runs down the slopes of a small gully and forms a small stream, which finds a channel downward through the ravine between two ridges. As the stream proceeds on its course, it picks up more and more water draining in similar fashion from high points in the area through which the stream is passing. As a result of this continuing accumulation of runoff, the stream becomes larger until eventually it either becomes or joins a large river making its way to the sea—or it may finally empty into a lake or some other inland body of water.

In normal weather conditions, the natural channels through which this runoff passes can generally contain and dispose of all the runoff. However, during the winter in the high mountains, runoff is commonly interrupted by snow conditions; that is, instead of running off, the potential runoff accumulates in the form of snow. When this accumulated mass melts in the spring, the runoff often attains proportions that overwhelm the natural channels, causing flooding of surrounding areas. In the same fashion, unusually heavy rainfall may overtax the natural channels.

Artificial Drainage.— When artificial structures are introduced into an area, the natural drainage arrangements of the area are upset. When, for example, an area originally containing many hills and ridges is graded off flat, the previously existing natural drainage channels are removed, and much of the effect of gravity on runoff is lost. When an area of natural soil is covered by artificial paving, a quantity of water that previously could have been absorbed will now present drainage problems.

In short, when man-made structures, such as bridges, buildings, and so forth, are erected in an area, it is usually necessary to design and construct an artificial drainage system to offset the extent to which the natural drainage system has been upset. Storm sewers are usually the primary feature of an artificial

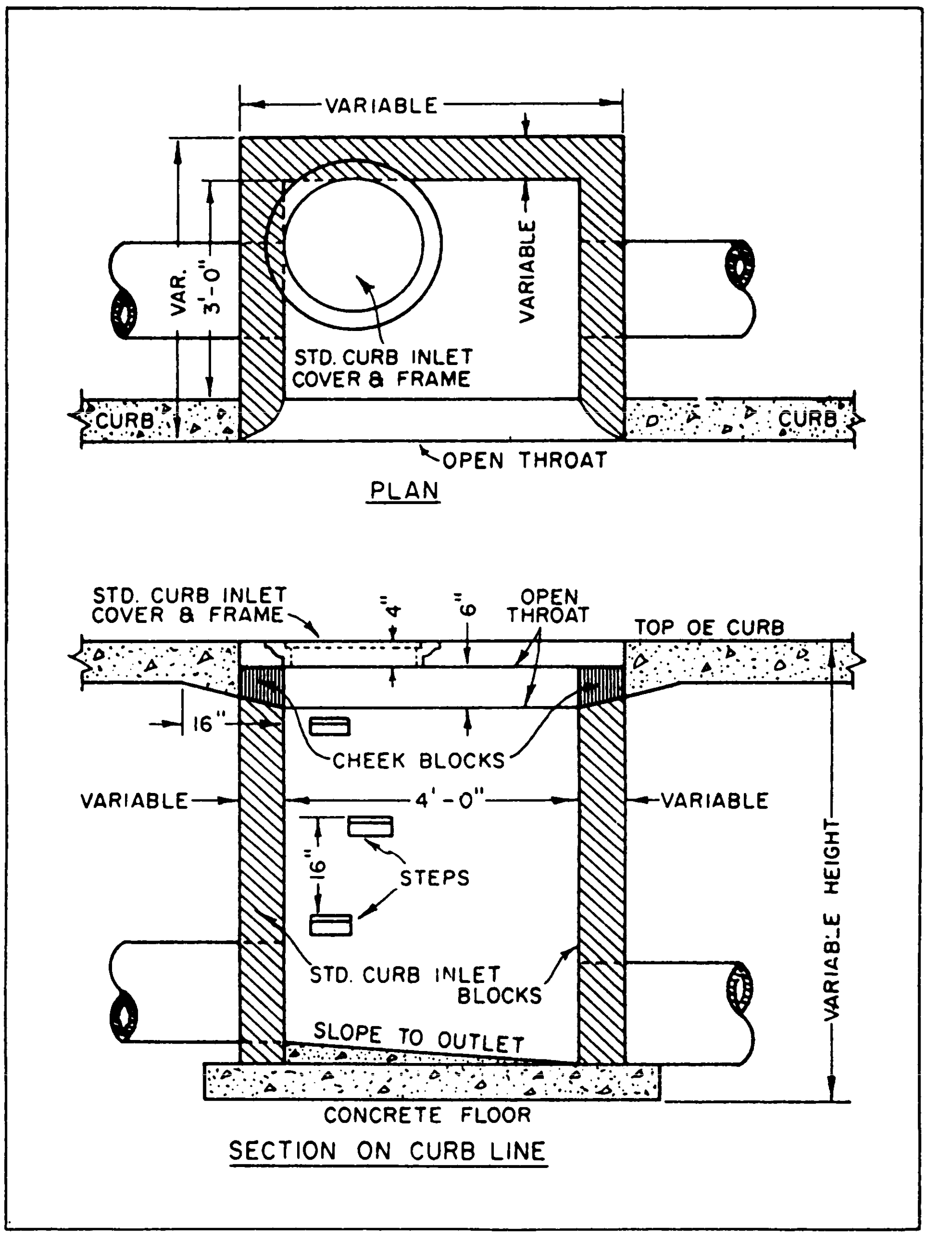


Figure 10-1.—Working drawing for a typical curb inlet.

drainage system; however, there are other features, such as drainage ditches. Both storm sewers and ditches carry surface runoff. The only real difference between a drainage ditch and a storm sewer is the fact that the ditch lies on the surface and the storm sewer lies below the surface.

Similarly, there is no essential difference in mechanical principle between an artificial and a natural drainage system. Like a natural channel, an artificial channel must slope downward and must become progressively larger as it proceeds along its course, picking up more runoff as it goes. Like a natural system, an artificial system must reach a disposal point—usually a stream whose ultimate destination is the sea or a standing inland body of water. At the terminal point of the system where the accumulated runoff discharges into the disposal point, the runoff itself is technically known as **discharge.** The discharge point in the system is called the **outfall.**

Ditches.— A surface drainage system consists principally of ditches that form the drainage channels. A ditch may consist simply of a depression formed in the natural soil, or it may be a paved ditch. Where a ditch must pass under a structure (such as a highway embankment, for example), an opening called a **culvert** is constructed. A **pipe** culvert has a circular opening; a **box** culvert has a rectangular opening. Walls constructed at the ends of a culvert are called **end walls.** An end wall, running perpendicular to the line through the culvert, may have extensions called **wings** (or **wing walls),** running at an oblique angle to the line through the culvert.

Storm Sewers.—An underground drainage system (that is, a storm sewer) consists, broadly speaking, of a buried pipeline called the **trunk** or **main,** and a series of **storm water inlets,** which admit surface runoff into the pipeline. An inlet consists of a surface opening that admits the surface water runoff and an inner chamber called a **box** (sometimes called a **catch basin).** A box is usually rectangular but may be cylindrical. An inlet with a surface opening in the side of a curb is called a **curb** inlet. A working drawing of a curb inlet is shown in figure 10-1. An inlet with a horizontal surface opening covered by a grating is called a **grate** (sometimes a **drop)** inlet. A general term applied in some areas to an inlet that is neither a curb nor a grate inlet is **yard** inlet.

Appurtenances.—Technically speaking, the term *storm sewer* applies to the pipeline; the inlets are called **appurtenances.** There are other appurtenances, the most common of which are **manholes** and **junction boxes.** A manhole is a box that is installed, of necessity, at a point where the trunk changes direction, gradient, or both. The term *manhole* originally related to the access opening at one of these points; however, a curb inlet and a junction box nearly always have a similar access opening for cleaning, inspection, and maintenance purposes. One of these openings is often called a manhole, regardless of where it is located. However, strictly speaking, the access opening on a curb inlet should be called a curb-inlet opening; and on a junction box, a junction-box opening. Distances between manholes are normally 300 feet, but this distance may be extended to a maximum of 500 feet when specified.

The access opening for a manhole, curb inlet, or junction box consists of the cover and a supporting metal **frame.** A frame for a circular **cover** is shown in figure 10-2. Some covers are rectangular. The frame usually rests on one or more courses of **adjusting blocks** so that the rim elevation of the cover can be varied slightly to fit the surface grade elevation by varying the vertical dimensions, or the number of courses, of the adjusting blocks.

A junction box is similar to a manhole but is installed, of necessity, at a point where two or more trunk lines converge. The walls of an inlet, manhole, or junction box maybe constructed of special concrete masonry units or of cast-in-place concrete. The bottom consists of a formed slab, sloped in the

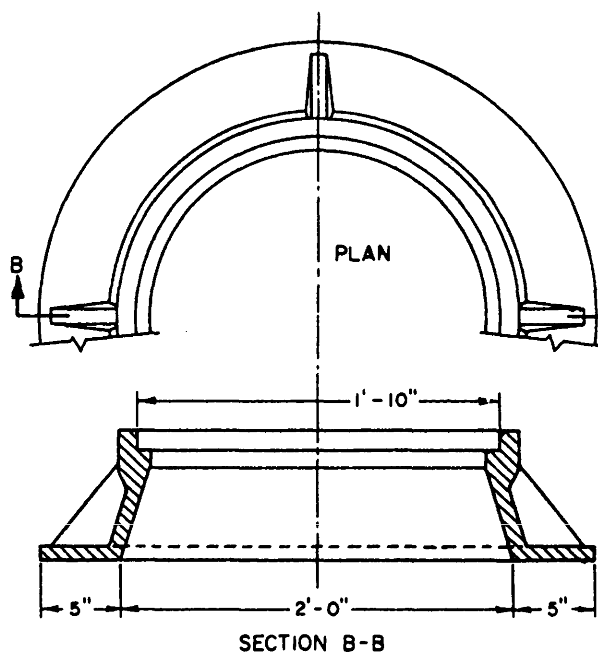


Figure 10-2.—Frame for an access opening.

direction of the line gradient and often shaped with channels for carrying the water across the box from the inflowing pipe to the outflowing pipe.

STORM SEWER ROUTE SURVEY.— The character of the route survey for a storm sewer depends on the circumstances. The nature of the ground may be such as to indicate, without the necessity for reconnaissance and preliminary location surveys, just where the line must go. This is likely to be the case in a development area; that is, an area that will be closely built up and in which the lines of the streets and locations of the buildings have already been determined. In these circumstances, the reconnaissance and preliminary surveys may be said to be done on paper.

On the other hand, a line—or parts of it—often must be run for considerable distances over rough, irregular country. In these circumstances the route survey consists of reconnaissance, preliminary location, and final-location surveys. If topographic maps of the area exist, they are studied to determine the general area along which the line will be run. If no such maps exist, a reconnaissance party must select one or more feasible route areas, run random traverses through these, and collect enough topo data to make the planning of a tentative route possible.

After these data have been studied, a tentative route for the line is selected. A preliminary survey party runs this line, making any necessary adjustments required by circumstances encountered in the field, taking profile elevations, and gathering enough topo data in the vicinity of the line to make design of the system possible.

The system is then designed, and a plan and profile are made. Figure 10-3 shows a storm sewer plan and profile. The project here is the installation of 230 feet of 18-inch concrete sewer pipe (CSP) with a curb inlet (CI "A"). The computational length of sewer pipe is always given in terms of horizontal feet covered. The actual length of a section is, of course, greater than the computational length because of the slope.

The pipe in figure 10-3 is to run downslope from a curb inlet to a manhole in an existing sewer line. The reason for the distorted appearance of the curb inlet and manhole, which look much narrower than they would in their true proportions, is the exaggerated vertical scale of the profile. The appearance of the pipe is similarly distorted.

The pipe to be installed is to be placed at a gradient of 2.39 percent. The invert elevation of the outflowing 21-inch pipe at the manhole is 91.47 feet; that of the inflowing 18-inch pipe is to be 92.33 feet. Obviously, there is a drop here of 0.86 foot. Of this drop, 0.25 foot is because of the difference in diameters; the other 0.61 foot is probably because of structural and velocity head losses.

From the invert in at the manhole, the new pipe will extend 230 horizontal feet to the invert at the center line of the curb inlet. The difference in elevation between the invert elevation at the manhole and the invert elevation at the curb inlet will be the product of 2.39 (the grade percentage) times 2.30 (number of 100-foot stations in 230 horizontal feet), or 5.50 feet. Therefore, the invert elevation at the curb inlet will be 92.33 feet (invert elevation at the manhole) plus 5.50 feet, or 97.83 feet. The invert elevation at any intermediate point along the line can be obtained by similar computation.

The plan shown in figure 10-3 is greatly simplified for the sake of clearness—it contains the bare minimum of data required for locating the new line. Plans used in actual practice usually contain more information.

The plan and profile constitute the paper location of the line. A final-location survey party runs the line in the field. Where variations are required because of circumstances discovered in the field (such as the discovery of a large tree or some similar obstruction lying right on the line), the direction of the line is altered (after receiving approval to do so) and the new line is tied to the paper location. The final-location party may simply mark the location of the line and take profile elevations, or it may combine the final-location survey and the stakeout (which is part of the construction survey, rather than the route survey) in the same operation.

Other Route Surveys

While highways and the various types of utilities have differing design requirements that must be considered when conducting route surveys, you have probably observed in your studies that much of route surveying is similar regardless of the type of construction being planned. This is especially true during the reconnaissance phase. Therefore, with a firm understanding of the preceding paragraphs and of the EA3 TRAMAN discussion of route surveying, you should have little difficulty in planning and performing other types of route surveys. For roads and highways, however, you also must have an

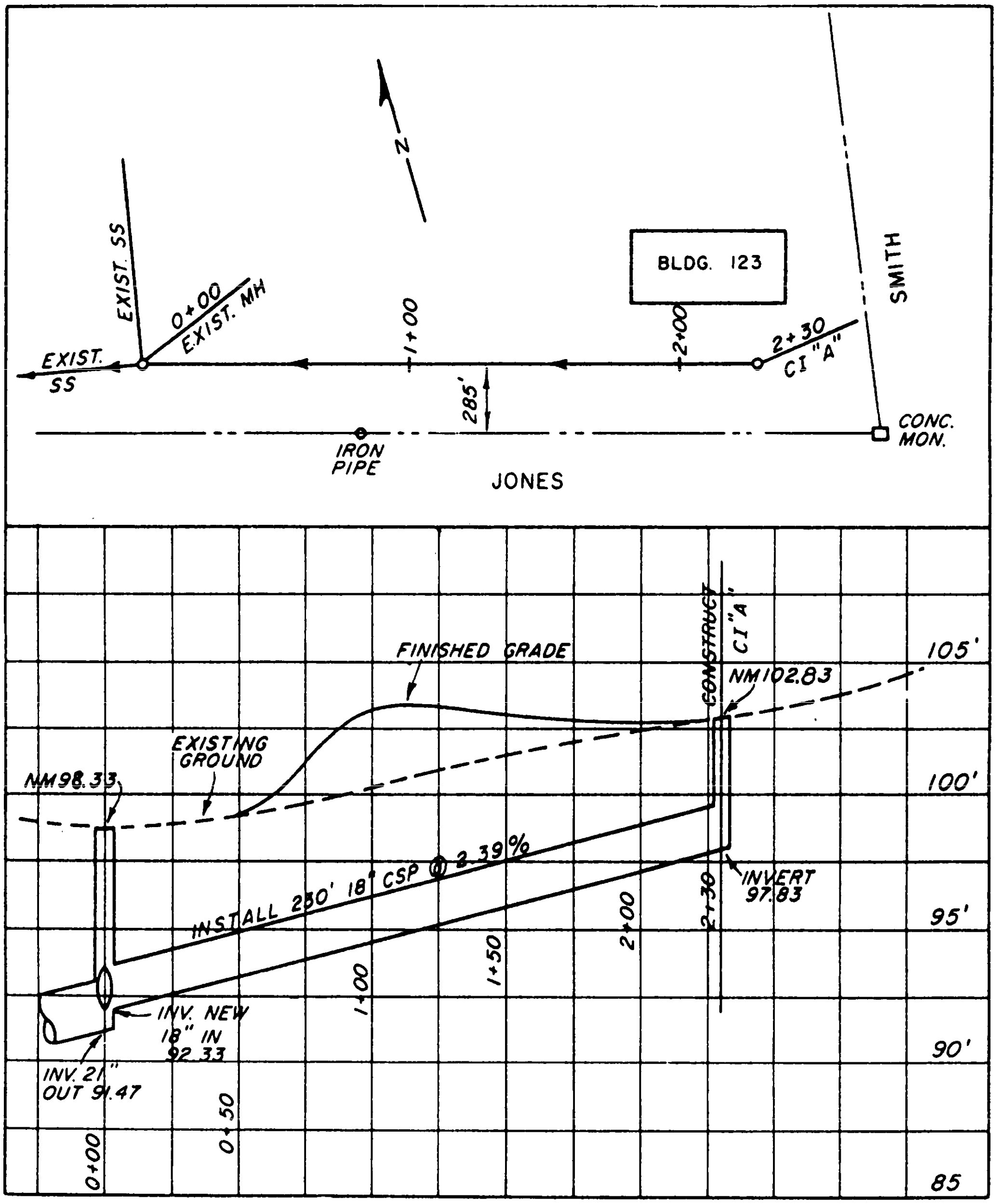


Figure 10-3.—Storm sewer plan and profile.

understanding of horizontal and vertical curves. Those will be discussed in the next chapter.

Earthwork Computations

Computing earthwork volumes is a necessary activity for nearly all construction projects and is often accomplished as a part of route surveying, especially for roads and highways. Suppose, for example, that a volume of cut must be removed between two adjacent stations along a highway route. If the area of the cross section at each station is known, you can compute the average-end area (the average of the two cross-sectional areas) and then multiply that average-end area by the known horizontal distance between the stations to determine the volume of cut.

To determine the area of a cross section easily, you can run a planimeter around the plotted outline of the section. Counting the squares, explained in chapter 7 of this traman, is another way to determine the area of a cross section. Three other methods are explained below.

AREA BY RESOLUTION.— Any regular or irregular polygon can be resolved into easily calculable geometric figures, such as triangles and trapezoids. Then, by computing the area of each triangle and trapezoid and determining the sum of the areas, you obtain the area of the polygon.

Take, for example, the plot of station 305 + 00 shown in figure 10-4. Figure 10-5 illustrates how this figure can be resolved into two triangles, *ABH* and *DFE,* and two trapezoids, *BCGH* and *CGFD.* For each of these figures, the approximate dimensions have been determined by the scale of the plot. From your knowledge of mathematics, you know that the area of each triangle can be determined using the following formula:

$$A \sqrt{s(s-a)(s-b)(s-c)}$$

Where:

s = one half of the perimeter of the triangle,

and that for each trapezoid, you can calculate the area using the formula:

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

When the above formulas are applied and the sum of the results are determined, you find that the total area of the cross section at station 305 is 509.9 square feet.

AREA BY FORMULA.— A regular section area for a three-level section can be more exactly determined by applying the following formula:

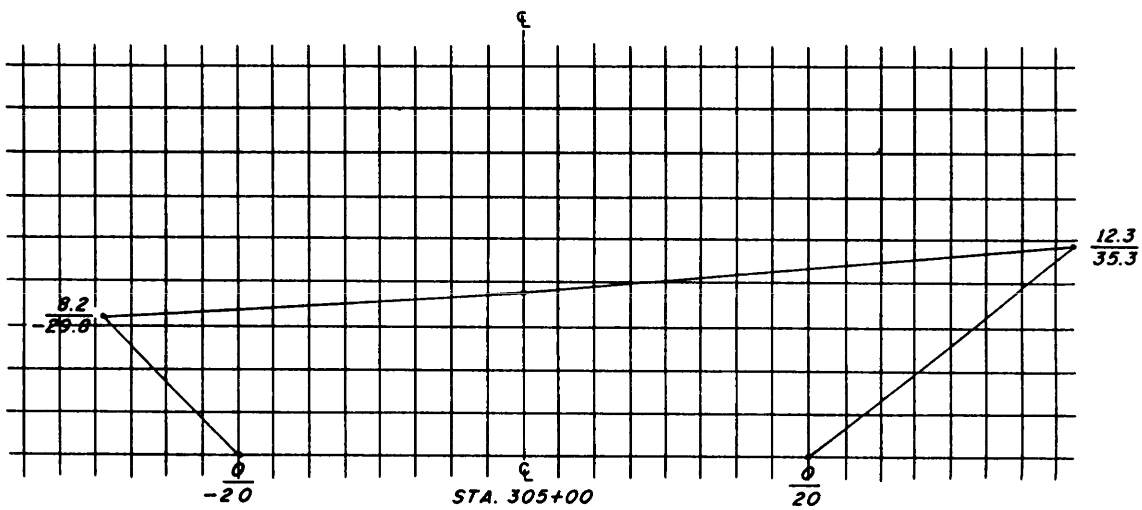


Figure 10-4.—A cross section plotted on cross-section paper.

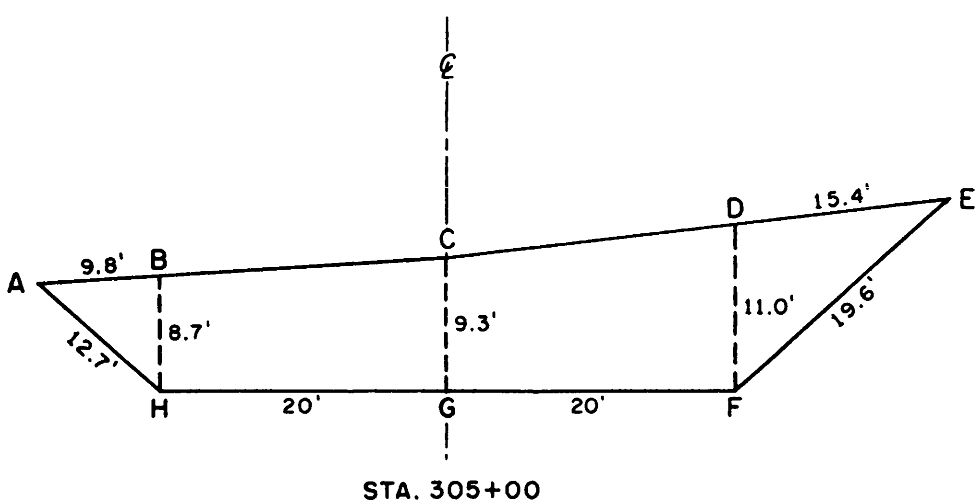


Figure 10-5.—Cross section resolved into triangles and trapezoids.

$$A = \frac{W}{4}(h_l + h_l) + \frac{C}{2}(d_l + d_l).$$

In this formula, W is the width of the highway; h_l and h_r are the vertical distances of the left and right slope stakes above grade; d_l and d_r are the center-line distances of the left and right slope stakes; and c is the depth of the center-line cut or fill. Applying the formula for station 305 + 00 (fig. 10-4), you get the following results:

A = ***(40/4)(8.2+ 12.3)+ (9.3/2)(29.8+ 35.3)= 507.71*** square feet.

AREA OF FIVE-LEVEL OR IRREGULAR SECTION.— Figures 10-6 and 10-7 are the field notes and plotted cross sections for two irregular sections. To

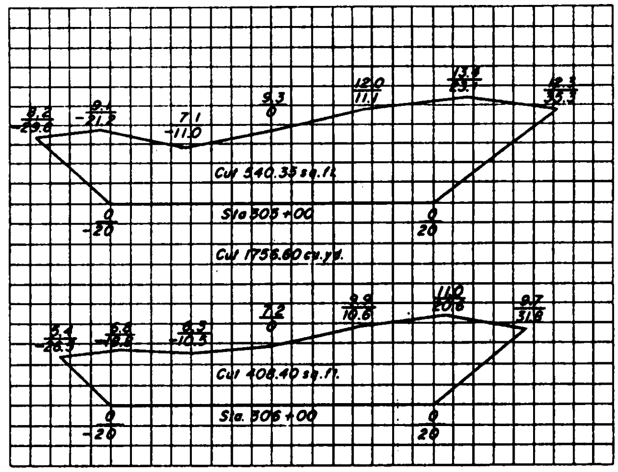


Figure 10-7.—Cross-section plots of stations 305 and 306 noted in figure 10-6.

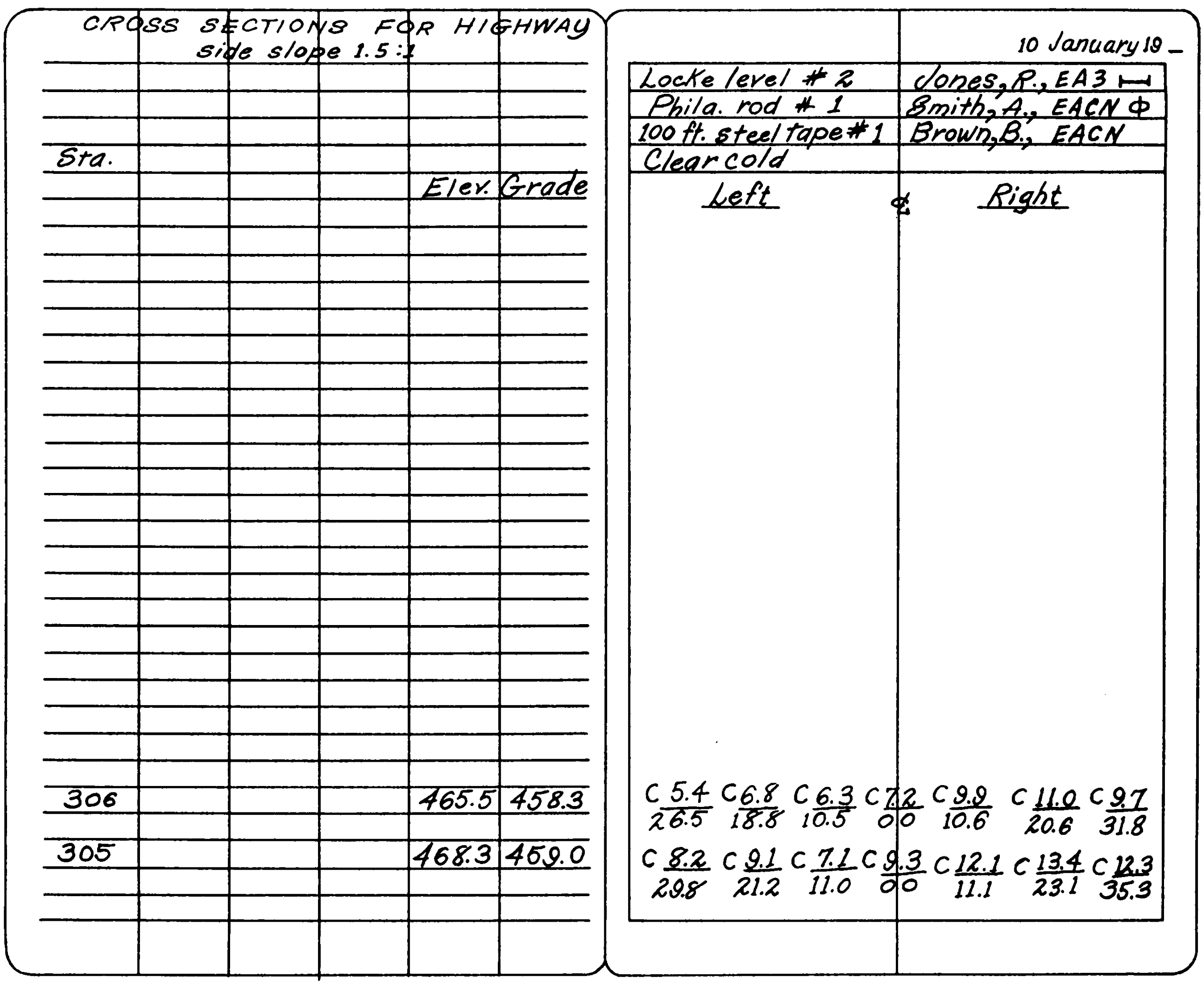


Figure 10-6.—Field notes for irregular sections.

determine the area of sections of this kind, you should use a method of determining area by coordinates.

For explanation purpose, let's consider station 305 (fig. 10-6). First, consider the point where the center line intersects the grade line as the point of origin for the coordinates. Vertical distances above the grade line are positive *Y* coordinates; vertical distances below the grade line are negative *Y* coordinates. A point on the grade line itself has a *Y* coordinate of 0. Similarly, horizontal distances to the right of the center line are positive *X* coordinates; distances to the left of the center line are negative *X* coordinates; and any point on the center line itself has an *X* coordinate of 0.

Plot the cross section, as shown in figure 10-7, and be sure that the *X* and *Y* coordinates have their proper signs. Then, starting at a particular point and going successively in a clockwise direction, write down the coordinates, as shown in figure 10-8.

After writing down the coordinates, you then multiply each **upper** term by the **algebraic** difference of the **following** lower term and the **preceding** lower term, as indicated by the direction of the arrows (fig. 10-8). The algebraic sum of the resulting products is the **double** area of the cross section. Proceed with the computation as follows:

8.2[–21.2 – (–20.0)]	=		–9.8
9.1[–11.0 – (–29.8)]	=	+171.1	
7.1[0 – (–21.2)]	=	+150.5	
9.3[11.1 – (–11.0)]	=	+205.5	
12.0[23.1 – 0]	=	+277.2	
13.4[35.3 – 11.1]	=	+324.3	
12.3[20.0 – 23.1]	=		–38.1
		+1,128.6	–47.9
		– 47.9	
		1,080.7	

Since the result (1,080.70 square feet) represents the **double** area, the area of the cross section is one half of that amount, or 540.35 square feet.

By similar method, the area of the cross section at station 306 (fig. 10-7) is 408.40 square feet.

EARTHWORK VOLUME.— As discussed previously, when you know the area of two cross sections, you can multiply the average of those cross-sectional areas by the known distance between them to obtain the volume of earth to be cut or filled. Consider figure 10-9 that shows the plotted cross sections of two sidehill sections. For this figure, when you multiply the average-end area (in fill) and the average-end area (in cut) by the distance between the two stations (100 feet), you obtain the estimated amount of cut and fill between the stations. In this case, the amount of space that requires filling is computed to be approximately 497.00 cubic yards and the amount of cut is about 77.40 cubic yards.

MASS DIAGRAMS.— A concern of the highway designer is economy on earthwork. He wants to know exactly where, how far, and how much earth to move in a section of road. The ideal situation is to balance the cut and fill and limit the haul distance. A technique for balancing cut and fill and determining the

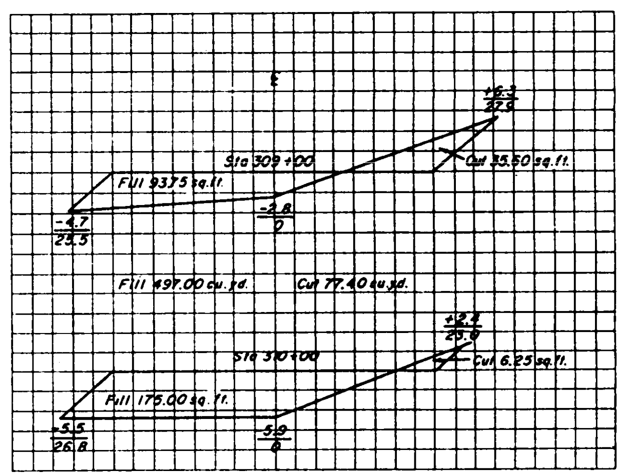


Figure 10-9.—Plots of two sidehill sections.

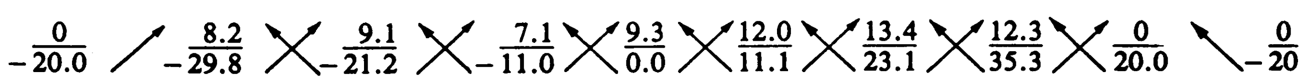


Figure 10-8.—Coordinates for cross-section station 305 shown in figure 10-7.

economical haul distance is the **mass diagram** method.

A **mass diagram** is a graph or curve on which the algebraic sums of cuts and fills are plotted against linear distance. Before these cuts and fills are tabulated, the swells and compaction factors are considered in computing the yardage. Earthwork that is in place will yield more yardage when excavated and less yardage when being compacted. An example of this is sand: 100 cubic yards in place yields 111 cubic yards loose and only 95 cubic yards when compacted. Table 10-1 lists conversion factors for various types of soils. These factors should be used when you are preparing a table of cumulative yardage for a mass diagram. Cuts are indicated by a rise in the curve and are considered positive; fills are indicated by a drop in the curve and are considered negative. The yardage between any pair of stations can be determined by inspection. This feature makes the mass diagram a great help in the attempt to balance cuts and fills within the limits of economic haul.

The limit of economic haul is reached when the cost of haul and the cost of excavation become equal. Beyond that point it is cheaper to waste the cut from one place and to fill the adjacent hollow with material taken from a nearby borrow pit. The limit of economic haul will, of course, vary at different stations on the project, depending on the nature of the terrain, the availability of equipment, the type of material, accessibility, availability of manpower, and other considerations.

The term *free-haul distance* means a distance over which hauling material involves no extra cost. This distance is usually taken to be about 500 feet—meaning that it is only for hauls longer than 500 feet that the limits of economic haul need to be considered.

Table 10-1.—Soil Conversion Factors (Conversion Factors for Earth-Volume Change)

Soil Type	Soil Condition	Converted to		
		In-place	Loose	Compacted
Sand	In place	1.00	1.11	0.95
	Loose	.90	1.00	.86
	Compacted	1.05	1.17	1.00
Loam	In place	1.00	1.25	0.90
	Loose	.80	1.00	.72
	Compacted	1.11	1.39	1.00
Clay	In place	1.00	1.43	0.90
	Loose	.70	1.00	.63
	Compacted	1.11	1.59	1.00
Rock (blasted)	In place	1.00	1.50	1.30
	Loose	.67	1.00	.87
	Compacted	.77	1.15	1.00
Hard coral	In place	1.00	1.50	1.30
	Loose	.67	1.00	.87
	Compacted	.77	1.15	1.00

Tabulating Cumulative Yardage.— The first step in making a mass diagram is to prepare a **table of cumulative yardage,** like the one shown in table 10-2. Under End Areas, you put the cross-sectional area at each station—sometimes this is cut, sometimes fill, and sometimes (as at stations 9 + 00 and 15 + 00) part cut and part fill. Under Volumes, you put the volumes of cut or fill between stations, computed from the average end areas and the distance between sections in cubic yards. Note that, besides the sections at each full station, sections are taken at every plus where both the cut and the fill are zero. Note also that cut volumes are designated as plus and fill volumes as minus.

Under Algebraic Sums Volumes, Cumulative, you put the cumulative volume at each station and each plus, computed, in each case, by determining the algebraic sum of the volume at that station or plus and the preceding cumulative total; for example, at station 8 + 00 the cumulative total is –563. At station 9 + 00 there is a volume of cut of +65 and a volume of fill of –305, making a net of –240. The cumulative total at station 9 + 00, then, is (–563)+ (–240), or –803.

Plotting Mass Diagram.— Figure 10-10 shows the values from the table of cumulative yardage plotted on a mass diagram. The vertical coordinates are cumulative volumes, plus or minus, from a **line of zero yardage,** each horizontal line representing an increment of 200 cubic yards. The horizontal coordinates are the stations, each vertical line representing a full 100-foot station.

As you can see, the mass diagram makes it possible for you to determine by inspection the yardage of cut or fill lying between any pair of stations. Between station 0 + 00 and station 3 + 50, for example, there are about 800 cubic yards of cut. Between station 3 + 50 and station 7 + 00, there are about 800 cubic yards of fill (descending curve). Between station 7 + 00 and station 10 + 50, there are about 850 cubic yards of fill (curve still descending), and so on.

Table 10-2.—Table of Cumulative Yardage

CUMULATIVE YARDAGE					
STATION	END AREAS (FT^2)		VOLUMES (YD^3)		ALGEBRAIC SUMS VOLUMES, CUMULATIVE
	CUT	FILL	CUT	FILL	
0 + 00	186	0	---	---	0
1 + 00	65	0	+465	---	+465
2 + 00	44	0	+202	---	+667
3 + 00	22	0	+122	---	+789
3 + 50	0	0	+20	---	+809
4 + 00	0	22	---	-20	+789
5 + 00	0	44	---	-122	+667
6 + 00	0	65	---	-202	+465
7 + 00	0	186	---	-465	0
8 + 00	0	119	---	-563	-563
9 + 00	35	46	+65	-305	-803
9 + 08	0	0	+5	-7	-805
10 + 00	0	22	---	-37	-842
10 + 50	0	0	---	-20	-862
11 + 00	22	0	+20	---	-842
12 + 00	44	0	+122	---	-720
13 + 00	87	0	+242	---	-478
14 + 00	218	43	+563	-80	5
15 + 00	64	22	+521	-120	+406
15 + 07	0	0	+8	-8	+406
16 + 00	32	0	+55	---	+461
16 + 50	0	0	+30	---	+491
17 + 00	0	32	---	-30	+461
18 + 00	0	61	---	-172	+289
19 + 00	0	157	---	-405	-116
20 + 00	90	95	+166	-466	-416

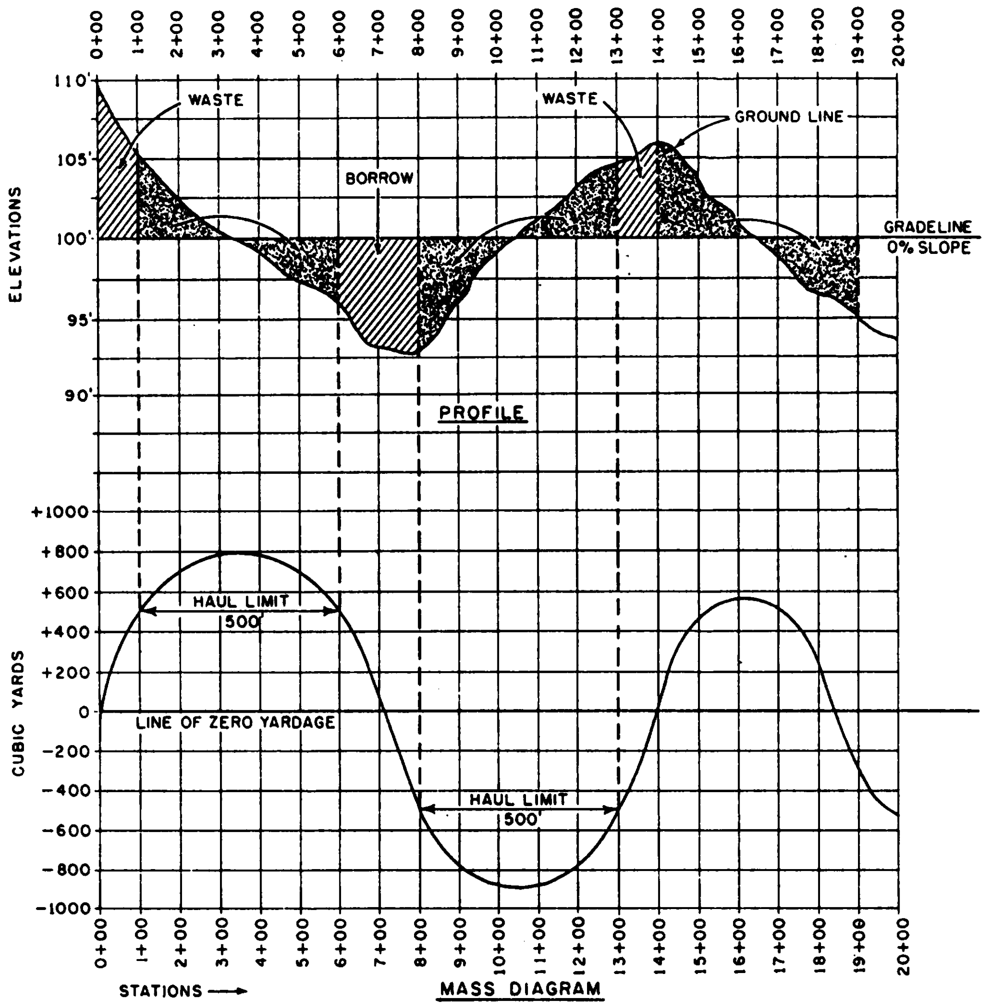


Figure 10-10.—Profile and mass diagram.

Remember that sections where the volume (yardage) changes from cut to fill correspond to a maximum in the mass diagram curve, and sections where it changes from fill to cut correspond to a minimum. The peaks and the lowest points of the mass diagram that represent the maximum or minimum yardage, occur at, or near, the grade line on the profile.

Balancing Cuts and Fills.— To understand the manner in which the mass diagram is used to balance cuts and fills and how haul limit is determined, let's examine figure 10-10. Here the profile of a road, from stations 0 + 00 to 20 + 00, has been plotted above the mass diagram. You can see that they are plotted on the same horizontal scale. The labeled sections and arrows on the profile show relatively what is to be done to the cuts and fills; and where the limit of economical haul is exceeded, the cut is wasted, and the fill is borrowed.

In figure 10-10, a 500-foot haul-limit line has been inserted into the mass diagram curve above and below the lines of zero yardage. (The 500-foot distance is laid out to scale horizontally parallel to the line of zero yardage.) The terminal points of these haul-limit distances were projected to the profile curve, as indicated. You can see that the cut lying between stations 1 + 00 and 3 + 50 can be hauled economically as far as station 6 + 00; that lying between stations 10 + 50 and 13 + 00, as far as station 8 + 00; and that lying between stations 14 + 00 and 16 + 50, as far as station 19 + 00. This leaves the cut between stations 0 + 00 and 1 + 00, the fill between stations 6 + 00 and 8 + 00, the cut between stations 13 + 00 and 14 + 00, and the fill between stations 19 + 00 and 20 + 00.

As indicated in figure 10-10, the cut between stations 0 + 00 and 1 + 00, lying outside the limit of economical haul distance, would be wasted; that is, dumped into a nearby spoil area or ravine. The cut between stations 1 + 00 and 3 + 50 would be dumped into the adjacent fill space between stations 3 + 50 and 6 + 00. The fill space between stations 6 + 00 and 8 + 00 would be filled with borrow; that is, material taken from a nearby borrow pit. The fill space between stations 8 + 00 and 10 + 50 would be filled with the cut between 10 + 50 and 13 + 00, and the space between stations 16 + 50 and 19 + 00 would be filled with the cut lying between stations 14 + 00 and 16 + 50. You will notice that the haul limit on the last section of the mass diagram (between stations 14 + 00 and 19 + 00) is almost on the line of zero yardage. This haul-limit distance also is called the **balance line,** because the volume of cut is equal to the volume of fill. If, for example, the balance line on the last section of the mass diagram in figure 10-10 is only about 400 feet, then instead of wasting the cut between stations 13 + 00 and 14 + 00, you would use that to fill the hollow between stations 19 + 00 and 20 + 00. Surplus cut remaining would naturally be wasted after allowing for shrinkage in the filled spaces.

CONSTRUCTION SURVEYS

In this section we will discuss construction surveying, as it pertains to the stakeout of various types of construction, such as bridges and culverts, sewer lines, airfield runways, and waterfront structures. For a refresher of stakeout surveys for other types of construction, such as buildings and pavements, you should review chapter 14 of the EA3 TRAMAN.

As mentioned early in this chapter, as-built surveying is performed for two purposes: (1) to determine the horizontal and vertical location of points as they are actually constructed in the field and (2) to determine the amount of work accomplished up to a given date. Towards the first of those purposes, little can be said that is not adequately covered in the EA3 TRAMAN; therefore, the below discussion of as-built surveying is geared towards the second purpose.

First, however, let's consider an aspect of both as-built and stakeout surveying that is of particular significance to the party chief; that is, the party chief must maintain close liaison with the other crews working on the project. Survey parties work independently on many types of surveys, such as establishing horizontal and vertical control, running preliminary lines, shooting topo, and gathering engineering data. But in stakeout, the survey party is an integral part of the construction team. Timing and scheduling are important. When line and grade stakes are not set at the right place and at the right time, the work of entire construction crews are delayed. The party chief must also be constantly aware of the need for replacing stakes that have been knocked out by accident or design. Frequently, changes in grade and alignment will be authorized in the field to best meet the conditions encountered. These field-change orders will, in many cases, require immediate computations in the field and revisions to the stakeout. It is best to obtain as-built data as soon as a section of the work is complete. This is particularly true if field changes have been made, since the press of further construction may prevent a timely return to the job to obtain the as-built data. When this data is not obtained, users of the plans may be seriously misled in supposing that the construction conformed to the original drawings.

As-Built Surveys for Monitoring Construction Progress

In the Seabees, the percentage of completion for construction projects is based on a **work in place** (WIP) concept. To explain this, let's consider a simple example in which Charlie company is required to paint out three rooms totaling 1,100 square feet of wall and ceiling surface. When half of the total square footage is completed, the work in place is 550 square feet and the painting work is 50 percent complete. When all surfaces have been painted, then the work is 100 percent complete.

Now let's assume that a construction battalion is tasked with the construction of 15 miles of bituminous-paved road. As you know from your study of chapter 3 of this TRAMAN, the construction of this road will include construction activities, such as clearing, excavation for base and subbase courses, installation of drainage structures, placement of base and subbase courses, prime coating, and laying the bituminous-surface course. Each of those activities represents a certain percentage of the total project. Let's assume that the construction activity for clearing is estimated to be 5 percent of the total project and that this activity involves the removal of 528,000 square yards of brush and overburden. When all of the clearing is completed and no other work has been accomplished, then the project is 5 percent complete; however, if only 130,000 square yards has been removed and no other work has been accomplished, then about 25 percent of the clearing activity has been completed and the project is $.05 \times .25 \approx 1$ percent complete.

For projects such as this, the EA surveyor is often required to perform as-built surveys to determine the work in place for each of the construction activities. These surveys are usually performed on a periodic basis, such as biweekly or monthly. The results of these surveys are then used to determine the completion percentage of the project.

When doing as-built surveys for the purpose of monitoring and reporting progress, the techniques, or methods, that you use are nothing unique. Simply use the method that is best suited for the job at hand. Also, for this type of as-built surveying, extreme accuracy is usually not required; for example, if you are determining how much of a total road surface has been paved, measurements to the nearest foot are usually sufficient.

Now let's look at some stakeout surveys.

Culverts and Bridges

As in other types of layout for construction, the stakeout of culverts and bridges generally includes providing line and grade. The procedures and precision required will vary with the magnitude and complexity of the job.

DITCHES AND CULVERTS.— For minor open drains or outfall ditches a few feet deep, a single line of stakes will serve for both alignment and grade. By running profile levels, you can determine the elevations of the tops of the stakes. As a guide to the construction workers, mark the cut on each stake to show the depth of drain below each station.

For drains that are very deep, you must cross-section the line and set slope stakes. The grade for a ditch is measured along the **flow line;** that is, along the bottom of the ditch.

When pipe culverts without wing walls and aprons are staked, only the alignment and invert grade are required; however, when head walls, wing walls, and aprons are used to intercept drainage water, to retain earthwork, and to prevent erosion, grade stakes, as well as horizontal alignment stakes, will be required. Large bridge culverts and box culverts require stakes and hubs for batter board alignment similar to those required for a building layout.

Figure 10-11 illustrates the stakeout of a box culvert that crosses below an airfield taxiway. The angle at which the culvert crosses below the taxiway may be written on the plans, or it may be taken from the plans.

Assume that this angle is 84°30′, as shown. To run the center line of the culvert, setup the transit at *A* and turn the 84°30′ angle from the center line of the taxiway.

Place reference stakes at *B, C, D,* and *E* along the culvert center line far enough beyond the limits of the culvert to make sure they are not disturbed by the construction work. In this case, points *B* and *D* are set arbitrarily at 5 feet (measured at right angles) from the location of the outside face of the culvert headwalls.

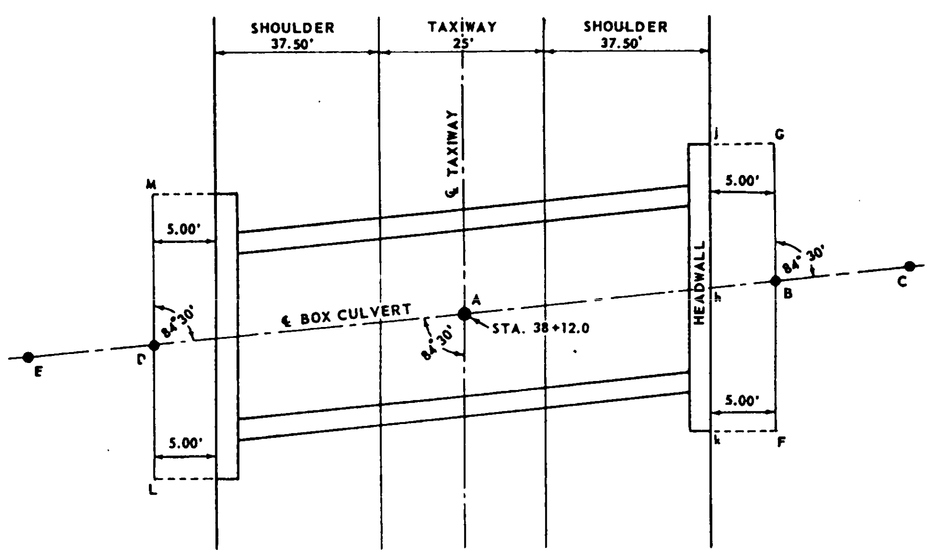


Figure 10-11.—Stakeout of a box culvert.

To facilitate the stakeout, set a stake at point *h*. From *h* the locations of points *j* and *k* may be measured and staked. The distance used is one half of the length of the headwall as that length is shown on the design plans. Set stakes at points *F* and *G* directly opposite and on lines at right angles to the ends of the headwalls. Set stakes similarly at *L* and *M*. Set grade stakes near *B* and *D* for the invert or flow line of the culvert.

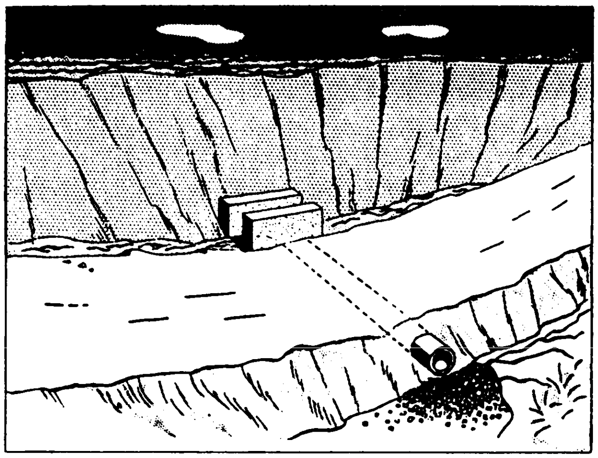


Figure 10-12.—Ditch inlet and pipe culvert

The stakes set in this way are sufficient to locate the forms for the headwalls and for the barrel of the culvert. Figure 10-12 shows one of a number of types of pipe inlets and culverts. The type shown is suitable for picking up side-surface drains adjacent to a landing strip or roadway embankment. Stakes for both horizontal alignment and elevations are required. Figure 10-13 shows the stakeout of a pipe culvert, wing wall, and apron.

BRIDGE SUBSTRUCTURES.— As you know from chapter 2 of this TRAMAN, the substructure of a fixed bridge consists of the end and intermediate supports and their foundations. Bridge substructures are divided into two main types of supports: end supports called **abutments** and intermediate supports called **bents** or **piers.**

Abutments.— The ground support at each end of a bridge is called an abutment. Construction plans will show the details of the abutments. Check the layout after excavation and before pouring the concrete. You must check abutment elevations, and when concrete is used, establish lines for setting forms. Abutments must be staked by following the construction plans,

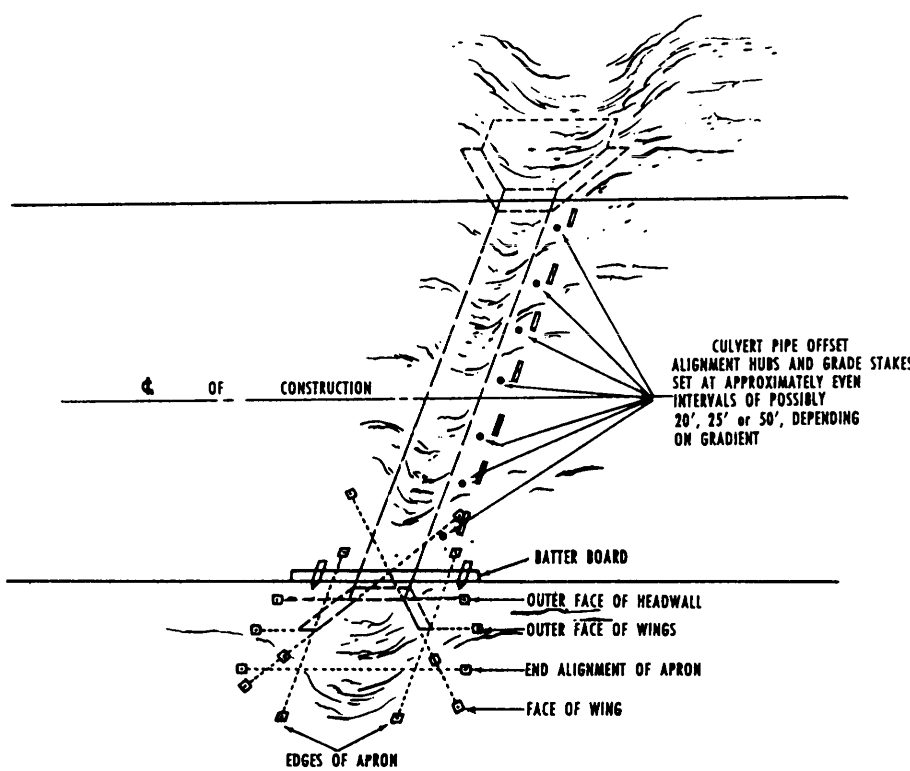


Figure 10-13.—Stakeout of a pipe culvert, wing wall, and apron.

and abutment stakes should be tied to the horizontal control system to meet accuracy requirements.

The following is a typical procedure for surveying an abutment that is to be at right angles to the center line of the bridge. In figure 10-14, the foundation of a concrete abutment, *ABDC,* is shown in the plan. *AB* is the face of the abutment foundation. Establish two convenient points, *H* and *J,* near the abutment *CD,* on the bridge center line. Set a stake at *E* (station 41 + 37.50)—the station designated on the plan for the abutment face.

Set up the transit at *E,* train on *H,* match the zeros, and turn 90° angles to locate *A* and *B* at the correct distance from *E.* Reference the line *AB* by setting stakes at *F* and *G* at the indicated distances from *A* and *B.* Set temporary stakes at *C* and *D* to mark the other corners of the foundation.

Sometimes the alignment of a bridge is not at right angles to the center line of the stream or road it crosses. When this occurs, the abutment is askew (other than a right angle) to the center line of the stream or road. Then slight modifications are necessary to stake out an askew abutment.

Figure 10-15 shows the plan for an askew near-side abutment of a railroad bridge over a highway. The outside line of the foundation is *ABCD.* The neat line of the face of the abutment is *MN.* Set stakes to define the direction of *MN* and ends *AD* and *BC.* The stakes *P, S, U, R, V,* and *T* are offset from the abutment so they will not be disturbed by foundation excavating. The general procedure is as follows:

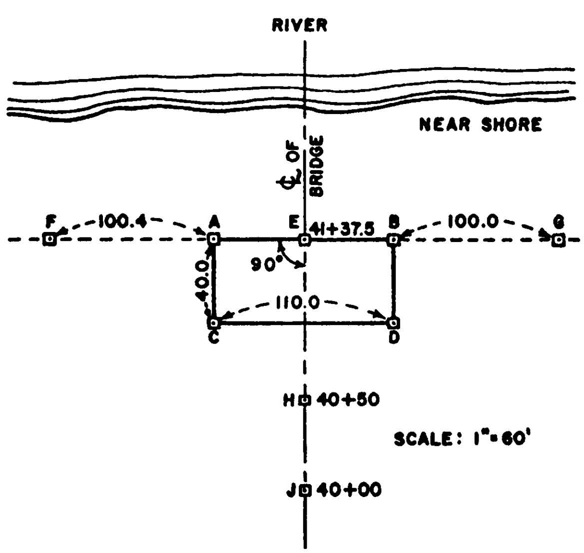


Figure 10-14.—Staking a right-angle abutment.

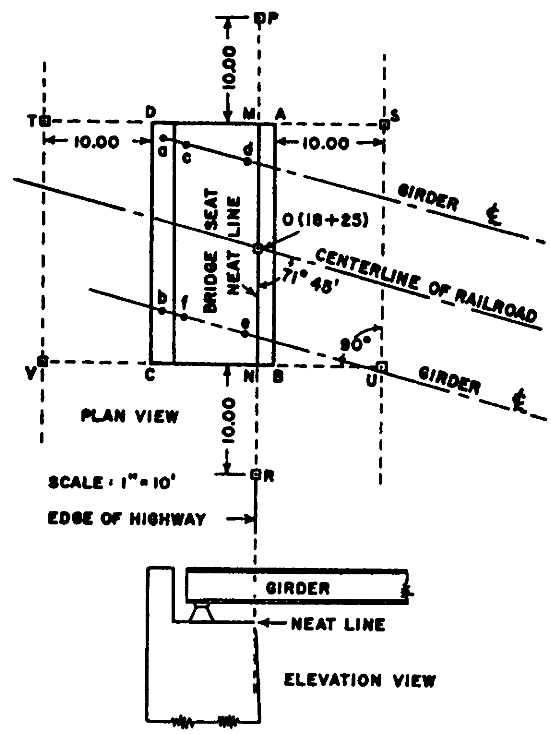


Figure 10-15.—Staking an askew abutment.

1. Take the dimensions for setting necessary stakes from the abutment plans. Set the temporary point *O* at the station location indicated.

2. With the instrument at *O,* sight along the center line of the railroad, turn the skew angle (71°45′), set the permanent stakes *P* and *R,* and set points *M* and *N.*

3. With the instrument at *M,* sight *R,* turn 90°, and set permanent stakes *S* and *T.*

4. With the instrument at *N,* sight *P,* turn 90°, and set permanent stakes *U* and *V.*

The face of the abutment is defined by *P* and *R.* Stakes *S, T, U,* and *V* define the face of the end forms. When construction begins, set stakes at *A, B, C,* and *D* by measuring from the offset stakes. (These stakes are knocked out as the excavation progresses.)

Concrete for the foundation is poured into the excavation; if forms are needed for the foundation, measure the distances from the reference offset stakes. Set the elevations of the top and bottom of the foundation from bench marks outside the excavation area.

When the foundation has been poured to grade and has had a day to set, mark temporary points on the top at *M* and *N* by measuring 10 feet plus the distance *AM* and *BN* from the offset stakes *S* and *U*. Check the forms by measuring the equal diagonals *MC* and *ND*. Mark points denoting elevation directly on the forms and give the data to the petty officer in charge of the construction project.

After the bridge seat is poured, mark point *O*. After the rear wall has been poured, mark points defining the girder center lines: *a, b, c, d, e,* and *f*. These points will be used for the accurate location of the bearing plates that will support the girders.

Abutment Wing Walls.— Figure 10-16 illustrates the stakeout of abutment wing walls. A typical procedure is as follows:

1. Set up the instrument at B; turn the wing angle from *G;* set reference stakes *H* and *I;* measure distances *BH* and *BI*. Set up at *A* and repeat this procedure to establish *J* and *K*. Use reference lines *FG, BH,* and *AJ* to set temporary stakes marking the corners of the excavation for the foundation. Then the method described earlier for abutments is followed. If abutment or wing-wall faces are battered (inclined, rather than vertical), lines are established for both top and bottom.

2. To stake out wing walls for askew abutments to the center line of a bridge, follow the procedure described for askew abutments. Set up the instrument over *N* (fig. 10-15); sight on *R;* turn the wing angles; set reference stakes to establish the wing line from *N*. Establish the wing line from *M* in the same manner.

Piers.— After the center line of the bridge is established, locate the piers by chaining if possible. If chaining is impracticable, locate the piers by triangulation. Set stakes establishing the center line on each side of the river. Lay out *CD* and *EF* approximately at right angles to the center line, as shown in figure 10-17. For well-proportioned triangles, the length of the base lines should equal at least one-half *CE*. To locate piers at *A* and *B,* you may use the following procedure:

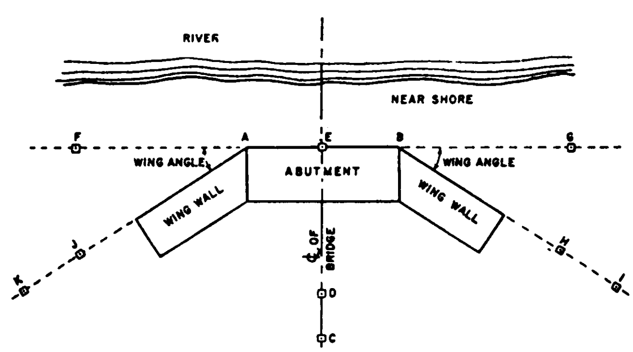


Figure 10-16.—Staking out abutment wing walls.

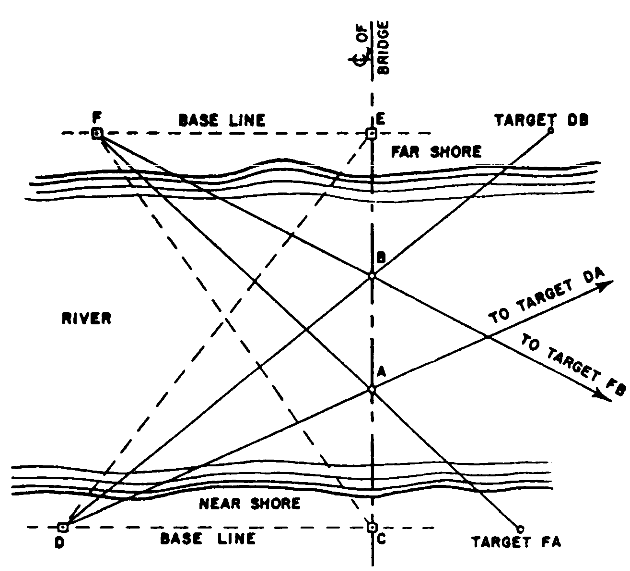


Figure 10-17.—Method of locating piers.

1. Establish base lines *CD* and *EF* and carefully reference them.

2. Measure the length of each base line with a degree of accuracy suitable for the required accuracy of the line *CE*.

3. Measure all angles of the triangles *CDE* and *EFC*.

4. Compute the distance *CE* from the triangle *CDE* and check against the same distance computed from triangle *EFC*. The difference in computed lengths must be within the prescribed limits of error.

5. Compute angles *BDC, ADC, BFE,* and *AFE*.

6. Draw a triangulation diagram, showing computed angles and distances and measured angles and distances.

7. Turn the computed angles *BDC, ADC, BFE,* and *AFE*.

8. Set targets *DA* and *DB* on the far shore and *FB* and *FA* on the near shore so that the intersecting lines can be reestablished without turning angles. Carefully reference these points.

9. Use two instruments to position piers. Occupy two points, such as *C* and *D,* simultaneously, using the intersection of sights *CE* and *DA* to locate the pier. Check the locations of points *A* and *B* if they are within the limits of error by sighting along the center line, *CE*.

Piles.— You may be required to position piles, record pile-driving data and mark piles for cutoff. Figure 10-18 shows points *A* and *B* established as a reference line 10 feet from the center line of a bridge. Stretch a wire rope between points *A* and *B* with a piece of tape or a wire rope clip at each pile-bent position (such as *C* or *D).*

Locate the upstream pile (pile No. 1) by measuring an offset of 4 feet from the line *AB* at *C.* A template is then floated into position and nailed to pile No. 1 after it is driven. The rest of the piles are positioned by the template.

If it is impractical to stretch a wire rope to the far shore, set up a transit at a convenient distance from the center line of the bridge. Position the piles by sighting on a mark located the same distance from the center line of the template. Before driving piles, you must measure the length of piles. Measure the distance between the piles by chaining.

During pile driving, keep a complete record of the following: location and number of piles, dimensions, kind of woods, total penetration, average drop of hammer, average penetration under last five blows, penetration under last blow, and amount of cutoff. Mark elevations on the two end piles by nailing two 3- by 12-inch planks to guide the saw in cutting the piles to the specified height.

BRIDGE GRADE STAKES.— Elevations are taken from bench marks set in, or near, the construction area. Consider permanency, accessibility, and convenience when setting bench marks. Set grade stakes for a bridge site in the same manner as the grade stakes on any route survey. Make sure that the senior petty officer in charge of the job has sufficient information so that the exact method being used to designate the grade can be understood.

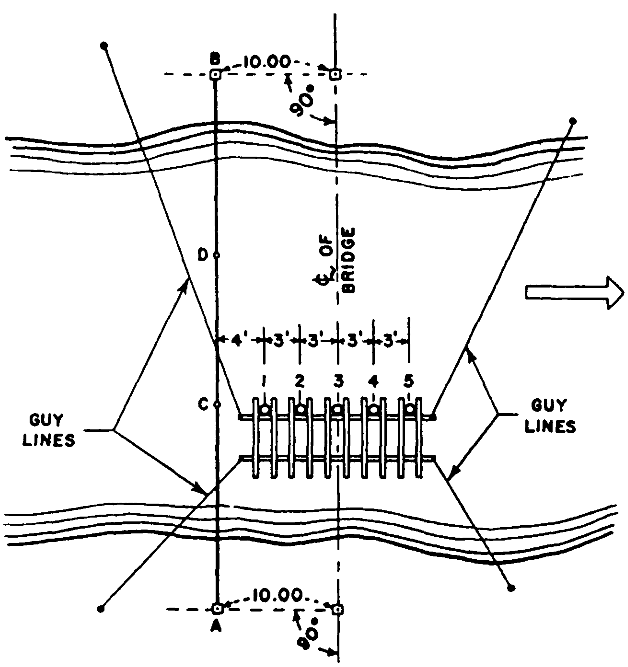


Figure 10-18.—Method of positioning piles.

Sewer Stakeout

To stake out a sewer, you obtain data from a plan and profile that shows (1) the horizontal location of each line in the system, (2) the horizontal location and character of each manhole, (3) the invert elevations at each manhole, and (4) the gradient of each line. You will also have detail drawings of each type of appurtenance. If manholes in the same category are of different types, you may identify them by letter symbol, as CI “A,” and so on. In addition, identification of a particular appurtenance may be by consecutive number, as CI “A” #3.

The stakeout consists of setting hubs and stakes to mark the alignment and indicate the depth of the sewer. The alignment may be marked by a row of offset hubs and stakes or by both offset hubs and a row of center-line stakes. Cuts may be shown on cut sheets (also called grade sheets or construction sheets) or may be marked on the stakes, or both. The cuts shown on the center-line stakes guide the backhoe operator or ditcher operator; they are usually shown to tenths; they generally represent the cut from the surface of the existing ground to the bottom of the trench, taking into account the depth to the invert, the barrel thickness, and the depth of any sand or gravel bed. The cuts marked on the stakes next to the hubs are generally shown to hundredths and usually represent the distance from the top of the hub to the invert; these cuts guide the pipe crew. The use of these cuts in transferring the information to batter boards or various types of offset string lines was described in chapter 14 of the EA3 TRAMAN.

If the survey party stakes only the offset hubs, then the construction crew usually sets center-line stakes for line only and uses the hubs as a guide for the depth of excavation. The extent of the stakeout and computations performed by the survey party and the corresponding extent of such work done by the construction crew depend on the capabilities and the availability of personnel and the work load. In any case, hubs and/or stakes are generally set at 25-foot intervals, though 50-foot and even 100-foot intervals have been known to suffice.

Sewer hubs are usually offset from 5 to 8 feet from the center line. Before you enter the field, you compute from the profile the invert elevation at every station where you will set a hub. Consider figure 10-19, for example. This is a plan showing a line running from a curb inlet through two manholes to an outfall. The dotted lines are offsets (greatly exaggerated for clearness) to points where you will set the hubs. Note that at stations 5 + 75 and 1 + 70.21, you set two hubs, one for the invert in and the other for the invert out.

The invert elevations at the manhole (MH) are given on the profile. Suppose that the invert out at CI "A" #2 is 122.87 feet. The gradient for this pipe is 2.18 percent. Station 8 + 50 lies 0.50 station from CI "A" #2; therefore, the invert elevation at station 8 + 50 is 122.87 feet minus (0.50 x 2.18), or 122.87 feet minus 1.09, or 121.78 feet. You compute the invert elevations at the other intermediate stations in the same manner.

Suppose now that you are starting the stakeout at CI "A" #2. The final-location party left a center-line stake at this station. You occupy this point, turn 90 degrees left from the line to MH "A" #1, and measure off the offset; for example, 8 feet. This is presuming that, if the ground slopes across the line, the high side is the side on which the hubs are placed in figure 10-19. Hubs are always placed on the high side to prevent them from being covered by earth dozed off to form a bench for the trench-digging rig.

You drive a hub 8 feet offset from station 9 + 00 and determine the elevation of the top of the hub. The vertical distance from the top of the hub to the invert at station 9 + 00 is the difference between the invert elevation and the elevation of the top of the hub. The invert elevation at station 9 + 00 is 122.87 feet. Suppose the elevation of the top of the hub is 126.94 feet. Then you would mark the guard stake for this hub, CI "A" #2 inv. C 4.07′. Suppose the elevation of the top of the hub driven at station 8 + 50 is 127.33. The invert elevation at this station is 121.78; therefore, you would mark the guard stake for this station, 8 + 50, C 5.55′.

The manner in which the construction crew will use these hubs to dig the trench to grade will vary according to the preference of the supervisor for one of several methods. One method involves the erection of a batter board across the trench at each hub. The top of each board is placed on the posts at a set distance above invert elevation; for example, 10 feet. Figure 10-20 illustrates this method.

Take station 9 + 00 in figure 10-19, for example. The elevation of the top of the hub is 126.94 feet and the invert elevation is 122.87 feet. To be 10 feet above invert elevation, the top of the batter board must be placed on the post 5.93 feet above the top of the hub. To get this distance, the field constructor would simply

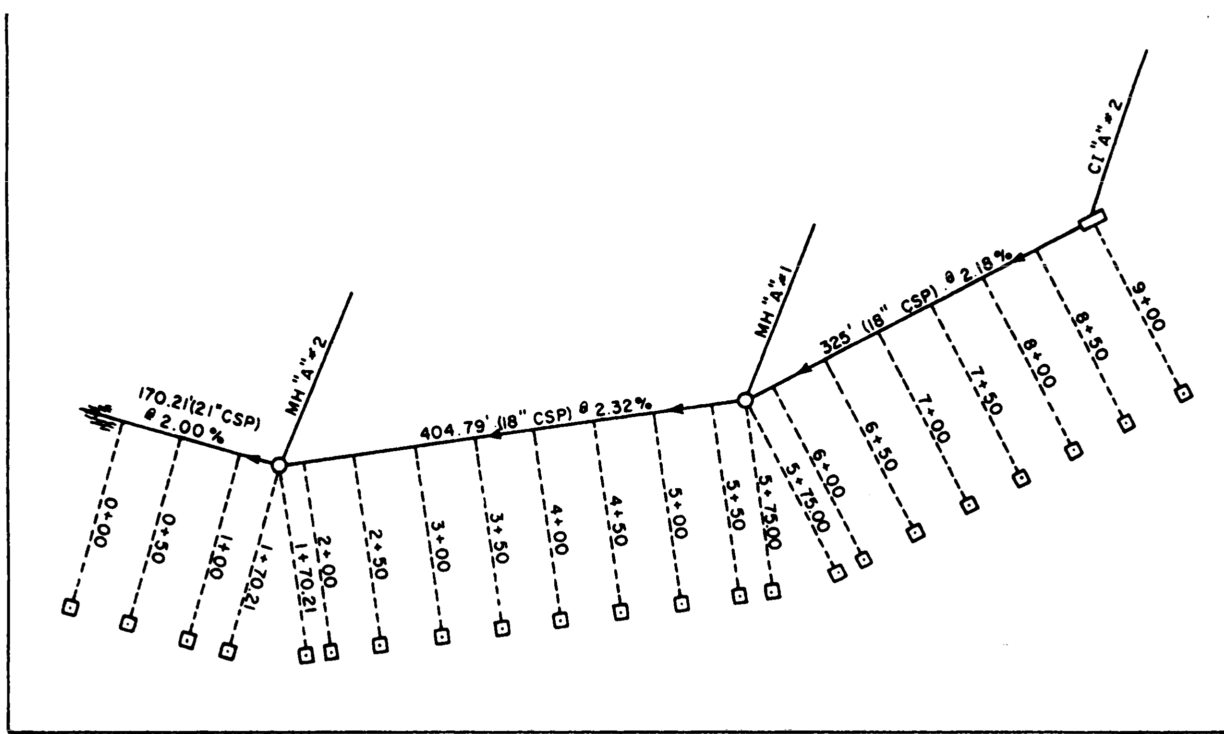


Figure 10-19.—Sewer stakeout plan.

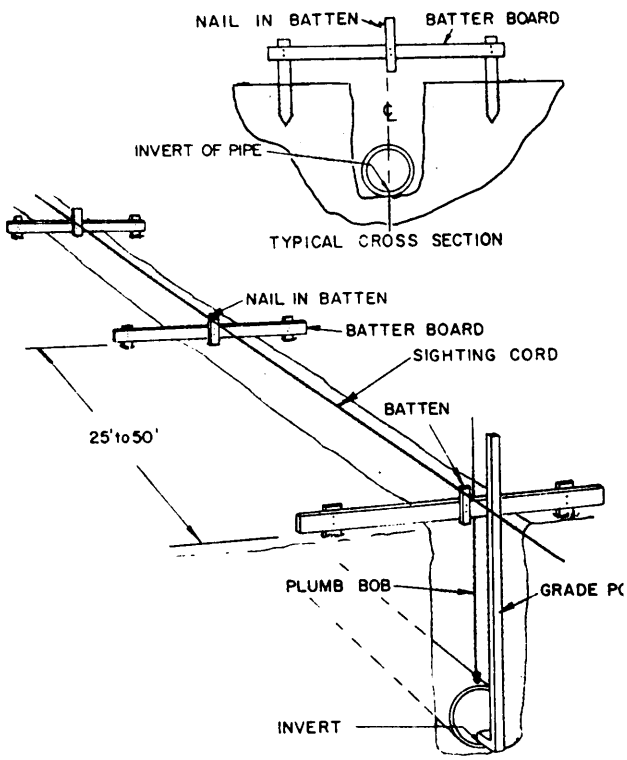


Figure 10-20.—Setting sewer line to grade.

subtract the specified cut from 10 feet. At station 8 + 50, for example, the height of the top of the batter board above the top of the hub would be 10 – 5.55, or 4.45 feet.

The offset is measured off from a point directly above the hub along the batter board; a mark here is directly over the center of the pipeline. Battens are nailed on the batter board to indicate sewer center-line alignment. A string is stretched and tacked along these battens; this string indicates the horizontal location of the line and follows the gradient of the line, but at a distance of 10 feet above the invert. The amount of cut required to be taken out at any point along the line can be determined by setting a measuring pole alongside the string. If the string indicates 8.5 feet, for example, another 1.5 feet of cut must be taken out.

Corners of rectangular manhole boxes are staked out much as building corners are staked out. For a box located where a line changes direction, it may be desired that the center line of the box bisect the angle between the lines. The box for a curb inlet must be exactly located with respect to a street curb to be constructed in the future; therefore, curb inlets are usually staked out with reference to the street plan, rather than with reference to the sewer plan.

Laser Method of Laying Pipe

Another useful device for controlling pipeline excavations and laying pipe is the laser. So many applications are being found for the laser that it may eventually be the only tool needed for the layout and control of construction projects. It can be quickly, accurately, and economically used for purposes such as distance measurement, alignment for tunnel borings, setting of pipes with desired grades, and setting of line and grade for many types of construction.

The laser is an intense light beam that can be concentrated into a narrow ray, containing only one color (red) or wavelength of light. The resulting beam can be projected for short or long distances and is clearly visible as an illuminated spot on a target. It is not disturbed by wind or rain, but it will not penetrate fog. A laser can be set up on a bracket or even attached to a transit telescope. The beam is aligned in the proper direction at the desired grade and can be left relatively unattended.

Today, instead of using batter boards and strings, lasers can be used to control the alignment for excavating trench and setting a pipe. The laser can be set so that it shines on the boom of a backhoe so that the equipment operator can clearly see the illuminated spot. By its position, the operator can closely control the depth of digging. For laying the pipe, the laser is set in the proper direction at the desired distance above the pipe invert. With the aid of the L-shaped pole or templet, as shown in figure 10-21, the workmen can control the invert elevation. It may also be possible to direct the laser beam from the inside of manholes through the pipes being laid and to control the grade without any interference from the backill operations. This can be done even if the pipes are too small for human access.

Underground Duct System Layout

The stakeout for an underground power line is similar to that for a sewer. For the ducts, cuts are

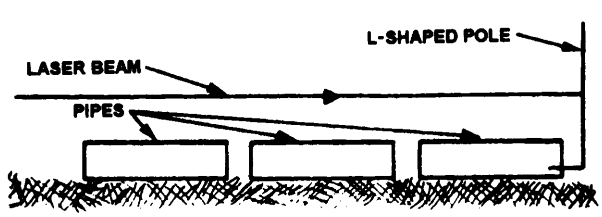


Figure 10-21.—Pipe laying with a laser.

measured to the elevation prescribed for the bottom of the duct, plus the thickness of the concrete encasement, if any. In an underground power system, the bottom of the manhole is usually about 2 feet below the bottoms of the incoming and outgoing ducts. Power and communications manholes are often combined; figure 10-22 shows plan and section views of a combination power and communications manhole.

Conduit and cable connections to buildings, street-lighting systems, traffic light systems, and the like, are low-voltage secondary lines. Duct connections from main-line manholes run to small-subsurface openings called **handholes** on the secondary line. The handhole contains connections for takeoff to the consumer outlet. Figure 10-23 shows plan and section views of a handhole.

Construction Sheets

Several construction situations have been mentioned in which line and grade for construction are obtained from a line (or perhaps from two lines) of

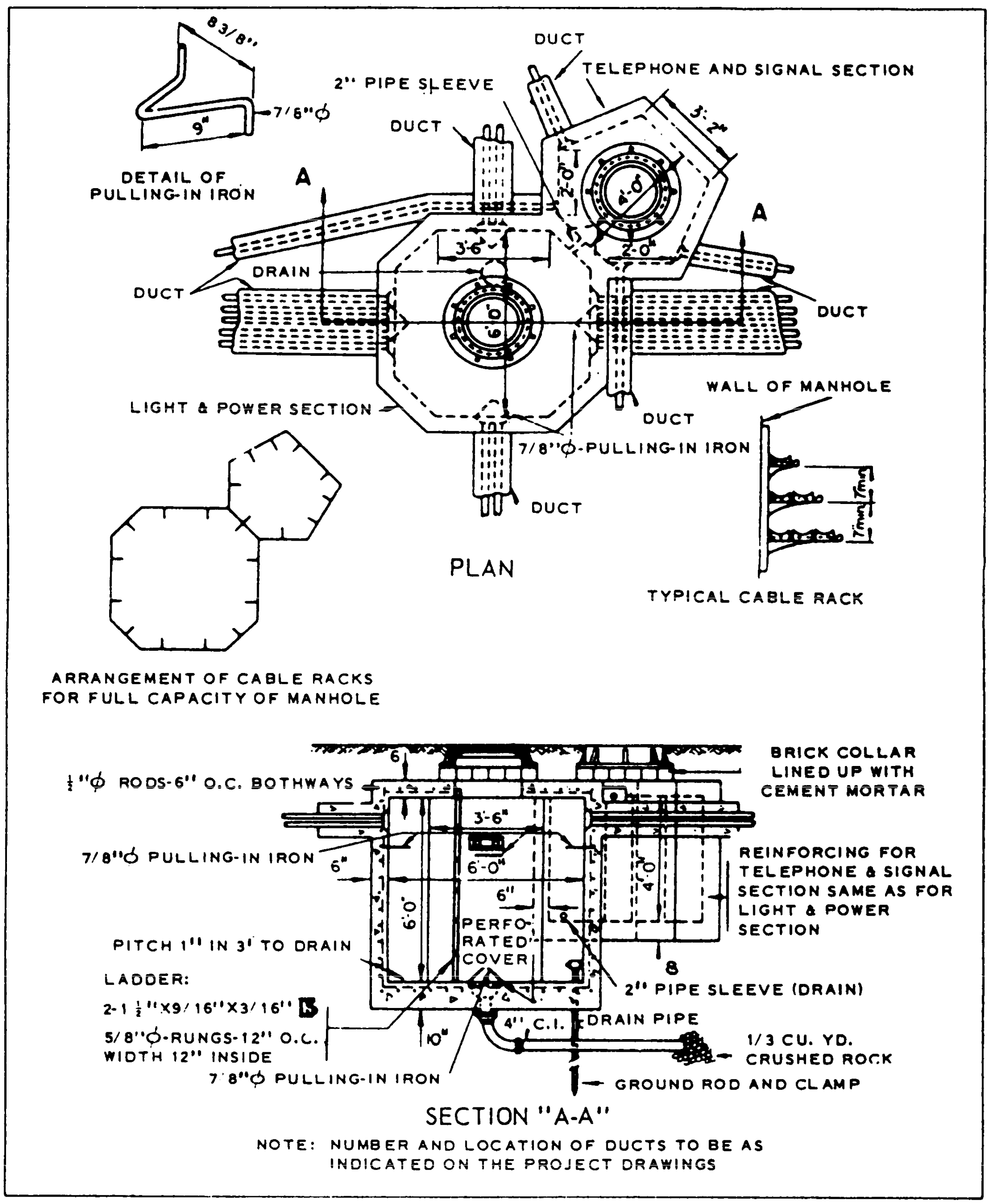


Figure 10-22.—Combination power and communication manhole.

offset hubs. A guard stake adjacent to one of these hubs usually gives the station and elevation of the hub, grade for the structure at this station, and the vertical distance between the top of the hub and grade, marked *C* or *F*.

This information is often recorded on a construction sheet (familiarly known as a cut sheet) like the one shown in figure 10-24. One advantage of the use of cut sheets that the information applying to every hub is preserved in the event that guard stakes are accidentally

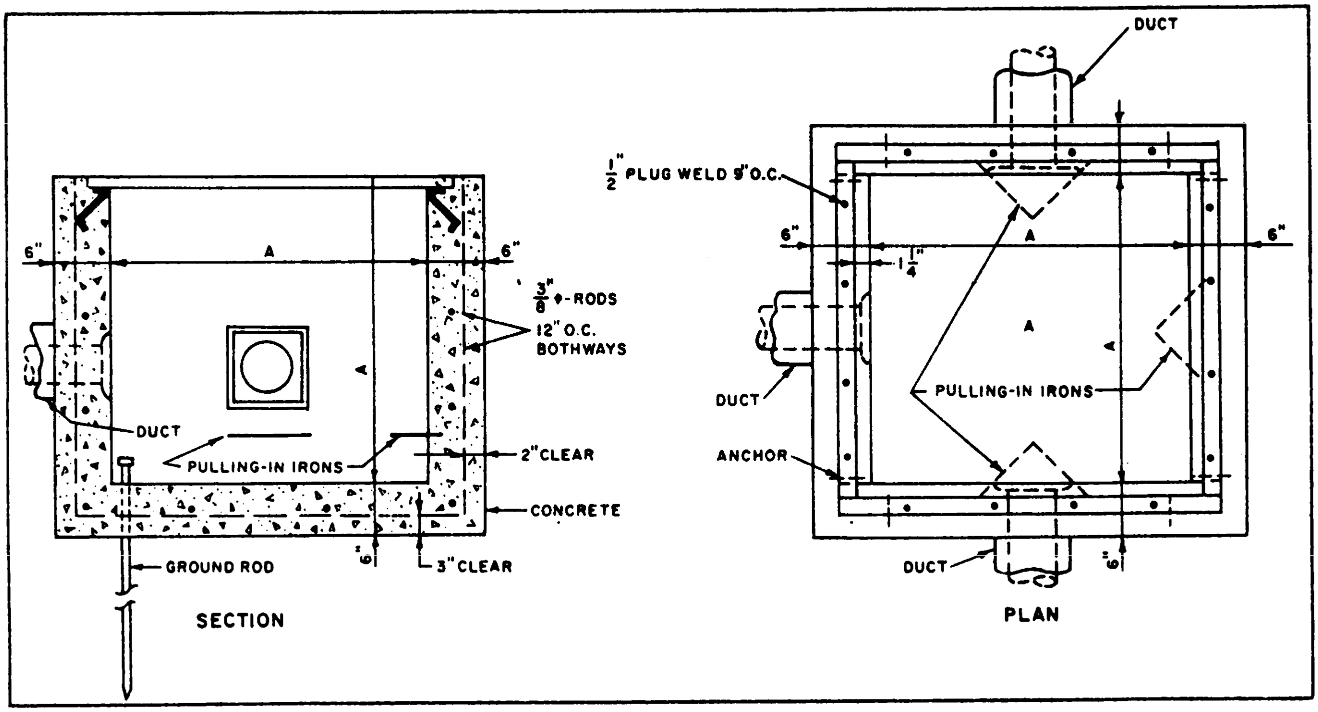


Figure 10-23.—Handhole.

CONSTRUCTION SHEET

PROJECT : MEMQ Area
CONSTRUCTION : Storm sewer
LOCATION : MH #2 out to MH #3 in
HUB OFFSET : 10' from ℄ sewer
GRADE TO : invert

BY: Brown, M., EA2 Date: 29 Feb. 19__

STATION	HUB ELEV.	GRADE	CUT OR FILL	REMARKS
0+00 (MH #2 out)	286.23	280.00	C 6.23	
0+50	286.40	279.50	C 6.90	
1+00	285.97	279.00	C 6.97	
1+50	284.33	278.50	C 5.83	
2+00	284.35	278.00	C 6.35	hub offset 8'
2+50	283.08	277.50	C 5.58	
2+87 (MH #3 in)	283.11	277.13	C 5.98	

Figure 10-24.—Typical construction sheet.

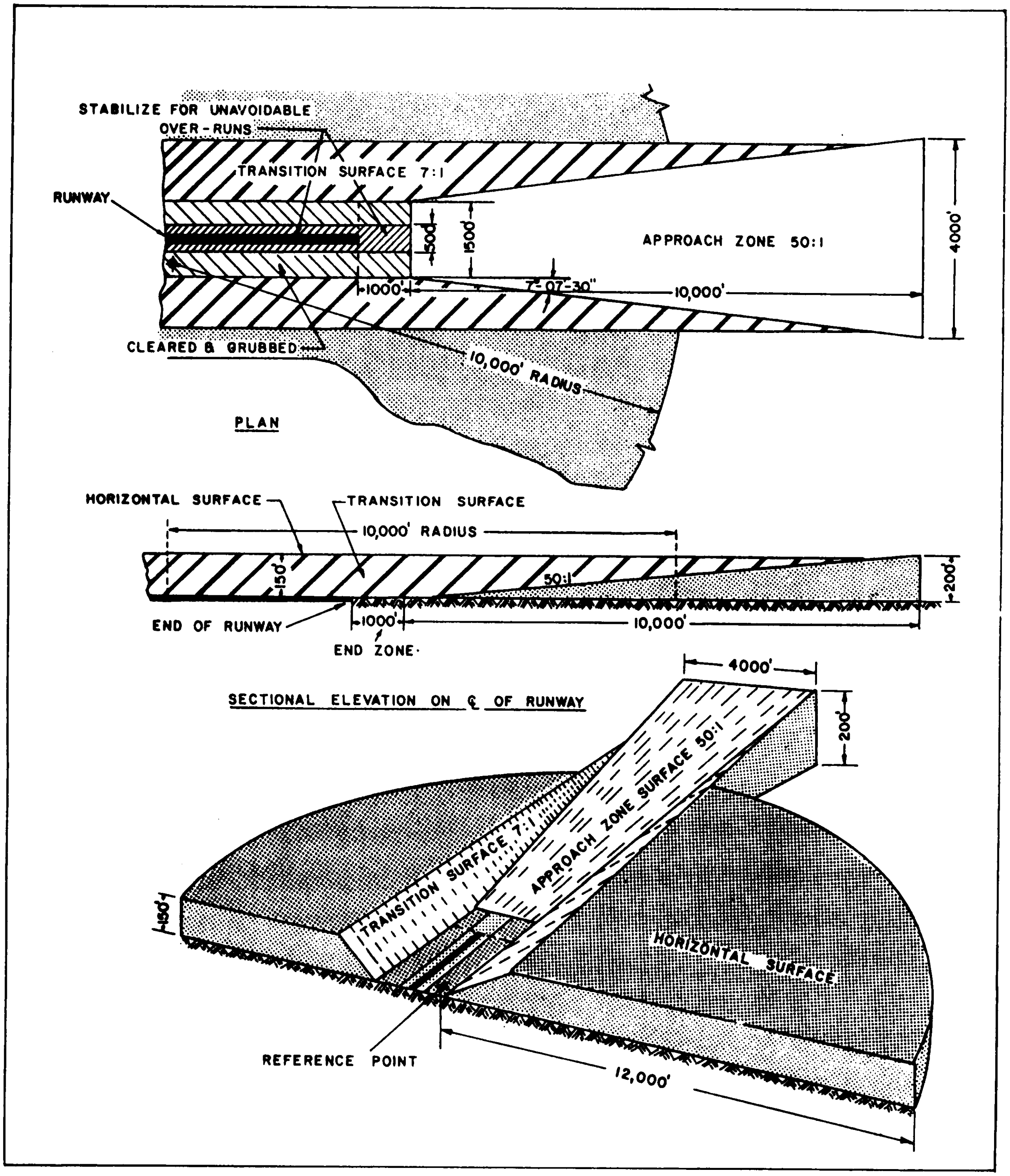


Figure 10-25.—Runway approach zone

displaced. Another advantage is that reproductions of the cut sheet can be given to construction supervisors so that they may always have access to all the essential construction data.

AIRFIELD SURVEYS

Airfield construction is of a special kind; for this reason, it is discussed here under a separate heading.

AIRFIELD ROUTE SURVEYS

The route for an airfield is the horizontal location of the runway center line; if there is more than one runway, there is, of course, more than one route. The principal consideration regarding the direction of a runway center line is the average direction of the prevailing wind in the area, since planes must take off into the wind. The azimuth of the center line will be as nearly as possible the same as the average azimuth of the prevailing wind. A study of the meteorological conditions is therefore a part of the reconnaissance survey. Other data gathered on this survey (which may be conducted on foot, by ground surface vehicle, by plane, or by all three) include the land formation, erosional markings, vegetation, configuration of drainage lines, flight hazards, approach zone obstructions, and soil types.

From the reconnaissance data, one or more preliminary center lines are selected for location by preliminary survey. For quick preliminary stakeout, there may be two parties, working away from station 0 + 00 located at the approximate midpoint of the center line. In such cases, stations along the azimuth may be designated as plus and those along the back azimuth as minus.

Level parties follow immediately behind the transit parties, taking profile levels and cross sections extending the width of the strip, plus an overage for shoulders and drainage channels. From the preliminary survey data, a plan and profile are made of each tentative location, and from these, a selection of a final location is made.

AIRFIELD STAKEOUT

Airfield runways, taxiways, hardstands, and aprons are staked out much as a highway is staked out. There are, however, certain special considerations applying to approach zones.

As you know from chapter 3, an approach zone is a trapezoidal area beyond the end zone at each end of a runway. It must be free of obstruction not only on the ground but also off the ground at a specific glide angle. The size of the approach zone depends on the type and stage of development of the field. For permanent naval air stations, the trapezoidal area might be 10,000 feet long with a width of 4,000 feet at the outer end. For purposes of explanation only, we will assume that these are the dimensions of the approach zone for which you are surveying.

The glide angle for most types of aircraft is 2 percent, usually given as 50:1, or a rise (or drop) of 1 vertical for 50 horizontal. Figure 10-25 shows, in plan, profile, and isometric, an approach zone and its adjacent transition surfaces and end of runway. You must stake out this approach zone and check it for clearance by the following procedure:

Figure 10-26 shows the approach zone in plan. The dotted line *BC* lies 750 feet from the center line. The angle at *B* can be determined by solving the

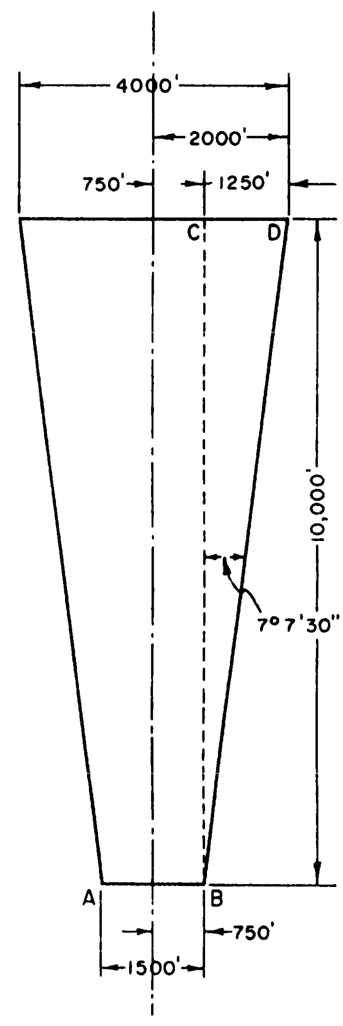


Figure 10-26.—Plan view of approach zone.

triangle *CBD,* tan B = 1,250/10,000, or 0.125000; therefore, angle B measures 7°7´30´´. Determining the distance from the dotted line to the edge of the approach zone at any station is similarly a simple right-triangle solution. Suppose that *AB* is located at station 0 + 00. Then at station 1 + 00, the distance from the dotted line to the edge of the approach zone is 100 tan 7°7´30´´, or 12.5 feet; therefore, the distance between the center line and the edge of the approach zone at this station is 750 + 12.5, or 762.5 feet.

To check for obstructions, you must setup a transit at the narrow end of the approach zone, set the telescope at a vertical angle equal to the one that the glide plane makes with the horizontal, and take observations over the whole approach zone, as indicated in figure 10-27. Determining the vertical angle is a simple right-triangle solution. If the glide angle is 50:1, then the tangent of the vertical angle is 1/50, or 0.020000, and the angle measures 1°8´45´´.

Figure 10-27 shows how the exact vertical location of the glide plane varies with the character of the surface of the end zone.

WATERFRONT SURVEYS

Under some circumstances it is possible to chain distances over the water; however, it is usually more

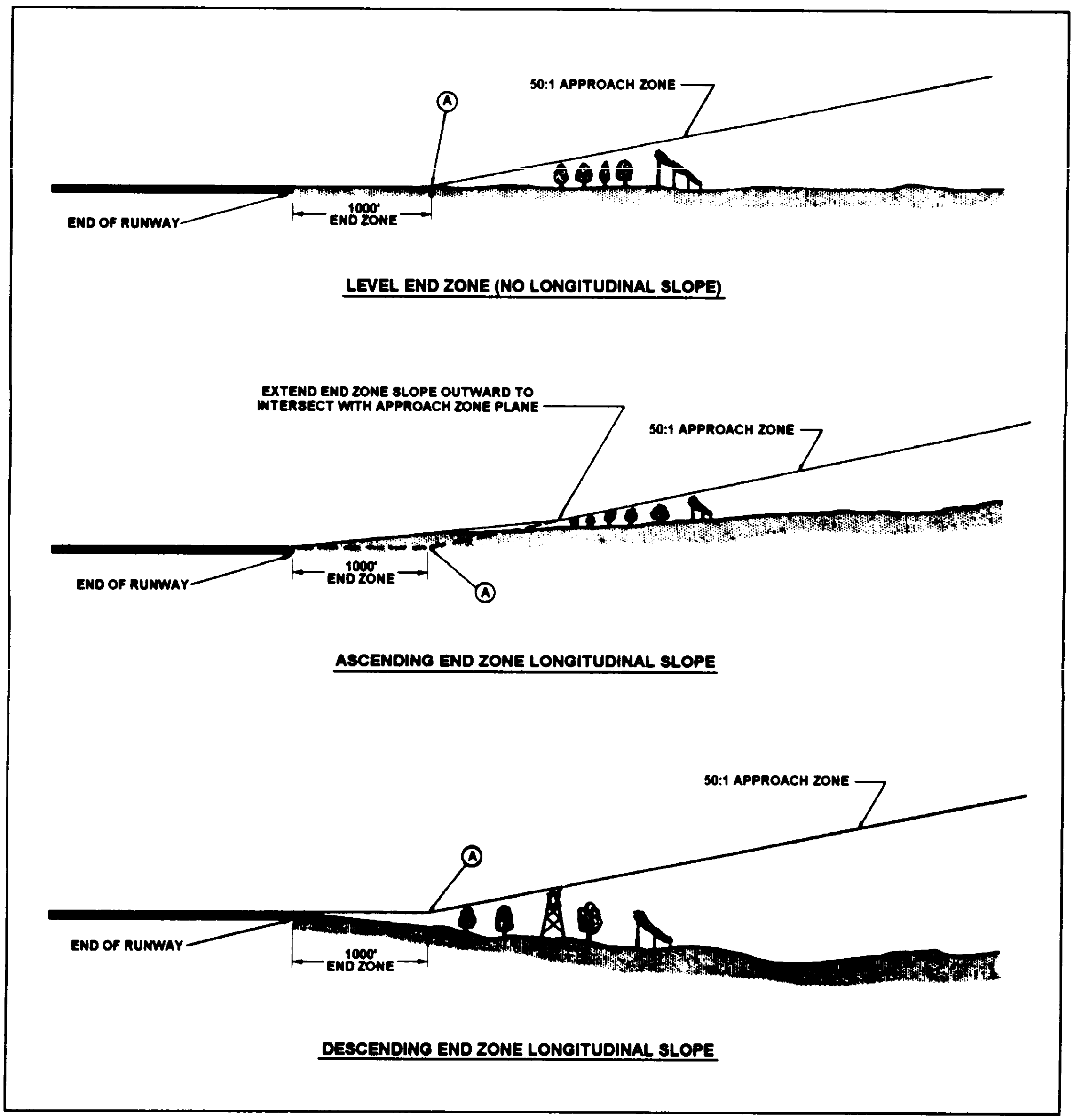


Figure 10-27.—Approach clearance for different types of end zones.

convenient to triangulate offshore distances from a shore base line. No matter how you get offshore distances, however, offshore points cannot be marked like ground points with hubs or stakes. Therefore, in the location of offshore points, there must usually be coordination between a survey party on the beach and a party afloat.

OFFSHORE LOCATION BY CHAINING

Figure 10-28 shows a situation in which offshore locations of piles for a wharf were determined by chaining. We will call each series of consecutive piles running offshore a **line** and each series running parallel to the shore a **row.** Alignment for each line was obtained by transit—set up on a shore base line offset from the inboard row of piles. In each line the distance from one pile to the next was chained, as shown.

In figure 10-28 the lines are perpendicular to the base line, which means that the angle turned from the base line was 90° and the distance from one transit setup to the next was the same as the prescribed distance between lines. If the lines were not perpendicular to the base line, both the angle turned from the base line, the distance from one transit setup to the next, and the distance from the base line to the first offshore pile in each line would have to be determined.

Consider figure 10-29, for example. Here the angle between each line and the base line (either as prescribed or as measured by protractor on a plan) is 60°40′. You can determine the distance between transit setups by solving the triangle *JAB* for *AB, JA* being drawn from transit setup *B* perpendicular to the

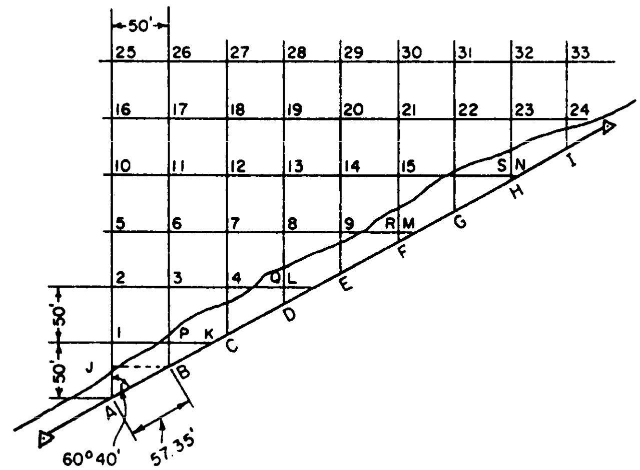


Figure 10-29.—Offshore location in line oblique to the base line.

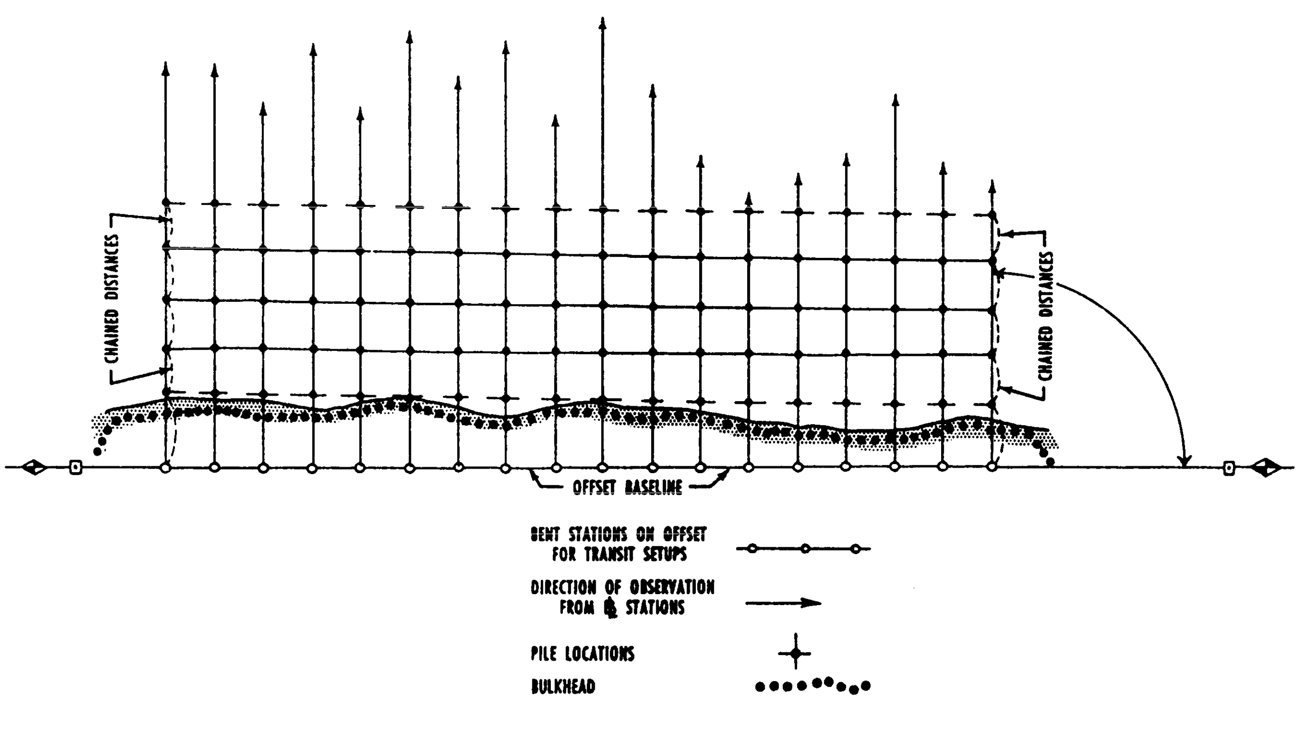


Figure 10-28.—Offshore location by chaining

line from transit setup *A* through piles 1, 2, 5, 10, 16, and 25. *AB* measures 50/sin 60°40′, or 57.35 feet. This, then, is the distance between adjacent transit setups on the base line.

The distance from the base line to the first offshore pile in any line also may be determined by right-triangle solution. For pile No. 1 this distance is prescribed as 50 feet. For piles 2, 3, and 4, first solve the triangle *A2L* for *2L,* which is 100/tan 29°20′, or 177.95 feet. The distance from 2 to *Q* is 150 feet; therefore, *QL* measures 177.95 – 150, or 27.95 feet. *QD* amounts to 27.95/tan 60°40′, or 15.71 feet. Therefore, the distance from transit setup *D* to pile No. 8 is 50 + 15.71, or 65.71 feet. Knowing the length of *QL* and the distance from setup point *B* to pile No. 3 by solving the right triangle *LB3* for *B3.*

You can determine the distance *E9* by solving the right triangle *M5A* and proceeding as before. You can determine the distance *F15, G22,* and *H23* by solving the right triangle *AN10* and proceeding as before. For pile No. 24, the distance *I24* amounts to 50 tan 29°20′, or 28.10 feet.

OFFSHORE LOCATION BY TRIANGULATION

For piles located farther offshore, the triangulation method of location is preferred. A pile location diagram is shown in figure 10-30. It is presumed that the piles in section *X* will be located by the method just described, while those in section *Y* will be located by triangulation from the two control stations shown.

The base line measures (1,038.83 – 433.27), or 595.56 feet, from control station to control station. The middle line of piles runs from station 7 + 41.05, making an angle of 84° with the base line. The piles

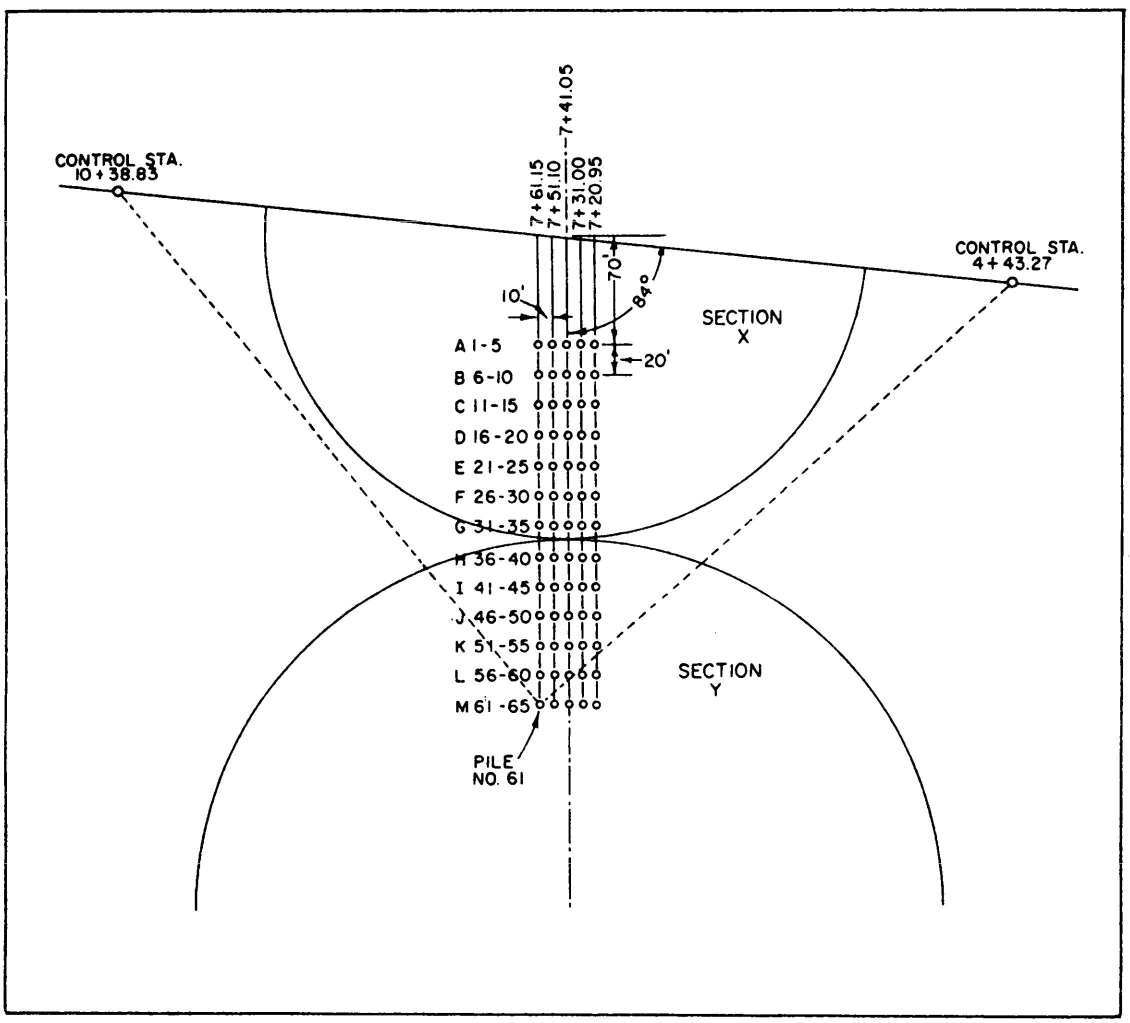


Figure 10-30.—File location diagram.

in each bent are 10 feet apart; bents are identified by letters; and piles, by numbers. The distance between adjacent transit setups in the base line is 10/sin 84°, or 10.05 feet.

Bents are located 20 feet apart. The distance from the center-line base line transit setup at station 7 + 41.05 to pile No. 3 is 70 feet. The distance from station 7 + 51.10 to pile No. 2 is 70 + 10 tan 6°, or 70 + 1.05, or 71.05 feet. The distance from station 7 + 61.15 to pile No. 1 is 71.05 + 1.05, or 72.10 feet. The distance from station 7 + 31.00 to pile No. 4 is 70 - 1.05, or 68.95 feet; and from station 7 + 20.95 to pile No. 5 is 68.95 – 1.05, or 67.90 feet.

You can determine the angle you turn, at a control station, from the base line to any pile location by triangle solution. Consider pile No. 61, for example. This pile is located 240 + 72.10, or 312.10 feet, from station 7 + 61.15 on the base line. Station 7 + 61.15 is located 1,038.83 – 761.15, or 277.68 feet, from control station 10 + 38.83. The angle between the line from station 7 + 61.15 through pile No. 61 and the base line measures 180°- 84°, or 96°. Therefore, you are dealing with the triangle *ABC* shown in figure 10-31. You want to know the size of angle A. First solve for b by the law of cosines, in which $b^2 = a^2 + c^2 - 2ac \cos B$, as follows:

$$b^2 = 312.10^2 + 277.68^2 - 2(312.10)(277.68) \cos 96°$$

$$b = 438.89 \text{ feet}$$

Knowing the length of *b,* you can now determine the size of angle *A* by the law of sines. Sin *A* = 312.10 sin 96°/438.89, or 0.70722. This means that angle *A* measures, to the nearest minutes, 45°00′.

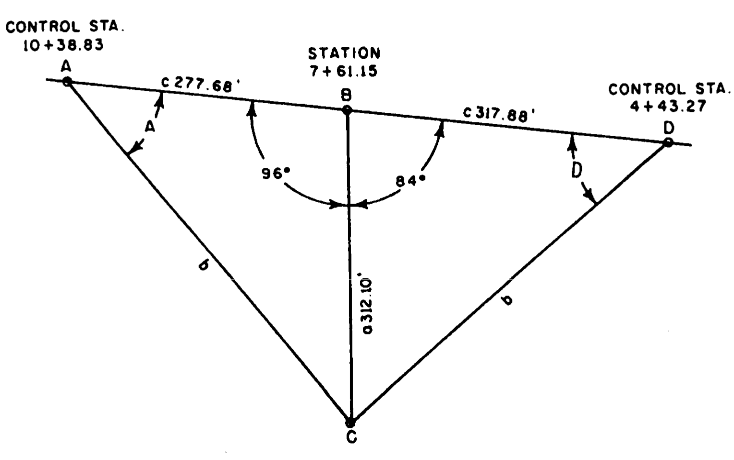


Figure 10-31.—Trigonometric solution for pile No. 61.

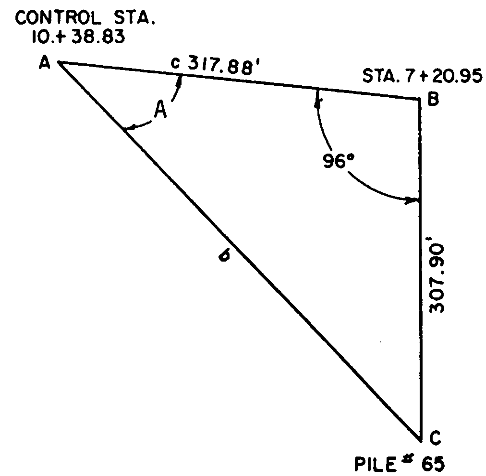


Figure 10-32.—Trigonometric solution for pile No. 65.

To determine the direction of this pile from control station 4 + 43.27, you would solve the triangle *DBC* shown in figure 10-31. You do this in the same manner as described above. First solve for *b* using the law of cosines and then solve for angle *D* using the law of sines. After doing this, you find that angle *D* equals 47°26′.

It would probably be necessary to locate in this fashion only the two outside piles in each bent; the piles between these two could be located by measuring off the prescribed spacing on a tape stretched between the two. For the direction from control station 10 + 38.83 to pile No. 65 (the other outside pile in bent M), you would solve the triangle shown in figure 10-32. Again, you solve for *b* using the law of cosines and then use the law of sines to solve for angle *A.*

For each control station, a **pile location sheet** like the one shown in figure 10-33 would be made up. If desired, the direction angles for the piles between No. 61 and No. 65 could be computed and inserted in the intervening spaces.

TRANSIT AT CONTROL STA. 10+38.83				
BENT	PILE #	BS STATION	ANGLE FROM BS	REMARKS
	61	7+61.15	45° 00'	∠ RIGHT
	62			
M	63			
	64			
	65	7+61.15	41° 10'	∠ RIGHT

Figure 10-33.—File location sheet.

DREDGING SURVEYS

The excavation of material in underwater areas is called **dredging,** and a **dredge** is an excavator afloat on a barge. A dredge may get itself into position by cross bearings, taken from the dredge on objects of known location on the beach, or by some other piloting method. Many times, however, dredges are positioned by survey triangulation. The method of determining direction angles from base line control points is the same as that just described.

LAND SURVEYING

Land surveying includes surveys for locating and monumenting the boundaries of a property; preparation of a legal description of the limits of a property and of the area included; preparation of a property map; resurveys to recover and remonument property corners; and surveys to subdivide property.

It is sometimes necessary to retrace surveys of property lines, to reestablish lost or obliterated corners, and to make ties to property lines and corners; for example, a retracement survey of property lines may be required to assure that the military operation of quarry excavation does not encroach on adjacent property where excavation rights have not been obtained. Similarly, an access road from a public highway to the quarry site, if it crosses privately owned property, should be tied to the property lines that are crossed so that correctly executed easements can be obtained to cross the tracts of private property.

EAs may be required to accomplish property surveys at naval activities outside the continental limits of the United States for the construction of naval bases and the restoration of such properties to property owners. The essentials of land surveying as practiced in various countries are similar in principle. Although the principles pertaining to the surveys of public and private lands within the United States are not necessarily directly applicable to foreign countries, a knowledge of these principles will enable the EA to conduct the survey in a manner required by the property laws of the nation concerned.

In the United States, land surveying is a survey conducted for the purpose of ascertaining the correct boundaries of real estate property for legal purposes. In accordance with federal and states laws, the right and/or title to landed property in the United States can be transferred from one person to another only by means of a written document, commonly called a **deed.** To constitute a valid transfer, a deed must meet a considerable number of legal requirements, some of which vary in different states. In all the states, however, a deed must contain an accurate description of the boundaries of the property.

A right in real property need not be complete, outright ownership (called **fee simple).** There are numerous lesser rights, such as **leasehold** (right to occupancy and use for a specified term) or **easement** (right to make certain specified use of property belonging to someone else). But in any case, a valid transfer of any type of right in real property usually involves an accurate description of the boundaries of the property.

As mentioned previously, the EA may be required to perform various land surveys. As a survey team or crew leader, you should have a knowledge of the principles of land surveys in order to plan your work accordingly.

PROPERTY BOUNDARY DESCRIPTION

A parcel of land may be described by **metes and bounds,** by giving the coordinates of the property corners with reference to the **plane coordinates** system, by a deed reference to a description in a previously **recorded deed,** or by references to block and individual property numbers appearing on a **recorded map.**

By Metes and Bounds

When a tract of land is defined by giving the bearings and lengths of all boundaries, it is said to be described by **metes and bounds.** This is an age-old method of describing land that still forms the basis for the majority of deed descriptions in the eastern states of the United States and in many foreign lands. A good metes-and-bounds description starts at a point of beginning that should be monumented and referenced by ties or distances from well-established monuments or other reference points. The bearing and length of each side is given, in turn, around the tract to close back on the point of beginning. Bearing may be true or magnetic grid, preferably the former. When magnetic bearings are read, the declination of the needle and the date of the survey should be stated. The stakes or monuments placed at each corner should be described to aid in their recovery in the future. Ties from corner monuments to witness points (trees, poles, boulders, ledges, or other semipermanent or permanent objects) are always helpful in relocating corners, particularly where the corner markers themselves lack permanence. In timbered country, blazes on trees on or adjacent to a boundary line are most useful in reestablishing the line at a future date. It is also advisable to state the names of abutting property owners along the several sides of the tract being described. Many metes-and-bounds descriptions fail to include all of these particulars and are frequently very difficult to retrace or locate in relation to adjoining ownerships.

One of the reasons why the determination of boundaries in the United States is often difficult is that early surveyors often confined themselves to **minimal** description; that is, to a bare statement of the **metes and bounds, courses and distances.** Today, good practice requires that a land surveyor include all relevant information in his description.

In preparing the description of a property, the surveyor should bear in mind that the description must clearly identify the location of the property and must give all necessary data from which the boundaries can be reestablished at any future date. The written description contains the greater part of the information shown on the plan. Usually both a description and a plan are prepared and, when the property is transferred, are recorded according to the laws of the county concerned. The metes-and-bounds description of the property shown in figure 10-34 is given below.

> "All that certain tract or parcel of land and premises, hereinafter particularly described, situate, lying and being in the Township of Maplewood in the County of Essex and State of New Jersey and constituting lot 2 shown on the revised map of the Taylor property in said township as filed in the Essex County Hall of Records on March 18, 1944.

> "Beginning at an iron pipe in the northwesterly line of Maplewood Avenue therein distant along same line four hundred and thirty-one feet and seventy-one-hundredths of a foot northeasterly from a stone monument at the northerly corner of Beach Place and Maplewood Avenue; thence running (1) North forty-four degrees thirty-one and one-half minutes West along land of. . ."

Another form of a lot description maybe presented as follows:

> "Beginning at the northeasterly corner of the tract herein described; said corner being the intersection of the southerly line of Trenton Street and the westerly line of Ives Street; thence running S6°29′54′′E bounded easterly by said Ives Street, a distance of two hundred and twenty-seven one hundredths (200.27) feet to the northerly line of Wickenden Street; thence turning an interior angle of 89°59′16′′ and running S83°39′50′′W bonded southerly by said Wickenden Street, a distance of one hundred and no one-hundredths (100.00) feet to a corner; thence turning an interior angle of. . . ."

You will notice that in the above example, interior angles were added to the bearings of the boundary lines. This will be another help in retracing lines.

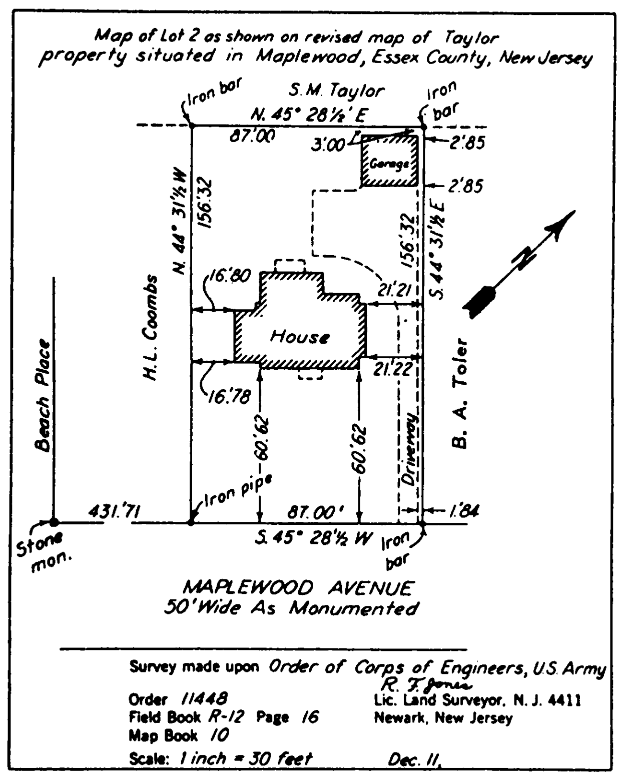


Figure 10-34.—Lot plan by metes and bounds.

By Rectangular System

In the early days (from 1785) of the United States, provisions were made to subdivide territorial lands into townships and sections thereof, along lines running with the cardinal directions of north-south, east-west. Later, as additional lands were added to the public domain, such lands were subdivided in a similar manner.

However, these methods of subdividing lands do not apply in the eastern seaboard (original 13 states) and in Hawaii, Kentucky, Tennessee, Texas, and West Virginia. For laws regulating the subdivision of public lands and the recommended surveying methods, check the instruction manual published by the Bureau of Land Management, Washington, D.C.

By Plane Coordinates

For many years the triangulation and traverse monuments of various domestic and foreign survey agencies have been defined by their geographic positions; that is, by their latitudes and longitudes. Property corners might be definitely fixed in position in the same way. The necessary computations are involved, and too few land surveyors are sufficiently well versed in the theory of geodetic surveying for this method to attain widespread use. In recent years, plane coordinate systems have been developed and used in many states and in many foreign countries. These grid systems involve relatively simple calculations, and their use in describing parcels of land is increasing. Every state in the American Union is now covered by a statewide coordinate system commonly called a **grid system.**

As with any plane-rectangular coordinate system, a projection employed in establishing a state coordinate system may be represented by two sets of parallel straight lines, intersecting at right angles. The network thus formed is the **grid.** A system of lines representing geographic parallels and meridians on a map projection is termed *graticule.* One set of these lines is parallel to the plane of a meridian passing approximately through the center of the area shown on the grid, and the grid line corresponding to that meridian is the **Y-axis** of the grid. The *Y*- axis is also termed the *central meridian* of the grid. Forming right angles with the *Y*- axis and to the **south** of the area shown on the grid is the **X-axis.** The point of intersection of these axes is the **origin** of coordinates. The position of a point represented on the grid can be defined by stating two distances, termed *coordinates.* One of these distances, known as the **X-coordinate,** gives the position in an **east-** and **-west** direction. The other distance, known as the **Y-coordinate,** gives the position in a **north-** and- **south** direction; this coordinate is always positive. The X -coordinates increase in size, numerically, from west to east; the Y -coordinates increase in size from south to north. All X -coordinates in an area represented on a state grid are made positive by assigning the origin of the coordinates: $X = 0$ plus a large constant. For any point, then, the X -coordinate equals the value of X adopted for the origin, plus or minus the distance (X') of the point east or west from the central meridian (Y -axis); and the Y -coordinate equals the perpendicular distance to the point from the X -axis. The linear unit of the state coordinate systems is the foot of 12 inches defined by the equivalence: 1 international meter = 39.37 inches exactly.

The linear distance between two points on a state coordinate system, as obtained by computation or scaled from the grid, is termed the *grid length* of the line correcting those points. The angle between a line on the grid and the Y -axis, reckoned clockwise from the south through 360°, is the **grid azimuth** of the line. The computations involved in obtaining a grid length and a grid azimuth from grid coordinates are performed by means of the formulas of plane trigonometry.

A property description by metes and bounds might include points located by coordinates as follows:

> "Commencing at U.S. Coast and Geodetic Survey Monument 'Bradley, Va', having coordinates y = 75,647.13 ft and x = 35,277.48 ft, as based on the Virginia Coordinate System, North Zone, as are all the coordinates, bearings, and distances in this description; thence S 36°30´E, 101.21 ft to the intersection of Able Street and Baker Avenue, whose coordinates are y = 75,565.77 ft and x = 35,337.45 ft, ..."

By Blocks, Tracts, or Subdivisions

In many counties and municipalities the land of the community is divided into subdivisions called **blocks, tracts,** or **subdivisions.** Each of these subdivisions is further subdivided into **lots.** Blocks and tracts usually have numbers, while a subdivision usually has a name. Each lot within a block, tract, or subdivision usually has a number.

From data obtained in a **tax map survey,** or **cadastral survey,** a **map book** is prepared that shows the location and boundaries of each major subdivision and of each of the lots it contains. The map book is filed in the county or city recorder's office, and henceforward, in deeds or other instruments, a particular lot is described as, for example, "Lot 72 of Tract 5417 as per map recorded in book 72, pages 16 and 17, of maps, in the office of the county/city recorder of [named] county/city"; or as "Lot 32 of Christopher Hills Subdivision as per. . . ."

JOB REQUIREMENTS OF THE LAND SURVEYOR

In resurveying property boundaries and in carrying out surveys for the subdivision of land, the EA performing land surveys has the following duties, responsibilities, and liabilities:

1. Locate in the public records all deed descriptions and maps pertaining to the property and properly interpret the requirements contained therein.

2. Set and properly reference new monuments and replace obliterated monuments.

3. Be liable for damages caused by errors resulting from incompetent professional work.

4. Attempt to follow in the tracks of the original surveyor, relocating the old boundaries and not attempting to correct the original survey.

5. Prepare proper descriptions and maps of the property.

6. May be required to connect a property survey with control monuments so that the grid coordinates of the property corners can be computed.

7. Report all easements, encroachments, or discrepancies discovered during the course of the survey.

8. When original monuments cannot be recovered with certainty from the data contained in the deed description, seek additional evidence. Such evidence must be substantial in character and must not be merely personal opinion.

9. In the absence of conclusive evidence as to the location of a boundary, seek agreement between adjoining owners as to a mutually acceptable location. The surveyor has no judicial functions; he may serve as an arbiter in relocating the boundary according to prevailing circumstances and procedures set forth by local authority.

10. When a boundary dispute is carried to the courts, he may be called upon to appear as an expert witness.

11. He must respect the laws of trespass. The right to enter upon property in conducting public surveys is provided by law in most localities. In a few political subdivisions, recent laws make similar provision with respect to private surveys. Generally, the military surveyor should request permission from the owner before entry on private property. When the surveyor lacks permission from an adjoiner, it is usually possible to make the survey without trespassing on the adjoiner's land, but such a condition normally adds to the difficulty of the task. The surveyor is liable for actual damage to private property resulting from his operations.

A primary responsibility of a land surveyor is to prepare boundary data that may be submitted as evidence in a court of law in the event of a legal dispute over the location of a boundary. The techniques of land surveying do not vary in any essential respect from those used in any other type of horizontal-location surveying—you run a land-survey boundary traverse, for example, just as you do a traverse for any other purpose. The thing that distinguishes land surveying from other types of surveying is that a land surveyor is often required to decide the location of a boundary on the basis of conflicting evidence.

For example, suppose you are required to locate, on the ground, a boundary line that is described in a deed as running, from a described point of beginning marked by a described object, N26°15´E, 216.52 feet. Suppose you locate the point of beginning, run a line therefrom the deed distance in the deed direction, and drive a hub at the end of the line. Then you notice that there is, a short distance away from the hub, a driven metal pipe that shows signs of having been in the ground a long time. Let's say that the bearing and distance of the pipe from the point of beginning are N26°14´E, 215.62 feet.

You can see that there is conflicting evidence here. By deed evidence the boundary runs N26°15´E, 216.52 feet; but the evidence on the ground seems to indicate that it runs N26°14´E, 215.62 feet. Did the surveyor who drove the pipe drive it in the wrong place, or did he drive the pipe in the right place and then measure the bearing and distance wrong? The land surveyor, on the basis of experience, judgment, and extensive research, must frequently decide questions of this kind. That is to say, he must possess the knowledge, experience, and judgment to select the best evidence when the existing situation is conflicting.

There are no specific rules that can be consistently followed. In the case mentioned, the decision as to the best evidence might be influenced by a number of considerations. The pipe is pretty close to the deed location of the end of the boundary. This might, everything else being equal, be a point in favor of considering the pipe bearing and distance, rather than the deed bearing and distance, to be correct. If the pipe were a considerable distance away, it might even be presumed that it was not originally intended to serve as a boundary marker. Additionally, the land surveyor would consider the fact that, if the previous survey was a comparatively recent one done with modern equipment, it would be unlikely that the measured bearing to the pipe would be off by much more than a minute or the distance to the pipe off by much more than a tenth of a foot. However, if the previous survey was an ancient one, done perhaps with compass and chain, larger discrepancies than these would be probable,

Further considerations would have to be weighed as well. If the deed said, "From [point of beginning] along the line of Smith N26°15'E, 216.52 feet," and you found the remains of an ancient fence on a line bearing N26°15'E, these remains would tend to vouch for the accuracy of the deed bearing regardless of a discrepancy in the actual bearing of the pipe or other marker found.

To sum up, in any case of conflicting evidence, you should (1) find out as much as you can about all the evidential circumstances and conditions, using all feasible means, including questioning of neighboring owners and local inhabitants and examination of deeds and other documents describing adjacent property, and (2) select the best evidence on the basis of all the circumstances and conditions.

As in many other professions, the primary—in this case, the surveyor—may be held liable for incompetent services rendered. For example, if the surveyor has been given, in advance, the nature of the structure to be erected on a lot, he may be held liable for all damages or additional costs incurred as a result of an erroneous survey; and pleading in his defense that the survey is not guaranteed will not stand up in court. Since a civilian professional surveyor must be licensed before he can practice his profession, he must show that degree of prudence, judgment, and skill reasonably expected of a member of his profession.

LAND SURVEY GENERAL PROCEDURE

As there are no universal rules for the weighing of evidence, so there are no universal, unvarying rules for land-survey procedures. The typical problem, however, usually breaks down into the following major action phases:

1. The location, study, and (when necessary) interpretation of all the available deeds, contracts, maps, wills, or other documents that contain a description of the boundaries. The principal repository for most of these instruments is usually the files in a city or county records office. The mere deciphering of ancient, handwritten documents is an art in itself. And here again it is not unusual to encounter conflicting evidence in the shape of documents that purport to describe the same property but that describe it differently. Or you may find a document in which some of the languages may bear more than one interpretation. In this last case you apply, as well as you can, a legal maxim to the effect that an ambiguous document should be given the sense that the maker of the document may be reasonably presumed to have intended.

2. The determination, after study of all the documents and related evidence, of what the true property description may be presumed to be, and from this a determination of what physical evidence of the boundary location exists in the field. Physical evidence means for the most part **monuments.** In land-surveying speech, a **monument** is any identifiable object that occupies a permanent location in the field and serves as a reference point or marker for a boundary. A monument may be a **natural** monument, such as a rock, a tree, or the edge of a stream; or it may be an **artificial** monument, such as a pipe or a concrete monument. Do not use perishable markers for monuments, such as a wooden marker that decays easily.

3. The location, in the field, of the existing physical evidence of the boundaries.

4. The establishment of the boundary. That involves those decisions previously mentioned as to the best evidence. It also involves the setting, referencing, and marking of points that should have been marked in previous surveys but were not or that were marked with markers that have since disappeared.

5. The preparation of the property description.

PLATS OF SURVEYED LANDS

The official plat of a township or other subdivision is the drawing on which is shown the direction and length of each line surveyed, established, retraced, or resurveyed; the relationship to adjoining official surveys; the boundaries, designation, and area of each parcel of land; and, insofar as practical, a delineation of the topography of the area and a representation of the culture and works of man within the survey limits. A subdivision of the public lands is not deemed to have been surveyed or identified until the notes of the field survey have been approved, a plat prepared, the survey accepted by the Director of the Bureau of Land Management as evidenced by a certification to that effect on the plat, and the plat has been filed in the district land office. Figure 10-35 shows a typical township plat. The original drawing shows both a graphical scale and a representative fraction for both the township as a whole and for the enlarged diagram. Because the plat has been photographically reduced, the representative fraction and scale are no longer true. Plats are drawn on sheets of uniform size, 19 inches by 24 inches in trimmed dimensions, for convenience in filing. The usual scale is 1 inch = 40 chains, equivalent to a representative fraction of 1:31,680. Where detail drawings of a portion of the survey area are required, scales of 1 inch = 20 chains or 1 inch = 10 chains may be used. A detail of a small area may be shown (fig. 10-34) as an inset on the main plat. Larger details are drawn on separate sheets. When the drawing is simple, with few topographic or hydrographic

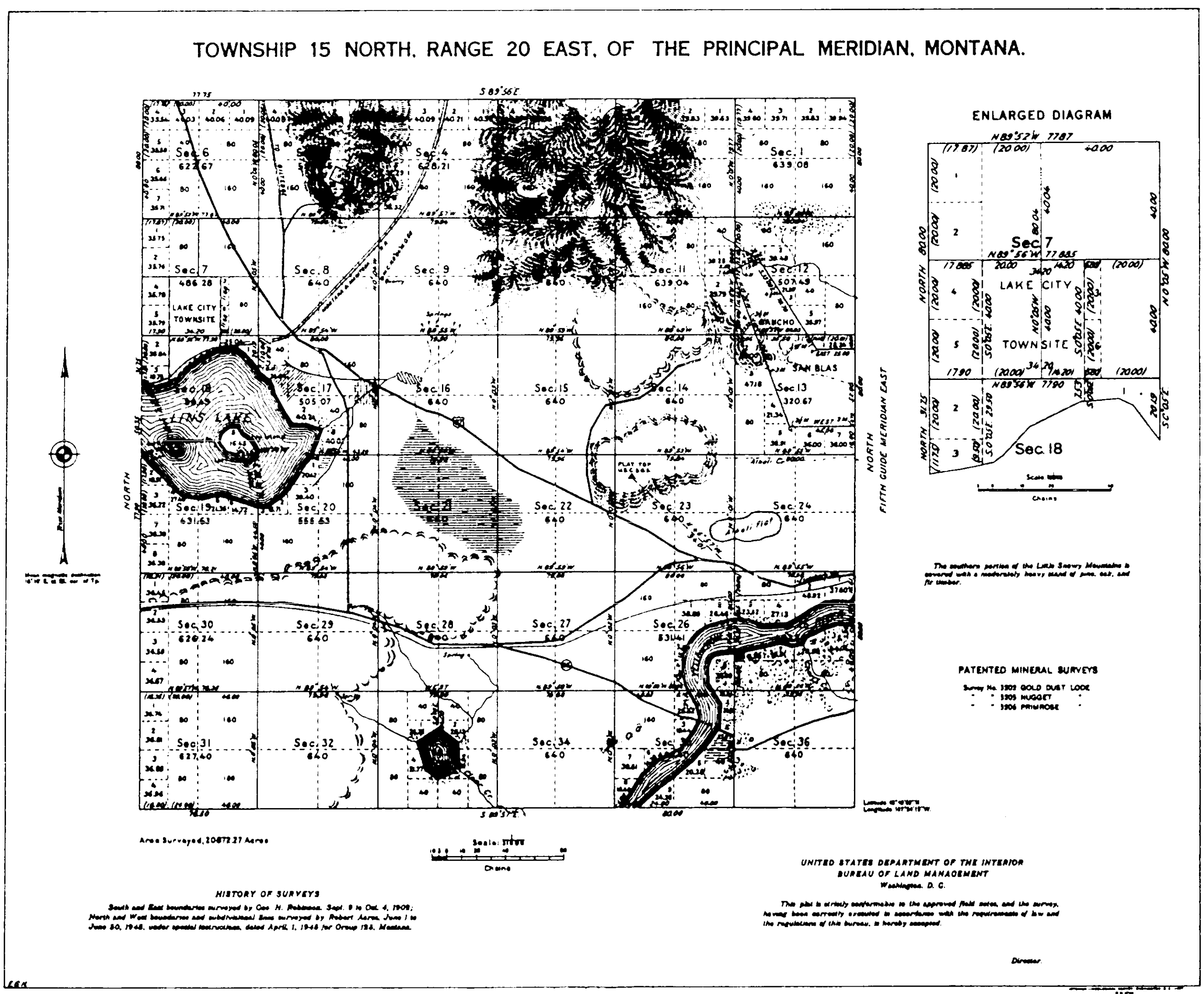


Figure 10-35.—Typical township plat.

features or works of man to be shown, the entire drawing is in black ink. When, as shown in figure 10-35, the features other than the survey lines are quite extensive, color printing is used. Survey lines, numbers, lettering, and railroads are printed in black; topographic relief, roads, highways, trails, culture, alkali flats, sandy-bottom draws, and sand dunes are shown in brown; rivers, lakes, streams, and marshes are shown by conventional symbols in blue; and timbered areas are indicated in green. Where such a green overprint might obscure other details, the presence of timber may be indicated in a note (fig. 10-35). These several colors are not shown on the reproduction of the plat presented in figure 10-35, although the various features are indicated in appropriate colors on the original map from which this figure was reproduced.

A property plat plan must contain the following:

1. Directional orientation, usually indicated by a north arrow.

2. Bearing and distance of each boundary.

3. Corner monuments.

4. Names of adjacent owners, inscribed in areas of their property shown.

5. Departing property lines. A departing property line is one that runs from a point on one of the boundaries of the surveyed lot through adjacent property. It constitutes a boundary between areas belonging to two adjacent owners,

6. Names of any natural monuments that appear on the plat (such as the name of a stream), or the character of any natural monuments (such as “10-inch oak tree”) that have no names.

7. Title block, showing name of owner, location of property, name of surveyor, date of survey, scale of plat, and any other relevant data.

The preceding items are those that usually appear on any plat. Some land surveyors add some or all of the following as well:

1. Grid lines or **ticks** (a grid tick is a marginal segment of a grid line, the remainder of the line between the marginal ticks being omitted), when determinable.

2. On a plat on which grid lines or ticks are shown, comer locations by grid plane coordinates.

3. Streams, roads, wooded areas, and other natural features, whether or not they serve as natural monuments.

4. Surveyor’s certificate. This is a statement (required by law in many states) in which the surveyor makes a personal affidavit as to the accuracy of the survey, A typical certificate might read as follows: I, (surveyor’s name), registered land surveyor, hereby certify that this plat accurately shows property of (owner’s name), as acquired in Deed Book 60, page 75, of the land record of (named) County, State of (name).

5. The area of the property.

LAND SURVEY PRECISION

Most land surveying of tracts of ordinary size is done by using transit-tape methods. For a large tract, however (such as a large government reservation), comers might be located by triangulation, or primary horizontal control might be by triangulation and secondary control by supplementary traversing.

The precision used for land surveying varies directly with the value of the land and also with such circumstances as whether or not important structures will be erected adjacent to the property lines. Obviously, a tract in lower Manhattan, New York (where land may sell for more than $1 million per acre), would be surveyed with considerably higher precision than would a rural tract.

Again there are no hard-and-fast rules. However, the prescribed order of precision for surveying the boundaries of a naval station might require the following:

1. Plumb bobs used for alignment and for transferring chained distances to the ground

2. Tape leveled by a Locke level

3. Tension applied by spring balance

4. Temperature correction made

5. Angles turned four times

If you turn angles four times with a 1-minute transit, you are measuring angles to approximately the nearest 15 seconds. The equivalent precision for distance measurement would be measurement to the nearest 0.01 foot. Four-time angles might be precise enough for lines up to 500.00 feet long. For longer lines, a higher angular precision (obtained by repeating six or eight times) might be advisable.

PROFILE & CROSS-SECTION LEVELS

DESIGNATION MCCOY AVE EXTENDED DATE 21 MAR 19 9-

STA	+	HI	−	ELEV
TP #1			6.08	132.10
7+50				
7+00				
6+50				
PC 6+09.22				
6+00				
	3.02	138.18		
BM #4				135.16

CORNETT
ROZEMA
NACE — INST GURLEY DUMPY LEVEL
LUFKIN — NO 12345

LEFT		℄	RIGHT	
		WEATHER		FAIR
		WIND		S 10
		TEMP		62°
135.0 / 3.2 / 50		133.7 / 4.5 / 0		132.0 / 6.2 / 50
137.1 / 1.1 / 50		135.9 / 2.3 / 0	134.6 / 3.6 / 20	134.3 / 3.9 / 50
135.1 / 3.1 / 50		134.1 / 4.1 / 0		133.6 / 4.6 / 50
132.3 / 5.9 / 50		134.6 / 3.6 / 0		133.2 / 5.0 / 50
134.7 / 3.5 / 50		134.6 / 3.6 / 0		134.6 / 3.6 / 50

NAIL IN TREE 60' LEFT OF ℄ STA 0+50

Figure 10-36.—Profile and cross-section levels.

QUESTIONS

Q1. *Into what three phases are route surveys usually broken?*

Q2. *For what reasons should overhead electrical pole lines be located on the side of a street that is most free from other lines and trees?*

Q3. *As it relates to the surface drainage of water, what does the term "runoff" mean?*

Q4. *Refer to figure 10-3. What is the invert of the pipe at station 1 + 50?*

Q5. *Refer to the field notes shown in figure 10-36. Assuming the road is 30 feet wide, what is the (a) area of the cross section at station 6 +00 and (b) volume between stations 6 + 00 and 6 + 50?*

Q6. *As related to muss diagrams, what is the limit of economic haul?*

Q7. *In which of the following ways does an as-built survey performed for the purpose of verifying the location of points as they are constructed in the field differ from an as-built survey that is performed for the purpose of monitoring construction progress?*

a. *The amount of time allowed to perform the survey*

b. *The equipment used to perform the survey*

c. *The degree of accuracy required*

Q8. *When staking out a sewer line, at what interval of distance should you usually set the center-line stakes or the offset hubs?*

Q9. *Refer to figure 10-29. What is the sine of the anglee that you should turn from station 10 + 38.83 to locate pile No. 8?*

Q10. *In land surveying, when a metes-and-bounds description is being prepared, what may be added to the bearings of the boundary lines to help in retracing the lines?*

CHAPTER 11

HORIZONTAL AND VERTICAL CURVES

As you know from your study of chapter 3, the center line of a road consists of series of straight lines interconnected by curves that are used to change the alignment, direction, or slope of the road. Those curves that change the alignment or direction are known as **horizontal curves,** and those that change the slope are **vertical curves.**

As an EA you may have to assist in the design of these curves. Generally, however, your main concern is to compute for the missing curve elements and parts as problems occur in the field in the actual curve layout. You will find that a thorough knowledge of the properties and behavior of horizontal and vertical curves as used in highway work will eliminate delays and unnecessary labor. Careful study of this chapter will alert you to common problems in horizontal and vertical curve layouts. To enhance your knowledge and proficiency, however, you should supplement your study of this chapter by reading other books containing this subject matter. You can usually find books such as *Construction Surveying,* FM 5-233, and *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail, in the technical library of a public works or battalion engineering division.

HORIZONTAL CURVES

When a highway changes horizontal direction, making the point where it changes direction a point of intersection between two straight lines is not feasible. The change in direction would be too abrupt for the safety of modem, high-speed vehicles. It is therefore necessary to interpose a curve between the straight lines. The straight lines of a road are called **tangents** because the lines are tangent to the curves used to change direction.

In practically all modem highways, the curves are **circular** curves; that is, curves that form circular arcs. The smaller the radius of a circular curve, the sharper the curve. For modern, high-speed highways, the curves must be flat, rather than sharp. That means they must be large-radius curves.

In highway work, the curves needed for the location or improvement of small secondary roads may be worked out in the field. Usually, however, the horizontal curves are computed after the route has been selected, the field surveys have been done, and the survey base line and necessary topographic features have been plotted. In urban work, the curves of streets are designed as an integral part of the preliminary and final layouts, which are usually done on a topographic map. In highway work, the road itself is the end result and the purpose of the design. But in urban work, the streets and their curves are of secondary importance; the best use of the building sites is of primary importance.

The principal consideration in the design of a curve is the selection of the length of the radius or the degree of curvature (explained later). This selection is based on such considerations as the design speed of the highway and the sight distance as limited by headlights or obstructions (fig. 11-1). Some typical radii you may encounter are 12,000 feet or longer on an interstate highway, 1,000 feet on a major thoroughfare in a city, 500 feet on an industrial access road, and 150 feet on a minor residential street.

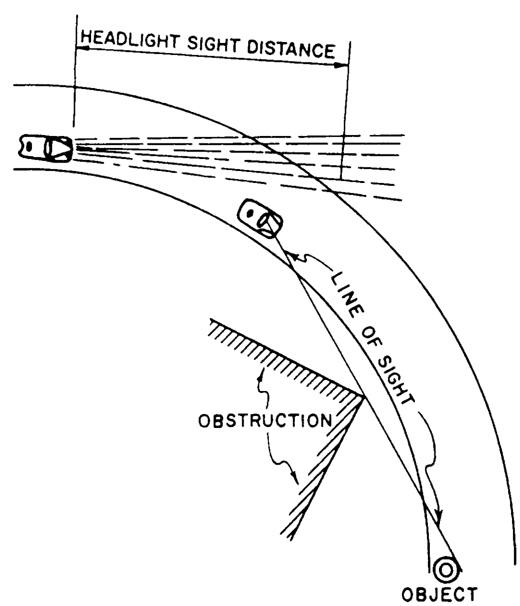


Figure 11-1.—Lines of sight.

TYPES OF HORIZONTAL CURVES

There are four types of horizontal curves. They are described as follows:

1. SIMPLE. The simple curve is an arc of a circle (view A, fig. 11-2). The radius of the circle determines the sharpness or flatness of the curve.

2. COMPOUND. Frequently, the terrain will require the use of the compound curve. This curve normally consists of two simple curves joined together and curving in the same direction (view B, fig. 11-2).

3. REVERSE. A reverse curve consists of two simple curves joined together, but curving in opposite direction. For safety reasons, the use of this curve should be avoided when possible (view C, fig. 11-2).

4. SPIRAL. The spiral is a curve that has a varying radius. It is used on railroads and most modem highways. Its purpose is to provide a transition from the tangent to a simple curve or between simple curves in a compound curve (view D, fig. 11-2).

ELEMENTS OF A HORIZONTAL CURVE

The elements of a circular curve are shown in figure 11-3. Each element is designated and explained as follows:

PI POINT OF INTERSECTION. The point of intersection is the point where the back and forward tangents intersect. Sometimes, the point of intersection is designated as *V (vertex).*

I INTERSECTING ANGLE. The intersecting angle is the deflection angle at the *PI.* Its value is either computed from the preliminary traverse angles or measured in the field.

Δ CENTRAL ANGLE. The central angle is the angle formed by two radii drawn from the

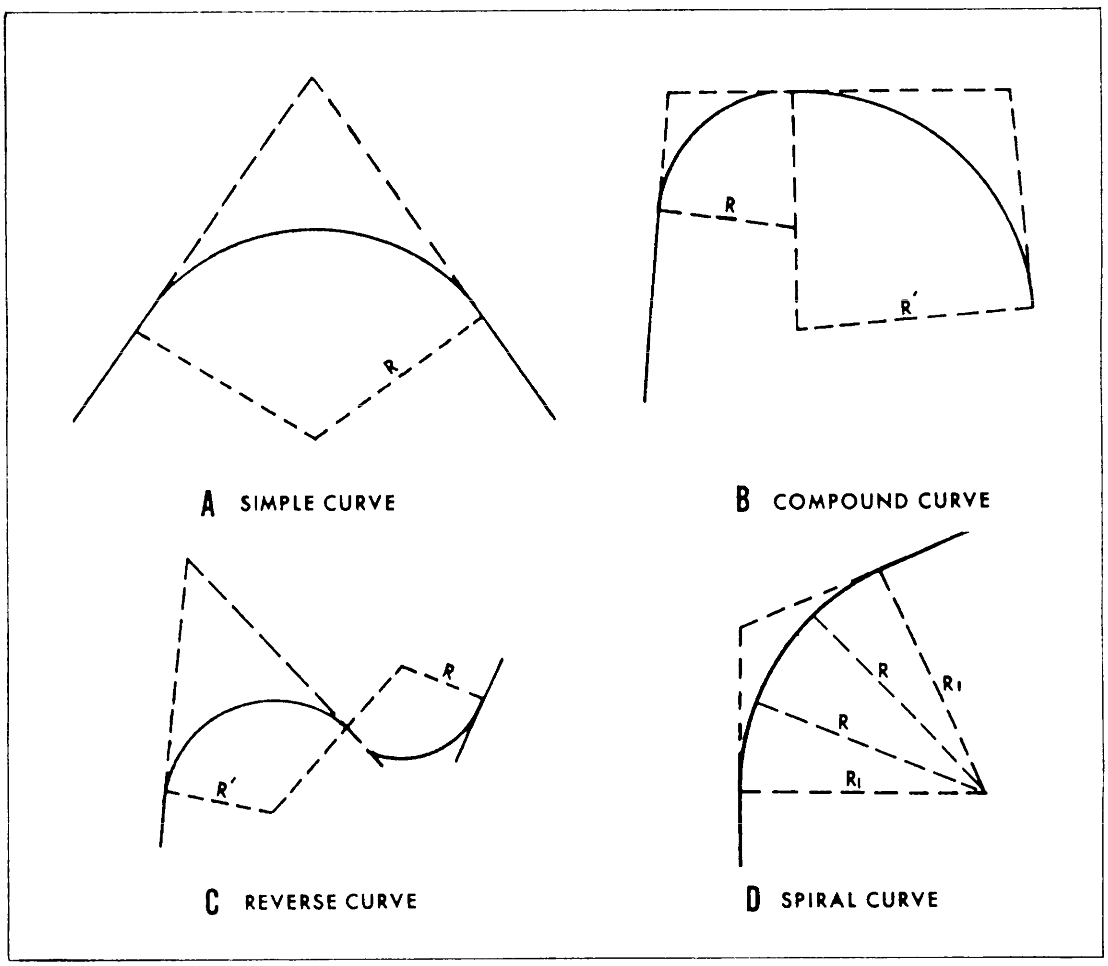


Figure 11-2.—Horizontal curves.

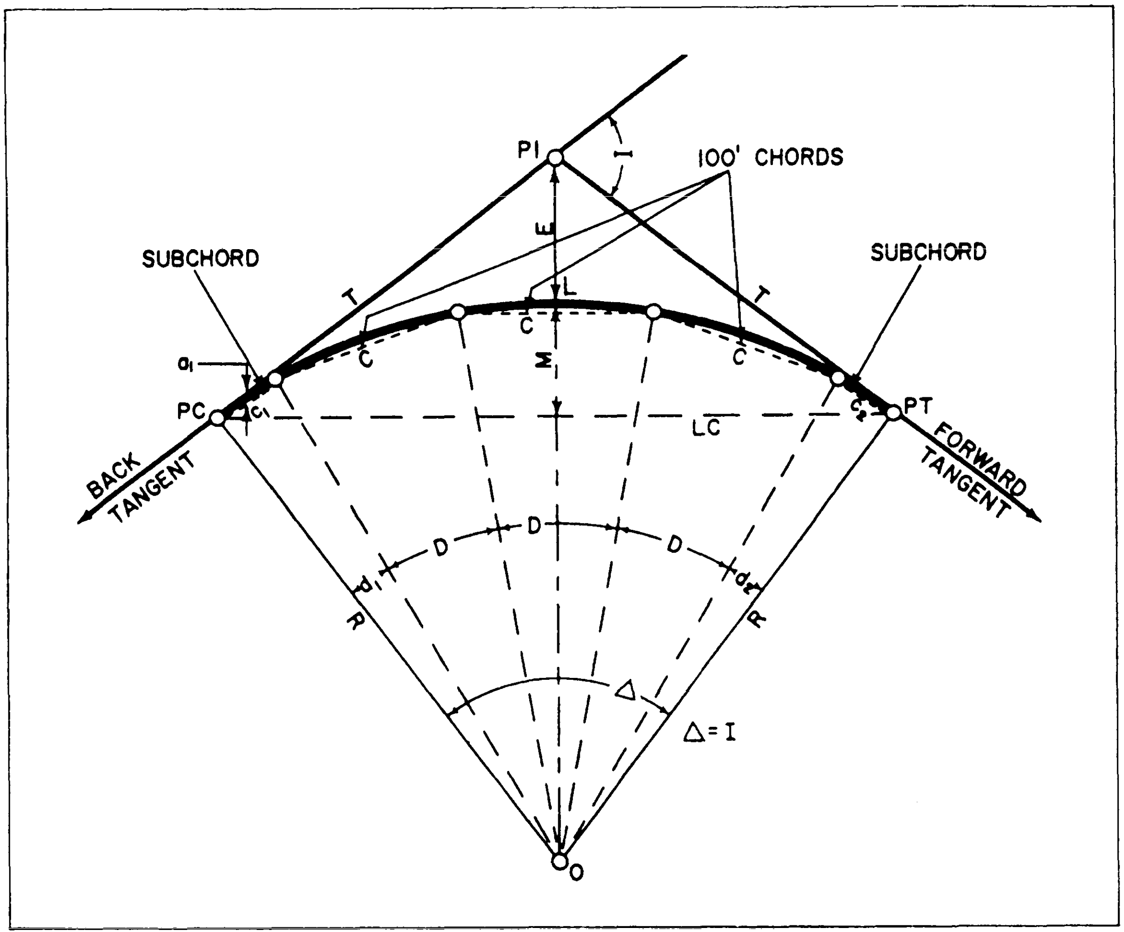


Figure 11-3.—Elements of a horizontal curve.

center of the circle *(O)* to the *PC* and *PT*. The value of the central angle is equal to the *I* angle. Some authorities call both the intersecting angle and central angle either *I* or Δ.

R RADIUS. The radius of the circle of which the curve is an arc, or segment. The radius is always perpendicular to back and forward tangents.

PC POINT OF CURVATURE. The point of curvature is the point on the back tangent where the circular curve begins. It is sometimes designated as *BC* (beginning of curve) or *TC* (tangent to curve).

PT POINT OF TANGENCY, The point of tangency is the point on the forward tangent where the curve ends. It is sometimes designated as *EC* (end of curve) or *CT* (curve to tangent).

POC POINT OF CURVE. The point of curve is any point along the curve.

L LENGTH OF CURVE. The length of curve is the distance from the *PC* to the *PT,* measured along the curve.

T TANGENT DISTANCE. The tangent distance is the distance along the tangents from the *PI* to the *PC* or the *PT*. These distances are equal on a simple curve.

LC LONG CHORD. The long chord is the straight-line distance from the *PC* to the *PT*. Other types of chords are designated as follows:

C The full-chord distance between adjacent stations (full, half, quarter, or one-tenth stations) along a curve.

C_1 The subchord distance between the *PC* and the first station on the curve.

C_2 The subchord distance between the last station on the curve and the *PT*.

E EXTERNAL DISTANCE. The external distance (also called the external secant) is the distance from the *PI* to the midpoint of the curve. The external distance bisects the interior angle at the *PI*.

M MIDDLE ORDINATE. The middle ordinate is the distance from the midpoint of the curve to the midpoint of the long chord. The extension of the middle ordinate bisects the central angle.

D DEGREE OF CURVE. The degree of curve defines the sharpness or flatness of the curve.

DEGREE OF CURVATURE

The last of the elements listed above (degree of curve) deserves special attention. Curvature may be expressed by simply stating the length of the radius of the curve. That was done earlier in the chapter when typical radii for various roads were cited. Stating the radius is a common practice in land surveying and in the design of urban roads. For highway and railway work, however, curvature is expressed by the degree of curve. Two definitions are used for the degree of curve. These definitions are discussed in the following sections.

Degree of Curve (Arc Definition)

The arc definition is most frequently used in highway design. This definition, illustrated in figure 11-4, states that the degree of curve is the central angle formed by two radii that extend from the center of a circle to the ends of an **arc** measuring 100 feet long (or 100 meters long if you are using metric units). Therefore, if you take a sharp curve, mark off a portion so that the distance along the arc is exactly 100 feet, and determine that the central angle is 12°, then you have a curve for which the degree of curvature is 12°; it is referred to as a 12° curve.

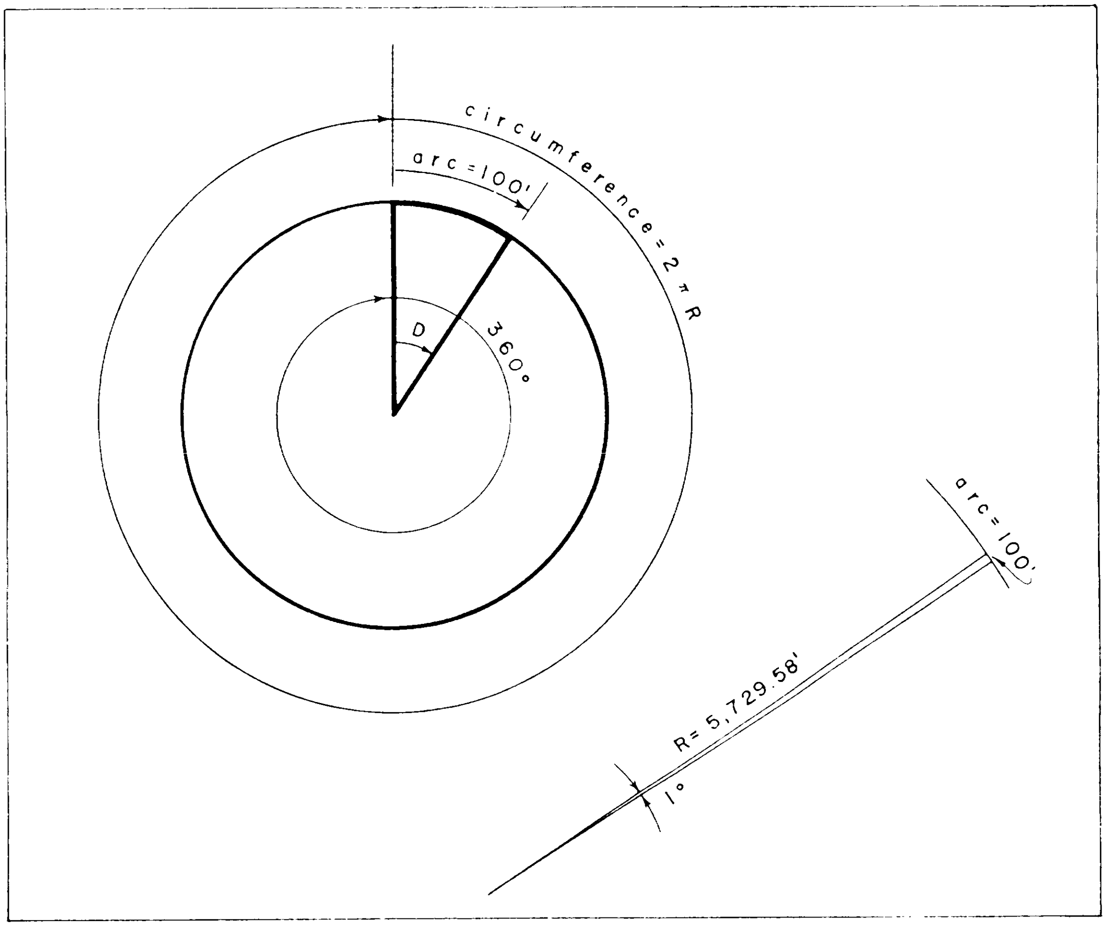


Figure 11-4.—Degree of curve (arc definition).

By studying figure 11-4, you can see that the ratio between the degree of curvature *(D)* and 360° is the same as the ratio between 100 feet of arc and the circumference *(C)* of a circle having the same radius. That may be expressed as follows:

$$\frac{D}{360^\circ} = \frac{100}{C}.$$

Since the circumference of a circle equals $2\pi R$, the above expression can be written as:

$$\frac{D}{360^\circ} = \frac{100}{2\pi R}.$$

Solving this expression for R:

$$R = \frac{5729.58}{D}$$

and also D:

$$D = \frac{5729.58}{R}.$$

For a 1° curve, $D = 1$; therefore $R = 5{,}729.58$ feet, or meters, depending upon the system of units you are using.

In practice the design engineer usually selects the degree of curvature on the basis of such factors as the design speed and allowable superelevation. Then the radius is calculated.

Degree of Curve (Chord Definition)

The chord definition (fig. 11-5) is used in railway practice and in some highway work. This definition states that the degree of curve is the central angle formed by two radii drawn from the center of the circle to the ends of a **chord** 100 feet (or 100 meters) long. If you take a flat curve, mark a 100-foot chord, and determine the central angle to be 0°30', then you have a 30-minute curve (chord definition).

From observation of figure 11-5, you can see the following trigonometric relationship:

$$\sin\left(\frac{D}{2}\right) = \frac{50}{R}.$$

Then, solving for R:

$$R = \frac{50}{\sin \frac{1}{2} D}.$$

For a 10 curve (chord definition), $D = 1$; therefore $R = 5{,}729.65$ feet, or meters, depending upon the system of units you are using.

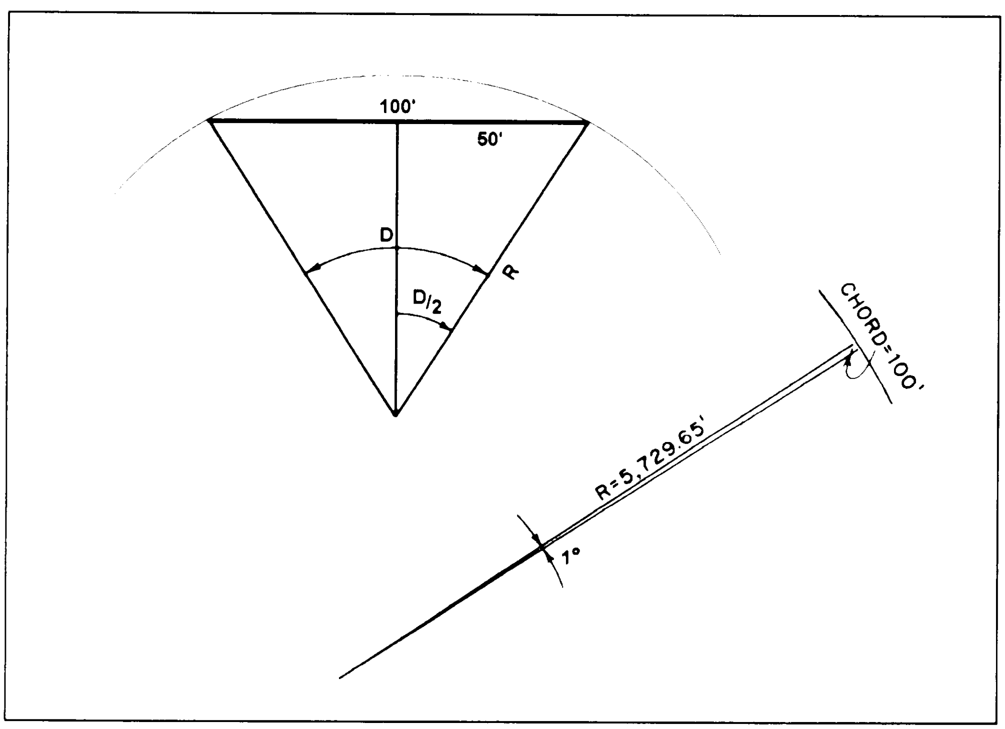


Figure 11-5.—Degree of curve (chord definition).

Notice that in both the arc definition and the chord definition, the radius of curvature is inversely proportional to the degree of curvature. In other words, the larger the degree of curve, the shorter the radius; for example, using the arc definition, the radius of a 1° curve is 5,729.58 units, and the radius of a 5° curve is 1,145.92 units. Under the chord definition, the radius of a 1° curve is 5,729.65 units, and the radius of a 5° curve is 1,146.28 units.

CURVE FORMULAS

The relationship between the elements of a curve is expressed in a variety of formulas. The formulas for radius *(R)* and degree of curve *(D),* as they apply to both the arc and chord definitions, were given in the preceding discussion of the degree of curvature. Additional formulas you will use in the computations for a curve are discussed in the following sections.

Tangent Distance

By studying figure 11-6, you can see that the solution for the tangent distance *(T)* is a simple right-triangle solution. In the figure, both T and R are sides of a right triangle, with T being opposite to angle $\Delta/2$. Therefore, from your knowledge of trigonometric functions you know that

$$\tan \frac{\Delta}{2} = \frac{T}{R}$$

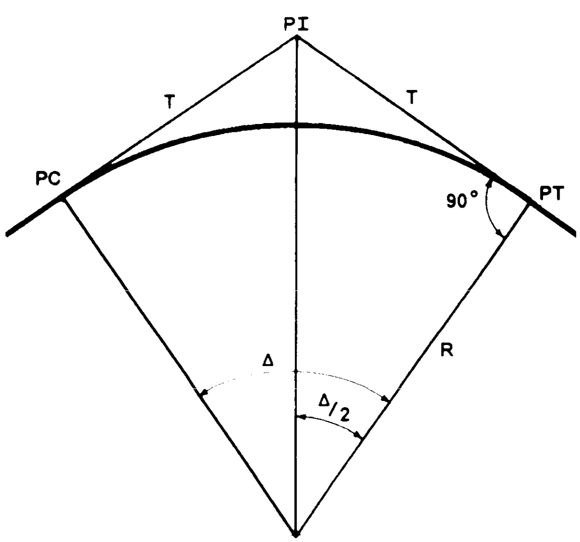


Figure 11-6.—Tangent distance.

and solving for T,

$$T = R \tan \frac{\Delta}{2}.$$

Chord Distance

By observing figure 11-7, you can see that the solution for the length of a chord, either a full chord *(C)* or the long chord *(LC),* is also a simple right-triangle solution. As shown in the figure, $C/2$ is one side of a right triangle and is opposite angle $\Delta/2$. The radius *(R)* is the hypotenuse of the same triangle. Therefore,

$$\sin \frac{\Delta}{2} = \frac{C/2}{R}$$

and solving for C:

$$C = 2R \sin \frac{\Delta}{2}.$$

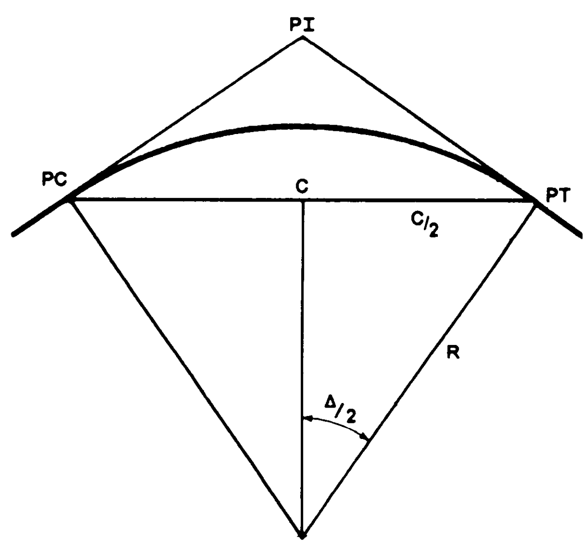


Figure 11-7.—Chord distance.

Length of Curve

In the arc definition of the degree of curvature, length is measured along the arc, as shown in view A of figure 11-8, In this figure the relationship between D, Δ, L, and a 100-foot arc length may be expressed as follows:

$$\frac{L}{100} = \frac{\Delta}{D}.$$

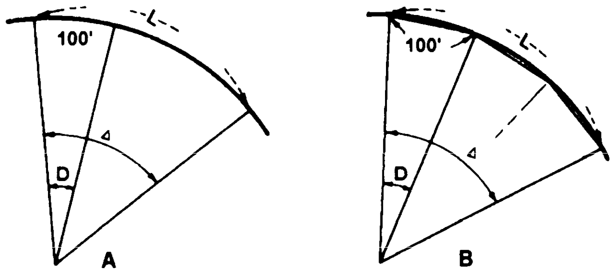


Figure 11-8.-Length of curve.

Then, solving for L,

$$L = 100 \frac{\Delta}{D}.$$

This expression is also applicable to the chord definition. However, L., in this case, is not the true arc length, because under the chord definition, the length of curve is the sum of the chord lengths (each of which is usually 100 feet or 100 meters), As an example, if, as shown in view B, figure 11-8, the central angle (Δ) is equal to three times the degree of curve (D), then there are three 100-foot chords; and the length of "curve" is 300 feet.

Middle Ordinate and External Distance

Two commonly used formulas for the middle ordinate (M) and the external distance (E) are as follows:

$$M = R\left(1 - \cos \frac{\Delta}{2}\right)$$

$$E = T \tan \frac{\Delta}{4} = R\left(\frac{1}{\cos \Delta/2} - 1\right).$$

DEFLECTION ANGLES AND CHORDS

From the preceding discussions, one may think that laying out a curve is simply a matter of locating the center of a circle, where two known or computed radii intersect, and then swinging the arc of the circular curve with a tape. For some applications, that can be done; for example, when you are laying out the intersection and curbs of a private road or driveway with a residential street. In this case, the length of the radii you are working with is short. However, what if you are laying out a road with a 1,000- or 12,000- or even a 40,000-foot radius? Obviously, it would be impracticable to swing such radii with a tape.

In usual practice, the stakeout of a long-radius curve involves a combination of turning **deflection angles** and measuring the length of chords (C, C_1, or C_2 as appropriate). A transit is set up at the PC, a sight is taken along the tangent, and each point is located by turning deflection angles and measuring the chord distance between stations. This procedure is illustrated in figure 11-9. In this figure, you see a portion of a curve that starts at the PC and runs through points (stations) A, B, and C. To establish the location of point A on this curve, you should set up your instrument at the PC, turn the required deflection angle ($d_1/2$), and then measure the required chord distance from PC to point A. Then, to establish point B, you turn deflection angle D/2 and measure the required chord distance from A to B. Point C is located similarly.

As you are aware, the actual distance along an arc is greater than the length of a corresponding chord; therefore, when using the arc definition, either a correction is applied for the difference between arc

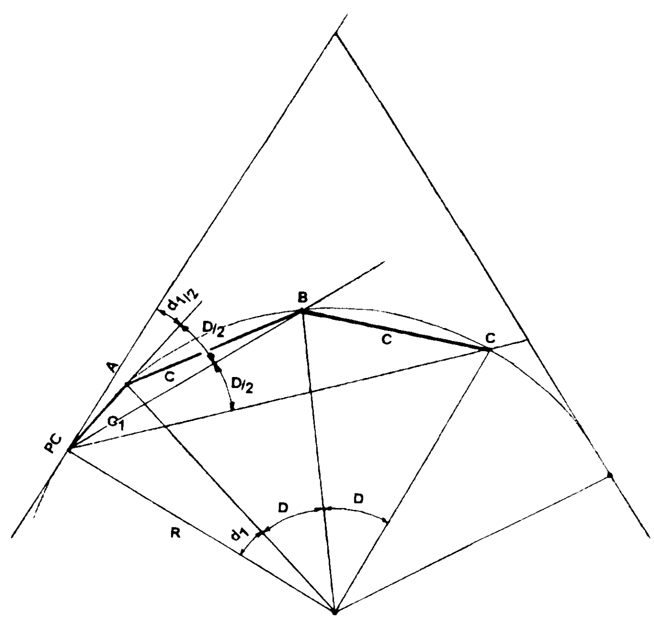


Figure 11-9.-Deflection angles and chords.

length and chord length, or shorter chords are used to make the error resulting from the difference negligible. In the latter case, the following chord lengths are commonly used for the degrees of curve shown:

100 feet—0 to 3 degrees of curve

50 feet—3 to 8 degrees of curve

25 feet—8 to 16 degrees of curve

10 feet-over 16 degrees of curve

The above chord lengths are the maximum distances in which the discrepancy between the arc length and chord length will fall within the allowable error for taping. The allowable error is 0.02 foot per 100 feet on most construction surveys; however, based on terrain conditions or other factors, the design or project engineer may determine that chord lengths other than those recommended above should be used for curve stakeout.

The following formulas relate to deflection angles: (To simplify the formulas and further discussions of deflection angles, the deflection angle is designated simply as d rather than $d/2$.)

$$d = \left(\frac{D}{2}\right)\left(\frac{C}{100}\right)$$

Where:

d = Deflection angle (expressed in degrees)

C = Chord length

D = Degree of curve

$$d = 0.3\ CD$$

Where:

d = Deflection angle (expressed in minutes)

C = Chord length

D = Degree of curve

$$\sin d = \frac{C}{2R}$$

Where:

d = Deflection angle (expressed in degrees)

C = Chord length

R = Radius.

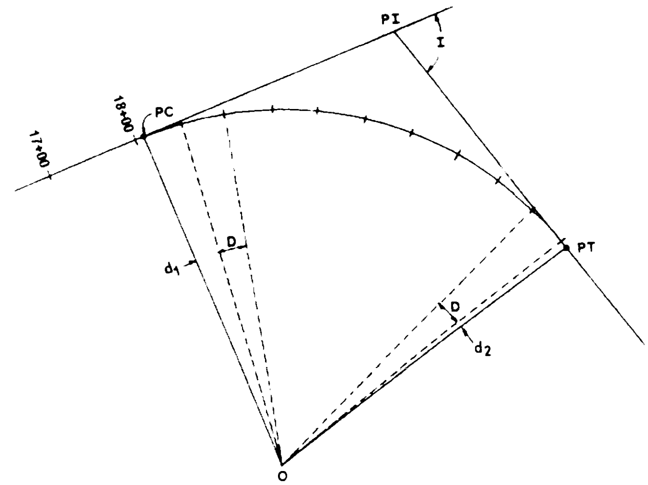


Figure 11-10.—Laying out a simple curve.

SOLVING AND LAYING OUT A SIMPLE CURVE

Now let's solve and lay out a simple curve using the arc definition, which is the definition you will more often use as an EA. In figure 11-10, let's assume that the directions of the back and forward tangents and the location of the *PI* have previously been staked, but the tangent distances have not been measured. Let's also assume that stations have been set as far as Station 18 + 00. The specified degree of curve *(D) is* 15°, arc definition. Our job is to stake half-stations on the curve.

Solving a Simple Curve

We will begin by first determining the distance from Station 18 + 00 to the location of the *PI*. Since these points have been staked, we can determine the distance by field measurement. Let's assume we have measured this distance and found it to be 300.89 feet. Next, we set up a transit at the *PI* and determine that deflection angle I is 75°. Since I always equals Δ, then Δ is also 75°, Now we can compute the radius of the curve, the tangent distance, and the length of curve as follows:

$R = 5{,}729.58/D = 381.97$ ft

$T = R \tan \Delta/2 = 293.09$ ft

$L = 100\ \Delta/D = 500$ ft

From these computed values, we can determine the stations of the *PI, PC,* and *PT* as follows:

Station at *PI* = (Sta. 18 + 00) + 300.89 =	21 + 00.89
Tangent distance =	(–) 2 + 93.09
Station at *PC*	18 + 07.80
Length of curve =	(+) 5 + 00.00
Station at *PT*	23 + 07.80

By studying figure 11-10 and remembering that our task is to stake half-station intervals, you can see that the first half station after the *PC* is Station 18 + 50 and the last half station before the *PT* is 23+ 00; therefore, the distance from the *PC* to Station 18 + 00 is 42.2 feet [(18 + 50) - (18 + 07.80)]. Similarly, the distance from Station 23+ 00 to the *PT* is 7.8 feet. These distances are used to compute the deflection angles for the subchords using the formula for deflection angles (*d*= .3CD) as follows:

$$\text{Deflection angle } d_1 = .3 \times 42.2 \times 15 = 189.9' = 3°09.9'$$

$$\text{Deflection angle } d_2 = .3 \times 7.8 \times 15 = 35.1' = 0°35.1'$$

A convenient method of determining the deflection angle *(d)* for each full chord is to remember that *d* equals *1/2D* for 100-foot chords, *1/4D* for 50-foot chords, *1/8D* for 25-foot chords, and *1/20D* for 10-foot chords. In this case, since we are staking 50-foot stations, *d* = 15/4, or 3°45'.

Previously, we discussed the difference in length between arcs and chords. In that discussion, you learned that to be within allowable error, the recommended chord length for an 8- to 16-degree curve is 25 feet. Since in this example we are using 50-foot chords, the length of the chords must be adjusted. The adjusted lengths are computed using a rearrangement of the formula for the sine of deflection angles as follows:

$$C_1 = 2R \sin d_1 = 2 \times 381.97 \times \sin 3°09.9' = 42.18 \text{ ft}$$

$$C_2 = 2R \sin d_2 = 2 \times 381.97 \times \sin 0°35.1' = 7.79 \text{ ft}$$

$$C = 2R \sin d = 2 \times 381.97 \times \sin 3°45' = 49.96 \text{ ft}$$

As you can see, in this case, there is little difference between the original and adjusted chord lengths; however, if we were using 100-foot stations rather than 50-foot stations, the adjusted difference for each full chord would be substantial (over 3 inches).

Now, remembering our previous discussion of deflection angles and chords, you know that all of the deflection angles are usually turned using a transit that is set up at the *PC*. The deflection angles that we turn are found by cumulating the individual deflection angles from the *PC* to the *PT* as shown below:

Station	Chord	Deflection angle
PC 18 + 07.80	--------	0°00.0′
18 + 50	C_1 42.18	3°09.9′
19 + 00	49.96	6°54.9′
19 + 50	49.96	10°39.9′
20 + 00	49.96	14°24.9′
20 + 50	49.96	18°09.9′
21 + 00	49.96	21°54.9′
21 + 50	49.96	25°39.9′
22 + 00	49.96	29°24.9′
22 + 50	49.96	33°09.9′
23 + 00	49.96	36°54.9′
PT 23 + 07.80	C_2 07.79	37°30′

Notice that the deflection angle at the *PT* is equal to one half of the *I* angle. That serves as a check of your computations. Had the deflection angle been anything different than one half of the *I* angle, then a mistake would have been made.

Since the total of the deflection angles should be one-half of the *I* angle, a problem arises when the *I* angle contains an odd number of minutes and the instrument used is a 1-minute transit. Since the *PT* is normally staked before the curve is run, the total deflection will be a check on the *PC* therefore, it should be computed to the nearest 0.5 degree. If the total deflection checks to the nearest minute in the field, it can be considered correct.

The curve that was just solved had an *I* angle of 75° and a degree of curve of 15°. When the *I* angle and degree of curve consists of both degrees and minutes, the procedure in solving the curve does not change; but you must be careful in substituting these values into the formulas for length and deflection angles; for example *I* = 42°15', *D* = 5°37'. The minutes in each angle must be changed to a decimal part of a degree. To obtain the required accuracy, you should convert them to five decimal places; but an alternate method for computing the length is to convert the *I* angle and degree of curve to minutes; thus, 42°15' = 2,535 minutes and 5°37' = 337 minutes. Substituting this information into the length formula gives the following:

$$L = 100 \times \frac{2{,}535}{337} = 752.23 \text{ feet.}$$

This method gives an exact result. By converting the minutes to a decimal part of a degree to the nearest fives places, you obtain the same result.

Simple Curve Layout

To lay out the simple curve (arc definition) just computed above, you should usually use the procedure that follows.

1. With the instrument placed at the *PI,* the instrumentman sights on the preceding *PI* or at a distant station and keeps the chainman on the line while the tangent distance is measured to locate the *PC.* After the *PC* has been staked out, the instrumentman then trains the instrument on the forward *PI* to locate the *PT.*

2. The instrumentman then sets up at the *PC* and measures the angle from the *PI* to the *PT.* This angle should be equal to one half of the *I* angle; if it is not, either the *PC* or the *PT* has been located in the wrong position.

3. With the first deflection angle (3°10') set on the plates, the instrumentman keeps the chainman on line as the first subchord distance (42.18 feet) is measured from the *PC.*

4. Without touching the lower motion screw, the instrumentman sets the second deflection angle (6°55') on the plates. The chainman measures the chord from the previous station while the instrumentman keeps the head chainman on line.

5. The crew stakes out the succeeding stations in the same manner. If the work is done correctly, the last deflection angle will point on the *PT.* That distance will be the subchord length (7.79 feet) from the last station before the *PT.*

When it is impossible to stake out the entire curve from the *PC,* a modified method of the procedure described above is used. Stake out the curve as far as possible from the *PC.* If a station cannot be seen from the *PC* for some reason, move the transit forward and set up over a station along the curve. Pick a station for a backsight and set the deflection angle for that station on the plates. Sight on this station with the telescope in the reverse position. Plunge the telescope and set

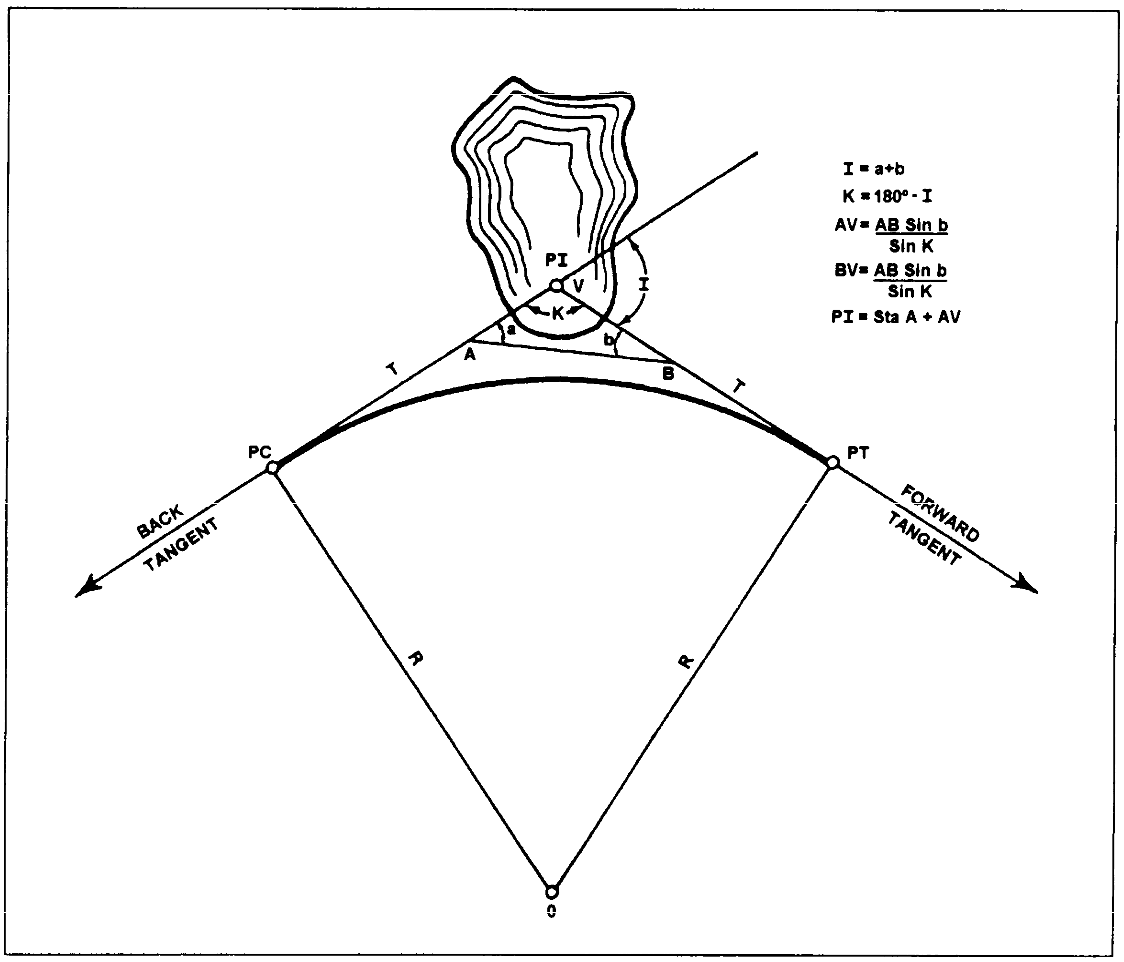


Figure 11-11.—Inaccessible *PI.*

the remainder of the stations in the same way as you would if the transit was set over the *PC*. If the setup in the curve has been made but the next stake cannot be set because of obstructions, the curve can be backed in. To back in a curve, occupy the *PT*. Sight on the *PI* and set one half of the *I* angle of the plates. The transit is now oriented so that, if the *PC* is observed, the plates will read zero, which is the deflection angle shown in the notes for that station. The curve stakes can then be set in the same order shown in the notes or in the reverse order. Remember to use the deflection angles and chords from the top of the column or from the bottom of the column. Although the back-in method has been set up as a way to avoid obstructions, it is also very widely used as a method for laying out curves. The method is to proceed to the approximate midpoint of the curve by laying out the deflection angles and chords from the *PC* and then laying out the remainder of the curve from the *PT*. If this method is used, any error in the curve is in the center where it is less noticeable.

So far in our discussions, we have begun staking out curves by setting up the transit at the *PI*. But what do you do if the *PI* is inaccessible? This condition is illustrated in figure 11-11. In this situation, you locate the curve elements using the following steps:

1. As shown in figure 11-11, mark two intervisible points *A* and *B* on the tangents so that line *AB* clears the obstacle.

2. Measure angles *a* and *b* by setting up at both *A* and *B*.

3. Measure the distance *AB*.

4. Compute inaccessible distance *AV* and *BV* using the formulas given in figure 11-11.

5. Determine the tangent distance from the *PI* to the *PC* on the basis of the degree of curve or other given limiting factor.

6. Locate the *PC* at a distance *T* minus *AV* from the point *A* and the *PT* at a distance *T* minus *BV* from point *B*.

Field Notes

Figure 11-12 shows field notes for the curve we solved and staked out above. By now you should be

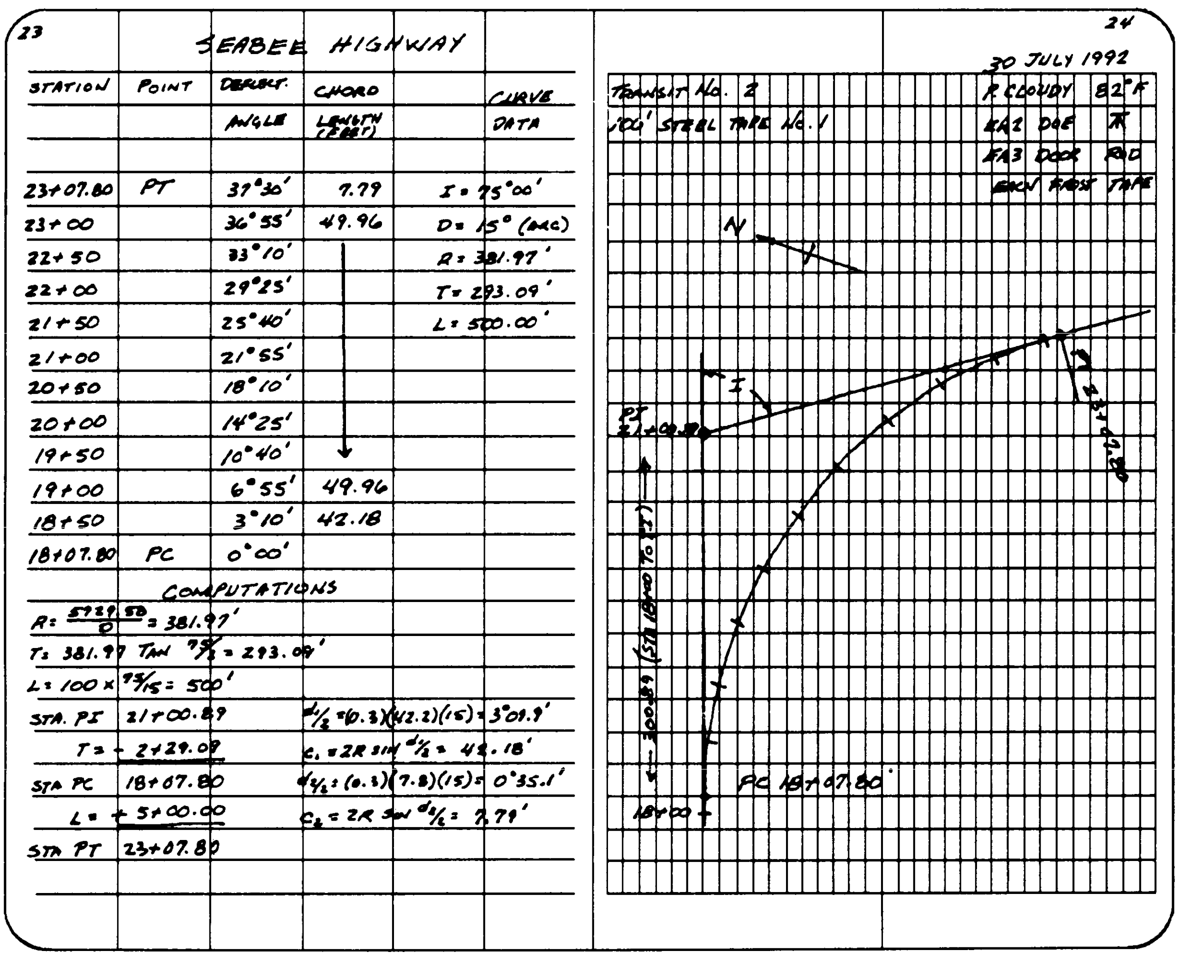


Figure 11-12.—Field notes for laying out a simple curve.

familiar enough with field notes to preclude a complete discussion of everything shown in these notes. You should notice, however, that the stations are entered in reverse order (bottom to top). In this manner the data is presented as it appears in the field when you are sighting ahead on the line. This same practice applies to the sketch shown on the right-hand page of the field notes.

For information about other situations involving inaccessible points or the uses of external and middle ordinate distance, spiral transitions, and other types of horizontal curves, study books such as those mentioned at the beginning of this chapter.

VERTICAL CURVES

In addition to horizontal curves that go to the right or left, roads also have vertical curves that go up or down. Vertical curves at a crest or the top of a hill are called **summit curves,** or **oververticals.** Vertical curves at the bottom of a hill or dip are called **sag curves,** or **underverticals.**

GRADES

Vertical curves are used to connect stretches of road that go up or down at a constant slope. These lines of constant slope are called **grade tangents** (fig. 11- 13). The rate of slope is called the **gradient,** or simply the **grade.** (Do not confuse this use of the term *grade* with other meanings, such as the design elevation of a finished surface at a given point or the actual elevation of the existing ground at a given point.) Grades that ascend in the direction of the stationing are designated as plus; those that descend in the direction of the stationing are designated as minus. Grades are measured in terms of percent; that is, the number of feet of rise or fall in a 100-foot horizontal stretch of the road.

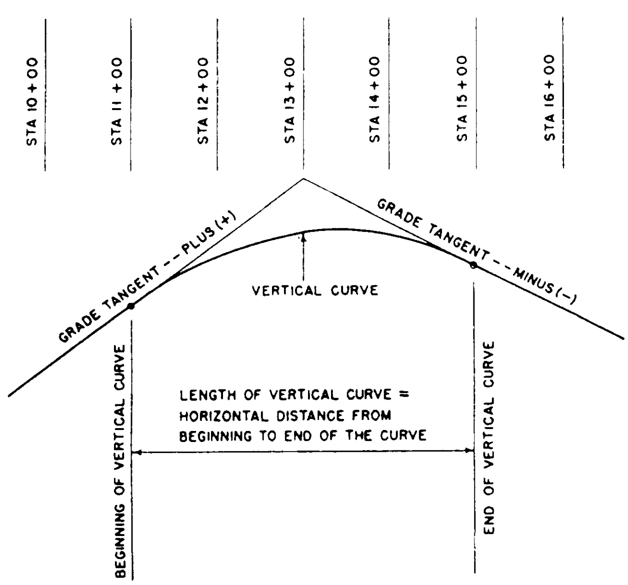


Figure 11-13.—A vertical curve.

After the location of a road has been determined and the necessary fieldwork has been obtained, the engineer designs or fixes (sets) the grades. A number of factors are considered, including the intended use and importance of the road and the existing topography. If a road is too steep, the comfort and safety of the users and fuel consumption of the vehicles will be adversely affected; therefore, the design criteria will specify **maximum grades.** Typical maximum grades are a 4-percent desired maximum and a 6-percent absolute maximum for a primary road. (The 6 percent means, as indicated before, a 6-foot rise for each 100 feet ahead on the road.) For a secondary road or a major street, the maximum grades might be a 5-percent desired and an 8-percent absolute maximum; and for a tertiary road or a secondary street, an 8-percent desired and a 10-percent (or perhaps a 12-percent) absolute maximum. Conditions may sometimes demand that grades or ramps, driveways, or short access streets go as high as 20 percent. The engineer must also consider **minimum grades.** A street with curb and gutter must have enough fall so that the storm water will drain to the inlets; 0.5 percent is a typical minimum grade for curb and gutter (that is, 1/2 foot minimum fall for each 100 feet ahead). For roads with side ditches, the desired minimum grade might be 1 percent; but since ditches may slope at a grade different from the pavement, a road may be designed with a zero-percent grade. Zero-percent grades are not unusual, particularly through plains or tidewater areas. Another factor considered in designing the finished profile of a road is the **earthwork balance;** that is, the grades should be set so that all the soil cut off of the hills may be economically hauled to fill in the low areas. In the design of urban streets, the best use of the building sites next to the street will generally be more important than seeking an earthwork balance.

COMPUTING VERTICAL CURVES

As you have learned earlier, the horizontal curves used in highway work are generally the arcs of circles. But vertical curves are usually **parabolic.** The parabola is used primarily because its shape provides a transition and, also, lends itself to the computational methods described in the next section of this chapter. Designing a vertical curve consists principally of deciding on the proper length of the curve. As indicated in figure 11-13, the length of a vertical curve is the **horizontal distance** from the beginning to the end of the curve; the length of the curve is NOT the distance along the parabola itself. The longer a curve is, the more gradual the transition will be from one grade to the next; the shorter the curve, the more abrupt the change. The change must be gradual enough to provide the required sight distance (fig. 11- 14). The sight distance requirement will depend on the speed for which the road is designed; whether passing or nonpassing distance is required; and other assumptions, such as one's reaction time, braking time, stopping distance, height of one's eyes, and height of objects. A typical eye level used for designs is 4.5 feet or, more recently, 3.75 feet; typical object heights are 4 inches to 1.5 feet. For a sag curve, the sight distance will usually not be significant during daylight; but the nighttime sight distance must be considered when the reach of headlights may be limited by the abruptness of the curve.

ELEMENTS OF VERTICAL CURVES

Figure 11-15 shows the elements of a vertical curve. The meaning of the symbols and the units of measurement usually assigned to them follow:

PVC Point of vertical curvature; the place where the curve begins.

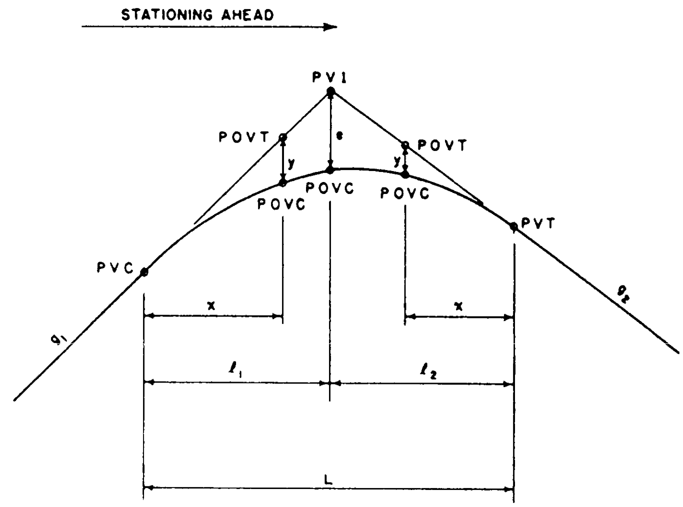


Figure 11-15.—Elements of a vertical curve.

PVI Point of vertical intersection; where the grade tangents intersect.

PVT Point of vertical tangency; where the curve ends.

POVC Point on vertical curve; applies to any point on the parabola.

POVT Point on vertical tangent; applies to any point on either tangent.

g_1 Grade of the tangent on which the *PVC* is located; measured in percent of slope.

g_2 Grade of the tangent on which the *PVT* is located; measured in percent of slope.

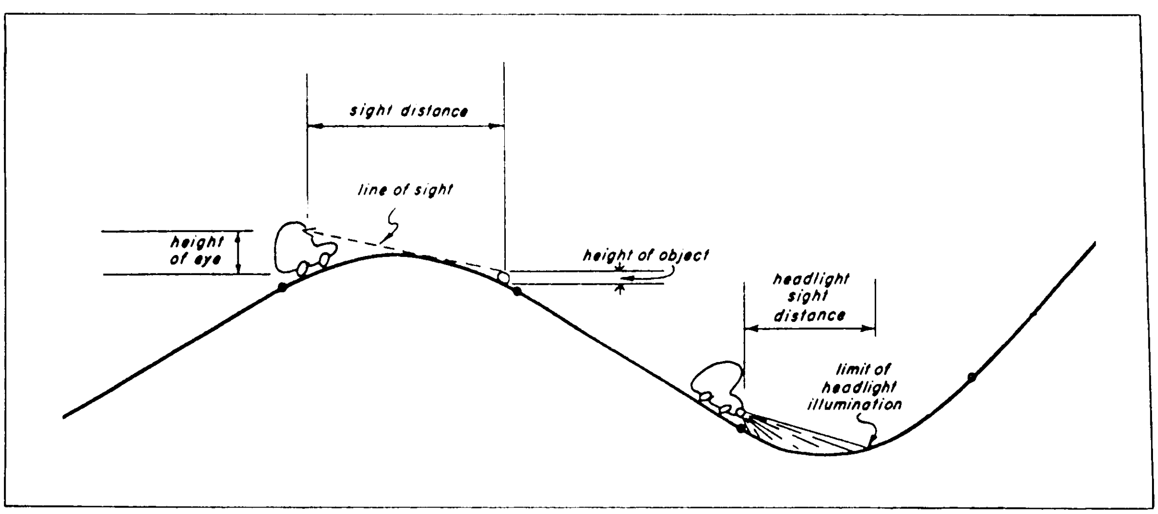


Figure 11-14.—Sight distance.

G The **algebraic difference** of the grades:

$$G = g_2 - g_1,$$

wherein plus values are assigned to uphill grades and minus values to downhill grades; examples of various algebraic differences are shown later in this section.

L Length of the curve; the **horizontal** length measured in 100-foot stations from the *PVC* to the PVT. This length may be computed using the formula ***L = G/r,*** where *r* is the rate of change (usually given in the design criteria). When the rate of change is not given, *L* (in stations) can be computed as follows: for a summit curve, **L = 125** x G/4; for a sag curve, **L = 100** x G/4. If *L* does not come out to a whole number of stations using these formulas, then it is usually extended to the nearest whole number. You should note that these formulas for length are for road design only, NOT railway.

l_1 Horizontal length of the portion of the *PVC* to the *PVI;* measured in feet.

l_2 Horizontal length of the portion of the curve form the *PVI* to the *PVT;* measured in feet.

e Vertical (external) distance from the *PVI* to the curve, measured in feet. This distance is computed using the formula e **= LG/8,** where *L* is the total length in stations and G is the algebraic difference of the grades in percent.

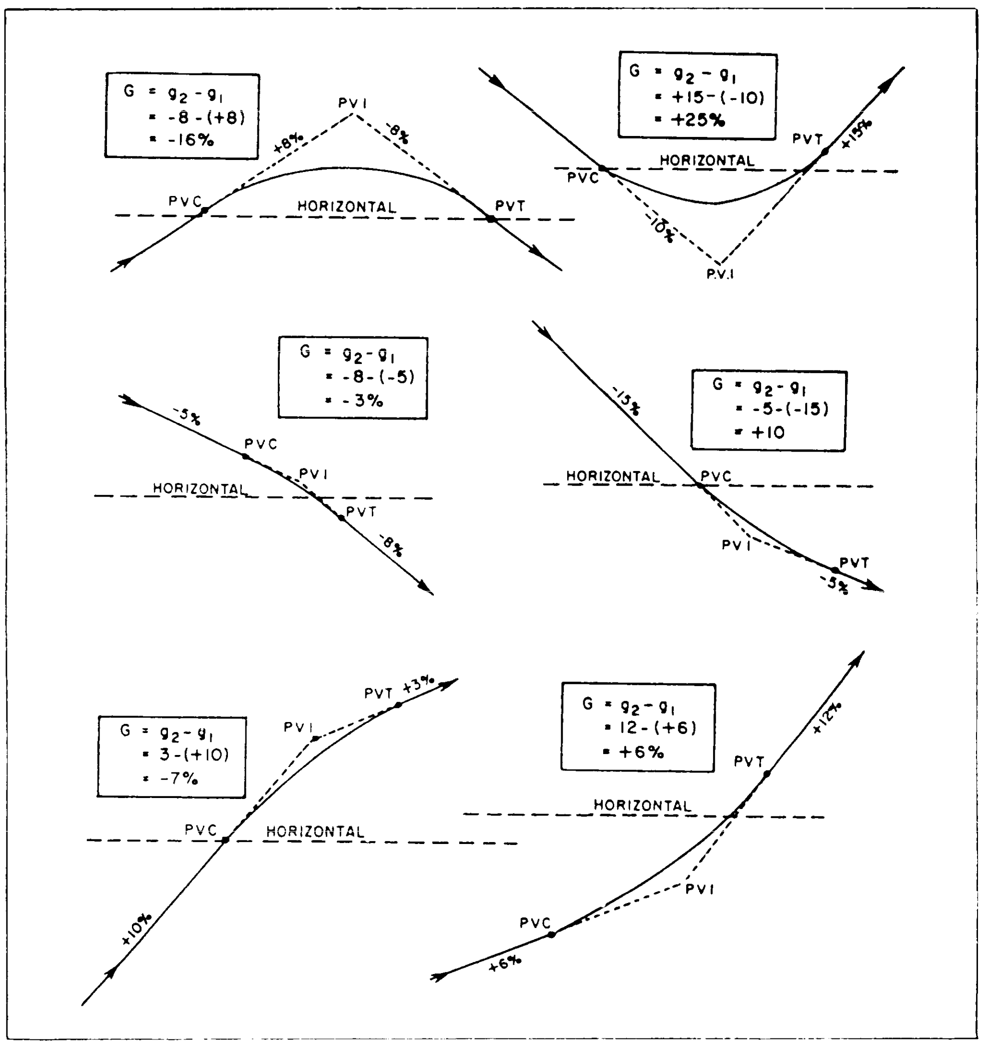


Figure 11-16.—Algebraic differences of grades.

x Horizontal distance from the *PVC* to any *POVC* or POVTback of the *PVI,* or the distance from the PVT to any *POVC* or *POVT* ahead of the *PW,* measured in feet.

y Vertical distance (offset) from any *POVT* to the corresponding *POVC,* measured in feet;

$$y = (x/l)^2(e),$$

which is the fundamental relationship of the parabola that permits convenient calculation of the vertical offsets.

The vertical curve computation takes place after the grades have been set and the curve designed. Therefore, at the beginning of the detailed computations, the following are known: g_1, g_2, l_1, l_2, L, and the elevation of the *PVI.* The general procedure is to compute the elevations of certain *POVTs* and then to use the foregoing formulas to compute G, then e, and then the *Ys* that correspond to the selected *POVTs.* When the y is added or subtracted from the elevation of the *POVT,* the result is the elevation of the *POVC.* The *POVC* is the finished elevation on the road, which is the end result being sought. In figure 11-15, the y is subtracted from the elevation of the *POVT* to get the elevation of the curve; but in the case of a sag curve, the y is added to the *POVT* elevation to obtain the *POVC* elevation.

The computation of G requires careful attention to the signs of g_1 and g_2. Vertical curves are used at changes of grade other than at the top or bottom of a hill; for example, an uphill grade that intersects an even steeper uphill grade will be eased by a vertical curve. The six possible combinations of plus and minus grades, together with sample computations of G, are shown in figure 11-16. Note that the algebraic sign for G indicates whether to add or subtract y from a *POVT.*

The selection of the points at which to compute the y and the elevations of the *POVT* and *POVC* is generally based on the stationing. The horizontal alignment of a road is often staked out on 50-foot or 100-foot stations. Customarily, the elevations are computed at these same points so that both horizontal and vertical information for construction will be provided at the same point. The *PVC, PVI,* and *PVT* are usually set at full stations or half stations. In urban work, elevations are sometimes computed and staked every 25 feet on vertical curves. The same, or even closer, intervals may be used on complex ramps and interchanges. The application of the foregoing fundamentals will be presented in the next two sections under symmetrical and unsymmetrical curves.

Symmetrical Vertical Curves

A symmetrical vertical curve is one in which the horizontal distance from the *PVI* to the *PVC* is equal to the horizontal distance from the *PW* to the *PVT.* In other words, l_1 equals l_2.

The solution of a typical problem dealing with a symmetrical vertical curve will be presented step by step. Assume that you know the following data:

g_1 = +97%

g_2 = −7%

L = 400.00′, or 4 stations

The station of the *PVI* = 30 + 00

The elevation of the *PVI* = 239.12 feet

The problem is to compute the grade elevation of the curve to the nearest hundredth of a foot at each 50-foot station. Figure 11-17 shows the vertical curve to be solved.

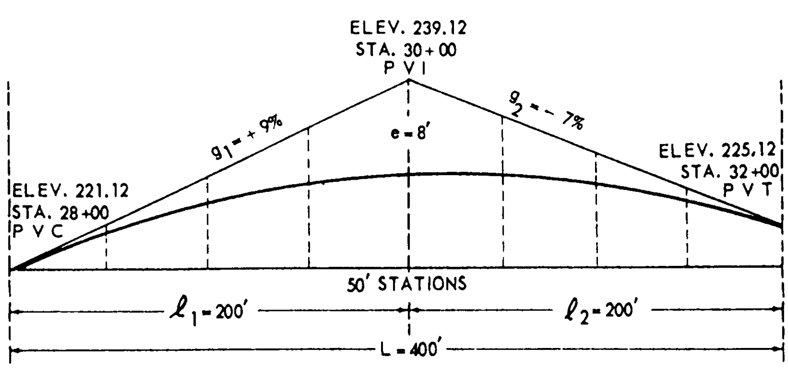


Figure 11-17.—Symmetrical vertical curve.

STEP 1: Prepare a table as shown in figure 11-18. In this figure, column 1 shows the stations; column 2, the elevations on tangent; column 3, the ratio of x/l; column 4, the ratio of $(x/l)^2$; column 5, the vertical offsets $[(x/l)^2(e)]$; column 6, the grade elevations on the curve; column 7, the first difference; and column 8, the second difference.

STEP 2: Compute the elevations and set the stations on the *PVC* and the *PVT*.

Knowing both the gradients at the *PVC* and *PVT* and the elevation and station at the *PVI,* you can compute the elevations and set the stations on the *PVC* and the *PVT*. The gradient (g_1) of the tangent at the *PVC is* given as +9 percent. This means a rise in elevation of 9 feet for every 100 feet of horizontal distance. Since *L* is 400.00 feet and the curve is symmetrical, l_1 equals l_2 equals 200.00 feet; therefore, there will be a difference of 9 x 2, or 18, feet between the elevation at the *PVI* and the elevation at the *PVC.* The elevation at the *PVI* in this problem is given as 239.12 feet; therefore, the elevation at the *PVC is*

239.12 – 18 = 221.12 feet.

Calculate the elevation at the *PVT* in a similar manner. The gradient (g_2) of the tangent at the *PVT* is given as –7 percent. This means a drop in elevation of 7 feet for every 100 feet of horizontal distance. Since l_1 equals l_2 equals 200 feet, there will be a difference of 7 x 2, or 14, feet between the elevation at the *PVI* and the elevation at the *PVT*. The elevation at the *PVI* therefore is

239.12 – 14 = 225,12 feet.

In setting stations on a vertical curve, remember that the length of the curve *(L)* is always measured as a horizontal distance. The half-length of the curve is the horizontal distance from the *PVI* to the *PVC.* In this problem, l_1 equals 200 feet. That is equivalent to two 100-foot stations and may be expressed as 2 + 00. Thus the station at the *PVC* is

30 + 00 **minus** 2 + 00, or 28 + 00.

The station at the *PVT* is

30 + 00 **plus** 2 + 00, or 32 + 00.

List the stations under column 1.

STEP 3: Calculate the elevations at each 50-foot station on the tangent.

From Step 2, you know there is a 9-foot rise in elevation for every 100 feet of horizontal distance from the *PVC* to the *PVI.* Thus, for every 50 feet of horizontal distance, there will be a rise of 4.50 feet in elevation. The elevation on the tangent at station 28 + 50 is

221.12 + 4.50 = 225.62 feet.

The elevation on the tangent at station 29 + 00 is

225.62 + 4.50 = 230.12 feet.

Stations	Elevations on tangent	x/l	$(x/l)^2$	Vertical offsets	Grade elevation on curve	First difference	Second difference
28+00 (*PVC*)	221. 12	0	0	0	221. 12		
						+4. 00	
+50	225. 62	¼	1/16	– 0. 50	225. 12		+1. 00
						+3. 00	
29+00	230. 12	½	¼	– 2. 00	228. 12		+1. 00
						+2. 00	
+50	234. 62	¾	9/16	– 4. 50	230. 12		+1. 00
						+1. 00	
30+00 (*P V I*)	239. 12	1	1	– 8. 00	231. 12		+1. 00
						. 00	
+50	235. 62	¾	9/16	– 4. 50	231. 12		+1. 00
						–1. 00	
31+00	232. 12	½	¼	– 2. 00	230. 12		+1. 00
						–2. 00	
+50	228. 62	¼	1/16	– . 50	228. 12		+1. 00
						–3. 00	
32+00 (*PVT*)	225. 12	0	0	0	225. 12		

Figure 11-18.—Table of computations of elevations on a symmetrical vertical curve.

The elevation on the tangent at station 29 + 50 is

230.12 + 4.50 = 234.62 feet.

The elevation on the tangent at station 30 + 00 is

234.62 + 4.50 = 239.12 feet.

In this problem, to find the elevation on the tangent at any 50-foot station starting at the *PVC,* add 4.50 to the elevation at the preceding station until you reach the *PVI.* At this point use a slightly different method to calculate elevations because the curve slopes downward toward the *PVT.* Think of the elevations as being divided into two groups—one group running from the *PVC* to the *PVI;* the other group running from the *PVT* to the *PVI.*

Going downhill on a gradient of –7 percent from the *PVI* to the *PVT,* there will be a drop of 3.50 feet for every 50 feet of horizontal distance. To find the elevations at stations between the *PVI* to the *PVT* in this particular problem, subtract 3.50 from the elevation at the preceding station. The elevation on the tangent at station 30 + 50 is

239.12-3.50, or 235.62 feet.

The elevation on the tangent at station 31 + 50 is

235.62-3.50, or 232.12 feet.

The elevation on the tangent at station 31 + 50 is

232.12-3.50, or 228.62 feet.

The elevation on the tangent at station 32+00 (PVT) is

228.62-3.50, or 225.12 feet,

The last subtraction provides a check on the work you have finished. List the computed elevations under column 2.

STEP 4: Calculate *(e),* the middle vertical offset at the *PVI.*

First, find the *(G),* the algebraic difference of the gradients using the formula

$$G = g_2 - g_1$$
$$G = -7 - (+9)$$
$$G = -16\%$$

The middle vertical offset *(e)* is calculated as follows:

$$e = LG/8 = [(4)(-16)]/8 = -8.00 \text{ feet.}$$

The negative sign indicates e is to be subtracted from the *PVI.*

STEP 5: Compute the vertical offsets at each 50-foot station, using the formula $(x/l)^2e$. To find the vertical offset at any point on a vertical curve, first find the ratio x/l; then square it and multiply by *e;* for example, at station 28 + 50, the ratio of $x/l = 50/200 = 1/4$.

Therefore, the vertical offset is

$$(1/4)^2 e = (1/16)\, e.$$

The vertical offset at station 28 + 50 equals

$$(1/16)(-8) = -0.50 \text{ foot.}$$

Repeat this procedure to find the vertical offset at each of the 50-foot stations. List the results under columns 3, 4, and 5.

STEP 6: Compute the grade elevation at each of the 50-foot stations.

When the curve is on a crest, the sign of the offset will be negative; therefore, subtract the vertical offset (the figure in column 5) from the elevation on the tangent (the figure in column 2); for example, the grade elevation at station 29 + 50 is

234.62 – 4.50 = 230.12 feet.

Obtain the grade elevation at each of the stations in a similar manner. Enter the results under column 6.

Note: When the curve is in a dip, the sign will be positive; therefore, you will **add** the vertical offset (the figure in column 5) to the elevation on the tangent (the figure in column 2).

STEP 7: Find the turning point on the vertical curve.

When the curve is on a crest, the turning point is the highest point on the curve. When the curve is in a dip, the turning point is the lowest point on the curve. The turning point will be directly above or below the *PVI* only when both tangents have the same percent of slope (ignoring the algebraic sign); otherwise, the turning point will be on the same side of the curve as the tangent with the least percent of slope.

The horizontal location of the turning point is either measured from the *PVC* if the tangent with the lesser slope begins there or from the *PVT* if the tangent with the lesser slope ends there. The horizontal location is found by the formula:

$$x_t = \frac{gL}{G}$$

Where:

x_t = distance of turning point from *PVC* or *PVT*

g = lesser slope (ignoring signs)

L = length of curve in stations

G = algebraic difference of slopes.

For the curve we are calculating, the computations would be (7 x 4)/16 = 1.75 feet; therefore, the turning point is 1.75 stations, or 175 feet, from the *PVT* (station 30 + 25).

The vertical offset for the turning point is found by the formula:

$$y_t = \left(\frac{x_t}{l}\right)^2 e.$$

For this curve, then, the computation is $(1.75/2)^2 \times 8 =$ 6.12 feet.

The elevation of the *POVT* at 30 + 25 would be 237.37, calculated as explained earlier. The elevation on the curve would be

$$237.37 - 6.12 = 231.25.$$

STEP 8: Check your work.

One of the characteristics of a symmetrical parabolic curve is that the second differences between successive grade elevations at full stations are constant. In computing the first and second differences (columns 7 and 8), you must consider the plus or minus signs. When you round off your grade elevation figures following the degree of precision required, you introduce an error that will cause the second difference to vary slightly from the first difference; however, the slight variation does not detract from the value of the second difference as a check on your computations. You are cautioned that the second difference will not always come out exactly even and equal. It is merely a coincidence that the second difference has come out exactly the same in this particular problem.

Unsymmetrical Vertical Curves

An unsymmetrical vertical curve is a curve in which the horizontal distance from the *PVI* to the *PVC* is different from the horizontal distance between the *PVI* and the *PVT*. In other words, l_1 does NOT equal l_2. Unsymmetrical curves are sometimes described as having unequal tangents and are referred to as dog legs. Figure 11-19 shows an unsymmetrical curve with a horizontal distance of 400 feet on the left and a horizontal distance of 200 feet on the right of the *PVI*. The gradient of the tangent at the *PVC* is –4 percent; the gradient of the tangent at the *PVT* is +6 percent. Note that the curve is in a dip.

As an example, let's assume you are given the following values:

Elevation at the *PVI* is 332.68

Station at the *PVI* is 42 + 00

l_1 is 400 feet

l_2 is 200 feet

g_1 is –4%

g_2 is +6%

To calculate the grade elevations on the curve to the nearest hundredth foot, use figure 11-20 as an example.

Figure 11-20 shows the computations. Set four 100-foot stations on the left side of the *PVI* (between the *PVI* and the *PVC*). Set four 50-foot stations on the right side of the *PVI* (between the *PVI* and the *PVT*). The procedure for solving an unsymmetrical curve problem is essentially the same as that used in solving a symmetrical curve. There are, however, important differences you should be cautioned about.

First, you use a different formula for the calculation of the middle vertical offset at the *PVI*. For an unsymmetrical curve, the formula is as follows:

$$e = \frac{l_1 l_2}{2(l_1 + l_2)}(g_2 - g_1).$$

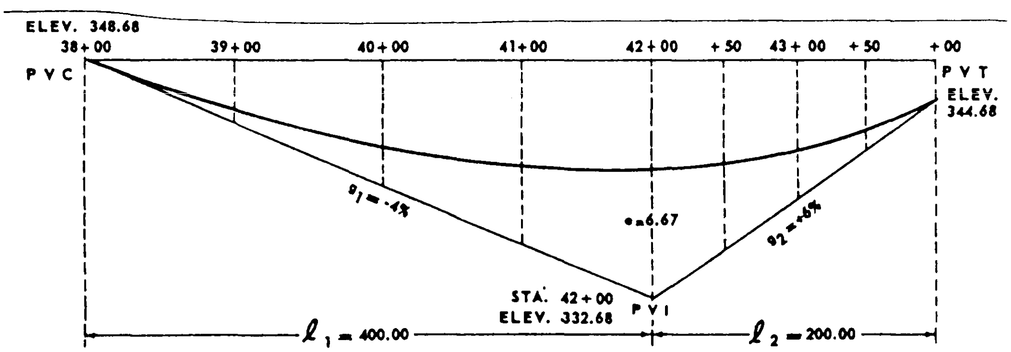


Figure 11-19.—Unsymmetrical vertical curve.

Col. 1 Stations	Col. 2 Elevations on tangent	Col. 3 x/l	Col. 4 $(x/l)^2$	Col. 5 Vertical offsets	Col. 6 Grade elevation on curve	
38+00 (*PVC*)	348. 68	0	0	0	348. 68	100 foot stations.
39+00	344. 68	¼	1/16	+ .42	345. 10	
40+00 ($g_1 = -4\%$)	340. 68	½	¼	+ 1. 67	342. 35	
41+00	336. 68	¾	9/16	+ 3. 75	340. 43	
42+00 (*PVI*)	332. 68	1	1	+ 6. 67	339. 35	50 foot stations.
42+50	335. 68	¾	9/16	+ 3. 75	339. 43	
43+00 ($g_2 = +6\%$)	338. 68	½	¼	+ 1. 67	340. 35	
43+50	341. 68	¼	1/16	+ .42	342. 10	
44+00 (*PVT*)	344. 68	0	0	0	344. 68	

Figure 11-20.—Table of computations of elevations on an unsymmetrical vertical curve.

In this example, then, the middle vertical offset at the *PVI* is calculated in the following manner:

$e = [(4 \times 2)/2(4 + 2)] \times [(+6) - (-4)] = 6.67$ feet.

Second, you are cautioned that the check on your computations by the use of second difference does NOT work out the same way for unsymmetrical curves as for a symmetrical curve. The second difference will not check for the differences that span the *PVI.* The reason is that an unsymmetrical curve is really two parabolas, one on each side of the *PVI,* having a common *POVC* opposite the *PVI;* however, the second difference will check out back, and ahead, of the first station on each side of the *PVI.*

Third, the turning point is not necessarily above or below the tangent with the lesser slope. The horizontal location is found by the use of one of two formulas as follows:

from the *PVC*

$$x_t = \frac{(l_1)^2 g_1}{2e}$$

or from the *PVT*

$$x_t = \frac{(l_2)^2 g_2}{2e}.$$

The procedure is to estimate on which side of the *PVI* the turning point is located and then use the proper formula to find its location. If the formula indicates that the turning point is on the opposite side of the *PVI,* you must use the other formula to determine the correct location; for example, you estimate that the turning point is between the *PVC* and *PVI* for the curve in figure 11-19. Solving the formula:

$x_t = (l_1)^2(g_1)/2e$

$x_t = [(4)^2(4)]/(2 \times 6.67) = 4.80$, or Station 42 + 80.

However, Station 42 + 80 is between the *PVI* and *PVT;* therefore, use the formula:

$x_t = (l_2)^2(g_2)//2e$

$x_t = [(2)^2(6)]/(2 \times 6.67) = 1.80$, or station 42 + 20.

Station 42 + 20 is the correct location of the turning point. The elevation of the *POVT,* the amount of the offset, and the elevation on the curve is determined as previously explained.

CHECKING THE COMPUTATION BY PLOTTING

Always check your work by plotting the grade tangents and the curve in profile on an exaggerated vertical scale; that is, with the vertical scale perhaps 10 times the horizontal scale. After the POVCs have been plotted, you should be able to draw a smooth parabolic curve through the points with the help of a ship's curve or some other type of irregular curve; if you can't, check your computations.

USING A PROFILE WORK SHEET

After you have had some experience computing curves using a table as shown in the foregoing examples, you may wish to eliminate the table and write your computations directly on a working print of the profile. The engineer will set the grades and indicate the length of the vertical curves. You may then scale the *PVI* elevations and compute the grades if the engineer has not done so. Then, using a calculator, compute the *POVT* elevations at the selected stations. You can store the computations in some calculators. That allows you access to the grades, the stations, and the elevations stored in the calculator from one end of the profile to the other. You can then check the calculator at each previously set *PVI* elevation. Write the tangent elevation at each station on the work sheet. Then compute each vertical offset: mentally note the $x/1$ ratio; then square it and multiply by e on your calculator. Write the offset on the work print opposite the tangent elevation. Next, add or subtract the offsets from the tangent elevations (either mentally or on the calculator) to get the curve elevations; then record them on the work sheet. Plot the POVC elevations and draw in the curve. Last, put the necessary information on the original tracing. The information generally shown includes grades; finished elevations; length of curve; location of *PVC, PVI, PVT,* and the *e.* Figure 11-21 shows a portion of a typical work sheet completed up to the point of drawing the curve.

FIELD STAKEOUT OF VERTICAL CURVES

The stakeout of a vertical curve consists basically of marking the finished elevations in the field to guide the construction personnel. The method of setting a grade stake is the same whether it is on a tangent or on a curve, so a vertical curve introduces no special problem. As indicated before, stakes are sometimes set closer together on a curve than on a tangent. But that will usually have been foreseen, and the plans will show the finished grade elevations at the required stations. If, however, the field conditions do require a stake at an odd plus on a curve, you may compute the needed *POVC* elevation in the field using the data given on the plans and the computational methods explained in this chapter.

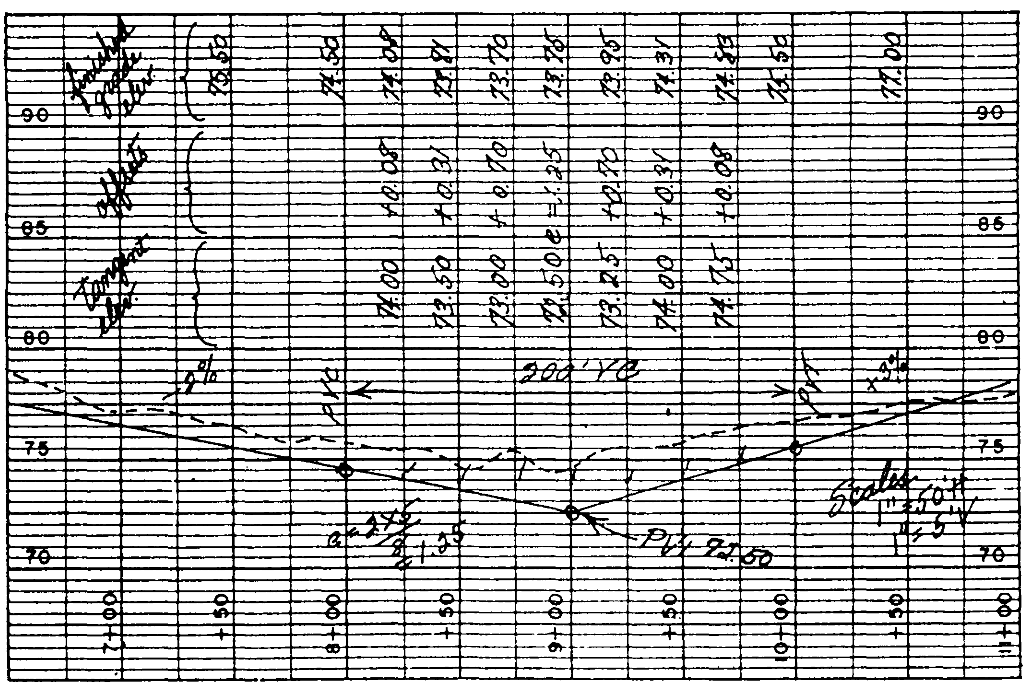


Figure 11-21.—Profile work sheet.

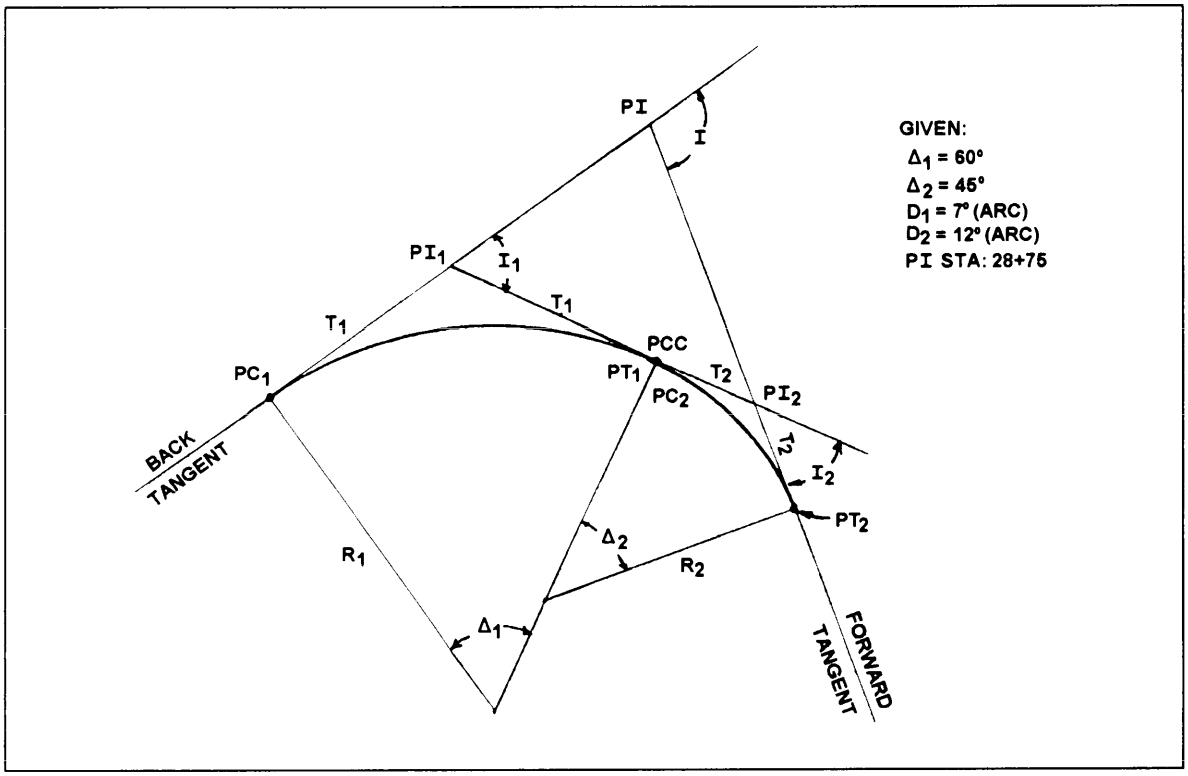


Figure 11-22.—Compound curve.

QUESTIONS

Q1. Using the data given for the compound curve shown in figure 11-22, compute the stations at PC_1, PI_1, PCC (point of compound curvature), PI_2, and PT_2.

Q2. Referring again to figure 11-22, assume that you are tasked to stakeout the compound curve using full stations. What deflection angles (d_1, d_2, and d) and chord lengths (C_1, C_2, and C) will you use for the 12° curve?

Q3. Assume that you are to set half stations for a 400-foot symmetrical vertical curve. The tangents (g_1 = + 3.2 percent, g_2 = –1.6 percent) intersect at Station 14 + 00. The tangent elevation at the PVI is 131.20 feet. Compute the following information for this curve:

a. Elevation at the PVC
b. Elevation at the PVT
c. Grade elevation on the curve at the PVI
d. Grade elevation on the curve at station 13 + 50
e. Station number and grade elevation on the curve at the turning point

Q4. Assume that you are to set half stations for a 600-foot vertical curve. The tangents (g_1 = –3 percent, g_2 = –8 percent) intersect at Station 15 + 00, which has an elevation of 640 feet above mean sea level. You may also assume that l_1 = 400 feet and l_2 = 200 feet. Compute the following information for this curve:

a. Elevation at the PVC
b. Elevation at the PVT
c. Grade elevation on the curve at the PVI
d. Grade elevation on the curve at station 13 + 50
e. Station number and grade elevation on the curve at the turning point

CHAPTER 12

ELECTRONIC SURVEYING EQUIPMENT

Chapter 12 of the EA3 TRAMAN introduced you to electronic surveying equipment, specifically electronic distance-measuring equipment. This chapter is intended to supplement what you learned in the EA3 TRAMAN discussion, and, in addition, introduces you to the basic principles and uses of other types of electronic surveying equipment.

As a rule, the EA seldom has the need or opportunity to use any of the equipment discussed in this chapter; however, when the need and occasion arise, the EA should have at least a basic familiarity with the different electronic equipment used in surveying. This chapter provides that familiarization.

ELECTRONIC DISTANCE-MEASURING (EDM) EQUIPMENT

When electronically determining the straight-line distance (horizontal or slope) between two points or stations, you use equipment that (1) sends an electronic impulse of known velocity or rate of speed and (2) measures the time it takes for the impulse to travel the length of the interval between the points. Then, by using the well-known equation of distance = rate x time, the length of the interval is determined.

Two types of electronic distance meters (simply referred to as EDMs) are commonly used. They are the **electromagnetic** (microwave) instruments and the **electro-optical** (light wave) instruments. In this section, we will briefly discuss both types of instruments; however, since there are many different makes and models of EDMs on the market and since you should always study the manufacturer's operating instructions before you try to use the equipment, only the basic principles of the operation and use of EDM equipment is covered. For in-depth discussions of EDM principles, you should read publications, such as *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail.

ELECTROMAGNETIC (MICROWAVE) EDM INSTRUMENTS

Electromagnetic EDMs, first developed in the 1950s, use high-frequency radio waves. The first generation of this equipment was very precise for measuring long distances; however, it was too bulky and heavy for the practicing surveyor's needs. Over the years, the equipment has undergone rapid improvement to the extent that modern electromagnetic EDMs are smaller, more portable, and are being equipped with direct readout capability.

When used, two identical and interchangeable instruments, such as shown in figure 12-1, are setup at both ends of the line that you are measuring. This line must be unobstructed, but intervisibility is not required; so, you can make observations in fog or during other unfavorable weather conditions. As illustrated in figure 12-2, the sending (master) instrument transmits a series of modulated radio waves to the receiving (remote) instrument. The remote instrument interprets these signals and sends them back to the master unit that measures the time required for the radio waves to make the round trip. The distance is computed based on the velocity of the radio waves. Because this velocity is affected by atmospheric conditions, corrections for temperature and barometric pressure are applied according to the operating instructions provided with the equipment.

ELECTRO-OPTICAL (LIGHT WAVE) EDM INSTRUMENTS

Electro-optical EDMs use the velocity of light waves to determine the distance between two points. The earliest of these instruments, typified by the Geodimeter, was developed during the same decade as the electromagnetic EDMs. Figure 12-3 shows an example of a Geodimeter. Like the electromagnetic instruments, the first generation of electro-optical instruments were heavy, bulky, and not well suited to the needs of the practicing surveyor; however, through later development, modern electro-optical EDMs are smaller, lighter, easier to use, and require less power. Modern short-range instruments have ranges from 0.3 miles to 3 miles. Longer range instruments, using coherent laser light, have ranges from 50 feet to 36 miles.

To use an electro-optical EDM, you set up the instrument at one end of the line being measured and a

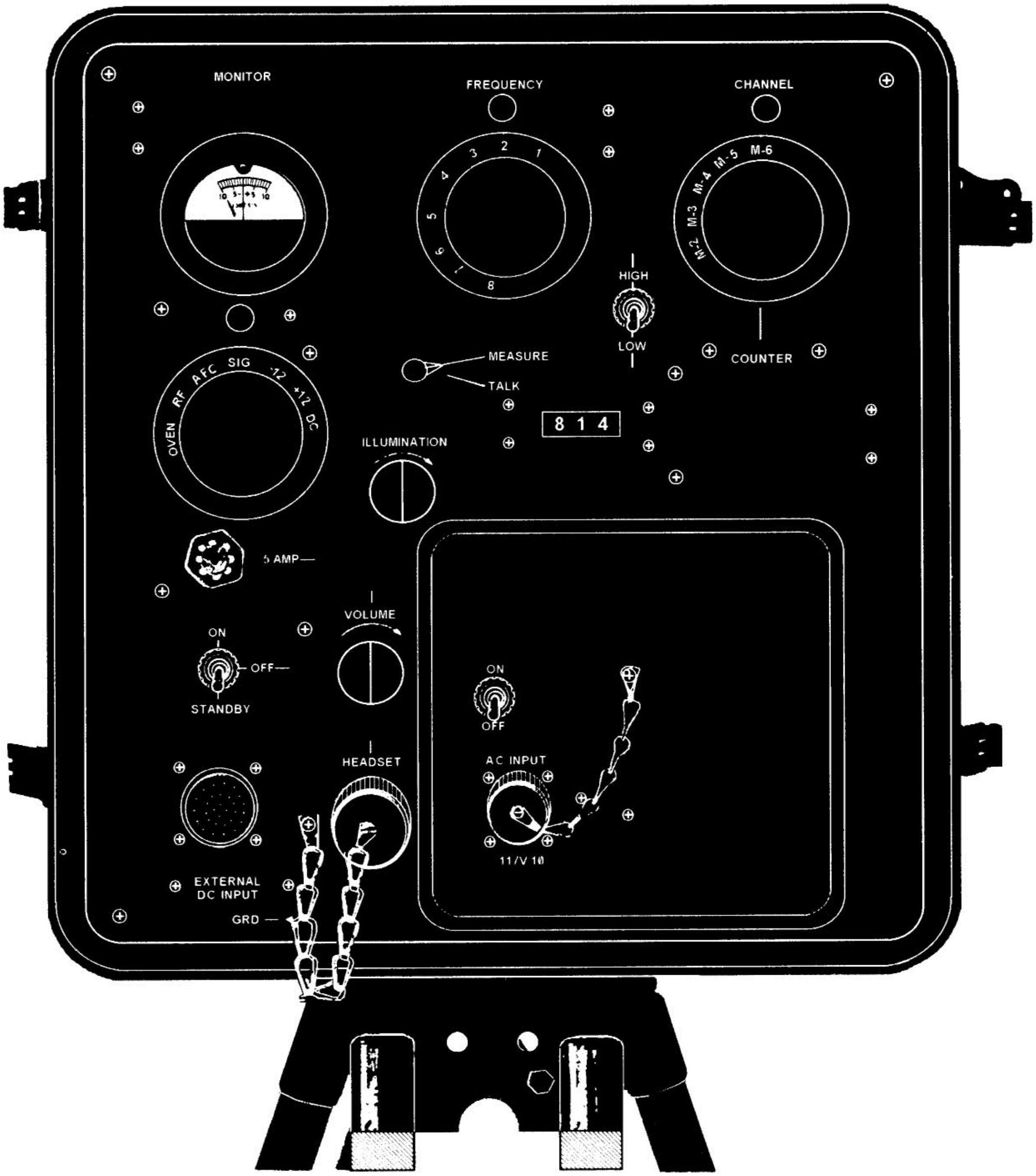


Figure 12-1.—An electromagnetic distance-measuring instrument.

reflector at the other end of the line. As with the electromagnetic EDM, the line must be free of obstacles; however, unlike using the electromagnetic device, the stations at both ends of the line must also be intervisible. After setup, the EDM sends a modulated beam of light to the reflector that, acting like a mirror, returns the light pulse back to the EDM. When the instrument receives the reflected light flash, it registers readings that are converted into linear distance between the EDM and the reflector (with corrections made for atmospheric conditions).

DIRECTION OF EDM MEASURED LINES

As you can see from the above discussion, an EDM transmitter, by itself, is useful for determining only the length of a line. So, how is both the length and direction of a line determined when EDM equipment is used? With some of the older models of EDMs, distance and direction are determined by separate setups of an EDM and a theodolite over the same station. In more recent EDM systems, the EDM transmitter is mounted on the theodolite or is built into the theodolite.

Figure 12-2.—Electromagnetic distance-measuring equipment in use.

REDUCTION OF SLOPE DISTANCE

As you learned in the EA3 TRAMAN, to reduce the slope distance of a line to horizontal distance, you need to know either the vertical angle of the line measured from the instrument or the difference in elevation between the ends of the line. With that information you can use the equations that you studied in chapter 12 of the EA3 TRAMAN to reduce the slope distance. As applied to chaining or transit-tape operations, the calculations are simple; however, as applied to EDM operations, the procedures are frequently a little more complicated, as you will see below. The methods of slope reduction that we will discuss in this chapter should be used only for slope distances that are less than 2 miles in length or for observed vertical angles that are less than 5 degrees. For a discussion of slope reduction when distances of over 2 miles or vertical angles greater than 5 degrees are encountered, you should study commercial publications, such as *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail.

Slope Reduction Using the Vertical Angle

When the slope distance and the vertical angle are obtained from separate setups of an EDM and a theodolite, additional information is required for reducing the slope distance. This information includes the heights above the ground (h.i.) of the EDM transmitter and the reflector or remote unit, the h.i. of

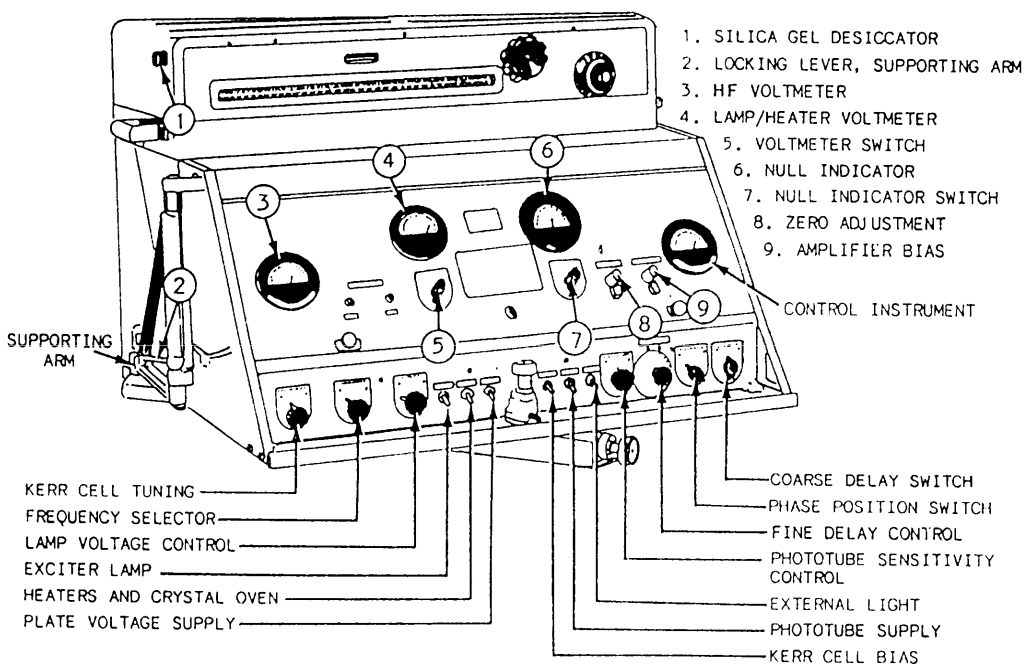


Figure 12-3.—An electro-optical distance-measuring instrument (Geodimeter).

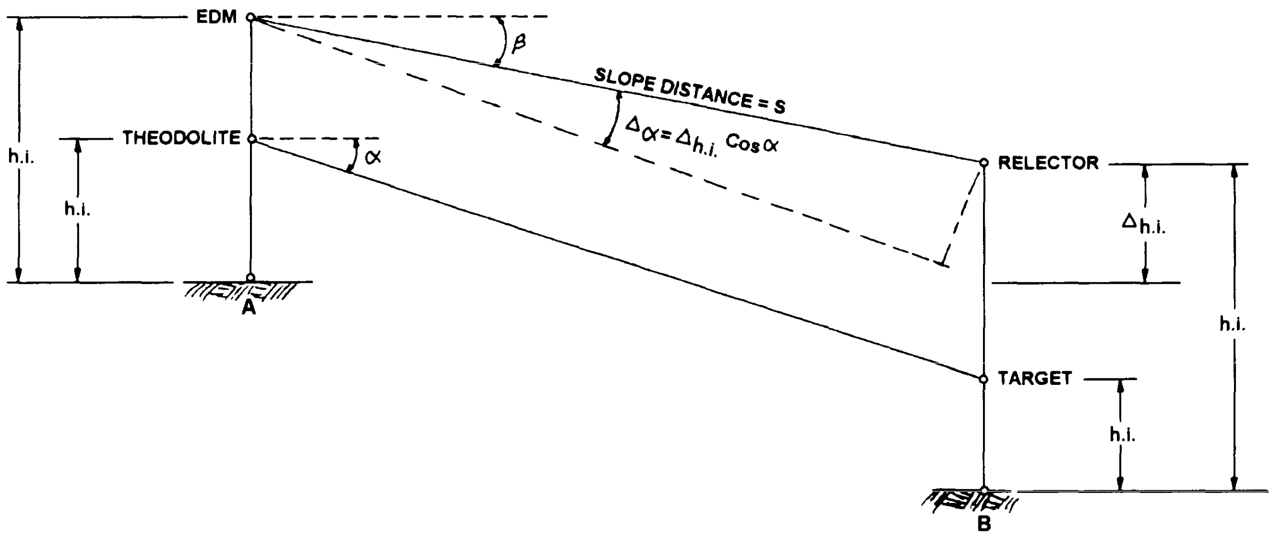


Figure 12-4.—Slope reduction using vertical angle and slope distance.

the theodolite, and the h.i. of the target. These differing heights of the equipment must be considered in the computations since they result in a correction that must be applied to the observed vertical angle before the slope distance can be reduced.

Figure 12-4 illustrates the situation in which the slope distance and vertical angle are obtained from separate setups of an EDM and a theodolite. In the figure, the EDM transmitter, reflector, theodolite, and target are each shown at their respective h.i. above the ground. Angle α is the observed vertical angle and Δ_α is the correction that must be calculated to determine the corrected vertical angle, ß, of the measured line. To reduce the slope distance, *s,* we must first make adjustment for the differing heights of the equipment. This adjusted difference in instrument heights ($A_{h.i.}$) can be calculated as follows:

$$\Delta_h = (h.i.\ reflector - h.i.\ target) - (h.i.\ EDM - h.i.\ theodolite).$$

With $\Delta_{h.i.}$ known, you can now solve for Δ_α that is needed to determine the corrected vertical angle. You can determine Δ_α as follows:

$$\Delta_\alpha = \frac{\Delta_{h.i.} \cos \alpha}{s \times (4.848 \times 10^{-6})}.$$

Now, solve for corrected vertical angle, ß, by using the formula:

$$\beta = \alpha + \Delta_\alpha.$$

NOTE: The sign of Δ_α is a function of the sign of the difference in h.i., which can be positive or negative. You should exercise care in calculating ß so as to reflect the proper sign of α, Δ and Δ_α.

Finally, you can reduce the slope distance, *s,* to the horizontal distance, *H,* by using the following equation:

$$H = s \cos \beta.$$

To understand how the above equations are used in practice, let's consider an example. Let's assume that the slope distance, *s,* from stations *A* to *B* (corrected for meteorological conditions and EDM system constants) is 2,762.55 feet. The EDM transmitter is 5.52 feet above the ground, and the reflector is 6.00 feet above the ground. The observed vertical angle is–4°30′00". The theodolite and target are 5.22 feet and 5.40 feet above the ground, respectively. Our job is to calculate the horizontal distance. To solve this problem, we proceed as follows:

$$\Delta_{h.i.} = (6.00 - 5.40) - (5.52 - 5.22) = 0.30 \text{ feet}$$

$$\Delta_\alpha = (0.30 \cos -4°30'30'')/[(2{,}762.55)(4.848 \times 10^{-6})] = 22.33''$$

$$\beta = -4°30'00'' + 0°00'22.33'' = -4°29'37.67''$$

$$H = 2{,}762.55 \cos -4°29'37.67'' = 2{,}754.04 \text{ feet.}$$

The above example is typical of situations in which the slope distance and the vertical angle are observed using separate setups of an EDM and a theodolite over the same station. Several models of the modern

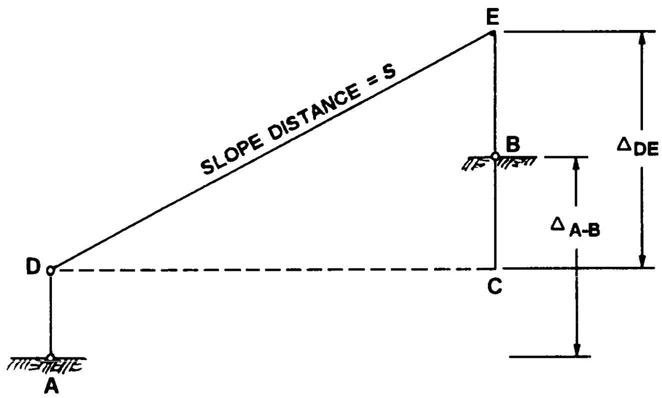


Figure 12-5.—Slope reduction using difference in elevation.

electro-optical systems, however, have the EDM transmitter built into the theodolite. In this way, the vertical angle and the slope distance can be observed simultaneously. In some of these models, there is a vertical offset between the electrical center of the transmitter and the optical center of the theodolite. Also, the height of the EDM reflector may not be at the same height as the target used to observe the vertical angle. For these conditions, you still need to consider these vertical offsets in the reamer described above.

Slope Reduction Using the Difference in Elevation Between End Points

Now let's refer to figure 12-5 to see how to reduce a slope distance using the difference in elevation between two stations.

In figure 12-5, the EDM transmitter is located at station *A* and has an h.i. equal to *AD*. The reflector, at station *B*, has an h.i. equal to *BE*. The ground elevations at *A* and *B* are known and the difference between these elevations is designated Δ_{A-B}. To reduce the slope distance, *s*, you first determine the difference in elevation between *D* and *E*. This can be done using the following equation:

$$\Delta_{DE} = \Delta_{A-B} - AD + BE.$$

In other words, $\Delta_{DE} = \Delta_{A-B}$ – h.i. of EDM + h.i. of reflector.

Now, looking again at figure 12-5, you see that *CDE* is a right triangle; therefore, since the slope distance was observed and recorded using the EDM, and having calculated A_{DE}, the horizontal distance, *CD*, can be simply determined using the Pythagorean theorem.

ELECTRONIC POSITIONING SYSTEMS

Three classes of modern positioning systems are used to determine positions on the surface of the earth. Two of the classes are the **initial positioning systems** and the **doppler positioning systems.** The initial positioning systems require experience with navigational systems on board aircraft, and the doppler systems deal with signals received from satellites. Both systems are beyond the scope of our discussions; however, the doppler positioning systems will be discussed briefly at the EA1 level in part 2 of this TRAMAN. The third class of positioning systems is the electronic positioning systems.

Electronic positioning systems consist of specially designed short-to-medium range EDMs that are attached to, or built into, a theodolite and can be used to determine distances and directions from a single setup of the instrument. Although many different electronic positioning systems are manufactured, each individual instrument is classed into one of three general groups as follows:

1. **Combined theodolite and EDM.** Instruments within this group consists of an optical-reading repeating or direction theodolite with an attached EDM transmitter that can be removed for independent use of the theodolite.

2. **Computerized theodolite and EDM.** The instruments in this group are similar to those within the combined theodolite and EDM group but have built-in electronic computers.

3. **Electronic tachometers.** The equipment in this integrated, digitized, electronic systems consist of a digitized theodolite, microprocessor, and EDM transmitter incorporated into one instrument. The instruments in this group also can be equipped with solid-state memory and magnetic tape or punched-paper-tape storage units for storage of data.

The above systems can be applied to nearly any type of surveying that is discussed in this or the EA3 TRAMAN; however, for the normal day-to-day work that the EA surveyor performs, you will have little need for these types of instruments since most of the surveys you perform require only lower-order precision. When its use is justified, however, an electronic tachometer is available as augment equipment for the Naval Mobile Construction Battalions. The equipment consists of an electronic digitized theodolite, an EDM unit, a microprocessor, a keyboard and display register, and a data storage unit. By inputting certain controlling data,

Figure 12-6.—Rotating laser level.

such as temperature and atmospheric pressure that the built-in atmospheric correction system needs, and by proper manipulation of the instrument controls, the operator can obtain horizontal angles, vertical angles, slope distances, horizontal distances, relative elevation, and coordinates of an unknown point. The data obtained is displayed through a liquid crystal display and can be transmitted and stored in a separate data collector. Complete operating instructions are provided with the tacheometer.

LASER EQUIPMENT

Laser light is of a single color, the light waves are in step with each other, and the light beam spreads only slightly as the distance from the light generator to the target increases. These characteristics make the laser useful for surveying equipment used in various types of construction layout. Although a wide variety of special-purpose laser instruments are manufactured, most of these have been designed for construction layout and are classified into two general groups as follows:

1. **Single-beam laser alignment instruments.** These instruments project a single beam of light that is visible on targets under all lighting conditions. Included in this group are laser equipped theodolites and transits, and lasers used for alignment of pipes, drains, and tunneling equipment.

2. **Rotating laser levels.** These are instruments in which the laser beam is rotated by rapidly spinning optics to provide a reference plane in space over open areas.

SINGLE-BEAM LASER ALIGNMENT INSTRUMENTS

A typical single-beam laser alignment instrument can be mounted on a transit-like framework with horizontal and vertical motions, a spirit level that is parallel to the axis of the laser, and both vertical and horizontal circles. A telescope is attached to the laser housing to allow the operator to sight the location of the transmitted laser spot. A separate fanning lens, when attached, allows the laser beam to be converted to a horizontal or vertical line instead of a spot.

ROTATING LASER LEVEL

A self-leveling, rotating laser is shown in figure 12-6. In this instrument, the laser unit is mounted vertically on a platform containing two orthogonally mounted sensors that act like spirit levels and deviate from center when the platform is not level. The amount of deviation is detected electronically, and the

Figure 12-7.—Laser-level rod equipped with a laser detector.

consequent electrical impulses drive servomotors that automatically level the base and make the axis of the laser vertical. The laser beam is emitted at an angle 90 degrees to the axis of the laser by an optical train, and the optics rotate to form a horizontal reference plane. This device also can be side-mounted so the axis of the laser is in a horizontal position, and a vertical plane can be formed by the rotating beam. An electronic sensing device, parallel to the axis of the laser, allows self-plumbing of the rotating beam. The instrument is self-leveling and self-plumbing within a range of 8 degrees. Beyond 8 degrees, it will not operate. This is a safety feature. The tolerance specified for the position of the reference plane with respect to true level or true vertical is 20 seconds of arc. Thus, in a distance of 330 feet, a deviation of 0.03 feet is possible.

Laser Rod

A laser rod equipped with a laser detector (fig. 12-7) contains a sliding battery-powered sensor on the front face of the rod. When within 0.45 feet above or below the rotating laser beam, this sensor locks onto the beam and emits a beep that indicates that a reading should be taken. The operator then reads the rod directly to the nearest 0.01 feet.

There are two modes for the sensor: the **lock** mode and the **float** mode. The lock mode means the sensor will seek the beam, average the position of the beam, and then lock onto it, giving a beep to alert the operator to read the scale. The float mode enables the sensor to fix on the laser beam and continue reading the beam, as the rod is moved up and down. The lock mode is used for normal leveling and determination of elevation or position. The float mode is useful when forms or stakes must be adjusted. The sensor is controlled by a mode switch at the top of the rod.

Uses and Advantages of the Laser Plane

Some uses and advantages of the laser plane areas follows:

1. The laser plane replaces the horizontal line of sight of the engineer's level, and the laser beam replaces a string line.

2. The operation of setting a grade stake to a given elevation is the same as using an engineer's level, except that there is no need for instructions from the operator of the instrument.

3. It is not necessary to have an operator stationed at the instrument when you desire to get on line or obtain a rod reading.

4. When a laser target is properly attached to a machine used in operations, such as grading, paving,

Figure 12-8.—Grading machine controlled by laser level and laser detector.

and tunneling, the operator of the machine can stay on the proper alignment and grade. Figure 12-8 shows a laser level mounted on a tripod and a power grader with laser detectors mounted on each end of the blade.

5. The laser level shuts off when the laser beam deflects from horizontal.

6. It increases the number of rod readings, as each rodman can set elevations without waiting for the instrumentman, thereby increasing the area of survey within a given time frame.

QUESTIONS

Q1. What two general types of electronic distance meters are in common use?

Q2. Assume that you have used an EDM to measure the slope distance from points A to B and that you observed the vertical angle using a separate theodolite. The slope distance is 730.65 meters and the observed vertical angle is 3°25´30´´. The recorded heights above the ground for the EDM, reflector, theodolite, and target are 1.75 meters, meters, 1.60 meters, and 1.70 meters, respectively. Calculate the horizontal distance.

Q3. You are using a specially designed short-range EDM mounted on an optical-reading repeating theodolite to locate the position of a point. To what class of positioning systems does your instrument belong?

Q4. For normal leveling operations, in what mode should the laser detector on your laser rod be set?

CHAPTER 13

MATERIALS TESTING

As you know by now, materials testing is a major part of an EAs responsibilities, especially for those EAs assigned to the Seabee construction battalions. The EA3 TRAMAN introduced you to the subject of materials testing. In that TRAMAN, you learned many of the basic soils and concrete tests that an EA performs. This chapter furthers your knowledge of the subject area.

In this chapter you will be introduced to several soils tests that the EA2 is expected to perform. You will study the constituent ingredients used in the production of concrete and will be introduced to many different procedures for testing those ingredients. You will learn about the tests used for concrete mixture design purposes and for determining the strength of concrete. Also, you will study bituminous materials, learn about methods used to test those materials, and will be introduced to various tests used in the design of bituminous pavement mixtures.

Although some of the tests discussed in this chapter are covered in seemingly thorough detail, it is not the intent of this TRAMAN to teach you how to perform the tests; instead, you will learn the purpose and principles of the tests, but only the fundamental procedures. For each test, the discussion identifies an authoritative source that you should refer to for detailed procedural guidance. Always use those sources when actually performing any of the materials tests.

SOILS TESTING

Soil compaction and density testing are two of the most common and important soils tests that an EA must learn to perform. Those tests, as well as the California bearing ratio test and hydrometer analysis, are discussed in this section.

COMPACTION TEST

Compaction is the process of increasing the density (amount of solids per unit volume) of soil by mechanical means to improve such soil properties as strength, permeability, and compressibility. Compaction is a standard procedure used in the construction of earth structures, such as embankments, subgrades, and bases for road and airfield pavement.

In the field, compaction is accomplished by rolling or tamping the soil with special construction equipment. In the laboratory, compaction can be accomplished by the impact of hammer blows, vibration, static loading, or any other method that does not alter the water content of the soil. Usually, however, laboratory compaction is accomplished by placing the soil into a cylinder of known volume and dropping a tamper of known weight onto the soil from a known height for a given number of blows. The amount of work done to the soil per unit volume of soil is called **compactive effort.**

For most soils and for a given compactive effort, the density of the soil will increase to a certain point, as the moisture content is increased. That point is called the **maximum density.** After that point, the density will start to decrease with any further increase in moisture content. The moisture content at which maximum density occurs is called the **optimum moisture content** (OMC). Each compactive effort for a given soil has its own OMC. As the compactive effort is increased, the maximum density generally increases and the OMC decreases.

The following discussion briefly describes the equipment and procedures of the ASTM compaction test that determines the OMC and the maximum density obtainable under a given compactive effort. You can find a full discussion of the test in *Materials Testing,* NAVFAC MO-330.

Equipment

The principal equipment used for the compaction test is the compaction cylinders and the compaction tamper that are shown in figure 13-1.

There are two compaction cylinders. The smaller cylinder **(Proctor mold)** is 4 inches in diameter and has a volume of 1/30 (0.0333) cubic feet. It is used for materials passing the No. 4 sieve. The Proctor mold is

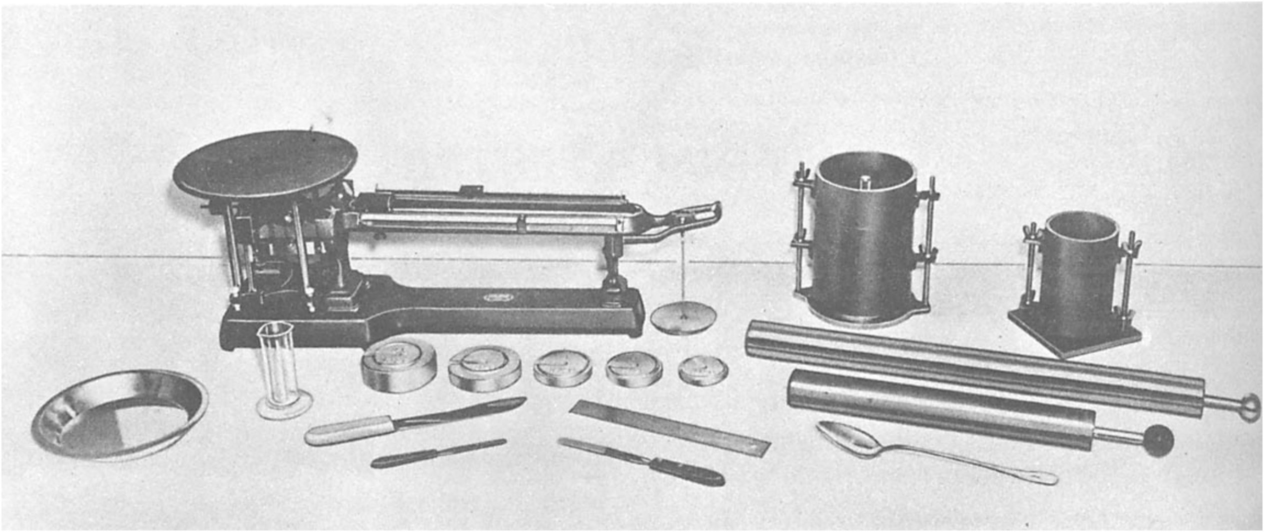


Figure 13-1.—Apparatus for soil compaction testing.

fitted with a detachable base plate and a removable extension collar that is 2 1/2 inches high.

The larger cylinder is the **CBR mold.** It is 6 inches in diameter, 7 inches high, and is fitted with a base plate and a 2-inch-high extension collar. When you are compacting a soil sample, a 2 1/2-inch-thick spacer disk is placed inside the CBR mold to control the thickness of the compacted sample. With the spacer disk in place, the volume of the mold is about 0.0735 cubic feet. The CBR mold is used for samples containing material retained on the No. 4 sieve.

The compaction tamper consists of a drop tamper in a cylindrical guide. The tamper has a drop weight that weighs 10 pounds and has a striking face that is 2 inches in diameter. The guide sleeve regulates the height of drop to 18 inches. To use the compaction tamper, you place the guide on top of the specimen and then draw the tamper to the top of the guide and allow it to drop.

Other items that you need to perform compaction testing are a balance or scale for weighing the material in grams, a 3/4-inch and a No. 4 sieve, moisture canisters, and tools, such as a mixing pan, spoon, trowel, spatula, and a steel straightedge for striking excess material from the top of the mold after compaction.

Sample Preparation and Compaction Procedures

About five specimens, containing successively increasing moisture contents, are needed to determine the OMC at which the maximum density for a given compactive effort will occur. For the Proctor mold, about 6 pounds for each specimen (about 30 pounds total) is needed. For the CBR mold, you will need about 12 to 14 pounds per specimen, or about 60 to 70 pounds total.

Before the compacting begins, the sample is air-dried and a moisture content of the air-dried material is determined. Airdrying is done by spreading out the material in the sun or in front of an electric fan. The water content of the air-dried material is determined as a basis for estimating the amount of water you need to add to each trial specimen. The driest specimen should contain just enough water to produce a damp mixture that crumbles readily. For each succeeding specimen, increase the water content by about 2 percent until the wettest specimen is quite wet and plastic.

The compaction procedures for nongravelly and gravelly soils are the same with two exceptions. First, the 4-inch Proctor mold is used for fine-grained soil, and the CBR mold is used for gravelly soil. Second, 25 tamper blows per layer are used for the Proctor mold, and 55 blows per layer are used in the CBR mold. That results in equal compactive efforts for the two mold sizes and soil volumes.

To compact the soil, you first attach the base plate and collar to the mold. Then you fill the mold to the top of the collar with the material placed in five equal layers, compacting each layer with the appropriate 25 or 55 equally distributed blows. After compacting the

SOIL COMPACTION TEST DATA

PROJECT	EXCAVATION NUMBER	SAMPLE NUMBER	NUMBER OF LAYERS	DATE
Motor Pool	3	MP-P1-3	5	01 SEP 19__

CONVERSION FACTORS	NUMBER OF BLOWS PER LAYER	WEIGHT OF TAMPER	HEIGHT OF DROP	MAXIMUM PARTICLE SIZE
1728 cu. in. per cu. ft. 453.6 gm. per lb.	25	10 LB	18"	0.187" (No. 4)
	SPECIFIC GRAVITY	**DIAMETER OF MOLD (in.)**	**HEIGHT OF SOIL SAMPLE (in.)**	**VOLUME OF SOIL SAMPLE (cu. ft.)**
	2.72	4.0	4.584	1/30

	UNITS										
RUN NUMBER		1		2		3		4		5	
WEIGHT OF WET SOIL + MOLD	LB.	12.8		13.1		13.3		13.4		13.2	
WEIGHT OF MOLD	LB.	8.7		8.7		8.7		8.7		8.7	
WEIGHT OF WET SOIL	LB.	4.1		4.4		4.6		4.7		4.5	
WET UNIT WEIGHT, $\gamma = \frac{\text{Weight of wet soil (lb.)}}{\text{Vol of soil sample (cu. ft)}}$	LB PER CU FT	123.0		132.0		138.0		141.0		135.0	
TARE NUMBER		12	13	14	15	16	17	18	19	20	21
A WEIGHT OF WET SOIL + TARE		47.7	44.7	44.1	42.8	44.1	45.6	45.1	46.7	45.2	45.6
B WEIGHT OF DRY SOIL + TARE		46.5	43.6	42.5	41.2	42.2	43.7	42.5	44.0	42.3	42.4
C WEIGHT OF WATER, W_w (A - B)		1.2	1.1	1.6	1.6	1.9	1.9	2.6	2.7	2.9	3.2
D WEIGHT OF TARE		22.6	22.2	21.5	20.8	22.2	23.2	21.4	22.5	22.2	21.9
E WEIGHT OF DRY SOIL, W_s (B - D)		23.9	21.4	21.0	20.4	20.0	20.4	21.1	21.5	20.1	20.5
WATER CONTENT, $w = (\frac{W_w}{W_s} \times 100)$	PERCENT	5.0	5.1	7.6	7.8	9.5	9.3	12.3	12.6	14.4	15.6
AVERAGE WATER CONTENT	PERCENT	5.1		7.7		9.4		12.5		15.0	
DRY UNIT WEIGHT, $\gamma_d = (\frac{\gamma}{1 + w/100})$	LB PER CU FT	117.0		122.6		126.1		125.3		117.4	

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)

DD Form 1210, AUG 57

Figure 13-2.—Data sheet for soil compaction test.

material, you remove the collar and weigh the mold and compacted material. Then take moisture content samples from the top and bottom of the specimen and determine the moisture content for each. If the two moisture contents differ, use the average between them.

A modification of the above procedure uses a 5 1/2-pound tamper and the material is placed in three equal layers, rather than five; otherwise, the test is the same. The procedures can be found in ASTM D 698.

Data and Calculations

Figure 13-2 shows the test results and calculations for a compaction test. As you can see, this test used a 10-pound tamper and Proctor mold. Five runs were made. After compaction, the weight of the compacted soil and mold was recorded for each run. From this, the weight of the mold was subtracted to get the weight of the soil for each run. Then the wet unit weight was computed using the formula shown.

Lines A, B, C, D, and E contain the data for the moisture-content test for each run. Note that for each run, there were two tests: one from the top of the mold and the other of soil from the bottom. The averages were set down beside average moisture content. Finally, the dry unit weight (density) in pounds per cubic foot (pcf) for each run was calculated by the formula shown. As you can see, for the same compactive effort, the density varied with the average moisture content.

The ultimate objective of the compaction test is to determine the OMC; that is, the moisture content that yields maximum density for a given compactive effort.

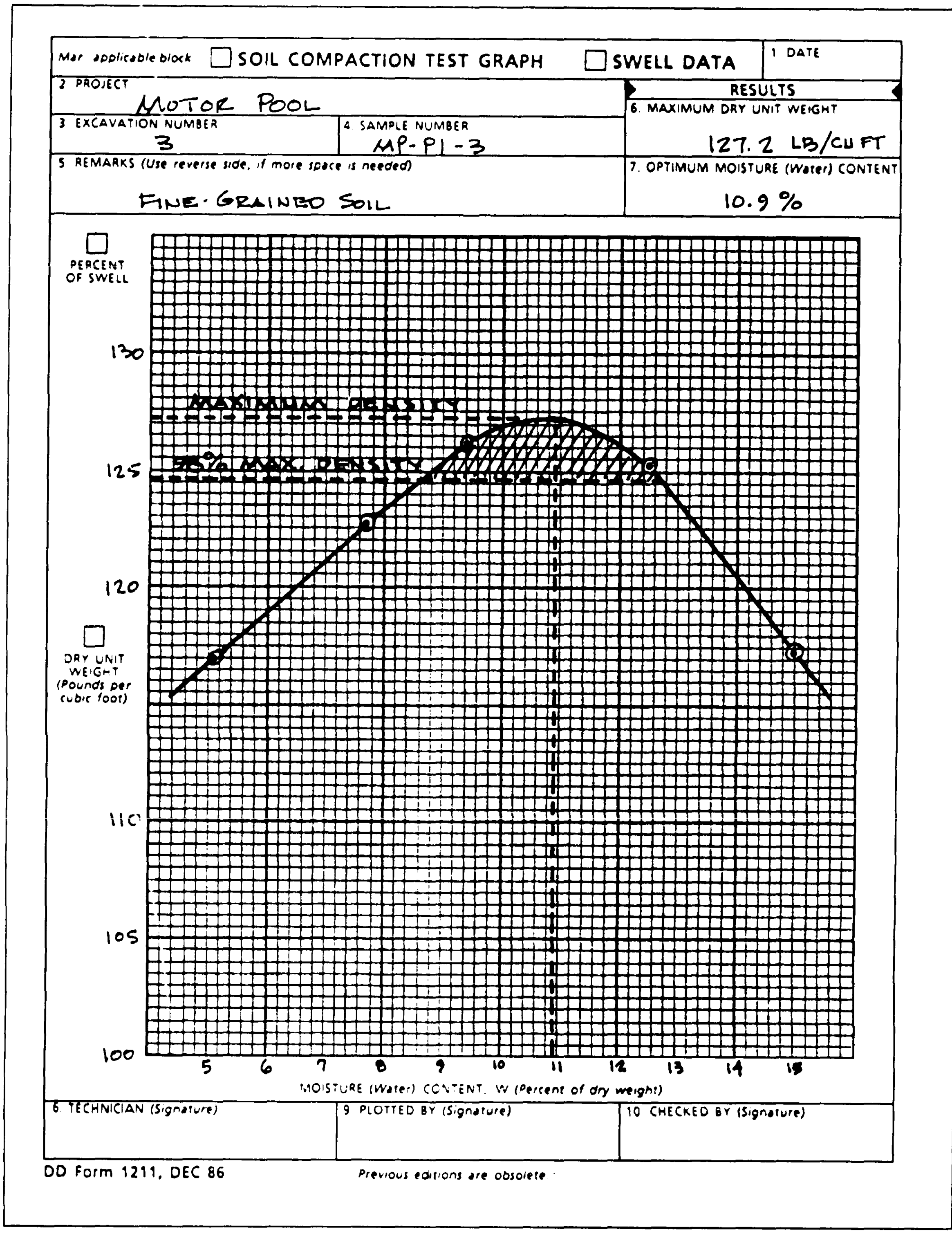


Figure 13-3.—Determination of optimum moisture content.

You determine this by applying the test results to plot a curve like the one shown in figure 13-3.

In this curve, the horizontal coordinates are the average moisture contents; the vertical coordinates are the dry densities. For the test results used in the example, the curve indicates that the maximum attainable density for the given compactive effort was 127.2 pcf for which the OMC was 10.9 percent.

The dotted line marked "98% maximum density" indicates that, in this case, the project specifications

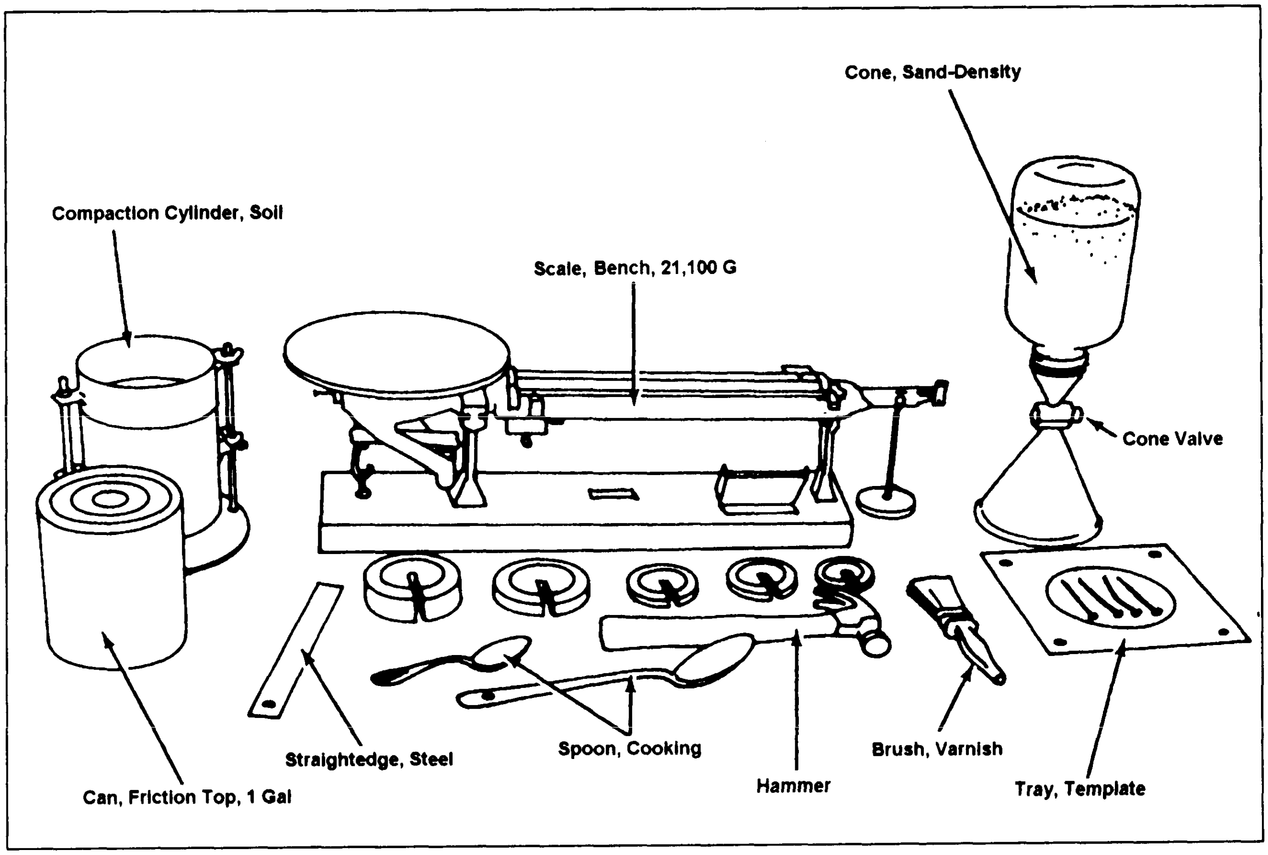


Figure 13-4.—Sand-displacement method apparatus.

required that 98 percent of the maximum density be obtained through compaction. The maximum attainable was 127.2 pcf; 98 percent of this is 124.7 pcf. The dotted line is drawn at the 124.7 pcf level. Any moisture content lying in the crosshatched area above this line would produce the specified density for a given compactive effort; therefore, the range of permissible moisture content is from 9 to 13 percent.

DENSITY TESTS

From the preceding discussion, you know that compaction testing is performed to determine the OMC and the maximum density that can be obtained for a given soil at a given compactive effort. You also know that, using the maximum density, you can determine a range of densities and moisture contents that will satisfy the compaction requirements for a project. During the construction of that project, however, a control must be in place to measure whether or not the compaction requirements have been met. That control is **density testing.** If the results of the density test determine that the compaction process has produced a density within the range specified, then the compaction is complete. On the other hand, if the test results reflect densities that are not within the specified range, additional rolling may be necessary or the moisture content may have to be adjusted.

Several different methods are used to determine the in-place density of a soil; however, the methods that EAs are most apt to use are the **sand-displacement** method and the **nuclear moisture-density meter** method.

Sand-Displacement Method

A full discussion of the procedures used in the sand-displacement method can be found in *Test Method for Pavement Subgrade, Subbase, and Base-Course Material,* MIL-STD-621A, and in NAVFAC MO-330. This method, often called the **sand-cone method,** may be used for both fine-grained and coarse-grained materials. In general, the test consists of digging out a sample of the material to be tested, using calibrated sand to determine the volume of the hole from which the sample was removed and to determine the dry unit weight of the sample.

EQUIPMENT AND TOOLS.— The essential equipment and tools that you will need to perform the test are shown in figure 13-4. In addition to these, you

Sand No. 1 Batch No. A Date ____

	1	2	3	Avg
Weight of apparatus filled with water, grams	11,295	11,299	11,303	
Weight of apparatus empty and dry, grams	4248	4249	4250	
Weight of water, grams	7047	7050	7053	7050

$$\text{Weight of water in pounds} = \frac{\text{Weight in grams}}{453.6} = \frac{7050}{453.6} = 15.542 \text{ pounds}$$

$$\text{Volume of apparatus} = \frac{\text{Weight water in pounds}}{62.3} = \frac{15.542}{62.3} = 0.249 \text{ cubic feet}$$

Figure 13-5.—Sample data sheet, calibration of sand-cone density apparatus.

will also need a baking pan, moisture content canisters, a paintbrush with moderately long bristles, and some modeling clay.

CALIBRATION.— The sand-displacement method includes three calibration procedures that must be completed before you conduct the test.

The first of the calibration procedures is the **apparatus calibration** that determines the volume of the jar and connecting cone (up through the cone valve). To perform the calibration, you first weigh the assembled apparatus (jar and cone) when it is empty, clean, and dry. Record this weight on a data sheet similar to figure 13-5. Then you weigh the apparatus when the jar and the smaller end of the cone is filled with water (making sure that no air is entrapped in the water). Record this weight on the data sheet and then empty the water from the apparatus. After repeating these steps at least three times, you can then determine the average weight of the water and compute the volume of the apparatus, using the formulas shown in figure 13-5.

The second calibration that you must make before performing the sand-cone test is **sand calibration.**

The sand that you use in the sand-cone test must be clean, dry, and free-flowing with a constant moisture content while the test is performed. Uniformly graded and well-rounded sand passing the No. 20 sieve and retained on the No. 40 sieve is most suitable for the test. Almost no material finer than the No. 200 sieve should be in the sand. This sand is usually purchased in bulk quantities that can be used for many sand-cone tests performed over extended lengths of time. The density of the sand may be determined soon after the sand is received; however, since the bulk density of the sand is affected by changes in temperature and humidity, you must recalibrate the sand before each test.

To calibrate (or recalibrate) the sand, you first weigh the assembled apparatus when it is empty, clean, and dry. This weight is recorded on line 2 of DD Form 1215 (fig. 13-6A). Next, the apparatus is filled with air-dried sand by pouring the sand into the apparatus through the large end of the cone. When the jar and lower end of the cone is filled and all excess sand is removed, weigh the sand-filled apparatus. Record that weight on line 1. Then by subtracting these weights, you can determine the weight of the sand (in grams). Finally, to determine the calibrated density of the sand, you convert the weight of the sand to pounds and divide by the volume of the apparatus.

UNIT WEIGHT DETERMINATION "VOLUME OF HOLE" METHODS		DATE 2 APR 1994
PROJECT HIGHWAY #203	TEST SITE ¢ STA 50+00 ¢ STA 52+00	SAMPLE NUMBER 203-6 203-7
ADDITIONAL SPECIFICATIONS FILL COMPACTION		

CONVERSION FACTORS

1 in. = 2.54 cm. 1 gm./cc. or 62.4 lb./cu. ft. = Unit weight of water
1 lb. = 453.6 gm. 1 cu. ft. = 1728 cu. in.

CALIBRATION OF STANDARD MATERIAL	STANDARD MATERIAL (Check one) ☒ SAND ☐ OIL ☐ OTHER (Specify)				
	UNITS				
APPARATUS OR TARE NUMBER		1	1		
1. WEIGHT OF APPARATUS OR TARE FILLED	gm	12530			
2. WEIGHT OF APPARATUS OR TARE EMPTY	gm	3711			
3. WEIGHT OF MATERIAL (1.-2.)	gm	8819	SAME		
4. VOLUME OF APPARATUS OR TARE	cu ft.	.2048			
5. UNIT WEIGHT OF MATERIAL (3./4.)	lb./cu. ft.	94.9			
6. AVERAGE UNIT WEIGHT OF MATERIAL	LB./CU. FT./				

CALIBRATION OF APPARATUS		TEMPLATE NUMBER 203-6	203-7	CONE NUMBER	
	UNITS				
7. INITIAL WEIGHT OF APPARATUS + SAND	gm	12530	12518		
8. FINAL WEIGHT OF APPARATUS + SAND	gm	10931	10897		
9. WEIGHT OF SAND IN TEMPLATE AND/OR CONE	gm	1599	1621		

"VOLUME OF HOLE"	UNITS				
10. INITIAL WEIGHT OF APPARATUS + MATERIAL	gm	10931	10897		
11. FINAL WEIGHT OF APPARATUS + MATERIAL	gm	6608	6631		
12. WEIGHT OF MATERIAL RELEASED (10.-11.)	gm	4323	4266		
13. WEIGHT OF MATERIAL IN HOLE (For oil, same as 12. For sand, 12.-9.)	gm	2724	2645		
14. VOLUME OF HOLE (13./6.)	cu. ft.	.0632	.0614		

DD Form 1215, AUG 57

Figure 13-6A.—Data sheet (DD Form 1215) for in-place soil density, sand-cone method.

An alternate method of sand calibration uses a container of known weight, such as a Proctor mold. In this method, you first weigh the mold and the attached base plate. Then, after attaching the mold collar, you pour the sand through the sand cone into the mold. Next, you remove the collar, strike off the excess sand, brush off the outside of the mold and base plate, and weigh the sand-filled mold (with the base plate attached). The difference in weights (filled and empty) divided by the known volume of the mold is equal to the density of the sand.

The third calibration **(surface calibration)** is discussed as part of the site preparation since it must be performed at the test site.

SITE PREPARATION.— Site preparation consists of preparing the test surface, seating the template tray, and surface calibration of the tray.

Begin your site preparation by choosing an area of the compacted surface that appears most level. You may have to remove some loose debris; however, make no attempt to pack or smooth the surface. Next, you seat the template tray flush on the surface, especially around the center hole. If necessary, seal any spaces around the center hole of the tray with modeling clay. Then force nails through the holes in the tray to hold it firmly in place. Now you are ready to perform the surface calibration.

Surface calibration accounts for surface irregularities of the area to be tested. With the valve closed, turn the sand-filled apparatus over and place the large cone over the center hole of the template tray. Open the valve and allow the sand to pass through until the large cone is completely filled. Do NOT shake or vibrate the apparatus. Then close the valve, weigh the apparatus with the remaining sand, and enter this weight on line 8 of DD Form 1215 (fig. 13-6A). The difference between the initial weight (line 7) and the final weight (line 8) is the weight of the sand that passed through the cone valve into the lower cone and the center hole of the template. Enter that weight on line 9.

After performing the surface calibration, recover as much of the sand from the tray as possible without disturbing the template tray or the soil in the hole. Brush the remaining sand particles lightly from within the tray. Leave the template in place for the volume-of-hole determination to be discussed next.

VOLUME-OF-HOLE DETERMINATION.— The volume-of-hole determination consists of digging out a soil sample through the center of the template and computing the volume of the resulting hole.

The hole that is dug through the center hole of the template tray should be about 6 inches deep and approximately the same diameter as the hole in the tray. When digging, keep the inside of the hole as free from pockets and sharp protuberances as possible. Make sure that **ALL** material removed from the hole is placed in a container of known and recorded weight (line 23, fig. 13-6B). Keep the lid on the container as much as possible to prevent excessive moisture loss until it is weighed. When all removed material has been placed in that container, immediately weigh it and record the weight of the container and the material on line 15. Mark the container for later identification when the soil moisture content is determined.

Next, place the sand-cone apparatus over the hole in the tray and open the valve to allow the sand to flow into the hole that you have just dug. When the sand stops flowing, close the valve and weigh the apparatus with its remaining sand. Record this weight on line 11 (fig. 13-6A). The weight of the sand required to fill the hole and the volume of the hole can then be determined by following the instructions printed on the data sheet.

DENSITY DETERMINATION.— Now that you have determined the volume of the hole, the only remaining requirements are to determine the moisture content and the dry density of the sample that was removed from the hole. The moisture content should be determined using the oven-dried method that you studied in the EA3 TRAMAN. Lines 15 through 21 of DD Form 1215 (fig. 13-6B) are used to record the moisture-content data.

The wet density or unit weight (line 25) is computed by dividing the wet soil weight (line 24) by 453.6 to convert the grams to pounds and then by the volume of the hole (line 14, fig. 13-6A). The dry density or unit weight is then computed using the formula shown on line 26 of DD Form 1215.

Nuclear Moisture-Density Meter Method

Another method for determining the moisture content and density of in-place soil uses a nuclear

WATER CONTENT DETERMINATION	UNITS	203-6	203-7		
TARE NUMBER		12	15		
15. WEIGHT WET SOIL & TARE	gm	4340	4170		
16. WEIGHT DRY SOIL & TARE	gm	4152	3995		
17. WEIGHT WATER *(15. -16.)*	gm	188	175		
18. WEIGHT TARE	gm	276	273		
19. WEIGHT DRY SOIL *(16. -18.)*	gm	3886	3722		
20. WATER CONTENT $(\frac{17.}{19.} \times 100)$	%	4.9	4.7		
21. AVERAGE WATER CONTENT	PERCENT	4.9	4.7		

UNIT WEIGHT DETERMINATION	UNITS	203-6	203-7	
TARE NUMBER		12	15	
22. WEIGHT WET SOIL & TARE	gm	4340	4170	
23. WEIGHT TARE	gm	276	273	
24. WEIGHT WET SOIL *(22. -23.)*	gm	4064	3897	
25. WET UNIT WEIGHT *(24./14.)*	LB./CU. FT.	142.0	139.8	
26. DRY UNIT WEIGHT $(25. \times \frac{100}{100 + 21.})$	LB./CU. FT.	135.1	133.7	

REMARKS

SPEC. DRY DENSITY 132 LB/CU FT

TESTS O.K.

L. Thomas

TECHNICIAN *(Signature)*	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)*
Paul Massion	Paul Massion	L. Thomas

DD Form 1215 Reverse, AUG 57

Figure 13-6B.—Reverse of data sheet (DD Form 1215) for sand-cone method.

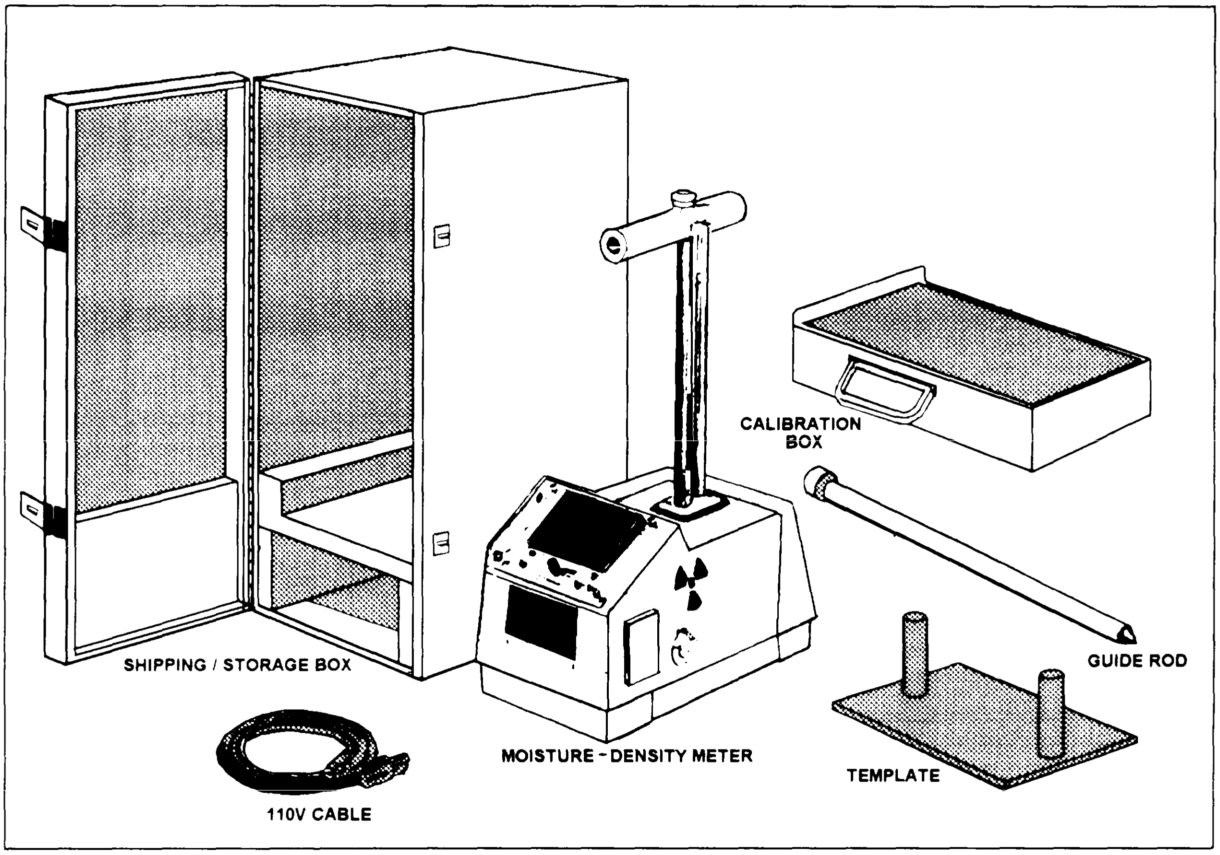


Figure 13-7.—Nuclear moisture-density meter.

moisture-density meter, such as the one illustrated in figure 13-7.

The meter contains sealed radioactive materials, typically cesium and a combination of americium mixed with beryllium powder. The cesium emits gamma radiation that the detector in the meter can count when it is passed through the soil. This count can be translated to density. The americium, interacting with the beryllium, emits neutrons following collision with hydrogen that are moderated and detected by the meter. The moisture content can be determined by measuring the hydrogen concentration in the soil.

When you are using the moisture-density meter, counts or readings are obtained and used with a calibration chart to determine the wet density and moisture content. The dry density is computed from the wet density.

CAUTION

Before using the nuclear moisture-density meter, you must complete specialized training and receive certification through the Naval Construction Training Center at either Gulfport, Mississippi, or Port Hueneme, California.

BEARING TESTS

The bearing capacity of a soil is expressed in terms of shear resistance, which means the capacity of the load-bearing portion of a material or member to resist displacement in the direction of the force exerted by the load.

There are various types of load-bearing tests. For description purposes we will briefly discuss the **California bearing ratio (CBR) test.**

The **California bearing ratio** is a measure of the shearing resistance of a soil under carefully controlled conditions of density and moisture. The CBR is determined by a penetration shear test and is used with empirical curves for designing flexible pavements.

The test procedure used to determine the CBR consists of two principal steps. First, the soil test

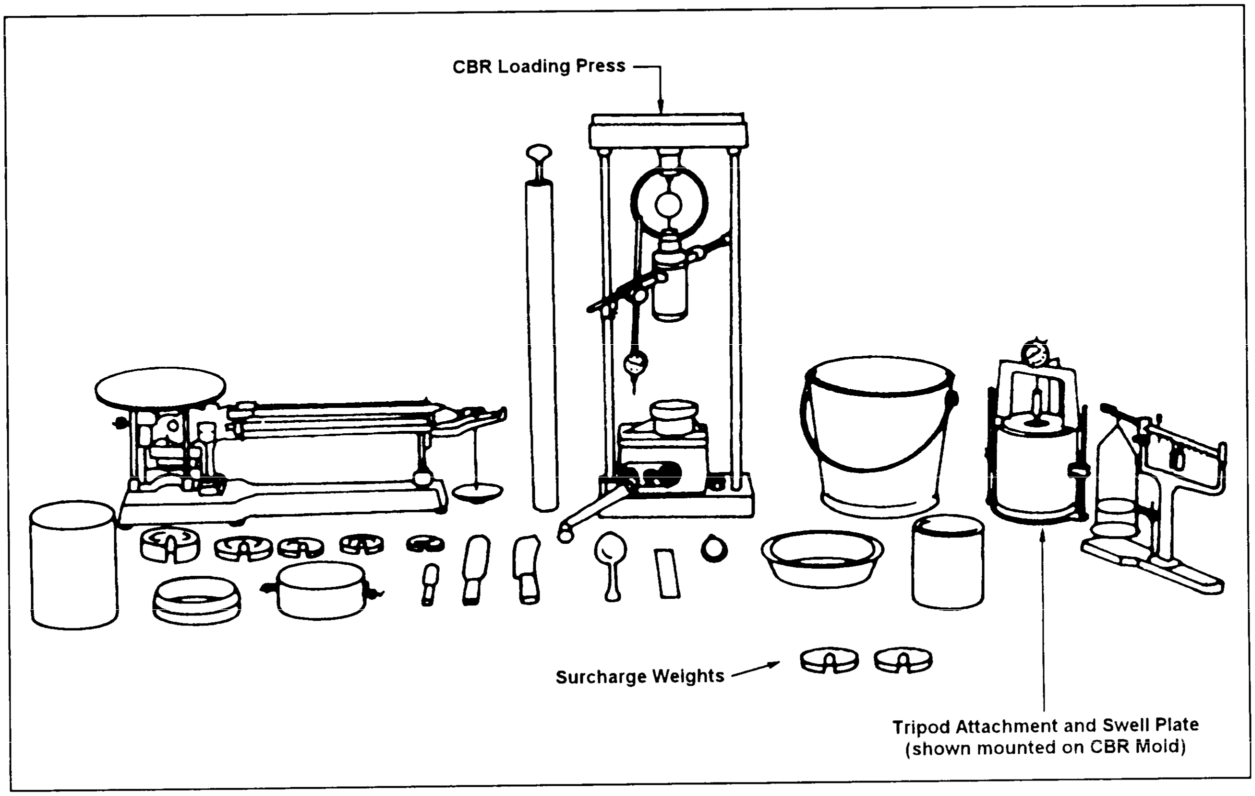


Figure 13-8.—Laboratory CBR test equipment and tools.

specimens are prepared; second, a penetration test is performed upon the prepared soil samples. Although one standardized procedure has been established for the penetration portion of the test, it is not possible to establish one procedure for the preparation of test specimens since soil conditions and construction methods vary widely. The soil test specimens are prepared to duplicate the soil conditions existing (or expected to occur later) in the field. Although penetration tests are most frequently performed on laboratory-compacted test specimens, they may also be performed upon undisturbed soil samples or in the field upon the soil in place. Detailed procedures for preparing the test samples and performing the test can be found in NAVFAC MO-330.

CBR Test Equipment and Tools

Figure 13-8 illustrates the equipment and tools needed to perform the CBR test. The principal piece of equipment is the CBR loading press. It is used to force the penetration piston into the compacted CBR specimen. The complete loading-press assembly (fig. 13-9) includes a penetration piston, proving ring and proving-ring dial, penetration dial, and a mechanical (or

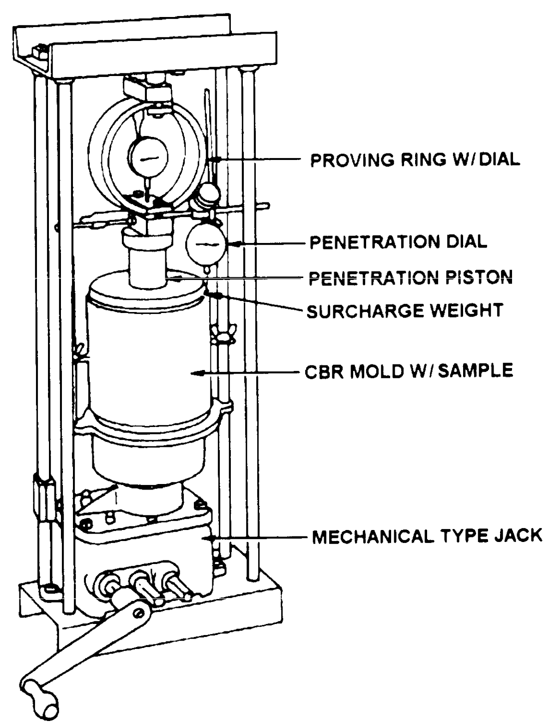


Figure 13-9.—Assembled CBR loading press.

motorized) type of jack. Three proving rings are available with capacities of 2,000, 5,000, and 7,000 pounds, respectively. The surcharge weights are used to approximate (within ± 5 pounds) the expected weight of the pavement and base in the field. The tripod attachment (when fitted with a dial indicator) and the swell plate are used to measure the expansion, or swell, of the material in the CBR mold. Other items needed to perform the test are equipment and tools, such as a balance or scale, a CBR mold, a 10-pound tamper, mixing bowls, spoons, spatulas, a soaking tank or bucket, and moisture canisters.

Preparation of Test Samples

When a bearing-ratio test is made of a compacted sample, you will use the 6-inch-diameter CBR mold with a 2 1/2-inch spacer disk in the mold beneath the sample. The use of the spacer reduces the depth of the sample to 4 1/2 inches. The use of another size spacer will result in volume and compactive effort changes that may not meet ASTM or other recognized standards for the CBR test.

The method of preparing the test specimens and the number of specimens depend upon such factors as the type of airfield or road and the soils encountered at the site. The soil sample should be tested in the laboratory at a density comparable to the density required at the construction site. There are situations where moisture conditions are favorable and the subgrade will not accumulate moisture approaching a saturated condition. In these cases, samples should be tested at a moisture content that approximates actual moisture conditions expected during the time the road or airfield is used. In all other conditions, the samples are laboratory tested in a saturated condition.

The saturated condition is attained by soaking the sample. First, place the sample in the mold and compact it. The compactive effort used and the number of compacted samples required depend upon the soil type, weight and type of field compaction equipment, and other job conditions. Normally, compactive efforts of 12, 26, and 55 blows per layer (for five layers) are used in each of three successive compaction tests. The 10-pound tamper is used for compacting the samples. After compacting the sample, trim it and remove the base plate and spacer disk. Then place a piece of filter paper over the trimmed or struck-off top of the sample and place the base plate over this top. Turn the mold over and set it in a bucket on the base plate. The bottom of the sample, which was next to the spacer disk during compaction, is now uppermost. Apply the appropriate

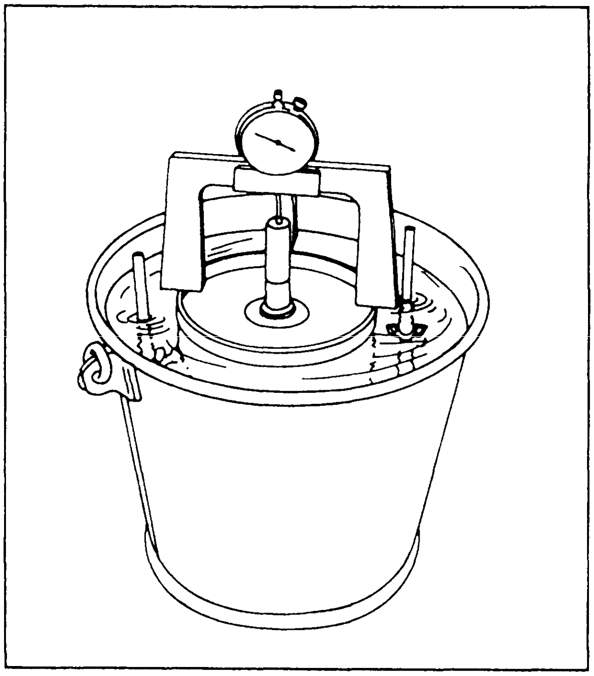


Figure 13-10.—Apparatus for soaking a CBR test sample.

number of surcharge weights needed to approximate the expected in-place weight of the pavement and base. One 5-pound surcharge weight is equivalent to 3 inches of overlying material. Then set in place the tripod attachment, dial, and swell plate, as shown in figure 13-10.

Immerse the mold and the sample in water in the bucket and leave them to soak for about 4 days. An initial reading of the tripod dial is made when the sample is first placed in the water. Then, at the end of the soaking period, the dial is read again to determine the amount of swell. A swell in excess of 3 percent of the initial height of the specimen is considered to be excessive. After making the final reading of the dial, you remove the sample and mold from the water and allow them to drain for about 15 minutes before conducting the penetration test.

Penetration Test

In the penetration test, the bearing capacity of a soil is determined by measuring the extent to which the sample, placed in a mold, is penetrated by a penetration piston. The sample (in the CBR mold) is placed in the loading press, as shown in figure 13-9. The piston is placed on top of the material, and a proving ring is placed between the top of the piston and the top of the loading press.

As the jack is cranked upward, the dial in the center of the proving ring records the pressure being applied to

CALIFORNIA BEARING RATIO TEST DATA	DATE 2 APR 1994

PROJECT: FRANKLIN AIRFIELD

☐ FIELD-IN-PLACE	TEST SITE: RUNWAY R-2		
☐ LABORATORY	EXCAVATION NUMBER: 2	SAMPLE NUMBER: SF-P1-4	TYPE: ☐ UNSOAKED ☐ SOAKED ☒ DRAINED ☐ UNDRAINED

CONDITION	NUMBER OF LAYERS	NUMBER OF BLOWS PER LAYER	WEIGHT OF HAMMER (lb.)	DROP (inches)
☐ UNDISTURBED ☒ DISTURBED	5	55	10	18

MOLD NUMBER	MOLD DIAMETER (in.)	MOLD HEIGHT (in.)	DEPTH, TOP TO SAMPLE (in.)	SAMPLE HEIGHT (in.)	SAMPLE VOLUME (cu. ft.)
7	6	7	2.5	4.5	.073

PROVING RING NUMBER	PROVING RING CONSTANT	PROVING RING CAPACITY	SURCHARGE WEIGHTS SOAKING (lb.)	SURCHARGE WEIGHTS PENETRATING (lb.)
3	12 LB/0.0001"	5000 LB.	25	25

FORMULAS

Total Load = Corrected Dail Reading x Proving Ring Constant

$$\text{Unit Load} = \frac{\text{Total Load}}{3} \qquad \text{CBR (\%)} = \frac{\text{Corrected Unit Load}}{\text{Standard Unit Load}} \times 100$$

CONVERSION FACTORS

1728 cu. in. per cu. ft.

453.6 gm. per lb.

PENETRATION DATA

PENETRATION (inches)	STD. UNIT LOAD (psi)	PROVING RING DIAL READING	CORRECTED RING DIAL READING	TOTAL LOAD (pounds)	UNIT LOAD (psi)	CORRECTED UNIT LOAD (psi)	CBR (%)
0.025	250	0.0068	0.0038	456	152	NO	
0.050	500	0.0105	0.0075	900	300	CORRECTION	
0.075	750	0.0141	0.0111	1332	444	NECESSARY	
0.100	1000	0.0170	0.0140	1680	560		56
0.150	1250	0.0210	0.0180	2160	720		
0.200	1500	0.0267	0.0235	2820	940		62.7
0.250	1700	0.0297	0.0267	3210	1070		
0.300	1900	0.0324	0.0294	3525	1175		
0.400	2300	0.0351	0.0321	3855	1285		
0.500	2600	0.0370	0.0340	3960	1320		

WATER CONTENT AND UNIT WEIGHT DATA

WEIGHT OF SOIL + MOLD (lb.) (gm)*	15.67	
WEIGHT OF MOLD (lb.) (gm)*	5.38	
WEIGHT OF WET SOIL (lb.) (gm)*	9.92	
VOLUME OF SAMPLE (cu. ft.)	0.073	
WET UNIT WEIGHT (lb. cu. ft.)	136.0	
TARE NUMBER	1	2
WEIGHT OF WET SOIL + TARE (gm.)	143.8	164.0
WEIGHT OF DRY SOIL + TARE (gm.)	131.5	150.3
WEIGHT OF WATER, W_w (gm.)	12.3	13.7
WEIGHT OF TARE (gm.)	50.2	60.7
WEIGHT OF DRY SOIL, W_s (gm.)	81.3	89.6
WATER CONTENT, w (%)	15.1	15.3
AVERAGE w (%)	15.2	
DRY UNIT WEIGHT (Density) (lb. cu. ft.)	118.0	

OPTIMUM MOISTURE CONTENT OF SOIL, w_{opt} (%): 11.2

THEORETICAL MAXIMUM UNIT WEIGHT (Density) (lb./cu. ft.): 127.2

ACTUAL WATER CONTENT OF SOIL, w (%): 8.6

ACTUAL UNIT WEIGHT (lb. cu. ft.): 99.7

DIFFERENCE (%): 2.6

PERCENT OF MAXIMUM $\left(\frac{\text{Actual}}{\text{Maximum}} \times 100\right)$: $\frac{99.7}{127.2} \times 100 = 78\%$

REMARKS

*Strike out unit weight not applicable.

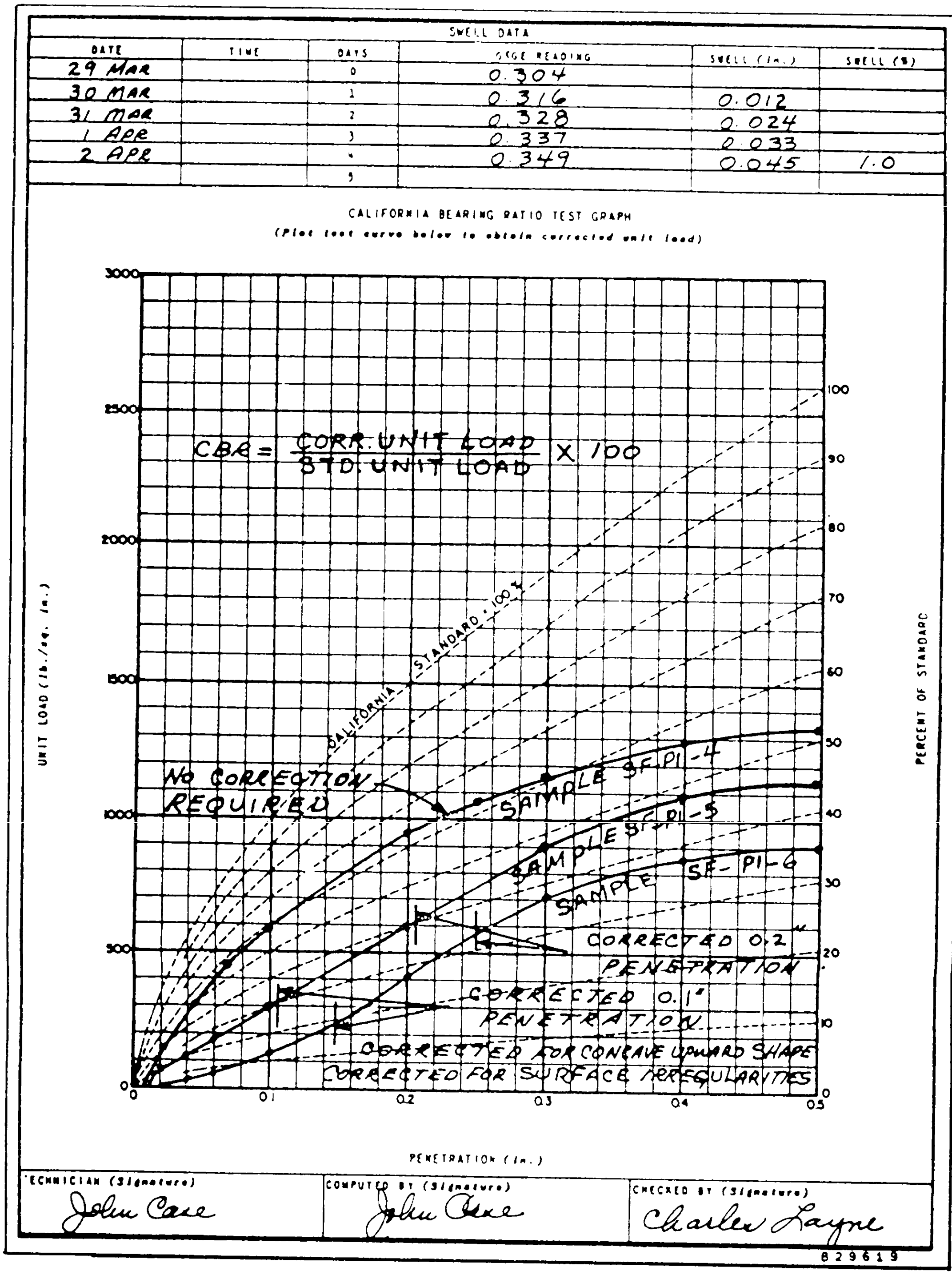
USE REVERSE SIDE FOR SWELL DATA AND GRAPH

DD Form 1212, AUG 57

Figure 13-11A.—Front of data sheet (DD Form 1212) for California bearing ratio test.

the piston. The penetration dial (fig. 13-9) measures the extent to which the piston penetrates the material in the CBR mold.

To better understand the test procedure, let's study figure 13-11A. This figure shows an example of the data for a CBR test. In this example, figure 13-11A indicates that the sample was compacted in five layers with the 10-pound tamper, 55 blows per layer. A surcharge weight of 25 pounds is listed. That means that a 6-inch-diameter circular section of, in this case, the surface and base course of the airfield pavement is expected to weigh 25 pounds. As previously described, this weight was simulated using surcharge weights totaling 25 pounds.



SWELL DATA

DATE	TIME	DAYS	GAGE READING	SWELL (in.)	SWELL (%)
29 MAR		0	0.304		
30 MAR		1	0.316	0.012	
31 MAR		2	0.328	0.024	
1 APR		3	0.337	0.033	
2 APR		4	0.349	0.045	1.0
		5			

Figure 13-11B.—Stress-penetration curves (reverse of CBR test data sheet DD Form 1212).

The 5,000-pound proving ring was used for which the proving-ring constant was 12 pounds for every 0.0001 read on the proving-ring dial; for example,when the proving-ring dial reads 0.0111, the force being exerted by the piston is 12 x 111, or 1,332 pounds.

In the penetration data portion of the data sheet, you see that the first column lists standard penetrations starting at 0.025 inch and increasing to 0.500 inch. The second column lists standard unit loads. The test was carried out by cranking the jack until the penetration dial reaches the standard penetration, then reading the load for that penetration on the proving-ring dial. Notice that for each dial reading there is a corrected dial reading that is 0.003 inch less that the uncorrected reading. This

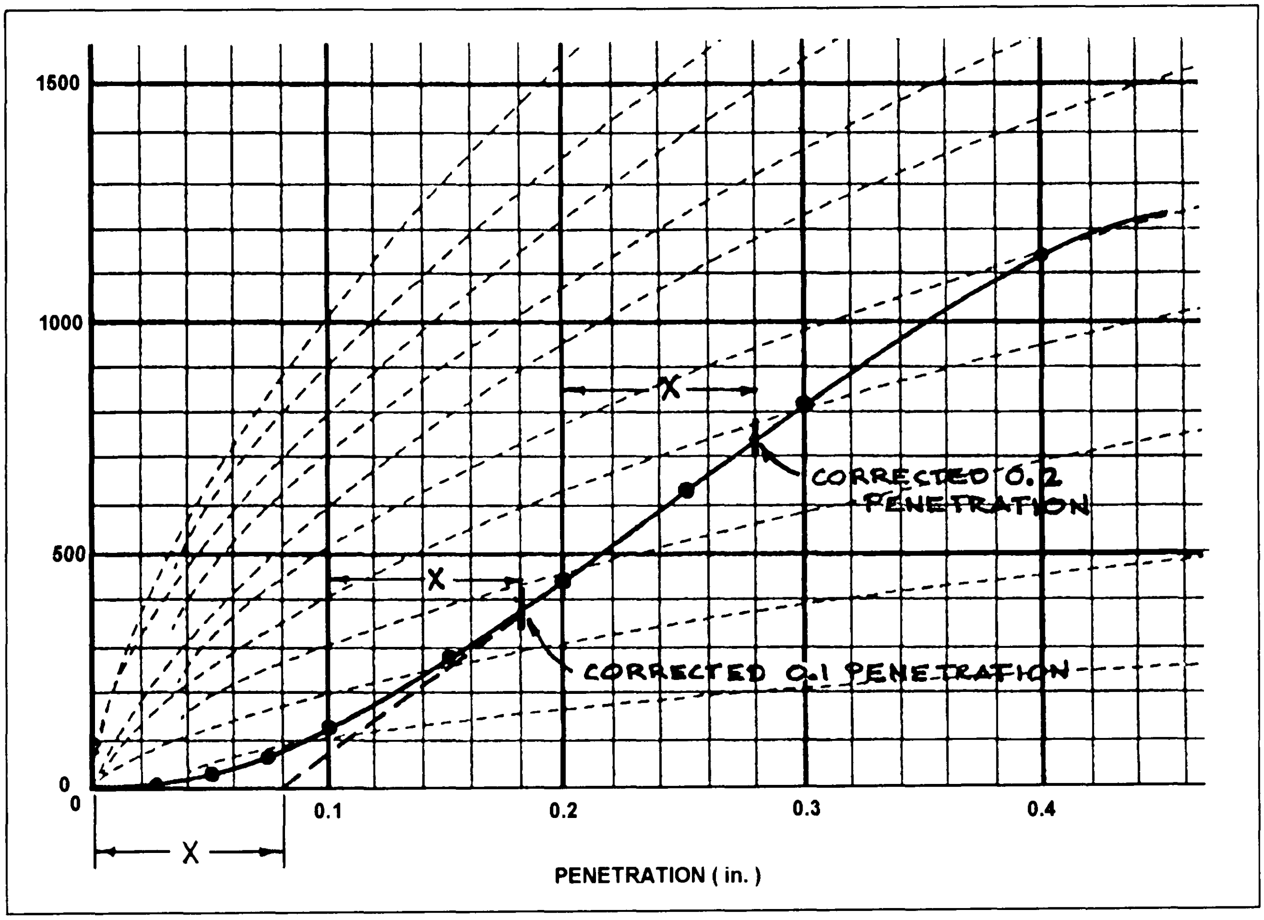


Figure 13-12.—Adjusting the zero point of the curve.

indicates that the proving-ring dial used for this test contained a previously determined index error of 0.003 inch. An error of this kind develops as a result of repeated compressions of the proving ring during testing.

The figures under **total load** are the results obtained by multiplying the corrected dial reading by the proving-ring constant. Each **unit load** was obtained by dividing the total load by 3.

Figure 13-11B is the reverse side of the CBR test data sheet. This side of the data sheet is used to plot the unit loads against the penetration depths to determine if a correction to the unit load is necessary.

In figure 13-11B you see the curve for sample SF-PI-4 that we have been discussing. The convex shape of this curve indicates that no corrections were necessary. Sometimes, however, surface irregularities in the soil sample or disturbances during the test will result in curves having an initially concave shape, such as shown in figure 13-11B for samples SF-PI-5 and SF-PI-6. This shape indicates that a correction is necessary to obtain the true or corrected load. In this case, you must first adjust the zero point of the curve. Figure 13-12 illustrates the procedure you should use to adjust the zero point. First, draw a line that is tangent to the steepest portion of the concave curve and extend the tangent to the zero base line. The point of intersection of the tangent and the base line is the new zero-penetration point. The distance of the new zero point from the original zero point (distance X) is the distance that the 0.1 and 0.2 points are moved to the right to establish the corrected unit load.

Finally, let's look again at figure 13-11A and discuss how the CBR values are determined. To compute the CBR values, you divide the unit load (or corrected unit load) at 0.1 and 0.2 inch by the standard unit loads of 1,000 and 1,500 psi, respectively. Each result is then multiplied by 100 to obtain the CBR in percent. The CBR is usually selected at 0.1 inch; however, when the CBR at 0.2 inch is greater, you should first rerun the test and then if the check tests give similar results at 0.2-inch penetration, the CBR at 0.2 inch should be used.

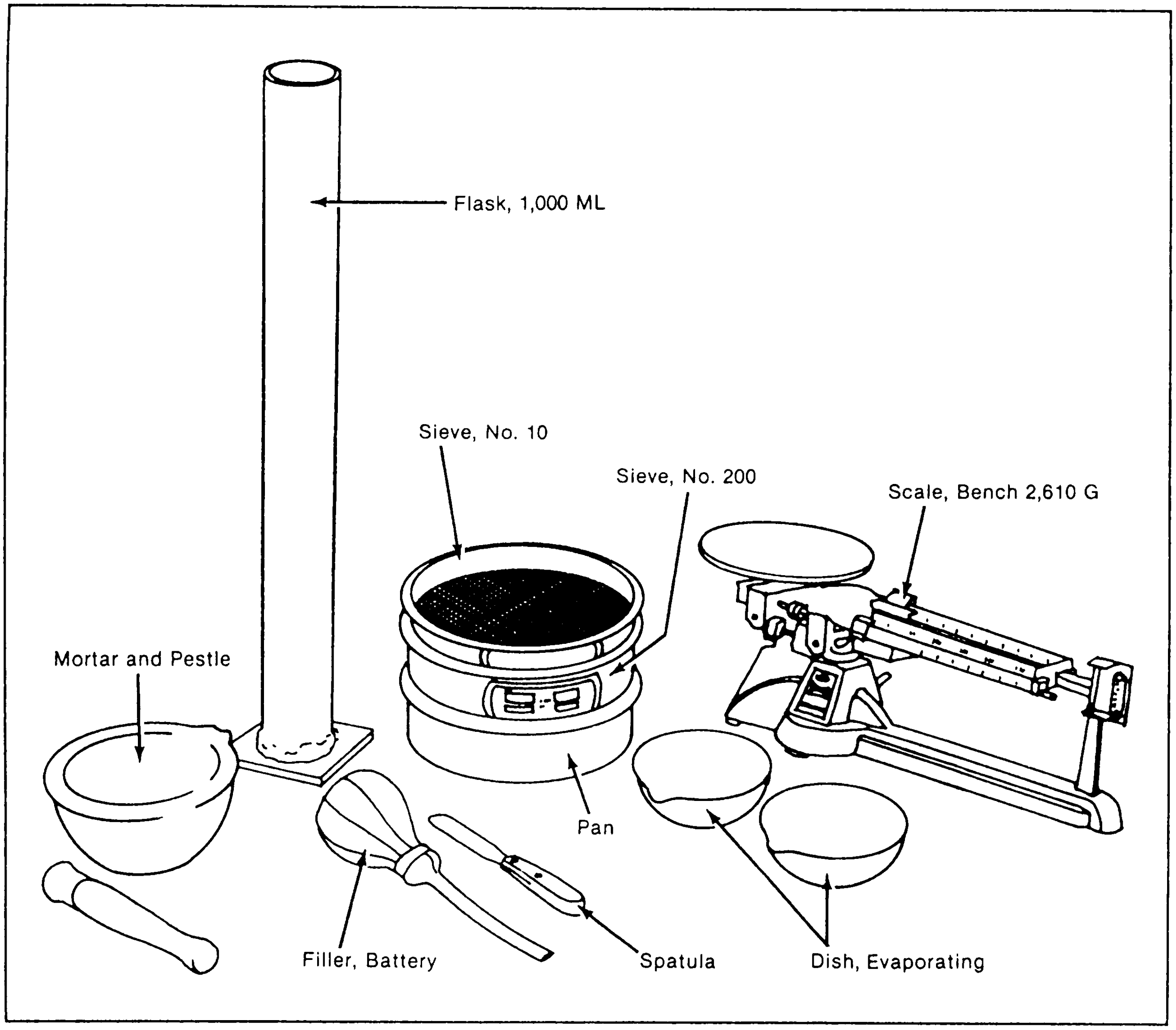


Figure 13-13.—Apparatus for grain size distribution by hydrometer analysis.

HYDROMETER ANALYSIS

You learned in the EA3 TRAMAN that a soil is considered susceptible to frost when it contains 3 percent or more by weight of particles smaller than 0.020 mm in diameter. To determine whether or not a soil contains an excessive amount of that size particle, you must perform a particle-size analysis of the materials passing the No. 200 (0.074-mm) sieve. You do this by hydrometer analysis. This TRAMAN discussion identifies the items used for a hydrometer analysis and will briefly summarize the procedures used. For a full discussion of the procedures, you should refer to NAVFAC MO-330 or to ASTM D 422. You also should review the topic of hydrometer analysis on page 15-24 of the EA3 TRAMAN before continuing with the following discussion.

Apparatus

Figure 13-13 shows some of the items that you will need to perform a hydrometer analysis. Another item you will need is an ASTM hydrometer (fig. 13-14). ASTM hydrometers are graduated by the manufacturer to read in either specific gravity or in grams per liter and are calibrated at a standard temperature of 68°F (20°C). Other needed items are a dispersion cup and stirrer (fig. 13-15), a thermometer accurate to 1°F (0.5°C), and a clock, or watch, with a second hand.

Sample Preparation and Test Procedure

Samples for hydrometer analysis are taken from representative material finer than the No. 10 sieve. The approximate size of the sample varies according to the type of soil being tested. For clays and silty soils, you

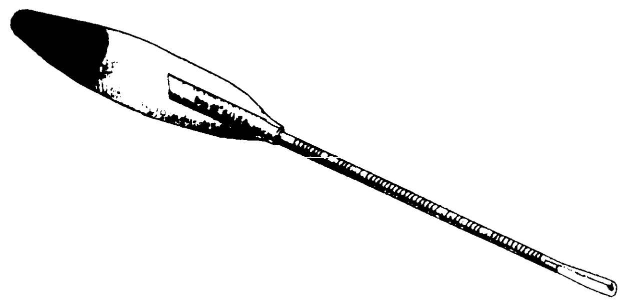


Figure 13-14.—ASTM hydrometer.

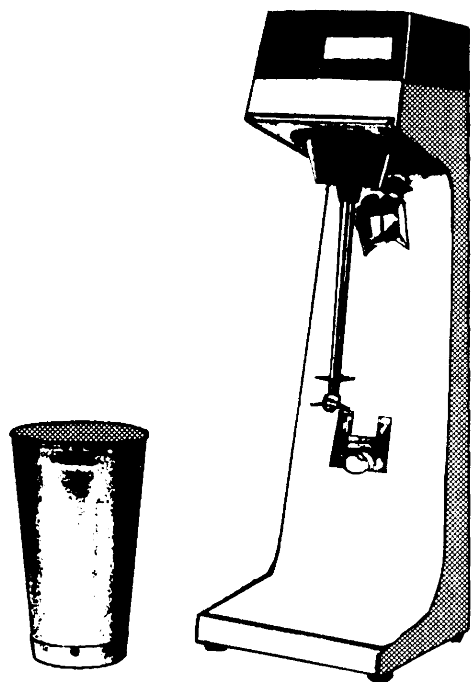


Figure 13-15.—Dispersion cup and stirrer.

will need 30 to 50 grams of air-dry material. When the sample is mostly sand, you will need approximately 75 to 100 grams.

First, place the sample in an evaporating dish. Then pour a solution of water (distilled or demineralized) and a dispersing agent, such as sodium hexametaphosphate, over the sample to make a soil-water slurry. Only enough water to submerge the sample completely and enough dispersing agent to keep the soil particles from flocculating (adhering to each other in clusters) should be used. After it has soaked for approximately 16 hours, the soil-water slurry is transferred to the dispersion cup (fig. 13-15) and is mixed for 1 to 10 minutes depending on the plasticity of the soil.

Next, you transfer the soil-water suspension to a 1,000-milliliter (mL) sedimentation cylinder and add distilled or demineralized water to fill the cylinder to the

HYDROMETER ANALYSIS

PROJECT: Heliport Proposal			DATE: 23 AUG 94
BORING NO.: B-1, 4	SAMPLE OR SPECIMEN NO.: B-1, 4A	CLASSIFICATION:	
DISH NO.: 1	GRADUATE NO.: 1		HYDROMETER NO.: 477252
DISPERSING AGENT USED: Calgon			QUANTITY: 20 Ml
DISPERSING AGENT CORRECTION: C_d = 1.5		MENISCUS CORRECTION: C_m = 0.5	

TIME	ELAPSED TIME MIN	TEMP °C	HYDRO READING (R')	CORRECTED READING (R)	PARTICLE DIAMETER (D), mm	TEMP CORRECTION (m)	R + m	PERCENT FINER PARTIAL	PERCENT FINER TOTAL
0833	0								
0834	1	19.0	60.0	60.5	.0385	-0.2	58.8	72.7	11.95
0835	2	19.0	57.0	57.5	.0280	-0.2	55.8	69.1	11.35
0837	4	19.0	52.0	52.0	.0200	-0.2	50.8	62.9	10.33
0848	15	19.5	42.0	42.5	.0130	-0.1	40.9	50.6	8.32
0903	30	20.0	33.0	33.5	.0090	0.0	32.0	39.6	6.51
0933	60	20.0	28.0	28.5	.0068	0.0	27.0	33.4	5.49
1033	120	20.5	24.0	24.5	.0048	+0.1	23.1	28.6	4.70
1233	240	22.0	20.0	20.5	.0035	+0.4	19.4	24.0	3.95
0833	1440	20.0	17.0	17.5	.0015	0.0	16.0	19.8	3.25

WEIGHT IN GRAMS		
Dish plus dry soil		219.5
Dish		138.7
Dry soil	W_o	80.8

Specific gravity of solids, G_s = 2.48

Corrected hydrometer reading (R) = hydrometer reading (R') + C_d + C_m

The particle diameter (D) is calculated from Stokes' equation using corrected hydrometer reading. Use nomographic chart for solution of Stokes' equation.

Hydrometer graduated in specific gravity

$$\text{Partial percent finer} = \frac{G_s}{G_s - 1} \times \frac{100}{W_o} (R + m)$$

Hydrometer graduated in grams per liter

$$\text{Partial percent finer} = \frac{100}{W_o} (R + m)$$

$$\text{Total percent finer} = \text{partial percent finer} \times \frac{W_s - W_l}{W_s}$$

W_s = total oven-dry wt of sample used for combined analysis

W_o = oven-dry wt in grams of soil used for hydrometer analysis

W_l = oven-dry wt of sample retained on No. 200 sieve

REMARKS: Frost Group = F-2
Original sample wt. = 2045. gms
Sample wt. retained on #200. 1799.6 gms

TECHNICIAN	COMPUTED BY	CHECKED BY
Cummings	Anderson	Gaines

DD Form 1794, FEB 71

Figure 13-16.—Data sheet for hydrometer analysis.

1,000-mL graduation. Bring the suspension to the temperature expected to prevail during the test.

Vigorously agitate the solution for 1 minute before taking and recording (fig. 13-16) your first hydrometer reading. Then, without further agitating the solution, take and record additional readings after elapsed times of 4, 15, and 30 minutes and 1, 2, 4, and 24 hours. Remove the hydrometer from the suspension after each reading and place it in a graduate of clean water.

Calculations

Readings taken with the hydrometer require correction due to the following factors: (1) the difference between the test temperature at each reading and the standard temperature of 68°F, (2) the affect of the dispersing agent on the liquid density of the soil-water suspension, and (3) the difficulty of reading the hydrometer at the meniscus of the murky soil-water suspension. The manner in which the correction factors are determined and applied to obtain corrected readings can be found in ASTM D 422 and NAVFAC MO-330. The corrected readings are used to determine the percent passing and the particle sizes corresponding to each reading.

As you know, the larger particles in a soil-water suspension settle more rapidly than the smaller particles; therefore, for each hydrometer reading, the percent passing is the percentage of soil remaining in suspension at the level at which the hydrometer measures the density of the soil-water suspension. That percentage, for each hydrometer reading, can be calculated using the formulas given in NAVFAC MO-330 or ASTM D 422. The particle sizes corresponding to each of those percentages is calculated on the basis of Stokes' law, that relates the terminal velocity of a free-falling sphere in a liquid to its diameter. To calculate the sizes, use the formulas given in ASTM D 422 or use the nomograph procedure discussed in NAVFAC MO-330.

CONCRETE AND CONCRETE TESTING

As you learned in the EA3 TRAMAN, concrete is one of the most economical, versatile, and universally used construction materials. It is one of the few building materials that can be produced directly on the jobsite to meet specific requirements. In this section, you will study the materials used to produce concrete and you will further your knowledge of concrete testing.

COMPOSITION

Concrete is a synthetic construction material made by mixing cement, fine aggregate, coarse aggregate, and water together in proper proportions. The following paragraphs discuss each of these materials:

Cement

Cement is a substance that hardens with time and holds or entraps objects or particles in a definite relationship to each other. For concrete, **portland cement** is usually used. Portland cement is manufactured by a standardized process consisting of grinding limestone and clay, mixing them in proportions, heating the mixture to a high temperature to form clinkers, and then pulverizing the clinkers so that 95 percent of the material will pass through a No. 200 sieve. The following paragraphs describe the various types of Portland cement:

- TYPE I. **Normal portland cement** is an all-purpose type used to make ordinary concrete pavements, buildings, bridges, masonry units, and the like.

- TYPE II. **Modified portland cement** is a type that generates less heat during the curing process than Type I. The hydration process generates heat that, in a large mass of concrete, can become high enough to affect the concrete adversely. Type II is also more sulphur-resistant than Type I. Sulphur exists in water or soil having a high alkali content and has an adverse effect on the concrete.

- TYPE III. **High-early-strength portland cement,** as the name suggests, is used where a high strength is needed quickly. That maybe due to a demand for early use, or in cold-weather construction to reduce the period of protection against low or freezing temperatures.

- TYPE IV. **Low-heat portland cement** has the heat-resistant quality of Type II, but to a higher degree. It develops strength at a slower rate than Type I but helps prevent the development of high temperatures in the structure with the attendant danger of thermal cracking upon later cooling.

- TYPE V. **Sulphate-resistant portland cement** has a higher degree of sulphate resistance than Type II and is for use where high sulphate resistance is desired.

Other types of cements maybe variations of the five types above or may be special types. Some of these types are as follows:

- TYPE IS. **Portland blast-furnace slag cement** uses granulated slag, which is rapidly chilled or quenched from its molten state in water, steam, or air. The slag (from 25 to 65 percent of the total weight of the cement) is interground with cement clinker. This cement is for general use in concrete construction.

- TYPE IP. **Pozzolan cement** uses a mixture of from 15 to 40 percent of pozzolan with the cement clinker. Pozzolan is a siliceous or siliceous and aluminous material, such as fly ash, volcanic ash, diatomaceous earth, or calcined shale. The strength of concrete made with pozzolanic cements is not as great as concrete made with the same amount of Portland cement, but its workability may be better for some uses.

- AIR-ENTRAINED CEMENT. Concrete made with **air-entrained cement** is resistant to severe frost action and to salts used for ice and snow removal. It is produced by adding air-releasing materials to the clinker, as it is ground. In general, air-entrainment may be controlled to a much greater extent by the use of admixtures with normal cements during mixing. This combination results in a concrete with tiny, distributed, and separated air bubbles (up to millions per cubic foot). The entrained air bubbles improve the workability of the fresh concrete. These bubbles reduce the capillary and water channel structure within hardened concrete and restrict the passage of water. That prevents the buildup of damaging water pressure in the pores when concrete is frozen; therefore, air-entrained concrete has greatly increased durability in outdoor locations exposed to freezing weather. types I, II, III, IS, and IP cements are available as air entrained. The letter *A* is added after the type to signify that it is air entrained; for example, air-entrained pozzolan cement is known as Type IP-A.

In addition to the types described above, there are white cement, waterproofed cement, and oil well cement. White cement is made from selected materials to prevent coloring, staining, or darkening of finished concrete. Waterproofed cement has water-repellent materials added. The finished and set concrete has a water-repellent action. Oil well cement is specially made to harden properly when used under high temperature in deep oil wells.

Identification of Cement

The EA assigned to a construction battalion may be asked to identify unknown material received by the supply department. Every effort should be made to identify the material directly by obtaining and, if necessary, translating, all labels, tags, shipping documents, manufacturing sheets, and all other papers that may contain applicable information. When this does not produce satisfactory results, the simple procedures outlined in the following paragraphs generally will supply enough information to permit a tentative, if not conclusive, identification. The positive identification of cement, because of the wide variety of related- or similar-appearing materials, requires a complete chemical analysis and physical tests.

Make the following tests to determine whether the material is a cement, and then attempt an identification of its type.

HARDENING.— Select a small sample of the material and mix it with enough water to make a plastic paste of a consistency similar to that generally used in cement mortars. Then mold it into a pat about 3 inches in diameter and 3/4 inch thick. Observe the paste several times an hour to determine whether or not the paste is setting (hardening). The cement has attained a final set when the surface is hard enough to be unmarked when a pencil point or a fingernail is pressed against it with moderate force. If it sets within 1 to 10 hours, the material is probably a cement.

COLOR.— If it has been fairly well established that the material in question is a cement, color may serve as a means of further classification. If the material is gray, it is likely to be a portland cement; if brownish gray, it may be a natural cement; if black, an aluminous cement; and if white, it probably is hydraulic lime, plaster, or possibly white Portland cement,

AIR-ENTRAINED CEMENT.— In the test to determine whether or not a given material contains an air-entraining agent, place a sample of the material in a glass cylinder to a depth of about 1 inch. Add water to a depth of about 6 inches and shake the cylinder and its contents vigorously. If a considerable volume of stable, persistent foam forms on the surface, the cement probably contains an air-entraining agent.

HIGH-EARLY-STRENGTH CEMENT.— A way to recognize high-early-strength cement (Type III) is to make a batch of concrete using the unknown material and at the same time a similar batch using a known cement. Concrete that contains high-early-strength cement will usually harden in less time than concrete containing regular portland cement. High-early-strength concrete, if molded into standard concrete beams and tested after 3 days for flexural strength, should have a modulus of rupture more than 150 pounds per square inch higher than similar specimens containing regular portland cement concrete. A discussion of flexural strength testing will follow later in this chapter.

Water

Water plays an important part in the concrete mix. Its principal uses are to make the mix workable and to start hydration. Any material in the water that retards or changes the hydration process is detrimental. A good rule of thumb is “if it’s good enough to drink, it may be used for concrete.”

ORDINARY WATER.— The materials found in some types of water include organic compounds, oil, alkali, or acid. Each has its effect on the hydration process. Organic material and oil tend to coat the aggregate and cement particles and to prevent the full chemical reaction and adherence. The organic material may also react with the chemicals in the cement and create a weakened cementing action, thus contributing to deterioration and structural failure of the concrete. Alkalis, acids, and sulfates in the water tend to react with the chemicals in the cement. The result is inadequate cementing and weakened concrete. Water must be free of these chemicals to be used in concrete mixing.

SEAWATER.— The salts in seawater are normally thought of as being corrosive; however, seawater is used sometimes in concrete mixing with satisfactory results. A loss of 10 to 20 percent in compressive strength can be expected when the same amount of seawater as fresh water is used. That can be compensated somewhat by reducing the water-cement ratio.

Aggregates

The aggregates normally used for concrete are natural deposits of sand and gravel, where available. In some localities, the deposits are hard to obtain and large rocks must be crushed to form the aggregate. Crushed aggregate usually costs more to produce and will require more cement paste because of its shape. More care must be used in handling crushed aggregate to prevent poor mixtures and improper dispersion of the sizes through the finished concrete. At times, artificial aggregates, such as blast-furnace slag or specially burned clay, are used.

TYPES OF AGGREGATE.— Aggregates are divided into two types as follows:

- FINE AGGREGATE. "Fine aggregate" is defined as material that will pass a No. 4 sieve and will, for the most part, be retained on a No. 200 sieve. For increased workability and for economy as reflected by use of less cement, the fine aggregate should have a rounded shape. The purpose of the fine aggregate is to fill the voids in the coarse aggregate and to act as a workability agent.

- COARSE AGGREGATE. Coarse aggregate is a material that will pass the 3-inch screen and will be retained on the No. 4 sieve. As with fine aggregate, for increased workability and economy as reflected by the use of less cement, the coarse aggregate should have a rounded shape. Even though the definition seems to limit the size of coarse aggregate, other considerations must be accounted for.

When properly proportioned and mixed with cement, these two groups yield an almost voidless stone that is strong and durable. In strength and durability, aggregate must be equal to or better than the hardened cement to withstand the designed loads and the effects of weathering.

It can be readily seen that the coarser the aggregate, the more economical the mix. Larger pieces offer less surface area of the particles than an equivalent volume of small pieces. Use of the largest permissible maximum size of coarse aggregate permits a reduction in cement and water requirements.

One restriction usually assigned to coarse aggregate is its maximum size. Larger pieces can interlock and form arches or obstructions within a concrete form. That allows the area below to become a void, or at best, to become filled with finer particles of sand and cement only. That results in either a weakened area or a cement-sand concentration that does not leave the proper proportion to coat the rest of the aggregate. The maximum size of coarse aggregate must be no larger than the sizes given in table 13-1. The capacity of the mixing equipment may also limit the maximum aggregate size.

GRADATION.— Gradation of aggregate refers to the amount of each size of particle used in the mix. Too large a proportion of coarse aggregate leaves voids that require more cement paste to fill. That affects the

Table 13-1.—Maximum Recommended Size of Coarse Aggregate

Structure	Minimum dimension—inches			
	2 1/2 - 5	6 - 11	12 - 29	30 or more
Reinforced wall, beams, and columns	1/2 - 3/4	3/4 - 1/2	1 1/2 - 3	1 1/2 - 3
Unreinforced walls	3/4	1 1/2	3	6
Slabs, heavily reinforced	3/4 - 1	1 1/2	1 1/2 - 3	1 1/2 - 3
Slabs, lightly reinforced	3/4 - 1 1/2	1 1/2 - 3	3	3 - 6

Note: Maximum size not to exceed one fifth of minimum dimension of a wall or similar structure, one third of slab thickness for horizontal slab, or three fourths of minimum clear spacing between reinforcing bars.

economy of the mix. Too much fine aggregate, besides preventing a good bonding, also increases the surface area that must be coated with cement paste. That weakens the concrete. Good gradation results in a dense mass of concrete with a minimum volume of voids, an economical mix, and a strong structure. Optimum strength, watertightness, and durability in the hardened concrete require careful control of aggregate gradation.

DURABILITY.— Durability is the ability to resist the elements of weathering and the load pressures. Weak or easily crushed rock or other mineral particles that break down under the applied loads will cause changes in the internal stresses and a breakdown of the concrete. Rocks or mineral particles that are absorptive or susceptible to swelling when saturated will disintegrate when acted upon by different weather conditions. Freezing moisture causes expansion stresses that can easily rupture absorptive rocks. Radiant heat from the sun causes rocks to swell. If the heat is then followed by sudden cooling because of a shower and temperature drop, shrinkage and a breakdown of some rocks frequently occur. The aggregate must be chosen to withstand these forces of nature.

DETERIORATION.— Deterioration of concrete, in many cases, can be traced to the aggregate. An excessive amount of organic material in or on the aggregate prevents the cement paste from forming an adequate bond with the aggregate particles. A large percentage of clay or fine silts adhering to the aggregate may prevent the cement paste from reaching the particles. That results in a structurally weak concrete that also is susceptible to breakdown by weathering. Washing the aggregate to remove the silts, clays, and organic material prevents this problem.

CHEMICAL COMPOSITION.— Chemical composition of the aggregate is also important. Any chemical reaction between aggregate and cement in the presence of water reduces the hardening and cementing process. Any reduction in the amount of water-cement paste caused by a chemical reaction reduces the amount available to bond to the aggregate. This result is similar to one caused by an insufficient amount of cement.

Tests for Aggregates

For aggregate tests to be worthwhile, the sample secured for testing must be representative of the supply of aggregates. If possible, samples should represent the processed and ready-for-use aggregate. Sufficient samples should be taken from the processing plant discharge to represent the material in the stockpile. The sample should contain at least four times as much material as is needed for testing and should be reduced to the size desired for testing by quartering. The standard method for sampling aggregate can be found in ASTM D 75.

Stockpile samples should be taken at or near the base, at about the middle, and at the top of the pile. Three or four such samples should be taken and recombined. A board shoved into the pile just above the point of sampling will prevent the material above the sampling point from falling or sifting into the sample.

Unprocessed sources of sand and gravel should be taken by channeling exposed faces, or they should be taken from pits if exposures are not available. Take care to ensure that the samples include only those materials that are below the overburden or strip zone.

TESTS FOR GRADATION.— A sieve analysis indicates whether an aggregate is coarse or fine and whether it is evenly or unequally distributed between the larger and smaller sizes. This information is useful in deciding whether the aggregate will make good concrete. Analysis methods can be found in ASTM C 136. Table 13-2 shows the acceptable gradation limits.

Table 13-2.—Desirable Gradation for Aggregates in Concrete

a. Coarse aggregate.

Sieve size in.	Percent passing indicated sieve: 3	2½	2 No. 357	1½ No. 467	1 No. 57	¾ No. 67	½ No. 7
3	100						
2½	88	100					
2	76	86	100				
1½	61	69	81	100			
1	44	49	58	72	100		
¾	33	38	44	55	76	100	
½	21	24	28	35	48	63	100
⅜	14	16	18	23	32	41	65
No. 4	----	----	----	----	----	----	----

b. Fine aggregate.

Sieve size U.S. Standard	Percentages by weight passing
4	95–100
8*	80–100
10	75–95
16*	50–85
20	40–75
30*	25–60
40	20–50
50*	10–30
60	10–25
100	2–10

*ASTM C 33 specifies U.S. Standard sieve sizes No. 8, 16, 30, and 50 instead of No. 10, 20, 40 and 60. Both ranges are provided for convenience.

Fine aggregate grading limits are specified by the American Society for Testing and Materials; however, since many gradings of fine aggregate can produce a good quality concrete, the engineer should compute the **fineness modulus** of the aggregate and compare it to the specified concrete class requirements.

The fineness modulus is an empirical factor that gives a relative measure of the proportions of fine and coarse particles in an aggregate. It is a value widely used to indicate the relative fineness or coarseness of a fine aggregate. To obtain the fineness modulus, sieve a 500-gram sample of sand through a series of sieves (Nos. 4, 8, 16, 30, 50, and 100). Convert the weight retained on each sieve into a cumulative percentage retained, starting with the No. 4 sieve. Divide the sum of the six percentages by 100. The resulting answer is the fineness modulus. Typical fineness modulus values are as follows:

Fine sand = 2.20 to 2.60

Medium sand = 2.60 to 2.90

Coarse sand = 2.90 to 3.20

TESTS FOR SOUNDNESS.— Soundness is the property of aggregate to resist disintegration when subjected to freezing and thawing. Two methods are used to test for soundness. In the **freeze-thaw test** method (ASTM C 666), concrete specimens, made with the aggregate in question, are placed in water and then subjected to alternate cycles of freezing and thawing. An alternate method, requiring considerably less equipment and time, is the **salt test.** This procedure involves solutions of special salts (sodium sulfate or magnesium sulfate) in which the aggregate is immersed and saturated. The crystals of these salts are permitted to grow that creates a disruptive force similar to freezing water. You can find the procedures to perform the salt test in ASTM C 88 and in NAVFAC MO-330.

TESTS FOR IMPURITIES.— The quality of aggregate is another important consideration. The presence of organic material, excessive quantities of silt or clay and shale, or other water-absorbing particles can be detrimental to the concrete strength, watertightness, and durability. Tables showing the recommended limits of deleterious materials in fine and coarse aggregate can be found in NAVFAC MO-330.

Test for Material Finer Than No. 200 Sieve.— The extremely fine mineral material (clay, silt, dust, or loam) occurring in most aggregates can affect concrete in two ways. The added surface area of the fine particles picks up the cement paste and reduces the amount available to bind and hold the aggregate. The small particles also tend to float up to the surface when the concrete is finished (especially when wet mixes are used). That results in a surface covered by hairline cracks and a tendency for the fines to dust off when dry. For some purposes a small amount of fine material may improve workability; however, amounts in excess of 3 to 5 percent of the total weight of the aggregate are generally considered harmful to the concrete.

The specific procedures that you should follow when testing for these fine materials can be found in ASTM C 117 and in NAVFAC MO-330. Briefly, you oven-dry and weigh a sample of the aggregate. Then the dried sample is brought to suspension in water and is carefully poured through a nest of sieves (No. 16 and No. 200) until the wash water is clear. Finally, the material remaining on the sieves is oven-dried and weighed. The percent of material finer than the No. 200 sieve is then calculated using the following formula:

$$P = \frac{W_d - W_{dw}}{W_d} \times 100$$

Where:

P = Percentage of fines

w_d = original dry weight of sample

W_{dw} = dry weight after washing

The method described above is accurate, but time-consuming. When time is critical and less accurate results are acceptable, you can place a 1,000-gram sample into a quart mason jar to a depth of about 2 inches. Then fill the jar three-fourths full of water, shake the mixture vigorously, and allow it to stand for 1 hour. The silt and clay will form a layer at the top of the sand. If the layer is more than 1/8 inch thick, the material has more than 3 percent fines and should be washed before using.

Test for Clay Lumps and Friable Particles.— This test is performed on the material remaining after you determine the material finer than the No. 200 sieve. The size of samples needed and the specific test procedures that you should use are in ASTM C 142 or in NAVFAC MO-330. Spread the sample in a thin layer on the bottom of a flat pan and cover it with distilled water. After about 24 hours, you break up all particles by crushing them between the fingers. Next, you remove the broken clay lumps and friable particles by wet sieving over the appropriate one of the following sieves: aggregate—No. 20; No. 4 to 3/8 inch—No. 8; over 3/8 inch—No. 4.

Oven-dry and weigh the material retained. Then you can calculate the percentage of clay lumps and friable particles using the following equation:

$$P = \frac{W_1 - W_2}{W_1} \times 100$$

Where:

P = percent of clay lumps and friable particles

W_1 = original weight of test sample

W_2 = weight of retained sample after wet sieving and drying

Test for Undesirable Lightweight Material.— Soft, laminated pieces of aggregate, such as chert or shale, are harmful to concrete. Coal and lignite, also, are harmful and are distinguished from the lightweight materials by the brownish black or black color of the particles. Visual examination of the coarse aggregate will often show these minerals. The amount of these minerals in an aggregate can be determined by submersing the aggregate in a liquid with a specific gravity that will allow the shale or other light particles to float and heavier particles to sink.

For specific testing procedures, you should refer to ASTM C 123 or to NAVFAC MO-330. Briefly, you perform the test by first sieving the dried sample over a No. 50 sieve for fine aggregate and a No. 4 sieve for coarse aggregate. Weigh the sample and then place it into a heavy liquid, such as zinc chloride (specific gravity of 1.95 at 78°F). Agitate the mixture to allow the lightweight particles to rise to the surface and skim them off. When repeated agitation causes no further particles to rise, you wash the sample in alcohol and then dry and weigh it. The percentage of undesirable, lightweight particles can then be calculated using the following formula:

$$L = \frac{W_1}{W_2} \times 100$$

Where:

L = percentage of lightweight material

W_1 = *dry* weight of lightweight material

W_2 = dry weight of initial sample retained on No. 50 sieve for fine aggregate or No. 4 sieve for coarse aggregate

Color Test for Organic Matter.— Any sand that gives a color darker than the standard of this test probably contains an excess of organic matter that will reduce the strength of the concrete in which the sand is used. If you determine that organic matter is present, it is possible that it can be removed by washing; if not, better sand should be obtained. If neither of these things can be done, it will be necessary to use a lower water-cement ratio and control the concrete production carefully to obtain the desired strength.

For the color test, you will need the items illustrated in figure 13-17. To perform the test, you add the sample being tested to a solution of sodium hydroxide and water. After allowing the sample to stand for 24 hours, you then compare the color of the liquid above the sample to a standard color solution consisting of tannic acid, alcohol, and sodium hydroxide. If the liquid above the sample is darker in color than the standard solution, the sand may contain organic impurities. NAVFAC MO-330 provides full details for preparing the solutions and performing the test.

As an alternative, the color of the liquid above the sample can be compared with the colors given in the ASTM standard color plate. Then decide whether the sand contains an excessive amount of organic matter.

SPECIFIC GRAVITY, ABSORPTION, AND SURFACE MOISTURE.— These tests must be performed on the aggregate before the necessary calculations can be made to design a concrete mixture. For aggregates used in portland cement concrete, measurements are made to determine the bulk specific gravity of the aggregates in a saturated, surface-dry (SSD) condition. Specific gravity is thus based on determining the total volume occupied by the aggregate particles, including the permeable pore space.

Absorption and surface moisture determinations are necessary to calculate the amount of mixing water used in a concrete mixture. Absorption, determined as a percentage, represents the moisture content of the aggregate when the aggregate is in a SSD condition. Surface moisture is the water that is present in both fine and coarse aggregate, exceeding that which corresponds to a SSD condition.

Concrete-mixture design is discussed at the EA1 level in Part 2 of this TRAMAN.

Specific Gravity and Absorption, Coarse Aggregate (ASTM C 127).— The summarized steps in determining the bulk specific gravity of SSD coarse

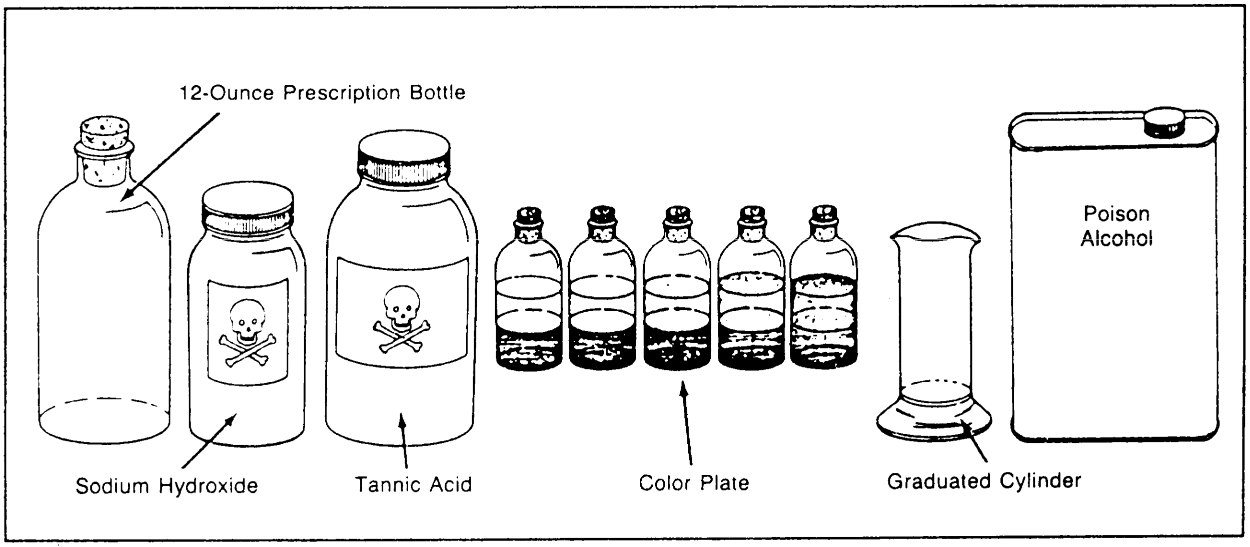


Figure 13-17.—Items required for testing sand for organic matter.

aggregate and the percentage of absorption are as follows:

1. Dry a representative sample of the aggregate (approximately 5,000 grams) to a constant weight at 110°C. Then cool the sample for 1 to 3 hours, immerse it in water, and allow it to soak for about 24 hours.

2. Remove the sample from the water and dry it to a saturated, surface-dry condition by rolling the sample in an absorbent cloth until visible films of water are removed and the particle surfaces appear slightly damp.

3. Weigh the sample in the SSD condition and record the weight to the nearest 0.5 gram. Then immediately place the sample into a container or wire basket and determine its immersed weight (or weight in water) at 23°C. Be sure that any entrapped air is removed by shaking the container or basket while it is immersed. Record the immersed weight to the nearest 0.5 gram.

4. Dry the sample to a constant weight at 110°C, cool it for 1 to 3 hours, and then weigh the oven-dried sample. Record the weight to the nearest 0.5 gram.

5. The bulk specific gravity (SSD condition) and the percentage of absorption can now be calculated using the following formulas:

$$\textit{SSD bulk specific gravity} = \frac{B}{B - C}$$

And:

$$\%\ \textit{absorption} = \left(\frac{B - A}{A}\right) \times 100$$

Where:

A = weight of oven-dried sample in air (in grams)

B = weight of SSD sample in air (in grams)

C = immersed weight of saturated sample (in grams)

Specific Gravity and Absorption, Fine Aggregate (ASTM C 128).— The procedures for determining the bulk specific gravity of the fine aggregate in a SSD condition and the percentage of absorption are as follows:

1. Dry a representative sample of the fine aggregate (about 1,000 grams) to a constant weight at 110°C. Then cool the sample, immerse it in water, and allow it to soak for about 24 hours.

2. After the soaking is completed, spread the sample on a flat, nonabsorbent surface and stir it to obtain uniform drying. Continue drying the sample until it approaches a SSD condition.

3. Next, you place a water-absorption cone (fig. 13-18) large end down on a smooth surface and fill it loosely with the aggregate. Then lightly tamp the surface of the aggregate 25 times with the metal tamper.

4. Lift the cone vertically from the sand and observe the action of the sample. If it retains its conical shape, free moisture is present and continued drying (Step 2) followed by repeated tamping (Step 3) is required. If the sample slumps slightly, the fine aggregate has reached the desired SSD condition.

5. Weigh exactly 500 grams of the SSD sample and place it in a partially water-filled pycnometer top-and-jar assembly (fig. 13-19). Fill the jar with additional water to approximately 90 percent of its capacity.

6. Agitate the sample in the pycnometer assembly to remove any entrapped air, adjust the water temperature to 23°C, and fill the pycnometer to its calibrated capacity. Then weigh the filled pycnometer to the nearest 0.1 gram and record the weight.

7. Remove the sample from the pycnometer and dry it to a constant weight at 110°C. Then cool the sample in air for about 1 hour and weigh it. Record this weight to the nearest 0.1 gram.

8. Determine the weight of the pycnometer filled to its calibrated capacity with water at 23° + 1.7°C. Record this weight.

9. You can now calculate the specific gravity of the SSD fine aggregate and the percentage of absorption by using the following formulas:

$$\textit{SSD bulk specific gravity} = \frac{500}{B + 500 - C}$$

And:

$$\textit{\% absorption} = \left(\frac{500 - A}{A}\right) \times 100$$

Where:

A = weight of the oven-dried specimen in air (in grams)
B = weight of pycnometer filled with water (in grams)
C = weight of pycnometer, sample, and water (in grams)

Surface Moisture (ASTM C 70 and ASTM C 566).— A summary of the ASTM procedures used to determine the total moisture content and the percentage of surface moisture in either fine or coarse aggregate are as follows:

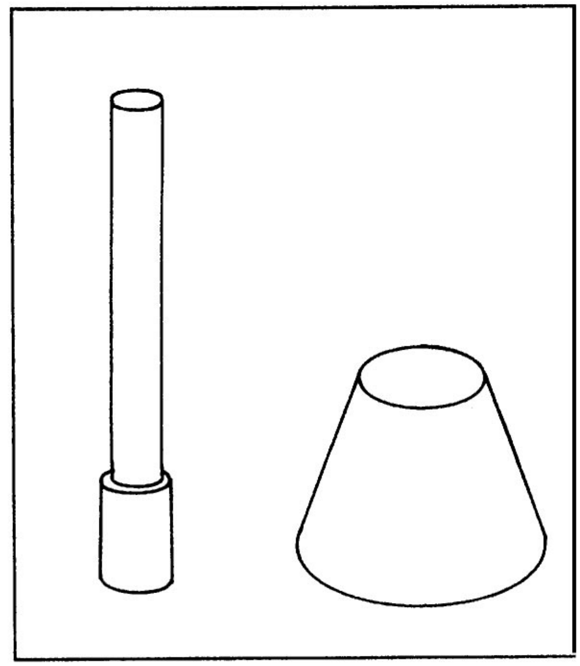


Figure 13-18.—Water-absorption cone and tamper.

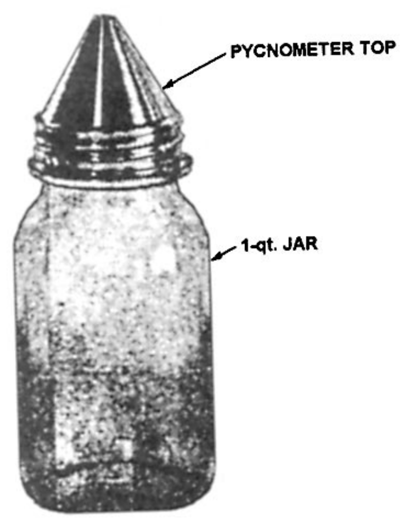


Figure 13-19.—Pycnometer top-and-jar assembly.

1. Secure and weigh a sample of the aggregate that is representative of the moisture content of the material being tested.

2. Dry the sample to a constant weight at 110°C. You should take care to avoid loss of material during testing. The sample is thoroughly dry when further

heating causes, or would cause, less than 0.1 percent additional loss in weight.

3. Weigh and record the weight of the oven-dried sample.

4. Calculate the total moisture content using the following formula:

$$P = (\frac{W - D}{D}) \times 100$$

Where:

P = total moisture content (percent)

W = weight of original sample (in grams)

D = weight of oven-dried sample (in grams)

The surface moisture is equal to the difference between the total moisture content and the absorption.

An alternate determination of surface moisture in fine aggregate is obtained by displacement as follows:

1. Select a representative sample of the fine aggregate weighing not less than 200 grams.

2. Weigh a pycnometer filled to the calibration mark with water.

3. Place the sample in the pycnometer half filled with water. Add additional water to the calibration mark and remove all entrapped air. Weigh the pycnometer, water, and sample.

4. Calculate the weight of the water displaced by the sample using the following formula:

$$V_s = W_c + W_s - W$$

Where:

V_s = weight of displaced water (in grams)

W_c = weight of water-filled pycnometer (in grams)

W_s = weight of sample (in grams)

W = weight of pycnometer, water, and sample (in grams)

5. Calculate the percent of surface moisture using the following formula:

$$P = (\frac{V_s - V_d}{W_s - V_s} \times 100$$

Where:

P = percent of surface moisture

V_s = weight of displaced water (in grams)

W_s = Weight of sample (in grams)

V_d = weight of sample in grams divided by the bulk specific gravity of the sample

ADMIXTURES

Several chemical agents, or admixtures, are available to improve workability, increase resistance to freezing and thawing, and compensate for inadequate curing time and conditions.

Accelerators

Sometimes it is desirable to accelerate the hydration reactions. The result is a high-early strength and a higher rate of heat production. This combination can be useful in winter operations. The addition of a chemical accelerator (generally calcium chloride) to the mix will produce the desired conditions. The amount specified is usually 2 percent of the weight of cement and rarely more than 3 percent. The main reaction with calcium chloride occurs within the first 3 days. The ultimate strength of concrete is not affected by the use of this chemical.

Retarders

Retarders are used when excessively high heat and too rapid setting of concrete would prevent full hydration. Many materials retard setting of concrete. Basically, these materials are types of fatty acids, starches, or sugars.

Workability Agents or Plasticizers

The workability of concrete is governed by the amount of aggregate in the mix. Where reduction of aggregate (or increase in cement) is impractical, workability is increased by adding a plasticizer. Air-entraining agents, when used, are plasticizers. Other substances include calcium chloride, lime, fly ash, and other pozzolans. Calcium chloride is also an accelerator. Lime increases the cementing properties of cement, as do pozzolans combined with lime. Fly ash is inexpensive compared to cement and is used as a partial replacement (up to as much as 50 percent) of the cement. It changes both the plastic and the hardened properties of concrete. Fly ash improves workability and reduces segregation, bleeding, and the heat of hydration. The concrete will not be as watertight as a cement-only concrete, nor will it have as much initial strength. Additional tests may have to be made to determine when to remove the forms. Its final strength, however, will be as great as a cement-only concrete.

Densifiers

Dense concrete is required in some types of construction, such as in prestressed structures. This density is achieved when cement particles are separated evenly throughout the mix or at least prevented from attaching to each other (flocculating). A detergent admixture will disperse the particles individually and will create a more uniform paste. These admixtures also reduce the formation of a cement gel that expands at the early stages of hydration and pushes the particles apart, thus increasing the volume. Prevention of this expansion results in a denser paste.

Waterproofing Agents

Watertightness can be controlled to a great extent by lowering the water-cement ratio. This may not always be practical, and sometimes even with a low water-cement ratio, capillaries still form through the concrete. Densifying or using an accelerator like calcium chloride improves the watertightness.

Air-Entraining Agents

The greatest improvement in watertightness and resistance to deterioration under freezing and thawing is obtained by incorporating 4 to 6 percent, by volume, of entrained air into the mix. Workability of fresh concrete is enhanced by such entrained air. Air-entrained cement contains the necessary admixture. Soaps, butylstearate, some of the fine pozzolans, and several proprietary compounds are available for use as air-entraining admixtures with ordinary cements. These agents minimize the formation of capillaries and plug the tiny holes with a water-repellant or sealing material. They provide small, uniformly spaced, discrete air voids that prevent the buildup of damaging pressures from the expansion of freezing water into ice.

CURING

Concrete does not develop its full strength until the chemical process of curing (or hydration) is complete. Curing takes place over an extended period—the most critical portion of which is from the day of placement through the 10th day. The extent and rate of curing depends upon the presence of moisture and the correct temperature within the mix.

Temperature

The ideal temperatures for concrete work are between 55°F and 70°F. Above this, rapid evaporation of moisture creates a problem. At lower temperatures, the curing or setting is delayed. Temperatures below 32°F stop the hydration process. Since the chemical action gives off some heat, some method must be used to keep the heat within the structure during times of low temperatures. Cold weather construction may even require heating the ingredients, or mix, and covering the emplaced concrete or providing a heated enclosure. In hot weather, extra care is required to prevent a high temperature rise and too rapid drying of the fresh concrete. Moistening the aggregate with cool water will lower the generated temperature. The water is kept cool as possible by the application of reflective white or aluminum paint to water supply lines and storage tanks. On massive construction, such as dams and heavy retaining walls, the mixing water is often cooled artificially or ice is substituted for part of the water. This ice must be melted by the time the concrete is fully mixed and ready to leave the mixer. Cement replacement materials (such as pozzolans of diatomaceous earth, pumicites, or fly ash) may be used to depress concrete temperature by reduction of the heat of hydration in a structure; however, pozzolans vary widely and may have adverse effects on strength, air content, and durability, if used in excessive amounts.

Moisture

Concrete curing depends upon chemical action in the presence of water. Any loss of moisture during the process by seepage or evaporation prevents complete hydration and development of optimum strength and watertightness. Saturating the subgrade on which the concrete will be placed will delay, if not prevent, seepage. Wood forms should be thoroughly wetted if they have not been treated otherwise. Covering the concrete without marring the surface as soon as possible after finishing is one method used to reduce evaporation. This covering may be some material, such as burlap, straw, or plastic film, or it may be a chemical curing compound that is sprayed over the finished surface. After the initial set is attained, water can be applied directly to the surface to keep the hydration process in action. This water application can be part of the temperature control. The increase on concrete compressive strength with age is shown by curves in

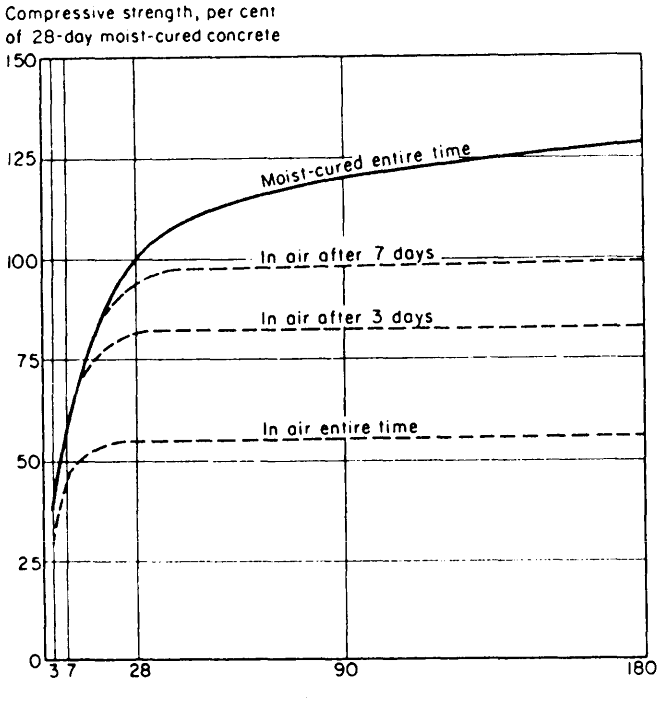


Figure 13-20.—Increase of concrete compressive strenth with curing age.

figure 13-20. Note the long-time gain in strength that occurs when proper temperature and moisture conditions are maintained.

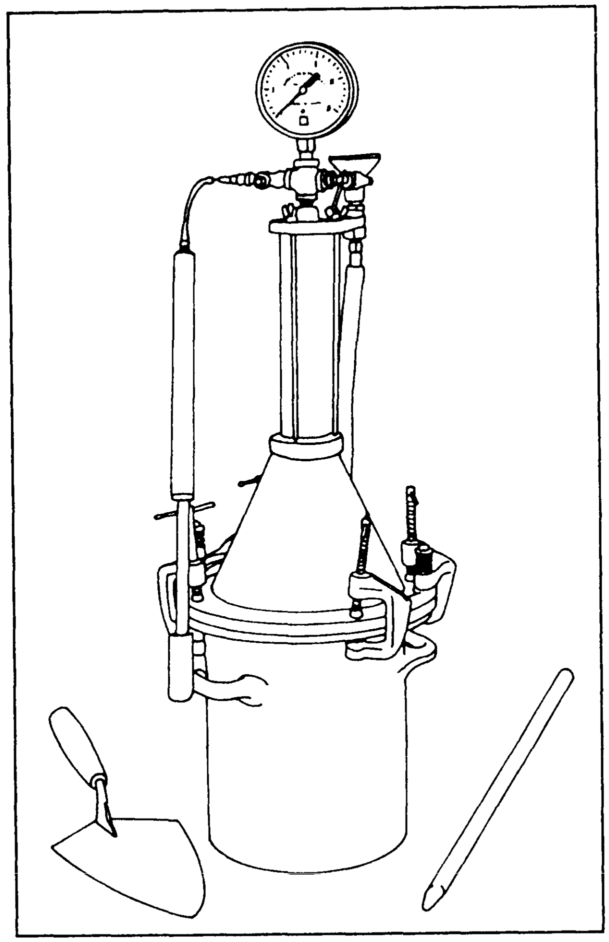


Figure 13-21.—Apparatus for air-content test.

CONCRETE TESTING

Several tests, such as slump, air content, and weight determination, are necessary to determine the quality of freshly mixed concrete. In addition, strengths tests are needed to determine whether a hardened concrete satisfies specified strength requirements. This section briefly discusses those tests.

Slump Test

As you know, the measure of the workability or consistency of a concrete mix is its slump. With too little slump, the mixture may be too difficult to work into the forms and around the reinforcing steel. On the other hand, with too much slump, the concrete ingredients may segregate and excessive bleeding or migration of water to the top surface of the freshly placed concrete may occur. Excess bleeding increases the water-cement ratio near the top surface of the concrete and results in a weak top layer with poor durability.

To determine whether a freshly mixed concrete satisfies the specified requirements for slump, you must perform a slump test. By now, you should be thoroughly familiar with the procedures of slump testing. If not, you should review the discussion of slump testing that is in the EA3 TRAMAN.

Air-Content Test (ASTM C 231)

An air-entraining admixture is added to the concrete mix so that enough air will be entrained to improve workability and durability of the mixture, but not enough to reduce strength substantially. Air-entraining cements may also be available for use in some military situations. The desired amount of air is generally from 4.0 to 7.5 percent of the total mix.

The equipment for determining the percentage of entrained air is included in the boxed test kit. The basic tool is the pressure type of indicator, as illustrated in figure 13-21. The equipment furnished in these kits varies with the manufacturers. Each kit contains the complete equipment for conducting the test, including a detailed instruction pamphlet and the calibration procedure for the particular meter. Before the air content of a concrete mixture can be determined, the entrained-air indicator must be calibrated accurately, and the correction factor for the aggregate contained in the concrete must be determined.

To perform the test, follow the procedures contained in NAVFAC MO-330 and in the instruction book furnished with the meter. The instruction book also describes the calculations for determining the entrained-air content.

Unit Weight (ASTM C 138)

The unit weight, or density, of concrete varies with the amount and density of the aggregate, the amount of entrapped or entrained air, and the water and cement contents. Conventional concrete used in structures, such as buildings and pavements, has a unit weight in the range of 140 to 150 pounds per cubic foot (pcf). For other types of concrete, the unit weight ranges from 15 pcf for lightweight insulating concrete to 400 pcf for heavyweight concrete.

To determine the unit weight of freshly mixed concrete, you will need a cylindrical metal measure (container) of either 1/10-, 1/5-, or 1/2-cubic-foot capacity. If necessary, you should calibrate the measure before performing the test procedures. To calibrate the measure, you first determine the tare weight of the measure, and then fill the measure with water at room temperature. Then determine the temperature, density, and weight (in pounds) of the water. To determine the density of the water, use table 13-3 and interpolate, if necessary. Next, calculate the calibration factor of the measure by dividing the density of the water by the weight of the water required to fill the measure.

The ASTM procedures for determining the unit weight are summarized as follows:

Table 13-3.—Density of Water

Temperature		lb/ft^3
°F	°C	
60	15.6	62.366
65	18.3	62.336
70	21.1	62.301
75	23.9	62.261
80	26.7	62.216
85	29.4	62.166

1. Fill the measure with fresh concrete consolidated in three layers, as described for the air-content test. After each layer is rodded, tap the sides of the container 10 to 15 times with a rubber or rawhide mallet to remove any air pockets.

2. After filling and consolidating, strike off the top surface, taking care to leave the measure level full.

3. Clean all excess concrete from the exterior of the measure. Then weigh it and determine the net weight of the concrete inside the measure by subtracting the tare weight of the measure from the gross weight of the measure and concrete.

4. Calculate the unit weight by multiplying the net weight of the concrete by the calibration factor for the measure.

Compressive Strength Test (ASTM C 39)

The compressive strength of hardened concrete is determined from compression tests on standard cylindrical specimens. As you know, compressive strength tests are used during concrete mix design to evaluate the performance of the materials and to establish mixture proportions that will give the required strength. The tests are used also to control the quality of the concrete in the field.

"Compressive strength" is defined as the average of the strengths of all cylinders of the same age made from a sample taken from a single batch of concrete. At least two cylinders, or preferably three, are required to constitute a test. So, if tests are to be made at 7 and 28 days, you will need four or six specimens. The standard specimen is 6 inches in diameter by 12 inches long and is capped with a suitable material to provide a smooth-bearing surface on each end of the specimen. You learned the procedures for preparing and capping compressive strength specimens in the EA3 TRAMAN. If necessary, you should review those procedures. The following paragraphs discuss only the procedures used to perform compression tests on the prepared specimens.

The equipment you will use to perform the compression test is a compression-testing machine, having a capacity of 250,000 pounds. An example of that machine, shown with a test cylinder in place, is illustrated in figure 13-22.

The procedures for conducting the compression test are as follows:

1. Prepare the testing machine by cleaning the bearing plates and, if needed, cleaning and lubricating

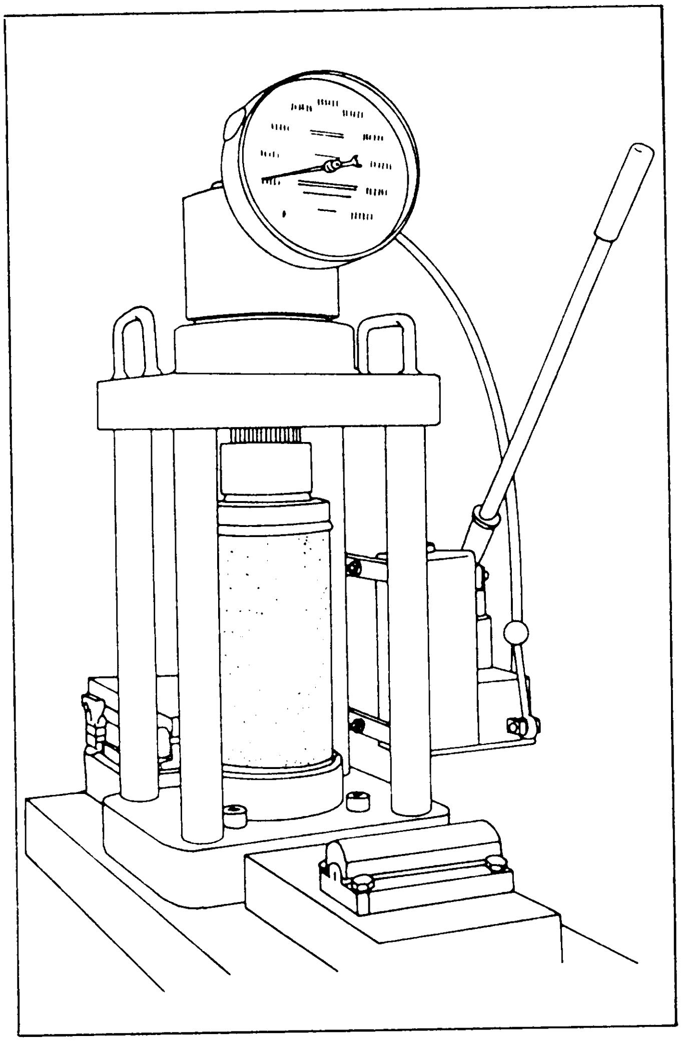


Figure 13-22.—Compression-testing machine.

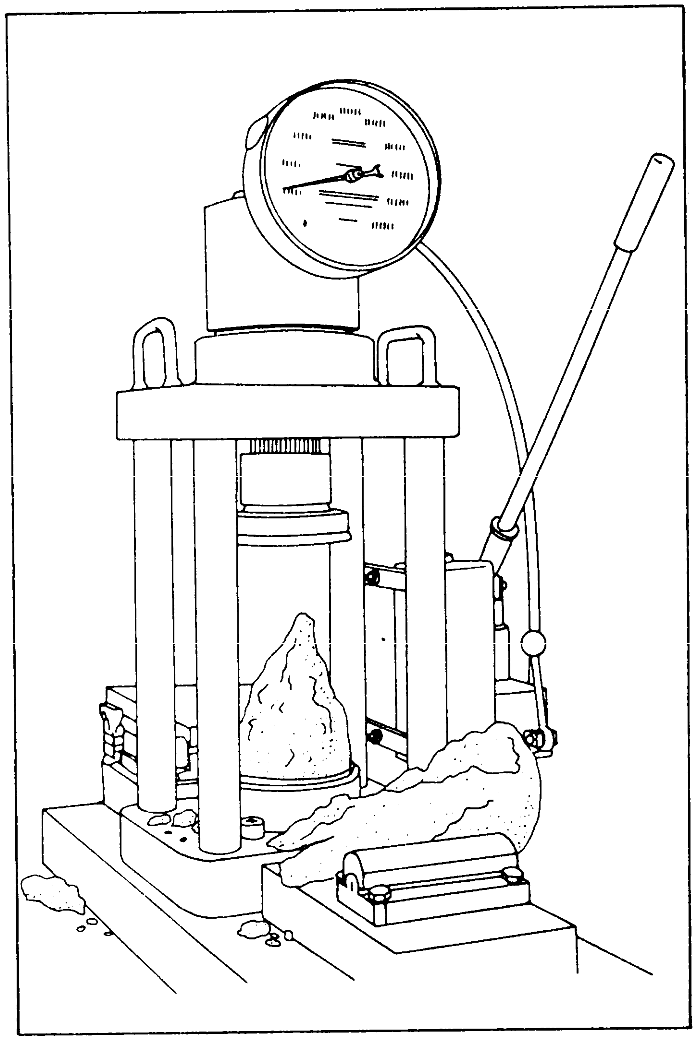


Figure 13-23.—Normal fracture of concrete test cylinder in compression.

the spherical seat. Check the operation of the machine. Keep the previously prepared test specimen moist by covering it with wet burlap during the period between removing the specimen from the curing environment and testing. That applies to each specimen you will test.

2. Determine the diameter of the test specimen to the nearest 0.01 inch by averaging two diameters measured at right angles to each other at midheight of the cylinder. Measure the length, including caps, to the nearest 0.1 inch. Record the dimensions on a prepared data sheet.

3. Place the specimen on the lower bearing block, bring the upper block almost to contact, and align the axis of the specimen with the center of thrust of the spherical head. Carefully and slowly bring the spherical head into contact with the specimen, rotating the movable portion gently by hand so that uniform seating is obtained. Apply the test load continuously and without shock at a rate of 20 to 50 pounds per square inch (psi). Observe and record the maximum load during the test. Observe the type of fracture and record any unusual features. The normal cone type of fracture is illustrated in figure 13-23.

4. Calculate the compressive strength of the concrete using the following formula:

$$f'_c = \frac{P}{A}$$

Where:

$f'c$ = compressive strength (in psi)

P = maximum load (in pounds)

A = cross-sectional area of specimen (in inches)

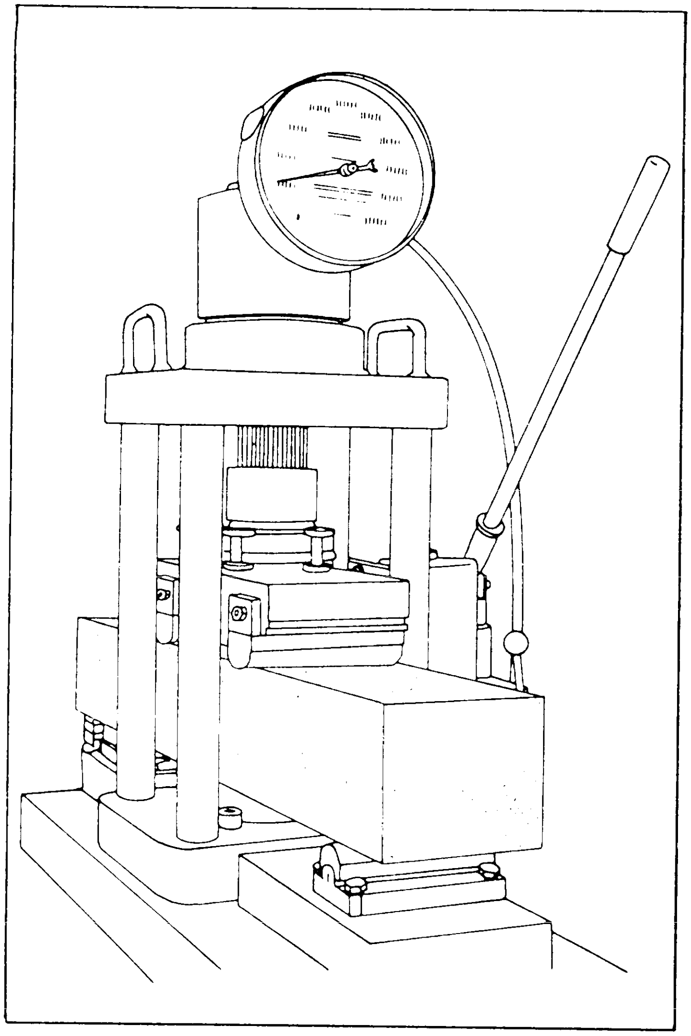


Figure 13-24.—Flexural-strength testing assembly for 6-inch by 6-inch by 21-inch concrete beam.

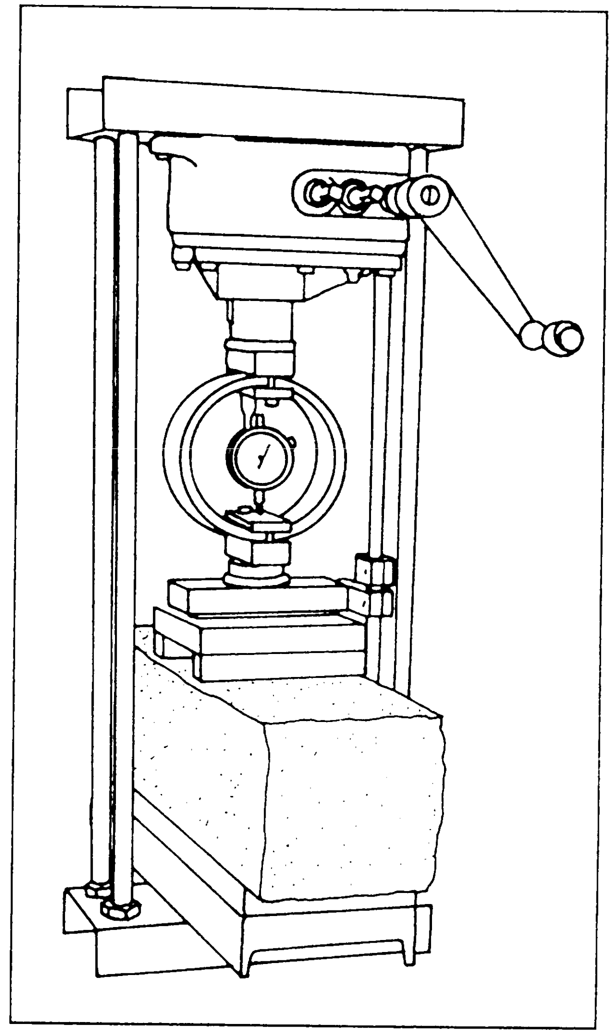


Figure 13-25.—Alternate testing assembly using CBR test equipment.

For each tested specimen, your test report should include the identification, diameter, length, maximum load, compressive strength, irregular fracture or defect in caps or specimen, and age of specimen at test. Report the average compressive strength of all cylinders from the same concrete sample.

Flexural-Strength Test (ASTM C 78)

Flexural strength is the ability to resist an applied bending force such as encountered by concrete pavements or other slabs on ground. A determination of the flexural strength is frequently necessary as part of the design of concrete mixtures to check compliance with established specifications or to provide information necessary to the design of an engineering structure.

In the flexural-strength test, a test load is applied to the sides of a test beam. Although the test can be performed upon beams sawed from existing concrete structures, it is more commonly performed upon beams that are cast for testing purposes. The standard test beam measures 6 inches by 6 inches by 21 inches. When performing the test for mix-design purposes, you will need at least five beam specimens for each mixture design being evaluated. Two of the specimens are broken at 7 days to permit an early evaluation of the mix. The remaining beams are broken at 28 days. The procedures for preparing test beams is discussed in the EA3 TRAMAN. If necessary, you should review those procedures. The following paragraphs discuss only the procedures used to perform the test.

When performing the flexural-strength test, you use a concrete beam tester with third-point loading. An example of that equipment is illustrated in figure 13-24. An alternate testing assembly can be made from the loading frame and certain attachments provided with the California bearing ratio (CBR) test set, the breaker (third-point loading), and the 10,000-pound capacity proving ring. That alternate assembly is shown in figure 13-25.

The procedures for conducting the flexural-strength test are as follows:

1. Assemble the loading device, as shown in figure 13-24. Turn the test beam so that the finished surface is to the side and centered in the loading assembly. Operate the testing apparatus until the loading blocks are brought into contact with the upper surface of the beam. Be sure to secure full contact between the loading (and supporting) surfaces and the beam. If the surface of the specimen is so rough that full contact is not secured, grind the specimen to secure full contact.

2. Apply the test load at a rate such that the increase in extreme fiber stress in the beam is between 125 and 175 pounds per square inch per minute. The extreme fiber stress corresponding to any load maybe estimated from the equation given in Step 4a below. Obtain readings on the proving-ring dial, and convert them to corresponding total loads in pounds by applying the proving-ring constant. Aside from the reading used to control the rate of application of the load, the only reading necessary is the one that corresponds to the maximum load applied to the beam.

3. After the specimen has broken, obtain dimensions of the cross section at which failure occurred to the nearest 0.1 inch. These dimensions represent the average width and average depth of the section in failure.

4. The flexural strength, expressed in terms of **modulus of rupture,** is given in psi, and can be calculated as follows:

a. If the specimen broke within the middle third of the span length, use the following equation:

$$R = \frac{PL}{bd^2}$$

Where:

R = modulus of rupture (in psi)

P = maximum applied load (in pounds)

L = span length (in inches)

b = average width of specimen (in inches)

d = average depth of specimen (in inches)

b. If the specimen broke outside the middle third of the span length by not more than 5 percent of the span length, calculate the modulus of rupture as follows:

$$R = \frac{3Pa}{bd^2}$$

Where:

R = modulus of rupture (in psi)

P = maximum applied load (in pounds)

a = distance (in inches) between the line of fracture and the nearest support, measured along the center line of the bottom surface of the beam

b = average width of specimen (in inches)

d = average depth of specimen (in inches)

c. If the specimen broke outside the middle third of the span length by more than 5 percent of the span length, discard the results of the test.

5. The report of the test for flexural strength should include the following information:

a. Identification number

b. Average width to the nearest 0.1 inch

c. Average depth to the nearest 0.1 inch

d. Span length

e. Maximum applied load

f. Modulus of rupture to the nearest 5 psi

g. Defects in specimen

h. Age of specimen

Values of the modulus of rupture vary widely, depending on the concrete tested. Specification relative to concrete pavements frequently require modulus of rupture in excess of 600 to 650 psi (28-day curing, third-point loading). The flexural strength (modulus of rupture) generally may be expected to be approximately 15 percent of the compressive strength for comparable conditions of age and curing.

An approximate relationship between modulus of rupture and compressive strength can be calculated from the following formula:

$$f'_c = \frac{R^2}{100}$$

Where:

f'_c = compressive strength (in psi)

R = modulus of rupture (in psi).

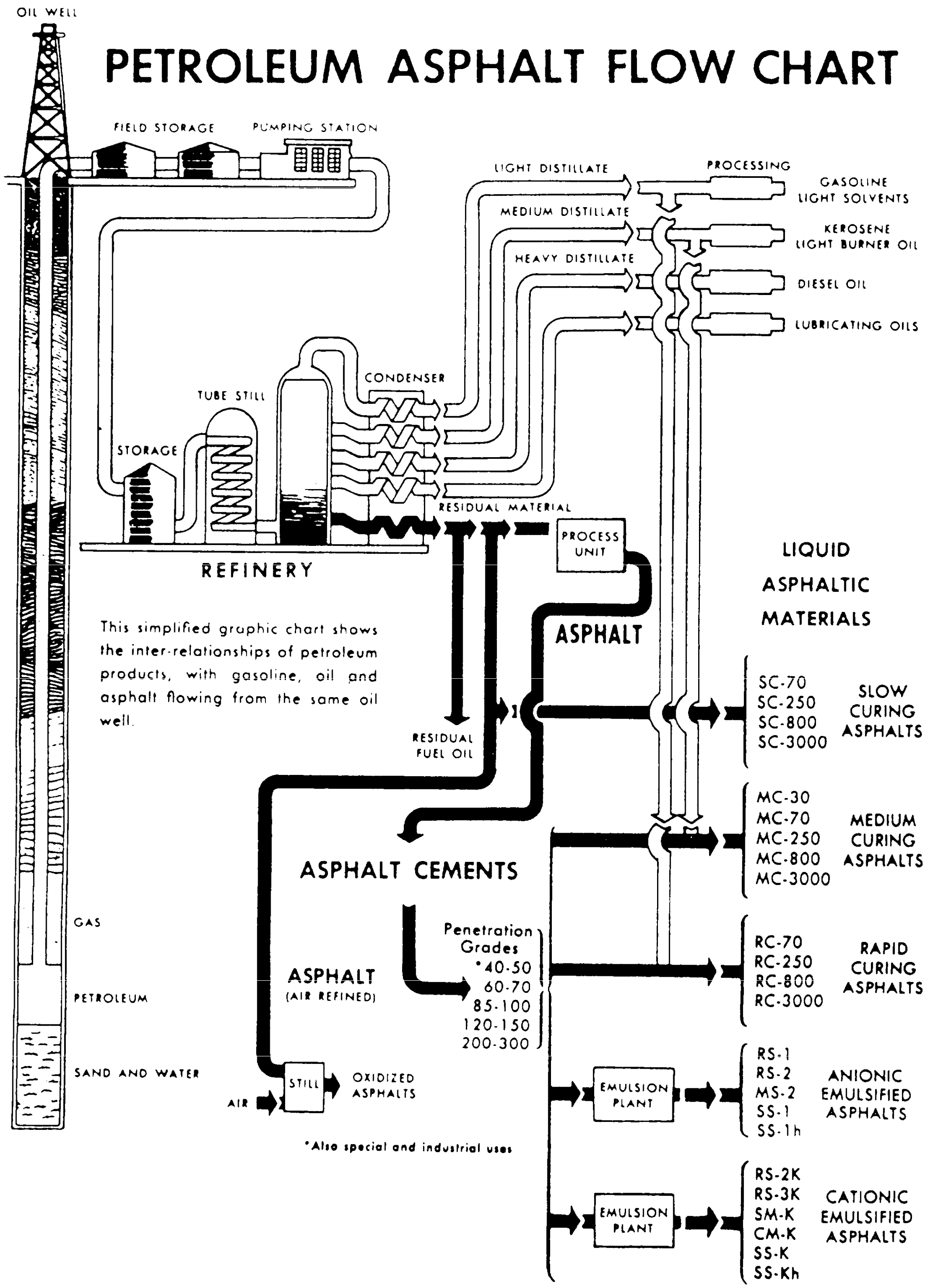


Figure 13-26.—Simplified flow chart showing recovery and refining of petroleum asphaltic materials.

Other Concrete Strength Tests

The compressive and flexural strength tests that you studied above are the two strength tests that you, as an EA, are expected to know how to perform. One should not gain the opinion, however, that those are the only ways to determine the strength of hardened concrete. Other methods, such as the rebound method (ASTM C 805) and the pullout test method (ASTM C 900), also are used.

The rebound method employs a rebound hammer that measures the rebound of a spring-loaded plunger striking a smooth concrete surface. A rebound number reading indicates the compressive strength of the concrete. In the pullout test, the enlarged end of a steel

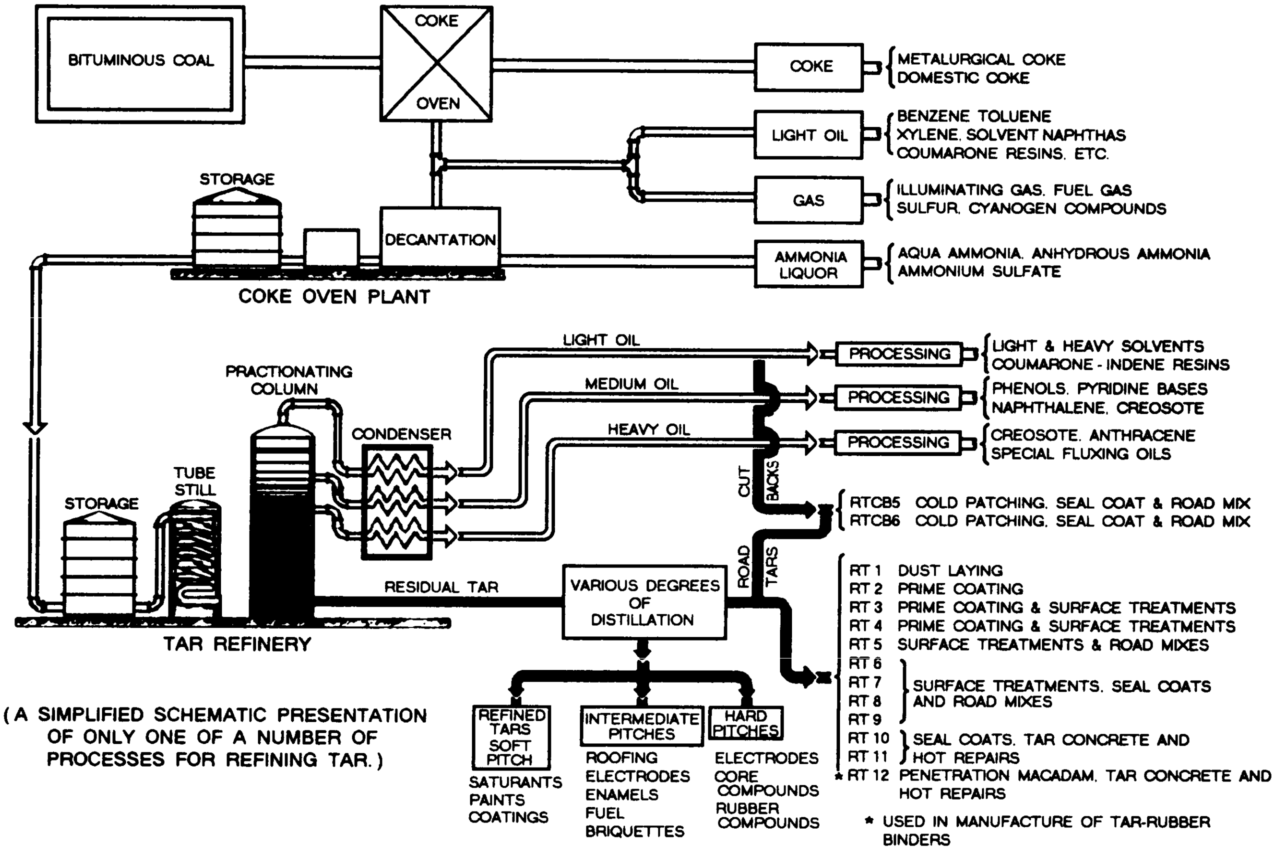


Figure 13-27.-Simplified flow chart showing production of road tars from bituminous coals.

rod is cast into the concrete to be tested. Then the force required to pull the rod from the concrete is measured. The measured strength is the direct shear strength of the concrete. By correlating the shear strength with the compressive strength, a measurement of the in-place strength is made.

BITUMENS AND BITUMINOUS-MATERIALS TESTING

Bituminous pavements are a mixture of well-graded mineral aggregates, mineral filler, and a bituminous cement or binder. They are used as the top portion of a flexible-pavement structure to provide a resilient, waterproof, load-distributing medium that protects the base course from detrimental effects of water and the abrasive action of traffic. This chapter discusses the materials used in the construction of bituminous surfaces and the methods of identifying and testing these materials.

BITUMINOUS-PAVEMENT MATERIALS

Bituminous-pavement materials are made up of a mixture of coarse and fine aggregate, bound together by a liquid or semisolid bituminous binder. The coarse aggregate is stone or gravel that is too large to pass the No. 8 sieve. The fine aggregate is fine gravel and sand, small enough to pass the No. 8 sieve, but too large to pass the No. 200. Fine rock dust that will pass the No. 200 sieve is called **mineral dust.** A small amount of this may be included in a paving mix, or a small amount of **mineral filler** may be added to the mix. Commonly used mineral fillers are portland cement, pulverized limestone (called limestone dust), silica and hydrated lime.

Aggregates

Aggregates may consist of crushed stone, crushed or uncrushed gravel, slag, sand, and mineral filler, or a combination of some of these materials. Aggregates normally constitute 90 percent or more, by weight, of bituminous mixtures, and their properties have an important effect upon the finished product.

Bituminous Cements

Bituminous cement is the adhesive agent in the bituminous mixture and may be either an asphaltic material or a tar. Asphalt may sometimes be obtained from natural deposits but are most generally obtained from the distillation of crude petroleum (fig. 13-26). Tars are obtained from the destructive distillation of bituminous coal (fig. 13-27). The functions of

Table 13-4.-Penetration Grades and AP Numbers of Asphalt Cement

Penetration grade	AP No.	Relative Consistency
40-50	7	Hard
60-70	5	
85-100	3	Medium
120-150	1	Soft
200-300	00	

bituminous cement are to hold the aggregate particles together and to seal the surface, which then resists the penetration of water.

Bituminous cements are available in several forms suitable for different procedures of mixing or application under wide variations in temperature. Some asphalts and tars are solid or semisolid at room temperature. Other grades are relatively viscous (thick) liquids at room temperatures, and all become liquid at higher temperatures. Mixing bitumens with petroleum solvents or water produces **cutbacks** or **emulsions** that become liquid at atmospheric temperatures. Such liquid asphalts and tars are used for cold mixes or applied as sprays in building pavements.

ASPHALTS.— Asphalts may be natural or manufactured and they maybe solid, semisolid or liquid in consistency. Natural asphalts occur in lakes (as lake asphalt), pits, or rock structures (as rock asphalts). Asphalt cement is one of the by-products from the refining of crude petroleum.

Generally, the military engineer depends upon the manufactured asphalts that are obtained when crude petroleum is refined for the purpose of separating the various fractions (fig. 13-26). The crude oil vapors are separated into gasoline, kerosene, and fuel oils, and the residue is asphalt cement and lubricating oils. The longer the process and the higher the temperatures, the harder the residue becomes because of the increased loss in volatiles.

Asphalt cement is commercially available in different standard ranges of consistency (grades). The ranges for the penetration grade are based on measurements by the penetration test in which the relative hardness of asphalt cement is determined by the distance that a standard needle, under a standard loading, will penetrate a sample in a given time under known temperature conditions. The asphalt petroleum (AP) number is a number from 00 to 7 that is assigned to these penetration ranges. Table 13-4 lists the ranges presently recognized along with relative consistencies corresponding to those ranges.

Asphalt cement is also graded on the basis of viscosity, using special testing equipment (not in the Naval Construction Force Table of Allowance) to measure the time that a given amount of liquid asphalt material will flow through a tube of standard dimensions under rigidly controlled temperature and pressure conditions. Multiplying that measured time by a calibration factor for the equipment gives a numerical designation called **kinematic** viscosity, measured in **stokes** (square centimeters per second) or **centistokes** (stokes 100).

The viscosity grades of asphalt cement are available in two series. One series includes grades AC-2.5, AC-5, AC-10, AC-20, and AC-40. The other series includes grades AR-1000, AR-2000, AR4000, AR-8000, and AR-16000. Normally, but not always, the lower viscosity-graded asphalts correlate with the softer asphalts having higher penetration values, and the higher viscosity-graded asphalts correlate with the lower penetration grades.

Since all asphalt cements are solid or semisolid at room temperature (77°F), they must be converted in one of three ways to a fluid state before they can be pumped or sprayed through pipes or nozzles and be mixed with aggregate. One way to liquify an asphalt cement is to heat it. Then, when it cools, it becomes a semisolid cementing material. The other methods to liquify asphalt cement are dissolution (producing cutback asphalt) and emulsification (producing emulsified asphalt).

CUTBACKS.– When asphalt cement is dissolved in volatile petroleum solvents (called cutterstock or flux oils), the resulting liquid is known as cutback asphalt. The idea behind cutback asphalt is that upon

Table 13-5.-Asphalt Cutback Composition (Expressed in Percent of Total Volume)

Type	Components		Grades: 30	70	250	800	3000
		Solvent	30	70	250	800	3000
Rapid curing RC	Asphalt cement		--------	65	75	83	87
		Gasoline or naphtha	--------	35	25	17	13
Medium curing MC	Asphalt cement		54	64	74	82	86
		Kerosene	46	36	26	18	14
Slow curing SC	Asphalt cement		--------	50	60	70	80
		Fuel oil	--------	50	40	30	20

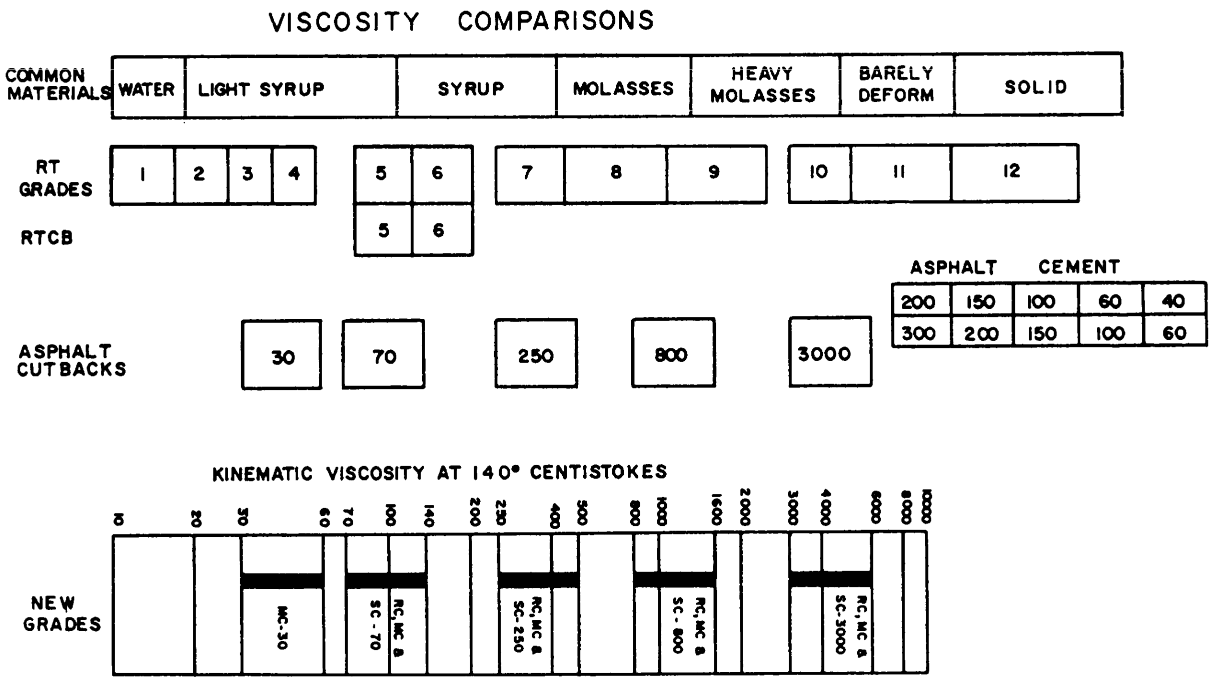


Figure 13-28.-Viscosity grades at room temperature.

exposure to air the solvents evaporate and the asphalt cement is left to perform its function.

The classification of the cutback is based on the rate of evaporation of the distillate that is in the mixture. Gasoline or naphtha (highly volatile) will produce a rapid-curing cutback (RC); kerosene (medium volatility), a medium-curing cutback (MC); and a fuel oil (low volatility), a slow-curing cutback (SC). At times, reference will be found to road oils, which are one of the SC grades of liquid asphalt, or in effect, a heavy petroleum oil. Table 13-5 shows the percentage of components by grade for the three types of asphalt cutbacks.

As more cutterstock is mixed with a given amount of asphalt cement, a thinner liquid results. In practice, different amounts of cutterstock are added to a given amount of asphalt cement to obtain various viscosities, or grades, of cutbacks. The number assigned to each grade corresponds to the lower limit of kinematic viscosity measured in stokes or centistokes. The upper limit of each grade is equal to twice the lower limit or grade number. Thus a number 70 cutback refers to a viscosity range of 70 to 140 centistokes. The other grades and their limits are 250 (250-500), 800 (800-1600), and 3000 (3000-6000); in addition, the MC has a 30 grade. Figure 13-28 shows the scale of viscosity grades. The higher the viscosity, the thicker the liquid.

Asphaltic penetrative soil binder is a special cutback asphalt composed of low penetration grade asphalt and a solvent blend of kerosene and naphtha. It is similar in character to a standard low viscosity, medium-curing

Table 13-6.-Characteristics of Bituminous Materials

Material	Form	Grade designation	Temperature of application ranges: Spraying [1] °F.	Spraying [1] °C.	Mixing °F.	Mixing °C.	Flashpoint (min) °F.	Flashpoint (min) °C.	Remarks
Penetrative Soil Binder	Liquid	–	130–150	55–65	–	–	80	27	Contains naphtha. Caution: Highly flammable.
Cutback (RC)	Liquids—asphalt residues fluxed with more volatile petroleum distillate.	RC–70	[2] 105–175	[2] 41–79	95–135	35–57			Rapid curing cutbacks contain highly volatile naphtha cutterstock. Naphtha evaporates quickly leaving asphalt cement binder permitting early use of surface. Caution: Highly flammable.
		–250	145–220	63–104	135–175	57–79	80	27	
		–800	180–255	[2] 82–124	170–210	77–99	80	27	
		–3000	[2] 215–290	[2] 102–143	200–240	93–116	80	27	
(MC)	do	MC–30	70–140	21–60	55–95	13–35	100	37	Medium curing cutbacks contain less volatile kerosene cutterstock. Kerosene evaporates less rapidly than naphtha. Caution: Flammable.
		–70	105–175	41–79	95–135	35–57	100	37	
		–250	145–220	63–104	135–175	57–79	150	65	
		–800	180–255	82–124	170–210	77–99	150	65	
		–3000	215–290	102–143	200–240	93–116	150	65	
(SC)	do	SC–70	105–175	41–79	95–135	35–57	150	65	Slow curing cutbacks contain slightly volatile diesel fuel cutterstock. Diesel fuel evaporates slowly. Caution: Flammable.
		–250	145–220	63–104	135–175	57–79	175+	79+	
		–800	180–255	82–124	170–210	71–99	200+	93+	
		–3000	215–290	102–143	200–240	93–116	225+	107+	
Asphalt Cements (AC).	Solids	40–50	—	—	300–350	149–177	—	—	Penetrations 40 to 100 used for crack and joint fillers. Penetrations 70 to 300 used for plant mixes, pentration macadam, and surface treatment. Use test (TM 5-530) to determine flashpoint.
		60–70	285–350	141–177	275–325	135–163	—	—	
		85–100	285–350	141–177	275–325	135–163	—	—	
		120–150	285–350	141–177	275–325	135–163	—	—	
		200–300	260–325	127–163	200–275	93–135	—	—	
Powdered Asphalt (PA).	Hard and solid asphalts ground to powder.	—	—	—	—	—	—	—	Used with SC to produce extra tough road surfaces.
Asphalt Emulsions (RS).	Liquids—asphalt particles held in an aqueous suspension by an emulsifying agent.	RS–1	50–140	10–60	Nonmixing	10–60	—	—	Freezing destroys emulsion. Use for road and plant mixes with coarse aggregates (SS). All emulsions with "K" suffix are cationic.
		RS–2	50–140	10–60	50–140	10–60	—	—	
		RS–2K	50–140	10–60	50–140	10–60	—	—	
		RS–3K	50–140	10–60	50–140	10–60	—	—	
(MS)	do	MS–2	50–140	10–60	50–140	10–60	—	—	
		SM–K	50–140	10–60	50–140	10–60	—	—	
		CM–K	50–140	10–60	50–140	10–60	—	—	
(SS)	do	SS–1	50–140	10–60	50–140	10–60	—	—	
		SS–1h	50–140	10–60	50–140	10–60	—	—	
		SS–K	50–140	10–60	50–140	10–60	—	—	
		SS–Kh	50–140	10–60	50–140	10–60	—	—	
Road Tars (RT)	Liquids	RT–1	60–125	15–52	—	—	—	—	Priming oils. RT–4 through RT–12 not generally used.
		RT–2	60–125	16–52	—	—	—	—	
		RT–3	80–150	27–66	—	—	—	—	
Road Tar Cutbacks (RTCB).	do	RTCB–5	60–120	16–49	—	—	—	—	Patching mixtures. Caution: Flammable.
		RTCB–6	60–120	16–49	—	—	—	—	
Rock Asphalt	Solids	—	—	—	—	—	—	—	Mixed and used locally where found. Cutback may be added if necessary.

[1] Low temperature is based on a viscosity of 200 centistokes kinematic viscosity and the higher temperature is based on a 50 centistokes viscosity.
[2] RC Cutbacks are seldom used for spraying.

cutback asphalt, but differs in many specific properties. It is used as a soil binder and dust palliative.

EMULSIONS.– Emulsification is the third process in which asphalt is liquified. In the emulsification process, hot asphalt cement is mechanically separated into minute globules and is dispersed in water that is treated with a small quantity of an emulsifying agent, such as soap, colloidal clay, or one of numerous other organic agents. The rate at which the asphalt globules separate from the water is called the **breaking** or setting time. This rate is generally dependent upon the emulsifier used and the proportion of water to asphalt.

Based in the breaking time, emulsions are described as rapid setting (RS), medium setting (MS), and slow setting (SS). They are also described by viscosity numbers (fig. 13-28).

Emulsions are also grouped according to their ability to mix with damp aggregate. The RS emulsion breaks so fast that it cannot be mixed; therefore, it is called a nonmixing emulsion. The MS and SS emulsions break slowly enough to permit good mixing; that is, each particle of the aggregate is uniformly coated. Emulsions may be satisfactorily used as a tack coat for bituminous pavements.

ROAD TARS.— Tars are products of the distillation of coal. No natural sources of tar exist. **Coal tar** is a general term applied to all varieties of tar obtained from coal. It is produced by one of several methods, depending on the desired end product. When

Table 13-7.—Typical Uses of Bituminous Materials

Purpose or use	Grade or designation: CB - Asphalt cutback[2]					
	RC Rapid curing	MC Medium curing	SC Slow curing	AC Asphalt cement with a penetration of -	AE Anionic and cationic asphalt emulsion	RT-RTCB Road tar and road tar cutback
Dust palliative	— DCA-70[3]	MC-30, 70, 250 A.P.S.B.[4]	SC-70, 250	—	SS-1, 1h	RT-1
Prime coat:						
Tightly bonded surfaces	—	MC-30	—	—	—	RT-2
Loosely bonded - fine grained surfaces.	—	MC-70	SC-70	—	—	RT-3
Loosely bonded - coarse grained surfaces.	—	MC-250	SC-250	—	—	RT-4
Tack coat	RC-250, 800	MC-250, 800	—	200-300	RS-1, 2	RT-4, 5, 6, 7, 8, 9
Surface treatment and seal coat:						
Coarse sand cover	RC-70, 250	MC-250, 800	—	—	RS-1, 2	
Clean coarse aggregate cover	RC-250, 800, 3000	MC-800	—	120-150, 200-300	—	RT-6, 7, 8, 9, 10
Graded gravel aggregate cover	—	MC-250, 800	SC-800	—	—	
Gravel mulch	—	MC-250	SC-250	—	—	
Mixed in-place - Roadmix:						
Open-graded aggregate:						
Sand	RC-70, 250	MC-800	—	—	—	RT-6
Maximum diameter 1 in., high percentage passing No. 10.	—	MC-800	—	—	MS-2	
Macadam aggregate	RC-250, 800	—	—	85-100	MS-2	RT-7
Dense-graded aggregate:						
High percentage passing No. 200	—	MC-250	SC-250	—	SS-1h	RT-5, 6, 7
Maximum diameter 1 in., medium percentage passing No. 200.	—	MC-250, 800	SC-250, 800	—	SS-1	RT-6, 7, 8, 9
Premix or cold patch:						
Open-graded aggregate	RC-250	MC-800	SC-800	—	MS-2	RT-5, 6, 7, 8 or
Dense-graded aggregate	—	MC-250	SC-250	—	—	RTCB-5, 6
Cold-laid plant mix:						
Open-graded aggregate:						
Sand	RC-250, 800	—	—	—	MS-2	
Maximum diameter 1 in., high percentage passing No. 10.	RC-800	—	SC-800	—	MS-2	
Macadam aggregate	RC-800, 3000	—	—	—	—	
Dense-graded aggregate:						
High percentage passing No. 200	—	MC-800	SC-800	—	SS-1	RT-5, 6, 7, 8, 9
Maximum diameter 1 in., medium percentage passing No. 200.	—	MC-800	SC-800	—	SS-1	
Aggregate precoating followed with asphalt	—	MC-30	SC-70	—	—	
Hot-laid plant mix	RC-3000	MC-3000	SC-3000	85-100, 120-150	—	RT-11, 12
Penetration macadam:						
Cold weather	RC-800, 3000	—	SC-3000	120-150	RS-1	RT-10, 11
Hot weather		—	—	85-100	RS-1	RT-12

[1] Prevailing temperature during construction also affects selection of bitumen and may be the determining factor rather than size and gradation of aggregate.
[2] Caution: Do not overheat aggregate when cutbacks are used to produce hot mixes.
[3] DCA-70 is a water emulsion of a polyvinyl acetate containing chemical modifiers (formerly UCAR-131). Proprietary product of Union Carbide Corporation, New York, N.Y.
[4] Asphaltic penetrative soil binder.

bituminous coal is destructively distilled, coke and gas are formed, and tar, ammonia, light oils, sulfur, and phenol may be recovered. Coke-oven tar is produced in the greatest amount, and its chemical, physical, and adhesive characteristics make it most suitable for road-tar purposes. Water-gas tar is obtained in the manufacture of carbureted (mixed with hydrocarbons) water gas. The nature of the carbureting oil largely determines the character of the water-gas tar produced. This tar may vary widely in specific gravities, viscosities, and other physical and chemical properties.

Road tars are manufactured in 12 grades of viscosity (figs. 13-27 and 13-28). There are also some special grades for use in rubberized-tar binders. Grades 1 through 7 are liquid at room temperature, and grades 8 through 12 are semisolid or solid. The difference occurs because of different amounts of the liquid coal distillates in the tar; the more distillate, the more liquid (or less solid) the tar. The **road-tar cutbacks** (RTCBs) are the products of cutting back the heavier or harder grades with coal tar distillates. Road-tar cutbacks are manufactured in two viscosity grades (5 and 6) only.

Tar, which is insoluble in petroleum distillates, is sometimes mixed with oil-resistant, unvulcanized rubber to form a rubberized-tar binder material.

CHARACTERISTICS AND USES OF BITUMENS

Selection of a particular bituminous material depends upon the type of pavement, climatic conditions, seasonal factors, and availability of equipment. In general, soft penetration grades of asphalt cement are preferred for use in cold climates, medium grades in moderate climates, and hard grades in warm climates. Heavier grades of asphalt cutbacks and tars are normally used in warm weather and lighter grades in cold weather.

Tables 13-6 and 13-7 list the bituminous materials, sources, curing, temperatures, and grades associated with bituminous operations.

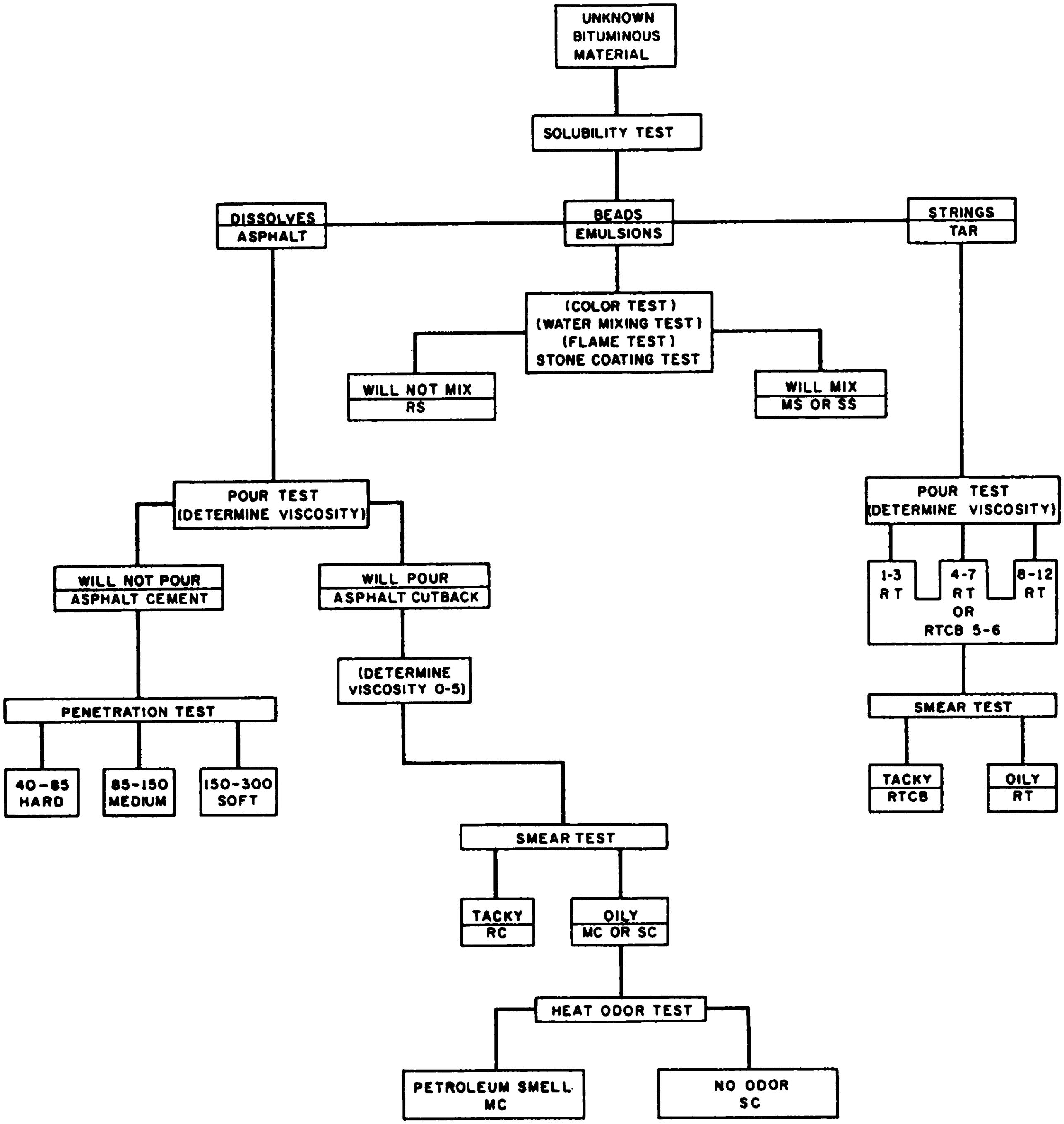


Figure 13-29.-Field identification of unknown bituminous materials.

Advantages and disadvantages of the bituminous materials used in construction are discussed.

Asphalt cement cutbacks are flammable. Also, all asphalts can be dissolved by petroleum products that may be spilled on them, such as during refueling at an airfield. Tars, on the other hand, are not affected by petroleum derivatives since they are products of coal. Tars, when used as a prime for base courses, also seem to possess better penetration qualities than asphalts. Tars are very temperature-susceptible, having a wide range in viscosity with normal ambient temperature changes. Tar can become so soft during warmer weather that the pavement will rut under traffic. In colder weather it can become so brittle that the pavement will crack.

Asphalt emulsions are not flammable and are liquid at normal temperatures. Since they are mixed with water, they can be used with a damper aggregate than required for the cutbacks. Additional water may be added to the emulsion up to proportions of 1:3 for use in slurry seal coats. Because emulsions contain water, they have certain disadvantages. During freezing weather the emulsions can freeze, and the components can separate. Also, emulsions are difficult to store for extended periods because they tend to “break” even in unopened drums. When emulsions are shipped, the water in the mixture takes up valuable space, which could be used to transport hard-to-obtain materials.

FIELD IDENTIFICATION OF BITUMENS

A fairly accurate identification of bituminous materials is necessary to make decisions regarding types and methods of construction, types and quantities of equipment, and applicable safety regulations. Field tests must be performed to identify a bituminous material as asphalt cement, asphalt cutback asphalt emulsion, road tar, or road-tar cutback and to field-identify the grade. Field identification of bitumens is summarized in figure 13-29.

Test for Solubility

The first procedure in the identification of an unknown bituminous material is to determine whether it is an asphalt, an emulsion, or a tar. Bituminous materials may be differentiated by a volubility test. To perform the test, you simply dissolve an unknown sample (a few drops, if liquid, or enough to cover the head of a nail, if solid) in any petroleum distillate. Kerosene, gasoline, diesel oil, or jet fuel is suitable for this test. One or more of these distillates is usually available to the EA in the field Since asphalt is derived from petroleum, it will dissolve in the petroleum distillate. If the material is an emulsion, it can be detected by the appearance of small black globules, or beads, which fall to the bottom of the container. Road tar will not dissolve. If the sample is an asphalt, the sample-distillate mix will be a dark, uniform liquid If it is a road tar, the sample will be a dark, stringy, undissolved mass in the distillate. You can make a check by spotting a piece of paper or cloth with the mix. If no stain results, the material is a tar; however, if a brown to black stain appears, then it is asphalt. The volubility test provides a positive method of identification.

Tests for Asphalt Cement

When the volubility test determines that the bituminous material is an asphalt you should then perform a **pour test** to distinguish whether the asphalt material is asphalt cement or asphalt cutback. In this test you place a small sample of asphalt into a container and attempt to pour it at mom temperature (77°F). Since asphalt cement is a solid at room temperature, it will not pour. Even the highest penetration grade (200 to 300) will not pour or immediately deform. The thickest asphalt cutback, however, will start to pour in 13 seconds at a temperature of 77°F.

The various grades of asphalt cement are distinguished by their hardness, as measured by a **field penetration test.** For purposes of field identification, the consistency of asphalt cement maybe approximated at room temperature as hard (penetration 40-85), medium (penetration 85- 150), and soft (penetration 150-300. These limitations are flexible, as complete accuracy is not essential. You can make an approximation of the hardness while in the field by attempting to push a sharpened pencil or nail into the asphalt at 77°F with a firm pressure of approximately 10 pounds. When the pencil point penetrates with difficulty or breaks, the asphalt cement is hard. When it penetrates slowly with little difficulty, the asphalt cement is medium. If the pencil penetrates easily, the asphalt cement is a high penetration or soft grade.

Tests for Asphalt Cutbacks

In addition to distinguishing asphalt cement from asphalt cutback as discussed above, the pour test will identify the viscosity grade of the cutback at a room temperature of 77°F. After the pour test, the approximate viscosity grade of the cutback is known, but the actual type (RC, MC, SC) is not. Asphalt cement is “cut back” with a petroleum distillate to make it more fluid. If the material does not pour, it is an asphalt cement. If it pours, it is a cutback or emulsion. It has been found that the cutbacks of a given viscosity grade will pour like the following substances:

30- Water

70- Light syrup

250- syrup

800- Molasses

3000- Barely deform

A **smear test** is used to distinguish an RC cutback from an MC or SC cutback. The test is based on the fact that RCs are cut back with a highly volatile material (naphtha or gasoline) that evaporates rapidly. To perform the test, you simply apply a thin smear of the material on a nonabsorbent surface, such as a piece of glazed paper. If the material is an RC, most of the volatiles will evaporate within 10 minutes, and the surface of the smear will become extremely tacky. This is not so for the lighter MC or SC grades, which remain fluid and oily for some time-for hours or days, in some cases. An 800- or 3000-grade MC or SC cutback however, also may become sticky in a few minutes. That is because these grades of cutback contain such small amounts of cutterstock, therefore, you should confirm the identification of the sample by a prolonged smear test.

A **prolonged smear test** is used to identify the 800 and 3000 grades of MC or SC cutback. In this test, a thin smear of asphalt cutback is placed on a nonabsorbent surface and allowed to cure for at least 2 hours. If at the end of that time, the smear is uncured and still quite tacky, the material is an MC or SC; however, if the smear is hard and only slightly tacky, then the material is not an MC or SC. An RC 3000 cutback will cure completely in 3 hours and an RC 800 in about 6 hours; but, an MC or SC will still be sticky even after 24 hours.

The odor given off from a heated cutback helps differentiate an MC (cutback with kerosene) from an SC (cutback with fuel oil). In the **heat-odor test,** you heat the unknown sample in a closed container to capture the escaping vapors. **(Use MINIMAL heat.)** An MC sample will give off a strong kerosene odor. An SC sample will not smell of kerosene, but may have a slight odor of hot motor oil.

Tests for Asphalt Emulsions

You can distinguish asphalt emulsions from other bitumens in various ways as follows:

1. By observing the color of the material. Emulsions are dark brown in color, but other bitumens are black.

2. Emulsions mixed in kerosene or some other petroleum distillate can be detected by the appearance of small black globules, or beads, which fall to the bottom of the container.

3. When an emulsion is mixed with water, the emulsion will accept the extra water and still remain a uniform liquid. Other bitumens will not mix with water.

4. Since an emulsion contains water, a small piece of cloth saturated with it will not burn. Other bitumens will burn or flame.

Once you have established that a bitumen in question is an emulsion, you can then determine whether it is a mixing grade (medium or slow setting) or a nonmixing grade (rapid setting). To do so, attempt to mix a small amount (6 to 8 percent by weight) of the emulsion with damp sand, using a metal spoon. A fast-setting (RS) emulsion will not mix with the sand, but a medium-setting (MS) or slow-setting (SS) emulsion will readily mix and completely coat the sand. Identifying the emulsion as a mixing or nonmixing type is sufficient for field conditions. Difference in viscosity is unimportant since there are so few grades. No distinction is necessary between MS and SS emulsions because both are mixing types and are used largely for the same purpose.

Tests for Tars

A **pour test** is used to identify the viscosity grades of tar. Viscosity grades of road tars are comparable to the viscosity grades of asphalt cutbacks and asphalt cement, as shown in figure 13-28. RT-1, the most fluid, is similar in viscosity to the MC-30 asphalt cutback. RT-8 is similar to grade 800 asphalt cutback. RT-12 has the approximate consistency of asphalt cement; that is, 200 to 300 penetration.

Referring again to figure 13-28, you see that road tars RT-4 to RT-7 and road-tar cutbacks RTCB-5 and RTCB-6 have similar viscosities; therefore, if an identified tar has a viscosity range of RT-4 to RT-7, you must perform a smear test to distinguish whether it is a road tar or a road-tar cutback. The test is performed in the manner previously described for cutback asphalt. Like rapid-curing cutback asphalts, road-tar cutbacks are thinned with highly volatile materials, which evaporate quickly, leaving a sticky substance within a 10-minute period. On the other hand, because the fluid coal oil in road tars evaporates slowly, road tars will remain at about the same consistency at the end of an identical period. It is not important to determine whether the road-tar cutback is RTCB-5 or RTCB-6 since both are used under approximately the same conditions.

LABORATORY TESTS OF BITUMENS

Laboratory testing provides a more positive identification of bituminous materials than is possible with field testing. That, however, is not the only purpose of the various laboratory tests. For example, specific gravity testing (discussed in NAVFAC MO-330) is sometimes needed for the purpose of other tests and for checking the uniformity of successive asphalt shipments. Other tests are performed for mix design purposes, for checking compliance with project specifications, and for establishing safe handling procedures.

Bituminous materials are manufactured to meet specifications established by the federal government, American Association of State Highway and Transportation Oficials (AASHTO), and American Society for Testing and Materials (ASTM). These specifications define the extreme limits permitted in the manufacture of the material and assure the user that the material will possess definite characteristics and fulfill the project requirements. Some of the different tests the EA should be able to perform in the laboratory are discussed below. Other tests that you are less likely to perform, but should be aware of, are discussed in NAVFAC MO-330.

Identification Tests

The laboratory identification kit for bitumens consists of a number of jars containing samples of bitumens in all the recognized categories. To use this kit, you must bring an unidentified sample to approximately the same temperature as the kit samples, and then, following instructions that come with the kit, make identification on the basis of similarity of color, feel, consistency, and odor.

A bituminous material suitable for use in pavement has a considerably higher ductility (which may be roughly defined as stretchability) than one that is suitable only for use as a waterproofer, roofing binder, or crack filler. Any crude method of determining the presence or absence of ductility (such as stretching the material like an elastic) will indicate whether or not the unidentified samples lies somewhere in the category of pavement material.

Distillation Test

If the unknown bitumen proves to be an asphalt and has an odor that indicates the presence of a distillate (such as the odor of kerosene or naphtha), a **distillation test** will indicate the character and approximate grade. In making this test, bear in mind that the basic material for RC and MC is asphaltic cement; that is, penetration asphalt. The basis for SC, however, is not asphaltic cement, but an asphalt residual oil too fluid to be penetration-tested for grade.

RC, MC, and SC all contain a distillate; that is, a volatile liquid that evaporates during the curing process. For RC and MC, the distillate is highly volatile and evaporates quickly; for SC, it is considerably less volatile.

The grade of RC, MC, or SC increases with the ratio of bitumen to distillate. Obviously, the higher the percentage of bitumen, the more solid the material will be, and, therefore, the higher the grade. For RC and MC, the percentage of bitumen for a given grade is the same, as shown in the following example:

Grade	30	70	250	800	3000
Percentage bitumen	54	64	74	82	86

These figures mean that for MC-30, for example, the percentage of bitumen is 54—the percentage of distillate being determinable, of course, by subtracting the percentage of bitumen from 100.

For SC the bitumen percentages are somewhat lower as follows:

Grade	70	250	800	3000
Percentage bitumen	50	60	70	80

From the distillation test, you can determine the bitumen percentage and whether the material is SC, RC, or MC. If it turns out to be RC or MC, the speed with which the distillate evaporates during the test (naphtha or gasoline will evaporate much more rapidly than kerosene) will indicate whether it is RC or MC.

Figure 13-30 shows the apparatus used in distillation testing. A measured quantity (measured by volume) of the bitumen is placed in a distillation flask

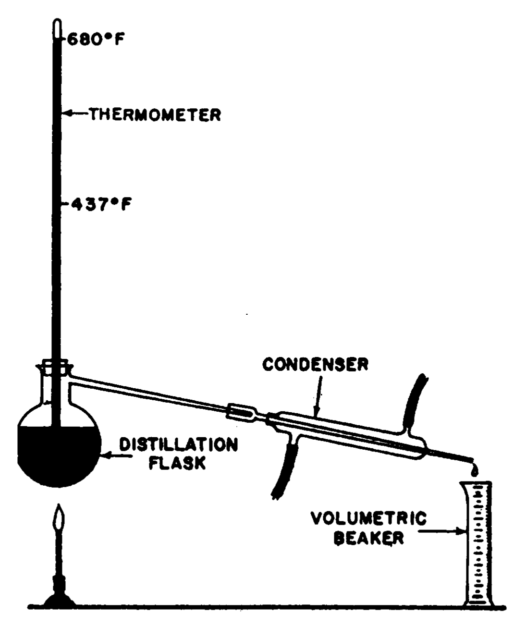


Figure 13-30.-Apparatus for distillation testing.

that has a thermometer running through the stopper, as shown. The flask and contents are heated. As the temperature rises, distillate is given off in the form of vapor. A condenser returns the vapor to liquid form, and the liquid (the distillate) is caught in a volumetric beaker. The test indicates what can be expected in the application and use of the materials. The distillation temperature ranges from 374°F to 680°F for RC asphalt cutbacks, from 437°F to 680°F for MC, and only at 680°F for SC. Road tars are distilled at temperatures that range from 338°F to 572°F, and tar-rubber blends from 170°F to 355°F. The amount distilled is expressed as a percentage of the total. The residue is the difference between the distillate and the total. The percentages of distillation may be as little as 1 percent for tar-rubber distilled at 170°C (338°F) to as much as 59 percent when RC and MC cutbacks and tars are heated to the higher temperatures.

Record the volume of bitumen remaining in the flask. If the residue is solid enough to be tested, it is subjected to the penetration test described later in this chapter. If it is solid enough for this test, the residue must be asphaltic cement, and the original material was either RC or MC. If it is not solid enough for penetration testing, the original material was SC.

Finally, you can determine the grade by calculating the percentage of bitumen and comparing it with the ranges previously given.

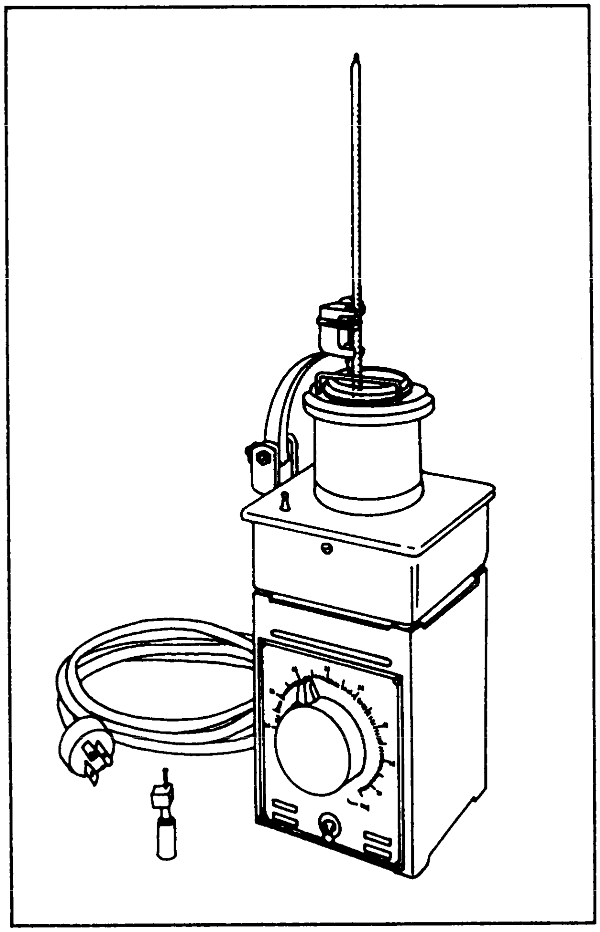


Figure 13-31.—Tag open-cup flash point tester.

Flash Point Tests

The **flash point** of a bitumen that contains a volatile distillate is the temperature at which it begins to give off ignitable vapor. The principal purpose of flash-point testing is to determine maximum safe mixing and applying temperatures; however, these tests are an aid to identification as well. Referring again to table 13-6, you see that RC and MC have flash points below 175°F. MC-30 and SC-70 have flash points around 150°F, but the other grades of SC have flash points above 175°F.

Testing for a flash point below 175°F is done with the **tag open-cup** equipment shown in figure 13-31. When testing for flash points above 175°F, use the **Cleveland open-cup** equipment shown in figure 13-32. When using either of these testers, you need to follow the procedures described in NAVFAC MO-330. While there are important procedural differences, flash-point testing using either equipment is similar in that you use the equipment to heat the test sample at a prescribed rate of temperature increase. Then, when the temperature reading on the thermometer nears the estimated flash point (table 13-6), you use an alcohol torch to begin passing a flame across the surface of the sample. The flash point is reached when the test flame produces a distinct flicker or flash on the surface of the sample. At this point you read the thermometer and record the temperature.

Penetration Test

Figure 13-33 shows an asphalt penetrometer that is used to determine the grade of asphalt cement. In performing the test, the needle is carefully brought to contact with the surface of the sample, then released so as to exert a pressure of 100 grams. The seconds after the needle is released, the distance it penetrated the sample is read, to the nearest 0.01 centimeter, on the penetrometer dial. The reported penetration is the average of at least three tests on the same material whose values do not differ more than four points between maximum and minimum. Detailed procedures can be found in NAVFAC MO-330.

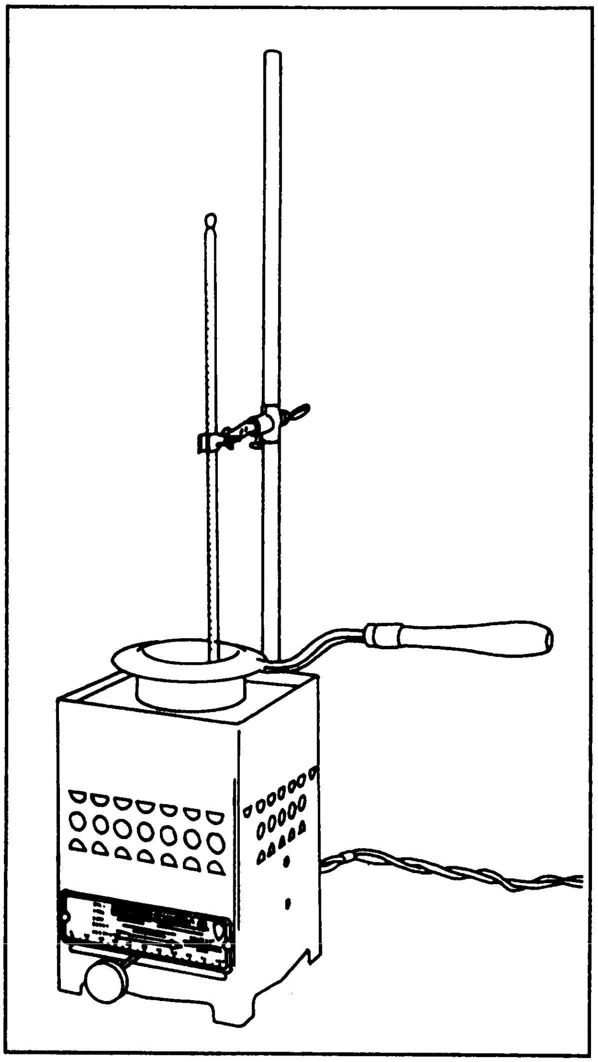


Figure 13-32.-Cleveland open-cup flash point tester.

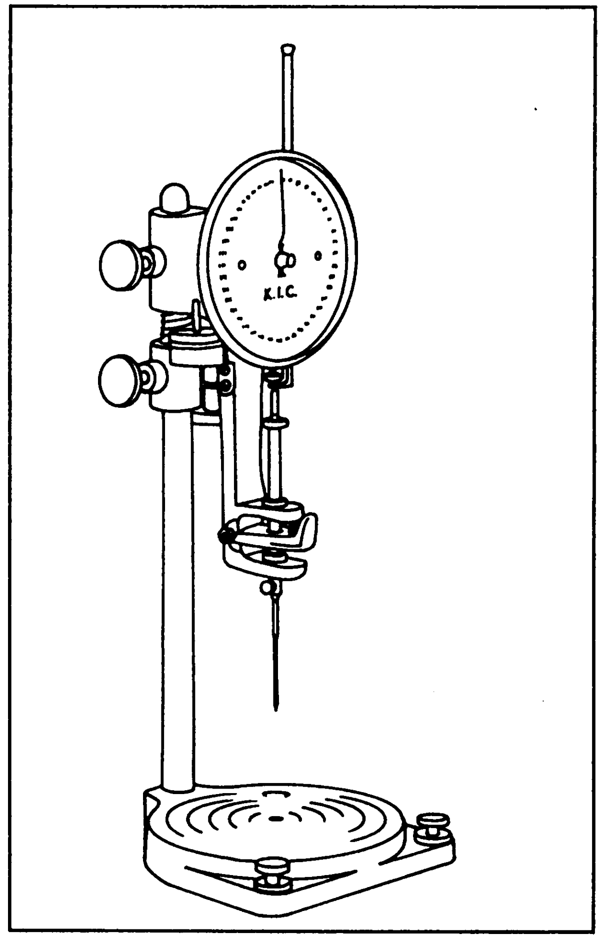


Figure 13-33.-Asphalt penetrometer.

In addition to grade determination, the penetration test is useful for other purposes, such as detecting overheating or prolonged heating of asphalts in storage tanks. Also, when the asphalt is extracted from a pavement, the penetration test is useful in determining how the asphalt has changed with age and weathering.

TESTS ON AGGREGATE

The desired characteristics of aggregates used for bituminous paving include angular shape, rough surface, hardness, and gradation. These qualities and grain distribution largely affect the quality of the resulting pavement. The larger, coarse aggregate particles are the main structural members of the pavement; however, if there were nothing but large particles, there would be many unfilled voids between adjacent particles. The fewer voids the mixture has, the more dense the pavement and, therefore, the more durable it is. Ideal density is obtained by filling the voids between the largest particles with smaller particles, and soon, right down through the whole range of sizes from coarsest to finest.

Common practice divides the aggregates used for bituminous paving into coarse aggregate (retained on the No. 10 sieve), fine aggregate (retained on the No. 200 sieve), and mineral filler. Usually 65 percent or more of the mineral filler will pass the No. 200 sieve. The distribution of the sizes determines how many voids will remain and aids in determining how much bitumen will be needed.

The EA must be able to perform a number of tests on aggregates to determine their acceptability y for bituminous construction. One test is the grain size distribution test that is done by sieve analysis, using the same procedure as described for soil in the EA3 TRAMAN. Tests for mineral dust and specific gravity are also needed. Instructions for conducting both these tests are contained in the following paragraphs.

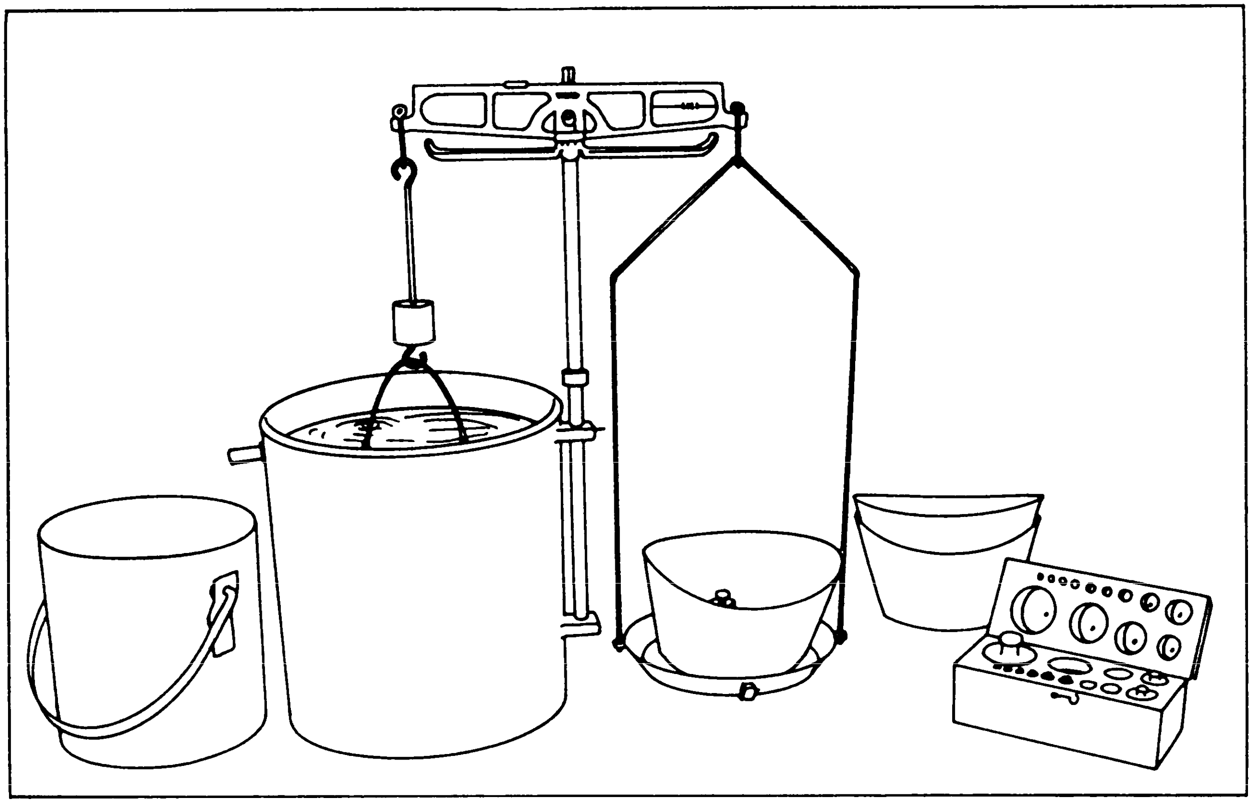


Figure 13-34.-Dunagan apparatus for specific gravity test.

Test for Mineral Dust

In bituminous paving, particles finer than the No. 200 sieve are referred to a **mineral dust.** To measure the amount of mineral dust in a selected sample, you perform a washed sieve analysis (discussed in the EA3 TRAMAN), using the No. 40 and No. 200 sieves. After all the material possible has passed the No. 200 sieve and has been discarded, the materials remaining on the sieve are returned to the original washed sample, oven-dried, and weighed The amount of mineral dust is then calculated, using the following formula:

$$\text{Percent finer than No. 200} = \frac{W_o - W_w}{W_o} \times 100$$

Where:

W_o = Original dry weight

W_w = Washed dry weight

Tests for Specific Gravity

The specific gravities of aggregates used in bituminous paving mixtures are required in the computation of the percent of air voids and percent of voids filled with bitumens. Apparent specific gravity used with aggregate blends showing water absorption of less than 2 1/2 percent is based upon the apparent volume of the material, which does not include those pore spaces in the aggregate that are permeable to water. Bulk-impregnated specific gravity is used for aggregate blends with 2 1/2 percent or greater water absorption The methods for determining absorption were discussed earlier in this chapter in the discussion of concrete aggregates.

The apparent specific gravity can be determined using the methods described in NAVFAC MO-330 for apparent and bulk specific gravity. It may also be determined using the Dunagan apparatus shown in figure 13-34. The procedures are as follows:

1. Select approximately 5,000 grams of aggregate from the sample, not including particles smaller than the 3/8-inch sieve.

2. Wash the aggregate to remove any dust or other coating and dry it to constant weight in the oven. Record the total weight of ovendry aggregate on the data sheet, as shown in figure 13-35.

3. Immerse the aggregate in water at 15°C to 25°C for a period of 24 hours.

SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS		DATE 19 JUN 199-		
PROJECT CAMP COVINGTON	JOB ROAD "A"			
COARSE AGGREGATE	UNITS *(Grams)*			
MATERIAL PASSING 1" SIEVE AND RETAINED ON 16 SIEVE				
SAMPLE NUMBER	CA			
1. WEIGHT OF OVEN - DRY AGGREGATE	378.3			
2. WEIGHT OF SATURATED AGGREGATE IN WATER	241.0			
3. DIFFERENCE *(Line 1 minus 2)*	137.3			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 1)}{(Line\ 3)}$	$\frac{378.3}{137.3} = 2.755$			
FINE AGGREGATE	UNITS *(Grams)*			
MATERIAL PASSING NUMBER 3/8" SIEVE				
SAMPLE NUMBER	FRBS			
4. WEIGHT OF OVEN - DRY MATERIAL	478.8			
5. WEIGHT OF FLASK FILLED WITH WATER AT 20° C	678.6			
6. SUM (Line 4 + 5)	1157.4			
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20° C,	977.4			
8. DIFFERENCE *(Line 6 minus 7)*	180.0			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 4)}{(Line\ 8)}$	$\frac{478.8}{180.0} = 2.660$			
FILLER	UNITS *(Grams)*			
SAMPLE NUMBER	LSD			
9. WEIGHT OF OVEN - DRY MATERIAL	466.5			
10. WEIGHT OF FLASK FILLED WITH WATER AT 20° C,	676.1			
11. SUM *(Line 9 + 10)*	1142.6			
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20° C,	973.8			
13. DIFFERENCE *(Line 11 minus 12)*	168.8			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 9)}{(Line\ 13)}$	$\frac{466.5}{168.8} = 2.762$			
BINDER	UNITS *(Grams)*			
SAMPLE NUMBER	6873			
14. WEIGHT OF PYCNOMETER FILLED WITH WATER	61.9595			
15. WEIGHT OF EMPTY PYCNOMETER	37.9215			
16. WEIGHT OF WATER *(Line 14 minus 15)*	24.0380			
17. WEIGHT OF PYCNOMETER + BINDER	47.8617			
18. WEIGHT OF BINDER *(Line 17 minus 15)*	9.9402			
19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER	62.1568			
20. WEIGHT OF WATER TO FILL PYCNOMETER *(Line 19 minus 17)*	14.2951			
21. WEIGHT OF WATER DISPLACED BY BINDER *(Line 16 minus 20)*	9.7429			
APPARENT SPECIFIC GRAVITY, $G = \frac{(Line\ 18)}{(Line\ 21)}$	$\frac{9.9402}{9.7429} = 1.020$			
TECHNICIAN *(Signature)* EA3 A. McDaniel	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)* EA2 Arthur Price		

DD Form 1216, 1 DEC 65

Figure 13-35.—Data sheet for specific gravity of bituminous mix components (DD Form 1216).

4. After soaking the sample, place it in the bucket, which is filled with water. Then turn the bucket and aggregate sharply back and forth to help remove any air.

5. Suspend the bucket from the brass hanger and bring the water level up to the overflow pipe.

6. Determine the submerged weight using weights placed in the scoop on the right-hand pan. Record the weights in the appropriate spaces on the data sheet. The calculations required for the determination of the apparent specific gravity of coarse aggregate are shown on the data sheet and are self-explanatory.

MIX DESIGN TESTS

Mixture design tests for bituminous pavement are carried out on samples mixed and compacted in the laboratory to determine the optimum bitumen content, the optimum aggregate content, and gradation required to produce a pavement that will meet given quality specifications. Mixes with various bitumen and aggregate contents and gradations are prepared, compacted to specified density, and tested. From the test results, design engineers determine optimum values.

Mix design test procedures vary considerably. this course can give only a general description of typical procedures. Mixture design is more fully discussed in NAVFAC MO-330 and at the EA1 level in Part 2 of this TRAMAN.

Selection of Sample Bitumen Contents

Bitumen content for laboratory test mixes must be estimated to get the tests started. Tests are made with a minimum of five contents: two above, two below, and one at a content estimated to be about right. Bitumen content is expressed in terms of percentage of bitumen by weight to the total weight of the mix. Percentages commonly run from 3 to 7, depending upon the type of binder used and the specification requirements.

Preparation of Aggregate

A quantity of aggregate of the selected blend sufficient to make the required number of test samples is dried at 230°F. The dry aggregate is separated into several size ranges by sieving, and a sieve analysis is then made of each range.

From this procedure, design engineers can determine trial percentages for test blends. Test blends are then made with these trial percentages. Again, a sieve analysis is made, this time to determine a blending gradation, such as shown in figure 13-36.

The explanation of figure 13-36 is as follows. The aggregate here was first sifted into four categories: coarse, fine, fine river bar sand (FRBS), and limestone dust (LSD)-the last being a commonly used mineral filler. All of the coarse aggregate consisted of material that would not pass the No. 8 sieve; 89.5 percent of fine aggregate consisted of material that would not pass the No. 80 sieve; and 90 percent of the FRBS consisted of material that would not pass the No. 200 sieve. These three sieves, then, were the ones used to make the original broad separation. Limestone dust was added to the extent of 2 percent.

After the sample was broadly divided, a sieve analysis was made of each broad division category, as shown. This analysis was studied by experts, who estimated, among other things, the probable void percentages that would exist in pavements made with the aggregate used in various combinations. Percentages that would minimize void percentages were estimated.

For trial blend No. 1, these percentages are listed under “percent used.” The percentages are 27 coarse, 63 fine, 8 FRD, and 2 LSD. A blend containing these percentages was made, and again the material in each category was sieve-analyzed, as shown. From these individual analyses, the blend analysis (that is, the sieve analysis for the mixed blend) was determined by adding together the percentages in each column.

Thus an aggregate gradation for the blend was obtained. If tests showed that this particular gradation produced a mix that met the specifications for the pavement, this gradation would be specified for the aggregate used in the highway.

Specimen Mixing and Compacting for Testing

To prepare an aggregate blend for testing, thoroughly mix and heat enough blend for two specimens (about 3,000 grams) to the desired mixing temperature. Trough the aggregate blend; then heat the test amount of bitumen to mixing temperature and pour it into the trough. Mix the aggregate and bitumen together thoroughly with a mechanical mixer if one is available. Then place the mix in a compaction mold and compact it with a tamper. Give the number of blows required to produce the density that will be attained under the traffic for which the pavement is being designed. NAVFAC DM-5.4, *Civil Engineering,* specifies 50 blows for secondary roads and 75 blows for

BITUMINOUS MIX DESIGN - AGGREGATE BLENDING

DATE 29 AUG 199–

PROJECT HIGHWAY #203 | JOB #47326 | AGGREGATE GRADATION NUMBER 2A

GRADATION OF MATERIAL

SIEVE SIZE (To be entered by Technician): →	1	3/4	1/2	3/8	4	8	20	40	80	200		
MATERIAL USED	PERCENT PASSING											
COARSE (CA)		100	70.0	34.5	3.0							
FINE (FA)			100	99.8	90.0	66.0	43.0	27.0	10.5	3.0		
FINE RIVER BAR SAND (FRBS)							100	99.0	80.0	10.0		
LIMESTONE DUST (LSD)								100	99.0	90.0		
DESIRED:												

COMBINED GRADATION FOR BLEND - TRIAL NUMBER 1

SIEVE SIZE (To be entered by Technician): →		1	3/4	1/2	3/8	4	8	20	40	80	200		
MATERIAL USED	% USED	PERCENT PASSING											
CA	27.0		27.0	18.9	9.3	0.8							
FA	63.0		63.0	63.0	62.9	56.7	41.6	27.1	17.0	6.6	1.9		
FRBS	8.0		8.0	8.0	8.0	8.0	8.0	8.0	7.9	6.4	0.8		
LSD	2.0		2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.8		
BLEND:			100	91.9	82.2	67.5	51.6	37.1	26.9	15.0	4.5		
DESIRED:													

COMBINED GRADATION FOR BLEND - TRIAL NUMBER ______

SIEVE SIZE (To be entered by Technician): →													
MATERIAL USED	% USED	PERCENT PASSING											
BLEND:													
DESIRED:													

DD Form 1217, DEC 65 PREVIOUS EDITION OF THIS FORM IS OBSOLETE

Figure 13-36.-Data sheet for aggregate gradation of trial blends (DD Form 1217).

primary roads. Seventy-five blows produce the equivalent of a tire pressure of 200 psi; 50 blows produce the equivalent of a tire pressure of 100 psi. After the compaction process, place the mold in a bearing-ratio jack and extract the compacted sample with extraction equipment.

Density and Voids Determination

Density of the specimens should be determined by weighing in air and in water. A direct weight in water of open-textured or porous specimens will give erroneous results because of absorption of water, and other means must be used to determine the volume of the specimen. One means of measuring the volume of a porous specimen is to coat the specimen with paraffin to seal all the voids and then weigh the coated specimen in air and in water. A correction is made for the weight and volume of the paraffin. The difference between these two weights, in grams, gives the volume of the specimen in cubic centimeters. You can then determine the unit weight (density) of the mix in pounds per cubic foot for each specimen by multiplying the specific gravity of the specimen by 62.4 pounds (weight of 1 cubic foot of water). Before carrying out the calculations for percent of voids, you must know the specific gravity of the aggregate blend and the asphalt content used.

Stability and Flow Determination

A full discussion of the method used to test for stability and flow can be found in NAVFAC MO-330;

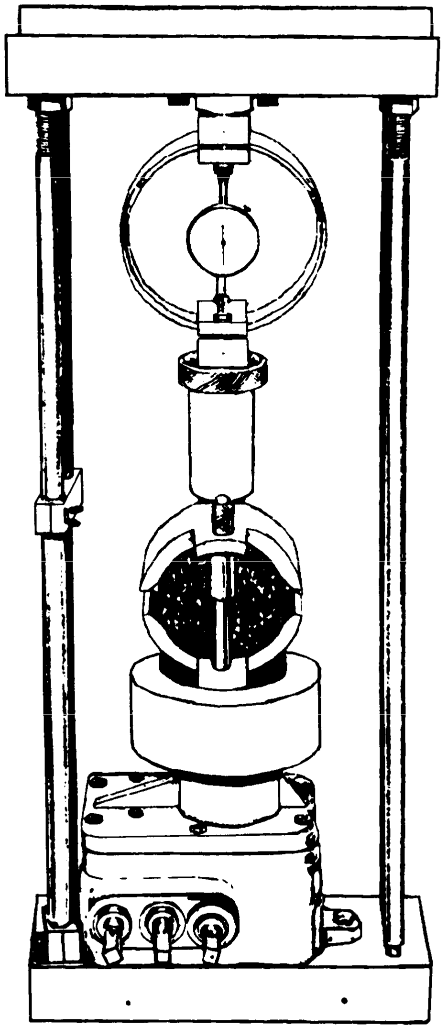


Figure 13-37.-Marshall stability testing head mounted in CBR jack.

however, we'll briefly discuss the method here. The apparatus used for testing stability and flow of the specimen is shown in figure 13-37. This figure shows a Marshall stability testing head containing the specimen, mounted on the plunger of a bearing-ratio jack. This test head consists of upper and lower breaking heads. A 5,000-pound proving ring with a dial is installed in the jack.The test for stability is made by applying pressure gradually, about 2 inches per minute, and reading the maximum pressure the specimen sustains before failing.

The test for flow is carried out simultaneously by holding a flow meter over the testing head guide rod (vertical rod shown running through the testing heads) and reading the meter at the instant the specimen fails under pressure. This reading indicates the flow value of the specimen in inches to the nearest 0.01 inch.

HAZARDOUS-MATERIAL PRECAUTIONS

Although the Navy has exacting definitions for the terms *hazardous material, hazardous chemical,* and *hazardous substance,* let's, for simplicity of discussion, lump them all together and simply say that these materials, because of their quantities, concentration, or hazardous properties, pose a substantial hazard to human safety and health or to the environment. The risks associated with these materials include flammability, toxicity, corrosivity, and reactivity. From your study of this chapter and the EA3 TRAMAN, you should be able to see readily how many of the materials you test, or use for testing, in the laboratory fall within the above definition. Heated asphalt can cause severe burns if allowed to come into contact with the skin, and asphalt cutbacks are highly flammable with low flash points. Some of the chemicals that you will use in materials testing are highly toxic and corrosive. Others react with water, forming explosive gases; however, not all of the hazardous materials that an EA uses are confined to the laboratory. For example, the ammonia used with reproduction equipment gives off highly toxic fumes. For these and other reasons, all such materials must be handled, used, stored, and disposed of properly and with caution. As a crew leader, you must recognize the threat that hazardous materials pose to all personnel present on the jobsite and take action to prevent mishaps.

Material Safety Data Sheets (MSDS) must be received and maintained for all hazardous materials in your work space. The MSDS identifies any hazards associated with exposure to a specific material. It identifies personal protective equipment and other safety precautions required as well as first aid or medical treatment required for exposure. By federal law, a crew leader is required to inform his or her crew members of the risks and all safety precautions associated with any hazardous material present on the jobsite. A good time for you to do this is during your daily standup safety lectures.

A safe practice concerning hazardous materials is to not draw more material than will be used in 1 day. Storing hazardous materials in the workspace or on the jobsite requires the use of approved storage containers. Some of these materials require separate storage; for example, flammable materials and corrosive materials cannot be stored together. When in doubt about storage requirements, consult with your supervisor or the safety officer.

Excess hazardous materials or hazardous waste products must be disposed of through an authorized hazardous material disposal facility. Check with your supervisor, safety officer, or hazardous materials representative for proper procedures.

QUESTIONS

Q1. What is the primary purpose of soil-compaction testing?

Q2. When performing a compaction test on a sandy soil, (a) what mold should you use and (b) how many tamper blows per layer are required?

Q3. What is the overall objective of density testing?

Q4. In the sand-displacement method of density testing, the sand is calibrated to determine its bulk density. Why must you do this before each test?

Q5. The California bearing ratio (CBR) test measures the capacity of a soil to resist what type of force?

Q6. Of the cements discussed in the TRAMAN, which one is most sulphate resistant?

Q7. When the cement paste in a concrete mix does not bond with the aggregate particles, what is the probable cause?

Q8. When a concrete mix contains an excessive amount of silt or clay, what surface defect may occur when the concrete is placed?

Q9. As related to aggregate used in concrete, define the term surface moisture.

Q10. What is the primary reason for adding an air-entraining agent to a concrete mix?

Q11. Define the term hydration as it applies to concrete.

Q12. In concrete flexural-strength testing, when should you use the formula $R = 3Pa/bd^2$*?*

Q13. In what three ways can asphalt be liquified?

Q14. To identify an unknown bituminous material what is the first field test that you should perform?

Q15. To distinguish the type and determine the approximate grade of an unknown asphalt cutback, what laboratory test should you perform?

PART II

EA1 ADVANCED

CHAPTER 14

TECHNICAL ADMINISTRATION AND SUPERVISION

The higher you ascend on the enlisted rating ladder, the more valuable you become to the Navy. This is understandable since you have more experience in your rating, have probably attended several Navy schools, and your attitudes are well-oriented to Navy life. In a sense, you are now in a position and better qualified to impart your knowledge and experience to the personnel serving under you. Your bearing, actions, and disposition will be under scrutiny not only by your seniors but also by your subordinates.

As a supervising EA1, your job is a many-sided task. It involves the procurement of necessary equipment, repair parts, and other materials; planning, scheduling, and directing work assignments; maintaining an adequate file of appropriate publications; interpreting and complying with current directives; collecting engineering data; making progress reports; carrying on a comprehensive and effective training program; interviewing subordinates, using the *Personnel Readiness Capability Program (PRCP)* guidelines; and drafting official correspondence.

This chapter discusses many of the duties and responsibilities of the EA1 supervisor. These discussions center on those topics that, for the most part, are considered to be unique to the Engineering Aid rating; in other words, those administrative and supervisory topics related specifically to supervising the engineering division and assisting the management division of the operations department in a Naval Mobile Construction Battalion.

Obviously, there are many other subjects that relate to the Navy or the Seabees, in general, that you must also be thoroughly familiar with to be an effective supervisor. Those topics, such as leadership principles, principles of administration, correspondence procedures, and so forth, can be found in the Navy's military requirements books that are required study for advancement in rating. General topics related to the Seabees as a whole, such as the *PRCP* program, are covered in the *NCF/Seabee PO1* training manual (TRAMAN). Some other topics that you should become familiar with, such as facilities maintenance management, project site approval requirements, and special project and military construction (MILCON) project submittal procedures, are also not discussed in this TRAMAN; however, a listing of reference sources concerning these and other topics is contained in appendix IV of this TRAMAN.

By now, you should be very familiar with the organization of a Seabee construction battalion and with the battalion's operations department. Therefore, we will begin our discussion of your responsibilities by first discussing the management division and the ways in which you will be expected to assist the management division. Then we will discuss your duties and responsibilities as they relate to supervising the engineering division of the operations department.

MANAGEMENT DIVISION

The management division of the operations department may be headed by the assistant operations officer or by the operations chief, acting in an advisory capacity to the operations officer and the operations staff. This division is sometimes referred to as the administrative division of the operations department. The management division is normally staffed by the operations Yeoman and the timekeeper. Sometimes these positions are filled by EAs.

The management division collects, compiles, and analyzes all information related to the construction operations. This information is used in the preparation of construction operations reports, including the Deployment Completion Report, Monthly Situation Report, and any other special reports required by higher authority. The engineering division will be required to assist in the preparation of these reports by supplying technical information concerning construction projects. Some reports may be compiled from existing records; others may require special investigation and research.

Some examples of reports that you maybe involved with are briefly discussed below.

LABOR DISTRIBUTION REPORTS AND TIMEKEEPING

Labor reporting, such as that included in a Monthly Situation Report and a Deployment Completion Report (both of which are discussed below), is of great importance to the operation of Seabee units. It provides management with data that is necessary to determine labor expenditures on project work for calculation of statistical labor costs and to compare actual construction performance with estimating standards. It also serves to determine the effectiveness of labor utilization in performing administrative and support functions, both for internal unit management and for development of planning standards by higher command.

For labor reporting to be effective, an accurate labor accounting or timekeeping system is mandatory. This system must permit the day-by-day accumulation of labor utilization data insufficient detail and in a reamer that allows ready compilation of information required by the operations officer in the management of manpower resources and in the preparation of reports to higher authority. The timekeeping system used in Naval Construction Force units is described in COMSECOND/THIRDNCBINST 5312.1 series. For the purpose of our TRAMAN discussion, only the most important aspects of the system are covered.

In the system, the basic unit for measuring labor is the **man-hour** which, as you know, is the amount of labor produced by one person working 1 hour of time. **Man-days** are computed on the basis of an 8-hour day regardless of the length of the scheduled workday. therefore, if an individual has worked a scheduled 9 hours in 1 day, he or she has expended $9 \div 8 = 1.125$ man-days of effort. Similarly, ten persons working 9 hours in a scheduled workday is equivalent to 11.25 man-days.

All labor is considered as being either productive labor or overhead. **Productive labor** includes all labor that directly or indirectly contributes to the accomplishment of the mission, including military operations and readiness, disaster control operations, training, and, of course, construction operations. For the latter-construction operations-productive labor is further accounted for in two categories as follows:

1. **Direct labor** includes all labor expended directly on assigned construction tasks, either in the field or in the shop, and which contributes directly to the completion of the end product. For EAs, this includes, for example, surveying on a tasked construction project, travel time to and from project sites, and the preparation of as-built drawings.

2. **Indirect labor** comprises all labor required to support construction operations, but which does not produce an end product itself. This category is further subdivided under various codes listed in COMSECOND/THIRDNCBINST 5312.1 series. One of the codes, X02 - operations and engineering, lists such work as drafting (other than as-built preparation), surveying (for other than tasked projects), materials testing, and timekeeping as indirect labor.

Overhead labor is not considered to be productive labor in that it does not contribute directly or indirectly to the end product. It includes all labor that must be reported regardless of the assigned mission. Examples of overhead labor are the work performed by personnel assigned to the S-1 department, leave and liberty, and time spent getting haircuts and going to the exchange during working hours. It also includes time lost due to inclement weather and waiting for transportation.

MONTHLY SITUATION REPORT (SITREP)

Each deployed battalion submits a monthly report of its construction operations to either Commander, SECOND Naval Construction Brigade (COM-SECONDNCB) or Commander, THIRD Naval Construction Brigade (COMTHIRDNCB). The recipient brigade depends upon which theater of operations the battalion is in. The report, transmitted in a naval message format, provides a review of the battalion's construction activities during the reporting period. For each project tasked to the battalion (including the main body and each detail site), the SITREP lists the scheduled and actual percentages of project completion, the remaining direct-labor man-days needed to complete the project, and the estimated usable completion date (UCD) of the project. For each tasked project, the SITREP provides also a brief comment describing the main work performed during the reporting period. Additionally, the SITREP includes a personnel summary for the main body and detail sites and a direct-labor capability analysis. The capability analysis compares the battalion's total remaining direct-labor man-day availability with the total remaining man-days needed to complete all project tasking.

For further discussion of the SITREP format and requirements, you should refer to the *NMCB Operations Officer's Handbook,* COMSECOND/THIRDNCB-INST 5200.2 series. This instruction, simply called the

Ops Officer's Handbook, also describes the manner in which planned and actual project percentages, man-days remaining, and other important project planning and management data are determined. As an EA supervisor, you should become thoroughly familiar with the *Ops Officer's Handbook.*

DEPLOYMENT COMPLETION REPORT

The Deployment Completion Report is the primary source of historical information for battalion accomplishments and lessons learned during deployment. It covers all battalion aspects for the deployment including project work, training, safety, administration, supply and logistics, and so forth. For each aspect, the report provides lessons learned, statistical data, and brief narrative discussions of matters that maybe of significance to other NCF units deploying to the deployment site.

Specific instruction for preparing a Deployment Completion Report is found in COMSECOND/ THIRDNCBINST 3121.1 series.

ENGINEERING DIVISION

The engineering division is under the direction of the engineering officer, who is normally a Civil Engineer Corps officer in his first duty assignment. The engineering officer and his staff are responsible for providing all engineering services and designs necessary for the successful conduct of the construction program.

ENGINEERING CHIEF

An EAC, when assigned to a construction battalion, normally has a wide range of duties and responsibilities. Most often he is the engineering chief. In this capacity, he works directly for the engineering officer and is responsible for the coordination and supervision of the engineering division. However, because the EAC has a wide diversity of experience and training as a Seabee chief petty officer, he is frequently assigned to other positions, such as MLO chief, training chief, quality control chief, and sometimes, officer in charge or assistant officer in charge of a Seabee detail. On some occasions, the EAC might even be assigned to the position of engineering officer. In cases such as these, the supervisory responsibilities inherent to the position of engineering chief fall upon the shoulders of the EA1. Another responsibility often assigned to the EAC (and which could, therefore, fall upon you) is managing the radiation safety program within the battalion. For this job you need to become thoroughly knowledgeable with not only the operation and safety requirements of the nuclear moisture-density meter but also with the requirements contained in NAVSUPINST 5101.11 series and other pertinent regulations and instructions dealing with the receipt, storage, handling, and transportation of radioactive materials.

DRAFTING AND REPRODUCTION SECTION

One of the sections under the engineering officer is the drafting and reproduction section. As implied by the name of this section, the personnel assigned to it perform drafting and reproduction of engineering drawings. Most drawings and specifications are furnished to the battalion; however, it is often required that the NMCB site adapt structures, prepare plans of existing structures, design alterations of existing structures, adapt standard plans for use of local nonstandard materials, design new structures, and perform other design work. All major work designed by the NMCB must be approved by the command that exercises operational control (COMSECONDNCB or COMTHIRDNCB). In nearly every case, the NMCB prepares as-built drawings of all constructions performed by the battalion.

Most of the functions listed in the preceding paragraph are performed by the EA personnel assigned to the drafting and reproduction section. They all assist in the preparation, revision, and reproduction of drawings and perform other functions assigned by the engineering officer.

Drafting Room Supervisor

Generally, an EA1 or EAC is in charge of the drafting and reproduction section. This is a job that requires a person of superior administrative and supervisory abilities. At times your work load may be piled up so high that you will never finish without working overtime. At other times you may not have enough work to go around. These extreme situations may be avoided by proper planning and work distribution. A good method is to prepare a prioritized list of all major jobs to be done and another list of minor jobs. Naturally, you should try to channel most of your manpower toward accomplishing the major jobs first. Then, during slack times, give out the minor jobs, or fill-in jobs, for accomplishment

Kit 80011 (or Kit 11) of the NMCB Table of Allowance (TOA) contains the essential drafting equipment and tools needed by a construction battalion.

One complete kit is intended to support three drafters, and there is normally a total of two kits carried in the battalion allowance. Full 100-percent accountability for the contents of each kit is essential. For this reason, each kit must be inventoried during turnover and at twice-monthly intervals throughout the deployment. The contents of the kits must also be inspected to make sure they are in a state of good repair. Any missing items or items that are damaged beyond economical and reasonable repair must be replaced. This is done using standard Navy supply procedures. Tool-kit inventory is a job that you should delegate to a responsible EA3; however, you should remember that, as the supervisor, you can still beheld accountable for the kits. You should remember, too, that the requirement for tool-kit inventory applies not only to Kit 11 but also to the surveying and soils kits.

Additional supplies and equipment are also stocked in the engineering office to supplement the kits. These supplies and equipment also should be inventoried periodically to maintain a reasonable supply level at all times. If possible, appoint one EA to serve in a collateral duty as your section supply petty officer. He will prepare requisitions for drafting supplies as needed and keep you informed of any need for equipment repair or replacement.

For the reproduction machine (usually a Blu-Ray whiteprinter), it is a good idea to have reserve spares for those parts that break down often. Most important of all, keep an ample supply of blueprint and sepia paper stored in a cool, dark space away from ammonia fumes or vapors.

Drafting Room Layout

Small crowded rooms hinder good work and make effective safety practices difficult. According to *Facility Planning Criteria for Navy and Marine Corps Shore Installations,* NAVFAC P-80, 90 square feet of floor space per person, exclusive of storage space, should be used for planning purposes. A length-to-width ratio of about 2:1 is desirable for a drafting room, because this ratio allows for the proper arrangement of drafting tables and good lighting.

An important factor to consider is the conservation of vision, since excessive light, as well as inadequate light, induces severe eyestrain. North-exposure windows are best for admitting daylight in the Northern Hemisphere. It is important that the lighting in the room be adequate in both quality and intensity; however, take care to avoid placing working areas in positions where they will be subjected to the glare of direct sunlight. Usually, excellent artificial lighting is achieved by the use of portable, adjustable lamps that can be clamped to the drawing table and moved so that the light falls in such a way as to minimize shadows and glare.

When you arrange the drafting room, try to separate work areas and storage space. Keep materials and instruments that are not in use in easily accessible cabinets and ensure that personnel do not have to walk around someone who is working to reach supplies. Keep prints where they can be reached quickly by any authorized person. If possible, have drafting equipment and reproduction equipment located in separate rooms.

Personnel Organization

The number of drafting personnel in a construction battalion is usually small; therefore, an elaborate organization following the series or the unit assembly system is not generally feasible. Instead, the parallel system is usually followed. In this system, each person is trained to do all the different job phases, and the same person carries a drawing through from start to finish. A senior person, however, may occasionally be assigned as checker and editor, and routine tasks, such as lettering, tracing, and insertion of corrections, may be assigned to junior personnel and strikers. However, to train personnel efficiently and to sustain interest and morale, you should maintain enough rotation to ensure that each person gets varied experience.

Filing System for Drawings

The filing system used for drawings should be the one you find to be most satisfactory-meaning that there are no specific rules on the subject. For a discussion of recommending filing practices, you should review chapter 16 of the EA3 TRAMAN.

An individual should be assigned daily to the task of logging in, card indexing, and filing any drawings or prints received. Tracings should be filed separately, and there should be a standing rule that tracings must never be removed from the file except with your approval as the supervising EA. About the only time removal is necessary is for reproduction purposes.

Any print issued to a constructor should be logged out by recording the date of issue and the name of the individual to whom it was issued. The purpose of this is to allow you to inform the constructors of any changes that must be made to prints used in the field.

Reproduction Room

As you know well by now, ammonia vapors are highly toxic; therefore, for any room containing ammonia-vapor reproduction equipment, ventilation is of vital importance. Check with the battalion safety chief to see if the ventilation in your reproduction room is adequate.

In addition, the reproduction room should be kept as dust-free as possible. Air conditioning is helpful in this regard; however, it does not take the place of good housekeeping practices.

Before a new reproduction machine is operated—even before it is installed-the potential operator must study the manufacturer's handbook carefully. The instructions it contains (both for safe and efficient installation and for safe and efficient operation) must be carefully followed

As alluded to previously, light-sensitive materials must be stored in lighttight spaces. The original containers of such materials are lighttight; therefore, the materials should remain in these containers as long as possible.

Engineering Technical Library

The overall battalion technical library contains reference publications related to construction and to subjects like ordnance, communications, military planning and training, medical and dental, professional development, and supply. Of concern to you is the engineering technical library. It should be consigned to the operations department on a subcustody basis by a designated central control office. That central control office may be the plans and training department, educational services office, or the supply department.

Publications that are required in the engineering technical library, as well as the entire battalion library, are listed in Section 12 of the TOA. Some of the NAVFAC publications that must be in the engineering library are listed below.

P-272 *Definitive Drawings for Naval Shore Facilities*

P-315 *Naval Construction Force Manual*

P-349 *NAVFAC Documentation Index*

P-357 *Abstracts of Manuals, Technical and Non-technical*

P-385 *Base Development Planning for Contingency Operations*

P-405 *Seabee Planner's and Estimator Handbook*

P-437 *Facilities Planning Guide, Volume I and Volume* 2

In addition to NAVFAC publications, numerous standards and military handbooks are also required. A few of these that you must have in the engineering library are as follows:

MIL-HDBK-1006/1 *Policy and Procedures for Project Drawing and Specification Preparation*

MIL-STD-12D *Abbreviations for Use on Drawings and in Technical-Type Publications*

MIL-STD-14A *Architectural Symbols*

MIL-STD-17B *Mechanical Symbols*

MTL-STD-1OOE *Engineering Drawing Practices*

ANSI Y14.1 *Drawing Sheet Size and Format*

ANSI Y14.5M *Dimensioning and Tolerancing*

ANSI Y32.4 *Graphic Symbols for Plumbing Fixtures for Diagrams Used in Architecture and Building Construction*

ANSI Y32.9 *Graphical Symbols for Electrical Wiring and Layout Diagrams Used in Architecture and Building Construction*

ANSI/AWS A3.O *Standard Welding Terms and Definitions*

ANSI/AWS 2.4 *Symbols for Welding and Nondestructive Testing*

Besides the aforementioned publications, the engineering technical library contains various commercial publications of interest to the EA, such as the current edition of *Architectural Graphic Standards* by Ramsey and Sleeper.

Maintaining the engineering technical library is another important collateral-duty job that you should delegate to a responsible EA3 working the drafting room. In this capacity the EA3, as the librarian, is responsible for arranging the publications, indexing, inventorying, and checking in or out publications. He should also be tasked with packing the entire library for embarkation to overseas deployment sites.

Checking and Editing Drawings

In any drafting layout, it is important that organization, format, conformance to applicable standards, and accuracy of every detail be checked thoroughly. Techniques in checking and editing drawings are acquired through actual experience and continuous study. Mistakes are readily seen by an individual who has long experience with the subject matter under consideration and a wide range of knowledge. Be systematic in checking and editing drawings. Review the suggested procedures described in chapter 4 of this TRAMAN; inasmuch as there are no set rules of procedure, perhaps you could develop your own system along these lines.

During the preparation of construction drawings, feel free to consult with the Builder, Steelworker, Electrician, Equipment Operator, or Utilitiesman concerning any problems that may arise. These personnel will have to construct from your drawings. By consulting with them beforehand, you may avoid designs that are not feasible. Much time and effort may be saved by simply questioning knowledgeable people in each trade involved. Working closely with the planning and estimating section is highly beneficial. Personnel in that section will know what materials are readily available and will eventually be required to make material estimates from your construction drawings. A wise drafting supervisor will have the planning and estimating section check all construction drawings before forwarding them for approval.

Training of Drafters

A detail drafter must know just about all there is to know about prescribed conventions, procedures, and practices before he can be assigned to a detail (that is, a complete drawing) job. The best way to train new personnel for detail work is to assign them to tracing, reproduction making, filing, and the like, with the additional requirement of continuous spare-time or downtime study of appropriate NAVFAC publications and military standards. That study should include MIL-HDBK-1006/1 and the publications, such as MIL-STD-100E, that are referred to in MIL-HDBK-1006/1. As you know, most drawings used in Seabee construction are prepared by professional architect-engineer firms. Those drawings are a valuable source of study for the new—and even the more experienced—drafter to “see how the professionals do it.” A study of typical drawings in NAVFAC P-437, *Facilities Planning Guide,* is also helpful. Other typical drawings and drafting conventions can be found in commercial publications, such as the *Architectural Graphic Standards.*

Work Assignments and Work Schedules

One of the most important responsibilities you will have as a drafting room supervisor is that of assigning work. To be able to do this, you must understand the work you must know exactly what you are asking each person to do and how it should be accomplished, and you must know each individual’s capabilities. A person may be proficient at one thing and not at another. Some individuals may be able to work well on projects that require cooperation with others; some work best alone. The varied aspects of each individual’s responsibilities and character should be taken into consideration in assigning work.

By now, you have probably had some experience with most of the work done by Seabee drafters. At one time or another, you probably have had to sit down and prepare a drawing similar to the one you will be assigning to a subordinate. Or, if you have not had the experience yourself, you probably have sat beside someone who did; and if you were alert to your opportunities, you profited by his experience.

But there is more to it than that. As a supervisor, you must learn to be able to think through the job without ever actually putting anything on paper. You must be able to foresee all of the steps necessary to do the job in order (1) to get all the information needed for the job from the person requesting it and (2) to pass this information onto the person assigned the job. Suppose, for example, that the operations officer has tasked the engineering officer to take a standard manufacturer’s preengineered metal building foundation design and modify it so that it will withstand wind forces of 150 miles per hour. The engineering officer has prepared sketches from his calculations and has given the sketches to you to prepare construction drawings. You should first study these sketches to make sure you fully understand them. Ask the engineering officer to clarify anything you do not understand. Add notes to the sketches to help personnel in the field construct the foundation Check dimensions to make sure they are compatible with the original manufacturer’s drawings. And finally, after you have checked the sketch and made necessary changes and additions, review the sketches with the engineering officer to make certain that your changes and additions do not disagree with the original intent of his design.

The next step is the actual assignment. If the person to whom you are assigning the work is experienced, the sketches and a few guidelines will be sufficient. But, if the person is not experienced, the work will include some on-the-job training. You must describe the sketch fully, explaining the purpose of the sketch, the steps necessary for accomplishment of the work, and all pertinent details. The drafter must be encouraged to ask you questions, and you must check his work as the drawing progresses. You must find his mistakes early to prevent his having to redo the entire drawing. Mistakes that are the fault of poor supervision will greatly demoralize an inexperienced drafter.

ENGINEERING WORK REQUEST

REQUESTED BY: Engineering Officer	DATE OF REQUEST: 25 July
DESIRED COMPLETION DATE: 10 Aug.	REQUEST NO. 5-002

WORK DESCRIPTION: Camp Covington General Warehouse. Redesign of Foundation For 150 mph Winds.

WORK GUIDELINE:
1. Do Not Change Manufacturer's Original Drawings.
2. Put Plan, Sections, And Details on One Sheet.
3. Mark Manufacturer's Foundation Plan "VOID" And Make reference to New Drawing.

SKETCH: See Enclosed Sketches

APPROVED BY: Engineering Officer	PRIORITY: Hot
ASSIGNED TO: EA3 BIGGS	
DATE STARTED:	DATE COMPLETED:

Figure 14-1.—Typical engineering division work request.

To help in assigning and controlling work, the drafting room supervisor must devise a work schedule. And, to keep account of requested work, he may use a work request form of his own design.

A suggested typical work request form is shown in figure 14-1. An ample supply of these request forms should be kept by the engineering officer and by you. This same work request form can be used for work performed by all of the sections within the engineering division, not just the drafting section. Properly filling out this form ensures that all information pertinent to the work assignment is obtained from the requester. Normally the requester knows what he wants but cannot explain it in writing, so the engineering chief or drafting room supervisor should fill out the work request form and make any necessary rough sketches. All pertinent information should be included to assure coordination of the job and to minimize errors in passing on information to the person assigned the work. The work request should be made out in duplicate, one copy being put into the supervisor's file of outstanding work requests and the other copy given to the person assigned to do the work.

Work requests serve as a handy reference as to what work is waiting assignment, what work is in progress, and what work has been completed. At all times, the engineering officer, who reports directly to the operations officer, will hold you, as the supervisor, accountable for work progress.

In conjunction with current work requests, a visual work schedule should be posted, and work progress should be indicated daily. A sample work schedule is shown in figure 14-2. This schedule will keep the

DRAFTING WORK SCHEDULE

As Of: 28 July -

Work Request No.	Work Description	Assigned To:	Date Started	% Complete	Desired Completion Date	Remarks
5-002	Warehouse Foundation Design	EA3 Biggs	25 July	75	10 Aug	
5-003	Revise Camp Elect. Plan	EA2 Larkin				Awaiting Design Info From Regiment
5-007	As-Builts, BOQs	EA2 Larkin	15 July	50	5 Aug	
5-010	Landscape Design For Main Camp Entrance	EA3 Zeikwich	20 July	30	10 Aug	
5-011	Design Retaining Wall CB Det Compound	EA3 Centudo	26 July	25	8 Aug	SEE LT May for additional info.
5-012	Cover Design for Monthly Ops Report	EACN Pitts	26 July	75	6 Aug	
5-013	As-Builts, Trap/Skeet Range				15 Aug	Awaiting Assignment
5-014	C.O.'s Briefing Charts	EACN Pitts	27 July	50	29 July	PRIORITY

Figure 14-2.—Typical drafting work schedule.

engineering officer informed as to your workload and work progress. It also will aid him in deciding on priorities for rush jobs.

Do not allow your personnel to assign priorities to work. Only you, the supervisor, or the engineering officer, when rush jobs or top priority jobs are requested, should be responsible for assigning priorities.

FIELD ENGINEERING SECTION

The field engineering section performs such field engineering work as the following:

1. Reconnaissance, preliminary, topographic, and location surveys
2. Construction stakeout; line and grade
3. Regular measurement of quantities of work in place
4. As-built location of structures for preparation of as-built record drawings
5. Measurement and computation of earthwork quantities
6. Calculations for establishing line and grade
7. Plotting survey data
8. Special surveys, such as property, triangulation, hydrographic, and the determination of true azimuth

In combat, the field crews gather needed intelligence by scouting, patrolling, and manning observation posts. They are also trained as damage survey teams for emergency recovery operations.

Survey Parties

As you learned in your previous studies, a survey party is organized and designated according to the type and purpose of the proposed survey. Whatever the purpose and scope of the survey, the job must first be planned.

You know that the first step in preparing for a field party mission is to decide upon a **job plan** by determining the answers to the following questions:

1. What is the exact nature of the job?
2. What is the best way to accomplish it?
3. How many men are required?
4. What tools, materials, and equipment are required?
5. What is the tactical situation in a wartime situation?

A large construction project requires continuous survey activity; that is, the survey can seldom be done in a single operation. Often, phases of a construction survey overlap preceding phases. When two or more survey missions are being carried on at the same time, the question of where and when to use available crews must be decided. Sometimes it is best to use all the crews on one phase of the surveying work sometimes it is best to shuttle crews from one phase to another.

The type of party sent out will depend, of course, on what the party is to do. You should already be familiar with a typical party organization; however, the paragraphs below serve as a refresher.

RECONNAISSANCE PARTY.— The manning level of a reconnaissance party is a flexible one. The number of personnel needed depends upon the purpose of the reconnaissance survey, engineering data required, terrain features, and mode of transportation. We have reconnaissance surveys for triangulation stations, routes, airfields and base sites. Each of these should be treated independently when you are planning. One consideration that also will affect the composition of the party is the choice of instruments and equipment. In a difficult situation, the weight and accessories of the survey instrument and equipment should be given careful consideration.

TRANSIT PARTY.— A transit party consists of at least three persons: instrumentman, head chainman, and party chief. The instrumentman operates the transit; the head chainman measures the horizontal distances; and the party chief, directing the survey, is usually the note keeper and may also serve as rear chainman. The party chief should be at the spot where any important measurement is made so that he can verify the reading personally. He should develop the ability to estimate distances and the sizes of angles so that he may detect any large error at the moment the dimension is called off.

STADIA PARTY.— A stadia party should consist of three persons: instrumentman, note keeper, and rodman. However, two rodmen should be used if there are long distances between observed points. That way, one can proceed to a new point, while the other is holding on a point being observed. The note keeper records the data called off by the instrumentman and makes the sketches required.

PLANE-TABLE PARTY.— A plane-table party should consist of at least three persons: instrumentman (or topographer), note keeper, and rodman. Again, a second rodman may be used when there are long distances between observed points. The note keeper records the data called off by the instrumentman and

Work Assignment — Field Party # 3

START: 3 AUG. 1986

Acting Chief of Party: C. Fox, EA 2
Rodmen: N. Alcott, P. Riley (EA 3)
Chainman: S. Dye, CN

DATE	PROJECT	TYPE OF WORK	SCOPE OF ASSIGNMENT	— STATION — BEGINNING OF JOB	REMARKS
Feb. 6, 1987	Topography.	Profile Levels.	Alice Peninsula.	Intersection of Hill & By Roads to W.	Following Hill Road Course to Rice's Jetty at end of road.
Feb. 7, 1987	"	"	"	Sta 65+96.1 ⊙ #4	Continuing previous days work.
Feb. 8, 1987	Bldg #20 Aviation Operations	Bldg. Layout.	Base "S" Comm. Bldg.	Approx. Airstrip Sta. 30+00	Includes staking out revetment around structure.
Feb. 9, 1987	Hill Road.	Ditch X Sections.	Railroad Bridge to HHW @ shore.	Hill Road Traverse Sta. 15+09.61	Interval stations at all changes in channel slope.

Figure 14-3.-A surveying work assignment sheet.

BENCH MARK SHEET

N. E. SEC. ACORN-6 AREA-AJAX.

BM NO.	LOCATION	ELEV.	TYPE	OTHER REF. DATA
A-17	100'N & 50'W of N.W. Cor. of Station Dispensary inside of fence corner. Bronze disk in concrete monument.	102.723	P.B.M.	U.S.C.& G.S. 1st Order
A-21	Spike in 24" tree root 10'So. of hydrant #10 and 35'E. of E. edge of taxiway #1 at Sta. 21+56	98.351	T.B.M.	Kelly-(Profile)

Figure 14-4.-A bench mark sheet.

reduces the data to corresponding horizontal distances and elevations. This data serves as the basis from which the topographer does the plotting. The rodman must be trained to recognize and properly occupy the necessary control points.

LEVELING PARTY.— Two persons, a levelman and a rodman can run a line of differential levels; however, the use of two rodmen will speed things up. For direct readings, the instrumentman keeps the notes; for target readings (which are, as you know, read by the rodman), it is usually more feasible to have the rodman keep the notes.

Work Assignments

When an order to proceed with certain work is received (usually from the engineering officer), the work (or part of it) is assigned to an available field party on a work assignment sheet. Figure 14-3 shows the type of information entered on a typical work assignment sheet.

Abstract Sheets

When field notes have been reduced to the data sought in the survey, this data is set down in an **abstract sheet.** Typical abstract sheets are **bench mark** sheets, **control point** sheets, **traverse** sheets, and **base line** sheets.

Part of a bench mark sheet is shown in figure 14-4. As you can see, the number, location, elevation and type of each bench mark in a designated area is given. A control point sheet is similar, except that it gives the horizontal locations of horizontal control points, as

CONTROL POINT SHEET

S.E. SECTION "KEY" ADVANCE BASE

(RIDGE DR., BOUNDARY AVE., SLOUGH RD., BRYAN RIVER)

CONTROL STATION	LOCATION	COORDINATE STA. (IF ANY)	TYPE	OTHER DATA
NO. 1	Concr. Mon at S.E. Corner of "Key" Base, 1 ft. outside fence corner. 100' W. of W. Wall of JAN. Pumping Station and 125' N. of ℄ of Jig Highway	0 0 0 / 0 0 0 Base Location	Permanent Control Point (PCP)	Top of Brass plug — Elev.=78.071 (1st Order)
NO. 2	24"x24" Granite Stone. Brass plug in N.E. quarter. Stone located 126' E. of old standpipe and 86' S.E. of S.E. Cor. of Transmission Tower #127 (R.E.C.)	N. 1200.01 W. 171.69 Base Location; 40°20'28" N. Lat. - 165°21'18" W. Long	PCP	This Pt. listed by U.S.G.S. as R-16-1931 ℄ Station
NO. A122	Secondary Traverse "A" 6"x6" Cedar Post flush w/grd. at ℄ intersection of Morris & Gravy Streets. Tack set 2" in from N. Edge and 1½" in from S. edge of post.	N. 1301.97 W. 676.52	Semi-Permanent	Used in Topo Survey of Base

Figure 14-5.-A control point sheet.

shown in figure 14-5. Traverse and base line sheets give the locations of traverse or base line stations, the latitude and departure of each course or baseline, and the coordinate location of each traverse or base line station. For a traverse sheet or base line sheet, the computational sheet used to compute latitudes, departures, and coordinates usually provides a satisfactory abstract.

Procedures for Checking Field Notes

You are already familiar with field and office work and therefore realize the ever-present possibility of errors in surveying. As supervisor, you should be aware that a large part of your job is checking to ensure that errors are detected. In the field, as mentioned before, you must keep the measurement situation in hand by ensuring that the measuring methods used are those that reduce the possibility of error to a minimum. For example, when tape corrections are called for, you must ensure that correct tension is applied, that temperatures are taken, and that temperature corrections are applied accurately.

You are also responsible for error-free computations. Obviously, you cannot check all computations by performing all the calculations involved; this would be the equivalent of doing all the computing yourself. You can, however, require computing procedures that will, if they are followed, reveal the existence of errors. For example, you can require that areas be obtained both by double meridian distance and by double parallel distance. There are, of course, numerous other computations in which the use of two methods will give results that can be checked against each other.

Finally, you must develop skill in the weighing of results for the **probability** of error. This is a skill that cannot be taught; it comes with experience. For example, after you have had a good deal of experience with contour mapping, you develop the ability to get the "feel" of the ground when you study contour lines. This often helps you spot a misdrawn contour line arrangement because the arrangement is inconsistent with real-life probability.

Survey Crew Training

The techniques of the actual operation of surveying instruments are, for the most part, fairly easy to learn; and a crew member learns these quickly in the field. These techniques, however, are a small part of the knowledge involved in the art and/or science of surveying. If a field crew member is shown only how to set up and level an instrument, how to hold a rod, and the like, he is receiving only a minimal amount of training.

The best way to train crew members, in the other things they need to know, is to keep them constantly informed of the overall purpose of the job. Suppose, for example, that the crew is setting offset grade hubs for a highway. Tell them, as you go along, how these hubs will be used as guides for bringing the subgrade to the desired elevation and for placing the highway surface to the prescribed finished grade. Besides training the crew, you will be making fieldwork much more interesting for everybody-including yourself. Furthermore, a field crew will do a better job when they know the purpose of what they are doing.

Another incentive in producing highly motivated field crews is competition. Let's say you have a level circuit to accomplish. If time permits and if you are not far behind in your workload organize two or more level parties to run the same circuit. Then you can determine how proficient the crews are by seeing how closely each crew comes to the correct closing benchmark elevation and the time it takes each crew to run the circuit. You also can use this method in transit work for things like timing the setup of the instrument, measuring horizontal and vertical angles, and measuring distances by stadia. Always find time for training. Perhaps, when waiting for transportation to and from work you can start an open discussion of various solutions to an actual or hypothetical survey problem.

When you are training surveyors, do not forget that the EAs assigned to the drafting room or soils laboratory are also responsible for knowing the techniques of surveying. Whenever the work load permits, the engineering chief should rotate a few personnel for short, on-the-job training periods. This creates interest and helps your personnel to prepare for advancement.

Combat Intelligence Engineering Data

The collecting, analyzing, and reporting of engineering data for combat intelligence is the responsibility of the engineering division of an NMCB deployed to a combat area. Normally the collecting of such data is the job of the field survey crews or an EA assigned to a reconnaissance patrol.

"Combat intelligent" is defined as that knowledge of the enemy, weather, and geographical features (terrain) required by a commander in planning and conducting tactical operations. The objective of combat intelligence is to minimize the uncertainties of the effects that the enemy, weather, and terrain may have on the accomplishment of the mission.

Of primary interest to the EA is the collection of terrain data. Terrain information includes stream data (widths, depths, condition of banks, and rates of flow); bridge data (types, widths, lengths, conditions, and load limits); existing roads (types, widths, and conditions); and topographic mapping, including all pertinent natural and man-made features. In general, a rough reconnaissance survey is performed.

Methods for collecting engineering data will depend on the situation. You maybe given a military map and told to take a reconnaissance patrol out to check the accuracy of the map. Or, you maybe tasked with obtaining data for establishing a suitable construction site for an entire advanced base that might require the efforts of several crews. Your experience as a surveyor will enable you to collect data and report your findings to the engineering officer who, with your assistance, can analyze the data and make recommendations to the battalion planning team.

Information pertinent to organization and deployment of a reconnaissance patrol is found in the *Seabee Combat Handbook* NAVEDTRA 12003. The battalion operation order will specify combat intelligence procedures.

MATERIALS TESTING SECTION

Personnel assigned to the quality control (QC) division of the operations department are responsible for ensuring that construction work is according to the job specifications; that is, the workmanship, materials used, prevailing conditions, and appearance of the finished structure are within the specified minimum standards. This involves constant and careful construction inspection and materials testing. While QC is capable of performing inspections, it needs support from the materials testing section of the engineering division to perform testing, such as in-place density and concrete strength determinations.

As the EA supervisor, a large portion of your job is making sure that QC is receiving the support that it needs. This includes, in part, coordinating testing requirements to ensure that all tests are completed on time, making sure that tests are performed using established standard procedures, analyzing test results for accuracy and validity, and advising QC of the testing results. In addition to providing support to QC, the materials testing section also performs tests, such as soil classification and compaction testing, that may be needed for the design of a new structure, road, or airfield, or the various tests that are associated with the design or proportioning of concrete or asphalt-concrete mixtures. Obviously, to do all of this testing, you must make sure that your EAs are properly trained. If you have been away from a construction battalion for some time, you may even find it necessary to do some refresher training yourself.

Work Assignments

As with the drafting and surveying section, requests for materials testing can be made using the engineering division work request (fig. 14-1). These can then be posted to a work schedule and handled using a priority-system method like that described previously.

Not all of the work requests, however, will be originated by a project supervisor or the QC division. Many of them should start with you. For this to happen, you must become thoroughly familiar with each of the projects the battalion is tasked with. This involves reviewing the project plans and specifications to see what tests are needed and reviewing all project schedules to know when the tests are required. Having done this, you can generate the work requests and post work to the schedule with tentative start dates that can be adjusted as changes occur. Obviously, you must coordinate closely with the project supervisors and QC to know when changes are needed.

Many of the materials tests are critical item tests that must be performed at a given point in construction before further construction work can proceed. For instance, asphalt paving operations on a road or parking area cannot start until the base material has been compacted to meet specifications. Current COM- SECONDNCB or COMTHIRDNCB and battalion instructions pertinent to quality control state minimum requirements and stress critical item inspections and tests that must be performed during construction. You should be particularly aware of these so that project work will not be delayed for materials testing.

You need to remember, too, that some tests are dependent upon other tests; for example, the results of in-place density testing using the nuclear moisture-density meter must be compared with the results of laboratory tests performed on the same material. For these pretests, you will not receive a work request; you must initiate them yourself. Never wait until the last minute to have these tests performed or you maybe the cause of unnecessary construction delay.

Analyzing Test Results

All materials tests have a specific purpose, and when carefully performed according to established standard procedures should provide results that can be reasonably expected. As a supervisor, you need to know what the end purpose is before you can decide what tests to perform and you need to know what to expect from the tests. With this knowledge, you are in a position that enables you to analyze the results of each test performed. When a test results in data that is greatly out of step with that expected, then you need to determine the cause; for example, if an in-place density test shows unexpectedly high results, what happened? Was the test performed improperly? Was a substance, such as cement, added to the soil that greatly increased the density of the in-place material as compared to previously performed laboratory tests? These things can, and do, sometimes happen.

In addition to analyzing the test results for accuracy and validity, you sometimes need to place the test data into a more usable form. Figure 14-6, for example, shows California bearing ratio data that is presented in a usable form. You can read about this in *Materials Testing,* NAVFAC MO-330.

Training of Testers

Lower rated personnel assigned as materials testers should be given assignments for spare-time reading of printed sources on testing procedures. Locally used data forms should be explained. New personnel should be assigned to learning on-the-job procedures in the laboratory and at the jobsite under experienced personnel. The purpose of what is being done should always be explained; for example, the ultimate effect of soil tests on the work of highway subgrading should be clearly shown. Some testing, such as fieldtests for soils, require extensive practice to become proficient. Even though field testing is a requirement at the senior EA level, you should see to it that the junior rated EAs get a chance to practice it as often as possible under the watchful eye of an experienced technician.

There is relatively little routine, day-to-day work in testing since the work of the materials testing

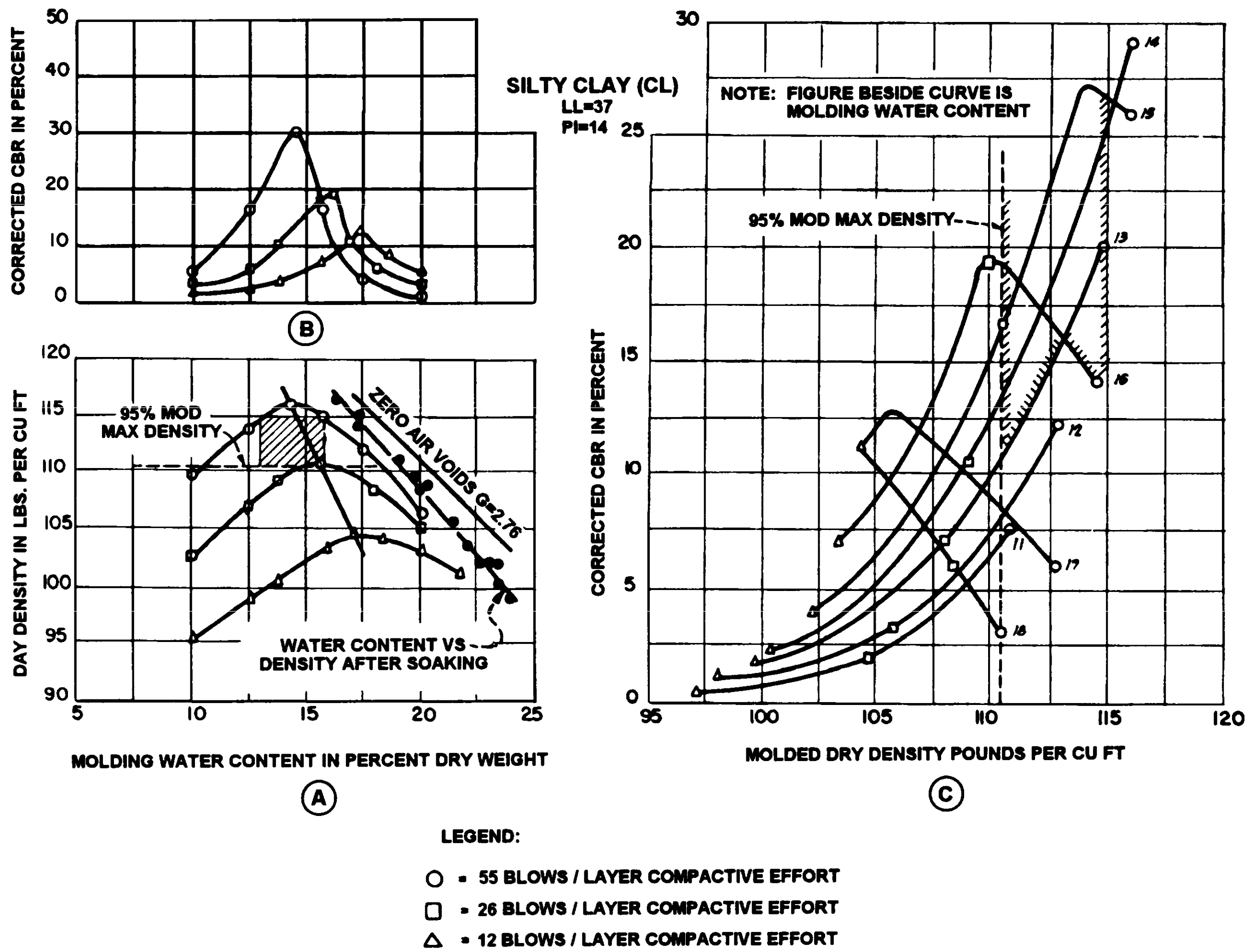


Figure 14-6.—Presentation of CBR data.

section is keyed to the construction currently being done. The person making soils tests in the laboratory today may be performing slump tests on the jobsite tomorrow. The testing section is usually small; and therefore, each person in the section must be trained to cope with all testing problems. In short, one of your main responsibilities as a supervisor is to train your people.

QUESTIONS

The following questions are strictly for your use in determining how well you understand the topics discussed in this chapter AND IN THE REFERENCES SPECIFICALLY CITED IN THIS CHAPTER. The intent of these questions is to help you to learn the topics contained in the chapter and in the references. Remember: when you participate in the advancement examination for EA1, you may be asked questions that are drawn not only from this TRAMAN but also from the cited references as well. Therefore, it is to your benefit to answer the review questions. You do NOT have to submit your answers to these review questions to anyone for grading. Similar review questions are included at the end of each chapter. After answering the questions, you may turn to appendix VI of this book to see how well you performed.

Q1. *In the normal 55-hour battalion workweek your EAs have produced 600 man-hours of labor. How many man-days of labor does this equate to?*

Q2. *In general, the majority of the work that EAs perform while in a battalion should be considered as what type of labor?*

Master Activity Description	MD Est.	Weighted Percent	Percent Complete (Work in place)	Percent Complete (Actual)
Move in and excavate	13	26	100	26
Prefab forms	4	?	100	?
Install forms	3	?	100	?
Place concrete	6	?	75	?
Rough electrical	8	?	75	?
Rough utilities	6	?	0	?
Finish electrical	3	?	0	?
Finish utilities and move out	7	?	0	?
Total	50			?

Figure 14-7.—Example end-of-month status for a project.

Q3. Figure 14-7 shows the end-of-month status for a Seabee project. For this project, what is the total percent of project completion that should be reported in the monthly SITREP? (You will need to determine the missing data)

Q4. A certain NCF project was originally estimated to require 600 man-days of direct labor. To date, 650 man-days have been expended and the project is 75-percent complete. Based on this information only, how many man-days of labor should be required to complete the remaining 25 percent of the project?

Q5. Assume that your battalion is deployed to Seabee Camp Shields, Okinawa. As part of your engineering tasking for the deployment, you are to prepare construction drawings for a future project to be sited at the camp. When completed to what command should the drawings be forwarded for final approval?

Q6. According to the TRAMAN, there are two reasons for you to have the ability to foresee all of the steps required to complete a job that you intend to assign to one of your EAs. What are those two reasons?

CHAPTER 15

FIELD ASTRONOMY AND TRIANGULATION

This chapter provides information that will aid you in carrying out your duties involving field astronomy and in establishing horizontal control using triangulation methods.

In regards to field astronomy, we will explain the basic elements of field astronomy and the use of different kinds of time-such as solar time, zone time, and Greenwich mean time-in determining direction from celestial observations. You will also learn how to determine latitude using a transit and how to determine the true azimuth of a line on the ground from celestial observation.

In the discussion of triangulation, we will explain the purpose and kinds of triangulation networks, the steps involved in a triangulation survey, and the computations involved in establishing horizontal control points using triangulation.

Also included in this chapter is a very brief introduction to satellite surveying systems. That discussion includes types of satellite surveying systems and the basic principles involved in locating point positions on the surface of the earth from observations taken on satellites.

DIRECTION FROM CELESTIAL OBSERVATIONS

Occasions may occur when you must determine the direction of the true meridian (astronomic north) in an area where no usefully located station monuments exist. In a case like this, you have to rely on astronomic observations taken on one of the celestial bodies, such as the sun or a star. To do this, you must understand the astronomical and trigonometric principles of field astronomy. To begin, let's first discuss time as it applies to field astronomy.

TIME

Before you can understand the procedure involved in determining direction from celestial observations, you must have some knowledge of different designations of time.

Solar Time

The sun is the most commonly used reference point for reckoning time, and time reckoned by the sun is solar time. Time reckoned according to the position of the actual physical sun is solar **apparent** time. When the sun is directly over a meridian, it is noontime, **local apparent** time, along that meridian. At the same instant it is midnight, local apparent time, on the meridian 180° away from that meridian, on the opposite side of the earth.

The time required for a complete revolution of the earth on its axis is a constant 24 hours with regard to a particular point on the earth; however, this time varies slightly with regard to the point's position with relation to the actual sun. Therefore, days reckoned by apparent time (that is, the position of the actual sun) vary slightly in length. This difficulty can be avoided by reckoning time according to a **mean** position of the sun, and this is called **mean** time. By mean time the interval from noon to noon along any meridian is always the same-24 hours.

We know that the earth, not the sun, actually moves, but for the purposes of this explanation, we will assume that the earth is motionless, with the heavenly bodies moving westward around it. As the sun moves along its course, it takes noontime with it, so to speak. In other words, when the mean sun is on a particular meridian, it is noontime along that meridian, not yet noon at any point west of that meridian, and already past noon at any point east of that meridian.

This means that, by local mean time, the time is different at any two points lying in different longitudes. To avoid the obvious disadvantages of a system in which the time is different at the opposite ends of a short street running east-west, the nations of the earth have generally established **zone** or **standard** time.

Zone Time

Under the zone time system, the earth has been divided along meridians into 24 time zones. The starting point is the Greenwich meridian, lying at 0° longitude. Every meridian east or west of Greenwich that is numbered 15° or a multiple of 15° (such as 30° east or west, 45° east or west, 60° east or west, and so on) is designated as a **standard time meridian.** Each time meridian runs through the center of its time zone, which means that the zone extends for 7°30′ on each side of the meridian. In each zone, the time is the same throughout the zone.

There is a 1 hour difference in time between a particular zone and the adjacent zone. When determining time in different zones, it is helpful to remember this phrase: **time is later as you move eastward.** So, if it is 1200 in your zone, it is 1300 in the next zone to the east and 1100 in the next zone to the west.

ZONE TIME AND GREENWICH MEAN TIME.— The time listed in most of the computational tables used in celestial observations is **Greenwich mean time (GMT)—** meaning the zone time in the Greenwich standard time zone. You must know how to convert the zone time at which you made a particular observation to Greenwich mean time. The procedure is as follows.

Each of the time zones has a number that is called the **zone description** (ZD). The Greenwich zone is numbered 0. The others are numbered from 1 through 12, east or west of Greenwich. To determine the ZD for any point on the earth, you divide the longitude by 15. If the remainder is greater than 7°30′, the quotient **plus** 1 is the ZD. Suppose, for example, that the longitude at the point of your observation is 142°41′W. Divide this by 15 and you get 9, with a remainder of 7°41′. Since the remainder is greater than 7°30′, the ZD is 9 + 1, or 10.

Zones east of Greenwich are minus and zones west of Greenwich are plus. To convert the zone time of an observation to the corresponding Greenwich meantime, you apply the ZD **according to its sign** to the zone time. For example, suppose the longitude at your point of observation is 75°15′37″E and the zone time is $16^h23^m14^s$. Divide the longitude by 15 and you get 5, with less than 7°30' left over. 'The longitude is east; therefore, the ZD is -5; and the GMT of the observation is $16^h23^m14^s - 5^h$, or $11^h23^m14^s$.

Suppose now that the longitude of the point of observation is 68°19′22″W and the zone time of the observation is $10^h15^m08^s$. Divide the longitude by 15 and you get 4, with more than 7°30′ left over. The ZD is therefore +5; and the GMT of the observation is $10^h15^m08^s + 5^h$, or $15^h15^m08^s$.

ZONE TIME AND DATE.— It may be the case that the date at Greenwich and the date at the point of observation are not the same at the time of observation. Suppose that on 1 May you are in longitude 176°15′22″W, and the zone time of your observation is 16^h24^m1 The ZD is +12. GMT of the observation is therefore $16^h24^m11^s + 12$, or 28^h24^m1 However, 28^h24^m1 on 1 May means 04^h24^m1 on 2 May, and you would refer to the tables for that GMT and date.

Suppose now that on 1 May you are in longitude 47°32′55″E and the zone time of the observation is $02^h15^m27^s$, bu but $02^h15^m27^s$ on 1 May can be considered as $26^h15^m27^s$ on 30 April. Therefore, GMT for the observation was $25^h15^m27^s - 3^h$, or $23^h15^m27^s$, on 30 April.

Importance of Exact Time

The importance of recording the **exact time** at which an observation is made may be illustrated as follows. Suppose a ship's navigator makes an error of only 1 minute in his time. This could produce an error of as much as 15 miles in the location of his computed and plotted line of position. A 1-minute time error produces a 15-minute error in longitude regardless of the latitude; and on the equator, a minute of longitude equals a nautical mile.

You must time the observation to the nearest second, and for this purpose, you must have an accurate watch. It is best that you have an accurate ordinary watch plus a stopwatch. You should set the ordinary watch to exact time shortly before the time of observation. Correct standard time can be obtained from a clock known to be closely regulated, or preferably from time signals broadcast by the U.S. Naval Observatory.

Remember, too, that in localities under daylight savings time, the time is 1 hour faster than standard time.

ELEMENTS OF FIELD ASTRONOMY

Although the earth is not actually a true sphere, it is presumed to be such for the purpose of astronomy. Astronomic determinations are based on the relationships that exist among sets of spherical coordinates: the **terrestrial system** stated in latitude and longitude; the **celestial system** of right ascension and declination, or its subsidiary system of hour angle and declination; and the **horizon system** in terms of altitude and azimuth.

Terrestrial System of Coordinates

The terrestrial system of coordinates refers to the location of points on the terrestrial sphere (the earth). In the terrestrial system, the fundamental reference lines (fig. 15-1) are the axis of the earth's rotation and the earth's equator. The ends of the axis of rotation are known as the poles, designated as the North and South

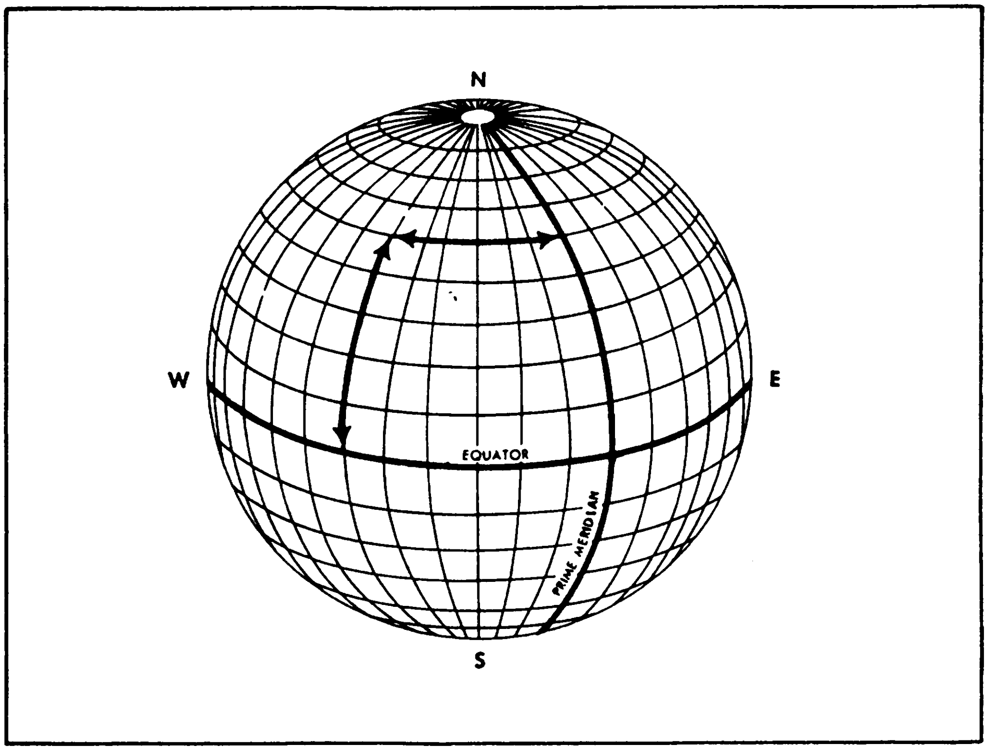


Figure 15-1.-Reference lines.

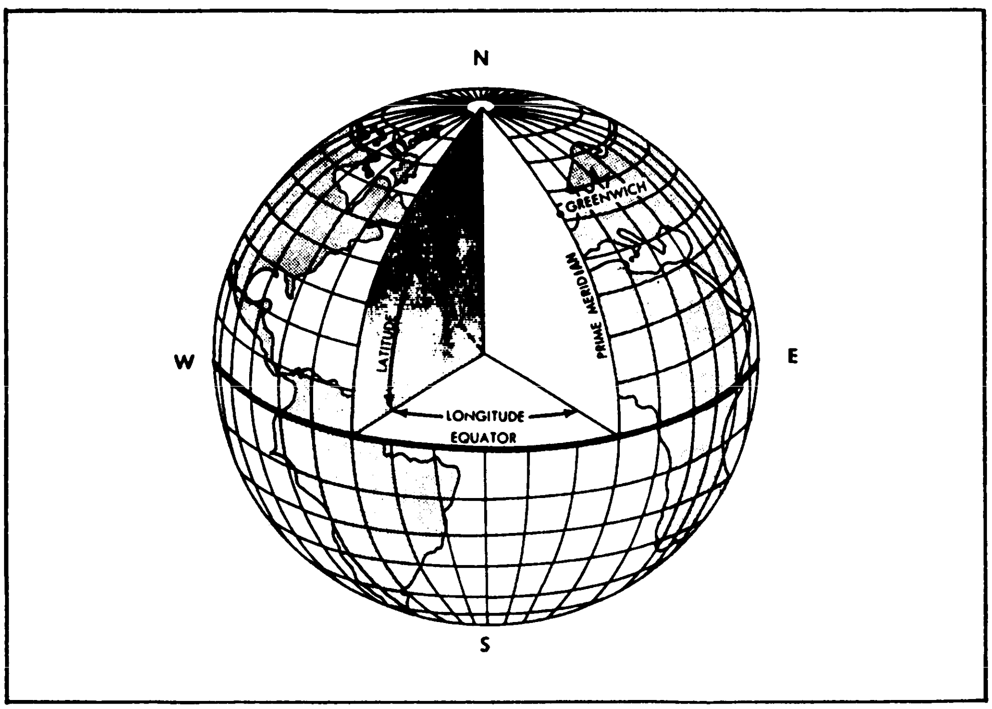


Figure 15-2.—Latitude, longitude, and reference lines.

A great circle passing through both poles is called a **meridian.** The **equator** is a great circle about the earth equidistant from the poles and perpendicular to the axis of rotation. Through any point removed from the equator, a circle whose plane is parallel to that of the equator is called a **parallel of latitude.** The numerical value of the parallels defines latitude and that of the meridians defines longitude.

As shown in figure 15-2, geographic **latitude** of a point may be defined as its angular distance above or below the equator. Latitudes are expressed in degrees and are measured from 0° to 90° north or south. The conventional symbol for latitude used in computation is the Greek letter **Φ (phi).**

As shown also in figure 15-2, the **longitude** of a point is the angular distance measured along the equator between the meridian passing through a point and a reference meridian. The chosen reference meridian is the Greenwich meridian that passes through Greenwich, England. That meridian is known as the primary or prime meridian. Longitude is also expressed in degrees but is measured from 0° to 180° west or east from the **prime meridian.** The conventional symbol for longitude is the Greek letter **λ** (lambda).

Celestial system of Coordinates

To explain the celestial system, let's first suppose that the earth is a glass sphere, with meridians and parallels traced in black and a light placed at the center. Suppose, too, that this sphere is placed at the center of another infinitely larger sphere, as shown in figure 15-3. This larger sphere is the imaginary **celestial sphere** on which all the heavenly bodies are presumed to be located.

The celestial sphere is a mathematical concept of a sphere of infinite radius whose center is at the center of the earth The points at which the earth's prolonged axis of rotation pierces the celestial sphere are known as the celestial poles. The plane of the earth's equator, extended to the celestial sphere, coincides with the **celestial equator.** Great circles through the celestial poles, comparable to the earth's meridians, are called **hour circles.** The angle between hour circles is the **hour angle.** Even though the earth rotates and the stars appear stationary among themselves, it is easier to think of the earth as being stationary, while the celestial sphere, with the celestial bodies attached, rotates from east to west, This is actually its apparent motion. When reference is made to a star's path or motion, it is this apparent motion that is referred to.

DECLINATION.— Similar to latitude, the declination of a celestial body (star, sun, or planet) is its angular distance north or south of the celestial equator. As with latitude, declination is expressed in degrees and is measured horn 0° to 90° north or south from the celestial equator. North and south declination values are given plus and minus signs, respectively. The conventional symbol for declination is the Greek letter **δ** (delta).

RIGHT ASCENSION.— The **vernal equinox,** also known as the **first point of Aries,** is an imaginary point on the celestial sphere where the **ecliptic** (or apparent path of the sun) crosses the equator from south to north on or about 21 March of each year. The vernal equinox moves westward along the equator about 50 seconds of arc per year. The right ascension of the sun or any star is the angular distance measured eastward along the celestial equator between the vernal equinox and the hour circle passing through the celestial body. Right ascension is normally expressed in units of time from 0 to 24 hours, although it can be expressed in degrees with 1 hour of time corresponding to 15°. The conventional symbol for right ascension is the Greek letter a (alpha), or it can be abbreviated RA.

HOUR ANGLE.— Right ascension and declination are independent coordinates of the celestial system, whereas the hour angle is a dependent coordinate. **Hour** angle is the angle between celestial meridians, or hour circles; but its origin is the meridian that passes through the observer's zenith (or point on the celestial sphere directly above the observer). The hour angle of a star is defined as the angular distance, measured **westward** along the celestial equator, between the observer's meridian and the hour circle or meridian of the star. This angle is often called the **local hour angle** (LHA), which will be discussed later.

GREENWICH HOUR ANGLE.— The coordinate for a heavenly body that corresponds to longitude is called the **Greenwich hour angle** (GHA). The Greenwich hour angle is the angular distance from the Greenwich meridian to the meridian of the heavenly body. It is always measured **westward** from the Greenwich meridian and is expressed in degrees from 0° to 360°. Another point to remember is that, while the longitude of a point on the earth always remains the same, the GHA of the celestial object is constantly increasing as the body moves westward on the celestial sphere.

Horizon System of Coordinates

To connect the celestial and terrestrial coordinates, you must have a third system, descriptive of the observer's position. The fundamental reference of this

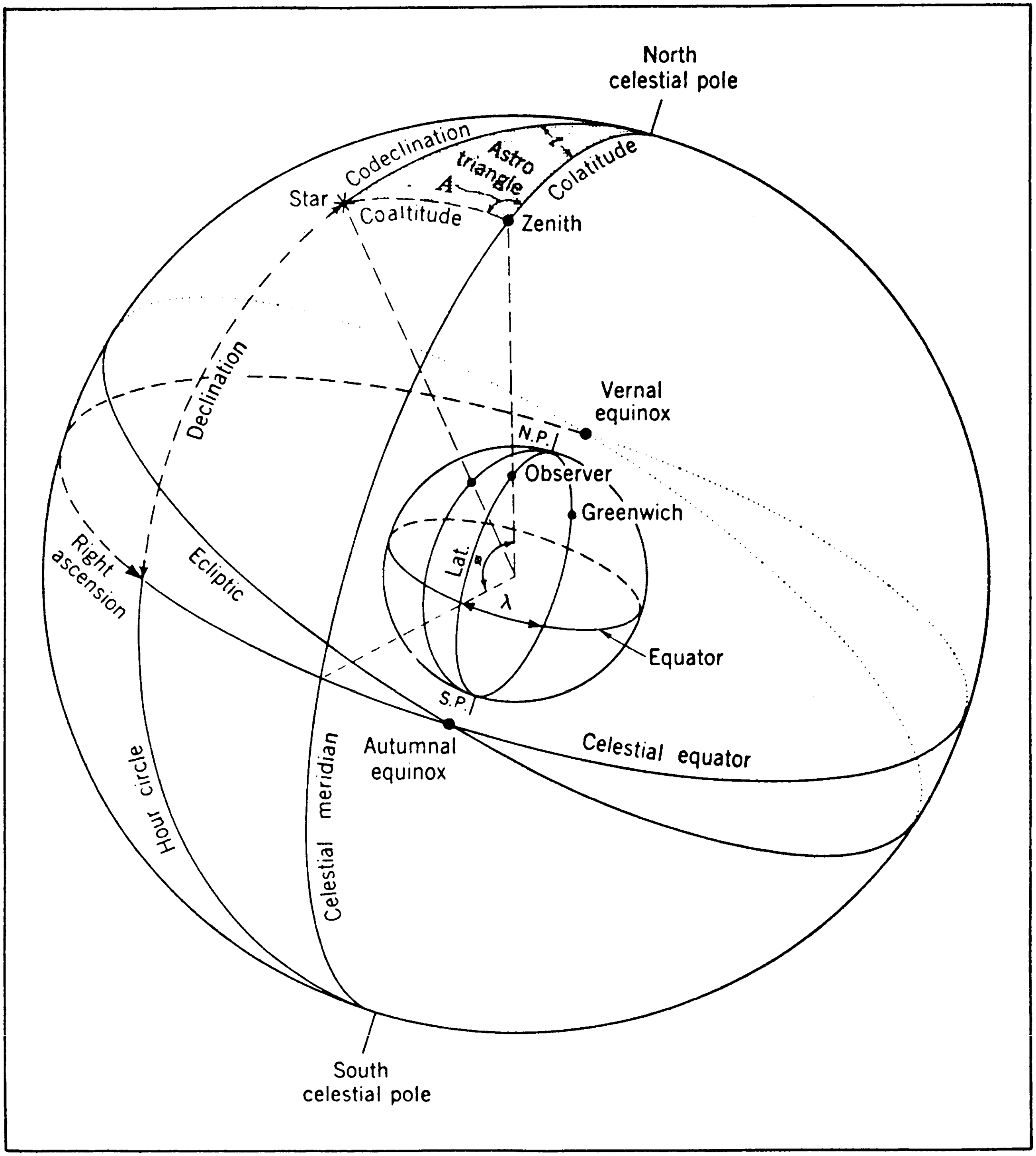


Figure 15-3.—Terrestrial and celestial coordinate system.

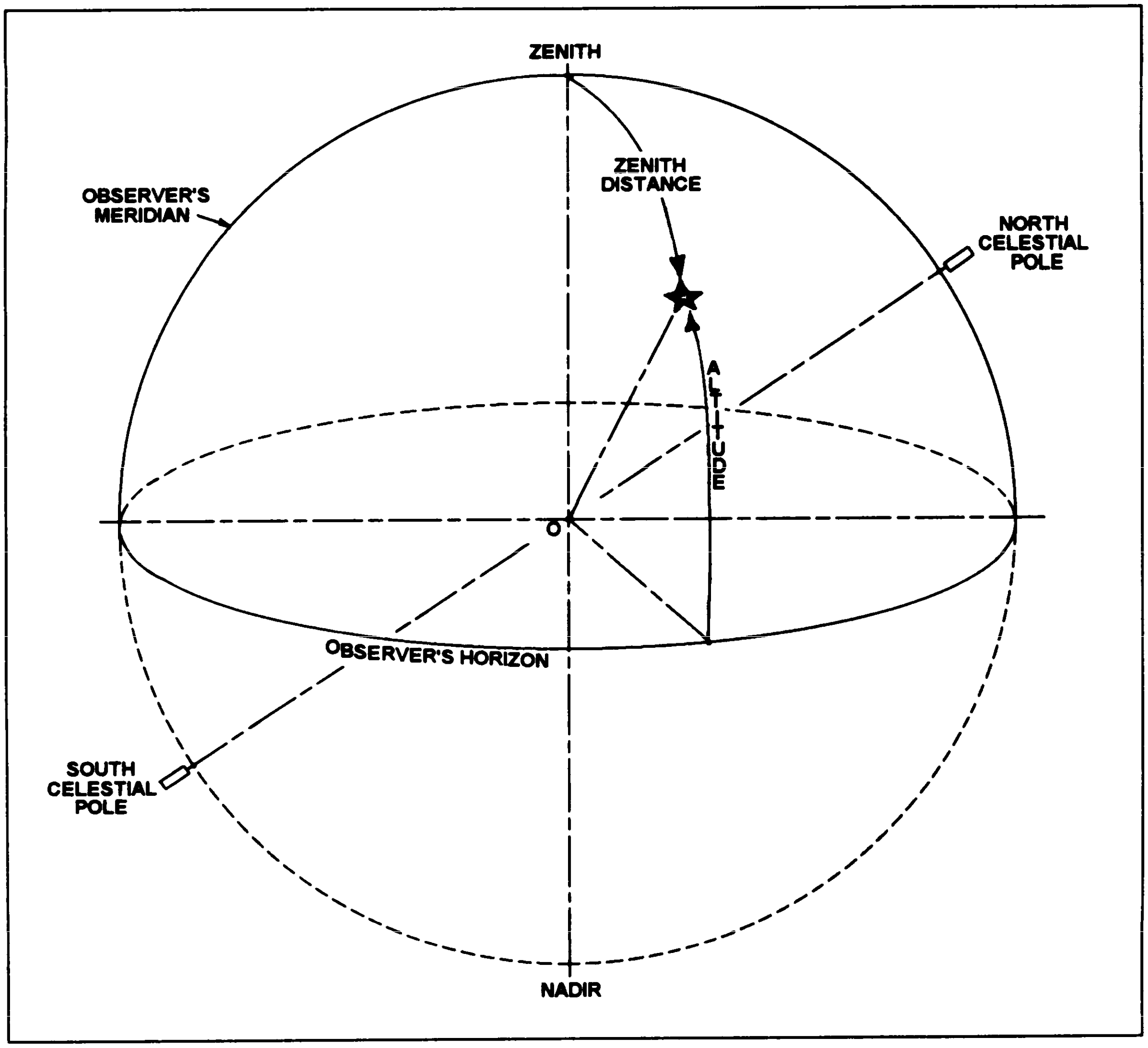


Figure 15-4.-Horizon system of coordinates.

system is the observer's horizon. Figure 15-4 illustrates the horizon system. In this figure, *O* represents both the earth and the location of the observer.

The **horizon** is a plane through the observer's position that is perpendicular to the direction of gravity at that point and that intercepts the celestial sphere in a great circle. The direction of gravity, commonly called the direction of the plumb line, does not necessarily pass through the earth's center. The horizon plane is considered tangent to the surface of the earth at the observer's position For most star observations, the distance from this plane to the center of the earth is too small to affect the computations. However, observations of the sun, planets, and some of the nearer stars, when used in the more precise computations, must account for the displacement of the horizon plane. This is called the correction for **parallax.**

The point where the plumb line, extended overhead, pierces the celestial sphere is known as the zenith. The point opposite this and underneath is the **nadir.** Great circles drawn through the zenith and **nadir** (with their planes perpendicular to that of the horizon) are called **vertical circles.** The angular distance of a celestial body measured along a vertical circle from the horizon is the **altitude** *(h)* of the body. The complement of the altitude is the **coaltitude,** or **zenith distance,** and is measured along the vertical circle from the zenith to the body.

The vertical circle through the poles, which also passes through the zenith, is called the observer's **meridian.** The **azimuth** of an object is the angle measured clockwise in the plane of the horizon from the observer's meridian to the vertical circle passing through the object. The northern intersection of the meridian with the horizon is used as the zero azimuth point. Azimuth is measured in degrees from 0° to 360°. The conventional symbol for azimuth is the letter *A or Z.*

Astronomical Triangle

The solutions of problems involving the three coordinate systems are made by means of spherical trigonometry. A figure of prime importance is the spherical triangle that lies on the celestial sphere and whose vertices are the pole, the zenith, and the celestial body involved. This is known as the **astronomical** or the **PZS** (pole-zenith-star) triangle. The **astronomical triangle** is shown in figure 15-3. As in the case of all spherical triangles, the sides can be expressed as the angles subtended at the center of the sphere. In the astronomical triangle, the side between the pole and the zenith is the **colatitude** (90° - **Φ**), between the pole and the star is the **codeclination** or polar distance (90° - **δ**), and between the zenith and the star is the **coaltitude,** or zenith distance (90° - h). The angle at the zenith is the azimuth angle *(A)* of the body. The angle at the pole is the hour angle *(t)*. The angle at the star is known as the **parallactic** angle and is little used in computations. If the three elements of the astronomic triangle are known, the others can be found by means of spherical trigonometry. The fundamental equation is the law of cosines. cos a = cos b $\cos c$ + sin b sin c cos a, in which a, b, and c are the sides of a spherical triangle, and A is the angle opposite side a (B and C are the angles opposite sides b and c, respectively). All formulas required for the solution of the astronomic triangle may be derived from this law of cosines.

Astronomical Tables Used by Surveyors

The declination and Greenwich hour angle of the sun, moon, and selected planets are given for every even hour of GMT for everyday in the year in the daily pages of the Nautical Almanac and the *Ephemeris of the Sun, Polaris, and Other Selected Stars. These* publications are prepared by the U.S. Naval Observatory and are available for sale at the U.S. Government Printing Office, Washington, D.C. Condensed tables of data are also available from various manufacturers of surveying equipment.

Suppose that you want to determine the GHA and declination of the sun for an observation made at zone time $10^h23^m18^s$ on 17 May 1986 in longitude **79°37′12″W.** The ZD is +5; therefore, GMT Of the observation was $15^h23^m18^s$.

Table 15-1 shows the relevant daily page of the 1986 Nautical Almanac. You can see that for $15^h00^m00^s$ on 17 May the GHA listed for the sun is **45°54.8′.** For the extra 23^m18^s you turn to a **table of increments and corrections** in the back of the book. Table 15-2 shows the relevant page of the table. Under 23^m and beside 18^s in the Sun column you find an increment of **5°49.5′.** The GHA of the sun at the time of observation, then, was **45°54.8′ + 5°49.5′,** or **51°44.3′.**

On the daily page of 17 May (table 15-1), the Nautical Almanac gives a sun declination for $15^h00^m00^s$ GMT on **N19°21.3′.** At the foot of the column, you see a small d and the figure 0.6. In the increments and corrections table (table 15-2), you see a column of v or d corrections for declination. You go down this column to the figure 0.6, where you find that the d correction in this case is 0.2'. Whether you add this correction or subtract it depends upon whether the declination of the sun is increasing or decreasing with time. A glance at the daily page shows that in this case, it is increasing; therefore, the declination of the sun at the time of observation was **N19°21.3′ + 0.2′,** or **N 19°21.5′.**

On an opposing daily page of the Nautical Almanac (table 5-3), the declinations of a select list of 57 prominent stars are given. Instead of the GHAs of these stars, however, the **sidereal hour angle** (SHA) of each star is given. The sidereal angle of a star is its arc distance westward from the vernal equinox or first point of Aries. The GHA of a star is its arc distance westward from the hour circle of the first point of Aries.

For GHA of a star, you first determine GHA of the first point of Aries in the same manner described for the sun. You can see Aries listed in tables 15-2 and 15-3. You then add this to the SHA of the star, as given in the daily page of the Nautical Almanac (table 15-3). This can be stated as follows: GHA star= GHA Aries + SHA star. If the result is greater than 360°, you subtract 360° from it.

For declination of a star, you use the declination listed on the daily page; this is good for a star at anytime of the day.

NOTE: The SHA and GHA of the vernal equinox are factors used in star observations; however, neither is applicable in observation of navigational plaints.

Table 15-1.—Sun and Moon Daily Page from the Nautical Almanac

	G.M.T. (UT) d h	SUN G.H.A. ° ′	SUN Dec. ° ′	MOON G.H.A. ° ′	MOON v ′	MOON Dec. ° ′	MOON d ′	MOON H.P. ′
	16 00	180 55.3	N18 58.9	96 41.1	11.7	N21 53.1	09.6	55.5
	01	195 55.3	18 59.5	111 11.8	11.7	21 43.5	09.8	55.6
	02	210 55.3	19 00.1	125 42.5	11.8	21 33.7	10.0	55.6
	03	225 55.3	. . 00.7	140 13.3	11.8	21 23.7	10.0	55.6
	04	240 55.3	01.3	154 44.1	11.9	21 13.7	10.1	55.7
	05	255 55.3	01.8	169 15.0	11.9	21 03.6	10.2	55.7
	06	270 55.3	N19 02.4	183 45.9	11.9	N20 53.4	10.4	55.7
	07	285 55.3	03.0	198 16.8	12.0	20 43.0	10.4	55.7
	08	300 55.2	03.6	212 47.8	12.0	20 32.6	10.6	55.8
F	09	315 55.2	. . 04.2	227 18.8	12.1	20 22.0	10.6	55.8
R	10	330 55.2	04.7	241 49.9	12.1	20 11.4	10.8	55.8
I	11	345 55.2	05.3	256 21.0	12.1	20 00.6	10.9	55.9
D	12	0 55.2	N19 05.9	270 52.1	12.2	N19 49.7	10.9	55.9
A	13	15 55.2	06.5	285 23.3	12.2	19 38.8	11.1	55.9
Y	14	30 55.2	07.1	299 54.5	12.2	19 27.7	11.2	55.9
	15	45 55.2	. . 07.6	314 25.7	12.3	19 16.5	11.2	56.0
	16	60 55.2	08.2	328 57.0	12.3	19 05.3	11.4	56.0
	17	75 55.1	08.8	343 28.3	12.4	18 53.9	11.5	56.0
	18	90 55.1	N19 09.4	357 59.7	12.4	N18 42.4	11.5	56.1
	19	105 55.1	09.9	12 31.1	12.4	18 30.9	11.7	56.1
	20	120 55.1	10.5	27 02.5	12.5	18 19.2	11.8	56.1
	21	135 55.1	. . 11.1	41 34.0	12.5	18 07.4	11.8	56.2
	22	150 55.1	11.6	56 05.5	12.5	17 55.6	12.0	56.2
	23	165 55.1	12.2	70 37.0	12.6	17 43.6	12.0	56.2
	17 00	180 55.0	N19 12.8	85 08.6	12.6	N17 31.6	12.2	56.3
	01	195 55.0	13.4	99 40.2	12.6	17 19.4	12.2	56.3
	02	210 55.0	13.9	114 11.8	12.7	17 07.2	12.3	56.3
	03	225 55.0	. . 14.5	128 43.5	12.6	16 54.9	12.5	56.4
	04	240 55.0	15.1	143 15.1	12.8	16 42.4	12.5	56.4
	05	255 55.0	15.6	157 46.9	12.7	16 29.9	12.6	56.4
	06	270 55.0	N19 16.2	172 18.6	12.8	N16 17.3	12.7	56.5
	07	285 54.9	16.8	186 50.4	12.8	16 04.6	12.8	56.5
S	08	300 54.9	17.3	201 22.2	12.8	15 51.8	12.8	56.5
A	09	315 54.9	. . 17.9	215 54.0	12.9	15 39.0	13.0	56.6
T	10	330 54.9	18.5	230 25.9	12.9	15 26.0	13.0	56.6
U	11	345 54.9	19.0	244 57.8	12.9	15 13.0	13.1	56.6
R	12	0 54.9	N19 19.6	259 29.7	12.9	N14 59.9	13.3	56.7
D	13	15 54.8	20.2	274 01.6	13.0	14 46.6	13.2	56.7
A	14	30 54.8	20.7	288 33.6	12.9	14 33.4	13.4	56.8
Y EXAMPLE →	15	45 54.8	21.3	303 05.5	13.0	14 20.0	13.5	56.8
	16	60 54.8	21.8	317 37.5	13.1	14 06.5	13.5	56.8
	17	75 54.8	22.4	332 09.6	13.0	13 53.0	13.6	56.9
	18	90 54.7	N19 23.0	346 41.6	13.0	N13 39.4	13.7	56.9
	19	105 54.7	23.5	1 13.6	13.1	13 25.7	13.8	56.9
	20	120 54.7	24.1	15 45.7	13.1	13 11.9	13.9	57.0
	21	135 54.7	. . 24.6	30 17.8	13.1	12 58.0	13.9	57.0
	22	150 54.7	25.2	44 49.9	13.1	12 44.1	14.0	57.0
	23	165 54.6	25.8	59 22.0	13.2	12 30.1	14.1	57.1
	18 00	180 54.6	N19 26.3	73 54.2	13.1	N12 16.0	14.2	57.1
	01	195 54.6	26.9	88 26.3	13.2	12 01.8	14.2	57.2
	02	210 54.6	27.4	102 58.5	13.2	11 47.6	14.3	57.2
	03	225 54.6	. . 28.0	117 30.7	13.2	11 33.3	14.4	57.2
	04	240 54.5	28.5	132 02.9	13.2	11 18.9	14.4	57.3
	05	255 54.5	29.1	146 35.1	13.2	11 04.5	14.6	57.3
	06	270 54.5	N19 29.6	161 07.3	13.2	N10 49.9	14.5	57.3
	07	285 54.5	30.2	175 39.5	13.2	10 35.4	14.7	57.4
	08	300 54.5	30.7	190 11.7	13.2	10 20.7	14.7	57.4
S	09	315 54.4	. . 31.3	204 43.9	13.2	10 06.0	14.8	57.5
U	10	330 54.4	31.9	219 16.1	13.3	9 51.2	14.9	57.5
N	11	345 54.4	32.4	233 48.4	13.2	9 36.3	14.9	57.5
D	12	0 54.4	N19 33.0	248 20.6	13.2	N 9 21.4	15.0	57.6
A	13	15 54.3	33.5	262 52.8	13.3	9 06.4	15.0	57.6
Y	14	30 54.3	34.1	277 25.1	13.2	8 51.4	15.1	57.7
	15	45 54.3	. . 34.6	291 57.3	13.2	8 36.3	15.2	57.7
	16	60 54.3	35.1	306 29.5	13.3	8 21.1	15.2	57.7
	17	75 54.2	35.7	321 01.8	13.2	8 05.9	15.3	57.8
	18	90 54.2	N19 36.2	335 34.0	13.2	N 7 50.6	15.4	57.8
	19	105 54.2	36.8	350 06.2	13.2	7 35.2	15.4	57.9
	20	120 54.2	37.3	4 38.4	13.2	7 19.8	15.4	57.9
	21	135 54.1	. . 37.9	19 10.6	13.2	7 04.4	15.5	57.9
	22	150 54.1	38.4	33 42.8	13.2	6 48.9	15.6	58.0
	23	165 54.1	39.0	48 15.0	13.1	6 33.3	15.6	58.0
		S.D. 15.8	*d* 0.6	S.D. 15.2		15.4		15.7

Lat. °	Twilight Naut. h m	Twilight Civil h m	Sunrise h m	Moonrise 16 h m	Moonrise 17 h m	Moonrise 18 h m	Moonrise 19 h m
N 72	▭	▭	▭	▭	08 39	11 23	13 44
N 70	▭	▭	▭	▭	09 19	11 39	13 47
68	////	////	01 37	07 14	09 47	11 51	13 50
66	////	////	02 15	08 02	10 07	12 01	13 53
64	////	00 55	02 42	08 32	10 23	12 10	13 55
62	////	01 44	03 02	08 55	10 37	12 17	13 57
60	////	02 14	03 19	09 13	10 48	12 23	13 58
N 58	00 49	02 36	03 32	09 28	10 58	12 28	14 00
56	01 34	02 54	03 44	09 40	11 06	12 33	14 01
54	02 01	03 08	03 55	09 52	11 14	12 37	14 02
52	02 22	03 21	04 04	10 01	11 21	12 41	14 03
50	02 39	03 32	04 12	10 10	11 27	12 44	14 04
45	03 11	03 55	04 29	10 28	11 40	12 52	14 06
N 40	03 34	04 13	04 43	10 43	11 50	12 58	14 07
35	03 53	04 27	04 55	10 56	11 59	13 04	14 09
30	04 08	04 39	05 06	11 07	12 07	13 08	14 10
20	04 32	05 00	05 23	11 26	12 21	13 16	14 12
N 10	04 50	05 16	05 39	11 42	12 33	13 23	14 14
0	05 05	05 31	05 53	11 57	12 44	13 30	14 16
S 10	05 19	05 45	06 07	12 12	12 55	13 37	14 18
20	05 32	05 58	06 22	12 28	13 07	13 43	14 20
30	05 44	06 13	06 39	12 46	13 20	13 51	14 22
35	05 51	06 22	06 49	12 57	13 28	13 56	14 23
40	05 58	06 31	07 00	13 09	13 36	14 01	14 25
45	06 05	06 41	07 13	13 23	13 46	14 07	14 26
S 50	06 13	06 53	07 29	13 41	13 59	14 14	14 28
52	06 17	06 58	07 36	13 49	14 04	14 17	14 29
54	06 21	07 05	07 45	13 58	14 11	14 21	14 30
56	06 25	07 11	07 54	14 08	14 17	14 25	14 31
58	06 29	07 19	08 05	14 19	14 25	14 29	14 33
S 60	06 34	07 27	08 17	14 33	14 34	14 34	14 34

Lat. °	Sunset h m	Twilight Civil h m	Twilight Naut. h m	Moonset 16 h m	Moonset 17 h m	Moonset 18 h m	Moonset 19 h m
N 72	▭	▭	▭	▭	04 49	03 42	03 02
N 70	▭	▭	▭	▭	04 06	03 24	02 54
68	22 21	////	////	04 31	03 38	03 10	02 48
66	21 41	////	////	03 42	03 16	02 58	02 43
64	21 13	23 06	////	03 11	02 58	02 48	02 39
62	20 53	22 13	////	02 48	02 43	02 39	02 35
60	20 36	21 42	////	02 29	02 31	02 32	02 32
N 58	20 22	21 19	23 11	02 13	02 20	02 25	02 29
56	20 10	21 01	22 22	02 00	02 11	02 19	02 26
54	19 59	20 46	21 54	01 48	02 03	02 14	02 24
52	19 50	20 33	21 32	01 38	01 55	02 09	02 22
50	19 42	20 22	21 15	01 28	01 48	02 05	02 20
45	19 24	19 59	20 43	01 09	01 34	01 55	02 15
N 40	19 10	19 41	20 19	00 53	01 22	01 48	02 11
35	18 58	19 26	20 01	00 39	01 11	01 41	02 08
30	18 47	19 14	19 45	00 27	01 02	01 35	02 05
20	18 30	18 53	19 21	00 07	00 47	01 24	02 00
N 10	18 14	18 37	19 03	24 33	00 33	01 15	01 56
0	18 00	18 22	18 47	24 20	00 20	01 06	01 52
S 10	17 46	18 08	18 34	24 06	00 06	00 57	01 47
20	17 31	17 54	18 21	23 52	24 47	00 47	01 43
30	17 14	17 39	18 08	23 36	24 36	00 36	01 38
35	17 04	17 31	18 02	23 26	24 30	00 30	01 35
40	16 53	17 22	17 55	23 15	24 23	00 23	01 31
45	16 39	17 11	17 47	23 02	24 14	00 14	01 27
S 50	16 23	16 59	17 39	22 46	24 04	00 04	01 22
52	16 16	16 54	17 35	22 39	23 59	25 20	01 20
54	16 07	16 48	17 31	22 31	23 53	25 17	01 17
56	15 58	16 41	17 27	22 21	23 47	25 14	01 14
58	15 47	16 34	17 23	22 10	23 41	25 11	01 11
S 60	15 35	16 25	17 18	21 58	23 33	25 08	01 08

Day	SUN Eqn. of Time 00ʰ m s	SUN Eqn. of Time 12ʰ m s	SUN Mer. Pass. h m	MOON Mer. Pass. Upper h m	MOON Mer. Pass. Lower h m	MOON Age d	MOON Phase
16	03 41	03 41	11 56	16 08	05 44	08	◐
17	03 40	03 39	11 56	18 55	06 32	09	
18	03 39	03 37	11 56	19 41	07 18	10	

Table 15-2.- Page from the Nautical Almanac (Table of Increments and Corrections)

22^m	SUN PLANETS	ARIES	MOON	v or d	Corr^n	v or d	Corr^n	v or d	Corr^n
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 30·0	5 30·9	5 15·0	0·0	0·0	6·0	2·3	12·0	4·5
01	5 30·3	5 31·2	5 15·2	0·1	0·0	6·1	2·3	12·1	4·5
02	5 30·5	5 31·4	5 15·4	0·2	0·1	6·2	2·3	12·2	4·6
03	5 30·8	5 31·7	5 15·7	0·3	0·1	6·3	2·4	12·3	4·6
04	5 31·0	5 31·9	5 15·9	0·4	0·2	6·4	2·4	12·4	4·7
05	5 31·3	5 32·2	5 16·2	0·5	0·2	6·5	2·4	12·5	4·7
06	5 31·5	5 32·4	5 16·4	0·6	0·2	6·6	2·5	12·6	4·7
07	5 31·8	5 32·7	5 16·6	0·7	0·3	6·7	2·5	12·7	4·8
08	5 32·0	5 32·9	5 16·9	0·8	0·3	6·8	2·6	12·8	4·8
09	5 32·3	5 33·2	5 17·1	0·9	0·3	6·9	2·6	12·9	4·8
10	5 32·5	5 33·4	5 17·4	1·0	0·4	7·0	2·6	13·0	4·9
11	5 32·8	5 33·7	5 17·6	1·1	0·4	7·1	2·7	13·1	4·9
12	5 33·0	5 33·9	5 17·8	1·2	0·5	7·2	2·7	13·2	5·0
13	5 33·3	5 34·2	5 18·1	1·3	0·5	7·3	2·7	13·3	5·0
14	5 33·5	5 34·4	5 18·3	1·4	0·5	7·4	2·8	13·4	5·0
15	5 33·8	5 34·7	5 18·5	1·5	0·6	7·5	2·8	13·5	5·1
16	5 34·0	5 34·9	5 18·8	1·6	0·6	7·6	2·9	13·6	5·1
17	5 34·3	5 35·2	5 19·0	1·7	0·6	7·7	2·9	13·7	5·1
18	5 34·5	5 35·4	5 19·3	1·8	0·7	7·8	2·9	13·8	5·2
19	5 34·8	5 35·7	5 19·5	1·9	0·7	7·9	3·0	13·9	5·2
20	5 35·0	5 35·9	5 19·7	2·0	0·8	8·0	3·0	14·0	5·3
21	5 35·3	5 36·2	5 20·0	2·1	0·8	8·1	3·0	14·1	5·3
22	5 35·5	5 36·4	5 20·2	2·2	0·8	8·2	3·1	14·2	5·3
23	5 35·8	5 36·7	5 20·5	2·3	0·9	8·3	3·1	14·3	5·4
24	5 36·0	5 36·9	5 20·7	2·4	0·9	8·4	3·2	14·4	5·4
25	5 36·3	5 37·2	5 20·9	2·5	0·9	8·5	3·2	14·5	5·4
26	5 36·5	5 37·4	5 21·2	2·6	1·0	8·6	3·2	14·6	5·5
27	5 36·8	5 37·7	5 21·4	2·7	1·0	8·7	3·3	14·7	5·5
28	5 37·0	5 37·9	5 21·6	2·8	1·1	8·8	3·3	14·8	5·6
29	5 37·3	5 38·2	5 21·9	2·9	1·1	8·9	3·3	14·9	5·6
30	5 37·5	5 38·4	5 22·1	3·0	1·1	9·0	3·4	15·0	5·6
31	5 37·8	5 38·7	5 22·4	3·1	1·2	9·1	3·4	15·1	5·7
32	5 38·0	5 38·9	5 22·6	3·2	1·2	9·2	3·5	15·2	5·7
33	5 38·3	5 39·2	5 22·8	3·3	1·2	9·3	3·5	15·3	5·7
34	5 38·5	5 39·4	5 23·1	3·4	1·3	9·4	3·5	15·4	5·8
35	5 38·8	5 39·7	5 23·3	3·5	1·3	9·5	3·6	15·5	5·8
36	5 39·0	5 39·9	5 23·6	3·6	1·4	9·6	3·6	15·6	5·9
37	5 39·3	5 40·2	5 23·8	3·7	1·4	9·7	3·6	15·7	5·9
38	5 39·5	5 40·4	5 24·0	3·8	1·4	9·8	3·7	15·8	5·9
39	5 39·8	5 40·7	5 24·3	3·9	1·5	9·9	3·7	15·9	6·0
40	5 40·0	5 40·9	5 24·5	4·0	1·5	10·0	3·8	16·0	6·0
41	5 40·3	5 41·2	5 24·7	4·1	1·5	10·1	3·8	16·1	6·0
42	5 40·5	5 41·4	5 25·0	4·2	1·6	10·2	3·8	16·2	6·1
43	5 40·8	5 41·7	5 25·2	4·3	1·6	10·3	3·9	16·3	6·1
44	5 41·0	5 41·9	5 25·5	4·4	1·7	10·4	3·9	16·4	6·2
45	5 41·3	5 42·2	5 25·7	4·5	1·7	10·5	3·9	16·5	6·2
46	5 41·5	5 42·4	5 25·9	4·6	1·7	10·6	4·0	16·6	6·2
47	5 41·8	5 42·7	5 26·2	4·7	1·8	10·7	4·0	16·7	6·3
48	5 42·0	5 42·9	5 26·4	4·8	1·8	10·8	4·1	16·8	6·3
49	5 42·3	5 43·2	5 26·7	4·9	1·8	10·9	4·1	16·9	6·3
50	5 42·5	5 43·4	5 26·9	5·0	1·9	11·0	4·1	17·0	6·4
51	5 42·8	5 43·7	5 27·1	5·1	1·9	11·1	4·2	17·1	6·4
52	5 43·0	5 43·9	5 27·4	5·2	2·0	11·2	4·2	17·2	6·5
53	5 43·3	5 44·2	5 27·6	5·3	2·0	11·3	4·2	17·3	6·5
54	5 43·5	5 44·4	5 27·9	5·4	2·0	11·4	4·3	17·4	6·5
55	5 43·8	5 44·7	5 28·1	5·5	2·1	11·5	4·3	17·5	6·6
56	5 44·0	5 44·9	5 28·3	5·6	2·1	11·6	4·4	17·6	6·6
57	5 44·3	5 45·2	5 28·6	5·7	2·1	11·7	4·4	17·7	6·6
58	5 44·5	5 45·4	5 28·8	5·8	2·2	11·8	4·4	17·8	6·7
59	5 44·8	5 45·7	5 29·0	5·9	2·2	11·9	4·5	17·9	6·7
60	5 45·0	5 45·9	5 29·3	6·0	2·3	12·0	4·5	18·0	6·8

EXAMPLE

23^m	SUN PLANETS	ARIES	MOON	v or d	Corr^n	v or d	Corr^n	v or d	Corr^n
s	° ′	° ′	° ′	′	′	′	′	′	′
00	5 45·0	5 45·9	5 29·3	0·0	0·0	6·0	2·4	12·0	4·7
01	5 45·3	5 46·2	5 29·5	0·1	0·0	6·1	2·4	12·1	4·7
02	5 45·5	5 46·4	5 29·8	0·2	0·1	6·2	2·4	12·2	4·8
03	5 45·8	5 46·7	5 30·0	0·3	0·1	6·3	2·5	12·3	4·8
04	5 46·0	5 46·9	5 30·2	0·4	0·2	6·4	2·5	12·4	4·9
05	5 46·3	5 47·2	5 30·5	0·5	0·2	6·5	2·5	12·5	4·9
06	5 46·5	5 47·4	5 30·7	0·6	0·2	6·6	2·6	12·6	4·9
07	5 46·8	5 47·7	5 31·0	0·7	0·3	6·7	2·6	12·7	5·0
08	5 47·0	5 48·0	5 31·2	0·8	0·3	6·8	2·7	12·8	5·0
09	5 47·3	5 48·2	5 31·4	0·9	0·4	6·9	2·7	12·9	5·1
10	5 47·5	5 48·5	5 31·7	1·0	0·4	7·0	2·7	13·0	5·1
11	5 47·8	5 48·7	5 31·9	1·1	0·4	7·1	2·8	13·1	5·1
12	5 48·0	5 49·0	5 32·1	1·2	0·5	7·2	2·8	13·2	5·2
13	5 48·3	5 49·2	5 32·4	1·3	0·5	7·3	2·9	13·3	5·2
14	5 48·5	5 49·5	5 32·6	1·4	0·5	7·4	2·9	13·4	5·2
15	5 48·8	5 49·7	5 32·9	1·5	0·6	7·5	2·9	13·5	5·3
16	5 49·0	5 50·0	5 33·1	1·6	0·6	7·6	3·0	13·6	5·3
17	5 49·3	5 50·2	5 33·3	1·7	0·7	7·7	3·0	13·7	5·4
18	5 49·5	5 50·5	5 33·6	1·8	0·7	7·8	3·1	13·8	5·4
19	5 49·8	5 50·7	5 33·8	1·9	0·7	7·9	3·1	13·9	5·4
20	5 50·0	5 51·0	5 34·1	2·0	0·8	8·0	3·1	14·0	5·5
21	5 50·3	5 51·2	5 34·3	2·1	0·8	8·1	3·2	14·1	5·5
22	5 50·5	5 51·5	5 34·5	2·2	0·9	8·2	3·2	14·2	5·6
23	5 50·8	5 51·7	5 34·8	2·3	0·9	8·3	3·3	14·3	5·6
24	5 51·0	5 52·0	5 35·0	2·4	0·9	8·4	3·3	14·4	5·6
25	5 51·3	5 52·2	5 35·2	2·5	1·0	8·5	3·3	14·5	5·7
26	5 51·5	5 52·5	5 35·5	2·6	1·0	8·6	3·4	14·6	5·7
27	5 51·8	5 52·7	5 35·7	2·7	1·1	8·7	3·4	14·7	5·8
28	5 52·0	5 53·0	5 36·0	2·8	1·1	8·8	3·4	14·8	5·8
29	5 52·3	5 53·2	5 36·2	2·9	1·1	8·9	3·5	14·9	5·8
30	5 52·5	5 53·5	5 36·4	3·0	1·2	9·0	3·5	15·0	5·9
31	5 52·8	5 53·7	5 36·7	3·1	1·2	9·1	3·6	15·1	5·9
32	5 53·0	5 54·0	5 36·9	3·2	1·3	9·2	3·6	15·2	6·0
33	5 53·3	5 54·2	5 37·2	3·3	1·3	9·3	3·6	15·3	6·0
34	5 53·5	5 54·5	5 37·4	3·4	1·3	9·4	3·7	15·4	6·0
35	5 53·8	5 54·7	5 37·6	3·5	1·4	9·5	3·7	15·5	6·1
36	5 54·0	5 55·0	5 37·9	3·6	1·4	9·6	3·8	15·6	6·1
37	5 54·3	5 55·2	5 38·1	3·7	1·4	9·7	3·8	15·7	6·1
38	5 54·5	5 55·5	5 38·4	3·8	1·5	9·8	3·8	15·8	6·2
39	5 54·8	5 55·7	5 38·6	3·9	1·5	9·9	3·9	15·9	6·2
40	5 55·0	5 56·0	5 38·8	4·0	1·6	10·0	3·9	16·0	6·3
41	5 55·3	5 56·2	5 39·1	4·1	1·6	10·1	4·0	16·1	6·3
42	5 55·5	5 56·5	5 39·3	4·2	1·6	10·2	4·0	16·2	6·3
43	5 55·8	5 56·7	5 39·5	4·3	1·7	10·3	4·0	16·3	6·4
44	5 56·0	5 57·0	5 39·8	4·4	1·7	10·4	4·1	16·4	6·4
45	5 56·3	5 57·2	5 40·0	4·5	1·8	10·5	4·1	16·5	6·5
46	5 56·5	5 57·5	5 40·3	4·6	1·8	10·6	4·2	16·6	6·5
47	5 56·8	5 57·7	5 40·5	4·7	1·8	10·7	4·2	16·7	6·5
48	5 57·0	5 58·0	5 40·7	4·8	1·9	10·8	4·2	16·8	6·6
49	5 57·3	5 58·2	5 41·0	4·9	1·9	10·9	4·3	16·9	6·6
50	5 57·5	5 58·5	5 41·2	5·0	2·0	11·0	4·3	17·0	6·7
51	5 57·8	5 58·7	5 41·5	5·1	2·0	11·1	4·3	17·1	6·7
52	5 58·0	5 59·0	5 41·7	5·2	2·0	11·2	4·4	17·2	6·7
53	5 58·3	5 59·2	5 41·9	5·3	2·1	11·3	4·4	17·3	6·8
54	5 58·5	5 59·5	5 42·2	5·4	2·1	11·4	4·5	17·4	6·8
55	5 58·8	5 59·7	5 42·4	5·5	2·2	11·5	4·5	17·5	6·9
56	5 59·0	6 00·0	5 42·6	5·6	2·2	11·6	4·5	17·6	6·9
57	5 59·3	6 00·2	5 42·9	5·7	2·2	11·7	4·6	17·7	6·9
58	5 59·5	6 00·5	5 43·1	5·8	2·3	11·8	4·6	17·8	7·0
59	5 59·8	6 00·7	5 43·4	5·9	2·3	11·9	4·7	17·9	7·0
60	6 00·0	6 01·0	5 43·6	6·0	2·4	12·0	4·7	18·0	7·1

Table 15-3.-Star and Planet Daily Page from the Nautical Almanac

1986 MAY 16, 17, 18 (FRI., SAT., SUN.)

G.M.T. (UT)	ARIES	VENUS −3.4		MARS 0.9		JUPITER −1.8		SATURN +0.3		STARS		
d h	G.H.A. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	G.H.A. ° ′	Dec. ° ′	Name	S.H.A. ° ′	Dec. ° ′
16 00	233 24.8	150 47.5	N24 33.8	301 40.3	S23 50.2	244 06.6	S 5 43.2	347 34.3	S19 31.4	Acamar	315 34.3	S40 21.5
01	248 27.2	165 46.7	34.1	316 42.0	50.2	259 08.7	43.0	2 36.9	31.4	Achernar	335 42.3	S57 18.2
02	263 29.7	180 45.8	34.3	331 43.8	50.3	274 10.8	42.9	17 39.6	31.4	Acrux	173 32.4	S63 01.6
03	278 32.2	195 45.0	34.6	346 45.5	50.3	289 12.8	42.7	32 42.2	31.4	Adhara	255 29.0	S28 57.2
04	293 34.6	210 44.2	34.8	1 47.3	50.4	304 14.9	42.6	47 44.9	31.3	Aldebaran	291 13.5	N16 29.0
05	308 37.1	225 43.3	35.1	16 49.0	50.4	319 17.0	42.5	62 47.5	31.3			
06	323 39.6	240 42.5	N24 35.3	31 50.8	S23 50.4	334 19.1	S 5 42.3	77 50.2	S19 31.3	Alioth	166 38.0	N56 02.2
07	338 42.0	255 41.6	35.5	46 52.5	50.5	349 21.2	42.2	92 52.8	31.2	Alkaid	153 14.5	N49 22.9
08	353 44.5	270 40.8	35.8	61 54.3	50.5	4 23.3	42.0	107 55.5	31.2	Al Na'ir	28 09.4	S47 01.6
F 09	8 47.0	285 39.9	36.0	76 56.1	50.6	19 25.4	41.9	122 58.1	31.2	Alnilam	276 07.6	S 1 12.5
R 10	23 49.4	300 39.1	36.2	91 57.8	50.6	34 27.5	41.7	138 00.8	31.2	Alphard	218 16.4	S 8 35.9
I 11	38 51.9	315 38.3	36.5	106 59.6	50.7	49 29.6	41.6	153 03.4	31.1			
D 12	53 54.3	330 37.4	N24 36.7	122 01.3	S23 50.7	64 31.7	S 5 41.4	168 06.1	S19 31.1	Alphecca	126 28.1	N26 45.5
A 13	68 56.8	345 36.6	36.9	137 03.1	50.7	79 33.8	41.3	183 08.8	31.1	Alpheratz	358 05.2	N29 00.7
Y 14	83 59.3	0 35.7	37.2	152 04.8	50.8	94 35.9	41.2	198 11.4	31.0	Altair	62 28.2	N 8 49.6
15	99 01.7	15 34.9	37.4	167 06.6	50.8	109 38.0	41.0	213 14.1	31.0	Ankaa	353 36.1	S42 22.7
16	114 04.2	30 34.1	37.6	182 08.4	50.9	124 40.1	40.9	228 16.7	31.0	Antares	112 51.3	S26 24.3
17	129 06.7	45 33.2	37.8	197 10.1	50.9	139 42.2	40.7	243 19.4	31.0			
18	144 09.1	60 32.4	N24 38.1	212 11.9	S23 51.0	154 44.3	S 5 40.6	258 22.0	S19 30.9	Arcturus	146 14.2	N19 15.1
19	159 11.6	75 31.5	38.3	227 13.7	51.0	169 46.4	40.4	273 24.7	30.9	Atria	108 11.3	S69 00.3
20	174 14.1	90 30.7	38.5	242 15.4	51.1	184 48.5	40.3	288 27.3	30.9	Avior	234 26.9	S59 28.1
21	189 16.5	105 29.8	38.7	257 17.2	51.1	199 50.6	40.1	303 30.0	30.8	Bellatrix	278 54.5	N 6 20.3
22	204 19.0	120 29.0	39.0	272 19.0	51.1	214 52.7	40.0	318 32.6	30.8	Betelgeuse	271 23.9	N 7 24.4
23	219 21.4	135 28.2	39.2	287 20.7	51.2	229 54.8	39.9	333 35.3	30.8			
17 00	234 23.9	150 27.3	N24 39.4	302 22.5	S23 51.2	244 56.9	S 5 39.7	348 37.9	S19 30.8	Canopus	264 05.8	S52 41.3
01	249 26.4	165 26.5	39.6	317 24.3	51.3	259 59.0	39.6	3 40.6	30.7	Capella	281 05.5	N45 59.3
02	264 28.8	180 25.6	39.8	332 26.0	51.3	275 01.1	39.4	18 43.2	30.7	Deneb	49 45.5	N45 13.5
03	279 31.3	195 24.8	40.0	347 27.8	51.4	290 03.2	39.3	33 45.9	30.7	Denebola	182 54.5	N14 39.0
04	294 33.8	210 23.9	40.3	2 29.6	51.4	305 05.3	39.1	48 48.5	30.6	Diphda	349 16.8	S18 03.7
05	309 36.2	225 23.1	40.5	17 31.4	51.5	320 07.4	39.0	63 51.2	30.6			
06	324 38.7	240 22.2	N24 40.7	32 33.1	S23 51.5	335 09.5	S 5 38.9	78 53.8	S19 30.6	Dubhe	194 16.3	N61 49.8
07	339 41.2	255 21.4	40.9	47 34.9	51.6	350 11.6	38.7	93 56.5	30.6	Elnath	278 39.1	N28 35.9
S 08	354 43.6	270 20.6	41.1	62 36.7	51.6	5 13.7	38.6	108 59.2	30.5	Eltanin	90 55.3	N51 29.1
A 09	9 46.1	285 19.7	41.3	77 38.5	51.6	20 15.8	38.4	124 01.8	30.5	Enif	34 07.4	N 9 48.5
T 10	24 48.6	300 18.9	41.5	92 40.2	51.7	35 17.9	38.3	139 04.5	30.5	Fomalhaut	15 46.7	S29 41.7
U 11	39 51.0	315 18.0	41.7	107 42.0	51.7	50 20.0	38.1	154 07.1	30.4			
R 12	54 53.5	330 17.2	N24 41.9	122 43.8	S23 51.8	65 22.1	S 5 38.0	169 09.8	S19 30.4	Gacrux	172 23.9	S57 02.4
D 13	69 55.9	345 16.3	42.1	137 45.6	51.8	80 24.2	37.9	184 12.4	30.4	Gienah	176 13.4	S17 28.1
A 14	84 58.4	0 15.5	42.3	152 47.4	51.9	95 26.3	37.7	199 15.1	30.4	Hadar	149 17.0	S60 18.7
Y 15	100 00.9	15 14.6	42.5	167 49.1	51.9	110 28.4	37.6	214 17.7	30.3	Hamal	328 24.5	N23 23.8
16	115 03.3	30 13.8	42.7	182 50.9	52.0	125 30.5	37.4	229 20.4	30.3	Kaus Aust.	84 10.8	S34 23.6
17	130 05.8	45 13.0	42.9	197 52.7	52.0	140 32.6	37.3	244 23.0	30.3			
18	145 08.3	60 12.1	N24 43.1	212 54.5	S23 52.1	155 34.7	S 5 37.1	259 25.7	S19 30.2	Kochab	137 17.5	N74 12.7
19	160 10.7	75 11.3	43.3	227 56.3	52.1	170 36.9	37.0	274 28.3	30.2	Markab	13 59.1	N15 07.7
20	175 13.2	90 10.4	43.5	242 58.1	52.2	185 39.0	36.9	289 31.0	30.2	Menkar	314 37.0	N 4 02.2
21	190 15.7	105 09.6	43.7	257 59.9	52.2	200 41.1	36.7	304 33.6	30.1	Menkent	148 31.7	S36 18.4
22	205 18.1	120 08.7	43.9	273 01.7	52.3	215 43.2	36.6	319 36.3	30.1	Miaplacidus	221 44.6	S69 39.9
23	220 20.6	135 07.9	44.1	288 03.4	52.3	230 45.3	36.4	334 39.0	30.1			
18 00	235 23.1	150 07.0	N24 44.2	303 05.2	S23 52.4	245 47.4	S 5 36.3	349 41.6	S19 30.1	Mirfak	309 10.6	N49 48.8
01	250 25.5	165 06.2	44.4	318 07.0	52.4	260 49.5	36.2	4 44.3	30.0	Nunki	76 23.6	S26 19.0
02	265 28.0	180 05.4	44.6	333 08.8	52.5	275 51.6	36.0	19 46.9	30.0	Peacock	53 51.2	S56 46.7
03	280 30.4	195 04.5	44.8	348 10.6	52.5	290 53.7	35.9	34 49.6	30.0	Pollux	243 53.1	N28 03.8
04	295 32.9	210 03.7	45.0	3 12.4	52.6	305 55.8	35.7	49 52.2	29.9	Procyon	245 21.5	N 5 15.7
05	310 35.4	225 02.8	45.2	18 14.2	52.6	320 57.9	35.6	64 54.9	29.9			
06	325 37.8	240 02.0	N24 45.3	33 16.0	S23 52.7	336 00.0	S 5 35.4	79 57.5	S19 29.9	Rasalhague	96 25.3	N12 33.9
07	340 40.3	255 01.1	45.5	48 17.8	52.7	351 02.1	35.3	95 00.2	29.9	Regulus	208 05.4	N12 02.2
08	355 42.8	270 00.3	45.7	63 19.6	52.8	6 04.2	35.2	110 02.8	29.8	Rigel	281 32.2	S 8 13.0
S 09	10 45.2	284 59.4	45.9	78 21.4	52.8	21 06.3	35.0	125 05.5	29.8	Rigil Kent.	140 19.6	S60 46.9
U 10	25 47.7	299 58.6	46.1	93 23.2	52.9	36 08.4	34.9	140 08.1	29.8	Sabik	102 35.9	S15 42.7
N 11	40 50.2	314 57.7	46.2	108 25.0	52.9	51 10.5	34.7	155 10.8	29.7			
D 12	55 52.6	329 56.9	N24 46.4	123 26.8	S23 53.0	66 12.6	S 5 34.6	170 13.5	S19 29.7	Schedar	350 04.8	N56 27.5
A 13	70 55.1	344 56.1	46.6	138 28.6	53.0	81 14.8	34.5	185 16.1	29.7	Shaula	96 49.6	S37 05.8
Y 14	85 57.6	359 55.2	46.7	153 30.4	53.1	96 16.9	34.3	200 18.8	29.7	Sirius	258 52.2	S16 41.8
15	101 00.0	14 54.4	46.9	168 32.2	53.1	111 19.0	34.2	215 21.4	29.6	Spica	158 52.8	S11 05.5
16	116 02.5	29 53.5	47.1	183 34.0	53.2	126 21.1	34.0	230 24.1	29.6	Suhail	223 07.9	S43 22.8
17	131 04.9	44 52.7	47.2	198 35.9	53.2	141 23.2	33.9	245 26.7	29.6			
18	146 07.4	59 51.8	N24 47.4	213 37.7	S23 53.3	156 25.3	S 5 33.8	260 29.4	S19 29.5	Vega	80 52.6	N38 45.9
19	161 09.9	74 51.0	47.6	228 39.5	53.3	171 27.4	33.6	275 32.0	29.5	Zuben'ubi	137 28.0	S15 59.3
20	176 12.3	89 50.1	47.7	243 41.3	53.4	186 29.5	33.5	290 34.7	29.5		S.H.A.	Mer. Pass.
21	191 14.8	104 49.3	47.9	258 43.1	53.4	201 31.6	33.3	305 37.3	29.5		° ′	h m
22	206 17.3	119 48.4	48.1	273 44.9	53.5	216 33.7	33.2	320 40.0	29.4	Venus	276 03.4	13 59
23	221 19.7	134 47.6	48.2	288 46.7	53.6	231 35.8	33.1	335 42.7	29.4	Mars	67 58.6	3 50
	h m									Jupiter	10 33.0	7 39
Mer. Pass.	8 21.0	v −0.8	d 0.2	v 1.8	d 0.0	v 2.1	d 0.1	v 2.7	d 0.0	Saturn	114 14.0	0 45

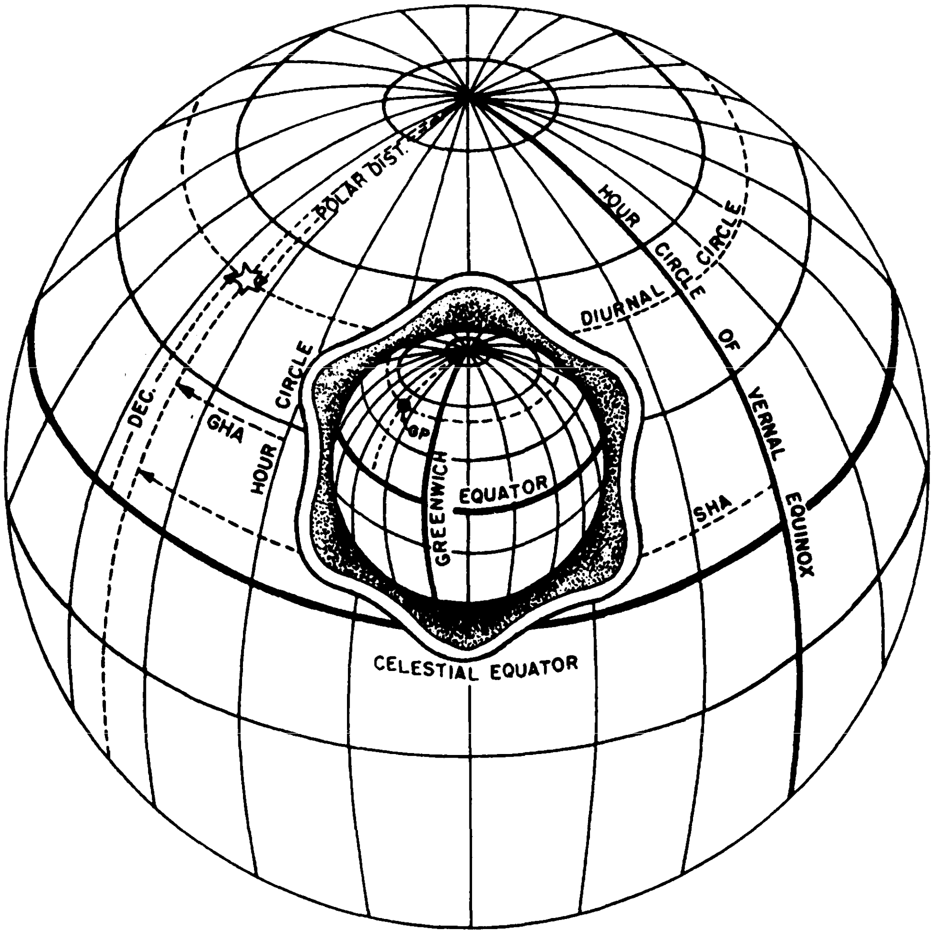


Figure 15-5.—The celestial sphere.

Declination

The GP you see on the small sphere in figure 15-5 corresponds to the star's location on the celestial sphere. The letters *GP* stand for geographic position and represent a point where a line drawn from the center of the earth to the body would intersect the earth's surface. The latitude of a point on the terrestrial sphere is measured from the equator northward or southward along the point's meridian to a maximum of 90°. Declination of a body on the celestial sphere is measured in exactly the same way—from the celestial equator (equinoctial) northward or southward along the body's hour circle.'The polar distance is the number of degrees, minutes, and tenths of minutes of arc between the heavenly body and the elevated pole. The elevated pole is the one above the horizon; in other words, the one with the same name as your latitude.

From the foregoing description, it follows that the polar distance of a body whose declination has the same name (north or south) as the elevated pole is always 90° minus its declination (δ). Polar distance of a body whose declination has a different name from that of the elevated pole is always 90° plus δ.

Declination of any navigational star is listed in the Nautical Almanac for each date. Declination of each body of the solar system is listed for every hour GMT.

Time Diagram

So far you have learned that a heavenly body is located on the celestial sphere by its Greenwich hour angle (corresponding to longitude) and its declination (corresponding to latitude). You have seen how both of these coordinates are measured and how, from them, the GP of a heavenly body can be located on the terrestrial sphere.

Before going further into nautical astronomy, you will probably find it helpful to learn something about using a diagram (called a time diagram) of the plane of the celestial equator. Not only will this make it easier for you to understand the ensuing discussion, but it will also simplify the solution of celestial navigation problems.

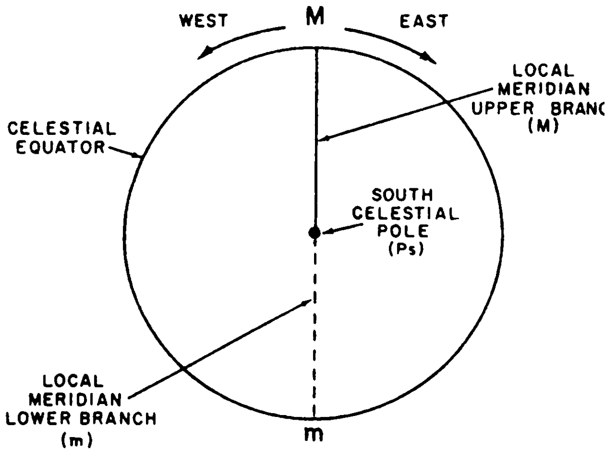


Figure 15-6.-Time diagram.

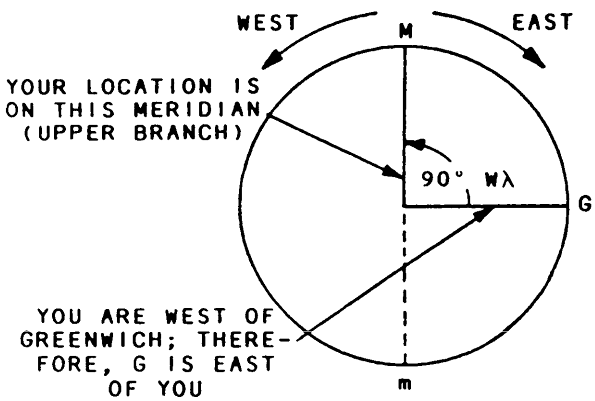


Figure 15-7.-Locating G on the time diagram location at 90° longitude.

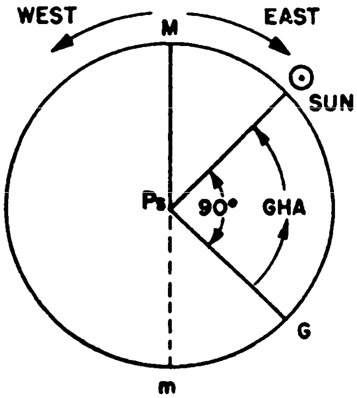


Figure 15-8.-GHA of the sun on a time diagram.

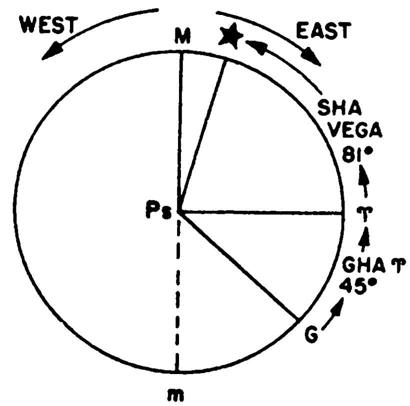


Figure 15-9.-Locating the vernal equinox and a star on a time diagram.

In the time diagram (fig. 15-6), the observer is theoretically located outside the celestial sphere, over its south pole. The diagram consists of a circle representing the celestial equator. The center of the circle is the south celestial pole. Counterclockwise direction is westerly. The local meridian is drawn in as a vertical line, thus placing the upper branch(M), which is the arc of a celestial meridian, between the poles at the top of the diagram and the lower branch *(m)* at the bottom. To avoid confusion, we show the lower meridian as a dashed line.

You locate the Greenwich meridian (G) by means of your longitude (symbol **λ**). If you were at longitude 90°W, G would appear on your diagram 90° clockwise from *M* because you are counterclockwise or west of G. A glance at figure 15-7 will confirm this location. What you really do, then, is measure from *M* toward Greenwich, the direction depending upon whether you are in east or west longitude.

Figure 15-8 shows another time diagram on which GHA of the sun is indicated. The upper branch of the sun's hour circle is shown as a solid line. The angle, or arc, of the celestial equator between the Greenwich meridian and the sun's hour circle is 90°. Therefore, GHA of the sun at this instant is 90°. Remember, GHA is always measured westward from G.

The GHA of a star is measured in the same direction from Greenwich to the star; however, because the SHA enters the picture here, your method of locating a star on the time diagram is somewhat different. First, you must locate the vernal equinox by its tabulated GHA. Let's say the GHA of the vernal equinox for the time of your observation is 45°. You locate the vernal equinox 45°W from Greenwich, as shown in figure 15-9. The symbol that resembles a pair of ram's horns represents the vernal equinox.

From the Nautical Almanac you find the SHA of the star in question. You already know that the SHA is measured to the west from the vernal equinox (first point of Aries). All you have to do here is find the SHA of this star and measure the SHA westward from the vernal equinox; you then have the star located on the time diagram. Let's say it is the star Vega, whose SHA is approximately 81°. Figure 15-9 shows Vega located on the time diagram.

Itis easy to see herethat the GHA of Vega must be equal to the GHA of the vernal equinox plus the SHA of Vega (or $GHA_{Vega} = GHA_{♈} + SHA_{Vega}$. In this example, the GHA of Vega is 81° plus 45°, or 126°.

Now let's use the time diagram to explain some more facts about nautical astronomy.

Local Hour Angle (LHA)

Local hour angle (LHA) is the name given to the angle of arc (expressed in degrees, minutes, and tenths of minutes) of the celestial equator between the celestial meridian of a point on the celestial sphere and the hour circle of a heavenly body. It is always measured westward from the local meridian through 360°.

Let's work this problem of LHA on a time diagram. Say you are at longitude 135° from M toward Greenwich which means, of course, that Greenwich will be shown east of *M*. Think it over for a moment—you are to the west of Greenwich; therefore, Greenwich is to the east of you.

Now that we know where Greenwich is and where you are, let's figure the LHA of the sun as it is shown in figure 15-8. Figure 15-10 shows us that the sun is 90° west of Greenwich. We know that the LHA is always measured westward from your location meridian(M) to the hour circle of the body (in this example, the sun). Therefore, the LHA here is the whole 360° around minus the 45° between the sun's hour circle and *M*. This 45° may be found by inspecting figure 15-10 or by subtracting 90° from 135°. Let's think this over—we are 135°W of Greenwich; therefore, *G* is 135° clockwise from us. The sun is 90°W or counterclockwise from *G*. The difference is the 45° we mentioned. Subtract this 45° from 360° and we get 315°, the LHA.

Look again at figure 15-10. As you can see, the sun is east (clockwise on the diagram) of your local meridian (M). Now let's suppose that you are at the same longitude (135°W), but the GHA of the sun is 225° instead of 90°. The time diagram will appear as shown in figure 15-11. 'The sun is now west of your meridian (M). The LHA is always measured westward from the local celestial meridian to the hour circle of the body. Therefore, the LHA is the 90° from *M* to the sun's hour circle.

Here are two general rules that will help you in finding the LHA when the GHA and longitude are known:

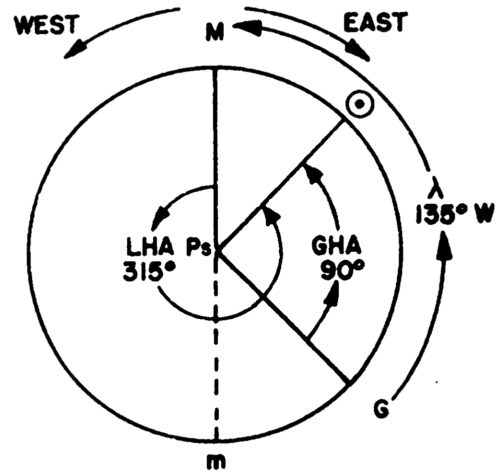


Figure 15-10.-LHA on the time diagram.

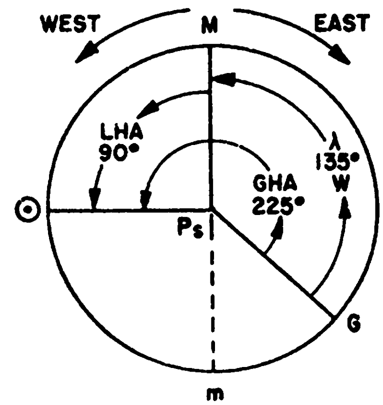


Figure 15-11.-LHA with the sun west of your celestial meridian.

1. LHA= GHA– λ_W (used when longitude is west)

2. LHA = GHA + λ_E (used when longitude is east)

In west longitude it may be necessary to add 360° to the GHA before the subtraction can be made. In east longitude, 360° is subtracted from the LHA if it exceeds this amount. Be sure, however, to check the accuracy of your work by referring to a time diagram. It offers a graphic means of obtaining the data you need.

As an illustration, suppose the GHA of the sun is 327°44′24″ and the longitude is 79°15′05″E. Since longitude is east, you use formula 2 above. Transposing to solve for the LHA, you have

$$\begin{aligned} LHA &= GHA + \lambda_E \\ &= 327°44'24'' + 79°15'05'' \\ &= 406°59'29''. \end{aligned}$$

This is over 360°, so you subtract 360° from the 406°59′29″. The result is 46°59′29″.

Meridian Angle

The meridian angle, like the LHA, is measured between the observer's celestial meridian and the hour circle of the observed body. The meridian angle, however, is measured east or west from the celestial meridian to the hour circle, through a maximum of 180°, instead of being measured always to the west, as done for the LHA, through 360°.

Polar Distance

The polar distance of a heavenly body at a given instant is simply the complement of its declination at that instant; that is, polar distance amounts to 90° minus the body's declination. The conventional symbol used to indicate polar distance is the letter p.

Altitude and Altitude Corrections

The angle measured at the observer's position from the horizon to a celestial object along the vertical circle through the object is the altitude of the object. Altitudes are measured from 0° on the horizon to 90° at the zenith. The complement of the altitude is the zenith distance, which is often more convenient to measure and to use in calculations. Your horizontal plane at the instant of observation is, of course, tangent to the earth's surface at the point of observation; however, the altitude value used in computations is related to a plane parallel to this one but passing through the center of the earth. The difference between the surface-plane altitude value and the center-of-the-earth-plane altitude value is the **parallax** correction.

Because of the vast distance between the earth and the fixed stars, the difference between the surface-plane altitude and the center-of-the-earth-plane altitude is small enough to be ignored. For the sun and for planets, however, a correction for parallax must be applied to the observed altitude (symbol h_o) to get the true altitude (h_n).

A second altitude correction is the correction for **refraction**– a phenomenon that causes a slight curve in light rays traveling to the observer from a body observed at low altitude.

A third altitude correction, applying to only the sun and moon, is semidiameter correction. The stars and the planets Venus, Mars, Jupiter, and Saturn, are pinpoint in observable size. The sun and moon, however, show sizable disks. The true altitude of either of these is the altitude of the center of the disk; but you cannot line the horizontal cross hair accurately on the center. To get an accurate setting, you must line the cross hair on either the lower edge (called the lower limb) or the upper edge (called the upper limb). In either case you must apply a correction to get the altitude of the center.

A combined parallax and refraction correction for the sun and planets and a refraction correction for stars keyed to observed altitudes are given in the two inside cover pages in the Nautical Almanac. Semidiameter corrections for the sun and moon are given in the daily pages of the almanac. If you observe the lower limb, you add the semidiameter correction to the observed altitude; if you observe the upper limb, you subtract it. The correction appears at the foot of the Sun or Moon column, beside the letters *S.D.*

Zenith Distance

The **zenith distance** of an observed body amounts, simply, to 90° minus the true (or corrected) altitude of the body. The letter z is the conventional symbol used to represent zenith distance.

DETERMINING LATITUDE

To determine the true azimuth of a line on the ground from a celestial observation, you must know the latitude of the point from which the celestial observation is made. If you can locate the point of observation precisely on an accurate map, such as a U.S. Geological Survey (USGS) quadrangle map, you can determine the latitude from the marginal latitude scale. If no such map is available, you can determine the latitude through a **meridian observation** of a heavenly body.

Latitude by Meridian Altitude Observation

In a meridian observation you determine the altitude of the body at the instant it crosses your celestial meridian. At this instant the body will be at the maximum altitude observable from your position.

When you are applying a meridian altitude to get the latitude, there are three possible situations, each illustrated in figure 15-12 and explained in the following paragraphs.

CASE I. When the body observed is toward the equator from the zenith, you can use the following formula to get the latitude:

$$\Phi = \delta + z$$

$$= \delta + (90° - h),$$

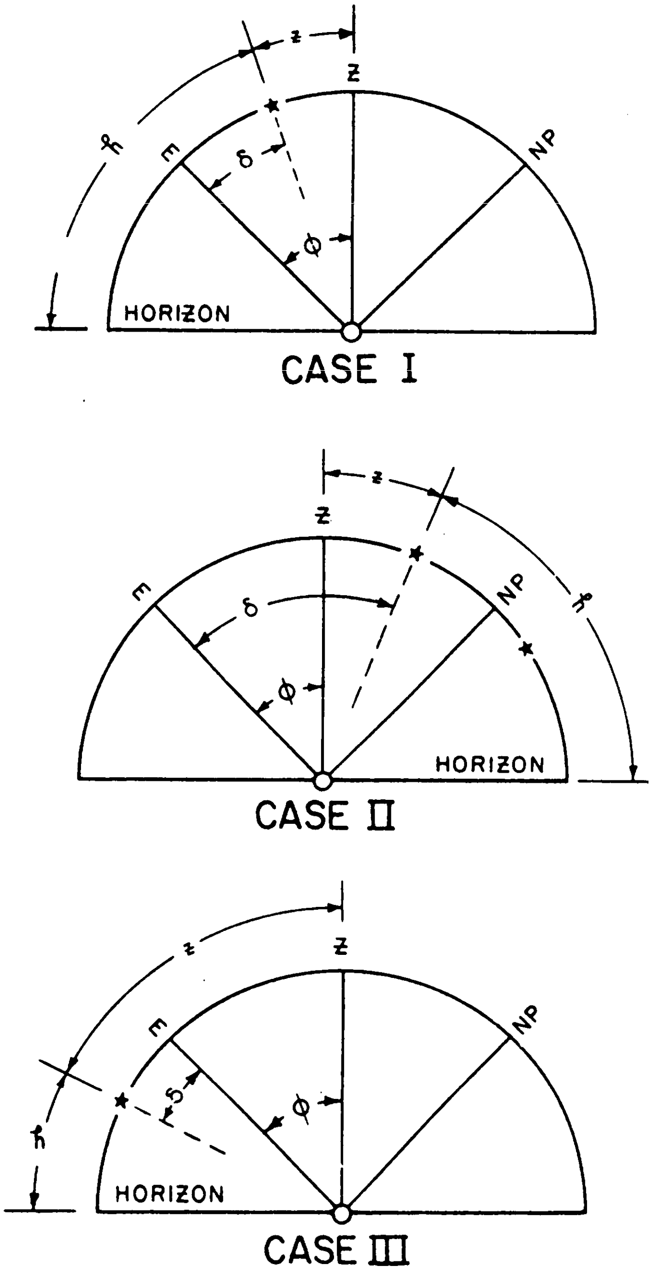


Figure 15-12.-Three possible situations in determining latitude by meridian altitude observation.

where:

Φ = latitude of place

δ = declination of observed body

h = corrected observed altitude

CASE II. When the body observed is toward the pole from the zenith, which is the case for circumpolar stars, you can get the latitude of the place of observation by using the following formulas:

$$\Phi = \delta - z$$
$$= \delta - (90° - h)$$

$\Phi = h \pm p$. Use this formula only for circumpolar star observations, where p is the polar distance (90° - δ).

CASE III. When the equator is between the body observed and the zenith, use the following formula to get the latitude:

$$\Phi = z - \delta$$
$$= (90° - h) - \delta$$

In the above situations, always remember that δ and Φ are positive when they are located north of the equator and negative when south of it.

Latitude by Altitude of the Sun at Noon

You can observe the altitude of the sun by two methods. In the first method, you follow the sun just before it is about to cross the approximate meridian. In the second method, you set the line of sight of the transit in the plane of a known meridian and wait for the sun to cross the line of sight. At this instant take the reading of the vertical angle. In either method your main objective is to measure the sun's altitude accurately. You should know the exact time so that you can compute the instant of local apparent noon. Then you will know exactly when you should be in the field to have everything ready just before the instant of observation.

If the instrument used is not a transit equipped with solar prism attachments, set the horizontal cross hair tangent to the lower edge of the sun's disk. By the first method referred to above, when you are observing for maximum altitude, follow the sun until it no longer rises. The moment the sun starts going down, record the vertical angle and determine the index error. In the second method above, the setting of the sun's disk is similar to the first method except that you get the reading at the instant the sun crosses your known meridian. In either method, you should correct the altitude observed in the field for index error, semidiameter, parallax, and refraction. You can eliminate index error in the second method by plunging the telescope and taking another reading as fast as possible.

The declination for the Greenwich time corresponding to the instant of local noon is taken from a table of the Nautical Almanac, the *Solar Ephemeris,* or *The Ephemeris.* The table for May 1985, taken from *The Ephemeris,* published by Bureau of Land Management, U.S. Department of Interior, and prepared by the Nautical Almanac office, U.S. Naval

Table 15-4.-Solar Ephemeris for May 1985

AT GREENWICH APPARENT NOON						POLARIS FOR THE MERIDIAN OF GREENWICH, CIVIL DATE AND MEAN TIME		
Date	THE SUN'S Apparent Declination	THE SUN'S Diff. for 1 Hour	THE SUN'S Semi-diameter	Time Semi-diameter Passing Mer.	Equation of Time, Subtract from / Add to Apparent Time	Upper Culmination	Elongation Lat. 40°	Declination
MAY, 1985								
	° ′ ″	″	′ ″	s	m s	h m	h m	+89° ′ ″
Thur. 16	N19 09 07.7	+34.45	15 50.47	67	3 41.28	10 38.3 A.M.	E.E. 4 42.0 A.M.	11 44.79
Fri. 17	19 22 44.7	33.63	15 50.27	67	3 39.69	10 34.4	4 38.1	11 44.49
Sat. 18	19 36 02.0	32.80	15 50.07	67	3 37.53	10 30.5	4 34.1	11 44.20
Sun. 19	19 48 59.3	31.97	15 49.88	67	3 34.81	10 26.6	4 30.2	11 43.92
Mon. 20	20 01 36.3	31.12	15 49.70	68	3 31.54	10 22.6	4 26.3	11 43.65
Tues. 21	20 13 52.9	30.26	15 49.52	68	3 27.73	10 18.7	4 22.4	11 43.41
Wed. 22	20 25 48.6	29.38	15 49.34	68	3 23.40	10 14.8	4 18.5	11 43.19
Thur. 23	20 37 23.4	28.50	15 49.17	68	3 18.55	10 10.9	4 14.6	11 42.98
Fri. 24	20 48 36.8	27.61	15 49.00	68	3 13.20	10 07.0	4 10.7	11 42.79
Sat. 25	20 59 28.7	26.71	15 48.84	68	3 07.36	10 03.1	4 06.7	11 42.60
Sun. 26	21 09 58.8	25.80	15 48.68	68	3 01.05	9 59.1	4 02.8	11 42.40
Mon. 27	21 20 06.9	24.87	15 48.52	68	2 54.27	9 55.2	3 58.9	11 42.20
EXAMPLE → Tues. 28	21 29 52.7	23.94	15 48.37	68	2 47.05	9 51.3	3 55.0	11 41.98
Wed. 29	21 39 16.2	23.01	15 48.22	68	2 39.39	9 47.4	3 51.1	11 41.74
Thur. 30	21 48 17.0	22.06	15 48.08	68	2 31.31	9 43.5	3 47.2	11 41.50
Fri. 31	N21 56 55.0	+21.11	15 47.93	68	2 22.83	9 39.6 A.M.	E.E. 3 43.2 A.M.	11 41.25
JUNE, 1985								
Sat. 1	N22 05 10.1	+20.15	15 47.79	68	2 13.94	9 35.6 A.M.	E.E. 3 39.3 A.M.	11 41.02
Sun. 2	22 13 02.1	19.18	15 47.66	68	2 04.67	9 31.7	3 35.4	11 40.81
Mon. 3	22 20 30.8	18.21	15 47.52	68	1 55.02	9 27.8	3 31.5	11 40.63
Tues. 4	22 27 36.2	17.24	15 47.39	69	1 45.02	9 23.9	3 27.6	11 40.47
Wed. 5	22 34 18.1	16.25	15 47.26	69	1 34.66	9 20.0	3 23.7	11 40.33
Thur. 6	22 40 36.4	15.26	15 47.13	69	1 23.97	9 16.1	3 19.8	11 40.20
Fri. 7	22 46 30.8	14.27	15 47.01	69	1 12.97	9 12.2	3 15.9	11 40.07
Sat. 8	22 52 01.3	13.27	15 46.89	69	1 01.66	9 08.3	3 11.9	11 39.92
Sun. 9	22 57 07.8	12.27	15 46.77	69	0 50.08	9 04.4	3 08.0	11 39.76
Mon. 10	23 01 50.1	11.26	15 46.66	69	0 38.22	9 00.4	3 04.1	11 39.58
Tues. 11	23 06 08.1	10.24	15 46.55	69	0 26.13	8 56.5	3 00.2	11 39.39
Wed. 12	23 10 01.7	9.22	15 46.45	69	0 13.82	8 52.6	2 56.3	11 39.20
Thur. 13	23 13 30.8	8.20	15 46.35	69	0 01.31	8 48.7	2 52.4	11 39.01
Fri. 14	23 16 35.3	7.18	15 46.25	69	0 11.36	8 44.8	2 48.5	11 38.82
Sat. 15	23 19 15.2	6.15	15 46.16	69	0 24.19	8 40.9	2 44.6	11 38.65
Sun. 16	23 21 30.4	5.12	15 46.08	69	0 37.14	8 37.0	2 40.7	11 38.49
Mon. 17	23 23 20.8	4.09	15 46.00	69	0 50.18	8 33.1	2 36.8	11 38.36
Tues. 18	23 24 46.5	3.05	15 45.92	69	1 03.28	8 29.2	2 32.8	11 38.25
Wed. 19	23 25 47.3	2.02	15 45.86	69	1 16.43	8 25.3	2 28.9	11 38.15
Thur. 20	23 26 23.3	+ 0.98	15 45.79	69	1 29.59	8 21.4	2 25.0	11 38.08
Fri. 21	23 26 34.5	− 0.05	15 45.74	69	1 42.73	8 17.4	2 21.1	11 38.01
Sat. 22	23 26 20.8	1.09	15 45.69	69	1 55.82	8 13.5	2 17.2	11 37.94
Sun. 23	23 25 42.3	2.12	15 45.64	69	2 08.85	8 09.6	2 13.3	11 37.86
Mon. 24	23 24 38.9	3.16	15 45.60	69	2 21.77	8 05.7	2 09.4	11 37.77
Tues. 25	23 23 10.8	4.19	15 45.56	69	2 34.57	8 01.8	2 05.5	11 37.66
Wed. 26	23 21 18.0	5.22	15 45.53	69	2 47.23	7 57.9	2 01.6	11 37.54
Thur. 27	23 19 00.4	6.24	15 45.50	69	2 59.71	7 54.0	1 57.7	11 37.42
Fri. 28	23 16 18.3	7.26	15 45.48	69	3 12.00	7 50.1	1 53.8	11 37.31
Sat. 29	23 13 11.8	8.28	15 45.46	69	3 24.07	7 46.2	1 49.9	11 37.22
Sun. 30	23 09 40.8	9.30	15 45.44	69	3 35.92	7 42.3	1 46.0	11 37.15
Mon. 31	N23 05 45.5	−10.31	15 45.43	69	3 47.51	7 38.4 A.M.	E.E. 1 42.0 A.M.	11 37.12

The sign + prefixed to the hourly change of declination indicates that {north / south} declinations are {increasing. / decreasing.}

The sign − prefixed to the hourly change of declination indicates that {south / north} declinations are {increasing. / decreasing.}

Observatory, is shown in table 15-4. The *Solar Ephemeris* is issued (on request) each year by major engineering instrument makers.

Find the sun's declination as follows:

1. Accepting the observation as having been made at the meridian, record the local apparent time as 12^h.

2. Add the longitudinal equivalent time to obtain Greenwich apparent time (GAT).

3. Add or subtract the equation of time (true solar time minus local civil time) from GAT to obtain GMT (Greenwich mean time). The equation of time is given in the *Solar Ephemeris* or Nautical Almanac for the instant of 0^h (midnight) daily at Greenwich for the whole year.

4. Correct the apparent declination for the date for the elapsed GMT from 0^h.

5. In case the local standard time of the observation is recorded, find the GMT at once by simply adding the time zone difference. Then, after all the necessary corrections are made, substitute the value to one of the formulas enumerated above, analyzing carefully to see which formula is appropriate.

EXAMPLE: Suppose that on 28 May 1985 in the Northern Hemisphere, you obtained a corrected meridian altitude *(h)* of the sun of $67°37'06''$ at longitude $86°08'W$. The sun bears south of the observer. The computation to get the corrected declination is as follows:

Local apparent time		12^h
Longitudinal equivalent time	+(+)	$5^h44^m32^s$ or $86°08'W$
Greenwich apparent time		$17^h44^m32^s$
Equation of time	–(+)	2^m47^s
Greenwich mean time (GMT)		$17^h41^m45^s$ (= 17.7^h)
Declination at 0^h (table 15-4)	+	$21°29'52.7''$

NOTE: $23.94''$ = Difference for 1 hour (table 15-4)

Correction for elapsed	$7'03.7''$
$\frac{23.94}{1^h} \times 17.7^h \times \frac{1'}{60''}$	
Corrected declination	21

From the computation shown above, you see that the declination is positive, so it is a north declination. The transit was pointed south, so this is a case in which the body observed was between the zenith and the equator. This is, then, a Case I situation, in which the latitude equals declination plus zenith distance ($90° - 67°37'06''$, or $22°22'54''$). Therefore, the latitude is equal to $21°36'56.4'' + 22°22'54''$, or $43°59'50.4''$.

SUN OBSERVATIONS FOR AZIMUTH

Sun observations, as compared with star observations, provide the surveyor with a more convenient and economical method for determining an accurate astronomic azimuth. A sun observation can be easily incorporated into a regular work schedule. It requires little additional field time, and when reasonable care is exercised and proper equipment is used, an accuracy within 10 seconds can be obtained.

Two methods are used for determining an azimuth by observing the sun: the **altitude method** and the **hour angle method.** The basic difference between these two is that the altitude method requires an accurate vertical angle and approximate time, whereas the hour angle requires a very accurate time but no vertical angle.

In the past, the altitude method has been more popular primarily because of the difficulty of obtaining accurate time in the field. The development of time signals and accurate timepieces, particularly digital watches with split time features and time modules for calculators, has eliminated this obstacle to the extent that the hour angle method is now preferred. The hour angle method is more accurate, faster, requires less training for proficiency, has fewer restrictions on time of day and geographic location, has more versatility (total-station instruments may be used), and is applicable to Polaris and other stars.

To apply the hour angle method, you measure the horizontal angle from a line to the sun. Then, knowing the accurate time of observation and your position (latitude and longitude), you can compute the azimuth of the sun. This azimuth is then combined with the horizontal angle to yield the azimuth of the line.

To compute the azimuth of the sun, use the following equation:

$$Z = \tan^{-1} \frac{\sin LHA}{\sin \Phi \cos LHA - \cos\Phi \tan\delta}$$

where:

Z = azimuth of the sun measured clockwise from north

LHA = local hour angle of the sun

δ = declination of the sun

Φ = latitude of the observer

Z is normalized from 0° to 360° by adding algebraically a correction as listed below.

When LHA is	Correction	
	If Z is positive	If Z is negative
0° to 180°	180°	360°
180° to 360°	0°	180°

The above equation is derived using spherical trigonometry to solve the pole-zenith-star (PZS) triangle for azimuth

Time and Date

To calculate the LHA of the apparent sun at the instant of observation, you must have accurate time that takes into account the rotation of the earth. Time that is based on the rotation of the earth can be obtained by adding a correction factor to Greenwich meantime.

Coordinated universal time (UTC) is another name for Greenwich mean time and is broadcast by the National Bureau of Standards on radio station WWV. (Inexpensive receivers that are pretuned to WWV are available.) The correction factor (designated DUT) that you must add to the coordinated universal time is also obtained from WWV by counting the number of double ticks following the minute tone. Each double tick represents a tenth-of-a-second correction and is positive the frost 7 seconds (ticks). Beginning with the ninth second, each double tick is a negative correction. The total correction, either positive or negative, will not exceed 0.7 second. By adding DUT to UTC, you get time (designated UT1) that is based on the actual rotation of the earth.

A stopwatch with a split (or lap) time feature is ideal for obtaining times of pointings. The stopwatch is set by starting it on a WWV minute tone and then checking it 1 minute later with a split time. If a significant difference is observed, start and check the stopwatch again. Split times are taken for each pointing on the sun and added to the beginning UTC time, corrected to UT1.

To enter the ephemeris tables, you must know the Greenwich date for the time of observation. For an afternoon observation (local time) in the Western Hemisphere, if the UT1 is between 12 and 24 hours, the Greenwich date is the same as the local date. If the UT1 time is between 0 and 12 hours, the Greenwich date is the local date plus 1 day.

For a morning observation (local time) in the Eastern Hemisphere, if the UT1 time is between 0 and 12, the Greenwich date is the same as the local date. If the UT1 time is between 12 and 24 hours, the Greenwich date is the local date minus 1 day.

For a morning observation in the Western Hemisphere and an afternoon observation in the Eastern Hemisphere, Greenwich and local dates are the same.

Latitude and Longitude

Both the observer's latitude and longitude are required for the hour angle method. Usually these values can be readily obtained by scaling from a map, such as a USGS 7.5-minute quadrangle sheet. For sun observations, locating the observer's position on the map and scaling must be performed to a reasonably high degree of accuracy.

Declination of the Sun

Declination (δ) of the sun is tabulated for O hours universal time of each day (Greenwich date) in table 15-5. You can interpolate for at the UT1 time of observation by using the following equation:

$$\delta = \delta 0^h + (\delta 24^h - \delta 0^h)\left(\frac{UT1}{24}\right)$$

A negative declination indicates that the sun is south of the equator, and a negative value must be used in the above equation and in the azimuth (Z) equation.

The Greenwich hour angle (GHA) of the sun is tabulated for 0 hours universal time of each day (Greenwich date) in the ephemeris. Interpolation is required at the UT1 time of observation and can be accomplished by using the following equation:

$$GHA = GHA\ 0^h + (GHA\ 24^h - GHA\ 0^h + 360)\left(\frac{UT1}{24}\right)$$

NOTE: The value at the beginning of the day of observation is 0^h. The value 24 hours later at the beginning of the next day is 24^h.

Table 15-5.—GHA for the Sun and Polaris for O Hours Universal Time

JUNE 1985

GREENWICH HOUR ANGLE FOR THE SUN AND POLARIS FOR 0 HOUR UNIVERSAL TIME

DAY	GHA (SUN)	DECLINATION	EQ. OF TIME APPT-MEAN	SEMI-DIAM.	GHA (POLARIS)	DECLINATION	GREENWICH TRANSIT
	° ' "	° ' "	M S	' "	° ' "	° ' "	H M S
1 SA	180 34 37.0	22 01 06.2	02 18.47	15 47.9	215 42 02.0	89 11 41.09	9 35 37.
2 SU	180 32 20.8	22 09 09.6	02 09.39	15 47.7	216 40 49.9	89 11 40.87	9 31 43.
3 M	180 29 58.9	22 16 49.9	01 59.93	15 47.6	217 39 37.0	89 11 40.67	9 27 48.
4 TU	180 27 31.5	22 24 07.0	01 50.10	15 47.4	218 38 24.3	89 11 40.51	9 23 54.
5 W	180 24 58.8	22 31 00.5	01 39.92	15 47.3	219 37 13.0	89 11 40.37	9 19 59.
6 TH	180 22 21.0	22 37 30.6	01 29.40	15 47.2	220 36 03.4	89 11 40.25	9 16 04.
7 F	180 19 38.2	22 43 36.9	01 18.55	15 47.1	221 34 55.4	89 11 40.12	9 12 10.
8 SA	180 16 50.8	22 49 19.3	01 07.39	15 46.9	222 33 48.5	89 11 39.98	9 08 15.
9 SU	180 13 59.1	22 54 37.8	00 55.94	15 46.8	223 32 41.9	89 11 39.82	9 04 20.
10 M	180 11 03.2	22 59 32.1	00 44.22	15 46.7	224 31 35.1	89 11 39.65	9 00 25.
11 TU	180 08 03.6	23 04 02.2	00 32.24	15 46.6	225 30 27.4	89 11 39.46	8 56 30.
12 W	180 05 00.6	23 08 07.9	00 20.04	15 46.5	226 29 18.5	89 11 39.27	8 52 35.
13 TH	180 01 54.4	23 11 49.3	00 07.63	15 46.4	227 28 08.2	89 11 39.07	8 48 41.
14 F	179 58 45.5	23 15 06.0	-00 04.96	15 46.3	228 26 56.3	89 11 38.88	8 44 46.
15 SA	179 55 34.2	23 17 58.2	-00 17.72	15 46.2	229 25 43.1	89 11 38.70	8 40 52.
16 SU	179 52 20.9	23 20 25.8	-00 30.60	15 46.1	230 24 28.7	89 11 38.53	8 36 57.
17 M	179 49 06.0	23 22 28.6	-00 43.60	15 46.0	231 23 13.8	89 11 38.39	8 33 03.
18 TU	179 45 49.9	23 24 06.6	-00 56.67	15 46.0	232 21 58.7	89 11 38.27	8 29 08.
19 W	179 42 33.0	23 25 19.9	-01 09.80	15 45.9	233 20 44.1	89 11 38.17	8 25 14.
20 TH	179 39 15.7	23 26 08.3	-01 22.95	15 45.8	234 19 30.4	89 11 38.09	8 21 20.
21 F	179 35 58.4	23 26 31.9	-01 36.11	15 45.8	235 18 18.0	89 11 38.03	8 17 25.
22 SA	179 32 41.6	23 26 30.7	-01 49.23	15 45.7	236 17 06.9	89 11 37.96	8 13 30.
23 SU	179 29 25.7	23 26 04.6	-02 02.29	15 45.7	237 15 56.9	89 11 37.89	8 09 36.
24 M	179 26 11.0	23 25 13.7	-02 15.27	15 45.6	238 14 47.2	89 11 37.80	8 05 41.
25 TU	179 22 58.0	23 23 58.0	-02 28.13	15 45.6	239 13 37.1	89 11 37.70	8 01 46.
26 W	179 19 47.1	23 22 17.6	-02 40.86	15 45.5	240 12 25.7	89 11 37.58	7 57 52.
27 TH	179 16 38.6	23 20 12.5	-02 53.43	15 45.5	241 11 12.5	89 11 37.46	7 53 57.
28 F	179 13 32.8	23 17 42.7	-03 05.81	15 45.5	242 09 57.0	89 11 37.34	7 50 03.
29 SA	179 10 30.1	23 14 48.4	-03 18.00	15 45.5	243 08 39.6	89 11 37.23	7 46 09.
30 SU	179 07 30.7	23 11 29.7	-03 29.96	15 45.4	244 07 21.2	89 11 37.16	7 42 15.

Now that you know how to compute for the GHA and eventually the LHA, the declination of the sun, and the latitude and longitude of your location, you are ready for the field procedure for determining the azimuth of a line.

Field Procedure

Horizontal angles from a line to the sun are obtained from direct and reverse pointings taken on the backssght mark of the sun. It is suggested that repeating theodolites be used as directional instruments, with the sighting sequence being as follows: direct on mark direct on sun, reverse on sun, and reverse on mark. Times are recorded for each pointing on the sun. Since a large difference usually exists in vertical angles between the backsight mark and the sun, it is imperative that both direct and reverse pointings be taken to eliminate instrument errors.

WARNING

DIRECT VIEWING OF THE SUN WITHOUT A PROPER FILTER WILL CAUSE SERIOUS EYE DAMAGE.

You must **NOT** observe the sun directly through the telescope without using an eyepiece or objective lens filter. If you do not have a filter, you can project the image of the sun and the cross hairs of the instrument onto a blank white surface held approximately 1 foot behind the eyepiece. The eyepiece and the telescope focus must be adjusted to obtain a sharp image. Usually only that position of the cross hair system situated within the sun's image is clearly visible. Although this method of sun observation works, viewing the sun with the aid of a falter is more convenient and slightly improves pointing accuracies. (When using a total-station instrument, you must use an objective lens filter to protect the electronic distance meter (EDM) components.)

Accurate pointings of the telescope cross hairs in the center of the sun is impractical. Rather than pointing to the center, you may take direct and reverse pointings on opposite edges (fig. 15-13). Pointings are made with the single portion of the vertical cross hair without regard to the location of the horizontal cross hair. You point the trailing edge of the sun by allowing it to move into the vertical cross hair. You point the leading edge by moving the vertical cross hair forward until the cross

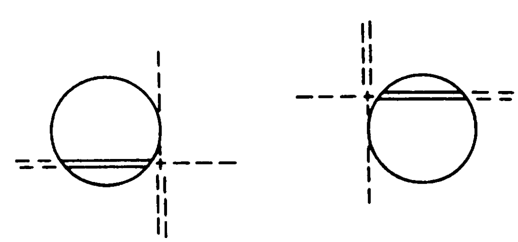


Figure 15-13.—Pointing the sun.

SUN OBSERVATION				
SET	POINT.	TELE.	TIME (STOPWATCH)	CIR. READ
1	B	D		0-00-12
	þ	D	0:24:32.8	345-38-02
	þ	R	0:26:11.2	165-50-23
	B	R		180-00-09
2	B	D		60-03-26
	þ	D	0:31:17.3	46-32-50
	þ	R	0:32:54.4	226-45-12
	B	R		240-03-24
3	B	D		180-06-43
	þ	D	0:37:06.8	107-21-04
	þ	R	0:38:40.7	287-32-48
	B	R		300-06-42

SUN OBSERVATION

THUR.
JUNE 13, 1985
CLEAR, CALM

LATITUDE = 36°04'00" N
LONGITUDE = 94°10'08" W

UTC (BY WWV) = 12:42:00
DUT = +0.2 DOUBLE TICKS)
STOPWATCH = 0.00:00

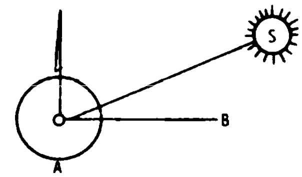


Figure 15-14.—Sun-observation example field notes.

hair becomes tangent to the sun's image. Averaging the direct and reverse angles results in an angle to the center of the sun.

Since the sun travels on a curved path, averaging the angles introduces a systematic error-the magnitude being a function of time between pointings. This error can be eliminated by computing an azimuth for each pointing and averaging the azimuths.

An alternate procedure is to take both direct and reverse pointings on the same edge (usually the trailing edge). A correction, dH, is calculated from the sun's semidiameter and is applied to the average horizontal angle. The semidiameter of the sun is tabulated in the ephemeris. The correction dH (a function of the sun's altitude), should be computed by using the following formula (both observations, direct and reverse, should be made within 4 minutes):

$$h = \sin^{-1} (\sin \Phi \sin \delta + \cos \Phi \cos \delta \cos LHA)$$

$$dH = \frac{\text{sun's semidiameter}}{\cos h}$$

When you are pointing the left edge (left when facing the sun), add dH to an angle right. When pointing the right edge, subtract the left edge, which is always the trailing edge at latitudes greater than 23.5°N; the left edge is always the leading edge at latitudes greater than 23.5°S. The number of sets of data varies, depending on accuracy requirements. For most applications, a minimum of three sets should be taken and an azimuth of the line (ZL) computed for each. A general equation for ZL is

$$ZL = Z + 360° - \text{angle right.}$$

ZL can be normalized to between 0° and 360° by adding or subtracting 360°.

After azimuths of the line have been computed, they are compared and, if found to be within an acceptable limit, averaged.

In working through the following example, refer to the field notes shown in figure 15-14. These notes illustrate the standard procedure of incrementing horizontal circles and micrometer settings for a directional theodolite.

EXAMPLE: Determine the true azimuth of a line (line *AB)* on the ground from a celestial observation.

1. Set the transit at station *A* and train it on *B*.

2. Adjust the horizontal circle at zero and lock the lower motion.

3. Train the telescope on the sun and record the time at the instant the vertical cross hair is aligned on the edge of the sun.

4. Read and record the horizontal angle.

5. Invert the telescope and take another reading.

6. Repeat Steps 3 and 4 until all the necessary sun shots are completed.

7. Proceed with the computation

The following calculations are for the field notes shown in figure 15-14:

Time correction:

$$\begin{array}{l} UTC = 12^h42^m00.0^s \\ DUT = + \qquad 0.2^s \\ \hline UT1 = 12^h42^m00.2^s \end{array}$$

Calculations for Set 1 of the observations:

Avg UT1 $= 12^h42^m00.2^s + \dfrac{24^m32.8^s + 26^m11.2^s}{2}$

$= 13^h07^m22.2^s$

Hor. Angle (telescope direct) $= 345°38'02'' - 0°00'12''$ (Initial reading of horizontal circle)

$= 345°37'50''$

Hor. Angle (telescope reverse) $= 165°50'23'' - 180°00'09''$

$= -14°09'46''$

$= 345°50'14''$

Hor. Angle (average) $= \dfrac{345°37'50'' + 345°50'14''}{2} = 345°44'02''$

GHA 0^h $= 180°01'54.4''$ (from table 15-5)

GHA 24^h $= 179°58'45.5''$ (from table 15-5)

GHA $=$ *GHA* 0^h + (*GHA* 24^h − *GHA* 0^h + 360°) (*UT*1/24)

$= 180°01'54.4'' + (179°58'45.5'' - 180°01'54.4'' + 360°) \times (13^h07^m22.2^s/24)$

$= 376°50'44.1''$ or $16°50'44.1''$

LHA $=$ *GHA* $- \lambda_W$

$= 16°50'44.1'' - 94°10'08'' = -77°19'23.9''$

Add 360°, since its west longitude; therefore,

LHA $= 360° - 77°18'23.9''$

$= 282°40'36.1''$

Solving declination (δ) of the sun on this date and time of day,

$\delta\ 0^h$ $= 23°11'49.3''$ (from table 15-5)

$\delta\ 24^h$ $= 23°15'06.0''$ (from table 15-5)

δ $= \delta\ 0^h + (\delta\ 24^h - \delta\ 0^h)$ (*UT*1/24)

$= 23°11'49.3'' + (23°15'06.0'' - 23°11'49.3'')\ (13^h07^m22.2^s/24)$

$= 23°13'36.9''$.

Solving for Z,

$$Z = \tan^{-1} \frac{\sin 282°40'36.1''}{(\sin 36°04'00'')(\cos 282°40'36.1'') - (\cos 36°04'00'')(\tan 23°13'36.9'')}$$

$$= \tan^{-1} 4.4813891$$

$$Z = 77°25'14.93''.$$

Note that LHA is between 180° and 360° and that Z is positive; therefore, the normalized correction equals 0.

Solving for h,

$$h = \sin^{-1} (\sin \Phi \sin \delta + \cos \Phi \cos \delta \cos LHA)$$

$$= \sin^{-1} (\sin 36°04'00'' \sin 23°13'36.9'' + \cos 36°04'00'' \cos 23°13'36.9'' \cos 282°40'36.1'')$$

$$= \sin^{-1} 0.3951889$$

$$h = 23°16'40''.$$

Semidiameter = 0°15'46.4" (from table 15-5)

$$dH = \frac{semidiameter}{\cos h}$$

$$= \frac{0°15'46.4''}{\cos 23°16'40''} = \frac{0°15.773333'}{0.9185999}$$

$$= 0°17'10.3''$$

As shown in figure 15-14, the left edge of the sun (indicated by the symbols in the "point" column) was pointed both direct and reverse. That being the case, the correction dH is added to the average horizontal angle as follows:

$$\text{Corrected horizontal angle} = 345°44'02.0'' + 0°17'10.3''$$

$$= 346°01'12.3''$$

Solving for the azimuth of line *AB* (Set 1), you obtain the following:

$$ZL = Z + 360° - \textit{corrected horizontal angle}$$

$$= 77°25'14.93'' + 360° - 346°01'12.3''$$

$$= 91°24'03''.$$

Now, if you use the same calculation procedures to obtain the azimuth of line *AB* for Sets 2 and 3, you find the following:

Set 2: $ZL = 91°24'06''$

Set 3: $ZL = 91°23'59''$

Average $ZL = 91°24'03''$

If you desire a bearing, you know that an azimuth of 91°24´03´´ equates to a bearing of S88°35´57´´E.

OBSERVATIONS ON POLARIS OR OTHER STARS

For most land surveying, the determination of astronomic azimuth by observing the sun is sufficient; however, in some cases, the required degree of accuracy may be such that observation of Polaris or another star may be required. Several observation methods and calculation procedures can be applied to determine azimuth from Polaris; however, we will not discuss them here. Instead you should refer to commercial publications, such as *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail, or *Elementary Surveying,* by Wolf and Brinker. You should also refer to these or other similar publications for a more thorough discussion of field astronomy in general.

This ends our discussion of field astronomy. Now let's take a brief look at a new development in surveying that is related to field astronomy and to triangulation which is the final topic in this chapter.

SATELLITE SURVEYING SYSTEMS

In the preceding discussion, you learned how the location of a point on the earth can be determined from observations taken on the sun or stars. A far more recent development uses satellites.

Satellite surveying systems are an offshoot of the space program and the U.S. Navy's activities related to navigation. Since their development, satellite surveying systems have been successfully used in nearly all areas of surveying and are capable of producing extremely accurate results.

The first generation of satellite surveying systems was the **Doppler positioning systems.** The success of the Doppler systems led to the U.S. Department of Defense development of a new navigation and positioning system using NAVSTAR (Navigation Satellite Timing And Ranging) satellites. This development ushered in the second generation of satellite surveying systems known as the **Global Positioning System** (GPS).

DOPPLER POSITIONING SYSTEMS

Imagine, if you will, the continuously changing pitch of a train whistle as it approaches and passes you. This is a classic example of the **Doppler phenomenon** in which the change in frequency is a function of range or distance. This phenomenon is the underlying principle of the Doppler positioning systems.

In the Doppler system, a precisely controlled radio frequency is continuously transmitted from a satellite as it orbits past an observer's station. As the satellite draws nearer the receiver, the received frequency increases. Then as the satellite passes the receiver, the frequency decreases below the transmitted level. With the transmitting frequency, satellite orbit, and precise timing of observations known, you can then compute the position of the receiving station.

The observer uses a specially designed receiver system that is manufactured by one of several commercial firms. Typically, the system is composed of an antenna to receive the transmitted frequency; a receiver to detect, amplify and decode the transmitted signal; a recording medium, such as a paper or magnetic tape; and a rugged carrying case.

To determine point locations using the Doppler system, you can use three basic methods. They are the **point-positioning, translocation,** and **short-arc** methods.

In the point-positioning method a receiver located at a single location of unknown position collects data from multiple satellite passes. From the measured data, the location of the receiver is determined using a coordinate system that is relative to the position of the satellite. Then the location is converted to a conventional coordinate system used by surveyors.

In translocation, receivers located at two or more stations track a satellite. The location of one of the stations—the control station—must be known. The control station, although its position is known, is first treated as an unknown and its coordinates are determined using the point-positioning method described above. The determined coordinates are then compared to the known coordinates and differences indicate errors in the system. Based on the errors, corrections are determined and applied to the positions of the unknown stations whose locations have also been determined using the point-positioning method.

The short-arc method is the same as the translocation method, except that corrections are also made for the orbital parameters of the satellite.

GLOBAL POSITIONING SYSTEMS

Because of its superiority, the global positioning system is phasing out the use of the Doppler positioning system; however, like the Doppler system, the global positioning system is based on observations of satellites. GPS satellites are in near-circular orbits around the globe at an altitude of approximately 12,400 miles above the earth. These satellites transmit unique signals that are encoded with information that enables ground receivers to measure the travel time of the signals from satellite to receiver. That travel time is then converted to distance using the velocity of electromagnetic energy through the atmosphere.

Determining point locations using GPS procedures consist essentially of measuring distances from points at unknown locations to satellites whose positions are known at the instant of observation. In concept this is identical to performing resection (chapter 9 of this TRAMAN), using distances that are measured from a point of unknown location to three or more stations whose positions are known.

For a more thorough discussion of both global positioning systems and Doppler positioning systems, you can refer to commercial books, such as *Elementary Surveying,* by Wolf and Brinker.

TRIANGULATION

In your previous studies you learned that a principal method of locating points in horizontal control is traversing. As you know, traversing requires that distances and angles be measured at all stations. In this chapter you will learn another method. This method— **triangulation** —requires that distances be measured only at the beginning, at specified intervals, and at the end of the survey.

Both the triangulation method and the traverse method of control are based on the character of the terrain, and not on the degree of precision to be attained; that is, each system is equally precise under the conditions in which each is used. Discussion of triangulation in this chapter normally is limited to triangles having sides less than 3,000 yards in length and to triangulation nets that do not extend more than 25,000 yards.

The triangulation method is used principally in situations where the chaining of distances is impossible or infeasible except with the use of electronic measuring devices. Suppose you want to locate a point, say, point *C,* which is offshore; and the measured baseline, *AB,* is located on the shore. In this situation the triangulation method is used because the chaining of distances is impossible. The chaining of long distances, especially in rough country, also is not always possible; therefore, triangulation is used to establish horizontal control in large-area surveys.

In some large-area surveys conducted by triangulation, you must consider factors involving the curvature of the earth; hence, in such cases, **geodetic** triangulation is involved. Whether or not the curvature of the earth must be considered depends upon the area covered and the precision requirements of the survey. The error resulting in horizontal measurements when you ignore the curvature of the earth amounts to about 1 foot in 34 1/2 miles. This means that in most ordinary surveying, an area of 100 square miles may be plane-triangulated without significant error. In this discussion we are concerned with plane triangulation only. For a discussion of geodetic triangulation, you should refer to commercial publications.

This section contains information on the three types of triangulation networks and the usual procedure for conducting a triangulation survey. Also covered are primary and secondary triangulation stations, types of signals used in marking triangulation stations, and checking for precision and locations of points.

SUPERVISION AND TRIANGULATION SURVEYS

In triangulation surveys, the duties of the EA1 are those of party chief; that is, he directs the triangulation survey. He keeps the triangulation notes and should be at the spot where any important measurement is made so that he can verify the readings personally. He is responsible for selecting triangulation stations and erecting triangulation signals and towers. He determines the degree of precision to be attained. He also performs the computations necessary to determine horizontal locations of the points in the triangulation system by bearing and distance.

Triangulation is used extensively as a means of control for topographic and similar surveys. A triangulation system consists of a series of triangles. At least one side of each triangle is also aside of an adjacent triangle; two sides of a triangle may form sides of adjacent triangles. By using the triangulation method of control, you do not need to measure the length of every line. However, two lines are measured in each system—one line at the beginning and one at the closing of the triangulation system. These lines are called **base lines** and are used as a check against the computed lengths of the other lines in the system. The recommended length of a base line is usually one sixth to one fourth of that of the sides of the principal triangles. The transcontinental system established by the U.S. Coast and Geodetic Survey (now the National Geodetic Survey) is an example of an extensive

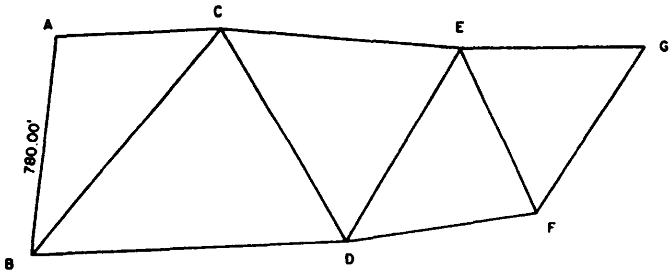


Figure 15-15.-Chain of single triangles.

high-order triangulation network to establish control across the United States.

TYPES OF TRIANGULATION NETWORKS

In triangulation there are three types of triangulation networks (or nets). They are the **chain of single triangles, chain of polygons,** and **chain of quadrilaterals.**

Chain of Single Triangles

The simplest triangulation system is the chain of single triangles shown in figure 15-15. Suppose *AB* is the base line and measures 780.00 feet in length. Suppose, also, that angle *A* (that is, the observed angle *BAC)* measures 98°54′ and that angle *ABC* measures 32°42′. (In actual practice you will use more precise values than these; we are using rough values to simplify the explanation.) Subtracting the sum of these two angles from 180°, we get 48°24′ for angle *ACB.*

Next, solve for sides *BC* and *AC* by using the law of sines as follows:

$$BC = AB\frac{\sin A}{\sin C}$$

$$= AB\frac{\sin 98°54'}{\sin 48°25'}$$

$$= 1030.50 \text{ ft}$$

$$AC = AB\frac{\sin B}{\sin C}$$

$$= AB\frac{\sin 32°42'}{\sin 48°24'}$$

$$= 563.50 \text{ ft}$$

Now that you know how to find the length of *BC,* you can proceed in the same manner to determine the lengths of *BD* and *CD.* Knowing the length of *CD,* you can proceed in the same manner to determine the lengths of *CE* and *DE,* knowing the length of *DE,* you can determine the lengths of *DF* and *EF,* and so on. You should use this method only when locating inaccessible points, not when a side of the triangle is to be used to extend control.

In comparison with the other systems about to be described, the chain of single triangles has two disadvantages. In the first place, it can be used to cover only a relatively narrow area. In the second place, it provides no means for cross-checking computed distances using computations made by a different route. In figure 15-15, for example, the only way to compute the length of *BC* is by solving the triangle *ABC,* the only way to compute the length of *CD* is by solving the triangle *BCD* (using the length of *BC* previously computed); and so on. In the systems about to be described, a distance maybe computed by solving more than one series of triangles.

Chain of Polygons

Technically speaking, of course, a triangle is a polygon; and therefore a chain of single triangles could be called a chain of polygons. However, in reference to triangulation figures, the term *chain of polygons* refers to a system in which a number of adjacent triangles are combined to forma polygon, as shown in figure 15-16. Within each polygon the common vertex of the triangles that compose it is an observed **triangulation station** (which is not the case in the chain of quadrilaterals described later).

You can see how the length of any line shown can be computed by two different routes. Assume that *AB* is the base line, and you wish to determine the length of line *EF.* You can compute this length by solving

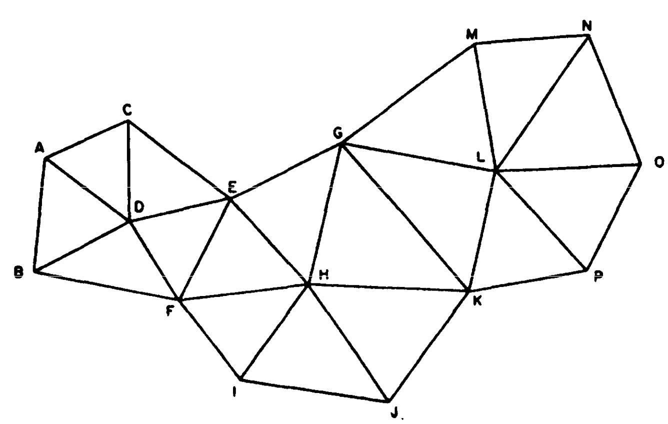


Figure 15-16.—Chain of polygons.

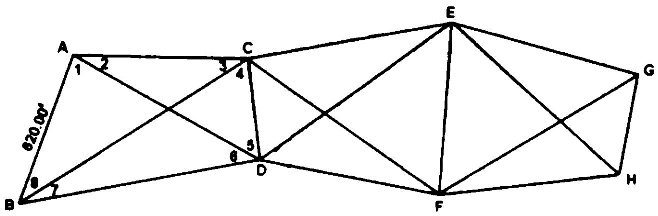


Figure 15-17.—Chain of quadrilaterals.

triangles *ADB, ADC, CDE,* and *EDF,* in that order, or by solving triangles *ADB, BDF,* and *FDE,* in that order. You can also see that this system can be used to cover a wide territory. It can cover an area extending up to approximately 25,000 yards in length or breadth.

Chain of Quadrilaterals

A quadrilateral, too, is technically a polygon; and a chain of quadrilaterals would be technically a chain of polygons. However, with reference to triangulation figures, the term *chain of quadrilaterals* refers to a figure arrangement like that shown in figure 15-17. Within each of the quadrilaterals shown, the triangles on which computations are based are not the four adjacent triangles visible to the eye, but four overlapping triangles—each of which has as sides two sides of the quadrilateral and one diagonal of the quadrilateral. For example, in quadrilateral *ACDB* there are four overlapping triangles as follows: *ADC, ADB, ABC,* and *BCD.* You can see that solving these four triangles will give you two computations for the length of each unknown side of the quadrilateral.

Consider, for example, the quadrilateral *ACDB.* Look at angle *BAC.* We will call the whole angle at a comer by the letter (as, angle A) and a less-than-whole angle at a corner by the number shown (as, angle 1). The angles at each station on the quadrilateral, as measured with a protractor to the nearest 0.5 degree and estimated to the nearest 0.1 degree, are sized as follows:

Angle	° Size	′	Angle	° Size	′
1	79	06	5	53	30
2	29	00	6	40	24
3	34	06	7	22	42
4	63	24	8	37	48

The angles that make up each of the four overlapping triangles, together with their natural sines, are as follows:

Triangle	Angle	° Size	′	Sine
ABC	A	108	06	0.950516
	3	34	06	0.560639
	8	37	48	0.612907
ADB	B	60	30	0.870356
	1	79	06	0.981959
	6	40	24	0.648120
ADC	C	97	30	0.991445
	2	29	00	0.484810
	5	53	30	0.803857
BCD	D	93	54	0.997684
	4	63	24	0.894154
	7	22	42	0.385906

Note that the total sum of the angles is 360°, which it should be for a quadrilateral, and that the sum of the angles in each triangle is 180°, which is also geometrically correct.

To solve the quadrilateral, you solve each of the overlapping triangles. First, you solve triangle *ABC* for sides *AC* and *BC,* using the law of sines as follows:

$$AC = AB \frac{\sin 8}{\sin 3}$$

$$= AB \frac{\sin 37°48'}{\sin 34°06'}$$

$$= 677.80 \text{ ft}$$

$$BC = AB \frac{\sin A}{\sin 3}$$

$$= AB \frac{\sin 108°06'}{\sin 34°06'}$$

$$= 1{,}051.16 \text{ ft}$$

Then, using similar computation procedures, you solve triangle *ABD* for sides *BD* and *AD,* triangle *ADC* for *AC* and *CD,* and triangle *BCD* for *BD* and *CD.* The solutions for each of the overlapping triangles are summarized as follows:

Triangle	Side	Length
ABC	AC	677.80
	BC	1,051.16
ADB	BD	939.35
	AD	832.59
ADC	AC	675.06
	CD	07.13
BCD	BD	942.08
	CD	406.59

As you can see, for each of the unknown sides of the quadrilateral *(AC, CD,* and *BD),* values have been obtained by two different routes. You can also see that there are discrepancies in the values, almost the same for *AC* and *BD* and smaller for *CD.* All the discrepancies shown are much larger than would be tolerable in actual practice; they reflect the high imprecision of the original protractor measurement of the angles. The example has been given here only to illustrate the basic principles and procedures of chain-of-quadrilateral triangulation. Later in this chapter you will see how observed angles (measured in the field with the required precision) are adjusted to ensure that values computed by different routes will be practically close enough to each other to satisfy precision requirements.

TRIANGULATION STATIONS, SIGNALS, AND INSTRUMENT SUPPORTS

All triangulation stations of third order or higher must be identified on the ground with a station marker, at least two reference markers, and, if necessary, an azimuth marker. These markers are usually embedded in or etched on a standard station monument. Station markers, monuments, and station referencing are discussed in the EA3 TRAMAN. For low-order surveys, unless otherwise required, the stations may be marked with 2-inch by 2-inch wooden hubs.

A **primary** triangulation station is both a sighted station and an instrument station; that is, it is a point sighted from other stations and also a point where an instrument is set up for sighting other stations. A **secondary** triangulation station is one that is sighted from primary stations but is not itself used as an instrument station. Only the primary stations are used to extend the system of figures.

Each triangulation station must be marked in a way that will make it visible from other stations from which it is sighted. A mark of this kind is called a triangulation **signal.** For a secondary station, the signal may be relatively simple, such as a pole set in the ground or in a pile of rocks, or a pole set on the ground and held erect by guys. An object already in place, such as a flag pole, a church spire, or a telegraph pole, will serve the purpose. When the instrument itself must be elevated for visibility, a **tower** is used.

Targets

A **target** is generally considered to be a nonilluminating signal. Target requirements can be met by three general types—tripods, bipeds, and poles—all of which may incorporate variations. The targets are constructed of wood or metal framework with cloth covers.

SIZE OF TARGET.— For a target to be easily visible against both light and dark backgrounds, it should be constructed in alternating belts of red and white or red and yellow. For ready bisection, it should be as narrow as possible without sacrificing distinctness. A target that subtends an angle of 4 to 6 seconds of arc will fulfill this purpose. Since 1 second of arc equals 0.5 centimeters at a 1-kilometer distance, an angle of 6 seconds requires a target 3 centimeters wide at 1 kilometer or 30 centimeters at 10 kilometers. Under adverse lighting conditions, the target width will have to be increased. Flags of an appropriate size may be added to aid in finding the target. All cloth used on targets should be slashed after construction to minimize wind resistance.

TRIPOD TARGET.— The **tripod target** is the most satisfactory from the standpoint of stability, simplicity of construction, durability, and accuracy. It ranges from a simple hood of cloth, cut and sewn into a pyramid shape and slipped over the instrument tripod, to the permanent tripod with the legs embedded in concrete, sides braced, a vertical pole emplaced, and the upper part boarded up and painted. Temporary tripod targets may be constructed of 2-inch by 2-inch lumber, pipes, poles, or bamboo joined at one end by wire or bolts threaded through drilled holes. The tripod must be

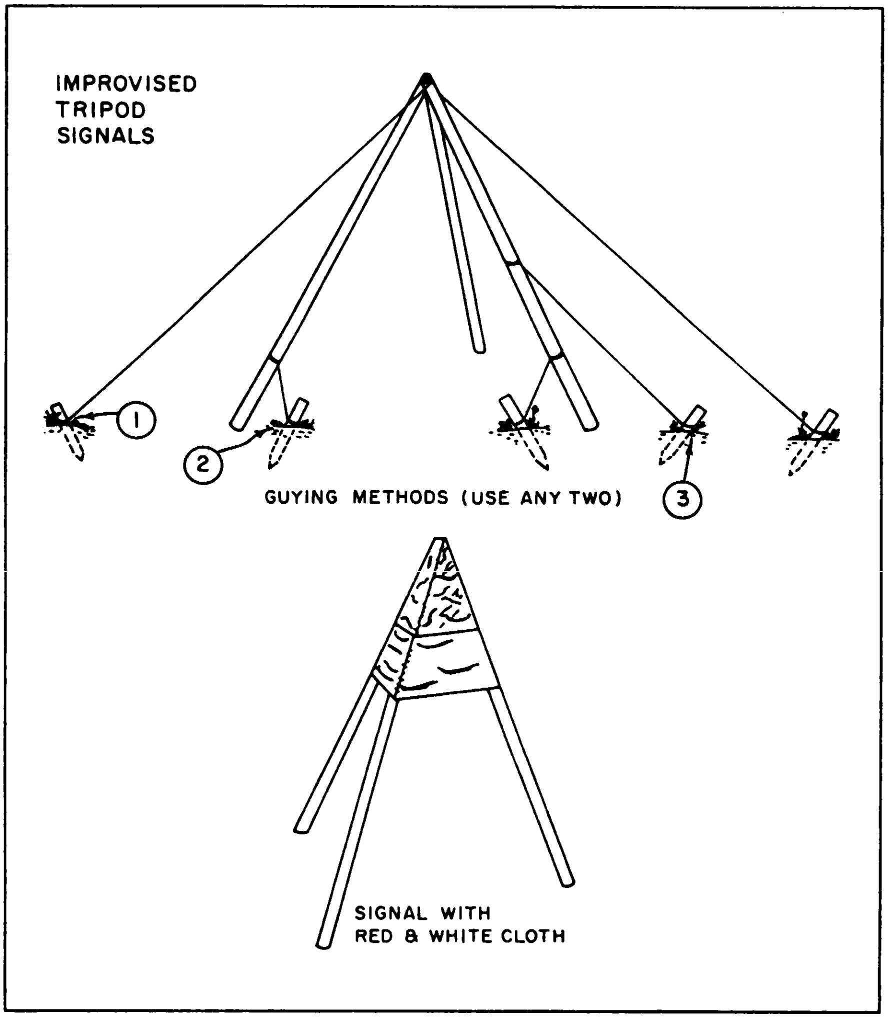


Figure 15-18.—Tripod targets.

well guyed and plumbed (fig. 15-18), and the legs should be set in depressions to prevent lateral movement. On uneven ground one leg may have to be shortened or dug in to maintain a symmetrical appearance from all directions. Signal cloth wrapped around the tripod should be used only on low-order (fourth-order) work as it is almost impossible to make it symmetrical around the station.

BIPOD TARGET.— Bipod targets are more simply constructed than tripods but are less stable and must be strongly guyed. Figure 15-19 shows a standard surveying biped target. It is carried disassembled in a canvas case about 53 inches long. It can be assembled, erected, and plumbed by two men in 15 minutes. If this target must be left standing in the weather for any extended period, the rope guys should be replaced with wire and two more wire guys added to each end of the crossbar. In soft ground the pointed legs will sink unevenly because of wind action and rain; therefore, they should be set in holes bored in the end of wooden stakes driven flush or in a short piece of 2-inch by 4-inch lumber laid flat in a shallow hole.

POLE TARGETS.— Pole targets (fig. 15-20) are seldom used because the station cannot be occupied while the target is in place. In certain cases, as when an unoccupied station must be sighted and cutting of lines of sight is difficult or impossible, a pole target that can be seen above the trees maybe erected The staff may be constructed of 2-inch by 2-inch lumber or cut poles, varying from about 2 inches to 6 inches in diameter. The method of joining sections of 2-inch by 2-inch lumber and the construction of a panel target are shown in figure 15-20. The targets must be plumbed by manipulation of the guy wires. Special care must be taken when warped or crooked boards are used to construct pole targets, and they must be checked for eccentricity.

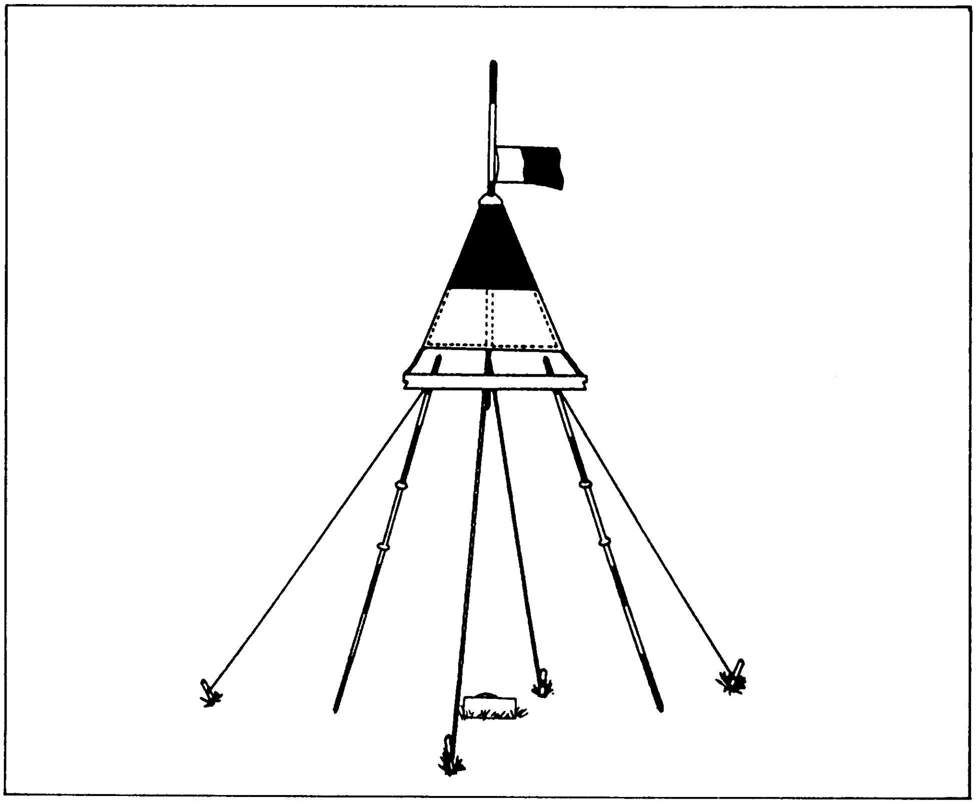


Figure 15-19.—Bipod target.

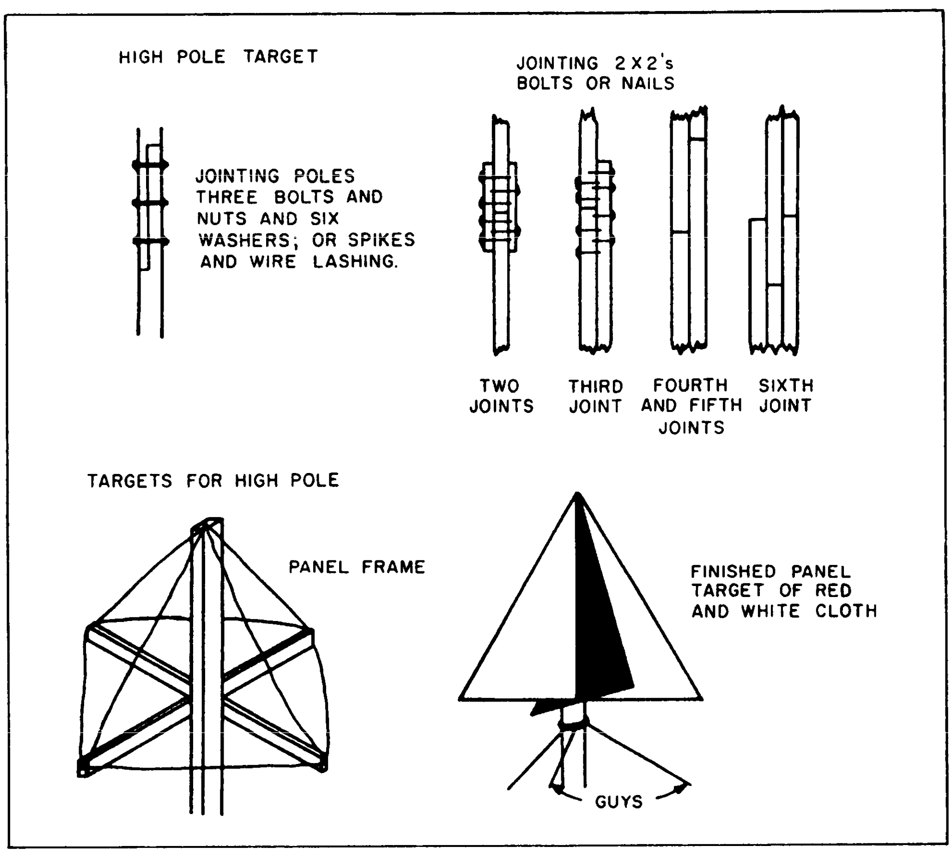


Figure 15-20.—Pole targets.

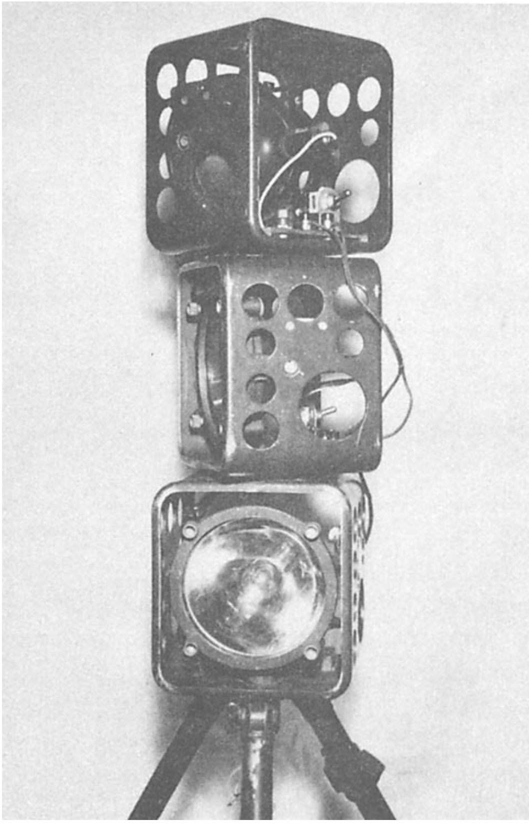


Figure 15-21.—5-inch signal light (stacked).

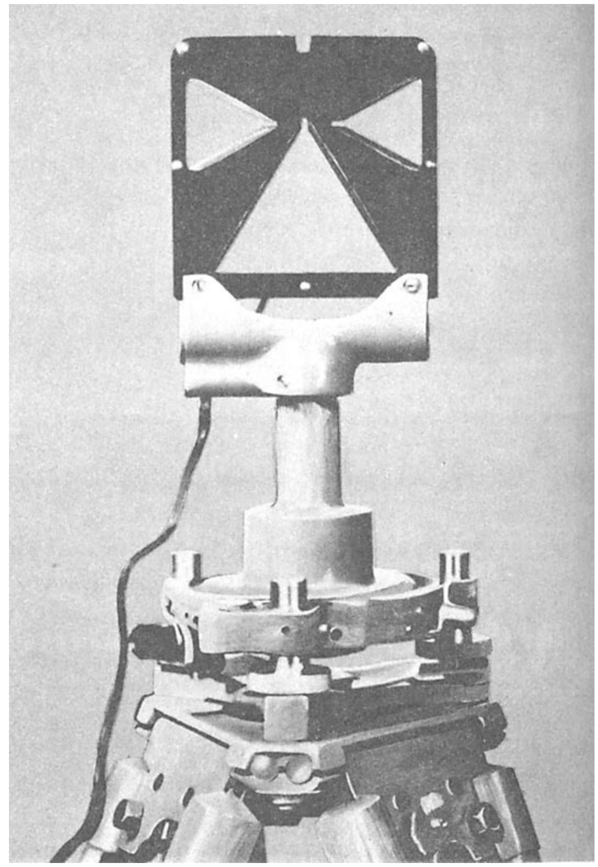


Figure 15-22.—Target set.

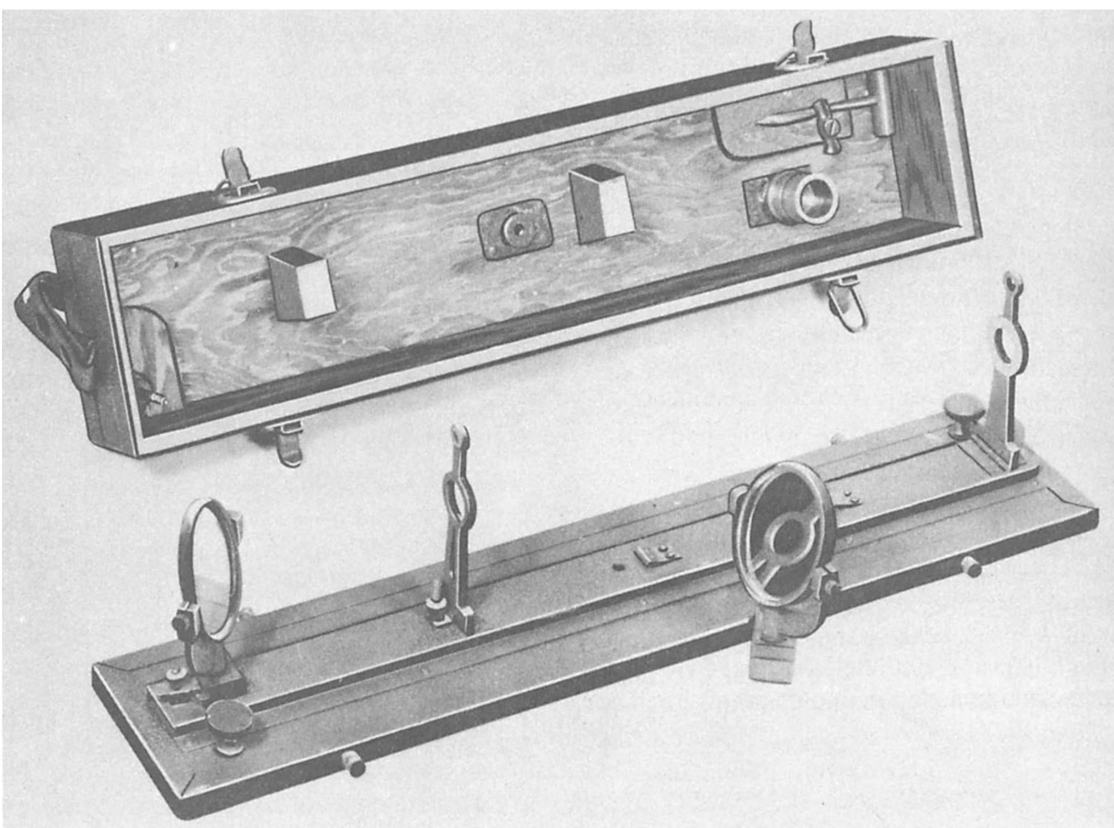


Figure 15-23.—Heliotrope.

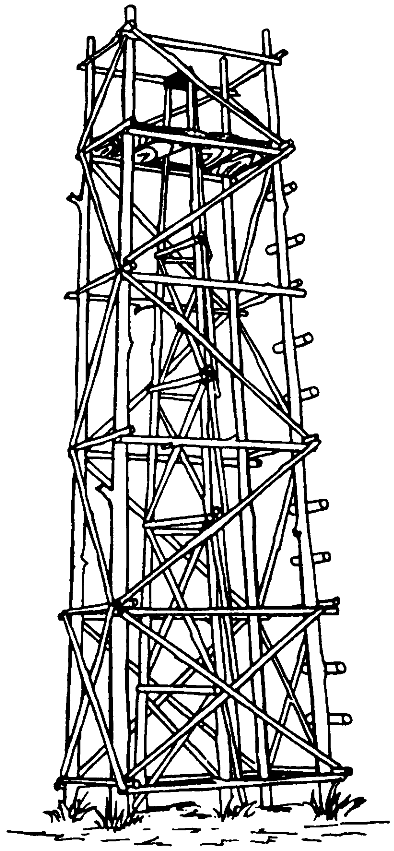


Figure 15-24.-Pole tower.

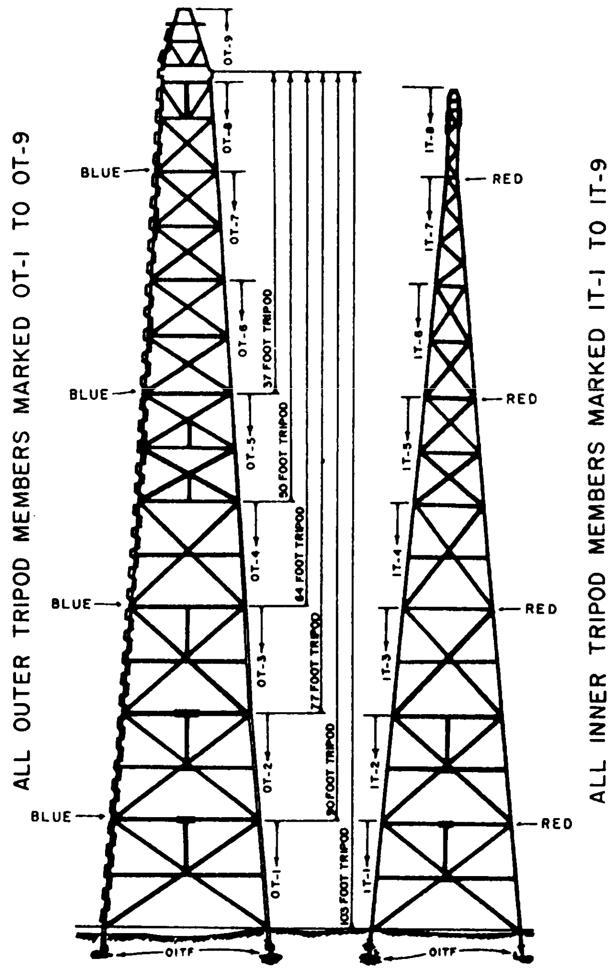


Figure 15-25.—Aluminum or steel tower.

Signals

Signals are those survey targets that either are illuminated by natural sunlight or are electrically lighted by use of wet or dry cell batteries. The observations for all first- and second-order triangulation and first-order traverse are usually done at night using signal lights, because of more stable atmospheric conditions, which allow for better pointings. Observations maybe made during daylight hours using lights, but for high-accuracy surveys, this is done only under extreme conditions.

Some examples of signals are signal lights (fig. 15-21), a target set (fig. 15-22), and a heliotrope (fig. 15-23). The target set is a precise lighting device that is generally used for short traverse lines. The heliotrope is a device that reflects the rays of the sun through a pair of mirrors set over a point and toward an observer on another station. When standard signals are not available, expedient lights can be used. Examples of expedient lights are the headlights of a vehicle, a masked lantern, or a boxed light bulb.

Supports (Towers)

Towers must be built on some stations to raise the lines of sight to clear obstructions or to lengthen the lines of sight to increase distances between stations of area surveys. A tower consists of an instrument stand (inner structure) and a platform to support the observer (outer structure). Towers fall roughly into three classes: prefabricated aluminum or steel, wooden, and expedient towers. The towers are usually constructed by a separate crew, whose size depends upon the type of tower being built. The expedient tower is usually a tower or high structure that is already in the area.

Two examples of towers are shown in figures 15-24 and 15-25.

TRIANGULATION PROCEDURES

A triangulation survey usually involves the following steps:

1. Reconnaissance—meaning the selection of the most feasible points for stations

2. Signal erection on these points

3. Measurement of angles
4. Determination of direction (or azimuth)
5. Base line measurement
6. Computations

Reconnaissance

The first consideration with regard to the selection of stations is, of cause, **intervisibility.** An observation between two stations that are not intervisible is impossible. Next comes **accessibility.** Obviously again, a station that is inaccessible cannot be occupied and between two stations otherwise equally feasible, the one that provides the easier access is preferable.

The next consideration involves **strength of figure.** In triangulation, the distances computed (that is, the lengths of triangle sides) are computed by way of the law of sines. Ths more nearly equal the angles of a triangle are, the less will be the ratio of error in the sine computations. The ideal triangle, then would be one in which each of the three angles measured 60°; this triangle would, of course, be both equiangular and equilateral.

Values computed from the sines of angles near 0° or 180° are subject to large ratios of error. As a general rule, you should select stations that will provide triangles in which no angle is smaller than 30° or larger than 150°.

Signal Erection

After the stations have been selected, the triangulation signals or triangulation towers should be erected When you erect triangulation towers or signals, remember that it is imperative for these stations to be intervisible. It is also important that the target be large enough to be seen at a distance; that is, the color of the target must be selected for good visibility against the background where it will be viewed. When observations are made during daylight hours with the sun shining, a heliotrope is a very effective target. When triangulation surveys are made at night, lights must be used for targets. Therefore, target sets with built-in illuminations are very effective.

Measurement of Angles

The precision with which angles in the system are measured will depend on the **order of precision** prescribed for the survey. The precision of a triangulation system may be classified according to (1) the average error of closure of the triangles in the system and (2) the ratio of error between the measured length of a base line and its length as computed through the system from an adjacent base line. Large government triangulation surveys are classified in precision categories as follows:

Order of Precision	Triangle Avg. Closure (Seconds)	Base Line Ratio
First	1	$\frac{1}{25,000}$
Second	3	$\frac{1}{10,000}$
Third	5	$\frac{1}{5,000}$

For third-order precision, angles measured with a 1-minute transit will be measured with sufficient precision if they are repeated six times. As explained in chapter 13 of the EA3 TRAMAN, six repetitions with a 1-minute transit measures angles to the nearest 5 seconds. To ensure elimination of certain possible instrumental errors, you should make half of the repetitions with the telescope erect and half with the telescope reversed. In each case, the horizon should be closed around the station.

Determination of Direction

As you learned earlier in this chapter, most astronomical observations are made to determine the true meridian from which all azimuths are referred In first-order triangulation systems, these observations are used to determine latitude and longitude. Once the true meridian is established, the azimuths of all other sides are computed from the true meridian.

To compute the coordinates of triangulation stations, you must determine the latitudes and departures of the lines between stations; to do this, you must determine the directions of these lines. The **latitude** of a traverse line means the length of the line as projected on the north-south meridian running through the point of origin. The **departure** of a traverse line means the length of the line as projected on the east-west parallel running through the point of origin Latitudes and departures are discussed in detail in chapter 7 of this TRAMAN.

MEASUREMENT OF EAST BASE LINE

From Stake No.	To Stake No.	Thermometers #1 Deg. F	Thermometers #2 Deg. F	Set Fwd. Ft.	Set Back Ft.
1	2	73.0	72.5		
2	3	73.0	73.0		
3	4	73.5	73.0		
4	5	72.5	72.5		
5	6	72.5	73.0	0.104	
6	7	73.0	73.5		
7	8	73.5	73.5		
8	9	73.5	73.0		

3 June 1994	Smith, J., EA1 Recorder
Cloudy, Warm	Jones, R., EA3 Marker
Measuring Forward	Brown, B., CN, H.Chnmn
100-Ft. tape #2	Adams, G., CN, R.Chnmn
Tensiometer #4	
Tape Supported at	0 & 100 Ft.
Thermometers #1 & #2	

Figure 15-26.—Field notes for base line measurement.

Base Line Measurement

The accuracy of all directions and distances in a system depends directly upon the accuracy with which the length of the base line is measured. Therefore, base line measurement is vitally important. A transit must be used to give precise alignment while measuring a base line. For third-order triangulation measurement with a steel tape, you are required to incorporate all the tape corrections described in the EA3 TRAMAN. For measurement over rough terrain, end supports for the tape must be provided by posts driven in the ground or by portable tripods. These supports are usually called **chaining bucks.** The slope between bucks is determined by measuring the difference in elevation between the tops of the bucks with a level and rod.

On the top of each buck, a sheet of copper or zinc is tacked down, which provides a surface on which tape lengths can be marked Bucks are setup along the base line at intervals of one-tape length. The tape, with thermometers fastened at each end, is stretched between the supports and brought to standard tension by a tensiometer (spring balance). When the proper tension is indicated, the position of the forward end is marked on the metal strip with a marking awl or some other needle-pointed marker. At the same time, the thermometer readings are taken.

If stakes, driven at tape-length intervals, are used as tape supporters, the end of the tape may begin to lie slightly off the metal marking strip on the buck after a few tape intervals have been laid off. To take care of this situation, the head chairman carries a finely divided (to 0.001 ft) pocket scale. With this scale he measures the distance that the tape must be **set back** or **set forward** to bring the end again on the marking strip. The set back or set forward is entered in the field notes and deducted from or added to the tape length for that particular interval.

Figure 15-26 shows field notes for a base line measurement. In this case the tape was supported on stakes, driven at full-tape, 100-foot intervals. With the exception of the interval between stakes 5 and 6, the amounts to the standard tape length (with the tape supported at both ends, and with standard tension applied), as corrected for temperature and for slope. For the interval between stakes 5 and 6 (where there is, as you can see, a forward set), the horizontal distance amounts to the standard tape length plus 0.104 foot, as corrected for temperature and for slope. The length of the base line will, of course, amount to the sum of the horizontal distances.

Note that in this case the line is being measured forward. After the forward measurement, the line is again measured in the backward direction. If the backward measurement varies slightly from the forward measurement, the average is taken as the length of the base line. A large discrepancy would, of course, indicate a mistake in one measurement or the other.

Rather than using chaining operations to perform base line measurements, an electronic distance meter (EDM) can be used. The use of EDM equipment greatly simplifies the measurement of base lines in triangulation. Chapter 12 of this TRAMAN gives a general discussion of EDMs and EDM principles.

Computations

In triangulation of ordinary precision or higher, the observed angles are **adjusted** before the lengths of the triangle sides are computed. The most rigorous and accurate of adjustment methods is the **least squares** method that involves the computation of the most probable values of the adjusted quantities. In many advanced surveying textbooks, the least squares method

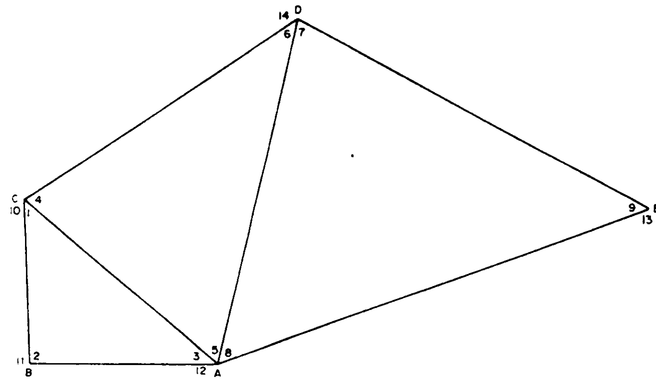


Figure 15-27.—Chain of triangles.

is preferred; however, calculation of the probable values of the unknowns involves a level of mathematics (calculus) that is beyond that required of the Engineering Aid. Therefore, in this text we will discuss more elementary adjustment procedures that, while less accurate than the method of least squares, yield satisfactory results.

There are two steps in angle adjustment, called **station adjustment** and **figure adjustment.** Station adjustment applies the fact that the sum of the angles around a point is 360°. Figure adjustment applies the fact that the sum of the interior angles of a polygon is $(n - 2) \times 180°$, with n representing the number of sides of the polygon.

ADJUSTING A CHAIN OF TRIANGLES.— In station adjustment you compute the sum of the

Table 15-6.—Station Adjustment for Chain of Triangles, Figure 15-27

Station	Angle	Observed Value (6 repetitions) °	'	"	Value adjusted for station °	'	"
A	3	41	02	02	41	01	56
	5	61	10	41	61	10	35
	8	56	08	48	56	08	42
	12	201	38	54	201	38	47
	Sum	360	00	25	360	00	00
B	2	92	47	30	92	47	34
	11	267	12	21	267	12	26
	Sum	359	59	51	360	00	00
C	1	46	10	12	46	10	10
	4	75	31	02	75	31	00
	10	238	18	52	238	18	50
	Sum	360	00	06	360	00	00
D	6	43	18	19	43	18	20
	7	74	43	03	74	43	05
	14	241	58	33	241	58	35
	Sum	359	59	55	360	00	00
E	9	49	07	58	49	07	58
	13	310	52	01	310	52	02
	Sum	359	59	59	360	00	00

Table 15-7.—Figure Adjustment for Chain of Triangles, Figure 15-27

Triangle	Angle	Value after Station Adjustment °	′	″	Value after Figure Adjustment °	′	″
	1	46	10	10	46	10	16
ABC	2	92	47	34	92	47	41
	3	41	01	56	41	02	03
	Sum	179	59	40	180	00	00
	4	75	31	00	75	31	02
ACD	5	61	10	35	61	10	37
	6	43	18	20	43	18	21
	Sum	179	59	55	180	00	00
	7	74	43	05	74	43	10
ADE	8	56	08	42	56	08	47
	9	49	07	58	49	08	03
	Sum	179	59	45	180	00	00

measured angles around each station, determine the extent to which it differs from 360°, and distribute this difference over the angles around the station according to the number of angles.

Figure 15-27 shows a chain of triangles. Station adjustment for this chain of triangles is given in table 15-6.

At station *A*, as you can see, the sum of the observed interior angles 3, 5, and 8 plus the observed exterior closing angle 12 comes to 360°00′25″. This differs from 360° by 25 seconds. The number of angles around the station is four; therefore, the correction for each angle is one fourth of 25, or 6 seconds, with 1 second left over. The sum of the observed angles is in excess of 360°; therefore, 6 seconds was subtracted from the observed value of each interior angle and 7 seconds from the observed value of the exterior angle. The angles around the other stations were similarly adjusted, as shown.

The next step is the figure adjustment for each of the triangles in the chain. For a triangle, the sum of the interior angles is 180°. The figure adjustment for each of the three triangles illustrated in figure 15-27 is shown in table 15-7.

As you can see, the sum of the three adjusted observed interior angles in triangle *ABC* (angles 1, 2, and 3) comes to 179°59′40″. This is 20 seconds less than 180°, or 20/3, or 6 seconds for each angle, with 2 seconds left over. Therefore, 6 seconds was added to the station adjusted value of angle 1, and 7 seconds each was added to the measured values of angles 2 and 3. The angles in the other two triangles were similarly adjusted.

ADJUSTING A CHAIN OF QUADRILATERALS.— The station adjustment for a chain of quadrilaterals is the same as that for a chain of triangles. The next step is a figure adjustment like that for a chain of triangles, except that the sum of the interior angles of a quadrilateral is (4 - 2) 180°, or 360°.

Next, for a quadrilateral, comes another figure adjustment, based on the four overlapping triangles within the quadrilateral. To understand this figure adjustment, study the quadrilateral shown in figure 15-28. The diagonals in this quadrilateral intersect to

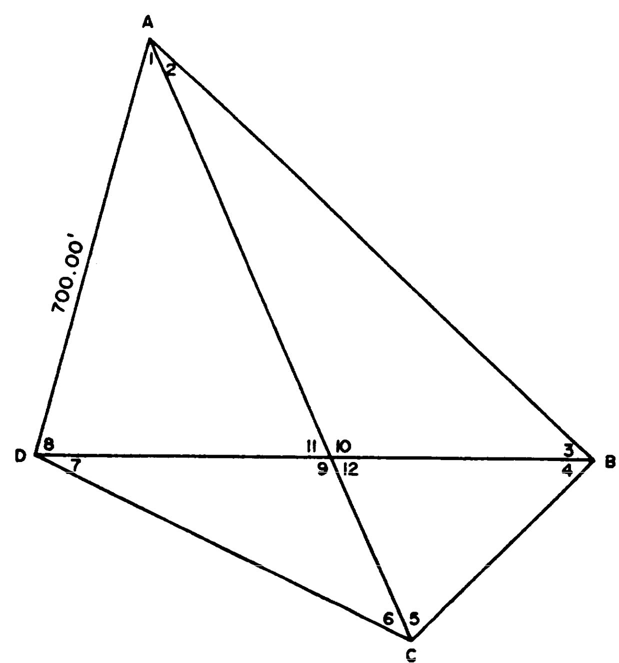


Figure 15-28.—Quadrilateral.

form vertically opposite angles 9-10 and 11-12. From your knowledge of geometry, you know that when two straight lines intersect the vertically opposite angles thus formed are equal. From the fact that the sum of the angles in any triangle is 180°, it follows that for any pair of vertically opposite angles in figure 15-28, the sums of the other two angles in each of the corresponding triangles must be equal.

For example: In figure 15-28, angles 11 and 12 are equal vertically opposite angles. Angle 11 lies in a triangle in which the other two angles are angles 1 and 8; angle 12 lies in a triangle in which the other two angles are angles 4 and 5. It follows, then, that the sum of angle 1 plus angle 8 must equal the sum of angle 5 plus angle 4. By similar reasoning, the sum of angle 2 plus angle 3 must equal the sum of angle 6 plus angle 7.

Suppose now, that the values of angles 2, 3, 6, and 7, after adjustment for the sum of interior angles, areas follows:

Angle	Value after First Figure Adjustment		
	°	′	″
2	23	44	37
3	42	19	08
Sum	66	03	45
6	39	37	47
7	26	25	50
Sum	66	03	37

The difference between the two sums is 8 seconds. This means that, to make the sums equal, 4 seconds should be subtracted from the 2-3 sum and added to the 6-7 sum. To subtract 4 seconds from the 2-3 sum, you subtract 2 seconds from each angle; to add 4 seconds to the 6-7 sum, you add 2 seconds to each angle.

The final step in quadrilateral adjustment is related to the fact that you can compute the length of a side in a quadrilateral by more than one route. The final step in adjustment is to ensure that, for a given side, you will get the same result, to the desired number of significant figures, regardless of the route your computations take.

This final adjustment is called the **log-sine** adjustment, because it uses the logarithmic sines of the angles. The method is based on the use of **side equations** to derive an equation from which the sides are eliminated and only the sines of the angles remain. This equation is derived as follows:

Suppose that in figure 15-28, *AB* is the baseline and the length of *CD* is to be computed. By the law of sines,

$$\frac{AD}{\sin 3} = \frac{AB}{\sin 8} \therefore AD = AB\frac{\sin 3}{\sin 8}$$

By the same law,

$$\frac{CD}{\sin 1} = \frac{AD}{\sin 6} \therefore CD = AD\frac{\sin 1}{\sin 6}$$

Substituting the value of *AD,* we have

$$CD = AB\frac{\sin 3 \sin 1}{\sin 8 \sin 6}$$

Again by the law of sines we have

$$\frac{CD}{\sin 4} = \frac{BC}{\sin 7} \therefore CD = BC\frac{\sin 4}{\sin 7}$$

By the same law,

$$\frac{BC}{\sin 2} = \frac{AB}{\sin 5} \therefore BC = AB\frac{\sin 2}{\sin 5}$$

Substituting this value for *BC,* we have

$$CD = AB\frac{\sin 2 \sin 4}{\sin 5 \sin 7}$$

We now have two values for *CD,* as follows:

$$CD = AB\frac{\sin 1 \sin 3}{\sin 6 \sin 8}$$

$$CD = AB\frac{\sin 2 \sin 4}{\sin 5 \sin 7}$$

It follows that

$$AB\frac{\sin 1 \sin 3}{\sin 6 \sin 8} = AB\frac{\sin 2 \sin 4}{\sin 5 \sin 7}$$

Canceling out *AB,* we have

$$\frac{\sin 1 \sin 3}{\sin 6 \sin 8} = \frac{\sin 2 \sin 4}{\sin 5 \sin 7}$$

By the law of proportions, this can be expressed as

$$\frac{\sin 1 \sin 3 \sin 5 \sin 7}{\sin 2 \sin 4 \sin 6 \sin 8} = 1$$

You know that in logarithms, instead of multiplying you just add logarithms; also, instead of dividing one number by another, you just subtract the logarithm of the second from the logarithm of the first. Note that the logarithm of 1 is 0.000000. Therefore, the above equation can be expressed as follows:

(log sin 1 + log sin 3 + log sin 5 + log sin7) - (log sin 2 + log sin 4 + log sin 6 + log sin 8) = 0

Suppose, now, that after the second figure adjustment, the values of the angles shown in figure 15-28 are as follows:

Angle	Value after 2d Figure Adjustment			Angle	Value after 2d Figure Adjustment		
	°	′	″		°	′	″
1	38	44	06	2	23	44	35
3	42	19	06	4	44	51	59
5	69	04	20	6	39	37	49
7	26	25	52	8	75	12	13

A table of logarithmic functions shows the log sines of these angles to be as follows:

Angle	Log Sine	Angle	Log Sine
1	9.796380 – 10	2	9.604912 – 10
3	9.828176 – 10	4	9.848470 – 10
5	9.970361 – 10	6	9.804706 – 10
7	9.678478 – 10	8	9.985354 – 10
Sum	9.243395 – 10	Sum	9.243442 – 10

By subtracting the two sums, you get the following:

$$\begin{array}{r} 9.243442-10 \\ -9.243395-10 \\ \hline 0.000047 \end{array}$$

Therefore, the difference in the sums of the log sines is 0.000047. Since there are eight angles, this means the average difference for each angle is 0.0000059.

The next question is how to convert this log sine difference per angle into terms of angular measurement To do this, you first determine, by reference to the table of log functions, the average difference in log sine, per second of arc, for the eight angles involved. This is determined from the D values given in the table. For each of the angles shown in figure 15-28, the D value is as follows:

Angle	D Value (″)
1	2.62
3	2.32
5	0.82
7	4.23
2	4.78
4	2.12
6	2.55
8	0.57
Sum	20.01

The average difference in log sine per 1 second of arc, then, is 20.01/8, or 2.5. The average difference in log sine is 5.9; therefore, the average adjustment for each angle is 5.9 +2.5, or about 2 seconds. The sum of the log sines of angles 2, 4, 6, and 8 isS greater than that of angles 1, 3, 5, and 7. There for, you add 2 seconds each to angles 1, 3, 5, and 7 and subtract 2 seconds each from angles 2, 4, 6, and 8.

CHECKING FOR PRECISION

Early in this chapter the fact was stated that the precision of a triangulation survey may be classified according to (1) the average triangle closure and (2) the discrepancy between the measured length of a base line and its length as computed through the system from an adjacent base line.

Average Triangle Closure

The check for average triangle closure is made after the station adjustment. Suppose that, for the quadrilateral shown in figure 15-28, the values of the

as follows:

Angle	Value after Station Adjustment		
	°	′	″
1	38	44	06
2	23	44	38
3	42	19	09
4	44	52	01
5	69	04	21
6	39	37	48
7	26	25	51
8	75	12	14

The sum of the angles that make up each of the overlapping triangles within the quadrilateral is as follows:

Triangles	Angles	°	′	″	Triangles	Angles	°	′	″
ABC	2	23	44	38	ABD	1	38	44	06
	3	42	19	09		2	23	44	36
	4	44	52	01		8	75	12	14
	5	69	04	21		3	42	19	09
Sum		180	00	09			180	00	07
ACD	1	38	44	06	DBC	7	26	25	51
	6	39	37	48		4	44	52	01
	7	26	25	51		6	39	37	48
	8	75	12	14		5	69	04	21
Sum		179	59	59			180	00	01

The sum of the closing errors for the four triangles is (09 + 01 + 07 + 01), or 18 seconds. The average triangle closure for the four triangles, then, is 18/4, or 04.5 seconds. For third-order triangulation, the maximum average triangle closure is 05 seconds; therefore, for the third-order work this closure would be acceptable.

Base Line Discrepancy

If *AD* is the base line in figure 15-28, then *BC* would be the adjacent baseline. Letés assume that the baseline *AD* measures 700.00 feet and compute the length of *BC* on the basis of the angles we have adjusted. These angles now measure as follows:

Angle	Value after Final Adjustment °	′	″	Angle	Value after Final Adjustment °	′	″
1	38	44	08	2	23	44	33
3	42	19	08	4	44	51	57
5	69	04	22	6	39	37	47
7	26	25	54	8	75	12	11

The natural sine of each of these angles is as follows:

Angle	Sine	Angle	Sine
1	0.625727	2	0.402627
3	0.673257	4	0.705448
5	0.934035	6	0.637801
7	0.445130	8	0.966837

You can compute the length of *BC* by (1) solving triangle *ABD* for *AB* and triangle *ABC* for *BC* and (2) solving triangle *ACD* for *DC* and triangle *DBC* for *BC*.

Using the law of sines and solving triangle *ABD* for side *AB*, we have

$$AB = AD\,\frac{\sin 8}{\sin 3}$$

$$= AD\,\frac{\sin 75°12'11''}{\sin 42°19'08''}$$

$$= 1{,}005.243 \text{ ft}$$

Solving triangle *ABC* for side *BC*, we have

$$BC = AB\,\frac{\sin 2}{\sin 5}$$

$$= AB\,\frac{\sin 23°44'33''}{\sin 69°04'22''}$$

$$1{,}005.243\,\frac{(0.402627)}{(0.934035)}$$

$$= 433.322 \text{ ft}$$

Solving triangle *ACD* for side *CD*, we have

$$CD = AD\,\frac{\sin 1}{\sin 6}$$

$$= AD\,\frac{\sin 38°44'08''}{\sin 39°37'47''}$$

$$700.00\,\frac{(0.625727)}{(0.637824)}$$

$$= 686.724 \text{ ft}$$

Solving triangle *DBC* for side *BC*, we have

$$BC = CD\,\frac{\sin 7}{\sin 4}$$

$$= CD\,\frac{\sin 26°25'54''}{\sin 44°51'57''}$$

$$686.724\,\frac{(0.445130)}{(0.7.5449)}$$

$$= 433.315 \text{ ft}$$

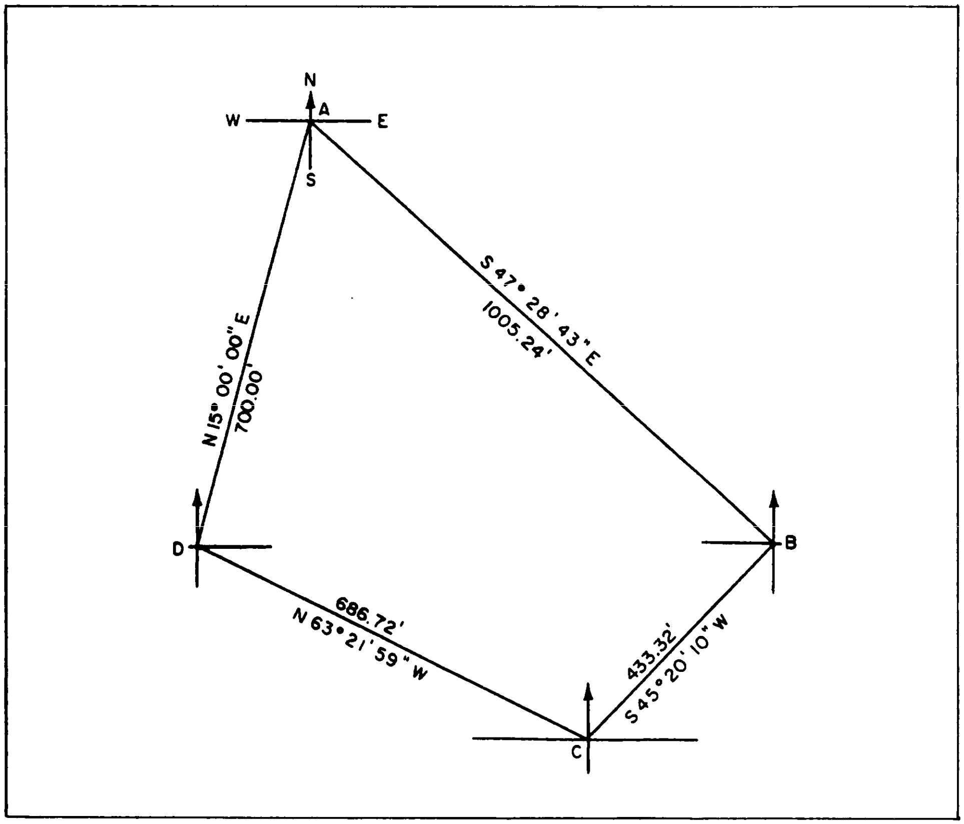


Figure 15-29.-Bearing and distances of a quadrilateral.

Thus we have, by computation of two routes, values for *BC* of 433.322 feet and 433.315 feet. There is a discrepancy here of 0.007 feet For third-order work this would usually be considered within tolerable limits; and the computed value of *BC* would be taken to be the average between the two, or (to the nearest 0.01 foot) 433.32 feet.

Suppose, now, that the precision requirements for the base line check are 1/5,000. This means that the ratio between the difference in lengths of the measured and computed base line must not exceed 1/5,000. You measure the base line *BC* and discover that it measures 433.25 feet. For a ratio of error of 1/5,000, the maximum allowable error (discrepancy between computed and measured value of base line) is 433.25/5,000, or 0.08 feet. The error here is (433.32 – 433.25), or 0.07 foot, which is within the allowable limit.

LOCATIONS OF POINTS

The end result desired in a triangulation survey is the horizontal locations of the points in the system, by bearing and distance. Methods of converting deflection angles to bearings and converting bearings to exterior or interior angles are described in the EA3 TRAMAN. The following paragraphs explain how to determine the bearings of lines of a quadrilateral.

Bearing and Distance

Figure 15-29 shows the quadrilateral we have been working on, with the computed values of the sides inscribed. Take station *D* as the starting point. Suppose that, by an appropriate method, you have determined the bearing of *DA* to be N15°00´00´´E, as shown. To have a good picture of how you proceed to compute for the bearing of the next line, *AB*, you must superimpose the meridian line through the starting point, laying off approximately the known bearing; in this case, N15°00´00´´E. Now draw your meridian through point *A*. From figure 15-29 you can see that the line *AB* bears southeast, and you can find its bearing by subtracting 15°00´00´´ from angle *A*. Angle *A* is the sum of angles 1 and 2 (38°44´08´´ + 23°44´35´´), or 62°28´43´´, as you should recall from figure 15-28. The bearing angle of *AB*, then, is 62°28´43´´ – 15°00´00´´, or 47°28´43´´. Therefore, the complete bearing of line *AB* is S47°28´43´´E.

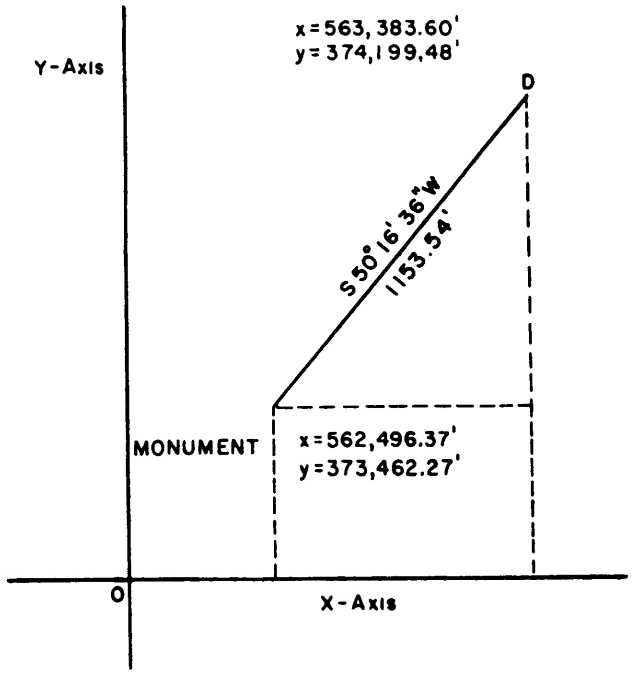


Figure 15-30.—Coordinates.

You would find the bearing of *BC* and *CD* similarly, except that you have to watch for the angle you are after. Always remember that a bearing angle does not exceed 90° and is always reckoned from north or south. To find the bearing of *BC,* you must find the sum of angle *B* (angles 3 and 4, fig. 15-28) plus the bearing angle of *AB* and then subtract it from 180°; you can see that *BC* bears southwest, so just add this designation to the proper place in the bearing angle for *BC.* In this case, the bearing of *BC* will be 180°00′00′′ – (42°19′08′′ + 44°51′59′′ + 47°28′43′′), or S45°20′10′′W. The bearing of *CD* is equal to angle *C* minus the bearing angle of *BC.*

Coordinates

Suppose that you are tying the quadrilateral shown in figure 15-29 into a state grid system. The nearest monument in this system lies 1,153.54 feet from station *D,* bearing S50°16′36′′W from *D,* as shown in figure 15-30. This means that the bearing from the monument to *D* is N50°16′36′′E. Suppose that the grid coordinates of the monument are y = 373,462.27 feet and x =562,496.37 feet.

The latitude of the line from the monument to station D is 1,153.54 cos 50°16′36′′, or 737.21 feet. The departure of the same line is 1,15354 sin 50°16′36′′, or 887.23 feet.

The y coordinate of station *D* equals the y coordinate of the monument plus the latitude of the line from the monument to *D,* or 373,462.27 + 737.21, or 374,199.48 feet. The x coordinate of station *D* equals the x coordinate of the monument plus the departure of the line from the monument to *D,* or 562,496.37 + 887.23, or 563,383.60 feet.

Knowing the coordinates of station *D,* you can now determine the coordinates of station *A.* The latitude of *DA* is 700.00 cos 15°00′00′′, or 676.15 feet. The departure of *DA* is 700.00 sin 15°00′00′′, or 181.17 feet. The y coordinate of station *A* is equal to the y coordinate of station *D* plus the latitude of *DA,* or

SET	TRANSIT AT	TRAINED AT	TEL	TIME	HORIZ. CIRC. RDG	
						Monday
1	A	B	D		0:00:20"	Jun 24, 1985
	A	B	D	0:14:25	334°30'05"	Clear, Calm
	A	B	R	0:16:15	154°42'05"	Temp 70° F
	A	B	R		180°00'15"	

UTC (WWV) = 11:52:00

DUT = +0.3 (+3 double ticks)

STOPWATCH 0:00:00

LATITUDE: 46°04'00"N

LONGITUDE: 84°10'00"W

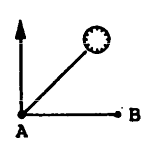


Figure 15-31.—Sun observation field notes.

374,199.48 + 676.15, or 674,875.63 feet. The x coordinate of station *A* is equal to the x coordinate of station *D* plus the departure of *DA*, or 563,383.60 + 181.17, or 563,564.77 feet. The coordinates of the other stations can be similarly determined.

QUESTIONS

Q1. Into how many time zones has the earth been divided?

Q2. What is the Greenwich mean time at longitude 35°27´20´´E if the local zone time is 0900?

Q3. Define the declination of a celestial body.

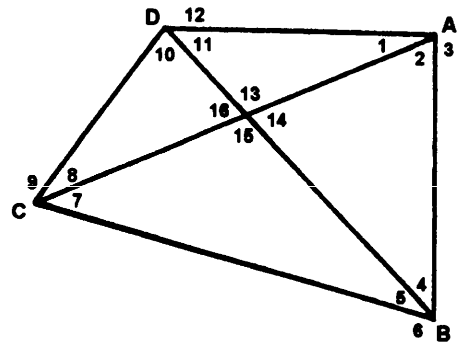
Q4. In a time diagram, where is the observer assumed to be located?

Q5. The sun is observed in the direction of the equator from the zenith of the observer's location. What is the observer's latitude if the observed declination is N15°10´ and the corrected meridian altitude is 62°07´?

Q6. Refer to figure 15-31 and use table 15-5. What is the computed bearing of the line AB?

Q7. What is the primary advantage of a chain of polygons over a chain of triangles?

Q8. What is the primary difference between a primary triangulation station and a secondary triangulation station?



ANGLE NO.	MEASURED VALUE	ANGLE NO.	MEASURED VALUE
1	30° 57' 05"	7	42° 01' 18"
2	61° 07' 50"	8	29° 14' 38"
3	267° 54' 59"	9	288° 44' 22"
4	38° 28' 37"	10	70° 21' 55"
5	38° 22' 22"	11	49° 26' 17"
6	283° 09' 10"	12	240° 11' 36"

Figure 15-32.-Quadrilateral.

Q9. After the quadrilateral shown in figure 15-32 is first figure adjusted what is the value of angle 5?

CHAPTER 16

SOILS: SURVEYING AND EXPLORATION/CLASSIFICATION/FIELD IDENTIFICATION

In this chapter you will be introduced to the topics of geological and pedological surveys and will learn about various methods used for this type of surveying. Additionally, you will further your knowledge of soils exploration and you will learn how to classify soils based on their textural and plasticity-compressibility characteristics using the Unified Soils Classification System. Finally, you will learn various field tests that are useful for expedient soil classification.

Much of the discussion in this chapter assumes that you are by now knowledgeable of the physical properties of soils and that you are experienced with laboratory testing procedures, such as mechanical analysis and Atterberg limits, that are necessary for accurate identification and classification of soils. Should it be necessary, you may find it helpful to review chapter 15 of the EA3 TRAMAN and chapter 13 in Part 1 of this TRAMAN before beginning your study of this chapter.

SURVEY SUPPORT FOR GEOLOGY AND PEDOLOGY

In this section you will be provided a brief familiarization with the topics of geological and pedological surveying and mapping. Although these topics could have been included in a separate discussion of topographic surveying, they have been included in this chapter since both are related to soil exploration and investigation.

GEOLOGICAL SURVEYS

In essence, surveys in support of geology are topographic surveys; however, you must be aware of the other specialized data that may be included as required by the geologist or the soil engineer when you are collecting data for engineering studies for naval construction projects.

The end product of most topographic surveys is a topographic map. In geology or other related sciences, the topographic survey is the first part of a series of interrelated surveys. The end product is a map containing not only topographical information but also other specialized data keyed to it. In geologic surveys, a geologist makes systematic observations of the physical characteristics, distribution, geologic age, and structure of the rocks as well as the groundwater and mineral resources that the rocks contain. These observations are expressed in finished form as geologic maps and texts. The objective of the geological survey is to portray, in plan or in cross section, geological data required for subsequent constructions or for other uses.

Pure geological data has little direct application to naval problems; however, if the field information is interpreted into specialized lines, it is of considerable use in Naval Construction Force (NCF) planning and operations. NCF requirements may necessitate regional geological study and mapping, surveys of more limited areas, or development of detailed geological data at a construction site.

Methods of Geological Surveying

Most geological data is gathered from an examination of rocks in the field. In addition, examination of drainage and relief patterns on detailed maps or aerial photographs provides considerable supplementary data on rock structures and distribution.

In the field, the geologist conducts his survey by examining the rock. He looks to see if it is exposed at the surface and not covered by soil or other material. At such exposures, called outcrops, he systematically records the physical characteristics of the rock, thickness of exposure, inclination of the rock, inclination of rock bedding, and development of joints or fractures. In addition, he determines the age of the rock from fossils or the sequence of rock units. Rock investigations are not confined to surface exposures, as the deeper seated rocks are examined by using samples obtained from auger or boreholes. The information gathered by the geologist is placed on a map base by plotting the rock types in color with other data incorporated as symbols or annotations. As an amplification of the map data, more complete descriptions of outcrops are entered in notebooks with the entries keyed to the field map. Surveyors support the geologist by preparing basic topographic maps on which they plot the results of geological investigations and then make such tie measurements to geological features as the geologist may require.

The geologist uses simple survey methods in plotting geological features on a field map. Where an outcrop can be located with reference to a cultural or relief feature, it is generally plotted on a map by spot recognition. In other cases, the relationship of a geological feature to a recognizable topographic feature is established by using a magnetic compass to determine direction and by pacing or taping to measure distance. Slope or small differences in elevation are measured by using a clinometer or hand level, while an altimeter is used where there are large differences in elevation. When the geological survey is keyed to a large-scale plan, the geologist generally uses a plane table and plots data with accuracy commensurate with the accuracy of the base plan.

Base Map Surveys

The survey for the base map should normally take place before the geological survey, because the geologist uses the map in the field to plot his data and to determine his position by identification of topographic details. If aerial photographs are available, the base map need not be made before the geological survey since the geologist can use the aerial photograph as a plotting base and later transfer the data to a base map. However, if possible, the base map should be prepared in advance, even in this case, as the number of aerial photographs needed to cover an area is generally too large to be handled in the field.

Plane table topography is the method best suited to relatively open country. In the absence of detailed instructions, the following specifications are generally satisfactory:

1. BASE DIRECTION. To determine a base direction, take from a known base a side in a triangulation net or a course of a basic control traverse.

2. LOCAL HORIZONTAL CONTROL. Use plane table traverses run in closed circuits or between known control stations of a higher order of accuracy or locate plane table stations by graphical triangulation.

3. LOCAL VERTICAL CONTROL. Where the terrain is relatively level, carry elevation along traverses by vertical angle or stadia-arc measurements, adjusting elevations on closure at a basic control station. For rugged terrain mapped at one of the larger contour intervals, barometric or trigonometric leveling is suitable.

4. SIGHTS. Use telescopic alidade.

5. DISTANCE MEASUREMENTS. Use, in general, stadid or graphical triangulation to locate points and stations. Certain measurements can be made most conveniently by pacing or rough taping.

6. CONTOURING. Locate and determine the elevations of controlling points on summits, in valleys and saddles, and at points of marked change of slope. Interpolate and sketch contours in the field, using these elevations for control.

7. ACCURACY. Distance measurements by stadia should be accurate to 1 part in 500. Side-shot points located by pacing or other rough measurements should be accurate to within 25 feet. Take sights for traverse lines or graphical triangulation with care to obtain the maximum accuracy inherent in the telescopic alidade. The error in the elevation of any point, as read from the finished map, should not exceed one half of the contour interval.

Topography may be located more conveniently in heavily timbered country by stadia measurements from transit-stadia traverse than by the use of the plane table, although the time required for plotting will be increased. The specifications listed above are generally applicable. Read horizontal angles on traverses to 1 minute and horizontal angles for side shots that will be plotted by protractor to the nearest quarter of a degree. Read vertical angles for elevation determination to 1 minute or use the stadia arc. Keep complete and carefully prepared stadia notes and sketches to assure correct plotting.

When the geologist indicates that a map of a lower order of accuracy will fulfill his needs, plane table or compass traverses are suitable.

Use of Aerial Photographs

If aerial photographs are available, the geologist generally uses them instead of a map. The most satisfactory results are obtained from large-scale photographs, 1:15,000 or larger. Some topographic features, such as some ravines, rocky knobs, or sinkholes, are too small to be shown on maps. These features, as well as the larger topographic fares, such as stream channels and swamps, can be observed directly from aerial photographs. The photos also can be used to prepare a base map for portrayal of the field data by tracing planimetric details from an uncontrolled mosaic with spot elevations added from field surveys. The geologist may satisfactorily use contact prints of aerial photographs in place of the base map except where large-scale plans for engineering purposes are to be the base. In such a case the distortion within an aerial photograph does not permit plotting of geological data commensurate with the accuracy of the final plan.

Map Base for Detailed Geological Surveys

Detailed geological surveys generally cover a specific map area geographic region, or specified site from scales of 1:62,500 to 1:600 or larger. In general, the very large scales are used for specific engineering or mineral development problems.

SITE PLANS AND PROPILES.— Geological data affecting foundation designs at construction sites are plotted on plans drawn to scales of 1 inch = 50, 100, 200, or 400 feet. Contour intervals may range from 1 to 10 feet, depending upon the roughness of the terrain Plane table mapping is suited to plotting the topographic features, ranges, and reference points used to locate drill holes, rock outcrops, and other geologic data. When plotting contours on a 1- or 2-foot interval, you should try to locate points that are actually on the contours or to determine elevations at the intersection of closely spaced grid lines staked out on the site. In addition to a plan, the geologist may require that profiles be drawn along selected lines or that the boring logs of test holes be plotted to suitable scales.

USING A TOPOGRAPHIC MAP AS A BASE MAP.— The base map for a detailed geological survey is a complete topographic map or plan with relief expressed by contours. Simple colors and symbolization of basic details are used so that they will not conflict with the overlay of geological information that is shown by colors and symbols. Published topographic maps are used where suitable. The geological survey is expedited if the map base is from a quarter to double the scale of the map on which the information is to be presented. Enlargements of the base map, rather than other maps of a larger scale, are generally used to satisfy these requirements. This permits the direct reduction of geological data to the scale of the final map with a minimum amount of drafting.

When no topographic map is available or if the existing maps are not suitable, a base map or plan must be prepared from detailed topographic surveys. Culture and relief (contours) should be shown in the greatest detail possible. The survey for the base should conform to third-order accuracy where large geographic areas are concerned. Maps made from aerial photographs by precise instrument methods can be used in place of field surveys. Altitude or elevation of the intersection of boreholes and the surface should be accurate to the nearest one-half foot.

PEDOLOGICAL SURVEYS

Sometimes there is a requirement for pedological mapping for the purpose of locating the limits of sand or gravel deposits suitable for concrete aggregates, road materials, or for other construction operations. In such a case, the pedological survey conducted under the direction of the soils engineer and the surveyor's mission would be one of support to the soils engineer's objective.

The engineer's objective in a pedological survey is to prepare data in plan and profile symbolizing soils and outcropping on maps, overlays, and sketches for subsequent engineering uses. The following approaches may be used in conjunction with a soils survey operation:

1. Aerial photography may be used when an extensive area is to be surveyed. Usually no survey measurements are required in this case.

2. Maps of an area that extend several square miles are required when an initial study or technical reconnaissance is needed for an engineering project. Low-order survey measurements usually suffice for the preparation of a reconnaissance sketch upon which the soils engineer can plot the pertinent data.

3. A sketch of an airfield, for example, is frequently required by the soils analyst before construction planning can be initiated. In this case, the surveyor applies low-order measurements to prepare a sketch (1 inch = 100, 200, or 400 feet) upon which the soils engineer plots the results of soil tests and findings.

Aerial Photography

Photo coverage of the area under consideration aids in the establishment of control for the pedological survey. The use of vertical aerial photographs in the planning phase of outlining ground control will speed the survey regardless of the size of the area to be covered If controlled photographs are available, the survey engineer can locate points by pricking or keying them to the photographs. An uncontrolled photograph may be satisfactory for the surveys of low-order accuracy mentioned in the preceding paragraph. According to the soils analyst's instructions, the survey party chief prepares maps or overlays upon which he plots the control and ties them to the pedological features. The pedological interpretation of aerial photographs is the responsibility of the terrain analysts.

Plane Table Traverse

The plane table traverse is best adapted to relatively open country for the preparation of the basic sketch upon which the soils engineer plots pertinent data. In the absence of detailed instructions from the soils engineer, the following procedures are generally satisfactory for preparing a sketch of an area of several square miles (3 miles by 3 miles maximum for initial exploration):

1. SCALE: 1:12,500 or 1:25,000.

2. TRAVERSE CONTROL. Run in circuits or between known positions of a higher order of accuracy.

3. SIGHTING. Use a peep sight or telescopic alidade.

4. DISTANCE MEASUREMENTS. Pace or obtain a rough measurement with tape. When a telescopic alidade is available, use stadia measurements where possible (to reduce the time required for the survey, rather than to increase the accuracy).

5. BASE DIRECTION. To determine a base direction, select known bases: railroad or highway tangents, recognizable features, or reliable topographic maps. In the absence of these known bases, use magnetic north as determined by compass observations.

6. COMPASS. Use military compass, forestry compass, or pocket transit.

7. DISTANCE BETWEEN BASIC CONTROL POINTS. Maintain 3 miles as the extreme maximum distance between stations.

8. ACCURACY. Distances should be measured in such a manner that points can be plotted within 25 feet. For the scales suggested, measurements to 1 part in 100 will suffice. Take sights with peep-sight alidade carefully to maintain directions of an accuracy comparable to distances.

9. TOPOGRAPHY. Topography is usually not required on reconnaissance surveys for pedology, particularly in areas of low relief. Where suitable deposits of sand, gravel, or stone have been located route surveys from the site to the point of use may be required for the location of haulage roads, conveyors, or other means of transporting the material. In hilly terrain, a rough topographic map, obtained by clinometer, pocket transit, or stadia, may be required to make the location of a favorable route easier.

Compass Traverse

In heavily wooded areas, compass traversing is more convenient than plane table traversing; however, more time is required for plotting by the compass traverse method. Traverse lines between stations should be long to reduce the number of observed bearings. Points between stations are located by offsets from the traverse lines. Where local attraction affects compass readings, points are plotted by intersection. Survey readings may be plotted in the field. Notes should be kept in case the traverse must be retraced. In the absence of detailed instructions from the soils engineer, the basic guides for plane table traverse apply.

Field Sheets and Site Plans

The survey engineer must furnish the soils analyst with suitable maps, overlays, and sketches for the plotting of pedological data. After the preparation of a reconnaissance field sheet of an area of several square miles, the soils analyst may require a sketch of a particular site in which many samples are taken for a more detailed study. In the absence of detailed instructions, the surveyor prepares a sketch on a scale of 1 inch = 400 feet and provides ranges and reference points to aid in plotting or tieing in specific positions of auger holes, drill holes, and lines of exposed rock or other pedological features. For plotting the data of a range, cross section, or series of boreholes, the soils analyst may require the surveyor to provide a basic plot on a scale of 1 inch = 100 feet or of 1 inch = 200 feet. Survey measurements will be conducted accordingly.

SOIL SURVEYS

The survey of soil conditions at the site of proposed military construction provides information about the nature, extent, and condition of soil layers; the position of the water table; drainage characteristics; and sources of possible construction materials. The survey of soil conditions is vital to both the planning and execution of military construction operations.

OBJECTIVES OF A SOIL SURVEY

The overall objective of a soil survey is to gather (explore) as much information of engineering significance as possible pertaining to the subsurface conditions in a specified area. Soil samples are collected for laboratory tests to determine if the existing soil conditions could support the type of structure planned for construction without adding other material for stabilization. The exploration is conducted in a specific manner to determine the following information:

1. Location, nature, and classification of soil layers
2. Condition of soils in place (density and moisture content)
3. Drainage characteristics
4. Groundwater and bedrock
5. Development of a soil profile.

Location, Nature and Classification of Soil Layers

Adequate and economic earthwork and foundation design of a structure can be done only when the types and depths of soil are known. By the classification of the soils (discussed later in this chapter), you can predict the extent of problems concerning drainage, frost action, settlement, stability, and similar factors. While you can estimate the soil characteristics by field observations, for laboratory testing, you should obtain samples of the major soil types as well as less extensive deposits that may conversely influence design.

Condition of Natural Soils

The moisture content and density of a soil in its natural state plays an important part in design and construction. The moisture content of a soil in place may be so high as to require the selection of a different site. If the natural soil is sufficiently dense and meets the required specifications, no compaction of subgrade is required. On the other hand, extremely dense soil lying in cut sections maybe difficult to excavate with ordinary tractor-scraper units. Such dense soil often needs to be scarified or rooted before excavation.

Drainage Characteristics

Drainage characteristics, both surface and subsurface, of a soil greatly affect the strength of the soil. This characteristic is controlled by a combination of factors. Some of these factors are void ratio, soil structure and stratification, temperature of soil, depth to water table, and the extent of local disturbance by roots and worms. Coarse-grained soils have better internal drainage than fine-grained soils.

Groundwater and Bedrock

All structures must be constructed at an elevation that ensures they will not be adversely affected by the groundwater table. If a proposed grade line lies below the elevation of the water table, either the grade line must be raised or the water table must be lowered by artificial drainage.

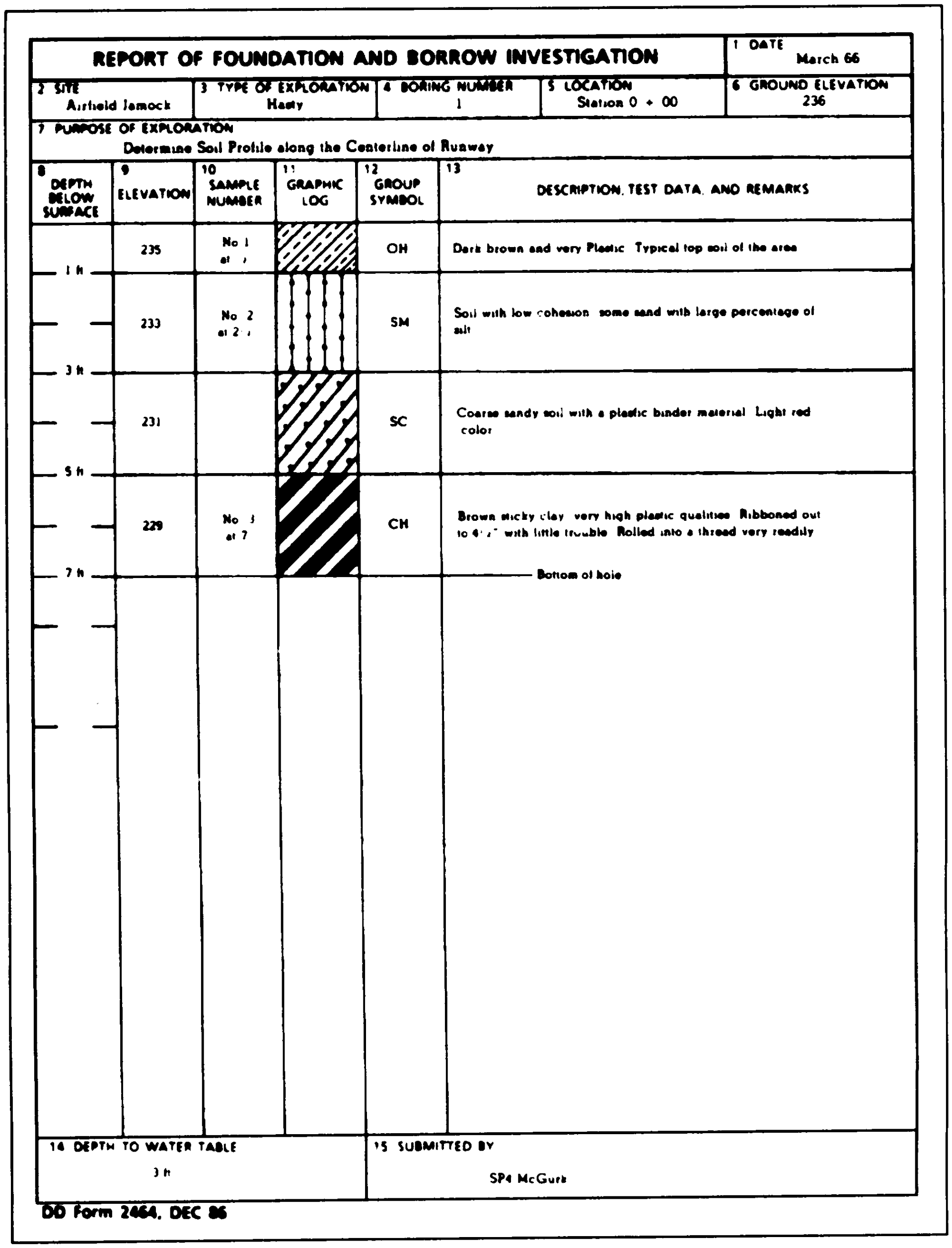
The unexpected discovery of bedrock within the limits of an excavation greatly increases the time and equipment required to excavate. If the amount of rock is extensive, a change in grade or even a change of site may be the only way out.

Field Notes and Soil Profile

The engineer or EA in charge of the soil survey must keep accurate field notes and logs. This person is responsible for surveying, numbering, and recording each boring, test pit, or other exploration investigation.

A log is kept of each test hole. It should show the depth below the surface (or the top and bottom elevations) of each soil layer, the field identification of each soil present at the site, and the number and type of each sample taken. Other items of information you need to include in the log are the density of each soil, changes in moisture content, depth to groundwater, and depth to rock. Keep a detailed field log of each auger boring or test pit made during the soil survey. A typical boring log is shown in figure 16-1.

When you complete the survey, consolidate the information contained in the separate logs. Classify and show the depth of soil layers in each log. It is also helpful for the log keeper to show the natural water contents of fine-grained soils, when possible. Record this along the side of each log. Note the elevation of the groundwater table. This elevation is simply that of any free water standing in the test hole. To permit the water to reach maximum elevation, the engineer or EA should allow 24 hours to elapse before measuring it. This gives a more accurate measurement.



REPORT OF FOUNDATION AND BORROW INVESTIGATION

1 DATE	2 SITE	3 TYPE OF EXPLORATION	4 BORING NUMBER	5 LOCATION	6 GROUND ELEVATION
March 66	Airfield Jamock	Hasty	1	Station 0 + 00	236

7 PURPOSE OF EXPLORATION: Determine Soil Profile along the Centerline of Runway

8 DEPTH BELOW SURFACE	9 ELEVATION	10 SAMPLE NUMBER	11 GRAPHIC LOG	12 GROUP SYMBOL	13 DESCRIPTION, TEST DATA, AND REMARKS
1 ft	235	No 1 at [illegible]		OH	Dark brown and very Plastic Typical top soil of the area
3 ft	233	No 2 at 2 [illegible]		SM	Soil with low cohesion some sand with large percentage of silt
5 ft	231			SC	Coarse sandy soil with a plastic binder material Light red color
7 ft	229	No 3 at 7		CH	Brown sticky clay very high plastic qualities Ribboned out to 4 [illegible] with little trouble Rolled into a thread very readily
					Bottom of hole

14 DEPTH TO WATER TABLE	15 SUBMITTED BY
3 ft	SP4 McGurk

DD Form 2464, DEC 86

Figure 16-1.—Typical boring log.

The **soil profile** (fig. 16-2) is a graphical representation of a vertical cross section from the surface downward through the soil layers. It shows the location of test holes and of any ledge rock encountered, a profile of the natural ground to scale, field identification of each soil type, thickness of each soil stratum, profile of the water table, and profile of the finished grade line. Standard soil symbols should be used to indicate the various soil layers. The standard procedure is to add the proper color symbols representing the various soil types you discover.

The soil profile has many practical uses in the location, design, and construction of roads, airfields, dams, and buildings. It greatly influences the location of the finished grade line; these should, of course, be located so as to take full advantage of the best soils available at the site. The profile also shows whether soils to be excavated in the course of construction are suitable for use in embankments or whether you require borrow soils instead. It may show the existence of undesirable soils, such as peat or other highly organic soils; it may also show the existence of bedrock too close to the surface. It aids in planning drainage facilities since these

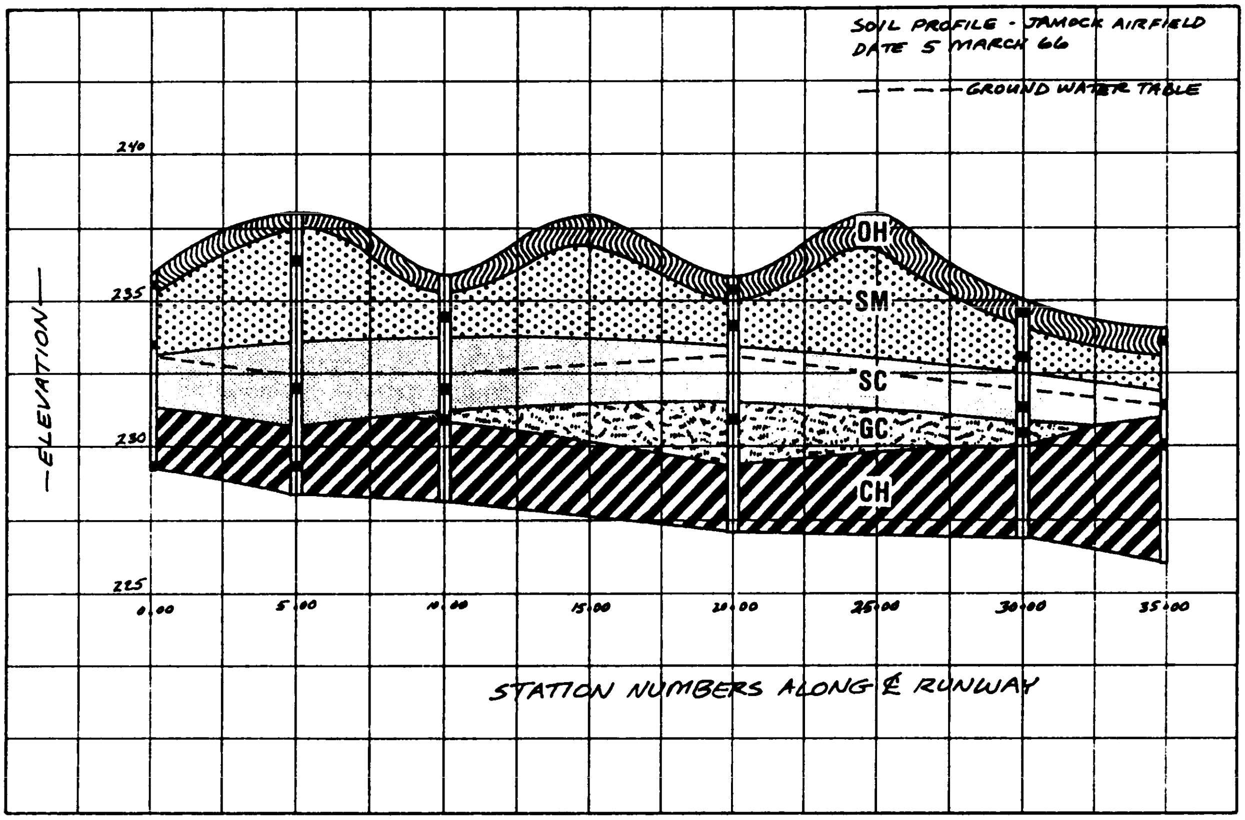


Figure 16-2.—Typical soil profile.

are planned to take advantage of well-draining soils. Considerations relating to frost action become more important when frost-susceptible soils are shown on the profile.

SOURCES OF INFORMATION

Various sources of information are available. Published information and previous soil analyses are sources you may secure without field exploration. Time sources are used mostly to locate, within a large general area, small areas that you may want to investigate further. For final site selection, actual field investigations must be made. Published information sources include engineer intelligence reports, geologic and topographic maps and reports, agricultural soil maps and reports, and air photographs.

Intelligence reports that include maps and studies of soil conditions are usually available for areas in which military operations have been planned. Among the most comprehensive of these are the Terrain Intelligence Folios prepared by the Intelligence Branch of the U.S Army Corps of Engineers, in cooperation with the U.S. Geological Survey.

Geologic maps and brief descriptions of regions or quadrangles are published in the folios of the U.S. Geological Survey. Generally, the smallest rock unit mapped is a formation; geologic maps indicate the extent of formations by means of letter symbols, color, or symbolic patterns. Letter symbols on the map indicate the location of sand and gravel pits; sometimes the back of the map sheet has a brief discussion entitled “Mineral Resources,” that describes the location of construction materials.

Ordinary **topographic maps** may be of some use in estimating soil conditions and can be used in conjunction with geologic maps. Inspection of the drainage pattern (as indicated by contour lines) can provide clues as to the nature of rocks, depth of weathering, soil, and drainage.

Agricultural soils maps and reports are available for many of the developed agricultural areas of the world. These studies are usually concerned primarily with surface soils to a depth of about 6 feet. Information given includes topography, drainage, vegetation, temperature, rainfall, water sources, and rock location. Soils are usually classified according to texture, color, structure, chemical and physical composition, and morphology (topographic features produced by erosion).

The use of **aerial photographs** to show and identify soils is based upon your ability to recognize typical patterns formed under similar conditions. An example might be soil profile and weathering. Principal elements that can be identified on a photograph and that provide a trained observer with clues to the identification of soils are landform, slopes, drainage patterns, erosional characteristics, soil color or “tone,” vegetation, and land use.

The form or cofiguration of the land in different types of deposits is definitely characteristic and can be identified on aerial photographs; for example, in desert areas, characteristic dune shapes indicate areas covered by sand subject to movement by wind.

Prevailing ground slopes are clues as to the texture of the soil. Steep slopes are characteristic of granular materials, while relatively flat and smoothly rounded slopes may indicate more plastic soils.

The absence of surface drainage or a very simple drainage pattern often indicates pervious soil. A highly integrated drainage pattern often indicates impervious soils that are plastic and usually lose strength when wet. Drainage patterns tend to reflect underlying rock structure.

The pattern of erosion often provides clues as to the character of the soil. For instance, the cross section or shape of a gully is controlled mainly by the cohesiveness of the soil. Each abrupt change in grade, direction, or cross section indicates a change in the soil profile or rock layers. Short, V-shaped gullies with steep gradients are typical of noncohesive soils; U-shaped gullies with steep gradients indicate deep, uniform silt deposits. Cohesive soils generally develop round, saucer-shaped gullies.

The color of soil is shown on aerial photographs by shades of gray; they range from almost white to almost black. Soft, light colors or tones generally indicate pervious, well-drained soils. Large, flat areas of sand are frequently indicated by uniform, light gray color tones, a flat appearance, and a lack of conformity; this indicates a natural surface drainage. Clays and organic soils frequently appear as dark gray to black areas. In general, a sharp change in color tones represents a change in soil texture.

The character of the vegetation may reflect the surface soil type; however, its significance is often difficult to interpret because of the effects of climate and other factors. To those with local experience, both cultivated and natural vegetation cover are good indicators of soil type.

Knowing the use to which agricultural land is put is often helpful in soil identification. For example, orchards require well-draining soils; therefore, the presence of an orchard implies a sandy soil.

FIELD OBSERVATIONS

Through the use of the various types of published information and aerial photographs, the exploration of a general area maybe narrowed down to several smaller areas suitable for further investigation. The extent and method of collecting more detailed information by field observations depends on the time available.

Rapid ground observation along the proposed highway or airfield location may yield valuable information when conditions do not permit you to make a complete or deliberate soil survey. Observe the soil profile along the natural banks of streams, eroded areas, bomb craters, road cuts, or other places where you see stratified areas. Such observations may indicate types of soil and depths of layers. Scrape off loose surface soils before you examine and make field identification. Samples may be taken from exposed soils for testing in a field laboratory; however, sampling and testing are normally at a minimum in this type of soil survey. Surface soils may be exposed by the use of pick and shovel, particularly in areas of questionable soils or at critical points in the location. Soils identified in the hasty survey may be located by field sketches or on available maps or photographs.

METHODS FOR COLLECTING SAMPLES

A deliberate investigation is made when time and equipment are available and when a more thorough investigation of the subsoil is needed than can be obtained by hasty field observations. The two most commonly used methods of obtaining soil samples for deliberate investigations are **test pits** and **test holes.**

A **test pit** is an open excavation that is large enough for a man to enter and study the soil in its undisturbed condition. This method provides the most satisfactory means for observing the natural condition of the soil and the collection of undisturbed samples. The test pit is usually dug by hand; however, power excavation by dragline, clamshell, bulldozer, backhoe, or a large 24-inch (diameter) power-driven earth auger can expedite the digging-if the equipment is available. Excavations below the groundwater table require the use of pneumatic caissons or the lowering of the water table. Load-bearing tests can also be performed on the soil in the bottom of the pit.

The use of the hand auger is the most common method of digging **test holes.** It is best suited to cohesive soils; however, it can be used on cohesionless soils above the water table, provided the diameter of the individual aggregate particles is smaller than the bit clearance of the auger. By adding a pipe extension, you may use the earth auger to a depth of about 30 feet in relatively soft soils. The sample is completely disturbed but is satisfactory for determining the soil profile, classification, moisture content, compaction capabilities, and similar properties. Auger borings are principally used for work at shallow depths.

Wash boring is probably the most common method used commercially to make deep test holes in all soil deposits except rock or other large obstructions. The test hole is made by a chopping bit fastened to a wash pipe inside a 2-, 4-, or 6-inch (diameter) steel casing. The wash pipe is churned up and down, while the bit, from which water flows under pressure, loosens the soil. The water then carries the soil particles to the surface where they collect inside the casing. An experienced operator can detect from the appearance of the wash water when a change in the type of soil being penetrated has occurred. Wash samples are samples taken directly from the wastewater. They are so disturbed, however, that their value is limited. This method of sampling should not be used if any other means is available.

Dry-sample boring makes use of the wash boring method to sink the hole. When a change of soil type occurs or sometimes at specified depth intervals, the washing is stopped and the bit is replaced by a **sampler.** The sampler (an open-end pipe) is driven into the relatively disturbed soil in the bottom of the hole to extract a sample. The sample is removed and preserved in a sample bottle until tested in the laboratory.

The **undisturbed sampling** process is used to obtain samples with negligible disturbance and deformation for testing for shear strength, compressibility, and permeability. These samples can best be obtained from relatively cohesive soils. Methods that you can use to obtain undisturbed samples are discussed in the EA3 TRAMAN.

The **core boring** process is used to obtain samples from boulders, sound rock frozen ground, and highly resistant soils. The cutting element may consist of diamonds, chilled shot, or steel-tooth cutters. The drill cuts an angular ring in the rock leaving a central core which enters the **core barrel** of the drill and is retained by a holding device when the drill is removed from the hole. This is the best method for determining the characteristic and condition of subsurface rock

PLANNING FIELD EXPLORATIONS

The location of test holes or test pits depends upon the particular situation. Soil tests should be made on samples that are representative of the major soil types in the area. In view of this, the first step in exploration is to develop a general picture of the subgrade conditions to assist in determining the representative soils. Field reconnaissance should be made to study landforms and soil conditions in ditches and cuts. Techniques have been developed whereby aerial photographs can be used for delineating areas of similar soil conditions. Full use should be made of all existing data.

Subgrade Areas

To determine subgrade conditions in an area to be used for road or for airport runway, taxiway, and apron construction, the next step after field reconnaissance is usually to make preliminary borings at strategic points. An arbitrary spacing of these borings at uniform intervals does not give a true picture and is not recommended. Intelligent use of various procedures permit strategic spacing of the preliminary borings to obtain maximum information with a minimum number of borings.

Obtain soil samples for classification purposes in these preliminary borings. After these samples are classified, develop soil profiles. Representative soils should then be selected for detailed testing. Test pits or larger diameter borings should then be made to obtain the samples needed for testing or to permit in-place tests to be made. The types and number of samples required depend on the characteristics of the subgrade soils. Subsoil investigations in areas of proposed pavement must include measurements of in-place water content, density, and strength to determine the depth to which compaction must extend and to ascertain whether soft layers exist in the subsoil.

Borrow Areas

When material is to be borrowed from adjacent areas, make borings carried 2 to 4 feet below the anticipated depth of borrow in these areas. Classify and test samples for water content, density, and strength.

Explore areas within a reasonable haul from the site for possible sources of select material suitable for use as a subbase. Exploration procedures are similar to those described for subgrades. You need test pits or large auger borings drilled with power augers for gravelly materials.

RECOMMENDED PROCEDURES FOR SOIL SURVEYS

The following guide and step-by-step procedures will help the military engineer when conducting soil surveys:

- considerations include soil types, securing of samples, density and moisture content of soil in place, drainage characteristics, and depth to groundwater and bedrock.

- Published information includes geological and topographic reports with maps and agricultural soil bulletins with maps. These require careful interpretation and knowledge of local terms. Aerial photographs used to predict subsurface conditions and previous explorations for nearby construction projects are also useful.

- Field information requires general observation of road cuts, stream banks, eroded slopes, earth cellars, mine shafts, and existing pits and quarries. Test holes may be made with a hand auger or a power auger, if necessary and available. Test pits are necessary where a hand auger cannot penetrate or where large samples are required.

- Local inhabitants, preferably trained observers such as contractors, engineers, and quarry workers, can provide valuable information.

Preparation

Planning of the general layout will determine the extent of the various soil types, vertically and laterally, within the zone where earthwork may occur. Large cuts and fills are the most important areas for detailed exploration.

- Airfield exploration. Place borings at high and low spots, wherever a soil change is expected and in transitions from cut to fall. There is no maximum or minimum spacing requirement between holes; however, the number of holes must be sufficient to give a complete and continuous picture of the soil layers throughout the area of interest. As a general rule, the number of exploration borings required on a flat terrain with uniform soil conditions will be less than in a terrain where the soil conditions change frequently.

Exploration borings should be conducted at the point of interest and located in a manner to get the maximum value for each boring. This may require exploration boring in the centerline as well as edges of runways or roads, but no specific pattern should be employed except as perhaps a staggered or offset pattern to permit the greatest coverage. It is accepted policy to conduct the exploration borings at the edge of existing pavements, unless these pavements have failed completely. In this case, the reason for the failure should be found.

- Depth exploration. Take a cut section 4 feet below subgrade, if possible, and a fill section 4 feet below original ground level, if possible. Effort should be made to locate the groundwater table.

Procedures

- Log the exploration holes or pits.
- Locate and number the samples.
- Determine the elevation and exact location of each hole and tie into the site layout.

Technical Soils Report

A good program for soils testing not only requires that careful and complete tests be performed but also that the tests be completed as quickly as possible and that the data be clearly and accurately presented in a technical soils report. The organization and presentation of the soils report is highly important. The report must be well-organized and must be presented in a logical and concise format with emphasis on technical conclusions. For further discussion and a suggested outline for a soils report, you should refer to *Materials Testing,* NAVFAC MO-330.

SOIL CLASSIFICATION

The principal objective of soil classification is the prediction of engineering properties and behavior of a soil based on a few simple laboratory or field tests. The results of these tests are then used to identify the soil and put it into a group of soils that have similar engineering characteristics. Although there are several different methods of soil classification, the method adopted for use by the military is the **Unified Soil Classification System** (USCS).

Soils seldom exist in nature separately as sand, gravel, or any other single component. Soils usually form mixtures with varying proportions of different size particles. Each component contributes to the characteristics of the mixture. The USCS is based on the textural or plasticity-compressibility characteristics that indicate how a soil will behave as a construction material.

In the USCS, all soils are divided into three major divisions: (1) coarse grained, (2) fine grained, and (3) highly organic. As you know from your previous studies, coarse-grained and fine-grained soils are distinguished by the amount of material that is either retained on or that passes a No. 200 sieve. If 50 percent or more of the soil by weight is retained on a No. 200 sieve, then the soil is coarse-grained. It is fine-grained if more than 50 percent passes the No. 200 sieve. Highly organic soils can generally be identified by visual examination. The major divisions are further subdivided into soil groups. The USCS uses 15 groups and each group is distinguished by a descriptive name and letter symbol, as shown in table AV-1 of appendix V. The letter symbols are derived either from the terms descriptive of the soil fractions, the relative value of the liquid limit (high or low), or the relative gradation of the soil (well graded or poorly graded). The letters that are used in combination to form the 15 soil groups areas follows:

SOIL TYPE	GRADATION	LIQUID LIMIT (LL)
Gravel—G Sand—S Silt—M Clay—C Organic—O Peat—Pt	Well graded—W Poorly graded—P	LL over 50—H LL under 50—L

COARSE-GRAINED SOILS

Coarse-grained soils are divided into two major divisions: gravels and sands. If more than half of the coarse fraction by weight is retained on a No. 4 sieve, the soil is a gravel. It is classed as a sand if more than half of the coarse fraction is smaller than a No. 4 sieve. In general practice there is no clear-cut boundary between gravelly and sandy soils, and as far as behavior is concerned, the exact point of division is relatively unimportant. Where a mixture occurs, the primary name is the predominant fraction and the minor fraction is used as an adjective. For example, a sandy gravel is a mixture containing more gravel than sand by weight.

For the purpose of systematizing the discussion, it is desirable to further divide coarse-grained soils into three groups on the basis of the amount of fines (materials passing a No. 200 sieve) they contain.

GW, GP, SW, and SP Groups

Coarse-grained soils with less than 5-percent nonplastic fines may fall into the groups GW, GP, SW, or SP. The shape of the grain size distribution curve determines the second letter of the symbol.

GW AND SW GROUPS.— The GW groups contain well-graded gravels and gravel-sand mixtures that contain little or no nonplastic fines. The presence of the fines must not noticeably change the strength characteristics of the coarse-grained fraction or interfere with its free-draining characteristics. The SW groups contain well-graded sands and gravelly sands with little or no plastic fines.

GP AND SP GROUPS.— The GP group includes poorly graded gravels and gravel-sand mixtures containing little or no nonplastic fines. The SP group contains poorly graded sands and gravelly sands with little or no nonplastic fines. These soils will not meet the gradation requirements established for the GW and SW groups.

GM, GC, SM, and SC Groups

Coarse-grained soils containing more than 12-percent fines may fall into the groups designated GM, GC, SM, and SC. The use of the symbols M and C is based upon the plasticity characteristics of the material passing the No. 40 sieve. The liquid limit and

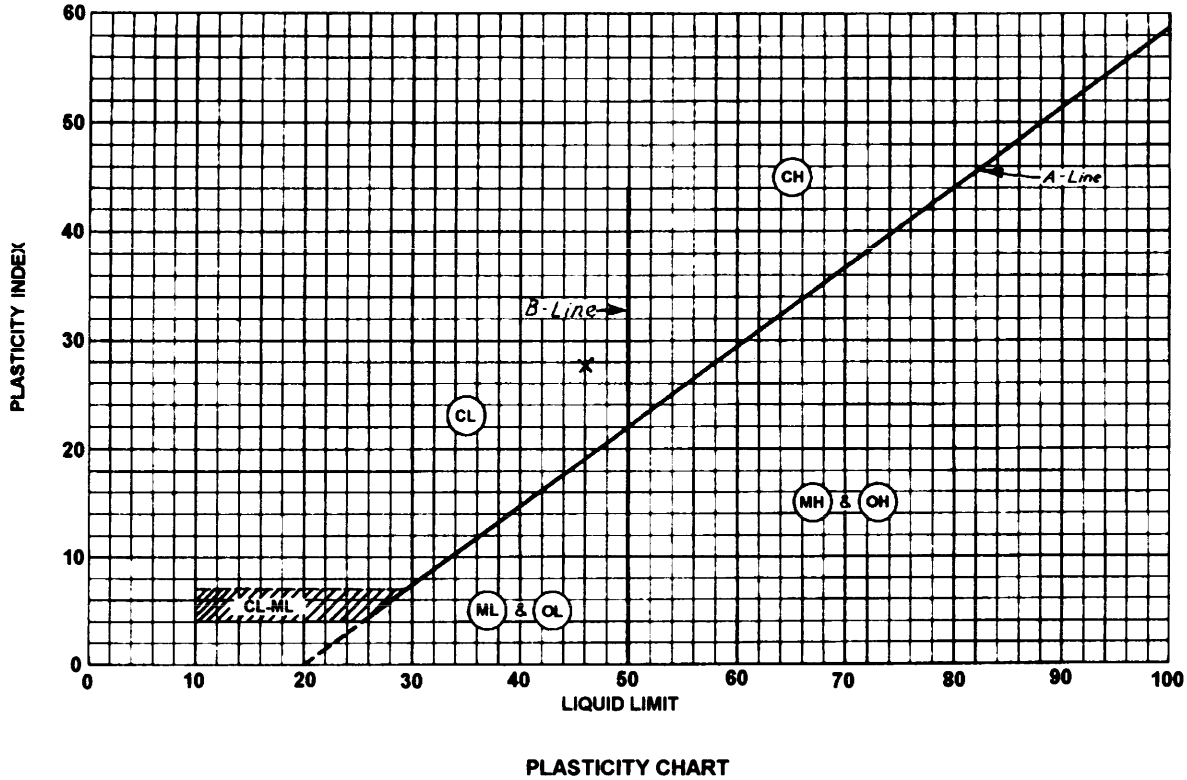


Figure 16-3.-Plasticity chart.

plasticity index are used in specifying the laboratory criteria for these groups. Reference also is made to the plasticity chart shown in figure 16-3 that is based upon established relationships between the liquid limit and plasticity index for many different fine-grained soils. The symbol M is used to indicate that the material passing the No. 40 sieve is silty in character. An M usually designates a fine-grained soil of little or no plasticity. The symbol C is used to indicate that the binder soil is predominately clayey in character.

GM AND SM GROUPS.— Typical of the soils included in the GM group are silty gravels and gravel-sand-silt mixtures. Similarly, the SM group contains silty sands and sand-silt mixtures. For both of these groups, the Atterberg limits must plot below the A-line of the plasticity chart (fig. 16-3). The plasticity index must be less than 4.

GC AND SC GROUPS.— The GC group includes clayey gravels and gravel-sand-clay mixtures. Similarly, SC includes clayey sands and sand-clay mixtures. For both of these groups, the Atterberg limits must plot above the A-line with a plasticity index for more than 7.

Borderline Soils

Coarse-grained soils that contain between 5 and 12 percent of material passing the No. 200 sieve are classed as border line and are given a dual symbol, such as GW-GM. Similarly, coarse-grained soils that contain more than 12 percent of material passing the No. 200 sieve, and for which the limits plot in the shaded portion of the plasticity chart (fig. 16-3), are classed as border line and require dual symbols, such as SM-SC. It is possible in rare instances for a soil to fall into more than one borderline zone. In this case, if appropriate symbols were used for each possible classification, the result would be a multiple designation consisting of three or more symbols. This approach is unnecessarily complicated. It is considered best to use only a double symbol in these cases. You should select the two that you believe to be most representative of the probable behavior of the soil. In cases of doubt, the symbols representing the poorer of the possible groupings should be used. For example, a well-graded sandy soil with 8 percent passing the No. 200 sieve, an LL of 28 and a PI of 9 would be designated as SW-SC. If the Atterberg limits of this soil are such as to plot in the shaded portion of the plasticity chart (for example, LL 20 and PI 5), the soil is designated either SW-SC or SW-SM; it depends on the judgment of the engineer from the standpoint of the climatic region in which the soil is located.

FINE-GRAINED SOILS

The fine-grained soils are not classified on the basis of grain size distribution, but according to plasticity and compressibility. Laboratory classification criteria are based on the relationship between the liquid limit and plasticity index as designated in the plasticity chart in figure 16-3. This chart was established by the determination of limits for many soils, together with an analysis of the effect of limits upon physical characteristics.

Examination of the chart shows that there are two major groupings of fine-grained soils. Thase are the L groups, which have liquid limits less than 50, and the H groups, which have liquid limits equal to and greater than 50. The symbols L and H have general meanings of low and high compressibility, respectively. Fine-grained soils are further divided with relation to their position above or below the A-line of the plasticity chart.

ML and MH Groups

Typical soils of the ML and MH groups are inorganic silts. Those of low compressibility are in the ML group. Others are in the MH group. All of these soils plot below the A-line of the plasticity chart. The ML group includes very fine sands, rock flours (rock dust), and silty or clayey fine sand or clayey silts with low plasticity. Loess type soils usually fall into this group. Diatomaceous and micaceous soils usually fall into the MH group but may fall into the ML group when the liquid limit is less than 50. Plastic silts fall into the MH group.

CL and CH Groups

In these groups, the symbol C stands for clay, with L and H denoting low or high liquid limits. These soils plot above the A-line and are principally inorganic clays. In the CL group are included gravelly clays, sandy clays, silty clays, and lean clays. In the CH group are inorganic clays of high plasticity.

OL and OH Groups

The soils in these two groups are characterized by the presence of organic matter; hence the symbol O. All of these soils generally plot below the A-line. Organic silts and organic silt-clays of high plasticity fall into the OL group, while organic clays of high plasticity plot in the OH zone of the plasticity chart. Many of the organic silts, silt-clays, and clays deposited by the rivers along the lower reaches of the Atlantic seaboard have liquid limits above 40 and plot below the A-line. Peaty soils may have liquid limits of several hundred percent and plot well below the A-line because of their high percentage of decomposed vegetational matter. A liquid limit test, however, is not a true indicator in cases in which a considerable portion consists of other than soil matter.

Borderline Soils

Fine-grained soils that have limits that plot in the shaded portion of the plasticity chart are borderline cases and are given dual symbols, such as CL-ML. Several soil types that exhibit low plasticity plot in this general region on the chart where no definite boundary between silty and clayey soils exists.

HIGHLY ORGANIC SOILS

A special classification (Pt) is reserved for the highly organic soils, such as peat, which have characteristics that are undesirable for construction materials and foundations. No laboratory criteria are established for these soils, as they generally can be readily identified in the field by their distinctive color and odor, spongy feel, and fiequently, fibrous textures. Particles of leaves, grass, branches, or other fibrous vegetable matter are common components of these soils.

COEFFICIENT OF UNIFORMITY

In table AV-1 of appendix V, you can see that well-graded gravels (GW) and well-graded sands (SW) must meet certain requirements with regard to C_u and C_c. C_u means the **coefficient of uniformity** with regard to the plotted grain size curve for the material. To see how the coefficient of uniformity is determined, let's consider an example.

Suppose that the sieve analysis of a soil sample identified as FT-P1-1 is as follows:

Sieve	Percent Passing
3/8	100.0
No. 4	85.8
10	74.4
20	51.2
40	30.2
100	16.3
200	3.1

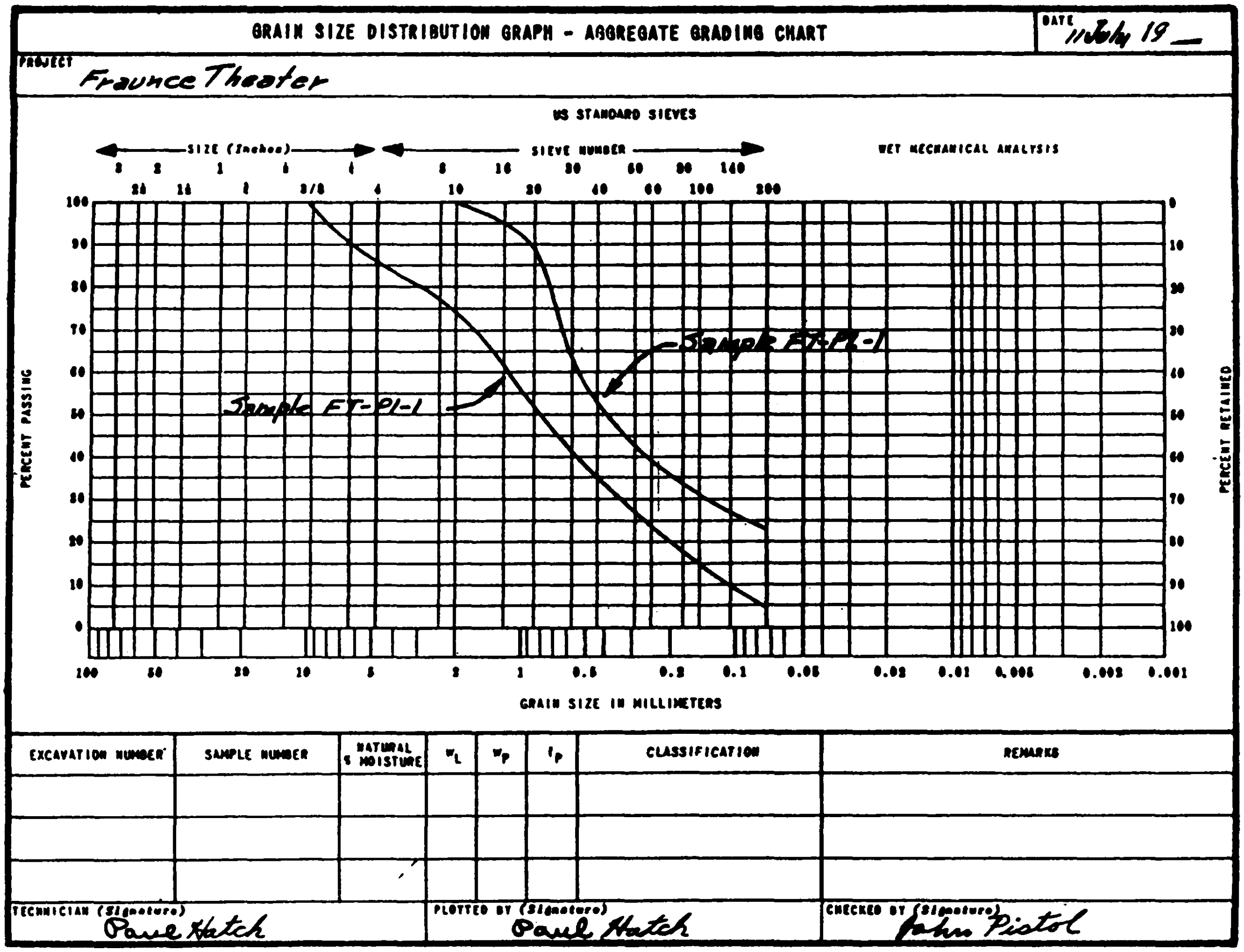


Figure 16-4.—Grain size distribution chart.

You should plot these values on a form like the one shown in figure 16-4. The graph on this form is a logarithm type of layout; coordinates horizontally are sieve sizes (at the top) and grain sizes in millimeters (at the bottom). Vertical coordinates are percents passing.

The formula for determining C_u is as follows:

$$C_u = \frac{D_{60}}{D_{10}}$$

D_{60} means the grain size, in millimeters, indicated by the gradation curve at the 60-percent passing level. In figure 16-4, follow the 60-percent passing line to the point where it intersects the gradation curve for FT-P1-1; then drop down and read the grain size in millimeters indicated below. You read about 1.25mm.

D_{10} means, similarly, the grain size indicated by the gradation curve at the 10-percent passing level. In figure 16-4, this is about 0.11mm.

C_u for this sample, then, is 1.25/0.11, or about 11.4.

COEFFICIENT OF CURVATURE

C_c means the **coefficient of curvature** of the gradation curve. Sometimes the symbol C_g for **coefficient of gradation)** is used instead of C_c. The formula for determining C_c or C_g is as follows:

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

D_{30} is the grain size, in millimeters, indicated by the gradation curve at the 30-percent passing level. In figure 16-4, it is (for FT-P1-1) about 0.35. Therefore, C_c is 0.35^2 divided by (0.11 x 1.25), or about 0.89.

FT-P1-1 is obviously a sand, since more than half of its coarse fraction passes the No. 4 sieve. It is a clean sand, since less than 5 percent of it (see table AV-1, appendix V) passes the No. 200 sieve. However, it is not a well-graded sand (SW), because although its C_u is greater than 6 (prescribed for SW in appendix V), its C_c is less than 1, the minimum prescribed for SW.

Therefore, it is in the SP (poorly graded sands, gravelly sands, little or no fines) category.

SAMPLE CLASSIFICATION PROBLEMS

The following soil classification problems are presented to show you how the soil classification chart (table AV-1, appendix V) is used to classify soils.

Sample Problem 1. From a sieve analysis, a soil shows a C_u of 20 and a C_c of 1.3 and contains 12-percent gravel, 88-percent sand, and no fines (smaller than No. 200). When you are classifying this soil, the first question is whether the soil is coarse-grained or fine-grained. To be Coarse-grained, a soil must have less than 50-percent fines. This soil contains no fines; therefore, it is a coerse-grained soil with the first letter in the symbol either G (gravel) or S (sand). Since it contains more sand (88 percent) than gravel (12 percent), the first letter in the symbol must be S.

The next task is to determine the second letter in the symbol. Since the soil contains no fines, it has no plasticity characteristics; therefore, the second letter of the symbol must be either W (well graded) or P (poorly graded). Since the soil has a C_u greater than 6 and a C_c between 1 and 3, it must be well-graded. Therefore, the symbol for the soil is SW, meaning "well-graded sand."

Sample Problem 2. A sieve analysis shows that a soil contains (50-Percent gravel, 20-percent sand, and 20-percent fines. Plasticity tests show that the portion passing the No. 40 sieve has an LL of 35 and a PI of 8. Since the soil contains less than 50-percent fines, it is a coarse-grained soil. The first letter is therefore either G (gravel) or S (sand). Since gravel predominates over sand, the first letter is G.

The next questions are (1) does the soil contain less than 12-percent fines and (2) is it nonplastic? The answer to both questions is negative, since the sieve analysis shows 20-percent fines, and an LL and PI have been obtained. It follows that the second letter in the symbol must be either C (clay) or M (silt). If you plot LL 35 and PI 8 on the plasticity chart (fig. 16-3), you will find that the plotted point lies below the A-line. Therefore, the complete symbol is GM, meaning "silty gravel."

Sample Problem 3. A sieve analysis shows that a soil contains 10-percent sand and 75-percent fines. Plasticity tests show that the portion passing the No. 40 sieve has an LL of 40 and a PI of 20. Since the soil contains more than 50-percent fines, it is a fine-grained soil; therefore, the first letter in the symbol is either O (organic), M (silt), or C (clay). Assume that the soil shows no indication of being organic (principal indications are black color and musty odor); it follows that the first letter must be either M or C.

If you plot an LL of 40 and a PI of 20 on the plasticity chart, you find that the plotted point lies above the A-line; therefore, the first letter in the symbol is C. Since the liquid limit is less than 50 (which brings the plotted point to the left of the B-line), the second letter of the symbol is L (low plasticity or compressibility). The complete symbol is CL, meaning "clay with low compressibility."

FIELD IDENTIFICATION

Sometimes the lack of time and facilities makes laboratory soil testing impossible in military construction. Even when laboratory tests are to follow, field identification tests must be made during the soil exploration. Soil types need to be identified so that duplicate samples for laboratory testing are held to a minimum. Several simple tests used in field identification are described in this section. Each test may be performed with a minimum of time and equipment. However, the classification derived from these tests should be considered an approximation. The number of tests used depends on the type of soil and the experience of the individual using them. Experience is the greatest asset in field identification; learning the technique from an experienced technician is the best method of acquiring the skill. If assistance is not available, you can gain experience by getting the "feel" of the soil during laboratory testing. An approximate identification can be made by spreading a dry sample on a flat surface and examining it. All lumps should be pulverized until individual grains are exposed but not broken; breaking changes the grain size and the character of the soil. A rubber-faced or wooden pestle are recommended. For an approximate identification, however, you can mash a sample underfoot on a smooth surface.

Field tests may be performed with little or no equipment other than a small amount of water. However, accuracy and uniformity of results is greatly increased by the proper use of certain items of equipment. For testing purposes, the following equipment or accessories may be used:

- SIEVES. A No. 40 U.S. standard sieve is perhaps the most useful item of equipment. Any screen with about 40 openings per lineal inch could be used. An approximate separation may be made by sorting the materials by hand. Generally, No. 4 and No. 200 sieves are used for separating gravel, sand, and fines.

- PIONEER TOOLS. Use a pick and shovel or a set of entrenching tools for collecting samples. A hand auger is useful if samples are desired from depths of more than a few feet below the surface.

- STIRRER. The spoon issued as part of the mess equipment serves in mixing materials with water to the desired consistency. It also can aid in collecting samples.

- KNIFE. Use a combat knife or pocketknife for collecting samples and trimming them to the desired size.

- MIXING BOWL. Use a small bowl with a rubber-faced pestle to pulverize the fine-grained portion of the soil. Both may be improvised. You could use a canteen cup and wood pestle.

- PAPER. Several sheets of heavy paper are needed for rolling samples.

- PAN AND HEATING ELEMENT. Use a pan and heating element to dry samples.

- SCALES. Use balances or scales to weigh samples.

The Unified Soil Classification System, as shown in appendix V, considers three soil properties: (1) percentage of gravel, sand, or fines, (2) shape of the grain size distribution curve, and (3) plasticity. Other observed properties should also be included in the soil description, whether made in the field or in the laboratory.

The following descriptions represent some of the typical characteristics used in describing soil:

- Dark brown to white or any suitable color shade description

- Coarse-grained, maximum particle size 2 3/4 inches, estimated 60-percent gravel, 36-percent sand, and 4-percent fines (passing through No. 200 sieve)

- Poorly graded (gap-graded, insufficient fine gravel)

- Gravel particles subrounded to rounded, or predominately gravel

- Nonplastic

- Mostly sand with a small amount of nonplastic fines (silt)

- Slightly calcareous, no dry strength, dense in the undisturbed state

VISUAL EXAMINATION

Visual examination should establish the color, grain size, grain shapes (of the coarse-grained portion), some idea of the gradation, and some properties of the undisturbed soil.

Color is often helpful in distinguishing between soil types, and with experience, one may find it useful in identifying the particular soil type. Color may also indicate the presence of certain chemicals. Color often varies with moisture content of a soil. For this reason, the moisture content at the time of color identification should be included. Some of the more familiar color properties are listed below.

- Generally, colors become darker as the moisture content increases and lighter as the soil dries.

- Some fine-grained soils (OL, OH) with dark drab shades of brown or gray, including almost black, contain organic colloidal matter.

- In contrast, clean, bright looking shades of gray, olive green, brown, red, yellow, and white are associated with inorganic soils.

- Gray-blue or gray- and yellow-mottled colors frequently result from poor drainage.

- Red, yellow, and yellowish brown result from the presence of iron oxides.

- White to pink may indicate considerable silica, calcium carbonate, or aluminum compounds.

The maximum particle size of each sample considered should always be estimated if not measured. This establishes the upper limit of the gradation curve. Gravels range down to the size of peas. Sands start just below this size and decrease until the individual grains can barely be seen by the naked eye. The eye can normally see individual grains about 0.05mm in size or about the size of the No. 200 screen. Thus silt and clay particles (which are smaller than this dimension) are not detected as individual grains.

While the sample for grain sizes is being examined, the shapes of the visible particles can be determined. Sharp edges and flat surfaces indicate an angular shape; smooth, curved surfaces are associated with a rounded shape. Particles may not be completely angular or completely rounded. These particles are called subangular or subaounded, depending on which shape predominates.

Laboratory analysis must be performed when accurate grain size distribution is to be determined. However, you can approximate the distribution by visual examination using the following steps:

1. Separate the larger grain particles from the rest of the soil sample by picking them out one at a time.

2. Examine the remainder of the soil and estimate the proportion of visible individual particles (larger than the No. 200 sieve) and the fines.

3. Convert these estimates into percentages by weight of the total sample. If the fines exceed 50 percent, the soil is considered fine-grained (M, C, or O); if the coarse material exceeds 50 percent, the soil is coarse-grained (G or S).

4. Examine the coarse-grained soil for gradation of particle sizes from the largest to the smallest. A good distribution of all sizes without too much or too little of any one size means the soil is well-graded (W). Overabundance or lack of any size means the material is poorly graded (P).

5. Estimate the percentage of the fine-grained portion of the coarse-grained soil. If nonplastic fines are less than 5 percent of the total, the soil maybe classified either as a GW, GP, SW, or SP type, depending on the other information noted above.

6. If the fine-grained portion (Step 5 above) exceeds 12 percent, the soil is either silty (M) or clayey (C) and requires further testing to identify.

7. Fine-grained portions (Step 5 above) between 5- and 12-percent (nonplastic fines or fines not interfering with drainage, or 0 to 12 percent plastic fines) total are border line and require a double symbol (GW-GM or SW-SM).

8. Fine-grained soils (M, C, or O) from Step 3 above require other tests to distinguish them further. Grain size distribution of fine portions is normally not performed in field identification. However, should it become necessary, you can approximate the grain size of the fines by shaking them in a jar of water and allowing the material to settle. The materials settle in layers of different sizes from which the proportion can be estimated. It should be kept in mind that gravel and sand settle into a much denser mass than either clay or silt.

If you use the characteristics determined up to this point, it is possible to evaluate the soil as it appeared in place (undisturbed). Gravels or sands can be described qualitatively as loose, medium, or dense. Clays maybe hard, stiff, or soft. The ease or difficulty with which the sample was removed from the ground is a good indicator. Soils that have been cultivated or farmed can be further evaluated as loose and compressible. Highly organic soils can be spongy and elastic. In addition, moisture content of the soil influences the in-place characteristics. This condition should be recognized and reported with the undisturbed soil properties.

BREAKING OR DRY-STRENGTH TEST

The breaking test is done only on the material passing the No. 40 sieve. This test as well as the roll test and the ribbon test, is used to measure the cohesive and plastic characteristics of the soil. The test normally is made on a small pat of soil about 1/2 inch thick and about 1 1/2 inches in diameter. The pat is prepared by molding a portion of the soil in the wet plastic state into the size and shape desired and then allowing the pat to dry completely. Samples may be tested for dry strength in their natural condition as they are found in the field However, you should not depend too much on such tests because of the variations that exist in the drying environment under field conditions. You may approximate the dry strength by such a test however, and verify it later by a carefully prepared sample.

After the prepared sample is thoroughly dry, attempt to break it using the thumbs and forefingers of both hands (fig. 16-5). If you are able to break it, then try to powder it by rubbing it with the thumb and fingers of one hand.

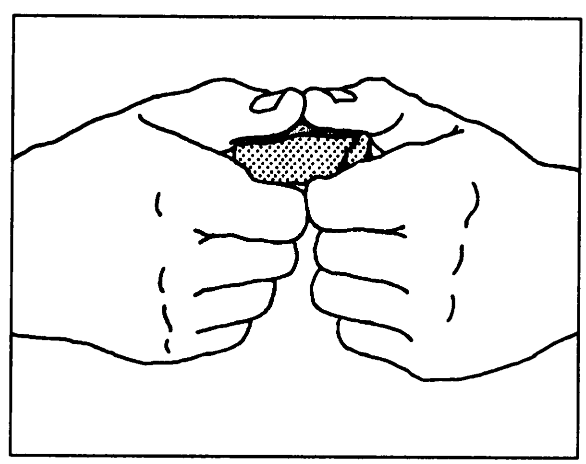


Figure 16-5.-Breaking or dry-strength test.

The typical reactions that are obtained in this test for various types of soils are described below.

1. Very highly plastic soils (CH). The pat cannot be broken or powdered by finger pressure.

2. Highly plastic soils (CH). The pat can be broken with great effort, but cannot be powdered.

3. Medium plastic soils (CL). The pat can be broken and powdered with some effort.

4. Slightly plastic soils (ML, MH, or CL). The pat can be broken quite easily and powdered readily.

5. Nonplastic soils (ML, MH, OL, or OH). The pat has little or no dry strength and crumbles or powders when picked up.

ROLL OR THREAD TEST

This test is performed only on the material passing a No. 40 sieve. First, you mix a representative portion of the sample with water until it can be molded or shaped without sticking to your fingers. This moisture content is referred to as being just below the sticky limit.

Next, prepare a nonabsorbent rolling surface by placing a sheet of glass or heavy wax paper on a flat or level support. Place the sample on this surface and shape it into an elongated cylindrical shape. Then attempt to roll the cylindrical sample rapidly into a thread approximately 1/8 inch in diameter (fig. 16-6). If the moist soil rolls into a thread, it has some plasticity. The number of times it can be rolled into a thread without crumbling is a measure of the degree of plasticity of the soil. Materials that cannot be rolled in this manner are nonplastic or have extremely low plasticity.

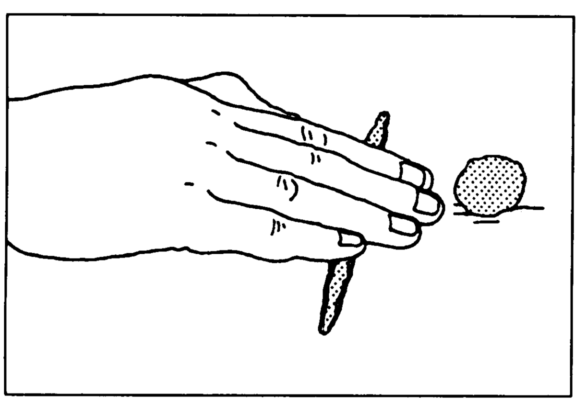


Figure 16-6.-Roll or thread test.

The results of this test indicate the following:

1. High plasticity (CH). The soil can be molded into a ball or cylinder and deformed under firm finger pressure without crumbling or cracking.

2. Medium plasticity (CL). The soil can be molded, but it cracks or crumbles under finger pressure.

3. Low plasticity (CL, ML, or MH). The soil cannot be lumped into a ball or cylinder without breaking up.

4. Organic material (OL or OH). The soil forms a soft, spongy ball or thread when molded.

5. Nonplastic soil (ML or MH). The soil cannot be rolled into a thread at any moisture content.

From the thread test, the cohesiveness of the material near the plastic limit may also be described as weak, firm, or tough. The higher the soil is on the plasticity chart, the stiffer the threads are as they dry out and the tougher the lumps are if the soil is remolded after rolling.

RIBBON TEST

The ribbon test is performed only on the material passing the No. 40 sieve. The sample prepared for use in this test should have a moisture content that is slightly below the sticky limit. Using this material, form a roll of soil about 1/2 to 3/4 inch in diameter and about 3 to 5 inches long. Place this material in the palm of your hand and, starting at one end, flatten the roll, forming a ribbon 1/8 to 1/4 inch thick. This is done by squeezing it between your thumb and forefinger (fig. 16-7). Handle the sample carefully to form the maximum length of ribbon that can be supported by the cohesive properties of the material. If the soil sample holds together for a length of 6 to 10 inches without breaking, the material is then considered to be both highly plastic and highly compressive (CH). If the soil cannot be ribboned, it is nonplastic (ML or MH). If it can be ribboned, it is nonplastic (ML or MH). If it can be ribboned only with difficulty into short lengths, the soil is considered to have low plasticity (CL). The roll test and the ribbon test complement each other in giving a clearer picture of the degree of plasticity of soil.

WET-SHAKING TEST

The wet-shaking test is performed only on the material passing the No. 40 sieve. In the preparation of a portion of the sample for use in this test, enough material to form a ball of material about 3/4 inch in

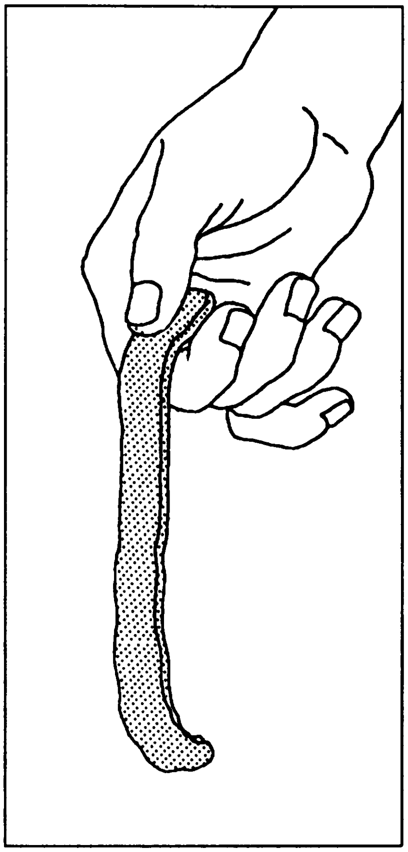


Figure 16-7.-Ribbon test.

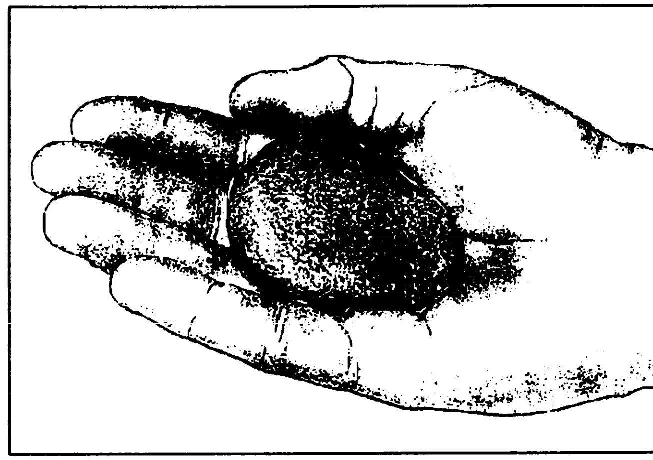


Figure 16-8.-Livery appearance produced by wet-shaking test.

diameter is moistened with water. This sample should be just wet enough that the soil does not stick to your fingers upon remolding or just below the sticky limit.

For testing, the sample is then placed in the palm of the hand and shaken vigorously. This is usually done by jarring the hand on the table or some other firm object or by jarring it against the other hand. The soil is said to have given a reaction to this test if, when it is shaken, water comes to the surface of the sample producing a smooth, shiny appearance. This appearance is frequently described as livery (fig. 16-8).

The sample is then squeezed between the thumb and forefinger of the other hand. As this is done, the surface water quickly disappears and the surface becomes dull. The sample becomes firm, resisting deformation, and cracks occur as pressure is continued. Finally the sample crumbles like a brittle material.

The vibration caused by shaking the soil sample tends to reorient the soil grains, decrease the voids, and force water, which had been within these voids, to the surface. Pressing the sample between the fingers tends to disarrange the soil grains and increase the void spaces. The water is then drawn into the soil. If the water content is still adequate, shaking the broken pieces causes them to liquefy again and flow together, and the complete cycle may be repeated. This process can occur only when the solid grains are bulky in shape and noncohesive in character. Very fine sands and silts fall into this category and are readily identified by the wet-shaking test. Since it is rare that fine sands and silts occur without some amount of clay mixed with them, there are varying degrees of reaction to this test. Even a small amount of clay tends to retard this reaction greatly. Some of the descriptive terms applied to the different rates of reaction to this test are as follows:

- SUDDEN OR RAPID. A rapid reaction to the shaking test is typical of nonplastic, fine sands and silts. A material known as rock flour that falls into the silt-size ranges also gives this type of reaction.

- SLUGGISH OR SLOW. A sluggish reaction indicates slight plasticity such as might be found from a test of some organic or inorganic silts or silts containing a small amount of clay. Even a slight content of colloidal clay imparts some plasticity and materially slows up the reaction to the shaking test. Extremely slow or no reaction is typical of all inorganic clays and of the highly plastic organic clays.

- NO REACTION. Obtaining no reaction at all to this test does not indicate a complete absence of silt or fine sand.

ODOR TEST

Organic soils of the OL and OH groups usually have a distinctive, musty, slightly offensive odor. With experience, you can use this odor as an aid in identifying these groups. This odor is especially apparent from fresh samples. The odor gradually reduces when exposed to air but can again become effective when you heat a wet sample. Organic soils are undesirable as foundation or base course material. They are usually removed from the construction site and wasted.

BITE OR GRIT TEST

The bite or grit test is a quick and useful method that is used to identify sand silt, or clay. In this test, a small pinch of solid material is ground lightly between the teeth. The soils are identified as follows:

- SANDY SOILS. The sharp, hard particles of sand grate harshly between your teeth and are highly objectionable. This is true even of the fine sand.

- SILTY SOILS. The silt grains are so much smaller than sand grains that they do not feel nearly so harsh between your teeth. They are not particularly gritty although their presence is still easily detected.

- CLAYEY SOILS. The clay grains are not at all gritty, but feel smooth and powdery like flour between the teeth. Dry lumps of clayey soils stick when lightly touched with your tongue.

SLAKING TEST

The slaking test is used to assist in determining the quality of certain soil shales and other soft rocklike materials. To perform this test, place the soil in the sun or in an oven to dry. Then allow it to soak in water for at least 24 hours. After this, examine the strength of the soil. Certain types of shale disintegrate completely and lose all strength.

ACID TEST

The acid test is used to determine the presence of calcium carbonate. It is performed by placing a few drops of hydrochloric acid on a piece of soil. A fizzing reaction (effervescence) to this test indicates the presence of calcium carbonate. The degree of reaction gives an indication of the concentration. Calcium carbonate normally is desirable in a soil because of the cementing action it adds to the stability. (Some very dry noncalcareous soils appear to effervesce after they absorb the acid. This effect can be eliminated in all dry soils by moistening the soil before applying the acid.) This cementing action normally develops only after a long curing period and cannot be counted upon for strength in most military construction. The primary use for this test is to give abetter value of fine-grained soils that you have tested in place.

SHINE TEST

The shine test is another means of measuring the plasticity characteristics of clays. A slightly moist or dry piece of highly plastic clay has a definite shine when rubbed with a fingernail, a pocketknife blade, or any smooth metal surface. On the other hand, a piece of lean clay does not display any shine, but remains dull.

FEEL TEST

The feel test is a general-purpose test that requires experience and practice before reliable results can be obtained. Two characteristics you can determine by the feel test are consistency and texture.

The natural moisture content of a soil is of value as an indicator of the drainage characteristics, nearness to the water table, or other factors that may affect this property. A piece of undisturbed soil is tested by squeezing it between the thumb and forefinger to determine its consistency. The consistency is described by such terms as hard, stiff, brittle, friable, sticky, plastic, or soft. Remold the soil by working it in your hands. Observe changes, if any. You can use the feel test to estimate the natural water content relative to the liquid or plastic limit of the soil. Clays that turn almost liquid on remolding are probably near or above the liquid limit. If the clay remains stiff and crumbles upon being remolded, the natural water content is below the plastic limit.

The term texture, as applied to the fine-grained portion of a soil, refers to the degree of fineness and uniformity. The texture is described by such expressions as floury, smooth, gritty, or sharp, depending upon the sensation produced by rubbing the soil between the fingers. Sensitivity to this sensation may be increased by rubbing some of the material on a tender skin area such as the wrist. Fine sand feels gritty. Typical dry silts will dust readily and feel relatively soft and silky to the touch. Clay soils are powdered only with difficulty but become smooth and gritless like flour.

QUESTIONS

Q1. The purpose of a geological survey is to take which of the following actions?

1. *Locate rock formations in the field and determine their physical characteristics*
2. *Determine rock age and distribution*
3. *Determine types of rock and their mineral content*
4. *All of the above*

Original sample weight: 2,459 grams		
Sieve size	Weight of sieve	Weight of sieve and sample
1/2	210	210
1/4	230	624
No. 4	205	332
No. 8	225	691
No. 20	215	612
No. 60	235	581
No. 100	250	612
No. 200	260	515

Figure 16-9.—Sieve analysis data.

Q2. *Is it true or false that surveys made in support of pedology concern the locations of the limits of sand or gravel deposits suitable for use as construction materials?*

Q3. *Structures must be constructed at an elevation that will ensure that they will not be adversely affected by the groundwater table. If the proposed grade line lies below the elevation of the groundwater line, you may have to*

1. *change the location*
2. *lower the groundwater table by means of artificial drainage systems*
3. *raise the proposed grade*
4. *do either 2 or 3 above, depending upon land characteristics*

Q4. *From the sieve analysis data shown in figure 16-9, determine and plot the grain size distribution using figure 16-10. For this soil*

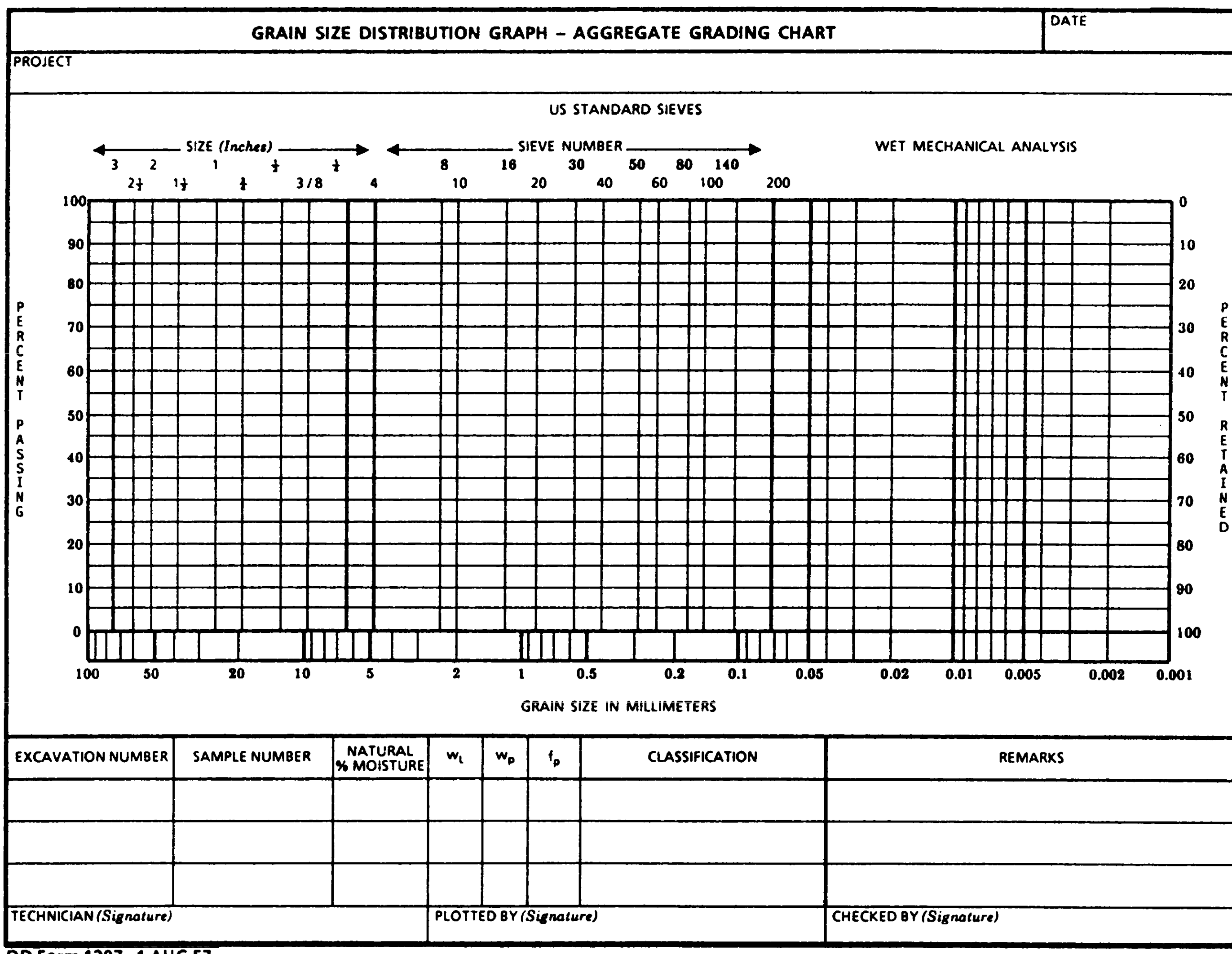
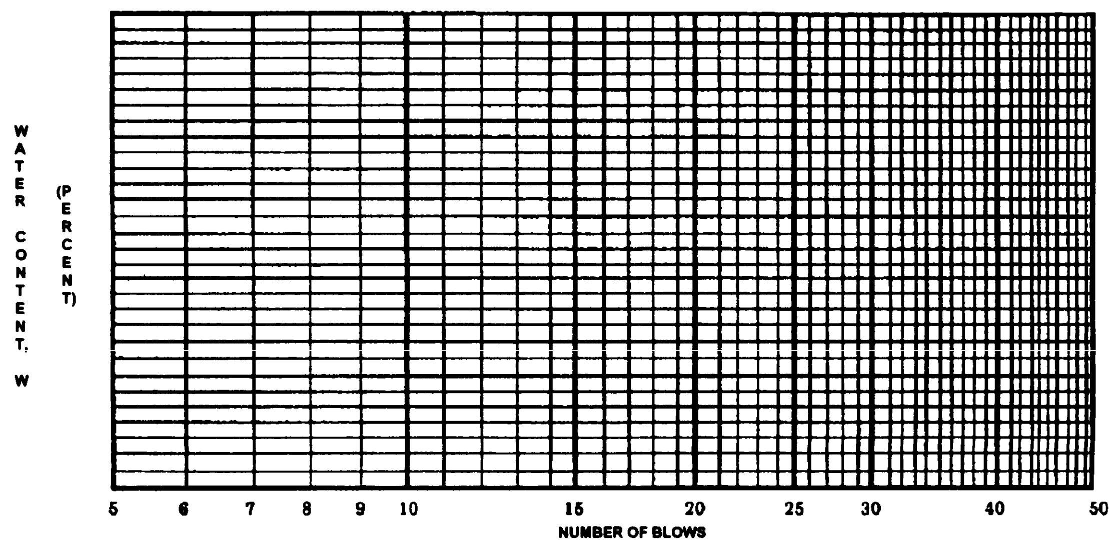


Figure 16-10.—Grain size distribution graph.

ATTERBUERG LIMITS DETERMINATION		DATE
PROJECT	EXCAVATION NUMBER	SAMPLE NUMBER

LIQUID LIMIT, W_L						
RUN NUMBER	1	2	3	4		
TARE NUMBER						
A. WEIGHT OF WET SOIL + TARE	43.61	43.78	43.07	44.89		
B. WEIGHT OF DRY SOIL + TARE	40.07	40.62	39.96	41.27		
C. WEIGHT OF WATER, W_W						
D. WEIGHT OF TARE	33.12	33.29	32.36	32.13		
E. WEIGHT OF DRY SOIL, W_s						
WATER CONTENT, W =						
NUMBER OF BLOWS	15-17-16	23-24-25	29-28-30	33-33		

W_L LL=	W_P PL=	IP PI =



PLASTIC LIMIT, W_P					NATURAL WATER CONTENT
RUN NUMBER	1	2	3		
TARE NUMBER					
F. WEIGHT OF WET SOIL + TARE	55.36	54.75	60.30		
G. WEIGHT OF DRY SOIL + TARE	54.93	54.23	59.87		
H. WEIGHT OF WATER, W_W					
I. WEIGHT OF TARE	53.13	52.64	57.49		
J. WEIGHT OF DRY SOIL, W_s					
WATER CONTENT, W =					
PLASTIC LIMIT, I_P (Average w)					

REMARKS		
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DD Form 1209, AUG 57

Figure 16-11.—Atterberg limits determination.

sample, what is the (a) percentage of gravel, (b) percentage of sand, (c)percentage of fines, and (d) the USCS classification?

Q5. For a certain soil sample, assume that 60 percent of the material passes the No. 200 sieve, that there is no indication that the material contains organic matter and that Atterberg limits testing has been performed Figure 16-11 is the partially completed record entries for the Atterberg limits determination. Based on this information and using the plasticity chart shown in figure 16-3, what is the (a) liquid limit, (b) plasticity index, and (c) USCS classification of the soil sample?

Q6. Which of the following field tests can be used to approximate the cohesive and plastic characteristics of a soil sample?

1. *Dry strength*
2. *Ribbon*
3. *Roll*
4. *Each of the above*

CHAPTER 17

MIX DESIGN: CONCRETE AND ASPHALT

Chapter 7 of the EA3 TRAMAN discusses the properties that comprise a good quality concrete and introduces the use of concrete as a construction material. In Part 1, chapter 13, of this TRAMAN, you learned about the different types of portland cement, the methods used to identify cement, and the purpose and effect of various admixtures that are often used in the production of concrete. You also studied the physical requirements for water and aggregates used in concrete and the various tests used to determine the suitability of water and aggregates as ingredients in a concrete mixture. The discussion of concrete in this chapter is directed towards the design of concrete mixtures. This discussion presupposes that you are well versed in the previous topics. If you are not, then it is strongly recommended that you review the aforementioned chapters before you begin the study of this chapter.

Also covered in this chapter is bituminous mixture design. Once again, it is strongly recommended that you first review chapter 13 of this TRAMAN to refresh your knowledge of bituminous pavement materials and the testing methods used in the control of bituminous mixtures.

DESIGN OF CONCRETE MIXTURES

From your previous studies, you know that the basic ingredients used in the production of concrete are cement (usually portland cement), water, and both fine and coarse aggregates. You also know that certain admixtures are used occasionally to meet special requirements. Design of a concrete mixture consists of determining the correct amount of each ingredient needed to produce a concrete that has the necessary consistency or workability in the freshly mixed condition and that has desired strength and durability characteristics in the hardened condition.

Two methods of proportioning concrete mixtures are discussed in this chapter. One method—the **trial batch method**—is based on an estimated weight of concrete per unit volume. The other method, based on calculations of the absolute volume occupied by the ingredients used in the concrete mixture, is called the **absolute volume method.** Our discussion of these methods is only intended to provide you with a basic understanding of mixture design. For a thorough discussion, you should refer to the most recent edition of *Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete,* (ACI 211.1), published by the American Concrete Institute (ACI).

MIX PROPORTIONS

Concrete mixture proportions for a particular application are determined by the end use of the concrete and by anticipated conditions at the time of placement. Their selection involves achieving a balance between reasonable economy and the requirements for placeability, strength, durability, density, and appearance that may be found in the job specifications. Before proportioning a concrete mixture, you must have certain information about a job, such as the size and shape of structural members, the concrete strength required, and the exposure conditions. Other important factors discussed in this chapter are the water-cement ratio, aggregate characteristics, amount of entrained air, and slump.

Water-Cement Ratio

The water-cement ratio is determined by the strength, durability, and watertightness requirements of the hardened concrete. The ratio is usually specified by the structural design engineer, but you can arrive at tentative mix proportions from knowledge of a prior job. Always remember that a change in the water-cement ratio changes the characteristics of the hardened concrete. Use table 17-1 to select a suitable

Table 17-1.—Maximum Permissible Water-Cement Ratios for Concrete in Severe Exposures

Type of structure	Structure wet continuously or frequently and exposed to freezing and thawing+	Structure exposed to sea water or sulfates
Thin sections (railings, curbs, sills, ledges, ornamental work) and sections with less than 1 in. cover over steel	0.45	0.40
All other structures	0.50	0.45

* BASED ON REPORT OF THE DURABILITY OF CONCRETE IN SERVICE.

+ CONCRETE SHOULD ALSO BE AIR-ENTRAINED.

Courtesy of American Concrete Institute

82X

Table 17-2.—Relationship Between Water-Cement Ratio and Compressive Strength of Concrete

Compressive strength at 28 days, psi*	Water-cement ratio, by weight	
	Non-air-entrained concrete	Air-entrained concrete
6000	0.41	—
5000	0.48	0.40
4000	0.57	0.48
3000	0.68	0.59
2000	0.82	0.74

* VALUES ARE ESTIMATED AVERAGE STRENGTH FOR CONCRETE CONTAINING NOT MORE THAN THE PERCENTAGE OF AIR SHOWN ON TABLE 9-4.

Courtesy of American Concrete Institute

82X

water-cement ratio for normal weight concrete that will meet anticipated exposure conditions. Note that the water-cement ratios in table 17-1 are based on concrete strength under certain exposure conditions. If possible, perform tests using job materials to determine the relationship between the water-cement ratio you select and the strength of the finished concrete. If you cannot obtain laboratory test data or experience records for the relationship, use table 17-2 as a guide. Enter table 17-2 at the desired f'_c (specified compressive strength of the concrete in pounds per square inch, psi) and read across to determine the maximum water-cement ratio. You can interpolate between the values. When both exposure conditions and strength must be considered, use the lower of the two indicated water-cement ratios. If flexural strength, rather than compressive strength, is the basis of design, such as a pavement, perform tests to determine the relationship between the water-cement ratio and the flexural strength. An approximate relationship between flexural strength and compressive strength is as follows:

$$f'_c = \left(\frac{R}{k}\right)^2$$

where:

f'_c = compressive strength, psi

R = flexural strength, psi

k = a constant, usually between 8 and 10

Aggregate

Use fine aggregate to fill the spaces between the coarse aggregate particles and to increase the workability of a mix. In general, aggregate that does not have a large grading gap or an excess of any size, but gives a smooth grading curve, produces the best mix. Fineness modulus and fine aggregate grading are discussed in Part 1, chapter 13, of this TRAMAN.

Use the largest practical size of coarse aggregate in the mix. The maximum size of coarse aggregate that produces concrete of maximum strength for a given cement content depends upon the aggregate source as well as the aggregate shape and grading. The larger the maximum size of the coarse aggregate, the less paste (water and cement) required for a given concrete quality. The maximum size of aggregate should never exceed one fifth of the narrowest dimension between side forms, one third of the depth of slabs, or three fourths of the distance between reinforcing bars.

Entrained Air

Use entrained air in all concrete exposed to freezing and thawing, and sometimes under mild exposure conditions, to improve workability. Always use entrained air in paving concrete regardless of climatic conditions. Table 17-3 gives recommended total air contents of air-entrained concretes. When mixing water remains constant, air entrainment increases slump. When cement content and slump remain constant, less mixing water is required. The resulting decrease in the water-cement ratio helps to offset possible strength decreases and improves other paste properties, such as permeability. The strength of air-entrained concrete may equal, or nearly equal, that of non-air-entrained concrete when cement contents and slump are the same. The upper half of table 17-3 gives the approximate percent of entrapped air in non-air-entrained concrete, and the lower half gives the recommended average total air content percentages for air-entrained concrete based on level of exposure.

MILD EXPOSURE.—"Mild" exposure includes indoor or outdoor service in a climate that does not expose the concrete to freezing or deicing agents. When you want air entrainment for a reason other than durability, such as to improve workability or cohesion or to improve strength in low cement factor concrete, you can use air contents lower than those required for durability.

MODERATE EXPOSURE.—"Moderate" exposure means service in a climate where freezing is expected but where the concrete is not continually exposed to moisture or free water for long periods before freezing or to deicing agents or other aggressive

Table 17-3.—Approximate Mixing Water and Air Content Requirements for Different Slumps and Nominal Maximum Sizes of Aggregates

Slump in.	Water, lb per cu yd of concrete for indicated nominal maximum sizes of aggregate							
	3/8 in.*	1/2 in.*	3/4 in.*	1 in.*	1-1/2 in.*	2 in.†*	3 in.†‡	6 in.†‡
Non-air entrained concrete								
1 to 2	350	335	315	300	275	260	220	190
3 to 4	385	365	340	325	300	285	245	210
6 to 7	410	385	360	340	315	300	270	–
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
1 to 2	305	295	280	270	250	240	205	180
3 to 4	340	325	305	295	275	265	225	200
6 to 7	365	345	325	310	290	280	260	–
Recommended average§ total air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

* THESE QUANTITIES OF MIXING WATER ARE FOR USE IN COMPUTING CEMENT FACTORS FOR TRIAL BATCHES. THEY ARE MAXIMA FOR REASONABLY WELL-SHAPED ANGULAR COARSE AGGREGATES GRADED WITHIN LIMITS OF ACCEPTED SPECIFICATIONS.

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chemicals. Examples are exterior beams, columns, walls, girders, or slabs that do not contact wet soil or receive direct application of deicing salts.

SEVERE EXPOSURE.—"Severe" exposure means service where the concrete is exposed to deicing chemicals or other aggressive agents or where it continually contacts moisture or free water before freezing. Examples are pavements, bridge decks, curbs, gutters, sidewalks, or exterior water tanks or sumps.

Slump

The slump test (discussed in chapter 15 of the EA3 TRAMAN) measures the consistency of concrete. Do not use it to compare mixes having wholly different proportions or containing different sizes of aggregates. When different batches are tested, changes in slump indicate changes in materials, mix proportions, or water content. Table 17-4 gives recommended slump ranges for various types of construction.

TRIAL BATCH METHOD

The following are some basic guidelines and an example to help you in performing the steps related to mix design by the trial batch method.

Basic Guidelines

In the trial batch method of mix design, use actual job materials to obtain mix proportions. The size of the trial batch depends upon the equipment you have and how many test specimens you make. Batches using 10 to 20 pounds of cement may be big enough, although

Table 17-4.—Recommended Slumps for Various Types of Construction

Types of construction	Slump, in. Maximum*	Slump, in. Minimum
Reinforced foundation walls and footings	3	1
Plain footings, caissons, and substructure walls	3	1
Beams and reinforced walls	4	1
Building columns	4	1
Pavements and slabs	3	1
Mass concrete	2	1

* MAY BE INCREASED 1 IN. FOR METHODS OF CONSOLIDATION OTHER THAN VIBRATION.

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larger batches produce more accurate data. Use machine mixing if possible, since it more nearly represents job conditions. Always use a machine to mix concrete containing entrained air. Be sure to use representative samples of aggregate, cement, water, and air-entraining admixture in the trial batch. Prewet the aggregate and allow it to dry to a saturated, surface-dry condition. Then place it in covered containers to maintain this condition until you use it. This simplifies calculations and eliminates errors caused by variations in aggregate moisture content. When the concrete quality is specified in terms of the water-cement ratio, the trial batch procedure consists basically of combining paste (water, cement, and usually entrained air) of the correct proportions with the proper amounts of fine and coarse aggregates to produce the required slump and workability. Then calculate the large quantities per sack or per cubic yard.

Example Using Trial Batch Method

Let's suppose that you are to determine the mix proportions for a concrete retaining wall exposed to fresh water in a severe climate. The minimum wall thickness is 10 inches, with 2 inches of concrete covering the reinforcement. The required average 28-day compressive strength is 4,600 psi. It should be noted that this average compressive strength is not the same as the design strength used for structural design but a higher figure expected to be produced on the average. For an in-depth discussion of determining how much the average strength should exceed the design strength, you should refer to *Recommended Practice for Evaluation of Strength Test Results of Concrete*, ACI 214.

The steps in proportioning a mix to satisfy the above requirements are as follows:

1. **Determine the water-cement ratio.** Table 17-1 indicates that a maximum water-cement ratio of 0.50 by weight satisfies the exposure requirements and that the concrete should be air entrained. Table 17-2 shows that a maximum water-cement ratio of approximately 0.42 by weight satisfies the strength requirements for Type IA (air-entraining) portland cement with a compressive strength of 4,600 psi. As discussed previously, since both strength and exposure conditions are being considered, you will choose the lower of the two water-cement ratios, or 0.42.

2. **Determine the maximum size of coarse aggregate.** Since the maximum size of coarse aggregate must not exceed one fifth of the minimum wall thickness or three fourths of the space between the reinforcement and the surfaces, the maximum size of coarse aggregate you should use is 1 1/2 inches.

3. **Determine the slump.** Assuming in this case that vibration will be used to consolidate the concrete, table 17-4 shows the recommended slump to be 1 to 3 inches.

4. **Determine the amount of mixing water and air content.** To determine the amount of mixing water per cubic yard of concrete, use table 17-3. Using the lower half of this table, you can see that for 1 1/2-inch aggregates and a 3-inch slump, the recommended amount of mixing water is 275 pounds. You also see that for extreme exposure, the recommended air content is 5.5 percent.

NOTE: It is not normal practice to buy air-e ntraining cement (Type IA) and then add an air-entraining admixture; however, if the only cement available is Type IA and it does not give the needed air content, addition of an air-entraining admixture would be necessary to achieve frost resistance.

5. **Determine the amount of cement required.** Using the amount of mixing water and the water-cement ratio (Steps 1 and 4 above), the required cement content per cubic yard of concrete is 275 ÷ 0.42 = 655 pounds.

6. **Determine the quantity of coarse aggregate.** Let's assume that the fineness modulus of sand is 2.6. Using table 17-5, you find that for 1 1/2-inch aggregate and a fineness modulus of 2.6, you should use 0.73 cubic feet of coarse aggregate on a dry-rodded basis for each cubic foot of concrete. So, for 1 cubic yard of concrete,

Table 17-5.—Volume of Coarse Aggregate per Unit of Volume of Concrete

Maximum size of aggregate in.	Volume of dry-rodded coarse aggregate per unit volume of concrete for different fineness moduli of sand			
	2.40	2.60	2.80	3.00
3/8	0.50	0.48	0.46	0.44
1/2	0.59	0.57	0.55	0.53
3/4	0.66	0.64	0.62	0.60
1	0.71	0.69	0.67	0.65
1 1/2	0.75	0.73	0.71	0.69
2	0.78	0.76	0.74	0.72
3	0.82	0.80	0.78	0.76
6	0.87	0.85	0.83	0.81

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Table 17-6.—First Estimate of Weight of Fresh Concrete

Maximum size of aggregate, in.	First estimate of concrete weight, lb per cu yd	
	Non-air-entrained concrete	Air-entrained concrete
3/8	3840	3690
1/2	3890	3760
3/4	3960	3840
1	4010	3900
1 1/2	4070	3960
2	4120	4000
3	4160	4040
6	4230	4120

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the volume needed is 27 × 0.73 = 19.71 cubic feet. Now, assuming that you determined the dry-rodded weight of the coarse aggregate to be 104 pounds per cubic foot, the dry weight of the aggregate is 19.71 × 104 = 2,050 pounds.

7. **Determine the amount of fine aggregate.** Table 17-6 shows that the weight of 1 cubic yard of air-entrained concrete having 1 1/2-inch maximum size aggregate should be 3,960 pounds. From this figure you simply subtract the weight of the water (275 pounds), cement (655 pounds), and coarse aggregate (2,050 pounds) to determine the weight of the fine aggregate needed for a cubic yard of the concrete. Doing that, you find that you need 980 pounds of fine aggregate (sand).

Now you know the weights of all the materials needed to produce 1 cubic yard of this air-entrained concrete. As you are well aware, 1 cubic yard equals 27 cubic feet; therefore, to reduce the above weights to a 1-cubic-foot laboratory trial batch, simply divide the individual weights by 27. That being done, you find that you need 24.2 pounds of cement, 10.2 pounds of water, 36.3 pounds of sand, and 75.9 pounds of coarse aggregate to batch 1 cubic foot of concrete.

Adjusting for Slump and Air Content

Let's assume now that you have mixed the above trial batch and determined that the slump measures 1 inch. To adjust for slump, you should increase or decrease the amount of water per cubic yard by 10 pounds for each 1 inch of desired increase or decrease in slump. Then you maintain the same water-cement ratio by increasing or decreasing the amount of cement to maintain the same ratio as that with which you started. You can adjust for a 3-inch slump as follows:

Water	275 pounds + 20 pounds	=	295 pounds
Cement	295 pounds ÷ 0.42	=	702 pounds
Fine aggregate			1,060 pounds
Coarse aggregate			2,050 pounds

If the desired air content was not achieved, recheck the admixture content for proper air content and reduce or increase the mixing water by 5 pounds per cubic yard of concrete for each 1 percent by which the air content is to be increased or decreased, and recalculate the cement to maintain the same water-cement ratio. To find the most economical proportions, make more trial batches, varying the percentage of fine aggregate. In each batch, keep the water-cement ratio, aggregate gradation, air content, and slump approximately the same.

ABSOLUTE VOLUME METHOD

You also can proportion concrete mixtures using absolute volumes.

Basic Guidelines

For this procedure, select the water-cement ratio, slump, air content, maximum aggregate size, and estimate the water requirement as you did in the trial batch method. Before making calculations, you must have certain other information, such as the specific gravities of the fine and coarse aggregate, the dry-rodded unit weight of the coarse aggregate, and the fineness modulus of the fine aggregate. If you know the maximum aggregate size and the fineness modulus of the fine aggregate, you can estimate the volume of dry-rodded coarse aggregate per cubic yard from table 17-5. Now you can determine the dry-rodded unit weight of coarse aggregate and calculate the quantities per cubic yard of water, cement, coarse aggregate, and air. Finally, subtract the sum of the absolute volumes of these materials in cubic feet from 27 cubic feet per 1 cubic yard to give the specific volume of fine aggregate.

Example Using Absolute Volume Method

Determine the mix proportions for a retaining wall, using the following specifications and conditions:

Required 28-day compressive strength (f'_c)	3,000 psi
Maximum size aggregate	3/4 in.
Exposure condition	Moderate freeze-thaw exposure—exposure to air
Fineness modulus of fine aggregate	2.70
Specific gravity of portland cement	3.15
Specific gravity of fine aggregate	2.65
Specific gravity of coarse aggregate	2.60
Dry-rodded unit weight of coarse aggregate	102 lb/cu ft
Dry-rodded unit weight of fine aggregate	100 lb/cu ft
Slump	3 in.
Cement	Type IA

To determine the mix proportions, proceed as follows:

1. **Estimate the air content.** From table 17-3, the air content should be 5 percent (3/4-inch aggregate, air-entrained concrete, moderate exposure).

2. **Estimate the mixing water content.** From table 17-3, you should use 305 pounds of mixing water per cubic yard of concrete (3-inch slump, 3/4-inch aggregate, air-entrained concrete).

3. **Determine the water-cement ratio.** From table 17-2, a water-cement ratio of 0.59 will satisfy the strength requirement for 3,000 psi concrete. From table 17-1, you find that a water-cement ratio of 0.50 will satisfy the exposure conditions. Since 0.50 is the smaller of the ratios, that is what you should use.

4. **Calculate the cement content.** By using the weight of the mixing water content (Step 2) and the water-cement ratio (Step 3), you can determine the cement content as follows:

- $C = \dfrac{water\ lb/cu\ yard}{water\text{–}cement\ ratio}$

- $C = \dfrac{305\ lb/cu\ yd}{0.50} = 610\ lb$

5. **Calculate the coarse aggregate content.** By using table 17-5 and interpolating between fineness moduli of 2.6 and 2.8, you find that for 3/4-inch aggregate having a fineness modulus of 2.7, the volume of dry-rodded aggregate per unit volume of concrete is 0.63. Therefore, the volume of coarse aggregate needed for 1 cubic yard of concrete is 0.63 x 27 = 17.01 cubic feet. Since the dry-rodded weight of the coarse aggregate is 102 pounds per cubic foot, then the weight of the coarse aggregate for a cubic yard of the concrete is 17.01 x 102= 1,735 pounds.

6. **Calculate the absolute volumes.** For one cubic yard of air-entrained concrete, the volume of the air can be determined by simply multiplying the air content by 27. For this mixture, the air content from Step 1 above is 5 percent; therefore, the volume of air is 0.05 x 27 = 1.35 cubic feet.

For the cement, water, and coarse aggregate, the absolute volumes can be calculated using the following equation:

$$\textit{Absolute volume} = \frac{W}{G \times 62.4}$$

where:

W = weight of the material

G = specific gravity of the material

62.4 = weight of water per cubic foot

By substitution into this formula, the absolute volumes of the cement, water, and coarse aggregate are calculated as follows:

- Volume of cement (W = 610 pounds and G = 3.15)
  = 610 ÷ (3.15 x 62.4) = 3.10 cubic feet
- Volume of water (W = 305 pounds and G = 1)
  = 305 ÷ (1 x 62.4) = 4.89 cubic feet
- Volume of coarse aggregate (W = 1,735 pounds and G = 2.60)
  = 1,735 ÷ (2.60 x 62.4) = 10.69 cubic feet

7. **Determine the fine aggregate content.** To determine the weight of the fine aggregate needed for a cubic yard of the oncrete, you first need to add together the volumes obtained in Step 6 above. The resulting sum is then subtracted from 27 cubic feet to obtain the volume of the fine aggregate in a cubic yard of the concrete. This is shown as follows:

Cement	= 3.10 cubic feet
Water	= 4.89 cubic feet
Coarse aggregate	= 10.69 cubic feet
Air	= 1.35 cubic feet
	= 20.03 cubic feet
Absolute volume of fine aggregate	= 27 – 20.03
	= 6.97 cubic feet

Now, having calculated the volume of the fine aggregate and having been given its specific gravity, you can use the formula shown in Step 6 above to solve for the weight of the fine aggregate as follows:

Weight of fine aggregate = 6.97 x 2.65 x 62.4

= 1,152 pounds

8. **Determine the quantities for the first trial batch.** Let's assume that the size of our laboratory trial batch is 1 cubic yard. For a batch of this size, you need the following quantities of the ingredients:

- Cement Type IA
  = 610 pounds 94 pounds per sack
  = 6.49 sacks
- Water
  = 305 pounds 8.33 pounds per gallon
  = 36.6 gallons
- Coarse aggregate = 1,735 pounds
- Fine aggregate = 1,152 pounds
- Air content = 5.0 percent

If needed, more trial batches should be mixed to obtain the desired slump and air content while you keep the water-cement ratio constant.

Variation in Mixtures

The proportions at which you arrive in determining mixtures will vary somewhat depending upon which method you use. The variation is the result of the empirical nature of the methods and does not necessarily imply that one method is better than another. You start each method by assuming certain needs or requirements and then proceed to determine the other variables. Since the methods begin differently and use different procedures, the final proportions vary slightly. This is to be expected and points out further the necessity of trial mixtures in determining the final mixture proportions.

Adjustments for Moisture in Aggregates

The initial mix design assumes that the aggregates are saturated, surface dry (SSD); that is, neither the fine aggregates nor the coarse aggregates have any free water on the surface that would be available as mixing water. This is a laboratory condition and seldom occurs in the field. The actual amount of water on the sand and gravel can be determined only from the material at the mixing site. Furthermore, the moisture content of the aggregates will change over a short period of time; therefore, their condition must be monitored and appropriate adjustments made as required. Coarse aggregates are free draining and rarely hold more than 2 percent (by weight) of free surface moisture (FSM) even after heavy rains. A good field test for estimating the FSM on fine aggregates is the squeeze test described below.

- The squeeze test.

1. Take samples for the squeeze test from a depth of 6 to 8 inches below the surface of the piled sand. This negates the effect of evaporation at the surface of the pile.

2. Squeeze a sample of the sand in your hand. Then open your hand and observe the sample. The amount of FSM can be estimated using the following criteria:

a. Damp sand (0- to 2-percent FSM). The sample will tend to fall apart (fig. 17-1). The damper the sand, the more it tends to cling together.

b. Wet sand (2- to 4-percent FSM). The sample clings together without excess water (fig. 17-2).

c. Very wet sand (5- to 8-percent FSM). The sand will ball and glisten or sparkle with water (fig. 17-3). The hand will have moisture on it and may even drip.

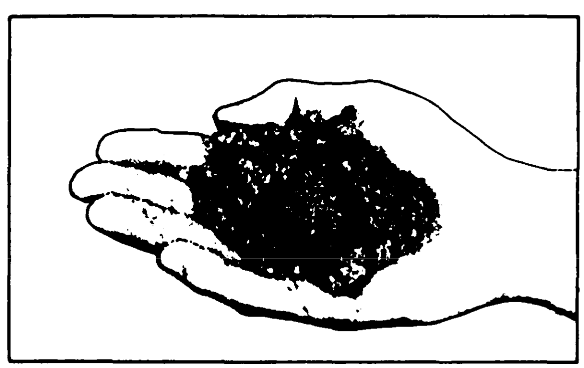

Figure 17-1.—Damp sand.

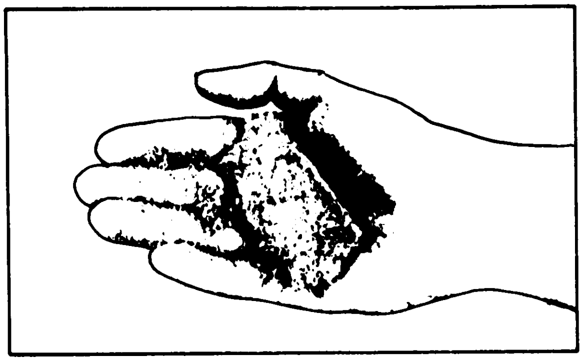

Figure 17-2.—Wet sand.

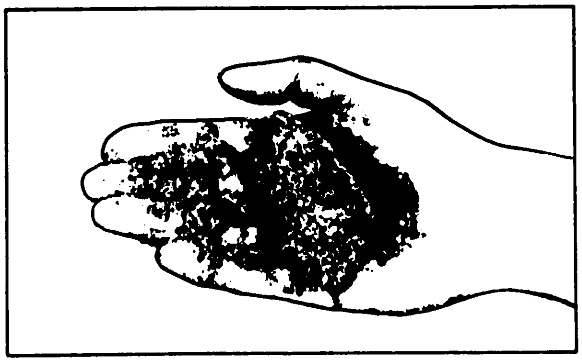

Figure 17-3.—Very wet sand.

The procedure for adjusting the mixing water caused by free surface moisture is as follows:

- Determine the approximate FSM of the fine aggregate by the squeeze test.
- Estimate the FSM of the coarse aggregate by observation. Usually, 2-percent FSM is the maximum amount gravel will hold without actually dripping.
- Multiply the percentages of FSM on the aggregates by their respective weights per cubic yard. This will yield the weight of the FSM on the aggregates.
- Divide the total weight of the FSM by 8.33 pounds per gallon to determine the number of gallons of water. Subtract those gallons from the mixing water requirements in the original mix design.
- If you are batching your concrete mix by weight, you need to account for the weight contributed by the FSM by increasing the total weights of the aggregates per cubic yard by the weights of the FSM.

Example Problem: Using the final mix proportions as determined, adjust the design mix to account for 6-percent FSM on the fine aggregate (FM = 2.70) and 2-percent FSM on the coarse aggregate. Original mix design for a 1-cubic-yard trial batch was

Cement:	6.49 sacks (Type IA)
Water:	36.6 gallons
Coarse aggregate:	1,735.0 pounds
Fine aggregate:	1,153.0 pounds
Air content:	5.0 percent

Step 1. Determine the amount of water (in gallons) on the coarse and fine aggregate.

- Coarse aggregate = 1,735 x 0.02 = 34.70 pounds
- Fine aggregate = 1,153 x 0.06 = 69.18 pounds
- Total weight of water = 103.88 pounds

  Converted to gallons = 12.47 gallons

Step 2. Adjust the original amount of mixing water by subtracting the amount of water contributed by the aggregates. The adjusted water requirement then is 24.13 gallons (36.6 - 12.47).

Step 3. Adjust the weights of the aggregates by the amount contributed by the water.

- Coarse aggregate = 1,735 + 34.7 = 1,770 pounds
- Fine aggregate = 1,153 + 69.18 = 1,222 pounds

Step 4. The adjusted mix design to account for the actual field conditions is now

Cement:	6.49 sacks (Type IA)
Water:	24.13 gallons
Coarse aggregate:	1,770.0 pounds
Fine aggregate:	1,122.0 pounds
Air content:	5.0 percent

You should check the moisture content of the aggregates and make appropriate adjustments as conditions change (such as after rains, after periods of dryness, or when the new material arrives). This quality control step assures that the desired concrete is produced throughout the construction phase.

Materials Estimation

After proportioning the mix, you must estimate the total amount of material needed for the job. This is simply done by computing the total volume of concrete

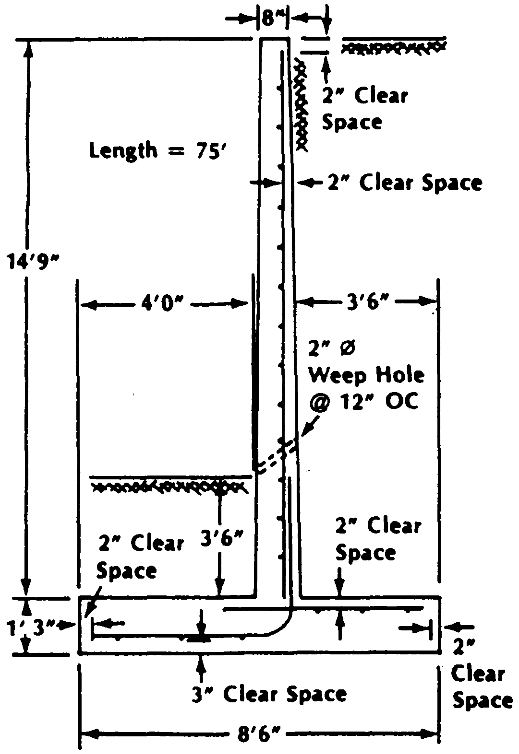

Figure 17-4.—Retaining wall.

to be poured, adding a waste factor, and multiplying this volume times the amount of each component in the 1-cubic-yard mix design. The manner of doing this is described in the following example.

Example Problem: Using the mix design determined previously in this chapter, determine the total amount of materials needed to construct the 75-foot-long retaining wall shown in figure 17-4. The 1-cubic-yard mix design is recapped below.

Cement:	6.49 sacks (Type IA)
Water	36.6 gallons
Coarse aggregate:	1,735.0 pounds
Fine aggregate:	1,153.0 pounds
Air content:	5.0 percent

To determine the total quantity of each of the above ingredients needed for the retaining wall, you must first calculate the total volume of concrete required. As you should know by now, an easy way to do this is to break the retaining wall into simple geometric shapes and then determine and accumulate the volumes of those shapes. Since you should know how to do this, we will simply say that the total volume of the retaining wall is 63.7 cubic yards. To this figure you add a 10-percent waste factor so that the adjusted amount of concrete needed for the project is 70.07 cubic yards. (Had the initial volume needed been greater than 200 cubic yards, you would have used a 5-percent waste factor.)

Now that you know the total amount of concrete needed, you can determine the total quantity of each of the concrete ingredients by simply multiplying the amount of each ingredient needed for 1 cubic yard by the total amount of concrete required for the retaining wall. As an example, you need 1,153 x 70.07 = 80,790.7 pounds, or 40.4 tons, of fine aggregate for the retaining wall. The other ingredients are computed in the same way. That being done, you find that the following quantities of ingredients are need for the project:

Cement:	455.0 sacks (Type IA)
Water:	2,567.0 gallons
Coarse aggregate:	60.8 tons
Fine aggregate:	40.4 tons

BITUMINOUS MIX DESIGN

Hot-mix bituminous concrete for pavements is a mixture of blended aggregate filled with bituminous cement binder. The materials are heated while being mixed to promote fluidity of the bitumen for thorough coverage of the aggregate particles. The design of a bituminous concrete mix consists of the determination of an economical blend and gradation of aggregates together with the necessary content of bituminous cement to produce a mixture that will be durable, have the stability to withstand traffic loads, and be workable for placement and compaction with the construction equipment available.

The procedures described in this section are performed during the design of a hot-mix bituminous concrete. They include testing, plotting the results on graphs, and checking the readings against values from the design tables. Testing of the ingredients and the mix is started before and continued throughout the paving operations. Specific test procedures are not covered in this discussion; instead, you should refer to chapter 13 of this TRAMAN and to *Materials Testing,* NAVFAC MO-330.

GENERAL PROCEDURES AND GUIDELINES

The objective of hot-mix design is to determine the most economical blend of components that will produce a final product that meets specified requirements. The following is a list of general procedures:

1. Prepare a sieve analysis of each of the aggregates available.

2. Determine the aggregate blend that will achieve the specified gradation *(Paving and Surfacing Operations,* TM 5-337). Plot the selected blend proportions on a graph with the allowable limits to see that it conforms.

3. Determine the specific gravity of the components.

4. Using selected percentages of bitumen (TM 5-337), make trial mixes, and compute the design test properties of the mix.

5. Plot the test properties on individual graphs using the selected bitumen percentages. Draw smooth curves through the plotted points.

6. Select the optimum bitumen content (AC) for each test property from the curves of the Marshall test results. For a discussion of the Marshall stability test, you can refer to chapter 13 of this TRAMAN and to NAVFAC MO-330.

7. Average the bitumen content values (from Step 6) and, from the graphs, read the test property value corresponding to this average.

8. Check these read values with the satisfactoriness of mix criteria.

The selection of the mix ratios of materials is tentative. The bitumen should be the same as the one to be used in construction. The aggregates and fillers must meet definite requirements. In general, several blends should be considered for laboratory mix-design tests.

Gradation specifications are based on limits established by the U.S. Army Corps of Engineers as satisfactory. Within these limits, the following variables are considerations that will affect the final mix design:

1. Use of mix (surface course, binder course, or road mix)
2. Binder (asphalt, cement, or tar)
3. Loading (low tire pressure—100 psi and under, or high tire pressure—over 100 psi)
4. Maximum size of aggregate (in stockpile or based on thickness of the pavement course)

Once the gradation specifications have been selected, you should check the available materials to determine how to proportion the blend to meet these specifications. You should study sieve analyses of the available aggregates and compute a series of trial blends. You may have to make adjustment of the blend after testing the design and prepared mix. The considerations for establishing and adjusting the blend are explained in TM 5-337.

The determination of optimum bitumen content is based on a definite design and testing procedure known as the Marshall method. This method is explained in chapter 13 of this TRAMAN and in NAVFAC MO-330.

The final step is the preparation of a job-mix formula to be furnished to the construction unit.

It is recognized that at times it will be necessary to shorten the design procedure as much as possible to expedite military construction. For additional information, refer to TM 5-337.

EXAMPLE OF MARSHALL METHOD OF HOT-MIX DESIGN

A typical mix design is illustrated by the calculations and graphs shown on figures 17-5 through 17-10.

Aggregate Grading

An aggregate grading chart is shown in figure 17-5 (DD Form 1207). This chart shows the gradation curves of the three aggregates that are available for the mix. The sieve analyses are run in the manner as described in the EA3 TRAMAN. Calculations may be made and data recorded on standard sieve analysis data sheets before the curves are drawn. A gradation curve is not shown for the mineral filler to be used.

Aggregate Blending

The front and back sides of a data and computation sheet for aggregate blending is shown in figures 17-6A and 17-6B (DD Form 1217). The gradation of the available aggregates should be recorded on the upperpart (fig. 17-6A) of the form. The lower part (fig. 17-6A) may be used for the computation of the trial blend. Several attempts may be required before a blend meeting specifications is obtained. The cold feeds (quantities per batch) of aggregate to the asphalt plant

GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADING CHART

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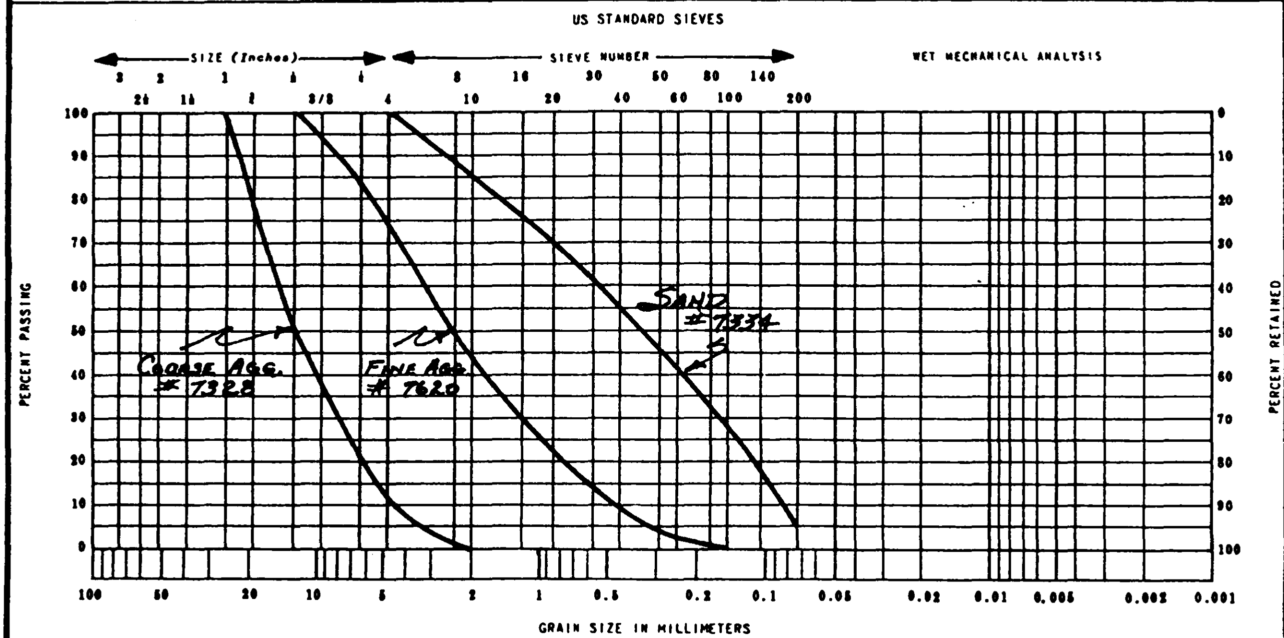
PROJECT HIGHWAY #203



EXCAVATION NUMBER	SAMPLE NUMBER	NATURAL % MOISTURE	w_L	w_P	I_P	CLASSIFICATION	REMARKS
	7328						COARSE AGGREGATE
	7620						FINE AGGREGATE
	7334						SAND

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DD FORM 1 AUG 57 1207

GPO 931160

Figure 17-5.—Aggregate grading chart, stockpile materials.

BITUMINOUS MIX DESIGN - AGGREGATE BLENDING		DATE: 2 APR 19__
PROJECT: HIGHWAY #203	JOB: NO. 47236	AGGREGATE GRADATION NUMBER: 2A

GRADATION OF MATERIAL

SIEVE SIZE (To be entered by Technician): →	1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	
MATERIAL USED	PERCENT PASSING											
COARSE AGGREGATE (CA)	100	72	46	33	12	2	0	0	0	0	0	
FINE AGGREGATE (FA)	100	100	98	94	75	54	33	13	2	0	0	
FINE RIVER BAR SAND (FRBS)	100	100	100	100	100	98	90	76	58	35	3	
LIMESTONE DUST (LSD)	100	100	100	100	100	100	100	100	98	95	90	
DESIRED:	100	80-95	68-86	60-77	45-60	34-49	26-40	19-30	14-23	8-16	3-7	

COMBINED GRADATION FOR BLEND - TRIAL NUMBER FINAL

SIEVE SIZE (To be entered by Technician): →		1"	3/4"	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	
MATERIAL USED	% USED	PERCENT PASSING											
CA	45	45.0	32.4	20.7	14.9	5.4	0.9	0	0	0	0	0	
FA	30	30.0	30.0	29.4	28.2	22.5	16.2	9.9	3.9	0.6	0	0	
FRBS	20	20.0	20.0	20.0	20.0	20.0	19.6	18.0	15.2	11.6	7.0	0.6	
LSD	5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	4.9	4.8	4.5	
BLEND:		100.0	87.4	75.1	68.1	52.9	41.7	32.9	24.1	17.1	11.8	5.1	
DESIRED:		100.0	87.5	77.0	68.5	52.5	41.5	33.0	24.5	18.5	12.0	5.0	

COMBINED GRADATION FOR BLEND - TRIAL NUMBER ____________

SIEVE SIZE (To be entered by Technician): →													
MATERIAL USED	% USED	PERCENT PASSING											
BLEND:													
DESIRED:													

DD FORM 1 DEC 65 1217 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 17-6A.—Bituminous mix design, aggregate blending, data sheet (front).

COMBINED GRADATION FOR BLEND - TRIAL NUMBER ______													
SIEVE SIZE *(To be entered by Technician)*: →													
MATERIAL USED	% USED	PERCENT PASSING											
BLEND:													
DESIRED:													

COMBINED GRADATION FOR BLEND - TRIAL NUMBER ______													
SIEVE SIZE *(To be entered by Technician)*: →													
MATERIAL USED	% USED	PERCENT PASSING											
BLEND:													
DESIRED:													

REMARKS		
TECHNICIAN *(Signature)*	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)*

Figure 17-6B.—Bituminous mix design, aggregate blending, data sheet (back).

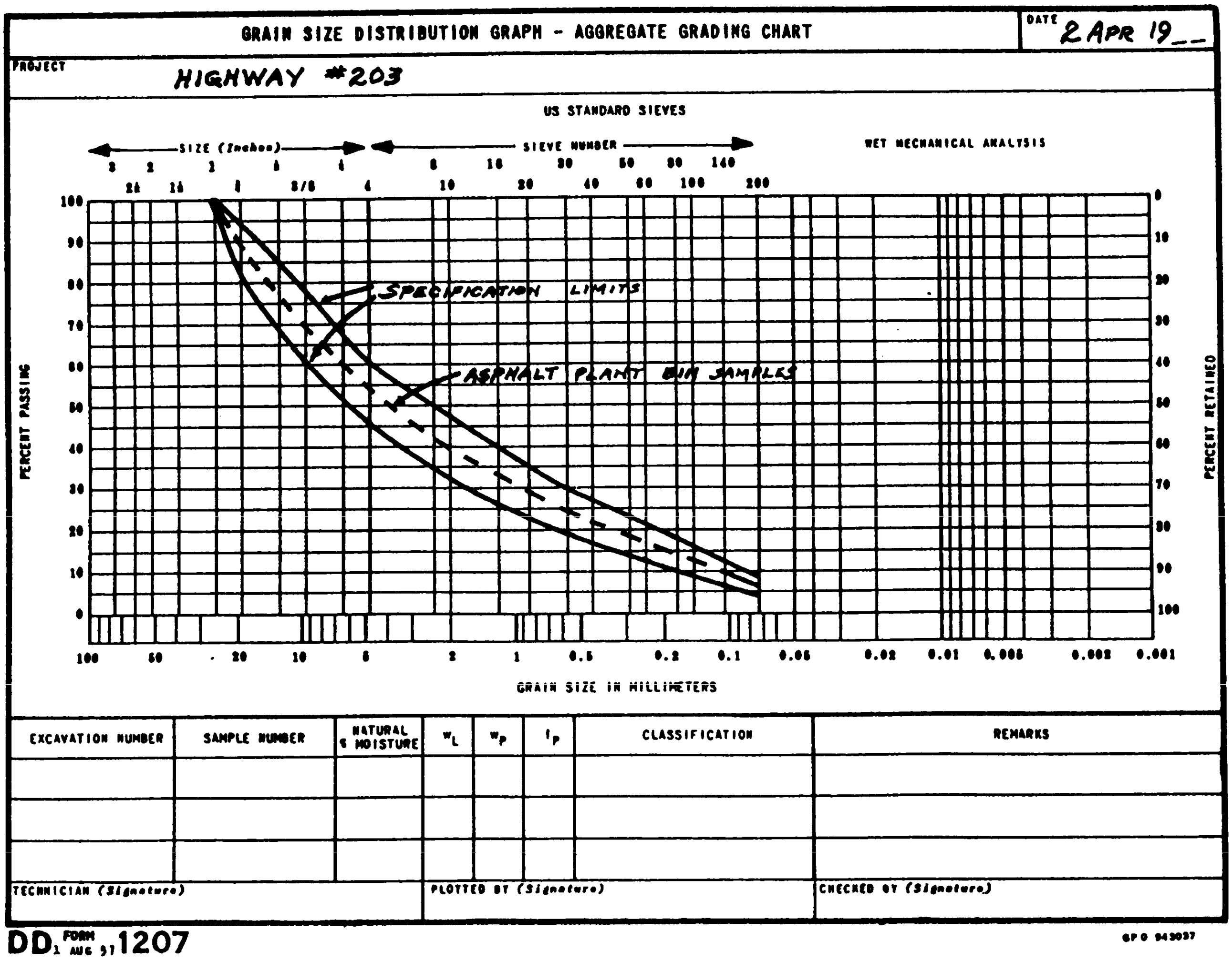


Figure 17-7.—Aggregate grading chart, specification limits and gradation of blended aggregate.

SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS		DATE 2 APR 19__		
PROJECT HIGHWAY #203	JOB No. 47236			
COARSE AGGREGATE	UNITS *(Grams)*			
MATERIAL PASSING 1" SIEVE AND RETAINED ON 16 SIEVE				
SAMPLE NUMBER	CA			
1. WEIGHT OF OVEN - DRY AGGREGATE	378.3			
2. WEIGHT OF SATURATED AGGREGATE IN WATER	241.0			
3. DIFFERENCE *(Line 1 minus 2)*	137.3			
APPARENT SPECIFIC GRAVITY, G = (Line 1)/(Line 3)	378.3/137.3 = 2.755			
FINE AGGREGATE	UNITS *(Grams)*			
MATERIAL PASSING NUMBER 3/8" SIEVE				
SAMPLE NUMBER	FRBS			
4. WEIGHT OF OVEN - DRY MATERIAL	478.8			
5. WEIGHT OF FLASK FILLED WITH WATER AT 20°C	678.6			
6. SUM *(Line 4 + 5)*	1157.4			
7. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C,	977.4			
8. DIFFERENCE *(Line 6 minus 7)*	180.0			
APPARENT SPECIFIC GRAVITY, G = (Line 4)/(Line 8)	478.8/180.0 = 2.660			
FILLER	UNITS *(Grams)*			
SAMPLE NUMBER	LSD			
9. WEIGHT OF OVEN - DRY MATERIAL	466.5			
10. WEIGHT OF FLASK FILLED WITH WATER AT 20°C,	676.1			
11. SUM *(Line 9 + 10)*	1142.6			
12. WEIGHT OF FLASK + AGGREGATE + WATER AT 20°C,	973.8			
13. DIFFERENCE *(Line 11 minus 12)*	168.8			
APPARENT SPECIFIC GRAVITY, G = (Line 9)/(Line 13)	466.5/168.8 = 2.762			
BINDER	UNITS *(Grams)*			
SAMPLE NUMBER	6873			
14. WEIGHT OF PYCNOMETER FILLED WITH WATER	61.9595			
15. WEIGHT OF EMPTY PYCNOMETER	37.9215			
16. WEIGHT OF WATER *(Line 14 minus 15)*	24.0380			
17. WEIGHT OF PYCNOMETER + BINDER	47.8617			
18. WEIGHT OF BINDER *(Line 17 minus 15)*	9.9402			
19. WEIGHT OF PYCNOMETER + BINDER + WATER TO FILL PYCNOMETER	62.1568			
20. WEIGHT OF WATER TO FILL PYCNOMETER *(Line 19 minus 17)*	14.2951			
21. WEIGHT OF WATER DISPLACED BY BINDER *(Line 16 minus 20)*	9.7429			
APPARENT SPECIFIC GRAVITY, G = (Line 18)/(Line 21)	9.9402/9.7429 = 1.020			
TECHNICIAN *(Signature)*	COMPUTED BY *(Signature)*	CHECKED BY *(Signature)*		

DD FORM 1 DEC 65 1216 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 17-8.—Specific gravity of bituminous mix components, data sheet.

MARSHALL METHOD - COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES													DATE OF COMPUTATION 2 APR 19__	
JOB NUMBER 47236			PROJECT HIGHWAY #203					DESCRIPTION OF BLEND SURFACE COURSE 45/30/20/5 AGG BLEND						
SPECIMEN NUMBER	ASPHALT CEMENT (Percent)	THICK-NESS (Inches)	WEIGHT (Grams)		VOLUME CC	SPECIFIC GRAVITY		AC BY VOLUME (Percent)	VOIDS (Percent)		UNIT WEIGHT TOTAL MIX (Lb./Cu.Ft.)	STABILITY (Pounds)		FLOW UNITS OF 1/100 IN.
			IN AIR	IN WATER		ACTUAL	THEO-RIZED		TOTAL MIX	FILLED		MEASURED	CON-VERTED	
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
					(d - e)	(d)/(f)		(b x g)/(Sp.Gr. of AC)	(100-100(g)/(h))	(i)/(i + j)	(g x 62.4)		*	
A-1	3.5		1228.3	716.3	512.0	2.339						2020	2020	11
A-2	3.5		1219.5	712.2	507.3	2.404						1862	1936	10
A-3	3.5		1205.5	705.3	500.2	2.410						1821	1894	8
A-4	3.5		1206.2	708.4	497.8	2.423						1892	1868	8
AVG.	3.5		—	—	—	2.409	2.579	8.3	6.6	55.7	150.3	—	1955	9
B-1	4.0		1276.9	747.3	529.6	2.411						2110	2026	10
B-2	4.0		1252.6	733.3	519.3	2.412						2025	2025	9
B-3	4.0		1243.5	730.7	512.8	2.425						1995	1995	9
B-4	4.0		1230.4	722.8	507.6	2.424						2080	2101	9
AVG.	4.0		—	—	—	2.418	2.550	9.5	5.5	66.3	150.9	—	2037	9
C-1	4.5		1254.4	738.2	516.2	2.430						2050	2050	12
C-2	4.5		1238.3	726.8	511.5	2.421						2095	2095	9
C-3	4.5		1239.0	724.9	514.1	2.410						2110	2110	10
C-4	4.5		1273.5	752.0	521.5	2.442						2045	2045	10
AVG.	4.5		—	—	—	2.426	2.539	10.7	4.5	70.4	151.4	—	2075	10
* From conversion table			COMPUTED BY						CHECKED BY					

DD FORM 1 DEC 65 1218 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 17-9A.—Test results, Marshall stability test (front).

MARSHALL METHOD - COMPUTATION OF PROPERTIES OF ASPHALT MIXTURES	DATE OF COMPUTATION 3 APR. 19__
JOB NUMBER	PROJECT
DESCRIPTION OF BLEND	

SPECIMEN NUMBER	ASPHALT CEMENT (Percent)	THICKNESS (Inches)	WEIGHT (Grams) IN AIR	WEIGHT (Grams) IN WATER	VOLUME CC	SPECIFIC GRAVITY ACTUAL	SPECIFIC GRAVITY THEORIZED	AC BY VOLUME (Percent)	VOIDS (Percent) TOTAL MIX	VOIDS (Percent) FILLED	UNIT WEIGHT TOTAL MIX (Lb./Cu.Ft.)	STABILITY (Pounds) MEASURED	STABILITY (Pounds) CONVERTED	FLOW UNITS OF 1/100 IN.
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o
					(d - e)	(d)/(f)		(b x g)/(Sp.Gr. of AC)	(100-100 (g)/(h))	(i)/(i + j)	(g x 62.4)		*	
D-1	5.0		1237.9	727.0	510.9	2.423						1875	1875	14
D-2	5.0		1300.0	763.6	536.3	2.424						2130	1981	10
D-3	5.0		1273.6	746.9	526.7	2.418						1900	1824	12
D-4	5.0		1247.9	731.8	516.1	2.418						1855	1855	12
AVG.	5.0		—	—		2.421	2.519	11.9	3.9	75.3	151.5	—	1884	12
E-1	5.5		1237.3	724.1	513.2	2.411						1450	1450	12
E-2	5.5		1264.0	740.6	523.4	2.415						1530	1469	14
E-3	5.5		1286.4	752.4	534.0	2.409						1615	1550	13
E-4	5.5		1253.4	733.8	519.7	2.412						1505	1505	16
AVG.	5.5		—	—	—	2.412	2.500	13.0	3.6	78.3	150.5	—	1494	14

* From conversion table	COMPUTED BY	CHECKED BY

DD FORM 1 DEC 65 1218 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 17-9B.—Test results, Marshall stability test (back).

BITUMINOUS MIX CURVES

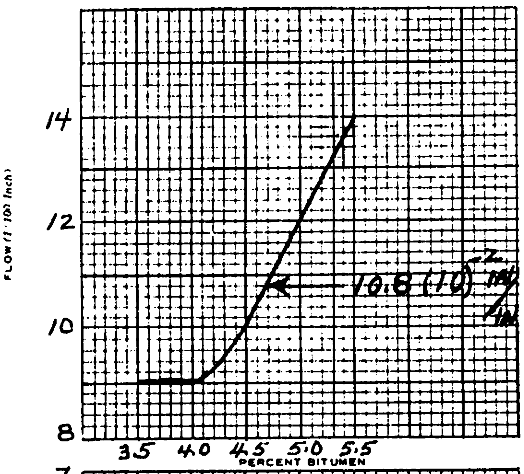
DATE: 2 APR 19__

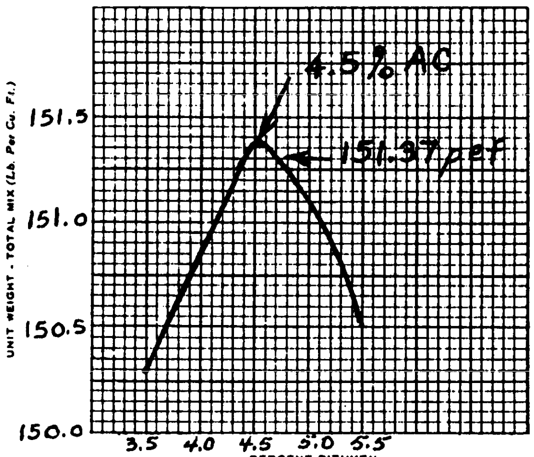
PROJECT: AIRFIELD NO.3

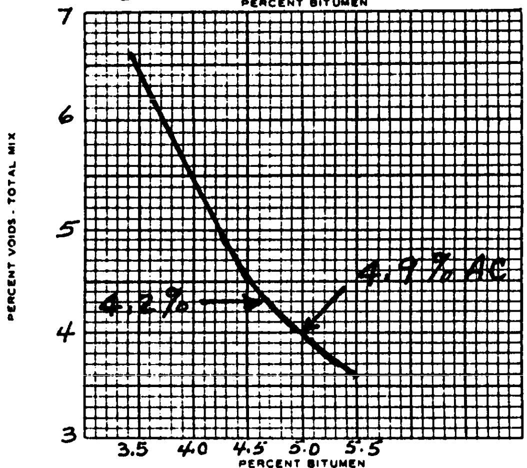
JOB: NO. 47239 (SURFACE COURSE)

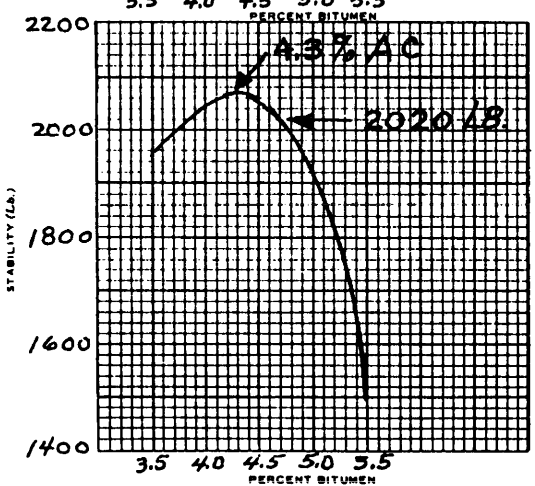
RECAP OF MARSHALL TEST RESULTS

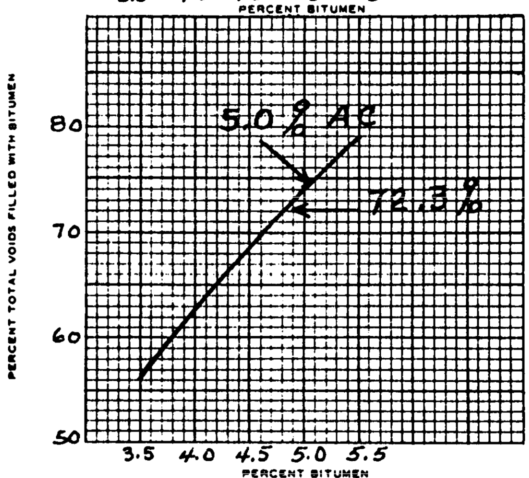
PERCENT BITUMEN CONTENT	3.5	4.0	4.5	5.0	5.5
UNIT WEIGHT - AGGREGATE ONLY					
UNIT WEIGHT - TOTAL MIX	150.3	150.9	151.4	151.1	150.5
STABILITY	1955	2037	2075	1884	1494
FLOW	9	9	10	12	14
PERCENT VOIDS - AGGREGATE ONLY					
PERCENT VOIDS - TOTAL MIX	6.6	5.5	4.5	3.9	3.6
PERCENT OF TOTAL VOIDS FILLED WITH BITUMEN	55.7	63.3	70.4	75.3	78.3











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DD FORM 1 DEC 65 1219 PREVIOUS EDITION OF THIS FORM IS OBSOLETE.

Figure 17-10.—Asphalt mix curves, Marshall test properties.

are set according to the proportions obtained in the computation of the final trial blend.

Aggregate Blending Limits

Figure 17-7 is an aggregate grading chart (DD Form 1207), showing the specification limits for the mix and the gradation of the blend when mixed in the proportions shown in figure 17-6A, trial No. 1.

Specify Gravity of Bituminous Mix Components

A specific gravity data sheet is shown in figure 17-8 (DD Form 1216). This form is used for computing the specific gravity of all the bituminous mix components. If more aggregate fractions are used than are provided for on the form, additional forms may be used. Procedures for performing these tests are discussed in chapter 13 of this TRAMAN.

Marshall Stability Computations

DD Form 1218 (figs. 17-9A and 17-9B) is a data and computation sheet used in the Marshall stability test. The specific gravity values of the aggregates and the aggregate fraction percentages from the trial blending furnish the information to compute the fractional weights and to prepare the test specimens. Record the measurements made on the test specimens in the upper right-hand corner of the form. Determine, as described in chapter 13 of this TRAMAN, the stability, flow, unit weight of total mix, and percentage of voids filled with binder to complete the form.

Marshall Method Computations

Transfer the values from DD Form 1218 (figs. 17-9A and 17-9B) for each binder content computation to DD Form 1219 (fig. 17-10). Each graph on the form represents a different test property. Plot the values for each property on their respective graph using the binder contents as ordinates. Draw a smooth curve through the plotted points.

Marshall Test Criteria

Table 17-7 lists the criteria for determining optimum asphalt content (OAC). For each test property, you should consider the type of mix to be used and the expected load. The optimum bitumen content for each property is designated as a definite point on the curve for that property. The bitumen content percentages (one for each property) are averaged, and the average is used to read the corresponding value of each test property. The value, as determined, should be referred to the criteria portion of table 17-7 to see if it is within the permissible limits so that the mix will perform satisfactorily.

Test Variation for Aggregates with 10 Percent or More Larger Than 1-Inch Maximum Size

The procedure described in the Marshall method and the examples as given in the preceding paragraphs are applicable to hot-mix design where the amount of aggregate larger than the 1-inch sieve is less than 10 percent of the total. When the larger than (plus) 1-inch material exceeds 10 percent of the total, the following variations are made in the procedure:

1. Mix bitumen at the selected content with the **entire** aggregate, including the plus 1-inch portion.

2. Pass the mixed hot batch through a 1-inch sieve. Discard the plus 1-inch portion.

3. Make compacted specimens from the portion that passes the 1-inch sieve and perform the Marshall test, except do not calculate the voids of the compacted specimens at this time.

4. Determine the bulk specific gravity of the plus 1-inch aggregate, and, with the specific gravity of the compacted specimens, compute the adjusted specific gravity (GA) as follows:

$$G_A = \frac{100}{\frac{A}{C} + \frac{B}{D}} \times f$$

where:

A = weight of dry, plus 1-inch material expressed as a percentage of the total batch weight (bitumen plus aggregate)

B = portion of total batch remaining after the dry, plus 1-inch portion is removed (100%-A%)

C = bulk specific gravity of plus 1-inch aggregate

D = actual specific gravity of compacted specimen

f = empirical factor = 0.995

Table 17-7.—Marshall Test Specifications and Determination of Optimum Asphalt Content

(1) Property	(2) Course	(3) Criteria (75 Blows) *** High press	(3) Criteria (50 Blows) Low press	(4) Determination of OAC High press	(4) Determination of OAC Low press
a. Aggregate blends showing water absorption up to 2 1/2% (used with ASTM apparent specific gravity).					
Stability	Surface	1800 or higher	500 or higher	Peak of curve	Peak of curve
Unit wt	Surface	---	---	Peak of curve	Peak of curve
Flow	Surface	16 or less	20 or less	Not used	Not used
% Voids total mix	Surface	3% - 5%	3% - 5%	4% -	4%
% Voids filled w/AC	Surface	70% - 80%	75% - 85%	75%	80%
Stability	Binder	1800 or higher	500 or higher	Peak of curve*	Peak of curve*
Unit wt	Binder	---	---	Peak of curve*	Peak of curve*
Flow	Binder	16 or less	20 or less	Not used	Not used
% Voids total mix	Binder	5% - 7%	4% - 6%	6%	5%
% Voids filled w/AC	Binder	50% - 70%	65% - 75%	60%*	70%*
Stability	Sand asphalt	**	500 or higher	**	Peak of curve
Unit wt	Sand asphalt	---	---	**	Peak of curve
Flow	Sand asphalt	**	20 or less	Not used	Not used
% Voids total mix	Sand asphalt	**	5% - 7%	**	6%
% Voids filled w/AC	Sand asphalt	**	65% - 75%	**	70%
b. Aggregate blends showing water absorption greater than 2 1/2% (used with bulk impregnated specific gravity).					
Stability	Surface	1800 or higher	500 or higher	Peak of curve	Peak of curve
Unit wt	Surface	---	---	Peak of curve	Peak of curve
Flow	Surface	16 or less	20 or less	Not used	Not used
% Voids total mix	Surface	2% - 4%	2% - 4%	3%	3%
% Voids filled w/AC	Surface	75% - 85%	80% - 90%	80%	85%
Stability	Binder	1800 or higher	500 or higher	Peak of curve*	Peak of curve*
Unit wt	Binder	---	---	Peak of curve*	Peak of curve*
Flow	Binder	16 or less	20 or less	Not used	Not used
% Voids total mix	Binder	4% - 6%	3% - 5%	5%	4%
% Voids filled w/AC	Binder	55% - 75%	70% - 80%	65%	75%
Stability	Sand asphalt	**	500 or higher	**	Peak of curve
Unit wt	Sand asphalt	---	---	**	Peak of curve
Flow	Sand asphalt	**	20 or less	Not used	Not used
% Voids total mix	Sand asphalt	**	4% - 6%	**	5%
% Voids filled w/AC	Sand asphalt	**	70% - 80%	**	75%

*If the inclusion of bitumen contents at these points in the average causes the voids total mix to fall outside the limits, then the optimum bitumen should be adjusted so that the voids total mix are within the limits.
**Criteria for sand asphalt to be used in designing pavement for high pressure tires have not been established.
***High pressure tires are those above 100 psi. Low pressure tires are those with 100 psi or under.

5. Calculate the voids by using the adjusted specific gravity, and apply the design criteria for this value.

6. Use stability and flow values as measured on the compacted specimens.

JOB-MIX FORMULA (AC MIXES)

When the mix has proven itself to be satisfactory, the percentages by weight of the aggregate and the averaged optimum bitumen content should be combined to establish the job-mix formula. Figure 17-6A lists the final percentages of the aggregate for a given job mix. By plotting the test results (figs. 17-9A and 17-9B) on DD Form 1219 (fig. 17-10) and applying the Marshall test criteria for determining optimum bitumen content, you make the determination that the mix requires 4.7 percent of asphalt cement. Accordingly, the aggregates must be 95.3 percent of the total mix. The selected blend contained 45-percent coarse aggregate (CA), 30-percent fine aggregate (FA), 20-percent fine river bar sand (FRBS), and a 5-percent limestone dust (LSD) mineral filler. The job-mix formula is computed as follows:

CA	=	95.3 × .45	=	42.9%
FA	=	95.3 × .30	=	28.6%
FRBS	=	95.3 × .20	=	19.0%
Mineral filler	=	95.3 × .05	=	4.8%
				95.3%
Asphalt cement	=			4.7%
Total	=			100.0%

MODIFIED TEST FOR COLD-MIX PAVEMENTS

This method is used as an aid in determining the asphalt content for cold-mix design of light-duty pavement. It can be used where asphalt cutbacks will be the binder. The procedures follow those used for hot-mix design (Marshall method), in general, with the following modifications:

- **Aggregates.** Aggregates should be dried to a moisture content expected during construction (up to a maximum of 2 percent, by weight).

- **Asphalt.** Mix selected bitumen with the aggregates, but at the temperature recommended for field application. The aggregates remain at room temperature.

- **Curing.** Before compaction, cure the mixture for at least 12 hours in an oven set at 140°F ($\pm$ 5°).

- **Cooling.** After molding, cool the specimens to room temperature in the molds. You must take care to remove the specimens, undisturbed and undamaged, from the molds.

- **Testing.** Heat the specimens in an oven to 100° ($\pm$ 2°) and test them in the Marshall machine. Heating will normally take about 2 hours.

- Selection of the design amount of asphalt. The asphalt contents at maximum density and maximum stability, after averaging, are used as the design amount.

SURFACE AREA METHOD OF MIX DESIGN

When laboratory equipment, except for sieve analysis, is not available, the following formulas may be used in place of laboratory procedures to determine the necessary asphalt content:

1. For asphalt cement:

$$P = 0.02a + 0.07b + 0.15c + 0.20d$$

where:

P = percent (expressed as a whole number) of asphalt material **by weight of dry aggregate**

a = percent (expressed as a whole number) of mineral aggregate retained on the No. 50 sieve

b = percent (expressed as a whole number) of mineral aggregate passing the No. 50 and retained on the No. 100 sieve

c = percent (expressed as a whole number) of mineral aggregate passing the No. 100 and retained on the No. 200 sieve

d = percent (expressed as a whole number) of mineral aggregate passing the No. 200 sieve

Absorptive aggregates, such as slag, limerock, vesicular lava, and coral, will require additional asphalt.

2. For asphalt emulsion:

$$P = 0.05A + 0.1B + 0.5C$$

where:

P = percent (expressed as a whole number) by weight of asphalt emulsion, based on weight of graded mineral aggregate

A = percent (expressed as a whole number) of mineral aggregate retained on the No. 8 sieve

B = percent (expressed as a whole number) of mineral aggregate passing the No. 8 sieve and retained on the No. 200 sieve

C = percent (expressed as a whole number) of mineral aggregate passing the No. 200 sieve

QUESTIONS

Q1. *Your battalion has been tasked to replace a 5-inch-thick 2,000-square-yard reinforced concrete parking lot located at a naval air facility in northern Japan (extreme exposure). Your job is to design a concrete mix and determine the total quantities of materials needed to complete the project. Based on the parameters listed below, what is the (a) maximum size of the coarse aggregate that you should use, (b) amount of water (in gallons) needed for a 1-cubic-yard trial batch (c) amount of sand (in pounds) needed for a 1-cubic-yard trial batch (d) number of sacks of Type IA cement needed for the project, and (e) the amount (in tons) of coarse aggregate needed for the project?*

Average 28-day compressive strength (based on flexural-design strength)	*3,500 psi*
Fineness modulus of fine aggregate	*2.6*
Specific gravity of portland cement	*3.15*
Specific gravity offine aggregate	*2.75*
Specific gravity of coarse aggregate	*2.65*
Dry-rodded weight of coarse aggregate	*110 lb/cu ft*
Dry-rodded weight of fine aggregate	*100 lb/cu ft*
Slump	*2 in*

CHAPTER 18

SOIL STABILIZATION

Soil stabilization may be broadly defined as the alteration or preservation of one or more soil properties to improve the engineering characteristics and performance of a soil. This chapter is intended to provide you with a brief overview of soil stabilization in terms of (1) stabilization methods, (2) the types and selection of various chemical stabilizers used in soil stabilization and (3) general guidance and information relative to the design and testing of soil-cement and soil-bituminous mixtures. For a thorough understanding of the subject of soil stabilization, you should combine the study of this chapter with the study of the various references cited within the chapter.

METHODS OF STABILIZATION

The two general methods of stabilization are mechanical and additive. The effectiveness of stabilization depends upon the ability to obtain uniformity in blending the various materials. Mixing in a stationary or traveling plant is preferred; however, other means of mixing, such as scarifies, plows, disks, graders, and rotary mixers, have been satisfactory.

The method of soil stabilization is determined by the amount of stabilizing required and the conditions encountered on the project. An accurate soil description and classification is essential to the selection of the correct materials and procedures. Table 18-1 lists the

Table 18-1.—Stabilization Methods Most Suitable for Specific Applications

Purpose	Soil type	Method
1. Subgrade stabilization a. Improved load carrying and stress distribution characteristics.	Fine granular	SA, SC, MB, C
	Coarse granular	SA, SC, MB, C
	Clays of low PI	C, SC, CMS, LMS, SL
	Clays of high PI	SL, LMS
b. Reduce frost susceptibility	Fine granular	CMS, SA, SC, LF
	Clays of low PI	CMS, SC, SL, LMS
c. Waterproofing and improved runoff	Clays of low PI	CMS, SA, LMS, SL
d. Control of shrinkage and swell	Clays of low PI	CMS, SC, C, LMS, SL
	Clays of high PI	SL
e. Reduce resiliency	Clays of high PI	SL, LMS
	Plastic silts or clays	SC, CMS
2. Base coarse stabilization a. Improvements of substandard materials	Fine granular	SC, SA, LF, MB
	Clays of low PI	SC, SL
b. Improved load carrying and stress distribution characteristics.	Coarse granular	SA, SC, MB, LF
	Fine granular	SC, SA, LF MB
c. Reduction of pumping	Fine granular	SC, SA, LF, MB, membranes
3. Dust palliative	Fine granular	CMS, SA, Oil or bituminous surface spray, APSB
	Plastic soils	CMS, SL, LMS, APSB, DCA 70

Where the methods of treatment are:
APSB = Asphalt Penetration Surface Binder
C = Compaction
CMS = Cement modified Soil
DCA70 = Polyvinylacetate emulsion
LF = Lime Fly ash
LMS = Lime Modified Soil
MB = Mechanical Blending
SA = Soil-Asphalt
SC = Soil-Cement
SL = Soil-Lime

most suitable treatments for various soil types to stabilize these soils for different objectives.

MECHANICAL METHOD

Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification. The soil blending may take place at the construction site, at a central plant, or at a borrow area. The blended material is then spread and compacted to required densities by conventional means.

ADDITIVE METHOD

Additive refers to a manufactured commercial product that, when added to the soil in the proper quantities, will improve the quality of the soil layer. This chapter is directed towards the use of portland cement, lime, lime-cement-fly ash, and bitumen, alone or in combination, as additives to stabilize soils. The selection and determination of the percentage of additives depend upon the soil classification and the degree of improvement in soil quality desired. Generally, smaller amounts of additives are required to alter soil properties, such as gradation, workability, and plasticity, than to improve the strength and durability sufficiently to permit a thickness reduction design. After the additive has been mixed with the soil, spreading and compacting are accomplished by conventional means.

Stabilization by Cementing Action

This method requires the addition of chemical agents to the soil to produce the hardened product. There are three main stabilizing agents that can be added, and the method of treatment bears the name of these agents: soil-cement, soil-lime, and lime-fly ash. The methods of chemical stabilization have much in common and involve somewhat similar construction practices. They depend upon hydration, pozzolanic action of lime with silica and alumina, alteration of the clay material, or a combination of these actions. The result is a semirigid, fairly brittle material with considerable compressive strength and moderate flexural strength when tested either statically or dynamicaly. The ultimate strength depends to a great degree on the density that is achieved during compaction and before the mix cures.

Bituminous Stabilization

In bituminous treatment, the end product performs differently—at least initially, and the product is much less brittle. Additionally, its behavior depends on the nature of the loading (static or dynamic) and the temperature when the load is applied.

MODIFICATION METHOD

Soil stabilization by modification usually results in something less than a thoroughly cemented, hardened or semihardened material. This type of stabilization may be accomplished by compacting, by mechanical blending, by adding cementing materials in small amounts, or by adding chemical modifiers. Cement and lime modifiers (cement-modified soil and lime-modified soil) are used in quantities too small to provide high-strength cementing action. They reduce the plasticity of clay soils. Calcium chloride or sodium chloride is added to the soil to retain moisture (and also control dust), to hold fine material for better compaction, and to reduce frost heave by lowering the freezing point of water in the soil. Bituminous materials, such as cutback asphalts or asphaltic penetrative soil binder (APSB), and certain chemicals, such as polyvinyl acetate emulsion (DCA-70), are used to waterproof the soil surface and to control dust.

GENERAL REQUIREMENTS FOR USE OF STABILIZERS

This section discusses different types of stabilizers. It also provides a method of selecting the type or types of stabilizers that you can use for various conditions. Before a proper stabilizer can be selected, however, you must first perform, or have performed, a sieve analysis and Atterberg limits tests for the particular type of soil you are concerned with. Both sieve analysis and Atterberg limits testing are discussed in the EA3 TRAMAN and in *Materials Testing,* NAVFAC MO-330.

LIME

Experience shows that lime will react with many medium, moderately fine, and fine-grained soils to produce decreased plasticity, increased workability, reduced swell, and increased strength. Soils classified according to the Unified Soil Classification System (USCS) as CH, CL, MH, ML, OH, OL, SC, SM, GC, GM, SW-SC, SP-SC, SM-SC, GW-GC, GP-GC, ML-CL, and GM-GC should be considered as potentially capable of being stabilized with lime.

CEMENT

Cement can be used as an effective stabilizer for a wide range of materials. In general, however, the soil should have a PI less than 30. For coarse-grained soils, the amount passing the No. 4 sieve should be greater than 45 percent.

Fly ash, when mixed with lime, can be used effectively to stabilize most coarse- and medium-grained soils. However, the PI should not be greater than 25. Soils classified by the USCS as SW, SP, SP-SC, SW-SC, SW-SM, GW, GP, GP-GC, GW-GC, GP-GM, GW-GM, GC-GM, and SC-SM can be stabilized with fly ash.

BITUMINOUS

Most bituminous soil stabilization has been performed with asphalt cement, cutback asphalt, and asphalt emulsions. Soils that can be stabilized effictively with bituminous materials usually contain less than 30 percent passing the No. 200 sieve and have a PI less then 10. Soils classified by the USCS as SW, SP, SW-SM, SP-SM, SW-SC, SP-SC, SM, SC, SM-SC, GW, GP, SW-GM, SP-GM, SW-GC, GP-GC, GM, GC, and GM-GC can be effectively stabilized with bituminous materials provided the above-mentioned gradation and plasticity requirements are met.

Combination stabilization is specifically defined as lime-cement, lime-asphalt, and lime-cement-fly ash (LCF) stabilization. Combinations of lime and cement often are acceptable expedient stabilizers. Lime can be added to the soil to increase the workability and mixing characteristics of the soil as well as reduce its plasticity. Cement can then be mixed into the soil to provide rapid strength gain. Combinations of lime and asphalt are often acceptable stabilizers. The lime addition may prevent stripping at the asphalt-aggregate interface and increase the stability of the mixture.

SELECTION OF A STABILIZER

In the selection of a stabilizer additive, the factors that must be considered are the type of soil to be stabilized, the purpose for which the stabilized layer will be used, the type of soil quality improvement desired, the required strength and durability of the stabilized layer, and the cost and environmental conditions.

The soil gradation triangle in figure 18-1 is based upon the pulverization characteristics of the soil. When

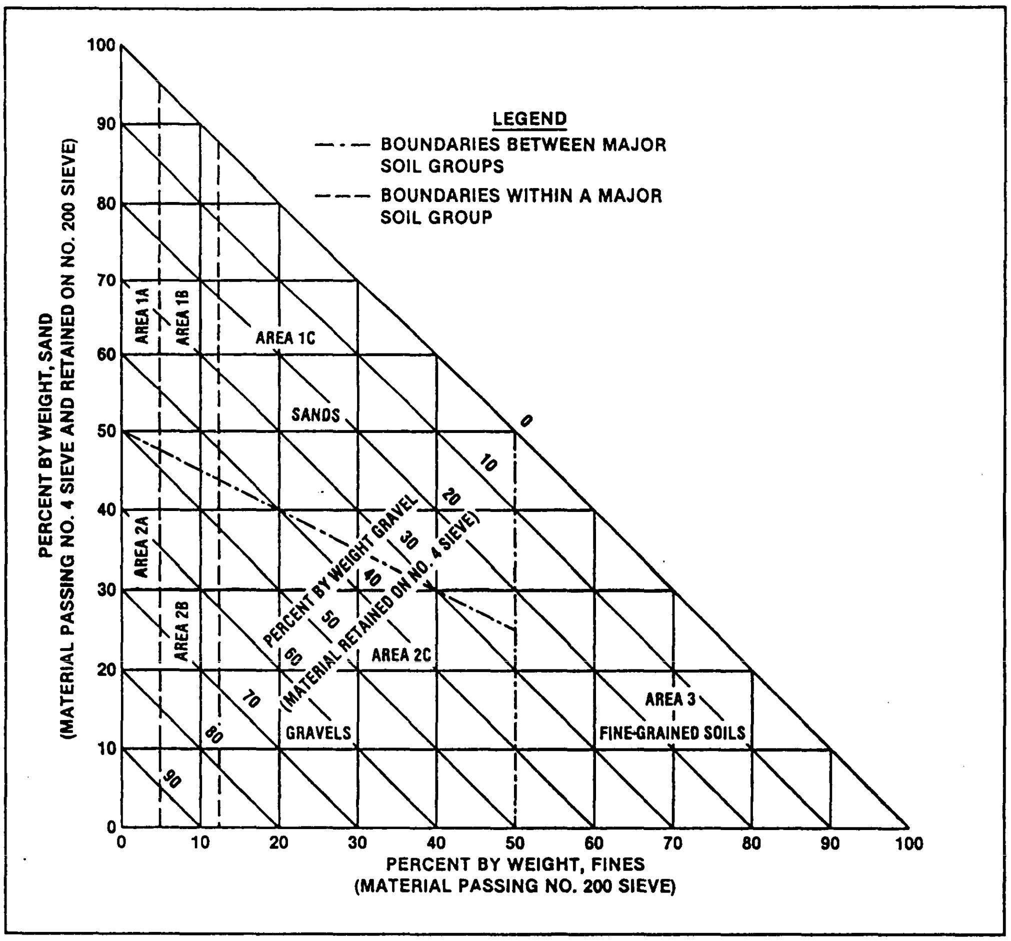

Figure 18-1.—Soil gradation triangle.

Table 18-2.—Guide for Selecting a Stabilizing Additive

Area	Soils class[1]	Type of stabilizing additive recommended	Restriction on LL and PI of soil	Restriction on percent passing No. 200 sieve[1]	Remarks
1A	SW or SP	Bituminous Portland cement Lime-cement-fly ash	 PI not to exceed 25		
1B	SW-SH or SP-SH or SW-SC or	Bituminous Portland cement Lime	PI not to exceed 10 PI not to exceed 30 PI not less than 12		
1C	SM or SC or SM-SC	Bituminous Portland cement Lime Lime-cement-fly ash	PI not to exceed 10 See footnote 2 PI not less than 12 PI not to exceed 25	Not to exceed 30% by weight	
2A	GW or GP	Bituminous Portland cement Lime-cement-fly ash	 PI not to exceed 25		Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
2B	GW-GH or GP-GH or GW-GC or GP-GC	Bituminous Portland cement Lime Lime-cement-fly ash	PI not to exceed 10 PI not to exceed 30 PI not less than 12 PI not to exceed 25		Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
2C	GM or GC or GM-GC	Bituminous Lime Lime-cement-fly ash	PI not to exceed 10 See footnote 2 PI not less than 12 PI not to exceed 25	Not to exceed 30% by weight	Well-graded material only Material should contain at least 45% by weight of material passing No. 4 sieve
3	CH or CL or HII or ML or OII or OL or ML-CL	Portland cement Lime	LL less than 40 and PI less than 20 PI not less than 12		Organic and strongly acid soils falling within this area are not susceptible to stabilization by ordinary means

[1] Soil classification corresponds to MIL-STD-619B. Restriction on liquid limit (LL) and plasticity index (PI) is in accordance with Method 103 in MIL-STD-621A.

[2] $PI \leq 20 + \frac{50 - \text{percent passing No. 200 sieve}}{4}$

these characteristics are combined with certain restrictions relative to liquid limit (LL) and soil gradation contained in table 18-2, they provide guidance for the selection of the additive best suited for stabilization. Figure 18-1 is entered with the percentage of gravel (percent material retained on the No. 4 sieve), sand (percent material passing the No. 4 sieve and retained on the No. 200 sieve), and fines (percent material passing the No. 200 sieve) to determine the area in which the soil gradation falls. The areas (1A, 2C, and 3) indicated at the intersection of the three material percentages are used to enter table 18-2 to select the type of stabilizing additive based on the various restrictions and remarks. For example, a soil having a PI of 15 and 57-percent gravel, 26-percent sand and 7-percent fines fall in area 2B of figure 18-1. Table 18-2 indicates that cement, lime, LCF, or bitumen could be considered. However, the PI of 15 eliminates bitumen, and the fact that only 33 percent of the material passes the No. 4

sieve indicates that lime or a combination LCF will be the best additive for Stabilization

SOIL-CEMENT STABILIZATION

In general, there are three types of soil-and-cement mixtures as follows:

- **Plastic soil-cement** is a hardened mixture of soil and cement that contains, at the time of placing, enough water to produce a consistency similar to plastering mortar. It is used to line or pave ditches, slopes, and other areas that are subject to erosion. It also maybe used for emergency road repair by mixing high-early-strength cement into the natural material in mudholes.

- **Cement-modified soil** is an unhardened or semihardened mixture of soil and cement. When relatively small quantities of portland cement are added to granular soil or silt-clay soil, the chemical and physical properties of that soil are changed. Cement reduces the plasticity and water-holding capacity of the soil and increases its bearing value. The degree of improvement depends upon the quantity of the cement used and the type of soil. In cement-modified soil, only enough cement is used to change the physical properties of the soil to the degree desired. Cement-modified soils may be used for base courses, subbases, treated subgrades, highway fills, and as trench backfill material.

- Compacted soil-cement, often referred to as simply soil-cement, is a mixture of pulverized soil and calculated amounts of portland cement and water that is compacted to a high density. The result is a rigid slab having moderate compressive strength and resistance to the disintegrating effects of wetting and drying and freezing and thawing. The remainder of our discussion of soil-cement is directed towards this type of soil-and-cement mixture.

MATERIALS FOR SOIL-CEMENT

Soil, portland cement, and water are the three basic materials needed to produce soil-cement. Low cost is achieved mainly by using inexpensive local materials. The soil that makes up the bulk of soil-cement is either in place or obtained nearby, and the water is usually hauled only short distances.

The word *soil, as* used in soil-cement, means almost any combination of gravel, sand, silt, and clay, and includes such materials as cinder, caliche, shale, laterite, and many waste materials including dirty and poorly graded sands from gravel pits.

The quantities of Portland cement and water to be added and the density to which the mixture must be compacted are determined from tests. The water serves two purposes: it helps to obtain maximum compaction (density) by lubricating the soil grains and it is necessary for hydration of the cement that hardens and binds the soil into a solid mass. Properly produced soil-cement contains enough water for both purposes.

The cement could be almost any type of portland cement that complies with the requirements of the latest ASTM (American Safety for testing and Materials), AASHTO(American Association of State Highway and Transportation Officials), or federal specifications. Types I (normal) and IA (air entrained) portland cements are the most commonly used.

The water used in soil-cement should be relatively clean and free from harmful amounts of alkalies, acid, or organic matter. Water fit to drink is satisfactory. Sometimes seawater has been used satisfactorily when fresh water has been unobtainable.

Practically all soils and soil combinations can be hardened with portland cement. They do not need to be well-graded aggregates since stability is attained primarily through hydration of cement and not by cohesion and internal friction of the materials. The general suitability of soils for soil-cement can be judged before they are tested on the basis of their gradation and their position in the soil profile. On the basis of gradation, soils for soil-cement construction can be divided into three broad groups as follows:

1. Sandy and gravelly soils with about 10- to 35-percent silt and clay combined have the most favorable characteristics and generally require the least amount of cement for adequate hardening. Glacial-and water-deposited sands and gravels, crusher-run limestone, caliche, lime rock and almost all granular materials work well if they contain 55 percent or more material passing the No. 4 sieve and 37 percent passing the No. 10 sieve. Stones over an inch or two in diameter are undesirable. Exceptionally well-graded materials may contain up to 65-percent gravel retained on the No. 4 sieve and have sufficient fine material for adequate binding. These soils are readily pulverized, easily mixed and can be used under a wide range of weather conditions.

2 Sandy soils deficient in fines, such as some beach sands, glacial sands, and windblown sands, make good soil-cement although the amount of cement needed for adequate hardening is usually slightly greater than with the soil in Group 1 above. Because of poor

gradation and absence of fines in these sands, construction equipment may have difficulty in obtaining traction. Traction can be vastly improved by keeping the sand wet and by using track-type equipment. These soils are likely to be "tender" and to require care during final packing and finishing so that a smooth, dense surface may be obtained.

3. Silty and clayey soils make satisfactory soil-cement but those containing high clay contents are harder to pulverize. Generally the more clayey the soil, the higher the cement content required to harden it adequately. Construction with these soils is more dependent on weather conditions. If the soil can be pulverized it is not too heavy textured for use in soil-cement.

SOIL-CEMENT TESTS

Laboratory tests determine three fundamental control factors for soil-cement. These factors are as follows:

1. Proper cement content
2. Proper moisture content
3. Roper density

An adequate cement content is the first requisite for quality soil-cement. Well before construction, the soils at a project site should be identified, the limits of each soil defined, and a representative sample of each soil type should be forwarded to the laboratory to determine the quantity of cement required to harden it. A soil survey of the construction area should be made.

Proper soil surveying, identification, and sampling are important. For instance, if one soil type was sampled and tested while actual construction involved a different soil type, the tests would be worthless and, in fact, detrimental since they would mislead the engineers. Obviously, it is important to sample and test the soils that will actually be used in soil-cement construction. A 75-pound sample of each type of soil is adequate for laboratory testing.

Sampling methods and procedures are discussed in the EA3 TRAMAN and in NAVFAC MO-330. Soil samples are usually taken from a graded roadway by digging a trench from the center line to the edge of the proposed pavement and to the depth of processing. Soil samples for proposed roadways not yet graded are taken with an auger from the various soil horizons of each soil type from the "dressed-down" face of exposed cuts or from the surface. Samples should be taken so that only one horizon of each soil type is represented by each sample. Similarly, it is not good practice to take a composite sample from various locations. Data obtained from a composite sample does not apply to soil in any single location and may be misleading. There are exceptions. For instance, in sampling pit material that is to be loaded during construction by a shovel operating over the vertical face of the pit, the sample is taken from the bottom to the top of the vertical face after the overburden is removed. On small projects, it is not uncommon to sample only the poorest soil on the job, and the cement content for this sample is used throughout the job. Be sure that complete identification is supplied with each sample.

The purpose of laboratory testing is to determine the minimum cement content needed to harden the material adequately and the optimum moisture content (OMC) and density values to be used for construction. The OMC and maximum density are determined by the **moisture-density test** and the required cement content is determined by either the **wet-dry test** for pavements located in nonfrost areas or the **freeze-thaw test** for pavements located in frost areas. A brief description of each test is provided below.

- The **moisture-density test** determines the OMC and maximum density for molding laboratory specimens and, in the field, to determine the quantity of water to be added and the density to which the soil-cement mixture should be compacted.

Before you start this test, select the cement contents that will be used in the wet-dry or freeze-thaw test. The cement contents are usually selected in 2-percent increments to encompass values given in table 18-3.

Table 18-3.—Basic Range of Cement Requirements

Soil classification*	Cement required (percent by weight)
GW, GP, SW, SP, GM, or SM . . .	3-5
SP, GM, SM, or GP	5-8
SM, SC, some GM, or GC	5-9
SP	7-11
CL or ML	7-12
ML, MH, or OH	8-13
CL or CH	9-15
OH, MH, or some CH	10-16

* See appendix V for soil classifications

Since maximum density varies only slightly with variations in the cement content, only the median value is used in preparing specimens for the test. Additional information on selecting the cement content can be found in chapter 5 of NAVFAC MO-330.

The procedures for determining the OMC are similar to those described in chapter 13 of this TRAMAN with the following exceptions:

1. Compaction is performed on five layers of approximately equal thickness to result in a total compacted depth of 5 inches.

2. Each layer is compacted by 25 uniformly spaced blows using a 10-pound tamper dropped from a height of 18 inches.

- The **wet-dry test** (ASTM D 559) determines the cement content for soil-cement mixtures used in nonfrost areas. The objective is to determine the minimum amount of cement that will enable the soil-cement mixture to pass the test. For the test, specimens are molded using the OMC and the cement contents described above for different soil classifications. Use the procedure for the OMC determination to mold the specimens, and take a 750-gram sample from the second layer for a moisture determination. Cure the specimens for 7 days in high humidity. After curing, the specimens are weighed and submerged in tap water at room temperature for 5 hours. They are then oven-dried for 42 hours at 160°F. Material loosened by wetting and drying is then removed using two firm strokes of a wire brush. After this, you then reweigh the specimens and subtract the new weight from the old weight to determine the amount of disintegration (soil-cement loss) that occurred during the cycle. The process is repeated for a total of 12 cycles. A passing grade ranges from 14-percent loss for sandy or gravelly soils down to 7 percent for clayey soil.

Additional information about the wet-dry test and an example of determining the soil-cement loss can be found in NAVFAC MO-330.

- The **freeze-thaw test** (ASTM D 560) determines the cement content for soil-cement mixtures used in areas subject to frost action due to repeated freezing and thawing. As in the wet-dry test, the objective of the freeze-thaw test is to determine the minimum amount of cement that enables the mixture to pass the test. For the test, specimens are molded and cured in the same manner as the wet-dry test. After 7 days of curing, the specimens are placed on moist blotters and are refrigerated for 24 hours at -10°F. They are then thawed in a moist atmosphere at 70°F for 23 hours. Then you brush the specimens as described above and, if necessary, remove any half-loose scales using a sharp-pointed instrument. After 12 cycles, the specimens are oven-dried and weighed. The soil-cement loss is determined the same way as in the wet-dry test. Again, passing grades range from 14-percent loss for sandy or gravelly soils down to 7 percent for clayey soil.

For additional information regarding the freeze-thaw test, you should refer to NAVFAC MO-330.

The principal requirement of a hardened soil-cement mixture is to withstand exposure to the elements. Strength is a requirement also; however, most soil-cement mixtures that have adequate resistance to the elements also have adequate strength. In the ranges of cement contents producing results meeting the requirements above, the strength of soil-cement specimens tested in compression at various ages should increase with age and with increases in cement. A sample that has an unconfined compressive strength of approximately 300 pounds per square inch (psi) after curing 7 days and shows increasing strength with age can be considered adequately stabilized. NAVFAC MO-330 has the procedures that you should follow when performing unconfined compression tests.

For a discussion of modified mix design for sandy soils and for approximate and rapid test procedures that you can use when complete testing is impracticable, you should refer to NAVFAC MO-330. Construction methods using soil-cement can be found in *Military, Soils Engineering,* FM5-541, and in commercial publications, such as *Moving the Earth,* by Herbert L. Nichols, Jr., and various publications from the Portland Cement Association.

BITUMINOUS STABILIZATION

Bituminous soil stabilization refers to a process by which a controlled amount of bituminous material is thoroughly mixed with an existing soil or aggregate material to form a stable base or wearing surface. Bitumen increases the cohesion and load-bearing capacity of the soil and renders it resistant to the action of water.

SOIL GRADATION

The recommended soil gradations for subgrade and base or subbase course materials are shown in

Table 18-4.—Recommended Gradations for Bituminous-Stabilized Subgrade Materials

Sieve size	Percent passing
3 inch	100
No. 4	50 - 100
No. 30	38 - 100
No. 200	2 - 30

tables 18-4 and 18-5, respectively. Mechanical stabilization may be required to bring the soil to proper gradation.

TYPES OF BITUMEN

Bituminous stabilization is generally accomplished using asphalt cement, cutback asphalt, or asphalt emulsion. The type of bitumen to be used depends upon the type of soil to be stabilized, method of construction, and weather conditions.

In frost areas, the use of tar as a binder should be avoided because of its high-temperature susceptibility. Asphalts are affected less by temperature changes, but a grade of asphalt suitable to the prevailing climate should be selected. As a general rule, the most satisfactory results are obtained using the most viscous liquid asphalt that can be readily mixed into the soil. For higher quality mixes in which a central plant is used, viscosity-grade asphalt cements should be used.

Most bituminous stabilization is performed in place. The bitumen is applied directly on the soil or soil-aggregate system, and the mixing and compaction operations are conducted immediately thereafter. For this type of construction, liquid asphalts, such as cutbacks and emulsions, are used. Emulsions are preferred over cutbacks because of energy constraints and pollution control efforts.

The specific type and grade of bitumen will depend on the characteristics of the aggregate, type of construction equipment, and climate conditions. Generally, the types of bituminous materials that will be used for the soil gradation are indicated in table 18-6.

MIX DESIGN AND METHODS OF TESTING MIXTURES

For guidance on the design of bituminous-stabilized base and subbase courses, you should refer to *Bituminous Pavements—Standard Practice,* TM5-822-8, and to NAVFAC MO-330.

The *Tentative Method of Testing Soil-Bituminous Mixtures,* ASTM D 915, provides for determination of water absorption, expansion, and extrusion characteristics of compacted soil or soil-aggregate mixtures. The method maybe used for determining the characteristics of a mixture of specified proportions under specified conditions of curing or noncuring. Also, it may be used for determining the effects on these characteristics of varying the curing and the proportions of the different ingredients. The test results are not intended to determine thickness or to predict relative field performance of the different bituminous materials.

Table 18-5.—Recommended Gradations for Bituminous-Stabilized Subbase Materials

Sieve size	1 1/2-in. Maximum	1-in. Maximum	3/4-in. Maximum	1/2-in. Maximum
1 1/2 in.	100	----	----	----
1 in.	84 ±9	100	----	----
3/4 in.	76 ±9	83 ±9	100	----
1/2 in.	66 ±9	73 ±9	82 ±9	100
3/8 in.	59 ±9	64 ±9	72 ±9	83 ±9
No. 4	45 ±9	48 ±9	54 ±9	62 ±9
No. 8	35 ±9	37 ±9	41 ±9	47 ±9
No. 16	27 ±9	28 ±9	32 ±9	36 ±9
No. 30	20 ±9	21 ±9	24 ±9	28 ±9
No. 50	14 ±7	16 ±7	17 ±7	20 ±7
No. 100	9 ±5	11 ±5	12 ±5	14 ±5
No. 200	5 ±2	5 ±2	5 ±2	5 ±2

Table 18-6.—Bituminous Requirements

Open-graded aggregate
Rapid- and medium-curing liquid asphalts RC-250, RC-800, and MC-3000
Medium-setting asphalt emulsion MS-2 and CMS-2
Well-graded aggregate with little or no material passing the No. 200 sieve
Rapid- and medium-curing liquid asphalts RC-250, RC-800, MC-250, and MC-800
Slow-curing liquid asphalts SC-250 and SC-800
Medium-setting and slow-setting asphalt emulsions MS-2, CMS-2, SS-1, and CSS-1
Aggregate with a considerable percentage of fine aggregate and material passing the No. 200 sieve
Medium-curing liquid asphalts MC-250 and MC-800
Slow-curing liquid asphalts SC-250 and SC-800
Slow-setting asphalt emulsions SS-1, SS-1h, CSS-1, and CSS-1h
Medium-setting asphalt emulsions MS-2 and CMS-2
The simplest type of bituminous stabilization is the application of liquid asphalt to the surface of an unbound aggregate road. For this type of operation, the slow- and medium-curing liquid asphalts SC-70, SC-250, MC-70, and MC-250 are used.

QUESTIONS

Q1. *What type or types of additive(s) is/are best to use for stabilizing a soil that has a PI of 30 and contains 40-percent gravel 45-percent sand, and 15-percent fines?*

Q2. *For a soil-cement mixture, what type of soil is likely to require the highest cement content?*

Q3. *Assume that you are tasked with determining the cement content needed for a soil-cement mixture that will be used for a project located at a Marine Corps camp in South Korea. At a minimum, what laboratory tests will you need to perform?*

Q4. *You are preparing to do an unconfined compression test on a soil-cement mixture using a soil that is 40-percent gravel. What compaction mold should you use?*

APPENDIX I

REFERENCES USED TO DEVELOP THE TRAMAN

NOTE: The following references were current at the time this TRAMAN was published, but you should be sure you have the current edition.

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APPENDIX II

USEFUL TABLES

Table AII-1.—Natural Sines and Cosines

MIN	0° SIN	0° COS	1° SIN	1° COS	2° SIN	2° COS	3° SIN	3° COS	4° SIN	4° COS	
0	0000000	1.00000	0.01745	0.99985	0.03490	0.99939	0.05234	0.99863	0.06976	0.99756	60
1	0.00029	1.00000	0.01774	0.99984	0.03519	0.99938	0.05263	0.99861	0.07005	0.99754	59
2	0.00058	1.00000	0.01803	0.99984	0.03548	0.99937	0.05292	0.99860	0.07034	0.99752	58
3	0.00087	1.00000	0.01832	0.99983	0.03577	0.99936	0.05321	0.99858	0.07063	0.99750	57
4	0.00116	1.00000	0.01862	0.99983	0.03606	0.99935	0.05350	0.99857	0.07092	0.99748	56
5	0.00145	1.00000	0.01891	0.99982	0.03635	0.99934	0.05379	0.99855	0.07121	0.99746	55
6	0.00175	1.00000	0.01920	0.99982	0.03664	0.99933	0.05408	0.99854	0.07150	0.99744	54
7	0.00204	1.00000	0.01949	0.99981	0.03693	0.99932	0.05437	0.99852	0.07179	0.99742	53
8	0.00233	1.00000	0.01978	0.99980	0.03723	0.99931	0.05466	0.99851	0.07208	0.99740	52
9	0.00262	1.00000	0.02007	0.99980	0.03752	0.99930	0.05495	0.99849	0.07237	0.99738	51
10	0.00291	1.00000	0.02036	0.99979	0.03781	0.99929	0.05524	0.99847	0.07266	0.99736	50
11	0.00320	0.99999	0.02065	0.99979	0.03810	0.99927	0.05553	0.99846	0.07295	0.99734	49
12	0.00349	0.99999	0.02094	0.99978	0.03839	0.99926	0.05582	0.99844	0.07324	0.99731	48
13	0.00378	0.99999	0.02123	0.99977	0.03868	0.99925	0.05611	0.99842	0.07353	0.99729	47
14	0.00407	0.99999	0.02152	0.99977	0.03897	0.99924	0.05640	0.99841	0.07382	0.99727	46
15	0.00436	0.99999	0.02181	0.99976	0.03926	0.99923	0.05669	0.99839	0.07411	0.99725	45
16	0.00465	0.99999	0.02211	0.99976	0.03955	0.99922	0.05698	0.99838	0.07440	0.99723	44
17	0.00495	0.99999	0.02240	0.99975	0.03984	0.99921	0.05727	0.99836	0.07469	0.99721	43
18	0.00524	0.99999	0.02269	0.99974	0.04013	0.99919	0.05756	0.99834	0.07498	0.99719	42
19	0.00553	0.99998	0.02298	0.99974	0.04042	0.99918	0.05785	0.99833	0.07527	0.99716	41
20	0.00582	0.99998	0.02327	0.99973	0.04071	0.99917	0.05814	0.99831	0.07556	0.99714	40
21	0.00611	0.99998	0.02356	0.99972	0.04100	0.99916	0.05844	0.99829	0.07585	0.99712	39
22	0.00640	0.99998	0.02385	0.99972	0.04129	0.99915	0.05873	0.99827	0.07614	0.99710	38
23	0.00669	0.99998	0.02414	0.99971	0.04159	0.99913	0.05902	0.99826	0.07643	0.99708	37
24	0.00698	0.99998	0.02443	0.99970	0.04188	0.99912	0.05931	0.99824	0.07672	0.99705	36
25	0.00727	0.99997	0.02472	0.99969	0.04217	0.99911	0.05960	0.99822	0.07701	0.99703	35
26	0.00756	0.99997	0.02501	0.99969	0.04246	0.99910	0.05989	0.99821	0.07730	0.99701	34
27	0.00785	0.99997	0.02530	0.99968	0.04275	0.99909	0.06018	0.99819	0.07759	0.99699	33
28	0.00814	0.99997	0.02560	0.99967	0.04304	0.99907	0.06047	0.99817	0.07788	0.99696	32
29	0.00844	0.99996	0.02589	0.99966	0.04333	0.99906	0.06076	0.99815	0.07817	0.99694	31
30	0.00873	0.99996	0.02618	0.99966	0.04362	0.99905	0.06105	0.99813	0.07846	0.99692	30
31	0.00902	0.99996	0.02647	0.99965	0.04391	0.99904	0.06134	0.99812	0.07875	0.99689	29
32	0.00931	0.99996	0.02676	0.99964	0.04420	0.99902	0.06163	0.99810	0.07904	0.99687	28
33	0.00960	0.99995	0.02705	0.99963	0.04449	0.99901	0.06192	0.99808	0.07933	0.99685	27
34	0.00989	0.99995	0.02734	0.99963	0.04478	0.99900	0.06221	0.99806	0.07962	0.99683	26
35	0.01018	0.99995	0.02763	0.99962	0.04507	0.99898	0.06250	0.99804	0.07991	0.99680	25
36	0.01047	0.99995	0.02792	0.99961	0.04536	0.99897	0.06279	0.99803	0.08020	0.99678	24
37	0.01076	0.99994	0.02821	0.99960	0.04565	0.99896	0.06308	0.99801	0.08049	0.99676	23
38	0.01105	0.99994	0.02850	0.99959	0.04594	0.99894	0.06337	0.99799	0.08078	0.99673	22
39	0.01134	0.99994	0.02879	0.99959	0.04623	0.99893	0.06366	0.99797	0.08107	0.99671	21
40	0.01164	0.99993	0.02908	0.99958	0.04653	0.99892	0.06395	0.99795	0.08136	0.99668	20
41	0.01193	0.99993	0.02938	0.99957	0.04682	0.99890	0.06424	0.99793	0.08165	0.99666	19
42	0.01222	0.99993	0.02967	0.99956	0.04711	0.99889	0.06453	0.99792	0.08194	0.99664	18
43	0.01251	0.99992	0.02996	0.99955	0.04740	0.99888	0.06482	0.99790	0.08223	0.99661	17
44	0.01280	0.99992	0.03025	0.99954	0.04769	0.99886	0.06511	0.99788	0.08252	0.99659	16
45	0.01309	0.99991	0.03054	0.99953	0.04798	0.99885	0.06540	0.99786	0.08281	0.99657	15
46	0.01338	0.99991	0.03083	0.99952	0.04827	0.99883	0.06569	0.99784	0.08310	0.99654	14
47	0.01367	0.99991	0.03112	0.99952	0.04856	0.99882	0.06598	0.99782	0.08339	0.99652	13
48	0.01396	0.99990	0.03141	0.99951	0.04885	0.99881	0.06627	0.99780	0.08368	0.99649	12
49	0.01425	0.99990	0.03170	0.99950	0.04914	0.99879	0.06656	0.99778	0.08397	0.99647	11
50	0.01454	0.99989	0.03199	0.99949	0.04943	0.99878	0.06685	0.99776	0.08426	0.99644	10
51	0.01483	0.99989	0.03228	0.99948	0.04972	0.99876	0.06714	0.99774	0.08455	0.99642	9
52	0.01513	0.99989	0.03257	0.99947	0.05001	0.99875	0.06743	0.99772	0.08484	0.99639	8
53	0.01542	0.99988	0.03286	0.99946	0.05030	0.99873	0.06773	0.99770	0.08513	0.99637	7
54	0.01571	0.99988	0.03316	0.99945	0.05059	0.99872	0.06802	0.99768	0.08542	0.99635	6
55	0.01600	0.99987	0.03345	0.99944	0.05088	0.99870	0.06831	0.99766	0.08571	0.99632	5
56	0.01629	0.99987	0.03374	0.99943	0.05117	0.99869	0.06860	0.99764	0.08600	0.99630	4
57	0.01658	0.99986	0.03403	0.99942	0.05146	0.99867	0.06889	0.99762	0.08629	0.99627	3
58	0.01687	0.99986	0.03432	0.99941	0.05175	0.99866	0.06918	0.99760	0.08658	0.99625	2
59	0.01716	0.99985	0.03461	0.99940	0.05205	0.99864	0.06947	0.99758	0.08687	0.99622	1
60	0.01745	0.99985	0.03490	0.99939	0.05234	0.99863	0.06976	0.99756	0.08716	0.99619	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	89°		88°		87°		86°		85°		

MIN	5° SIN	5° COS	6° SIN	6° COS	7° SIN	7° COS	8° SIN	8° COS	9° SIN	9° COS	
0	0.08716	0.99619	0.10453	0.99452	0.12187	0.99255	0.13917	0.99027	0.15643	0.98769	60
1	0.08745	0.99617	0.10482	0.99449	0.12216	0.99251	0.13946	0.99023	0.15672	0.98764	59
2	0.08774	0.99614	0.10511	0.99446	0.12245	0.99248	0.13975	0.99019	0.15701	0.98760	58
3	0.08803	0.99612	0.10540	0.99443	0.12274	0.99244	0.14004	0.99015	0.15730	0.98755	57
4	0.08831	0.99609	0.10569	0.99440	0.12302	0.99240	0.14033	0.99011	0.15758	0.98751	56
5	0.08860	0.99607	0.10597	0.99437	0.12331	0.99237	0.14061	0.99006	0.15787	0.98746	55
6	0.08889	0.99604	0.10626	0.99434	0.12360	0.99233	0.14090	0.99002	0.15816	0.98741	54
7	0.08918	0.99602	0.10655	0.99431	0.12389	0.99230	0.14119	0.98998	0.15845	0.98737	53
8	0.08947	0.99599	0.10684	0.99428	0.12418	0.99226	0.14148	0.98994	0.15873	0.98732	52
9	0.08976	0.99596	0.10713	0.99424	0.12447	0.99222	0.14177	0.98990	0.15902	0.98728	51
10	0.09005	0.99594	0.10742	0.99421	0.12476	0.99219	0.14205	0.98986	0.15931	0.98723	50
11	0.09034	0.99591	0.10771	0.99418	0.12504	0.99215	0.14234	0.98982	0.15959	0.98718	49
12	0.09063	0.99588	0.10800	0.99415	0.12533	0.99211	0.14263	0.98978	0.15988	0.98714	48
13	0.09092	0.99586	0.10829	0.99412	0.12562	0.99208	0.14292	0.98973	0.16017	0.98709	47
14	0.09121	0.99583	0.10858	0.99409	0.12591	0.99204	0.14320	0.98969	0.16046	0.98704	46
15	0.09150	0.99580	0.10887	0.99406	0.12620	0.99200	0.14349	0.98965	0.16074	0.98700	45
16	0.09179	0.99578	0.10916	0.99402	0.12649	0.99197	0.14378	0.98961	0.16103	0.98695	44
17	0.09208	0.99575	0.10945	0.99399	0.12678	0.99193	0.14407	0.98957	0.16132	0.98690	43
18	0.09237	0.99572	0.10973	0.99396	0.12706	0.99189	0.14436	0.98953	0.16160	0.98686	42
19	0.09266	0.99570	0.11002	0.99393	0.12735	0.99186	0.14464	0.98948	0.16189	0.98681	41
20	0.09295	0.99567	0.11031	0.99390	0.12764	0.99182	0.14493	0.98944	0.16218	0.98676	40
21	0.09324	0.99564	0.11060	0.99386	0.12793	0.99178	0.14522	0.98940	0.16246	0.98671	39
22	0.09353	0.99562	0.11089	0.99383	0.12822	0.99175	0.14551	0.98936	0.16275	0.98667	38
23	0.09382	0.99559	0.11118	0.99380	0.12851	0.99171	0.14580	0.98931	0.16304	0.98662	37
24	0.09411	0.99556	0.11147	0.99377	0.12880	0.99167	0.14608	0.98927	0.16333	0.98657	36
25	0.09440	0.99553	0.11176	0.99374	0.12908	0.99163	0.14637	0.98923	0.16361	0.98652	35
26	0.09469	0.99551	0.11205	0.99370	0.12937	0.99160	0.14666	0.98919	0.16390	0.98648	34
27	0.09498	0.99548	0.11234	0.99367	0.12966	0.99156	0.14695	0.98914	0.16419	0.98643	33
28	0.09527	0.99545	0.11263	0.99364	0.12995	0.99152	0.14723	0.98910	0.16447	0.98638	32
29	0.09556	0.99542	0.11291	0.99360	0.13024	0.99148	0.14752	0.98906	0.16476	0.98633	31
30	0.09585	0.99540	0.11320	0.99357	0.13053	0.99144	0.14781	0.98902	0.16505	0.98629	30
31	0.09614	0.99537	0.11349	0.99354	0.13081	0.99141	0.14810	0.98897	0.16533	0.98624	29
32	0.09642	0.99534	0.11378	0.99351	0.13110	0.99137	0.14838	0.98893	0.16562	0.98619	28
33	0.09671	0.99531	0.11407	0.99347	0.13139	0.99133	0.14867	0.98889	0.16591	0.98614	27
34	0.09700	0.99528	0.11436	0.99344	0.13168	0.99129	0.14896	0.98884	0.16620	0.98609	26
35	0.09729	0.99526	0.11465	0.99341	0.13197	0.99125	0.14925	0.98880	0.16648	0.98604	25
36	0.09758	0.99523	0.11494	0.99337	0.13226	0.99122	0.14954	0.98876	0.16677	0.98600	24
37	0.09787	0.99520	0.11523	0.99334	0.13254	0.99118	0.14982	0.98871	0.16706	0.98595	23
38	0.09816	0.99517	0.11552	0.99331	0.13283	0.99114	0.15011	0.98867	0.16734	0.98590	22
39	0.09845	0.99514	0.11580	0.99327	0.13312	0.99110	0.15040	0.98863	0.16763	0.98585	21
40	0.09874	0.99511	0.11609	0.99324	0.13341	0.99106	0.15069	0.98858	0.16792	0.98580	20
41	0.09903	0.99508	0.11638	0.99320	0.13370	0.99102	0.15097	0.98854	0.16820	0.98575	19
42	0.09932	0.99506	0.11667	0.99317	0.13399	0.99098	0.15126	0.98849	0.16849	0.98570	18
43	0.09961	0.99503	0.11696	0.99314	0.13427	0.99094	0.15155	0.98845	0.16878	0.98565	17
44	0.09990	0.99500	0.11725	0.99310	0.13456	0.99091	0.15184	0.98841	0.16906	0.98561	16
45	0.10019	0.99497	0.11754	0.99307	0.13485	0.99087	0.15212	0.98836	0.16935	0.98556	15
46	0.10048	0.99494	0.11783	0.99303	0.13514	0.99083	0.15241	0.98832	0.16964	0.98551	14
47	0.10077	0.99491	0.11812	0.99300	0.13543	0.99079	0.15270	0.98827	0.16992	0.98546	13
48	0.10106	0.99488	0.11840	0.99297	0.13572	0.99075	0.15299	0.98823	0.17021	0.98541	12
49	0.10135	0.99485	0.11869	0.99293	0.13600	0.99071	0.15327	0.98818	0.17050	0.98536	11
50	0.10164	0.99482	0.11898	0.99290	0.13629	0.99067	0.15356	0.98814	0.17078	0.98531	10
51	0.10192	0.99479	0.11927	0.99286	0.13658	0.99063	0.15385	0.98809	0.17107	0.98526	9
52	0.10221	0.99476	0.11956	0.99283	0.13687	0.99059	0.15414	0.98805	0.17136	0.98521	8
53	0.10250	0.99473	0.11985	0.99279	0.13716	0.99055	0.15442	0.98800	0.17164	0.98516	7
54	0.10279	0.99470	0.12014	0.99276	0.13744	0.99051	0.15471	0.98796	0.17193	0.98511	6
55	0.10308	0.99467	0.12043	0.99272	0.13773	0.99047	0.15500	0.98791	0.17222	0.98506	5
56	0.10337	0.99464	0.12071	0.99269	0.13802	0.99043	0.15529	0.98787	0.17250	0.98501	4
57	0.10366	0.99461	0.12100	0.99265	0.13831	0.99039	0.15557	0.98782	0.17279	0.98496	3
58	0.10395	0.99458	0.12129	0.99262	0.13860	0.99035	0.15586	0.98778	0.17308	0.98491	2
59	0.10424	0.99455	0.12158	0.99258	0.13889	0.99031	0.15615	0.98773	0.17336	0.98486	1
60	0.10453	0.99452	0.12187	0.99255	0.13917	0.99027	0.15643	0.98769	0.17365	0.98481	0
	84° COS	84° SIN	83° COS	83° SIN	82° COS	82° SIN	81° COS	81° SIN	80° COS	80° SIN	MIN

Table AII-1.—Natural Sines and Cosines—Continued

MIN	10° SIN	10° COS	11° SIN	11° COS	12° SIN	12° COS	13° SIN	13° COS	14° SIN	14° COS	
0	0.17365	0.98481	0.19081	0.98163	0.20791	0.97815	0.22495	0.97437	0.24192	0.97030	60
1	0.17393	0.98476	0.19109	0.98157	0.20820	0.97809	0.22523	0.97430	0.24220	0.97023	59
2	0.17422	0.98471	0.19138	0.98152	0.20848	0.97803	0.22552	0.97424	0.24249	0.97015	58
3	0.17451	0.98466	0.19167	0.98146	0.20877	0.97797	0.22580	0.97417	0.24277	0.97008	57
4	0.17479	0.98461	0.19195	0.98140	0.20905	0.97791	0.22608	0.97411	0.24305	0.97001	56
5	0.17508	0.98455	0.19224	0.98135	0.20933	0.97784	0.22637	0.97404	0.24333	0.96994	55
6	0.17537	0.98450	0.19252	0.98129	0.20962	0.97778	0.22665	0.97398	0.24362	0.96987	54
7	0.17565	0.98445	0.19281	0.98124	0.20990	0.97772	0.22693	0.97391	0.24390	0.96980	53
8	0.17594	0.98440	0.19309	0.98118	0.21019	0.97766	0.22722	0.97384	0.24418	0.96973	52
9	0.17623	0.98435	0.19338	0.98112	0.21047	0.97760	0.22750	0.97378	0.24446	0.96966	51
10	0.17651	0.98430	0.19366	0.98107	0.21076	0.97754	0.22778	0.97371	0.24474	0.96959	50
11	0.17680	0.98425	0.19395	0.98101	0.21104	0.97748	0.22807	0.97365	0.24503	0.96952	49
12	0.17708	0.98420	0.19423	0.98096	0.21132	0.97742	0.22835	0.97358	0.24531	0.96945	48
13	0.17737	0.98414	0.19452	0.98090	0.21161	0.97735	0.22863	0.97351	0.24559	0.96937	47
14	0.17766	0.98409	0.19481	0.98084	0.21189	0.97729	0.22892	0.97345	0.24587	0.96930	46
15	0.17794	0.98404	0.19509	0.98079	0.21218	0.97723	0.22920	0.97338	0.24615	0.96923	45
16	0.17823	0.98399	0.19538	0.98073	0.21246	0.97717	0.22948	0.97331	0.24644	0.96916	44
17	0.17852	0.98394	0.19566	0.98067	0.21275	0.97711	0.22977	0.97325	0.24672	0.96909	43
18	0.17880	0.98389	0.19595	0.98061	0.21303	0.97705	0.23005	0.97318	0.24700	0.96902	42
19	0.17909	0.98383	0.19623	0.98056	0.21331	0.97698	0.23033	0.97311	0.24728	0.96894	41
20	0.17937	0.98378	0.19652	0.98050	0.21360	0.97692	0.23062	0.97304	0.24756	0.96887	40
21	0.17966	0.98373	0.19680	0.98044	0.21388	0.97686	0.23090	0.97298	0.24784	0.96880	39
22	0.17995	0.98368	0.19709	0.98039	0.21417	0.97680	0.23118	0.97291	0.24813	0.96873	38
23	0.18023	0.98362	0.19737	0.98033	0.21445	0.97673	0.23146	0.97284	0.24841	0.96866	37
24	0.18052	0.98357	0.19766	0.98027	0.21474	0.97667	0.23175	0.97278	0.24869	0.96858	36
25	0.18081	0.98352	0.19794	0.98021	0.21502	0.97661	0.23203	0.97271	0.24897	0.96851	35
26	0.18109	0.98347	0.19823	0.98016	0.21530	0.97655	0.23231	0.97264	0.24925	0.96844	34
27	0.18138	0.98341	0.19851	0.98010	0.21559	0.97648	0.23260	0.97257	0.24954	0.96837	33
28	0.18166	0.98336	0.19880	0.98004	0.21587	0.97642	0.23288	0.97251	0.24982	0.96829	32
29	0.18195	0.98331	0.19908	0.97998	0.21616	0.97636	0.23316	0.97244	0.25010	0.96822	31
30	0.18224	0.98325	0.19937	0.97992	0.21644	0.97630	0.23345	0.97237	0.25038	0.96815	30
31	0.18252	0.98320	0.19965	0.97987	0.21672	0.97623	0.23373	0.97230	0.25066	0.96807	29
32	0.18281	0.98315	0.19994	0.97981	0.21701	0.97617	0.23401	0.97223	0.25094	0.96800	28
33	0.18309	0.98310	0.20022	0.97975	0.21729	0.97611	0.23429	0.97217	0.25122	0.96793	27
34	0.18338	0.98304	0.20051	0.97969	0.21758	0.97604	0.23458	0.97210	0.25151	0.96786	26
35	0.18367	0.98299	0.20079	0.97963	0.21786	0.97598	0.23486	0.97203	0.25179	0.96778	25
36	0.18395	0.98294	0.20108	0.97958	0.21814	0.97592	0.23514	0.97196	0.25207	0.96771	24
37	0.18424	0.98288	0.20136	0.97952	0.21843	0.97585	0.23542	0.97189	0.25235	0.96764	23
38	0.18452	0.98283	0.20165	0.97946	0.21871	0.97579	0.23571	0.97182	0.25263	0.96756	22
39	0.18481	0.98277	0.20193	0.97940	0.21899	0.97573	0.23599	0.97176	0.25291	0.96749	21
40	0.18509	0.98272	0.20222	0.97934	0.21928	0.97566	0.23627	0.97169	0.25320	0.96742	20
41	0.18538	0.98267	0.20250	0.97928	0.21956	0.97560	0.23656	0.97162	0.25348	0.96734	19
42	0.18567	0.98261	0.20279	0.97922	0.21985	0.97553	0.23684	0.97155	0.25376	0.96727	18
43	0.18595	0.98256	0.20307	0.97916	0.22013	0.97547	0.23712	0.97148	0.25404	0.96719	17
44	0.18624	0.98250	0.20336	0.97910	0.22041	0.97541	0.23740	0.97141	0.25432	0.96712	16
45	0.18652	0.98245	0.20364	0.97905	0.22070	0.97534	0.23769	0.97134	0.25460	0.96705	15
46	0.18681	0.98240	0.20393	0.97899	0.22098	0.97528	0.23797	0.97127	0.25488	0.96697	14
47	0.18710	0.98234	0.20421	0.97893	0.22126	0.97521	0.23825	0.97120	0.25516	0.96690	13
48	0.18738	0.98229	0.20450	0.97887	0.22155	0.97515	0.23853	0.97113	0.25545	0.96682	12
49	0.18767	0.98223	0.20478	0.97881	0.22183	0.97508	0.23882	0.97106	0.25573	0.96675	11
50	0.18795	0.98218	0.20507	0.97875	0.22212	0.97502	0.23910	0.97100	0.25601	0.96667	10
51	0.18824	0.98212	0.20535	0.97869	0.22240	0.97496	0.23938	0.97093	0.25629	0.96660	9
52	0.18852	0.98207	0.20563	0.97863	0.22268	0.97489	0.23966	0.97086	0.25657	0.96653	8
53	0.18881	0.98201	0.20592	0.97857	0.22297	0.97483	0.23995	0.97079	0.25685	0.96645	7
54	0.18910	0.98196	0.20620	0.97851	0.22325	0.97476	0.24023	0.97072	0.25713	0.96638	6
55	0.18938	0.98190	0.20649	0.97845	0.22353	0.97470	0.24051	0.97065	0.25741	0.96630	5
56	0.18967	0.98185	0.20677	0.97839	0.22382	0.97463	0.24079	0.97058	0.25769	0.96623	4
57	0.18995	0.98179	0.20706	0.97833	0.22410	0.97457	0.24108	0.97051	0.25798	0.96615	3
58	0.19024	0.98174	0.20734	0.97827	0.22438	0.97450	0.24136	0.97044	0.25826	0.96608	2
59	0.19052	0.98168	0.20763	0.97821	0.22467	0.97444	0.24164	0.97037	0.25854	0.96600	1
60	0.19081	0.98163	0.20791	0.97815	0.22495	0.97437	0.24192	0.97030	0.25882	0.96593	0
	79° COS	79° SIN	78° COS	78° SIN	77° COS	77° SIN	76° COS	76° SIN	75° COS	75° SIN	MIN

MIN	15°		16°		17°		18°		19°		
	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	
0	0.25882	0.96593	0.27564	0.96126	0.29237	0.95630	0.30902	0.95106	0.32557	0.94552	60
1	0.25910	0.96585	0.27592	0.96118	0.29265	0.95622	0.30929	0.95097	0.32584	0.94542	59
2	0.25938	0.96578	0.27620	0.96110	0.29293	0.95613	0.30957	0.95088	0.32612	0.94533	58
3	0.25966	0.96570	0.27648	0.96102	0.29321	0.95605	0.30985	0.95079	0.32639	0.94523	57
4	0.25994	0.96562	0.27676	0.96094	0.29348	0.95596	0.31012	0.95070	0.32667	0.94514	56
5	0.26022	0.96555	0.27704	0.96086	0.29376	0.95588	0.31040	0.95061	0.32694	0.94504	55
6	0.26050	0.96547	0.27731	0.96078	0.29404	0.95579	0.31068	0.95052	0.32722	0.94495	54
7	0.26079	0.96540	0.27759	0.96070	0.29432	0.95571	0.31095	0.95043	0.32749	0.94485	53
8	0.26107	0.96532	0.27787	0.96062	0.29460	0.95562	0.31123	0.95033	0.32777	0.94476	52
9	0.26135	0.96524	0.27815	0.96054	0.29487	0.95554	0.31151	0.95024	0.32804	0.94466	51
10	0.26163	0.96517	0.27843	0.96046	0.29515	0.95545	0.31178	0.95015	0.32832	0.94457	50
11	0.26191	0.96509	0.27871	0.96037	0.29543	0.95536	0.31206	0.95006	0.32859	0.94447	49
12	0.26219	0.96502	0.27899	0.96029	0.29571	0.95528	0.31233	0.94997	0.32887	0.94438	48
13	0.26247	0.96494	0.27927	0.96021	0.29599	0.95519	0.31261	0.94988	0.32914	0.94428	47
14	0.26275	0.96486	0.27955	0.96013	0.29626	0.95511	0.31289	0.94979	0.32942	0.94418	46
15	0.26303	0.96479	0.27983	0.96005	0.29654	0.95502	0.31316	0.94970	0.32969	0.94409	45
16	0.26331	0.96471	0.28011	0.95997	0.29682	0.95493	0.31344	0.94961	0.32997	0.94399	44
17	0.26359	0.96463	0.28039	0.95989	0.29710	0.95485	0.31372	0.94952	0.33024	0.94390	43
18	0.26387	0.96456	0.28067	0.95981	0.29737	0.95476	0.31399	0.94943	0.33051	0.94380	42
19	0.26415	0.96448	0.28095	0.95972	0.29765	0.95467	0.31427	0.94933	0.33079	0.94370	41
20	0.26443	0.96440	0.28123	0.95964	0.29793	0.95459	0.31454	0.94924	0.33106	0.94361	40
21	0.26471	0.96433	0.28150	0.95956	0.29821	0.95450	0.31482	0.94915	0.33134	0.94351	39
22	0.26500	0.96425	0.28178	0.95948	0.29849	0.95441	0.31510	0.94906	0.33161	0.94342	38
23	0.26528	0.96417	0.28206	0.95940	0.29876	0.95433	0.31537	0.94897	0.33189	0.94332	37
24	0.26556	0.96410	0.28234	0.95931	0.29904	0.95424	0.31565	0.94888	0.33216	0.94322	36
25	0.26584	0.96402	0.28262	0.95923	0.29932	0.95415	0.31593	0.94878	0.33244	0.94313	35
26	0.26612	0.96394	0.28290	0.95915	0.29960	0.95407	0.31620	0.94869	0.33271	0.94303	34
27	0.26640	0.96386	0.28318	0.95907	0.29987	0.95398	0.31648	0.94860	0.33298	0.94293	33
28	0.26668	0.96379	0.28346	0.95898	0.30015	0.95389	0.31675	0.94851	0.33326	0.94284	32
29	0.26696	0.96371	0.28374	0.95890	0.30043	0.95380	0.31703	0.94842	0.33353	0.94274	31
30	0.26724	0.96363	0.28402	0.95882	0.30071	0.95372	0.31730	0.94832	0.33381	0.94264	30
31	0.26752	0.96355	0.28429	0.95874	0.30098	0.95363	0.31758	0.94823	0.33408	0.94254	29
32	0.26780	0.96347	0.28457	0.95865	0.30126	0.95354	0.31786	0.94814	0.33436	0.94245	28
33	0.26808	0.96340	0.28485	0.95857	0.30154	0.95345	0.31813	0.94805	0.33463	0.94235	27
34	0.26836	0.96332	0.28513	0.95849	0.30182	0.95337	0.31841	0.94795	0.33490	0.94225	26
35	0.26864	0.96324	0.28541	0.95841	0.30209	0.95328	0.31868	0.94786	0.33518	0.94215	25
36	0.26892	0.96316	0.28569	0.95832	0.30237	0.95319	0.31896	0.94777	0.33545	0.94206	24
37	0.26920	0.96308	0.28597	0.95824	0.30265	0.95310	0.31923	0.94768	0.33573	0.94196	23
38	0.26948	0.96301	0.28625	0.95816	0.30292	0.95301	0.31951	0.94758	0.33600	0.94186	22
39	0.26976	0.96293	0.28652	0.95807	0.30320	0.95293	0.31979	0.94749	0.33627	0.94176	21
40	0.27004	0.96285	0.28680	0.95799	0.30348	0.95284	0.32006	0.94740	0.33655	0.94167	20
41	0.27032	0.96277	0.28708	0.95791	0.30376	0.95275	0.32034	0.94730	0.33682	0.94157	19
42	0.27060	0.96269	0.28736	0.95782	0.30403	0.95266	0.32061	0.94721	0.33710	0.94147	18
43	0.27088	0.96261	0.28764	0.95774	0.30431	0.95257	0.32089	0.94712	0.33737	0.94137	17
44	0.27116	0.96253	0.28792	0.95766	0.30459	0.95248	0.32116	0.94702	0.33764	0.94127	16
45	0.27144	0.96246	0.28820	0.95757	0.30486	0.95240	0.32144	0.94693	0.33792	0.94118	15
46	0.27172	0.96238	0.28847	0.95749	0.30514	0.95231	0.32171	0.94684	0.33819	0.94108	14
47	0.27200	0.96230	0.28875	0.95740	0.30542	0.95222	0.32199	0.94674	0.33846	0.94098	13
48	0.27228	0.96222	0.28903	0.95732	0.30570	0.95213	0.32227	0.94665	0.33874	0.94088	12
49	0.27256	0.96214	0.28931	0.95724	0.30597	0.95204	0.32254	0.94656	0.33901	0.94078	11
50	0.27284	0.96206	0.28959	0.95715	0.30625	0.95195	0.32282	0.94646	0.33929	0.94068	10
51	0.27312	0.96198	0.28987	0.95707	0.30653	0.95186	0.32309	0.94637	0.33956	0.94058	9
52	0.27340	0.96190	0.29015	0.95698	0.30680	0.95177	0.32337	0.94627	0.33983	0.94049	8
53	0.27368	0.96182	0.29042	0.95690	0.30708	0.95168	0.32364	0.94618	0.34011	0.94039	7
54	0.27396	0.96174	0.29070	0.95681	0.30736	0.95159	0.32392	0.94609	0.34038	0.94029	6
55	0.27424	0.96166	0.29098	0.95673	0.30763	0.95150	0.32419	0.94599	0.34065	0.94019	5
56	0.27452	0.96158	0.29126	0.95664	0.30791	0.95142	0.32447	0.94590	0.34093	0.94009	4
57	0.27480	0.96150	0.29154	0.95656	0.30819	0.95133	0.32474	0.94580	0.34120	0.93999	3
58	0.27508	0.96142	0.29182	0.95647	0.30846	0.95124	0.32502	0.94571	0.34147	0.93989	2
59	0.27536	0.96134	0.29209	0.95639	0.30874	0.95115	0.32529	0.94561	0.34175	0.93979	1
60	0.27564	0.96126	0.29237	0.95630	0.30902	0.95106	0.32557	0.94552	0.34202	0.93969	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	74°		73°		72°		71°		70°		

Table AII-1.—Natural Sines and Cosines—Continued

MIN	20°		21°		22°		23°		24°		
	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	
0	0.34202	0.93969	0.35837	0.93358	0.37461	0.92718	0.39073	0.92050	0.40674	0.91355	60
1	0.34229	0.93959	0.35864	0.93348	0.37488	0.92707	0.39100	0.92039	0.40700	0.91343	59
2	0.34257	0.93949	0.35891	0.93337	0.37515	0.92697	0.39127	0.92028	0.40727	0.91331	58
3	0.34284	0.93939	0.35918	0.93327	0.37542	0.92686	0.39153	0.92016	0.40753	0.91319	57
4	0.34311	0.93929	0.35945	0.93316	0.37569	0.92675	0.39180	0.92005	0.40780	0.91307	56
5	0.34339	0.93919	0.35973	0.93306	0.37595	0.92664	0.39207	0.91994	0.40806	0.91295	55
6	0.34366	0.93909	0.36000	0.93295	0.37622	0.92653	0.39234	0.91982	0.40833	0.91283	54
7	0.34393	0.93899	0.36027	0.93285	0.37649	0.92642	0.39260	0.91971	0.40860	0.91272	53
8	0.34421	0.93889	0.36054	0.93274	0.37676	0.92631	0.39287	0.91959	0.40886	0.91260	52
9	0.34448	0.93879	0.36081	0.93264	0.37703	0.92620	0.39314	0.91948	0.40913	0.91248	51
10	0.34475	0.93869	0.36108	0.93253	0.37730	0.92609	0.39341	0.91936	0.40939	0.91236	50
11	0.34503	0.93859	0.36135	0.93243	0.37757	0.92598	0.39367	0.91925	0.40966	0.91224	49
12	0.34530	0.93849	0.36162	0.93232	0.37784	0.92587	0.39394	0.91914	0.40992	0.91212	48
13	0.34557	0.93839	0.36190	0.93222	0.37811	0.92576	0.39421	0.91902	0.41019	0.91200	47
14	0.34584	0.93829	0.36217	0.93211	0.37838	0.92565	0.39448	0.91891	0.41045	0.91188	46
15	0.34612	0.93819	0.36244	0.93201	0.37865	0.92554	0.39474	0.91879	0.41072	0.91176	45
16	0.34639	0.93809	0.36271	0.93190	0.37892	0.92543	0.39501	0.91868	0.41098	0.91164	44
17	0.34666	0.93799	0.36298	0.93180	0.37919	0.92532	0.39528	0.91856	0.41125	0.91152	43
18	0.34694	0.93789	0.36325	0.93169	0.37946	0.92521	0.39555	0.91845	0.41151	0.91140	42
19	0.34721	0.93779	0.36352	0.93159	0.37973	0.92510	0.39581	0.91833	0.41178	0.91128	41
20	0.34748	0.93769	0.36379	0.93148	0.37999	0.92499	0.39608	0.91822	0.41204	0.91116	40
21	0.34775	0.93759	0.36406	0.93137	0.38026	0.92488	0.39635	0.91810	0.41231	0.91104	39
22	0.34803	0.93748	0.36434	0.93127	0.38053	0.92477	0.39661	0.91799	0.41257	0.91092	38
23	0.34830	0.93738	0.36461	0.93116	0.38080	0.92466	0.39688	0.91787	0.41284	0.91080	37
24	0.34857	0.93728	0.36488	0.93106	0.38107	0.92455	0.39715	0.91775	0.41310	0.91068	36
25	0.34884	0.93718	0.36515	0.93095	0.38134	0.92444	0.39741	0.91764	0.41337	0.91056	35
26	0.34912	0.93708	0.36542	0.93084	0.38161	0.92432	0.39768	0.91752	0.41363	0.91044	34
27	0.34939	0.93698	0.36569	0.93074	0.38188	0.92421	0.39795	0.91741	0.41390	0.91032	33
28	0.34966	0.93688	0.36596	0.93063	0.38215	0.92410	0.39822	0.91729	0.41416	0.91020	32
29	0.34993	0.93677	0.36623	0.93052	0.38241	0.92399	0.39848	0.91718	0.41443	0.91008	31
30	0.35021	0.93667	0.36650	0.93042	0.38268	0.92388	0.39875	0.91706	0.41469	0.90996	30
31	0.35048	0.93657	0.36677	0.93031	0.38295	0.92377	0.39902	0.91694	0.41496	0.90984	29
32	0.35075	0.93647	0.36704	0.93020	0.38322	0.92366	0.39928	0.91683	0.41522	0.90972	28
33	0.35102	0.93637	0.36731	0.93010	0.38349	0.92355	0.39955	0.91671	0.41549	0.90960	27
34	0.35130	0.93626	0.36758	0.92999	0.38376	0.92343	0.39982	0.91660	0.41575	0.90948	26
35	0.35157	0.93616	0.36785	0.92988	0.38403	0.92332	0.40008	0.91648	0.41602	0.90936	25
36	0.35184	0.93606	0.36812	0.92978	0.38430	0.92321	0.40035	0.91636	0.41628	0.90924	24
37	0.35211	0.93596	0.36839	0.92967	0.38456	0.92310	0.40062	0.91625	0.41655	0.90911	23
38	0.35239	0.93585	0.36867	0.92956	0.38483	0.92299	0.40088	0.91613	0.41681	0.90899	22
39	0.35266	0.93575	0.36894	0.92945	0.38510	0.92287	0.40115	0.91601	0.41707	0.90887	21
40	0.35293	0.93565	0.36921	0.92935	0.38537	0.92276	0.40141	0.91590	0.41734	0.90875	20
41	0.35320	0.93555	0.36948	0.92924	0.38564	0.92265	0.40168	0.91578	0.41760	0.90863	19
42	0.35347	0.93544	0.36975	0.92913	0.38591	0.92254	0.40195	0.91566	0.41787	0.90851	18
43	0.35375	0.93534	0.37002	0.92902	0.38617	0.92243	0.40221	0.91555	0.41813	0.90839	17
44	0.35402	0.93524	0.37029	0.92892	0.38644	0.92231	0.40248	0.91543	0.41840	0.90826	16
45	0.35429	0.93514	0.37056	0.92881	0.38671	0.92220	0.40275	0.91531	0.41866	0.90814	15
46	0.35456	0.93503	0.37083	0.92870	0.38698	0.92209	0.40301	0.91519	0.41892	0.90802	14
47	0.35484	0.93493	0.37110	0.92859	0.38725	0.92198	0.40328	0.91508	0.41919	0.90790	13
48	0.35511	0.93483	0.37137	0.92849	0.38752	0.92186	0.40355	0.91496	0.41945	0.90778	12
49	0.35538	0.93472	0.37164	0.92838	0.38778	0.92175	0.40381	0.91484	0.41972	0.90766	11
50	0.35565	0.93462	0.37191	0.92827	0.38805	0.92164	0.40408	0.91472	0.41998	0.90753	10
51	0.35592	0.93452	0.37218	0.92816	0.38832	0.92152	0.40434	0.91461	0.42024	0.90741	9
52	0.35619	0.93441	0.37245	0.92805	0.38859	0.92141	0.40461	0.91449	0.42051	0.90729	8
53	0.35647	0.93431	0.37272	0.92794	0.38886	0.92130	0.40488	0.91437	0.42077	0.90717	7
54	0.35674	0.93420	0.37299	0.92784	0.38912	0.92119	0.40514	0.91425	0.42104	0.90704	6
55	0.35701	0.93410	0.37326	0.92773	0.38939	0.92107	0.40541	0.91414	0.42130	0.90692	5
56	0.35728	0.93400	0.37353	0.92762	0.38966	0.92096	0.40567	0.91402	0.42156	0.90680	4
57	0.35755	0.93389	0.37380	0.92751	0.38993	0.92085	0.40594	0.91390	0.42183	0.90668	3
58	0.35782	0.93379	0.37407	0.92740	0.39020	0.92073	0.40621	0.91378	0.42209	0.90655	2
59	0.35810	0.93368	0.37434	0.92729	0.39046	0.92062	0.40647	0.91366	0.42235	0.90643	1
60	0.35837	0.93358	0.37461	0.92718	0.39073	0.92050	0.40674	0.91355	0.42262	0.90631	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	69°		68°		67°		66°		65°		

MIN	25°		26°		27°		28°		29°		
	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	
0	0.42262	0.90631	0.43837	0.89879	0.45399	0.89101	0.46947	0.88295	0.48481	0.87462	60
1	0.42288	0.90618	0.43863	0.89867	0.45425	0.89087	0.46973	0.88281	0.48506	0.87448	59
2	0.42315	0.90606	0.43889	0.89854	0.45451	0.89074	0.46999	0.88267	0.48532	0.87434	58
3	0.42341	0.90594	0.43916	0.89841	0.45477	0.89061	0.47024	0.88254	0.48557	0.87420	57
4	0.42367	0.90582	0.43942	0.89828	0.45503	0.89048	0.47050	0.88240	0.48583	0.87406	56
5	0.42394	0.90569	0.43968	0.89816	0.45529	0.89035	0.47076	0.88226	0.48608	0.87391	55
6	0.42420	0.90557	0.43994	0.89803	0.45554	0.89021	0.47101	0.88213	0.48634	0.87377	54
7	0.42446	0.90545	0.44020	0.89790	0.45580	0.89008	0.47127	0.88199	0.48659	0.87363	53
8	0.42473	0.90532	0.44046	0.89777	0.45606	0.88995	0.47153	0.88185	0.48684	0.87349	52
9	0.42499	0.90520	0.44072	0.89764	0.45632	0.88981	0.47178	0.88172	0.48710	0.87335	51
10	0.42525	0.90507	0.44098	0.89752	0.45658	0.88968	0.47204	0.88158	0.48735	0.87321	50
11	0.42552	0.90495	0.44124	0.89739	0.45684	0.88955	0.47229	0.88144	0.48761	0.87306	49
12	0.42578	0.90483	0.44151	0.89726	0.45710	0.88942	0.47255	0.88130	0.48786	0.87292	48
13	0.42604	0.90470	0.44177	0.89713	0.45736	0.88928	0.47281	0.88117	0.48811	0.87278	47
14	0.42631	0.90458	0.44203	0.89700	0.45762	0.88915	0.47306	0.88103	0.48837	0.87264	46
15	0.42657	0.90446	0.44229	0.89687	0.45787	0.88902	0.47332	0.88089	0.48862	0.87250	45
16	0.42683	0.90433	0.44255	0.89674	0.45813	0.88888	0.47358	0.88075	0.48888	0.87235	44
17	0.42709	0.90421	0.44281	0.89662	0.45839	0.88875	0.47383	0.88062	0.48913	0.87221	43
18	0.42736	0.90408	0.44307	0.89649	0.45865	0.88862	0.47409	0.88048	0.48938	0.87207	42
19	0.42762	0.90396	0.44333	0.89636	0.45891	0.88848	0.47434	0.88034	0.48964	0.87193	41
20	0.42788	0.90383	0.44359	0.89623	0.45917	0.88835	0.47460	0.88020	0.48989	0.87178	40
21	0.42815	0.90371	0.44385	0.89610	0.45942	0.88822	0.47486	0.88006	0.49014	0.87164	39
22	0.42841	0.90358	0.44411	0.89597	0.45968	0.88808	0.47511	0.87993	0.49040	0.87150	38
23	0.42867	0.90346	0.44437	0.89584	0.45994	0.88795	0.47537	0.87979	0.49065	0.87136	37
24	0.42894	0.90334	0.44464	0.89571	0.46020	0.88782	0.47562	0.87965	0.49090	0.87121	36
25	0.42920	0.90321	0.44490	0.89558	0.46046	0.88768	0.47588	0.87951	0.49116	0.87107	35
26	0.42946	0.90309	0.44516	0.89545	0.46072	0.88755	0.47614	0.87937	0.49141	0.87093	34
27	0.42972	0.90296	0.44542	0.89532	0.46097	0.88741	0.47639	0.87923	0.49166	0.87079	33
28	0.42999	0.90284	0.44568	0.89519	0.46123	0.88728	0.47665	0.87909	0.49192	0.87064	32
29	0.43025	0.90271	0.44594	0.89506	0.46149	0.88715	0.47690	0.87896	0.49217	0.87050	31
30	0.43051	0.90259	0.44620	0.89493	0.46175	0.88701	0.47716	0.87882	0.49242	0.87036	30
31	0.43077	0.90246	0.44646	0.89480	0.46201	0.88688	0.47741	0.87868	0.49268	0.87021	29
32	0.43104	0.90233	0.44672	0.89467	0.46226	0.88674	0.47767	0.87854	0.49293	0.87007	28
33	0.43130	0.90221	0.44698	0.89454	0.46252	0.88661	0.47793	0.87840	0.49318	0.86993	27
34	0.43156	0.90208	0.44724	0.89441	0.46278	0.88647	0.47818	0.87826	0.49344	0.86978	26
35	0.43182	0.90196	0.44750	0.89428	0.46304	0.88634	0.47844	0.87812	0.49369	0.86964	25
36	0.43209	0.90183	0.44776	0.89415	0.46330	0.88620	0.47869	0.87798	0.49394	0.86949	24
37	0.43235	0.90171	0.44802	0.89402	0.46355	0.88607	0.47895	0.87784	0.49419	0.86935	23
38	0.43261	0.90158	0.44828	0.89389	0.46381	0.88593	0.47920	0.87770	0.49445	0.86921	22
39	0.43287	0.90146	0.44854	0.89376	0.46407	0.88580	0.47946	0.87756	0.49470	0.86906	21
40	0.43313	0.90133	0.44880	0.89363	0.46433	0.88566	0.47971	0.87743	0.49495	0.86892	20
41	0.43340	0.90120	0.44906	0.89350	0.46458	0.88553	0.47997	0.87729	0.49521	0.86878	19
42	0.43366	0.90108	0.44932	0.89337	0.46484	0.88539	0.48022	0.87715	0.49546	0.86863	18
43	0.43392	0.90095	0.44958	0.89324	0.46510	0.88526	0.48048	0.87701	0.49571	0.86849	17
44	0.43418	0.90082	0.44984	0.89311	0.46536	0.88512	0.48073	0.87687	0.49596	0.86834	16
45	0.43445	0.90070	0.45010	0.89298	0.46561	0.88499	0.48099	0.87673	0.49622	0.96820	15
46	0.43471	0.90057	0.45036	0.89285	0.46587	0.88485	0.48124	0.87659	0.49647	0.86805	14
47	0.43497	0.90045	0.45062	0.89272	0.46613	0.88472	0.48150	0.87645	0.49672	0.86791	13
48	0.43523	0.90032	0.45088	0.89259	0.46639	0.88458	0.48175	0.87631	0.49697	0.86777	12
49	0.43549	0.90019	0.45114	0.89245	0.46664	0.88445	0.48201	0.87617	0.49723	0.86762	11
50	0.43575	0.90007	0.45140	0.89232	0.46690	0.88431	0.48226	0.87603	0.49748	0.86748	10
51	0.43602	0.89994	0.45166	0.89219	0.46716	0.88417	0.48252	0.87589	0.49773	0.86733	9
52	0.43628	0.89981	0.45192	0.89206	0.46742	0.88404	0.48277	0.87575	0.49798	0.86719	8
53	0.43654	0.89968	0.45218	0.89193	0.46767	0.88390	0.48303	0.87561	0.49824	0.86704	7
54	0.43680	0.89956	0.45243	0.89180	0.46793	0.88377	0.48328	0.87546	0.49849	0.86690	6
55	0.43706	0.89943	0.45269	0.89167	0.46819	0.88363	0.48354	0.87532	0.49874	0.86675	5
56	0.43733	0.89930	0.45295	0.89153	0.46844	0.88349	0.48379	0.87518	0.49899	0.86661	4
57	0.43759	0.89918	0.45321	0.89140	0.46870	0.88336	0.48405	0.87504	0.49924	0.86646	3
58	0.43785	0.89905	0.45347	0.89127	0.46896	0.88322	0.48430	0.87490	0.49950	0.86632	2
59	0.43811	0.89892	0.45373	0.89114	0.46921	0.88308	0.48456	0.87476	0.49975	0.86617	1
60	0.43837	0.89879	0.45399	0.89101	0.46947	0.88295	0.48481	0.87462	0.50000	0.86603	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	64°		63°		62°		61°		60°		

MIN	30°		31°		32°		33°		34°		
	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	
0	0.50000	0.86603	0.51504	0.85717	0.52992	0.84805	0.54464	0.83867	0.55919	0.82904	60
1	0.50025	0.86588	0.51529	0.85702	0.53017	0.84789	0.54488	0.83851	0.55943	0.82887	59
2	0.50050	0.86573	0.51554	0.85687	0.53041	0.84774	0.54513	0.83835	0.55968	0.82871	58
3	0.50076	0.86559	0.51579	0.85672	0.53066	0.84759	0.54537	0.83819	0.55992	0.82855	57
4	0.50101	0.86544	0.51604	0.85657	0.53091	0.84743	0.54561	0.83804	0.56016	0.82839	56
5	0.50126	0.86530	0.51628	0.85642	0.53115	0.84728	0.54586	0.83788	0.56040	0.82822	55
6	0.50151	0.86515	0.51653	0.85627	0.53140	0.84712	0.54610	0.83772	0.56064	0.82806	54
7	0.50176	0.86501	0.51678	0.85612	0.53164	0.84697	0.54635	0.83756	0.56088	0.82790	53
8	0.50201	0.86486	0.51703	0.85597	0.53189	0.84681	0.54659	0.83740	0.56112	0.82773	52
9	0.50227	0.86471	0.51728	0.85582	0.53214	0.84666	0.54683	0.83724	0.56136	0.82757	51
10	0.50252	0.86457	0.51753	0.85567	0.53238	0.84650	0.54708	0.83708	0.56160	0.82741	50
11	0.50277	0.86442	0.51778	0.85551	0.53263	0.84635	0.54732	0.83692	0.56184	0.82724	49
12	0.50302	0.86427	0.51803	0.85536	0.53288	0.84619	0.54756	0.83676	0.56208	0.82708	48
13	0.50327	0.86413	0.51828	0.85521	0.53312	0.84604	0.54781	0.83660	0.56232	0.82692	47
14	0.50352	0.86398	0.51852	0.85506	0.53337	0.84588	0.54805	0.83645	0.56256	0.82675	46
15	0.50377	0.86384	0.51877	0.85491	0.53361	0.84573	0.54829	0.83629	0.56280	0.82659	45
16	0.50403	0.86369	0.51902	0.85476	0.53386	0.84557	0.54854	0.83613	0.56305	0.82643	44
17	0.50428	0.86354	0.51927	0.85461	0.53411	0.84542	0.54878	0.83597	0.56329	0.82626	43
18	0.50453	0.86340	0.51952	0.85446	0.53435	0.84526	0.54902	0.83581	0.56353	0.82610	42
19	0.50478	0.86325	0.51977	0.85431	0.53460	0.84511	0.54927	0.83565	0.56377	0.82593	41
20	0.50503	0.86310	0.52002	0.85416	0.53484	0.84495	0.54951	0.83549	0.56401	0.82577	40
21	0.50528	0.86295	0.52026	0.85401	0.53509	0.84480	0.54975	0.83533	0.56425	0.82561	39
22	0.50553	0.86281	0.52051	0.85385	0.53534	0.84464	0.54999	0.83517	0.56449	0.82544	38
23	0.50578	0.86266	0.52076	0.85370	0.53558	0.84448	0.55024	0.83501	0.56473	0.82528	37
24	0.50603	0.86251	0.52101	0.85355	0.53583	0.84433	0.55048	0.83485	0.56497	0.82511	36
25	0.50628	0.86237	0.52126	0.85340	0.53607	0.84417	0.55072	0.83469	0.56521	0.82495	35
26	0.50654	0.86222	0.52151	0.85325	0.53632	0.84402	0.55097	0.83453	0.56545	0.82478	34
27	0.50679	0.86207	0.52175	0.85310	0.53656	0.84386	0.55121	0.83437	0.56569	0.82462	33
28	0.50704	0.86192	0.52200	0.85294	0.53681	0.84370	0.55145	0.83421	0.56593	0.82446	32
29	0.50729	0.86178	0.52225	0.85279	0.53705	0.84355	0.55169	0.83405	0.56617	0.82429	31
30	0.50754	0.86163	0.52250	0.85264	0.53730	0.84339	0.55194	0.83389	0.56641	0.82413	30
31	0.50779	0.86148	0.52275	0.85249	0.53754	0.84324	0.55218	0.83373	0.56665	0.82396	29
32	0.50804	0.86133	0.52299	0.85234	0.53779	0.84308	0.55242	0.83356	0.56689	0.82380	28
33	0.50829	0.86119	0.52324	0.85218	0.53804	0.84292	0.55266	0.83340	0.56713	0.82363	27
34	0.50854	0.86104	0.52349	0.85203	0.53828	0.84277	0.55291	0.83324	0.56736	0.82347	26
35	0.50879	0.86089	0.52374	0.85188	0.53853	0.84261	0.55315	0.83308	0.56760	0.82330	25
36	0.50904	0.86074	0.52399	0.85173	0.53877	0.84245	0.55339	0.83292	0.56784	0.82314	24
37	0.50929	0.86059	0.52423	0.85157	0.53902	0.84230	0.55363	0.83276	0.56808	0.82297	23
38	0.50954	0.86045	0.52448	0.85142	0.53926	0.84214	0.55388	0.83260	0.56832	0.82281	22
39	0.50979	0.86030	0.52473	0.85127	0.53951	0.84198	0.55412	0.83244	0.56856	0.82264	21
40	0.51004	0.86015	0.52498	0.85112	0.53975	0.84182	0.55436	0.83228	0.56880	0.82248	20
41	0.51029	0.86000	0.52522	0.85096	0.54000	0.84167	0.55460	0.83212	0.56904	0.82231	19
42	0.51054	0.85985	0.52547	0.85081	0.54024	0.84151	0.55484	0.83195	0.56928	0.82214	18
43	0.51079	0.85970	0.52572	0.85066	0.54049	0.84135	0.55509	0.83179	0.56952	0.82178	17
44	0.51104	0.85956	0.52597	0.85051	0.54073	0.84120	0.55533	0.83163	0.56976	0.82181	16
45	0.51129	0.85941	0.52621	0.85035	0.54097	0.84104	0.55557	0.83147	0.57000	0.82165	15
46	0.51154	0.85926	0.52646	0.85020	0.54122	0.84088	0.55581	0.83131	0.57024	0.82148	14
47	0.51179	0.85911	0.52671	0.85005	0.54146	0.84072	0.55605	0.83115	0.57047	0.82132	13
48	0.51204	0.85896	0.52696	0.84989	0.54171	0.84057	0.55630	0.83098	0.57071	0.82115	12
49	0.51229	0.85881	0.52720	0.84974	0.54195	0.84041	0.55654	0.83082	0.57095	0.82098	11
50	0.51254	0.85866	0.52745	0.84959	0.54220	0.84025	0.55678	0.83066	0.57119	0.82082	10
51	0.51279	0.85851	0.52770	0.84943	0.54244	0.84009	0.55702	0.83050	0.57143	0.82065	9
52	0.51304	0.85836	0.52794	0.84928	0.54269	0.83994	0.55726	0.83034	0.57167	0.82048	8
53	0.51329	0.85821	0.52819	0.84913	0.54293	0.83978	0.55750	0.83017	0.57191	0.82032	7
54	0.51354	0.85806	0.52844	0.84897	0.54317	0.83962	0.55775	0.83001	0.57215	0.82015	6
55	0.51379	0.85792	0.52869	0.84882	0.54342	0.83946	0.55799	0.82985	0.57238	0.81999	5
56	0.51404	0.85777	0.52893	0.84866	0.54366	0.83930	0.55823	0.82969	0.57262	0.81982	4
57	0.51429	0.85762	0.52918	0.84851	0.54391	0.83915	0.55847	0.82953	0.57286	0.81965	3
58	0.51454	0.85747	0.52943	0.84836	0.54415	0.83899	0.55871	0.82936	0.57310	0.81949	2
59	0.51479	0.85732	0.52967	0.84820	0.54440	0.83883	0.55895	0.82920	0.57334	0.81932	1
60	0.51504	0.85717	0.52992	0.84805	0.54464	0.83867	0.55919	0.82904	0.57358	0.81915	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	59°		58°		57°		56°		55°		

Table AII-1.—Natural Sines and Cosines—Continued

MIN	35°		36°		37°		38°		39°		
	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	
0	0.57358	0.81915	0.58779	0.80902	0.60182	0.79864	0.61566	0.78801	0.62932	0.77715	60
1	0.57381	0.81899	0.58802	0.80885	0.60205	0.79846	0.61589	0.78783	0.62955	0.77696	59
2	0.57405	0.81882	0.58826	0.80867	0.60228	0.79829	0.61612	0.78765	0.62977	0.77678	58
3	0.57429	0.81865	0.58849	0.80850	0.60251	0.79811	0.61635	0.78747	0.63000	0.77660	57
4	0.57453	0.81848	0.58873	0.80833	0.60274	0.79793	0.61658	0.78729	0.63022	0.77641	56
5	0.57477	0.81832	0.58896	0.80816	0.60298	0.79776	0.61681	0.78711	0.63045	0.77623	55
6	0.57501	0.81815	0.58920	0.80799	0.60321	0.79758	0.61704	0.78694	0.63068	0.77605	54
7	0.57524	0.81798	0.58943	0.80782	0.60344	0.79741	0.61726	0.78676	0.63090	0.77586	53
8	0.57548	0.81782	0.58967	0.80765	0.60367	0.79723	0.61749	0.78658	0.63113	0.77568	52
9	0.57572	0.81765	0.58990	0.80748	0.60390	0.79706	0.61772	0.78640	0.63135	0.77550	51
10	0.57596	0.81748	0.59014	0.80730	0.60414	0.79688	0.61795	0.78622	0.63158	0.77531	50
11	0.57619	0.81731	0.59037	0.80713	0.60437	0.79671	0.61818	0.78604	0.63180	0.77513	49
12	0.57643	0.81714	0.59061	0.80696	0.60460	0.79653	0.61841	0.78586	0.63203	0.77494	48
13	0.57667	0.81698	0.59084	0.80679	0.60483	0.79635	0.61864	0.78568	0.63225	0.77476	47
14	0.57691	0.81681	0.59108	0.80662	0.60506	0.79618	0.61887	0.78550	0.63248	0.77458	46
15	0.57715	0.81664	0.59131	0.80644	0.60529	0.79600	0.61909	0.78532	0.63271	0.77439	45
16	0.57738	0.81647	0.59154	0.80627	0.60553	0.79583	0.61932	0.78514	0.63293	0.77421	44
17	0.57762	0.81631	0.59178	0.80610	0.60576	0.79565	0.61955	0.78496	0.63316	0.77402	43
18	0.57786	0.81614	0.59201	0.80593	0.60599	0.79547	0.61978	0.78478	0.63338	0.77384	42
19	0.57810	0.81597	0.59225	0.80576	0.60622	0.79530	0.62001	0.78460	0.63361	0.77366	41
20	0.57833	0.81580	0.59248	0.80558	0.60645	0.79512	0.62024	0.78442	0.63383	0.77347	40
21	0.57857	0.81563	0.59272	0.80541	0.60668	0.79494	0.62046	0.78424	0.63406	0.77329	39
22	0.57881	0.81546	0.59295	0.80524	0.60691	0.79477	0.62069	0.78405	0.63428	0.77310	38
23	0.57904	0.81530	0.59318	0.80507	0.60714	0.79459	0.62092	0.78387	0.63451	0.77292	37
24	0.57928	0.81513	0.59342	0.80489	0.60738	0.79441	0.62115	0.78369	0.63473	0.77273	36
25	0.57952	0.81496	0.59365	0.80472	0.60761	0.79424	0.62138	0.78351	0.63496	0.77255	35
26	0.57976	0.81479	0.59389	0.80455	0.60784	0.79406	0.62160	0.78333	0.63518	0.77236	34
27	0.57999	0.81462	0.59412	0.80438	0.60807	0.79388	0.62183	0.78315	0.63540	0.77218	33
28	0.58023	0.81445	0.59436	0.80420	0.60830	0.79371	0.62206	0.78297	0.63563	0.77199	32
29	0.58047	0.81428	0.59459	0.80403	0.60853	0.79353	0.62229	0.78279	0.63585	0.77181	31
30	0.58070	0.81412	0.59482	0.80386	0.60876	0.79335	0.62251	0.78261	0.63608	0.77162	30
31	0.58094	0.81395	0.59506	0.80368	0.60899	0.79318	0.62274	0.78243	0.63630	0.77144	29
32	0.58118	0.81378	0.59529	0.80351	0.60922	0.79300	0.62297	0.78225	0.63653	0.77125	28
33	0.58141	0.81361	0.59552	0.80334	0.60945	0.79282	0.62320	0.78206	0.63675	0.77107	27
34	0.58165	0.81344	0.59576	0.80316	0.60968	0.79264	0.62342	0.78188	0.63698	0.77088	26
35	0.58189	0.81327	0.59599	0.80299	0.60991	0.79247	0.62365	0.78170	0.63720	0.77070	25
36	0.58212	0.81310	0.59622	0.80282	0.61015	0.79229	0.62388	0.78152	0.63742	0.77051	24
37	0.58236	0.81293	0.59646	0.80264	0.61038	0.79211	0.62411	0.78134	0.63765	0.77033	23
38	0.58260	0.81276	0.59669	0.80247	0.61061	0.79193	0.62433	0.78116	0.63787	0.77014	22
39	0.58283	0.81259	0.59693	0.80230	0.61084	0.79176	0.62456	0.78098	0.63810	0.76996	21
40	0.58307	0.81242	0.59716	0.80212	0.61107	0.79158	0.62479	0.78079	0.63832	0.76977	20
41	0.58330	0.81225	0.59739	0.80195	0.61130	0.79140	0.62502	0.78061	0.63854	0.76959	19
42	0.58354	0.81208	0.59763	0.80178	0.61153	0.79122	0.62524	0.78043	0.63877	0.76940	18
43	0.58378	0.81191	0.59786	0.80160	0.61176	0.79105	0.62547	0.78025	0.63899	0.76921	17
44	0.58401	0.81174	0.59809	0.80143	0.61199	0.79087	0.62570	0.78007	0.63922	0.76903	16
45	0.58425	0.81157	0.59832	0.80125	0.61222	0.79069	0.62592	0.77988	0.63944	0.76884	15
46	0.58449	0.81140	0.59856	0.80108	0.61245	0.79051	0.62615	0.77970	0.63966	0.76866	14
47	0.58472	0.81123	0.59879	0.80091	0.61268	0.79033	0.62638	0.77952	0.63989	0.76847	13
48	0.58496	0.81106	0.59902	0.80073	0.61291	0.79016	0.62660	0.77934	0.64011	0.76828	12
49	0.58519	0.81089	0.59926	0.80056	0.61314	0.78998	0.62683	0.77916	0.64033	0.76810	11
50	0.58543	0.81072	0.59949	0.80038	0.61337	0.78980	0.62706	0.77897	0.64056	0.76791	10
51	0.58567	0.81055	0.59972	0.80021	0.61360	0.78962	0.62728	0.77879	0.64078	0.76772	9
52	0.58590	0.81038	0.59995	0.80003	0.61383	0.78944	0.62751	0.77861	0.64100	0.76754	8
53	0.58614	0.81021	0.60019	0.79986	0.61406	0.78926	0.62774	0.77843	0.64123	0.76735	7
54	0.58637	0.81004	0.60042	0.79968	0.61429	0.78908	0.62796	0.77824	0.64145	0.76717	6
55	0.58661	0.80987	0.60065	0.79951	0.61451	0.78891	0.62819	0.77806	0.64167	0.76698	5
56	0.58684	0.80970	0.60089	0.79934	0.61474	0.78873	0.62842	0.77788	0.64190	0.76679	4
57	0.58708	0.80953	0.60112	0.79916	0.61497	0.78855	0.62864	0.77769	0.64212	0.76661	3
58	0.58731	0.80936	0.60135	0.79899	0.61520	0.78837	0.62887	0.77751	0.64234	0.76642	2
59	0.58755	0.80919	0.60158	0.79881	0.61543	0.78819	0.62909	0.77733	0.64256	0.76623	1
60	0.58779	0.80902	0.60182	0.79864	0.61566	0.78801	0.62932	0.77715	0.64279	0.76604	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	54°		53°		52°		51°		50°		

MIN	40° SIN	40° COS	41° SIN	41° COS	42° SIN	42° COS	43° SIN	43° COS	44° SIN	44° COS	
0	0.64279	0.76604	0.65606	0.75471	0.66913	0.74314	0.68200	0.73135	0.69466	0.71934	60
1	0.64301	0.76586	0.65628	0.75452	0.66935	0.74295	0.68221	0.73116	0.69487	0.71914	59
2	0.64323	0.76567	0.65650	0.75433	0.66956	0.74276	0.68242	0.73096	0.69508	0.71894	58
3	0.64346	0.76548	0.65672	0.75414	0.66978	0.74256	0.68264	0.73076	0.69529	0.71873	57
4	0.64368	0.76530	0.65694	0.75395	0.66999	0.74237	0.68285	0.73056	0.69549	0.71853	56
5	0.64390	0.76511	0.65716	0.75375	0.67021	0.74217	0.68306	0.73036	0.69570	0.71833	55
6	0.64412	0.76492	0.65738	0.75356	0.67043	0.74198	0.68327	0.73016	0.69591	0.71813	54
7	0.64435	0.76473	0.65759	0.75337	0.67064	0.74178	0.68349	0.72996	0.69612	0.71792	53
8	0.64457	0.76455	0.65781	0.75318	0.67086	0.74159	0.68370	0.72976	0.69633	0.71772	52
9	0.64479	0.76436	0.65803	0.75299	0.67107	0.74139	0.68391	0.72957	0.69654	0.71752	51
10	0.64501	0.76417	0.65825	0.75280	0.67129	0.74120	0.68412	0.72937	0.69675	0.71732	50
11	0.64524	0.76398	0.65847	0.75261	0.67151	0.74100	0.68434	0.72917	0.69696	0.71711	49
12	0.64546	0.76380	0.65869	0.75241	0.67172	0.74080	0.68455	0.72897	0.69717	0.71691	48
13	0.64568	0.76361	0.65891	0.75222	0.67194	0.74061	0.68476	0.72877	0.69737	0.71671	47
14	0.64590	0.76342	0.65913	0.75203	0.67215	0.74041	0.68497	0.72857	0.69758	0.71650	46
15	0.64612	0.76323	0.65935	0.75184	0.67237	0.74022	0.68518	0.72837	0.69779	0.71630	45
16	0.64635	0.76304	0.65956	0.75165	0.67258	0.74002	0.68539	0.72817	0.69800	0.71610	44
17	0.64657	0.76286	0.65978	0.75146	0.67280	0.73983	0.68561	0.72797	0.69821	0.71590	43
18	0.64679	0.76267	0.66000	0.75126	0.67301	0.73963	0.68582	0.72777	0.69842	0.71569	42
19	0.64701	0.76248	0.66022	0.75107	0.67323	0.73944	0.68603	0.72757	0.69862	0.71549	41
20	0.64723	0.76229	0.66044	0.75088	0.67344	0.73924	0.68624	0.72737	0.69883	0.71529	40
21	0.64746	0.76210	0.66066	0.75069	0.67366	0.73904	0.68645	0.72717	0.69904	0.71508	39
22	0.64768	0.76192	0.66088	0.75050	0.67387	0.73885	0.68666	0.72697	0.69925	0.71488	38
23	0.64790	0.76173	0.66109	0.75030	0.67409	0.73865	0.68688	0.72677	0.69946	0.71468	37
24	0.64812	0.76154	0.66131	0.75011	0.67430	0.73846	0.68709	0.72657	0.69966	0.71447	36
25	0.64834	0.76135	0.66153	0.74992	0.67452	0.73826	0.68730	0.72637	0.69987	0.71427	35
26	0.64856	0.76116	0.66175	0.74973	0.67473	0.73806	0.68751	0.72617	0.70008	0.71407	34
27	0.64878	0.76097	0.66197	0.74953	0.67495	0.73787	0.68772	0.72597	0.70029	0.71386	33
28	0.64901	0.76078	0.66218	0.74934	0.67516	0.73767	0.68793	0.72577	0.70049	0.71366	32
29	0.64923	0.76059	0.66240	0.74915	0.67538	0.73747	0.68814	0.72557	0.70070	0.71345	31
30	0.64945	0.76041	0.66262	0.74896	0.67559	0.73728	0.68835	0.72537	0.70091	0.71325	30
31	0.64967	0.76022	0.66284	0.74876	0.67580	0.73708	0.68857	0.72517	0.70112	0.71305	29
32	0.64989	0.76003	0.66306	0.74857	0.67602	0.73688	0.68878	0.72497	0.70132	0.71284	28
33	0.65011	0.75984	0.66327	0.74838	0.67623	0.73669	0.68899	0.72477	0.70153	0.71264	27
34	0.65033	0.75965	0.66349	0.74818	0.67645	0.73649	0.68920	0.72457	0.70174	0.71243	26
35	0.65055	0.75946	0.66371	0.74799	0.67666	0.73629	0.68941	0.72437	0.70195	0.71223	25
36	0.65077	0.75927	0.66393	0.74780	0.67688	0.73610	0.68962	0.72417	0.70215	0.71203	24
37	0.65100	0.75908	0.66414	0.74760	0.67709	0.73590	0.68983	0.72397	0.70236	0.71182	23
38	0.65122	0.75889	0.66436	0.74741	0.67730	0.73570	0.69004	0.72377	0.70257	0.71162	22
39	0.65144	0.75870	0.66458	0.74722	0.67752	0.73551	0.69025	0.72357	0.70277	0.71141	21
40	0.65166	0.75851	0.66480	0.74703	0.67773	0.73531	0.69046	0.72337	0.70298	0.71121	20
41	0.65188	0.75832	0.66501	0.74683	0.67795	0.73511	0.69067	0.72317	0.70319	0.71100	19
42	0.65210	0.75813	0.66523	0.74664	0.67816	0.73491	0.69088	0.72297	0.70339	0.71080	18
43	0.65232	0.75794	0.66545	0.74644	0.67837	0.73472	0.69109	0.72277	0.70360	0.71059	17
44	0.65254	0.75775	0.66566	0.74625	0.67859	0.73452	0.69130	0.72257	0.70381	0.71039	16
45	0.65276	0.75756	0.66588	0.74606	0.67880	0.73432	0.69151	0.72236	0.70401	0.71019	15
46	0.65298	0.75738	0.66610	0.74586	0.67901	0.73413	0.69172	0.72216	0.70422	0.70998	14
47	0.65320	0.75719	0.66632	0.74567	0.67923	0.73393	0.69193	0.72196	0.70443	0.70978	13
48	0.65342	0.75700	0.66653	0.74548	0.67944	0.73373	0.69214	0.72176	0.70463	0.70957	12
49	0.65364	0.75680	0.66675	0.74528	0.67965	0.73353	0.69235	0.72156	0.70484	0.70937	11
50	0.65386	0.75661	0.66697	0.74509	0.67987	0.73333	0.69256	0.72136	0.70505	0.70916	10
51	0.65408	0.75642	0.66718	0.74489	0.68008	0.73314	0.69277	0.72116	0.70525	0.70896	9
52	0.65430	0.75623	0.66740	0.74470	0.68029	0.73294	0.69298	0.72095	0.70546	0.70875	8
53	0.65452	0.75604	0.66762	0.74451	0.68051	0.73274	0.69319	0.72075	0.70567	0.70855	7
54	0.65474	0.75585	0.66783	0.74431	0.68072	0.73254	0.69340	0.72055	0.70587	0.70834	6
55	0.65496	0.75566	0.66805	0.74412	0.68093	0.73234	0.69361	0.72035	0.70608	0.70813	5
56	0.65518	0.75547	0.66827	0.74392	0.68115	0.73215	0.69382	0.72015	0.70628	0.70793	4
57	0.65540	0.75528	0.66848	0.74373	0.68136	0.73195	0.69403	0.71995	0.70649	0.70772	3
58	0.65562	0.75509	0.66870	0.74353	0.68157	0.73175	0.69424	0.71974	0.70670	0.70752	2
59	0.65584	0.75490	0.66891	0.74334	0.68179	0.73155	0.69445	0.71954	0.70690	0.70731	1
60	0.65606	0.75471	0.66913	0.74314	0.68200	0.73135	0.69466	0.71934	0.70711	0.70711	0
	COS	SIN	COS	SIN	COS	SIN	COS	SIN	COS	SIN	MIN
	49°		48°		47°		46°		45°		

Table AII-2.—Natural Tangents and Cotangents

MIN	0° TAN	0° COT	1° TAN	1° COT	2° TAN	2° COT	3° TAN	3° COT	4° TAN	4° COT	
0	0000000	0000000	0.01746	57.2900	0.03492	28.6363	0.05241	19.0811	0.06993	14.3007	60
1	0.00029	3437.75	0.01775	56.3506	0.03521	28.3994	0.05270	18.9755	0.07022	14.2411	59
2	0.00058	1718.87	0.01804	55.4415	0.03550	28.1664	0.05299	18.8711	0.07051	14.1821	58
3	0.00087	1145.92	0.01833	54.5613	0.03579	27.9372	0.05328	18.7678	0.07080	14.1235	57
4	0.00116	859.436	0.01862	53.7086	0.03609	27.7117	0.05357	18.6656	0.07110	14.0655	56
5	0.00145	687.549	0.01891	52.8821	0.03638	27.4899	0.05387	18.5645	0.07139	14.0079	55
6	0.00175	572.957	0.01920	52.0807	0.03667	27.2715	0.05416	18.4645	0.07168	13.9507	54
7	0.00204	491.106	0.01949	51.3032	0.03696	27.0566	0.05445	18.3655	0.07197	13.8940	53
8	0.00233	429.718	0.01978	50.5485	0.03725	26.8450	0.05474	18.2677	0.07227	13.8378	52
9	0.00262	381.971	0.02007	49.8157	0.03754	26.6367	0.05503	18.1708	0.07256	13.7821	51
10	0.00291	343.774	0.02036	49.1039	0.03783	26.4316	0.05533	18.0750	0.07285	13.7267	50
11	0.00320	312.521	0.02066	48.4121	0.03812	26.2296	0.05562	17.9802	0.07314	13.6719	49
12	0.00349	286.478	0.02095	47.7395	0.03842	26.0307	0.05591	17.8863	0.07344	13.6174	48
13	0.00378	264.441	0.02124	47.0853	0.03871	25.8348	0.05620	17.7934	0.07373	13.5634	47
14	0.00407	245.552	0.02153	46.4489	0.03900	25.6418	0.05649	17.7015	0.07402	13.5098	46
15	0.00436	229.182	0.02182	45.8294	0.03929	25.4517	0.05678	17.6106	0.07431	13.4566	45
16	0.00465	214.858	0.02211	45.2261	0.03958	25.2644	0.05708	17.5205	0.07461	13.4039	44
17	0.00495	202.219	0.02240	44.6386	0.03987	25.0798	0.05737	17.4314	0.07490	13.3515	43
18	0.00524	190.984	0.02269	44.0661	0.04016	24.8978	0.05766	17.3432	0.07519	13.2996	42
19	0.00553	180.932	0.02298	43.5081	0.04046	24.7185	0.05795	17.2558	0.07548	13.2480	41
20	0.00582	171.885	0.02328	42.9641	0.04075	24.5418	0.05824	17.1693	0.07578	13.1969	40
21	0.00611	163.700	0.02357	42.4335	0.04104	24.3675	0.05854	17.0837	0.07607	13.1461	39
22	0.00640	156.259	0.02386	41.9158	0.04133	24.1957	0.05883	16.9990	0.07636	13.0958	38
23	0.00669	149.465	0.02415	41.4106	0.04162	24.0263	0.05912	16.9150	0.07665	13.0458	37
24	0.00698	143.237	0.02444	40.9174	0.04191	23.8593	0.05941	16.8319	0.07695	12.9962	36
25	0.00727	137.507	0.02473	40.4358	0.04220	23.6945	0.05970	16.7496	0.07724	12.9469	35
26	0.00756	132.219	0.02502	39.9655	0.04250	23.5321	0.05999	16.6681	0.07753	12.8981	34
27	0.00785	127.321	0.02531	39.5059	0.04279	23.3718	0.06029	16.5874	0.07782	12.8496	33
28	0.00815	122.774	0.02560	39.0568	0.04308	23.2137	0.06058	16.5075	0.07812	12.8014	32
29	0.00844	118.540	0.02589	38.6177	0.04337	23.0577	0.06087	16.4283	0.07841	12.7536	31
30	0.00873	114.589	0.02619	38.1885	0.04366	22.9038	0.06116	16.3499	0.07870	12.7062	30
31	0.00902	110.892	0.02648	37.7686	0.04395	22.7519	0.06145	16.2722	0.07899	12.6591	29
32	0.00931	107.426	0.02677	37.3579	0.04424	22.6020	0.06175	16.1952	0.07929	12.6124	28
33	0.00960	104.171	0.02706	36.9560	0.04454	22.4541	0.06204	16.1190	0.07958	12.5660	27
34	0.00989	101.107	0.02735	36.5627	0.04483	22.3081	0.06233	16.0435	0.07987	12.5199	26
35	0.01018	98.2179	0.02764	36.1776	0.04512	22.1640	0.06262	15.9687	0.08017	12.4742	25
36	0.01047	95.4895	0.02793	35.8006	0.04541	22.0217	0.06291	15.8945	0.08046	12.4288	24
37	0.01076	92.9085	0.02822	35.4313	0.04570	21.8813	0.06321	15.8211	0.08075	12.3838	23
38	0.01105	90.4633	0.02851	35.0695	0.04599	21.7426	0.06350	15.7483	0.08104	12.3390	22
39	0.01135	88.1436	0.02881	34.7151	0.04628	21.6056	0.06379	15.6762	0.08134	12.2946	21
40	0.01164	85.9398	0.02910	34.3678	0.04658	21.4704	0.06408	15.6048	0.08163	12.2505	20
41	0.01193	83.8435	0.02939	34.0273	0.04687	21.3369	0.06438	15.5340	0.08192	12.2067	19
42	0.01222	81.8470	0.02968	33.6935	0.04716	21.2049	0.06467	15.4638	0.08221	12.1632	18
43	0.01251	79.9434	0.02997	33.3662	0.04745	21.0747	0.06496	15.3943	0.08251	12.1201	17
44	0.01280	78.1263	0.03026	33.0452	0.04774	20.9460	0.06525	15.3254	0.08280	12.0772	16
45	0.01309	76.3900	0.03055	32.7303	0.04803	20.8188	0.06554	15.2571	0.08309	12.0346	15
46	0.01338	74.7292	0.03084	32.4213	0.04833	20.6932	0.06584	15.1893	0.08339	11.9923	14
47	0.01367	73.1390	0.03114	32.1181	0.04862	20.5691	0.06613	15.1222	0.08368	11.9504	13
48	0.01396	71.6151	0.03143	31.8205	0.04891	20.4465	0.06642	15.0557	0.08397	11.9087	12
49	0.01425	70.1533	0.03172	31.5284	0.04920	20.3253	0.06671	14.9898	0.08427	11.8673	11
50	0.01455	68.7501	0.03201	31.2416	0.04949	20.2056	0.06700	14.9244	0.08456	11.8262	10
51	0.01484	67.4019	0.03230	30.9599	0.04978	20.0872	0.06730	14.8596	0.08485	11.7853	9
52	0.01513	66.1055	0.03259	30.6833	0.05007	19.9702	0.06759	14.7954	0.08514	11.7448	8
53	0.01542	64.8580	0.03288	30.4116	0.05037	19.8546	0.06788	14.7317	0.08544	11.7045	7
54	0.01571	63.6567	0.03317	30.1446	0.05066	19.7403	0.06817	14.6685	0.08573	11.6645	6
55	0.01600	62.4992	0.03346	29.8823	0.05095	19.6273	0.06847	14.6059	0.08602	11.6248	5
56	0.01629	61.3829	0.03376	29.6245	0.05124	19.5156	0.06876	14.5438	0.08632	11.5853	4
57	0.01658	60.3058	0.03405	29.3711	0.05153	19.4051	0.06905	14.4823	0.08661	11.5461	3
58	0.01687	59.2659	0.03434	29.1220	0.05182	19.2959	0.06934	14.4212	0.08690	11.5072	2
59	0.01716	58.2612	0.03463	28.8771	0.05212	19.1879	0.06963	14.3607	0.08720	11.4685	1
60	0.01746	57.2900	0.03492	28.6363	0.05241	19.0811	0.06993	14.3007	0.08749	11.4301	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	89°		88°		87°		86°		85°		

Table AII-2.—Natural Tangents and Cotangents—Continued

MIN	5° TAN	5° COT	6° TAN	6° COT	7° TAN	7° COT	8° TAN	8° COT	9° TAN	9° COT	
0	0.08749	11.4301	0.10510	9.51436	0.12278	8.14435	0.14054	7.11537	0.15838	6.31375	60
1	0.08778	11.3919	0.10540	9.48781	0.12308	8.12481	0.14084	7.10038	0.15868	6.30189	59
2	0.08807	11.3540	0.10569	9.46141	0.12338	8.10536	0.14113	7.08546	0.15898	6.29007	58
3	0.08837	11.3163	0.10599	9.43515	0.12367	8.08600	0.14143	7.07059	0.15928	6.27829	57
4	0.08866	11.2789	0.10628	9.40904	0.12397	8.06674	0.14173	7.05579	0.15958	6.26655	56
5	0.08895	11.2417	0.10657	9.38307	0.12426	8.04756	0.14202	7.04105	0.15988	6.25486	55
6	0.08925	11.2048	0.10687	9.35724	0.12456	8.02848	0.14232	7.02637	0.16017	6.24321	54
7	0.08954	11.1681	0.10716	9.33155	0.12485	8.00948	0.14262	7.01174	0.16047	6.23160	53
8	0.08983	11.1316	0.10746	9.30599	0.12515	7.99058	0.14291	6.99718	0.16077	6.22003	52
9	0.09013	11.0954	0.10775	9.28058	0.12544	7.97176	0.14321	6.98268	0.16107	6.20851	51
10	0.09042	11.0594	0.10805	9.25530	0.12574	7.95302	0.14351	6.96823	0.16137	6.19703	50
11	0.09071	11.0237	0.10834	9.23016	0.12603	7.93438	0.14381	6.95385	0.16167	6.18559	49
12	0.09101	10.9882	0.10863	9.20516	0.12633	7.91582	0.14410	6.93952	0.16196	6.17419	48
13	0.09130	10.9529	0.10893	9.18028	0.12662	7.89734	0.14440	6.92525	0.16226	6.16283	47
14	0.09159	10.9178	0.10922	9.15554	0.12692	7.87895	0.14470	6.91104	0.16256	6.15151	46
15	0.09189	10.8829	0.10952	9.13093	0.12722	7.86064	0.14499	6.89688	0.16286	6.14023	45
16	0.09218	10.8483	0.10981	9.10646	0.12751	7.84242	0.14529	6.88278	0.16316	6.12899	44
17	0.09247	10.8139	0.11011	9.08211	0.12781	7.82428	0.14559	6.86874	0.16346	6.11779	43
18	0.09277	10.7797	0.11040	9.05789	0.12810	7.80622	0.14588	6.85475	0.16376	6.10664	42
19	0.09306	10.7457	0.11070	9.03379	0.12840	7.78825	0.14618	6.84082	0.16405	6.09552	41
20	0.09335	10.7119	0.11099	9.00983	0.12869	7.77035	0.14648	6.82694	0.16435	6.08444	40
21	0.09365	10.6783	0.11128	8.98598	0.12899	7.75254	0.14678	6.81312	0.16465	6.07340	39
22	0.09394	10.6450	0.11158	8.96227	0.12929	7.73480	0.14707	6.79936	0.16495	6.06240	38
23	0.09423	10.6118	0.11187	8.93867	0.12958	7.71715	0.14737	6.78564	0.16525	6.05143	37
24	0.09453	10.5789	0.11217	8.91520	0.12988	7.69957	0.14767	6.77199	0.16555	6.04051	36
25	0.09482	10.5462	0.11246	8.89185	0.13017	7.68208	0.14796	6.75838	0.16585	6.02962	35
26	0.09511	10.5136	0.11276	8.86862	0.13047	7.66466	0.14826	6.74483	0.16615	6.01878	34
27	0.09541	10.4813	0.11305	8.84551	0.13076	7.64732	0.14856	6.73133	0.16645	6.00797	33
28	0.09570	10.4491	0.11335	8.82252	0.13106	7.63005	0.14886	6.71789	0.16674	5.99720	32
29	0.09600	10.4172	0.11364	8.79964	0.13136	7.61287	0.14915	6.70450	0.16704	5.98646	31
30	0.09629	10.3854	0.11394	8.77689	0.13165	7.59575	0.14945	6.69116	0.16734	5.97576	30
31	0.09658	10.3538	0.11423	8.75425	0.13195	7.57872	0.14975	6.67787	0.16764	5.96510	29
32	0.09688	10.3224	0.11452	8.73172	0.13224	7.56176	0.15005	6.66463	0.16794	5.95448	28
33	0.09717	10.2913	0.11482	8.70931	0.13254	7.54487	0.15034	6.65144	0.16824	5.94390	27
34	0.09746	10.2602	0.11511	8.68701	0.13284	7.52806	0.15064	6.63831	0.16854	5.93335	26
35	0.09776	10.2294	0.11541	8.66482	0.13313	7.51132	0.15094	6.62523	0.16884	5.92283	25
36	0.09805	10.1988	0.11570	8.64275	0.13343	7.49465	0.15124	6.61219	0.16914	5.91236	24
37	0.09834	10.1683	0.11600	8.62078	0.13372	7.47806	0.15153	6.59921	0.16944	5.90191	23
38	0.09864	10.1381	0.11629	8.59893	0.13402	7.46154	0.15183	6.58627	0.16974	5.89151	22
39	0.09893	10.1080	0.11659	8.57718	0.13432	7.44509	0.15213	6.57339	0.17004	5.88114	21
40	0.09923	10.0780	0.11688	8.55555	0.13461	7.42871	0.15243	6.56055	0.17033	5.87080	20
41	0.09952	10.0483	0.11718	8.53402	0.13491	7.41240	0.15272	6.54777	0.17063	5.86051	19
42	0.09981	10.0187	0.11747	8.51259	0.13521	7.39616	0.15302	6.53503	0.17093	5.85024	18
43	0.10011	9.98931	0.11777	8.49128	0.13550	7.37999	0.15332	6.52234	0.17123	5.84001	17
44	0.10040	9.96007	0.11806	8.47007	0.13580	7.36389	0.15362	6.50970	0.17153	5.82982	16
45	0.10069	9.93101	0.11836	8.44896	0.13609	7.34786	0.15391	6.49710	0.17183	5.81966	15
46	0.10099	9.90211	0.11865	8.42795	0.13639	7.33190	0.15421	6.48456	0.17213	5.80953	14
47	0.10128	9.87338	0.11895	8.40705	0.13669	7.31600	0.15451	6.47206	0.17243	5.79944	13
48	0.10158	9.84482	0.11924	8.38625	0.13698	7.30018	0.15481	6.45961	0.17273	5.78938	12
49	0.10187	9.81641	0.11954	8.36555	0.13728	7.28442	0.15511	6.44720	0.17303	5.77936	11
50	0.10216	9.78817	0.11983	8.34496	0.13758	7.26873	0.15540	6.43484	0.17333	5.76937	10
51	0.10246	9.76009	0.12013	8.32446	0.13787	7.25310	0.15570	6.42253	0.17363	5.75941	9
52	0.10275	9.73217	0.12042	8.30406	0.13817	7.23754	0.15600	6.41026	0.17393	5.74949	8
53	0.10305	9.70441	0.12072	8.28376	0.13846	7.22204	0.15630	6.39804	0.17423	5.73960	7
54	0.10334	9.67680	0.12101	8.26355	0.13876	7.20661	0.15660	6.38587	0.17453	5.72974	6
55	0.10363	9.64935	0.12131	8.24345	0.13906	7.19125	0.15689	6.37374	0.17483	5.71992	5
56	0.10393	9.62205	0.12160	8.22344	0.13935	7.17594	0.15719	6.36165	0.17513	5.71013	4
57	0.10422	9.59490	0.12190	8.20352	0.13965	7.16071	0.15749	6.34961	0.17543	5.70037	3
58	0.10452	9.56791	0.12219	8.18370	0.13995	7.14553	0.15779	6.33761	0.17573	5.69064	2
59	0.10481	9.54106	0.12249	8.16398	0.14024	7.13042	0.15809	6.32566	0.17603	5.68094	1
60	0.10510	9.51436	0.12278	8.14435	0.14054	7.11537	0.15838	6.31375	0.17633	5.67128	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	84°		83°		82°		81°		80°		

MIN	10° TAN	10° COT	11° TAN	11° COT	12° TAN	12° COT	13° TAN	13° COT	14° TAN	14° COT	
0	0.17633	5.67128	0.19438	5.14455	0.21256	4.70463	0.23087	4.33148	0.24933	4.01078	60
1	0.17663	5.66165	0.19468	5.13658	0.21286	4.69791	0.23117	4.32573	0.24964	4.00582	59
2	0.17693	5.65205	0.19498	5.12862	0.21316	4.69121	0.23148	4.32001	0.24995	4.00086	58
3	0.17723	5.64248	0.19529	5.12069	0.21347	4.68452	0.23179	4.31430	0.25026	3.99592	57
4	0.17753	5.63295	0.19559	5.11279	0.21377	4.67786	0.23209	4.30860	0.25056	3.99099	56
5	0.17783	5.62344	0.19589	5.10490	0.21408	4.67121	0.23240	4.30291	0.25087	3.98607	55
6	0.17813	5.61397	0.19619	5.09704	0.21438	4.66458	0.23271	4.29724	0.25118	3.98117	54
7	0.17843	5.60452	0.19649	5.08921	0.21469	4.65797	0.23301	4.29159	0.25149	3.97627	53
8	0.17873	5.59511	0.19680	5.08139	0.21499	4.65138	0.23332	4.28595	0.25180	3.97139	52
9	0.17903	5.58573	0.19710	5.07360	0.21529	4.64480	0.23363	4.28032	0.25211	3.96651	51
10	0.17933	5.57638	0.19740	5.06584	0.21560	4.63825	0.23393	4.27471	0.25242	3.96165	50
11	0.17963	5.56706	0.19770	5.05809	0.21590	4.63171	0.23424	4.26911	0.25273	3.95680	49
12	0.17993	5.55777	0.19801	5.05037	0.21621	4.62518	0.23455	4.26352	0.25304	3.95196	48
13	0.18023	5.54851	0.19831	5.04267	0.21651	4.61868	0.23485	4.25795	0.25335	3.94713	47
14	0.18053	5.53927	0.19861	5.03499	0.21682	4.61219	0.23516	4.25239	0.25366	3.94232	46
15	0.18083	5.53007	0.19891	5.02734	0.21712	4.60572	0.23547	4.24685	0.25397	3.93751	45
16	0.18113	5.52090	0.19921	5.01971	0.21743	4.59927	0.23578	4.24132	0.25428	3.93271	44
17	0.18143	5.51176	0.19952	5.01210	0.21773	4.59283	0.23608	4.23580	0.25459	3.92793	43
18	0.18173	5.50264	0.19982	5.00451	0.21804	4.58641	0.23639	4.23030	0.25490	3.92316	42
19	0.18203	5.49356	0.20012	4.99695	0.21834	4.58001	0.23670	4.22481	0.25521	3.91839	41
20	0.18233	5.48451	0.20042	4.98940	0.21864	4.57363	0.23700	4.21933	0.25552	3.91364	40
21	0.18263	5.47548	0.20073	4.98188	0.21895	4.56726	0.23731	4.21387	0.25583	3.90890	39
22	0.18293	5.46648	0.20103	4.97438	0.21925	4.56091	0.23762	4.20842	0.25614	3.90417	38
23	0.18323	5.45751	0.20133	4.96690	0.21956	4.55458	0.23793	4.20298	0.25645	3.89945	37
24	0.18353	5.44857	0.20164	4.95945	0.21986	4.54826	0.23823	4.19756	0.25676	3.89474	36
25	0.18384	5.43966	0.20194	4.95201	0.22017	4.54196	0.23854	4.19215	0.25707	3.89004	35
26	0.18414	5.43077	0.20224	4.94460	0.22047	4.53568	0.23885	4.18675	0.25738	3.88536	34
27	0.18444	5.42192	0.20254	4.93721	0.22078	4.52941	0.23916	4.18137	0.25769	3.88068	33
28	0.18474	5.41309	0.20285	4.92984	0.22108	4.52316	0.23946	4.17600	0.25800	3.87601	32
29	0.18504	5.40429	0.20315	4.92249	0.22139	4.51693	0.23977	4.17064	0.25831	3.87136	31
30	0.18534	5.39552	0.20345	4.91516	0.22169	4.51071	0.24008	4.16530	0.25862	3.86671	30
31	0.18564	5.38677	0.20376	4.90785	0.22200	4.50451	0.24039	4.15997	0.25893	3.86208	29
32	0.18594	5.37805	0.20406	4.90056	0.22231	4.49832	0.24069	4.15465	0.25924	3.85745	28
33	0.18624	5.36936	0.20436	4.89330	0.22261	4.49215	0.24100	4.14934	0.25955	3.85284	27
34	0.18654	5.36070	0.20466	4.88605	0.22292	4.48600	0.24131	4.14405	0.25986	3.84824	26
35	0.18684	5.35206	0.20497	4.87882	0.22322	4.47986	0.24162	4.13877	0.26017	3.84364	25
36	0.18714	5.34345	0.20527	4.87162	0.22353	4.47374	0.24193	4.13350	0.26048	3.83906	24
37	0.18745	5.33487	0.20557	4.86444	0.22383	4.46764	0.24223	4.12825	0.26079	3.83449	23
38	0.18775	5.32631	0.20588	4.85727	0.22414	4.46155	0.24254	4.12301	0.26110	3.82992	22
39	0.18805	5.31778	0.20618	4.85013	0.22444	4.45548	0.24285	4.11778	0.26141	3.82537	21
40	0.18835	5.30928	0.20648	4.84300	0.22475	4.44942	0.24316	4.11256	0.26172	3.82083	20
41	0.18865	5.30080	0.20679	4.83590	0.22505	4.44338	0.24347	4.10736	0.26203	3.81630	19
42	0.18895	5.29235	0.20709	4.82882	0.22536	4.43735	0.24377	4.10216	0.26235	3.81177	18
43	0.18925	5.28393	0.20739	4.82175	0.22567	4.43134	0.24408	4.09699	0.26266	3.80726	17
44	0.18955	5.27553	0.20770	4.81471	0.22597	4.42534	0.24439	4.09182	0.26297	3.80276	16
45	0.18986	5.26715	0.20800	4.80769	0.22628	4.41936	0.24470	4.08666	0.26328	3.79827	15
46	0.19016	5.25880	0.20830	4.80068	0.22658	4.41340	0.24501	4.08152	0.26359	3.79378	14
47	0.19046	5.25048	0.20861	4.79370	0.22689	4.40745	0.24532	4.07639	0.26390	3.78931	13
48	0.19076	5.24218	0.20891	4.78673	0.22719	4.40152	0.24562	4.07127	0.26421	3.78485	12
49	0.19106	5.23391	0.20921	4.77978	0.22750	4.39560	0.24593	4.06616	0.26452	3.78040	11
50	0.19136	5.22566	0.20952	4.77286	0.22781	4.38969	0.24624	4.06107	0.26483	3.77595	10
51	0.19166	5.21744	0.20982	4.76595	0.22811	4.38381	0.24655	4.05599	0.26515	3.77152	9
52	0.19197	5.20925	0.21013	4.75906	0.22842	4.37793	0.24686	4.05092	0.26546	3.76709	8
53	0.19227	5.20107	0.21043	4.75219	0.22872	4.37207	0.24717	4.04586	0.26577	3.76268	7
54	0.19257	5.19293	0.21073	4.74534	0.22903	4.36623	0.24747	4.04081	0.26608	3.75828	6
55	0.19287	5.18480	0.21104	4.73851	0.22934	4.36040	0.24778	4.03578	0.26639	3.75388	5
56	0.19317	5.17671	0.21134	4.73170	0.22964	4.35459	0.24809	4.03076	0.26670	3.74950	4
57	0.19347	5.16863	0.21164	4.72490	0.22995	4.34879	0.24840	4.02574	0.26701	3.74512	3
58	0.19378	5.16058	0.21195	4.71813	0.23026	4.34300	0.24871	4.02074	0.26733	3.74075	2
59	0.19408	5.15256	0.21225	4.71137	0.23056	4.33723	0.24902	4.01576	0.26764	3.73640	1
60	0.19438	5.14455	0.21256	4.70463	0.23087	4.33148	0.24933	4.01078	0.26795	3.73205	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	79°		78°		77°		76°		75°		

Table AII-2.—Natural Tangents and Cotangents—Continued

MIN	15° TAN	15° COT	16° TAN	16° COT	17° TAN	17° COT	18° TAN	18° COT	19° TAN	19° COT	
0	0.26795	3.73205	0.28675	3.48741	0.30573	3.27085	0.32492	3.07768	0.34433	2.90421	60
1	0.26826	3.72771	0.28706	3.48359	0.30605	3.26745	0.32524	3.07464	0.34465	2.90147	59
2	0.26857	3.72338	0.28738	3.47977	0.30637	3.26406	0.32556	3.07160	0.34498	2.89873	58
3	0.26888	3.71907	0.28769	3.47596	0.30669	3.26067	0.32588	3.06857	0.34530	2.89600	57
4	0.26920	3.71476	0.28801	3.47216	0.30700	3.25729	0.32621	3.06554	0.34563	2.89327	56
5	0.26951	3.71046	0.28832	3.46837	0.30732	3.25392	0.32653	3.06252	0.34596	2.89055	55
6	0.26982	3.70616	0.28864	3.46458	0.30764	3.25055	0.32685	3.05950	0.34628	2.88783	54
7	0.27013	3.70188	0.28895	3.46080	0.30796	3.24719	0.32717	3.05649	0.34661	2.88511	53
8	0.27044	3.69761	0.28927	3.45703	0.30828	3.24383	0.32749	3.05349	0.34693	2.88240	52
9	0.27076	3.69335	0.28958	3.45327	0.30860	3.24049	0.32782	3.05049	0.34726	2.87970	51
10	0.27107	3.68909	0.28990	3.44951	0.30891	3.23714	0.32814	3.04749	0.34758	2.87700	50
11	0.27138	3.68485	0.29021	3.44576	0.30923	3.23381	0.32846	3.04450	0.34791	2.87430	49
12	0.27169	3.68061	0.29053	3.44202	0.30955	3.23048	0.32878	3.04152	0.34824	2.87161	48
13	0.27201	3.67638	0.29084	3.43829	0.30987	3.22715	0.32911	3.03854	0.34856	2.86892	47
14	0.27232	3.67217	0.29116	3.43456	0.31019	3.22384	0.32943	3.03556	0.34889	2.86624	46
15	0.27263	3.66796	0.29147	3.43084	0.31051	3.22053	0.32975	3.03260	0.34922	2.86356	45
16	0.27294	3.66376	0.29179	3.42713	0.31083	3.21722	0.33007	3.02963	0.34954	2.86089	44
17	0.27326	3.65957	0.29210	3.42343	0.31115	3.21392	0.33040	3.02667	0.34987	2.85822	43
18	0.27357	3.65538	0.29242	3.41973	0.31147	3.21063	0.33072	3.02372	0.35020	2.85555	42
19	0.27388	3.65121	0.29274	3.41604	0.31178	3.20734	0.33104	3.02077	0.35052	2.85289	41
20	0.27419	3.64705	0.29305	3.41236	0.31210	3.20406	0.33136	3.01783	0.35085	2.85023	40
21	0.27451	3.64289	0.29337	3.40869	0.31242	3.20079	0.33169	3.01489	0.35118	2.84758	39
22	0.27482	3.63874	0.29368	3.40502	0.31274	3.19752	0.33201	3.01196	0.35150	2.84494	38
23	0.27513	3.63461	0.29400	3.40136	0.31306	3.19426	0.33233	3.00903	0.35183	2.84229	37
24	0.27545	3.63048	0.29432	3.39771	0.31338	3.19100	0.33266	3.00611	0.35216	2.83965	36
25	0.27576	3.62636	0.29463	3.39406	0.31370	3.18775	0.33298	3.00319	0.35248	2.83702	35
26	0.27607	3.62224	0.29495	3.39042	0.31402	3.18451	0.33330	3.00028	0.35281	2.83439	34
27	0.27638	3.61814	0.29526	3.38679	0.31434	3.18127	0.33363	2.99738	0.35314	2.83176	33
28	0.27670	3.61405	0.29558	3.38317	0.31466	3.17804	0.33395	2.99447	0.35346	2.82914	32
29	0.27701	3.60996	0.29590	3.37955	0.31498	3.17481	0.33427	2.99158	0.35379	2.82653	31
30	0.27732	3.60588	0.29621	3.37594	0.31530	3.17159	0.33460	2.98868	0.35412	2.82391	30
31	0.27764	3.60181	0.29653	3.37234	0.31562	3.16838	0.33492	2.98580	0.35445	2.82130	29
32	0.27795	3.59775	0.29685	3.36875	0.31594	3.16517	0.33524	2.98292	0.35477	2.81870	28
33	0.27826	3.59370	0.29716	3.36516	0.31626	3.16197	0.33557	2.98004	0.35510	2.81610	27
34	0.27858	3.58966	0.29748	3.36158	0.31658	3.15877	0.33589	2.97717	0.35543	2.81350	26
35	0.27889	3.58562	0.29780	3.35800	0.31690	3.15558	0.33621	2.97430	0.35576	2.81091	25
36	0.27921	3.58160	0.29811	3.35443	0.31722	3.15240	0.33654	2.97144	0.35608	2.80833	24
37	0.27952	3.57758	0.29843	3.35087	0.31754	3.14922	0.33686	2.96858	0.35641	2.80574	23
38	0.27983	3.57357	0.29875	3.34732	0.31786	3.14605	0.33718	2.96573	0.35674	2.80316	22
39	0.28015	3.56957	0.29906	3.34377	0.31818	3.14288	0.33751	2.96288	0.35707	2.80059	21
40	0.28046	3.56557	0.29938	3.34023	0.31850	3.13972	0.33783	2.96004	0.35740	2.79802	20
41	0.28077	3.56159	0.29970	3.33670	0.31882	3.13656	0.33816	2.95721	0.35772	2.79545	19
42	0.28109	3.55761	0.30001	3.33317	0.31914	3.13341	0.33848	2.95437	0.35805	2.79289	18
43	0.28140	3.55364	0.30033	3.32965	0.31946	3.13027	0.33881	2.95155	0.35838	2.79033	17
44	0.28172	3.54968	0.30065	3.32614	0.31978	3.12713	0.33913	2.94872	0.35871	2.78778	16
45	0.28203	3.54573	0.30097	3.32264	0.32010	3.12400	0.33945	2.94591	0.35904	2.78523	15
46	0.28234	3.54179	0.30128	3.31914	0.32042	3.12087	0.33978	2.94309	0.35937	2.78269	14
47	0.28266	3.53785	0.30160	3.31565	0.32074	3.11775	0.34010	2.94028	0.35969	2.78014	13
48	0.28297	3.53393	0.30192	3.31216	0.32106	3.11464	0.34043	2.93748	0.36002	2.77761	12
49	0.28329	3.53001	0.30224	3.30868	0.32139	3.11153	0.34075	2.93468	0.36035	2.77507	11
50	0.28360	3.52609	0.30255	3.30521	0.32171	3.10842	0.34108	2.93189	0.36068	2.77254	10
51	0.28391	3.52219	0.30287	3.30174	0.32203	3.10532	0.34140	2.92910	0.36101	2.77002	9
52	0.28423	3.51829	0.30319	3.29829	0.32235	3.10223	0.34173	2.92632	0.36134	2.76750	8
53	0.28454	3.51441	0.30351	3.29483	0.32267	3.09914	0.34205	2.92354	0.36167	2.76498	7
54	0.28486	3.51053	0.30382	3.29139	0.32299	3.09606	0.34238	2.92076	0.36199	2.76247	6
55	0.28517	3.50666	0.30414	3.28795	0.32331	3.09298	0.34270	2.91799	0.36232	2.75996	5
56	0.28549	3.50279	0.30446	3.28452	0.32363	3.08991	0.34303	2.91523	0.36265	2.75746	4
57	0.28580	3.49894	0.30478	3.28109	0.32396	3.08685	0.34335	2.91246	0.36298	2.75496	3
58	0.28612	3.49509	0.30509	3.27767	0.32428	3.08379	0.34368	2.90971	0.36331	2.75246	2
59	0.28643	3.49125	0.30541	3.27426	0.32460	3.08073	0.34400	2.90696	0.36364	2.74997	1
60	0.28675	3.48741	0.30573	3.27085	0.32492	3.07768	0.34433	2.90421	0.36397	2.74748	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	74°		73°		72°		71°		70°		

MIN	20° TAN	20° COT	21° TAN	21° COT	22° TAN	22° COT	23° TAN	23° COT	24° TAN	24° COT	
0	0.36397	2.74748	0.38386	2.60509	0.40403	2.47509	0.42447	2.35585	0.44523	2.24604	60
1	0.36430	2.74499	0.38420	2.60283	0.40436	2.47302	0.42482	2.35395	0.44558	2.24428	59
2	0.36463	2.74251	0.38453	2.60057	0.40470	2.47095	0.42516	2.35205	0.44593	2.24252	58
3	0.36496	2.74004	0.38487	2.59831	0.40504	2.46888	0.42551	2.35015	0.44627	2.24077	57
4	0.36529	2.73756	0.38520	2.59606	0.40538	2.46682	0.42585	2.34825	0.44662	2.23902	56
5	0.36562	2.73509	0.38553	2.59381	0.40572	2.46476	0.42619	2.34636	0.44697	2.23727	55
6	0.36595	2.73263	0.38587	2.59156	0.40606	2.46270	0.42654	2.34447	0.44732	2.23553	54
7	0.36628	2.73017	0.38620	2.58932	0.40640	2.46065	0.42688	2.34258	0.44767	2.23378	53
8	0.36661	2.72771	0.38654	2.58708	0.40674	2.45860	0.42722	2.34069	0.44802	2.23204	52
9	0.36694	2.72526	0.38687	2.58484	0.40707	2.45655	0.42757	2.33881	0.44837	2.23030	51
10	0.36727	2.72281	0.38721	2.58261	0.40741	2.45451	0.42791	2.33693	0.44872	2.22857	50
11	0.36760	2.72036	0.38754	2.58038	0.40775	2.45246	0.42826	2.33505	0.44907	2.22683	49
12	0.36793	2.71792	0.38787	2.57815	0.40809	2.45043	0.42860	2.33317	0.44942	2.22510	48
13	0.36826	2.71548	0.38821	2.57593	0.40843	2.44839	0.42894	2.33130	0.44977	2.22337	47
14	0.36859	2.71305	0.38854	2.57371	0.40877	2.44636	0.42929	2.32943	0.45012	2.22164	46
15	0.36892	2.71062	0.38888	2.57150	0.40911	2.44433	0.42963	2.32756	0.45047	2.21992	45
16	0.36925	2.70819	0.38921	2.56928	0.40945	2.44230	0.42998	2.32570	0.45082	2.21819	44
17	0.36958	2.70577	0.38955	2.56707	0.40979	2.44027	0.43032	2.32383	0.45117	2.21647	43
18	0.36991	2.70335	0.38988	2.56487	0.41013	2.43825	0.43067	2.32197	0.45152	2.21475	42
19	0.37024	2.70094	0.39022	2.56266	0.41047	2.43623	0.43101	2.32012	0.45187	2.21304	41
20	0.37057	2.69853	0.39055	2.56046	0.41081	2.43422	0.43136	2.31826	0.45222	2.21132	40
21	0.37090	2.69612	0.39089	2.55827	0.41115	2.43220	0.43170	2.31641	0.45257	2.20961	39
22	0.37123	2.69371	0.39122	2.55608	0.41149	2.43019	0.43205	2.31456	0.45292	2.20790	38
23	0.37157	2.69131	0.39156	2.55389	0.41183	2.42819	0.43239	2.31271	0.45327	2.20619	37
24	0.37190	2.68892	0.39190	2.55170	0.41217	2.42618	0.43274	2.31086	0.45362	2.20449	36
25	0.37223	2.68653	0.39223	2.54952	0.41251	2.42418	0.43308	2.30902	0.45397	2.20278	35
26	0.37256	2.68414	0.39257	2.54734	0.41285	2.42218	0.43343	2.30718	0.45432	2.20108	34
27	0.37289	2.68175	0.39290	2.54516	0.41319	2.42019	0.43378	2.30534	0.45467	2.19938	33
28	0.37322	2.67937	0.39324	2.54299	0.41353	2.41819	0.43412	2.30351	0.45502	2.19769	32
29	0.37355	2.67700	0.39357	2.54082	0.41387	2.41620	0.43447	2.30167	0.45538	2.19599	31
30	0.37388	2.67462	0.39391	2.53865	0.41421	2.41421	0.43481	2.29984	0.45573	2.19430	30
31	0.37422	2.67225	0.39425	2.53648	0.41455	2.41223	0.43516	2.29801	0.45608	2.19261	29
32	0.37455	2.66989	0.39458	2.53432	0.41490	2.41025	0.43550	2.29619	0.45643	2.19092	28
33	0.37488	2.66752	0.39492	2.53217	0.41524	2.40827	0.43585	2.29437	0.45678	2.18923	27
34	0.37521	2.66516	0.39526	2.53001	0.41558	2.40629	0.43620	2.29254	0.45713	2.18755	26
35	0.37554	2.66281	0.39559	2.52786	0.41592	2.40432	0.43654	2.29073	0.45748	2.18587	25
36	0.37588	2.66046	0.39593	2.52571	0.41626	2.40235	0.43689	2.28891	0.45784	2.18419	24
37	0.37621	2.65811	0.39626	2.52357	0.41660	2.40038	0.43724	2.28710	0.45819	2.18251	23
38	0.37654	2.65576	0.39660	2.52142	0.41694	2.39841	0.43758	2.28528	0.45854	2.18084	22
39	0.37687	2.65342	0.39694	2.51929	0.41728	2.39645	0.43793	2.28348	0.45889	2.17916	21
40	0.37720	2.65109	0.39727	2.51715	0.41763	2.39449	0.43828	2.28167	0.45924	2.17749	20
41	0.37754	2.64875	0.39761	2.51502	0.41797	2.39253	0.43862	2.27987	0.45960	2.17582	19
42	0.37787	2.64642	0.39795	2.51289	0.41831	2.39058	0.43897	2.27806	0.45995	2.17416	18
43	0.37820	2.64410	0.39829	2.51076	0.41865	2.38863	0.43932	2.27626	0.46030	2.17249	17
44	0.37853	2.64177	0.39862	2.50864	0.41899	2.38668	0.43966	2.27447	0.46065	2.17083	16
45	0.37887	2.63945	0.39896	2.50652	0.41933	2.38473	0.44001	2.27267	0.46101	2.16917	15
46	0.37920	2.63714	0.39930	2.50440	0.41968	2.38279	0.44036	2.27088	0.46136	2.16751	14
47	0.37953	2.63483	0.39963	2.50229	0.42002	2.38084	0.44071	2.26909	0.46171	2.16585	13
48	0.37986	2.63252	0.39997	2.50018	0.42036	2.37891	0.44105	2.26730	0.46206	2.16420	12
49	0.38020	2.63021	0.40031	2.49807	0.42070	2.37697	0.44140	2.26552	0.46242	2.16255	11
50	0.38053	2.62791	0.40065	2.49597	0.42105	2.37504	0.44175	2.26374	0.46277	2.16090	10
51	0.38086	2.62561	0.40098	2.49386	0.42139	2.37311	0.44210	2.26196	0.46312	2.15925	9
52	0.38120	2.62332	0.40132	2.49177	0.42173	2.37118	0.44244	2.26018	0.46348	2.15760	8
53	0.38153	2.62103	0.40166	2.48967	0.42207	2.36925	0.44279	2.25840	0.46383	2.15596	7
54	0.38186	2.61874	0.40200	2.48758	0.42242	2.36733	0.44314	2.25663	0.46418	2.15432	6
55	0.38220	2.61646	0.40234	2.48549	0.42276	2.36541	0.44349	2.25486	0.46454	2.15268	5
56	0.38253	2.61418	0.40267	2.48340	0.42310	2.36349	0.44384	2.25309	0.46489	2.15104	4
57	0.38286	2.61190	0.40301	2.48132	0.42345	2.36158	0.44418	2.25132	0.46525	2.14940	3
58	0.38320	2.60963	0.40335	2.47924	0.42379	2.35967	0.44453	2.24956	0.46560	2.14777	2
59	0.38353	2.60736	0.40369	2.47716	0.42413	2.35776	0.44488	2.24780	0.46595	2.14614	1
60	0.38386	2.60509	0.40403	2.47509	0.42447	2.35585	0.44523	2.24604	0.46631	2.14451	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	69°		68°		67°		66°		65°		

Table AII-2.—Natural Tangents and Cotangents—Continued

MIN	25°		26°		27°		28°		29°		
	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	
0	0.46631	2.14451	0.48773	2.05030	0.50953	1.96261	0.53171	1.88073	0.55431	1.80405	60
1	0.46666	2.14288	0.48809	2.04879	0.50989	1.96120	0.53208	1.87941	0.55469	1.80281	59
2	0.46702	2.14125	0.48845	2.04728	0.51026	1.95979	0.53246	1.87809	0.55507	1.80158	58
3	0.46737	2.13963	0.48881	2.04577	0.51063	1.95838	0.53283	1.87677	0.55545	1.80034	57
4	0.46772	2.13801	0.48917	2.04426	0.51099	1.95698	0.53320	1.87546	0.55583	1.79911	56
5	0.46808	2.13639	0.48953	2.04276	0.51136	1.95557	0.53358	1.87415	0.55621	1.79788	55
6	0.46843	2.13477	0.48989	2.04125	0.51173	1.95417	0.53395	1.87283	0.55659	1.79665	54
7	0.46879	2.13316	0.49026	2.03975	0.51209	1.95277	0.53432	1.87152	0.55697	1.79542	53
8	0.46914	2.13154	0.49062	2.03825	0.51246	1.95137	0.53470	1.87021	0.55736	1.79419	52
9	0.46950	2.12993	0.49098	2.03675	0.51283	1.94997	0.53507	1.86891	0.55774	1.79296	51
10	0.46985	2.12832	0.49134	2.03526	0.51319	1.94858	0.53545	1.86760	0.55812	1.79174	50
11	0.47021	2.12671	0.49170	2.03376	0.51356	1.94718	0.53582	1.86630	0.55850	1.79051	49
12	0.47056	2.12511	0.49206	2.03227	0.51393	1.94579	0.53620	1.86499	0.55888	1.78929	48
13	0.47092	2.12350	0.49242	2.03078	0.51430	1.94440	0.53657	1.86369	0.55926	1.78807	47
14	0.47128	2.12190	0.49278	2.02929	0.51467	1.94301	0.53694	1.86239	0.55964	1.78685	46
15	0.47163	2.12030	0.49315	2.02780	0.51503	1.94162	0.53732	1.86109	0.56003	1.78563	45
16	0.47199	2.11871	0.49351	2.02631	0.51540	1.94023	0.53769	1.85979	0.56041	1.78441	44
17	0.47234	2.11711	0.49387	2.02483	0.51577	1.93885	0.53807	1.85850	0.56079	1.78319	43
18	0.47270	2.11552	0.49423	2.02335	0.51614	1.93746	0.53844	1.85720	0.56117	1.78198	42
19	0.47305	2.11392	0.49459	2.02187	0.51651	1.93608	0.53882	1.85591	0.56156	1.78077	41
20	0.47341	2.11233	0.49495	2.02039	0.51688	1.93470	0.53920	1.85462	0.56194	1.77955	40
21	0.47377	2.11075	0.49532	2.01891	0.51724	1.93332	0.53957	1.85333	0.56232	1.77834	39
22	0.47412	2.10916	0.49568	2.01743	0.51761	1.93195	0.53995	1.85204	0.56270	1.77713	38
23	0.47448	2.10758	0.49604	2.01596	0.51798	1.93057	0.54032	1.85075	0.56309	1.77592	37
24	0.47483	2.10600	0.49640	2.01449	0.51835	1.92920	0.54070	1.84946	0.56347	1.77471	36
25	0.47519	2.10442	0.49677	2.01302	0.51872	1.92782	0.54107	1.84818	0.56385	1.77351	35
26	0.47555	2.10284	0.49713	2.01155	0.51909	1.92645	0.54145	1.84689	0.56424	1.77230	34
27	0.47590	2.10126	0.49749	2.01008	0.51946	1.92508	0.54183	1.84561	0.56462	1.77110	33
28	0.47626	2.09969	0.49786	2.00862	0.51983	1.92371	0.54220	1.84433	0.56501	1.76990	32
29	0.47662	2.09811	0.49822	2.00715	0.52020	1.92235	0.54258	1.84305	0.56539	1.76869	31
30	0.47698	2.09654	0.49858	2.00569	0.52057	1.92098	0.54296	1.84177	0.56577	1.76749	30
31	0.47733	2.09498	0.49894	2.00423	0.52094	1.91962	0.54333	1.84049	0.56616	1.76629	29
32	0.47769	2.09341	0.49931	2.00277	0.52131	1.91826	0.54371	1.83922	0.56654	1.76510	28
33	0.47805	2.09184	0.49967	2.00131	0.52168	1.91690	0.54409	1.83794	0.56693	1.76390	27
34	0.47840	2.09028	0.50004	1.99986	0.52205	1.91554	0.54446	1.83667	0.56731	1.76271	26
35	0.47876	2.08872	0.50040	1.99841	0.52242	1.91418	0.54484	1.83540	0.56769	1.76151	25
36	0.47912	2.08716	0.50076	1.99695	0.52279	1.91282	0.54522	1.83413	0.56808	1.76032	24
37	0.47948	2.08560	0.50113	1.99550	0.52316	1.91147	0.54560	1.83286	0.56846	1.75913	23
38	0.47984	2.08405	0.50149	1.99406	0.52353	1.91012	0.54597	1.83159	0.56885	1.75794	22
39	0.48019	2.08250	0.50185	1.99261	0.52390	1.90876	0.54635	1.83033	0.56923	1.75675	21
40	0.48055	2.08094	0.50222	1.99116	0.52427	1.90741	0.54673	1.82906	0.56962	1.75556	20
41	0.48091	2.07939	0.50258	1.98972	0.52464	1.90607	0.54711	1.82780	0.57000	1.75437	19
42	0.48127	2.07785	0.50295	1.98828	0.52501	1.90472	0.54748	1.82654	0.57039	1.75319	18
43	0.48163	2.07630	0.50331	1.98684	0.52538	1.90337	0.54786	1.82528	0.57078	1.75200	17
44	0.48198	2.07476	0.50368	1.98540	0.52575	1.90203	0.54824	1.82402	0.57116	1.75082	16
45	0.48234	2.07321	0.50404	1.98396	0.52613	1.90069	0.54862	1.82276	0.57155	1.74964	15
46	0.48270	2.07167	0.50441	1.98253	0.52650	1.89935	0.54900	1.82150	0.57193	1.74846	14
47	0.48306	2.07014	0.50477	1.98110	0.52687	1.89801	0.54938	1.82025	0.57232	1.74728	13
48	0.48342	2.06860	0.50514	1.97966	0.52724	1.89667	0.54975	1.81899	0.57271	1.74610	12
49	0.48378	2.06706	0.50550	1.97823	0.52761	1.89533	0.55013	1.81774	0.57309	1.74492	11
50	0.48414	2.06553	0.50587	1.97681	0.52798	1.89400	0.55051	1.81649	0.57348	1.74375	10
51	0.48450	2.06400	0.50623	1.97538	0.52836	1.89266	0.55089	1.81524	0.57386	1.74257	9
52	0.48486	2.06247	0.50660	1.97395	0.52873	1.89133	0.55127	1.81399	0.57425	1.74140	8
53	0.48521	2.06094	0.50696	1.97253	0.52910	1.89000	0.55165	1.81274	0.57464	1.74022	7
54	0.48557	2.05942	0.50733	1.97111	0.52947	1.88867	0.55203	1.81150	0.57503	1.73905	6
55	0.48593	2.05790	0.50769	1.96969	0.52985	1.88734	0.55241	1.81025	0.57541	1.73788	5
56	0.48629	2.05637	0.50806	1.96827	0.53022	1.88602	0.55279	1.80901	0.57580	1.73671	4
57	0.48665	2.05485	0.50843	1.96685	0.53059	1.88469	0.55317	1.80777	0.57619	1.73555	3
58	0.48701	2.05333	0.50879	1.96544	0.53096	1.88337	0.55355	1.80653	0.57657	1.73438	2
59	0.48737	2.05182	0.50916	1.96402	0.53134	1.88205	0.55393	1.80529	0.57696	1.73321	1
60	0.48773	2.05030	0.50953	1.96261	0.53171	1.88073	0.55431	1.80405	0.57735	1.73205	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	64°		63°		62°		61°		60°		

MIN	30° TAN	30° COT	31° TAN	31° COT	32° TAN	32° COT	33° TAN	33° COT	34° TAN	34° COT	
0	0.57735	1.73205	0.60086	1.66428	0.62487	1.60033	0.64941	1.53986	0.67451	1.48256	60
1	0.57774	1.73089	0.60126	1.66318	0.62527	1.59930	0.64982	1.53888	0.67493	1.48163	59
2	0.57813	1.72973	0.60165	1.66209	0.62568	1.59826	0.65024	1.53791	0.67536	1.48070	58
3	0.57851	1.72857	0.60205	1.66099	0.62608	1.59723	0.65065	1.53693	0.67578	1.47977	57
4	0.57890	1.72741	0.60245	1.65990	0.62649	1.59620	0.65106	1.53595	0.67620	1.47885	56
5	0.57929	1.72625	0.60284	1.65881	0.62689	1.59517	0.65148	1.53497	0.67663	1.47792	55
6	0.57968	1.72509	0.60324	1.65772	0.62730	1.59414	0.65189	1.53400	0.67705	1.47699	54
7	0.58007	1.72393	0.60364	1.65663	0.62770	1.59311	0.65231	1.53302	0.67748	1.47607	53
8	0.58046	1.72278	0.60403	1.65554	0.62811	1.59208	0.65272	1.53205	0.67790	1.47514	52
9	0.58085	1.72163	0.60443	1.65445	0.62852	1.59105	0.65314	1.53107	0.67832	1.47422	51
10	0.58124	1.72047	0.60483	1.65337	0.62892	1.59002	0.65355	1.53010	0.67875	1.47330	50
11	0.58162	1.71932	0.60522	1.65228	0.62933	1.58900	0.65397	1.52913	0.67917	1.47238	49
12	0.58201	1.71817	0.60562	1.65120	0.62973	1.58797	0.65438	1.52816	0.67960	1.47146	48
13	0.58240	1.71702	0.60602	1.65011	0.63014	1.58695	0.65480	1.52719	0.68002	1.47053	47
14	0.58279	1.71588	0.60642	1.64903	0.63055	1.58593	0.65521	1.52622	0.68045	1.46962	46
15	0.58318	1.71473	0.60681	1.64795	0.63095	1.58490	0.65563	1.52525	0.68088	1.46870	45
16	0.58357	1.71358	0.60721	1.64687	0.63136	1.58388	0.65604	1.52429	0.68130	1.46778	44
17	0.58396	1.71244	0.60761	1.64579	0.63177	1.58286	0.65646	1.52332	0.68173	1.46686	43
18	0.58435	1.71129	0.60801	1.64471	0.63217	1.58184	0.65688	1.52235	0.68215	1.46595	42
19	0.58474	1.71015	0.60841	1.64363	0.63258	1.58083	0.65729	1.52139	0.68258	1.46503	41
20	0.58513	1.70901	0.60881	1.64256	0.63299	1.57981	0.65771	1.52043	0.68301	1.46411	40
21	0.58552	1.70787	0.60921	1.64148	0.63340	1.57879	0.65813	1.51946	0.68343	1.46320	39
22	0.58591	1.70673	0.60960	1.64041	0.63380	1.57778	0.65854	1.51850	0.68386	1.46229	38
23	0.58631	1.70560	0.61000	1.63934	0.63421	1.57676	0.65896	1.51754	0.68429	1.46137	37
24	0.58670	1.70446	0.61040	1.63826	0.63462	1.57575	0.65938	1.51658	0.68471	1.46046	36
25	0.58709	1.70332	0.61080	1.63719	0.63503	1.57474	0.65980	1.51562	0.68514	1.45955	35
26	0.58748	1.70219	0.61120	1.63612	0.63544	1.57372	0.66021	1.51466	0.68557	1.45864	34
27	0.58787	1.70106	0.61160	1.63505	0.63584	1.57271	0.66063	1.51370	0.68600	1.45773	33
28	0.58826	1.69992	0.61200	1.63398	0.63625	1.57170	0.66105	1.51275	0.68642	1.45682	32
29	0.58865	1.69879	0.61240	1.63292	0.63666	1.57069	0.66147	1.51179	0.68685	1.45592	31
30	0.58905	1.69766	0.61280	1.63185	0.63707	1.56969	0.66189	1.51084	0.68728	1.45501	30
31	0.58944	1.69653	0.61320	1.63079	0.63748	1.56868	0.66230	1.50988	0.68771	1.45410	29
32	0.58983	1.69541	0.61360	1.62972	0.63789	1.56767	0.66272	1.50893	0.68814	1.45320	28
33	0.59022	1.69428	0.61400	1.62866	0.63830	1.56667	0.66314	1.50797	0.68857	1.45229	27
34	0.59061	1.69316	0.61440	1.62760	0.63871	1.56566	0.66356	1.50702	0.68900	1.45139	26
35	0.59101	1.69203	0.61480	1.62654	0.63912	1.56466	0.66398	1.50607	0.68942	1.45049	25
36	0.59140	1.69091	0.61520	1.62548	0.63953	1.56366	0.66440	1.50512	0.68985	1.44958	24
37	0.59179	1.68979	0.61561	1.62442	0.63994	1.56265	0.66482	1.50417	0.69028	1.44868	23
38	0.59218	1.68866	0.61601	1.62336	0.64035	1.56165	0.66524	1.50322	0.69071	1.44778	22
39	0.59258	1.68754	0.61641	1.62230	0.64076	1.56065	0.66566	1.50228	0.69114	1.44688	21
40	0.59297	1.68643	0.61681	1.62125	0.64117	1.55966	0.66608	1.50133	0.69157	1.44598	20
41	0.59336	1.68531	0.61721	1.62019	0.64158	1.55866	0.66650	1.50038	0.69200	1.44508	19
42	0.59376	1.68419	0.61761	1.61914	0.64199	1.55766	0.66692	1.49944	0.69243	1.44418	18
43	0.59415	1.68308	0.61801	1.61808	0.64240	1.55666	0.66734	1.49849	0.69286	1.44329	17
44	0.59454	1.68196	0.61842	1.61703	0.64281	1.55567	0.66776	1.49755	0.69329	1.44239	16
45	0.59494	1.68085	0.61882	1.61598	0.64322	1.55467	0.66818	1.49661	0.69372	1.44149	15
46	0.59533	1.67974	0.61922	1.61493	0.64363	1.55368	0.66860	1.49566	0.69416	1.44060	14
47	0.59573	1.67863	0.61962	1.61388	0.64404	1.55269	0.66902	1.49472	0.69459	1.43970	13
48	0.59612	1.67752	0.62003	1.61283	0.64446	1.55170	0.66944	1.49378	0.69502	1.43881	12
49	0.59651	1.67641	0.62043	1.61179	0.64487	1.55071	0.66986	1.49284	0.69545	1.43792	11
50	0.59691	1.67530	0.62083	1.61074	0.64528	1.54972	0.67028	1.49190	0.69588	1.43703	10
51	0.59730	1.67419	0.62124	1.60970	0.64569	1.54873	0.67071	1.49097	0.69631	1.43614	9
52	0.59770	1.67309	0.62164	1.60865	0.64610	1.54774	0.67113	1.49003	0.69675	1.43525	8
53	0.59809	1.67198	0.62204	1.60761	0.64652	1.54675	0.67155	1.48909	0.69718	1.43436	7
54	0.59849	1.67088	0.62245	1.60657	0.64693	1.54576	0.67197	1.48816	0.69761	1.43347	6
55	0.59888	1.66978	0.62285	1.60553	0.64734	1.54478	0.67239	1.48722	0.69804	1.43258	5
56	0.59928	1.66867	0.62325	1.60449	0.64775	1.54379	0.67282	1.48629	0.69847	1.43169	4
57	0.59967	1.66757	0.62366	1.60345	0.64817	1.54281	0.67324	1.48536	0.69891	1.43080	3
58	0.60007	1.66647	0.62406	1.60241	0.64858	1.54183	0.67366	1.48442	0.69934	1.42992	2
59	0.60046	1.66538	0.62446	1.60137	0.64899	1.54085	0.67409	1.48349	0.69977	1.42903	1
60	0.60086	1.66428	0.62487	1.60033	0.64941	1.53986	0.67451	1.48256	0.70021	1.42815	0
	59° COT	59° TAN	58° COT	58° TAN	57° COT	57° TAN	56° COT	56° TAN	55° COT	55° TAN	MIN

Table AII-2.—Natural Tangents and Cotangents—Continued

MIN	35° TAN	35° COT	36° TAN	36° COT	37° TAN	37° COT	38° TAN	38° COT	39° TAN	39° COT	
0	0.70021	1.42815	0.72654	1.37638	0.75355	1.32704	0.78129	1.27994	0.80978	1.23490	60
1	0.70064	1.42726	0.72699	1.37554	0.75401	1.32624	0.78175	1.27917	0.81027	1.23416	59
2	0.70107	1.42638	0.72743	1.37470	0.75447	1.32544	0.78222	1.27841	0.81075	1.23343	58
3	0.70151	1.42550	0.72788	1.37386	0.75492	1.32464	0.78269	1.27764	0.81123	1.23270	57
4	0.70194	1.42462	0.72832	1.37302	0.75538	1.32384	0.78316	1.27688	0.81171	1.23196	56
5	0.70238	1.42374	0.72877	1.37218	0.75584	1.32304	0.78363	1.27611	0.81220	1.23123	55
6	0.70281	1.42286	0.72921	1.37134	0.75629	1.32224	0.78410	1.27535	0.81268	1.23050	54
7	0.70325	1.42198	0.72966	1.37050	0.75675	1.32144	0.78457	1.27458	0.81316	1.22977	53
8	0.70368	1.42110	0.73010	1.36967	0.75721	1.32064	0.78504	1.27382	0.81364	1.22904	52
9	0.70412	1.42022	0.73055	1.36883	0.75767	1.31984	0.78551	1.27306	0.81413	1.22831	51
10	0.70455	1.41934	0.73100	1.36800	0.75812	1.31904	0.78598	1.27230	0.81461	1.22758	50
11	0.70499	1.41847	0.73144	1.36716	0.75858	1.31825	0.78645	1.27153	0.81510	1.22685	49
12	0.70542	1.41759	0.73189	1.36633	0.75904	1.31745	0.78692	1.27077	0.81558	1.22612	48
13	0.70586	1.41672	0.73234	1.36549	0.75950	1.31666	0.78739	1.27001	0.81606	1.22539	47
14	0.70629	1.41584	0.73278	1.36466	0.75996	1.31586	0.78786	1.26925	0.81655	1.22467	46
15	0.70673	1.41497	0.73323	1.36383	0.76042	1.31507	0.78834	1.26849	0.81703	1.22394	45
16	0.70717	1.41409	0.73368	1.36300	0.76088	1.31427	0.78881	1.26774	0.81752	1.22321	44
17	0.70760	1.41322	0.73413	1.36217	0.76134	1.31348	0.78928	1.26698	0.81800	1.22249	43
18	0.70804	1.41235	0.73457	1.36134	0.76180	1.31269	0.78975	1.26622	0.81849	1.22176	42
19	0.70848	1.41148	0.73502	1.36051	0.76226	1.31190	0.79022	1.26546	0.81898	1.22104	41
20	0.70891	1.41061	0.73547	1.35968	0.76272	1.31110	0.79070	1.26471	0.81946	1.22031	40
21	0.70935	1.40974	0.73592	1.35885	0.76318	1.31031	0.79117	1.26395	0.81995	1.21959	39
22	0.70979	1.40887	0.73637	1.35802	0.76364	1.30952	0.79164	1.26319	0.82044	1.21886	38
23	0.71023	1.40800	0.73681	1.35719	0.76410	1.30873	0.79212	1.26244	0.82092	1.21814	37
24	0.71066	1.40714	0.73726	1.35637	0.76456	1.30795	0.79259	1.26169	0.82141	1.21742	36
25	0.71110	1.40627	0.73771	1.35554	0.76502	1.30716	0.79306	1.26093	0.82190	1.21670	35
26	0.71154	1.40540	0.73816	1.35472	0.76548	1.30637	0.79354	1.26018	0.82238	1.21598	34
27	0.71198	1.40454	0.73861	1.35389	0.76594	1.30558	0.79401	1.25943	0.82287	1.21526	33
28	0.71242	1.40367	0.73906	1.35307	0.76640	1.30480	0.79449	1.25867	0.82336	1.21454	32
29	0.71285	1.40281	0.73951	1.35224	0.76686	1.30401	0.79496	1.25792	0.82385	1.21382	31
30	0.71329	1.40195	0.73996	1.35142	0.76733	1.30323	0.79544	1.25717	0.82434	1.21310	30
31	0.71373	1.40109	0.74041	1.35060	0.76779	1.30244	0.79591	1.25642	0.82483	1.21238	29
32	0.71417	1.40022	0.74086	1.34978	0.76825	1.30166	0.79639	1.25567	0.82531	1.21166	28
33	0.71461	1.39936	0.74131	1.34896	0.76871	1.30087	0.79686	1.25492	0.82580	1.21094	27
34	0.71505	1.39850	0.74176	1.34814	0.76918	1.30009	0.79734	1.25417	0.82629	1.21023	26
35	0.71549	1.39764	0.74221	1.34732	0.76964	1.29931	0.79781	1.25343	0.82678	1.20951	25
36	0.71593	1.39679	0.74267	1.34650	0.77010	1.29853	0.79829	1.25268	0.82727	1.20879	24
37	0.71637	1.39593	0.74312	1.34568	0.77057	1.29775	0.79877	1.25193	0.82776	1.20808	23
38	0.71681	1.39507	0.74357	1.34487	0.77103	1.29696	0.79924	1.25118	0.82825	1.20736	22
39	0.71725	1.39421	0.74402	1.34405	0.77149	1.29618	0.79972	1.25044	0.82874	1.20665	21
40	0.71769	1.39336	0.74447	1.34323	0.77196	1.29541	0.80020	1.24969	0.82923	1.20593	20
41	0.71813	1.39250	0.74492	1.34242	0.77242	1.29463	0.80067	1.24895	0.82972	1.20522	19
42	0.71857	1.39165	0.74538	1.34160	0.77289	1.29385	0.80115	1.24820	0.83022	1.20451	18
43	0.71901	1.39079	0.74583	1.34079	0.77335	1.29307	0.80163	1.24746	0.83071	1.20379	17
44	0.71946	1.38994	0.74628	1.33998	0.77382	1.29229	0.80211	1.24672	0.83120	1.20308	16
45	0.71990	1.38909	0.74674	1.33916	0.77428	1.29152	0.80258	1.24597	0.83169	1.20237	15
46	0.72034	1.38824	0.74719	1.33835	0.77475	1.29074	0.80306	1.24523	0.83218	1.20166	14
47	0.72078	1.38738	0.74764	1.33754	0.77521	1.28997	0.80354	1.24449	0.83268	1.20095	13
48	0.72122	1.38653	0.74810	1.33673	0.77568	1.28919	0.80402	1.24375	0.83317	1.20024	12
49	0.72167	1.38568	0.74855	1.33592	0.77615	1.28842	0.80450	1.24301	0.83366	1.19953	11
50	0.72211	1.38484	0.74900	1.33511	0.77661	1.28764	0.80498	1.24227	0.83415	1.19882	10
51	0.72255	1.38399	0.74946	1.33430	0.77708	1.28687	0.80546	1.24153	0.83465	1.19811	9
52	0.72299	1.38314	0.74991	1.33349	0.77754	1.28610	0.80594	1.24079	0.83514	1.19740	8
53	0.72344	1.38229	0.75037	1.33268	0.77801	1.28533	0.80642	1.24005	0.83564	1.19669	7
54	0.72388	1.38145	0.75082	1.33187	0.77848	1.28456	0.80690	1.23931	0.83613	1.19599	6
55	0.72432	1.38060	0.75128	1.33107	0.77895	1.28379	0.80738	1.23858	0.83662	1.19528	5
56	0.72477	1.37976	0.75173	1.33026	0.77941	1.28302	0.80786	1.23784	0.83712	1.19457	4
57	0.72521	1.37891	0.75219	1.32946	0.77988	1.28225	0.80834	1.23710	0.83761	1.19387	3
58	0.72565	1.37807	0.75264	1.32865	0.78035	1.28148	0.80882	1.23637	0.83811	1.19316	2
59	0.72610	1.37722	0.75310	1.32785	0.78082	1.28071	0.80930	1.23563	0.83860	1.19246	1
60	0.72654	1.37638	0.75355	1.32704	0.78129	1.27994	0.80978	1.23490	0.83910	1.19175	0
	54° COT	54° TAN	53° COT	53° TAN	52° COT	52° TAN	51° COT	51° TAN	50° COT	50° TAN	MIN

Table AII-2.—Natural Tangents and Cotangents—Continued

MIN	40° TAN	40° COT	41° TAN	41° COT	42° TAN	42° COT	43° TAN	43° COT	44° TAN	44° COT	
0	0.83910	1.19175	0.86929	1.15037	0.90040	1.11061	0.93252	1.07237	0.96569	1.03553	60
1	0.83960	1.19105	0.86980	1.14969	0.90093	1.10996	0.93306	1.07174	0.96625	1.03493	59
2	0.84009	1.19035	0.87031	1.14902	0.90146	1.10931	0.93360	1.07112	0.96681	1.03433	58
3	0.84059	1.18964	0.87082	1.14834	0.90199	1.10867	0.93415	1.07049	0.96738	1.03372	57
4	0.84108	1.18894	0.87133	1.14767	0.90251	1.10802	0.93469	1.06987	0.96794	1.03312	56
5	0.84158	1.18824	0.87184	1.14699	0.90304	1.10737	0.93524	1.06925	0.96850	1.03252	55
6	0.84208	1.18754	0.87236	1.14632	0.90357	1.10672	0.93578	1.06862	0.96907	1.03192	54
7	0.84258	1.18684	0.87287	1.14565	0.90410	1.10607	0.93633	1.06800	0.96963	1.03132	53
8	0.84307	1.18614	0.87338	1.14498	0.90463	1.10543	0.93688	1.06738	0.97020	1.03072	52
9	0.84357	1.18544	0.87389	1.14430	0.90516	1.10478	0.93742	1.06676	0.97076	1.03012	51
10	0.84407	1.18474	0.87441	1.14363	0.90569	1.10414	0.93797	1.06613	0.97133	1.02952	50
11	0.84457	1.18404	0.87492	1.14296	0.90621	1.10349	0.93852	1.06551	0.97189	1.02892	49
12	0.84507	1.18334	0.87543	1.14229	0.90674	1.10285	0.93906	1.06489	0.97246	1.02832	48
13	0.84556	1.18264	0.87595	1.14162	0.90727	1.10220	0.93961	1.06427	0.97302	1.02772	47
14	0.84606	1.18194	0.87646	1.14095	0.90781	1.10156	0.94016	1.06365	0.97359	1.02713	46
15	0.84656	1.18125	0.87698	1.14028	0.90834	1.10091	0.94071	1.06303	0.97416	1.02653	45
16	0.84706	1.18055	0.87749	1.13961	0.90887	1.10027	0.94125	1.06241	0.97472	1.02593	44
17	0.84756	1.17986	0.87801	1.13894	0.90940	1.09963	0.94180	1.06179	0.97529	1.02533	43
18	0.84806	1.17916	0.87852	1.13828	0.90993	1.09899	0.94235	1.06117	0.97586	1.02474	42
19	0.84856	1.17846	0.87904	1.13761	0.91046	1.09834	0.94290	1.06056	0.97643	1.02414	41
20	0.84906	1.17777	0.87955	1.13694	0.91099	1.09770	0.94345	1.05994	0.97700	1.02355	40
21	0.84956	1.17708	0.88007	1.13627	0.91153	1.09706	0.94400	1.05932	0.97756	1.02295	39
22	0.85006	1.17638	0.88059	1.13561	0.91206	1.09642	0.94455	1.05870	0.97813	1.02236	38
23	0.85057	1.17569	0.88110	1.13494	0.91259	1.09578	0.94510	1.05809	0.97870	1.02176	37
24	0.85107	1.17500	0.88162	1.13428	0.91313	1.09514	0.94565	1.05747	0.97927	1.02117	36
25	0.85157	1.17430	0.88214	1.13361	0.91366	1.09450	0.94620	1.05685	0.97984	1.02057	35
26	0.85207	1.17361	0.88265	1.13295	0.91419	1.09386	0.94676	1.05624	0.98041	1.01998	34
27	0.85257	1.17292	0.88317	1.13228	0.91473	1.09322	0.94731	1.05562	0.98098	1.01939	33
28	0.85308	1.17223	0.88369	1.13162	0.91526	1.09258	0.94786	1.05501	0.98155	1.01879	32
29	0.85358	1.17154	0.88421	1.13096	0.91580	1.09195	0.94841	1.05439	0.98213	1.01820	31
30	0.85408	1.17085	0.88473	1.13029	0.91633	1.09131	0.94896	1.05378	0.98270	1.01761	30
31	0.85458	1.17016	0.88524	1.12963	0.91687	1.09067	0.94952	1.05317	0.98327	1.01702	29
32	0.85509	1.16947	0.88576	1.12897	0.91740	1.09003	0.95007	1.05255	0.98384	1.01642	28
33	0.85559	1.16878	0.88628	1.12831	0.91794	1.08940	0.95062	1.05194	0.98441	1.01583	27
34	0.85609	1.16809	0.88680	1.12765	0.91847	1.08876	0.95118	1.05133	0.98499	1.01524	26
35	0.85660	1.16741	0.88732	1.12699	0.91901	1.08813	0.95173	1.05072	0.98556	1.01465	25
36	0.85710	1.16672	0.88784	1.12633	0.91955	1.08749	0.95229	1.05010	0.98613	1.01406	24
37	0.85761	1.16603	0.88836	1.12567	0.92008	1.08686	0.95284	1.04949	0.98671	1.01347	23
38	0.85811	1.16535	0.88888	1.12501	0.92062	1.08622	0.95340	1.04888	0.98728	1.01288	22
39	0.85862	1.16466	0.88940	1.12435	0.92116	1.08559	0.95395	1.04827	0.98786	1.01229	21
40	0.85912	1.16398	0.88992	1.12369	0.92170	1.08496	0.95451	1.04766	0.98843	1.01170	20
41	0.85963	1.16329	0.89045	1.12303	0.92224	1.08432	0.95506	1.04705	0.98901	1.01112	19
42	0.86014	1.16261	0.89097	1.12238	0.92277	1.08369	0.95562	1.04644	0.98958	1.01053	18
43	0.86064	1.16192	0.89149	1.12172	0.92331	1.08306	0.95618	1.04583	0.99016	1.00994	17
44	0.86115	1.16124	0.89201	1.12106	0.92385	1.08243	0.95673	1.04522	0.99073	1.00935	16
45	0.86166	1.16056	0.89253	1.12041	0.92439	1.08179	0.95729	1.04461	0.99131	1.00876	15
46	0.86216	1.15987	0.89306	1.11975	0.92493	1.08116	0.95785	1.04401	0.99189	1.00818	14
47	0.86267	1.15919	0.89358	1.11909	0.92547	1.08053	0.95841	1.04340	0.99247	1.00759	13
48	0.86318	1.15851	0.89410	1.11844	0.92601	1.07990	0.95897	1.04279	0.99304	1.00701	12
49	0.86368	1.15783	0.89463	1.11778	0.92655	1.07927	0.95952	1.04218	0.99362	1.00642	11
50	0.86419	1.15715	0.89515	1.11713	0.92709	1.07864	0.96008	1.04158	0.99420	1.00583	10
51	0.86470	1.15647	0.89567	1.11648	0.92763	1.07801	0.96064	1.04097	0.99478	1.00525	9
52	0.86521	1.15579	0.89620	1.11582	0.92817	1.07738	0.96120	1.04036	0.99536	1.00467	8
53	0.86572	1.15511	0.89672	1.11517	0.92872	1.07676	0.96176	1.03976	0.99594	1.00408	7
54	0.86623	1.15443	0.89725	1.11452	0.92926	1.07613	0.96232	1.03915	0.99652	1.00350	6
55	0.86674	1.15375	0.89777	1.11387	0.92980	1.07550	0.96288	1.03855	0.99710	1.00291	5
56	0.86725	1.15308	0.89830	1.11321	0.93034	1.07487	0.96344	1.03794	0.99768	1.00233	4
57	0.86776	1.15240	0.89883	1.11256	0.93088	1.07425	0.96400	1.03734	0.99826	1.00175	3
58	0.86827	1.15172	0.89935	1.11191	0.93143	1.07362	0.96457	1.03674	0.99884	1.00116	2
59	0.86878	1.15104	0.89988	1.11126	0.93197	1.07299	0.96513	1.03613	0.99942	1.00058	1
60	0.86929	1.15037	0.90040	1.11061	0.93252	1.07237	0.96569	1.03553	1.00000	1.00000	0
	COT	TAN	COT	TAN	COT	TAN	COT	TAN	COT	TAN	MIN
	49°		48°		47°		46°		45°		

Table AII-3.—Stadia Reduction

Minutes	0°		1°		2°		3°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
C = 0.75	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
C = 1.00	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
C = 1.25	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

Table AII-3.—Stadia Reduction—Continued

Minutes	4°		5°		6°		7°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26
8	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55
18	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72
24	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
38	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
C=0.75	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0.10
C=1.00	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
C=1.25	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

Minutes	8°		9°		10°		11°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0........	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2........	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4........	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6........	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8........	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10........	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12........	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14........	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16........	97.93	14.23	97.41	15.89	96.82	17.54	96.18	19.16
18........	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20........	97.90	14.34	97.37	16.00	96.78	17.65	96.14	19.27
22........	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24........	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26........	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28........	97.83	14.56	97.29	16.22	96.70	17.86	96.05	19.48
30........	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32........	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34........	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36........	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38........	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40........	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42........	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44........	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46........	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48........	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50........	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52........	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54........	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56........	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58........	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60........	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
C=0.75...	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
C=1.00...	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
C=1.25...	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

Table AII-3.—Stadia reduction—Continued

Minutes	12°		13°		14°		15°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15
8	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35
16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65
28	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00
42	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15
48	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35
56	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60	94.94	21.92	94.15	23.47	93.90	25.00	92.40	26.50
C=0.75	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
C=1.00	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
C=1.25	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

Table AII-3.—Stadia Reduction—Continued

Minutes	16°		17°		18°		19°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0........	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2........	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4........	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6........	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8........	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10........	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12........	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14........	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16........	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18........	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19
20........	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22........	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24........	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26........	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28........	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30........	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32........	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34........	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36........	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38........	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40........	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42........	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44........	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46........	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48........	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50........	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52........	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54........	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56........	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58........	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
60........	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
C=0.75...	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
C=1.00...	0.96	0.28	0.95	0.30	0.95	0.32	0.94	0.33
C=1.25...	1.20	0.35	1.19	0.38	1.19	0.40	1.18	0.42

Minutes	20°		21°		22°		23°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20	87.93	32.58	86.77	33.89	85.56	35.15	84.31	36.37
22	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26	87.81	32.72	86.65	34.01	85.44	35.27	84.18	36.49
28	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30	87.74	32.80	86.57	34.10	85.36	35.36	84.10	36.57
32	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52	87.31	33.28	86.13	34.57	84.90	35.80	83.63	37.00
54	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
C=0.75	0.70	0.26	0.70	0.27	0.69	0.29	0.69	0.30
C=1.00	0.94	0.35	0.93	0.37	0.92	0.38	0.92	0.40
C=1.25	1.17	0.44	1.16	0.46	1.15	0.48	1.15	0.50

Table AII-3.—Stadia Reduction—Continued

Minutes	24°		25°		26°		27°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
C = 0.75	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
C = 1.00	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
C = 1.25	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

Table AII-3.—Stadia Reduction—Continued

Minutes	28°		29°		30°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	77.96	41.45	76.50	42.40	75.00	43.30
2	77.91	41.48	76.45	42.43	74.95	43.33
4	77.86	41.52	76.40	42.46	74.90	43.36
6	77.81	41.55	76.35	42.49	74.85	43.39
8	77.77	41.58	76.30	42.53	74.80	43.42
10	77.72	41.61	76.25	42.56	74.75	43.45
12	77.67	41.65	76.20	42.59	74.70	43.47
14	77.62	41.68	76.15	42.62	74.65	43.50
16	77.57	41.71	76.10	42.65	74.60	43.53
18	77.52	41.74	76.05	42.68	74.55	43.56
20	77.48	41.77	76.00	42.71	74.49	43.59
22	77.42	41.81	75.95	42.74	74.44	43.62
24	77.38	41.84	75.90	42.77	74.39	43.65
26	77.33	41.87	75.85	42.80	74.34	43.67
28	77.28	41.90	75.80	42.83	74.29	43.70
30	77.23	41.93	75.75	42.86	74.24	43.73
32	77.18	41.97	75.70	42.89	74.19	43.76
34	77.13	42.00	75.65	42.92	74.14	43.79
36	77.09	42.03	75.60	42.95	74.09	43.82
38	77.04	42.06	75.55	42.98	74.04	43.84
40	76.99	42.09	75.50	43.01	73.99	43.87
42	76.94	42.12	75.45	43.04	73.93	43.90
44	76.89	42.15	75.40	43.07	73.88	43.93
46	76.84	42.19	75.35	43.10	73.83	43.95
48	76.79	42.22	75.30	43.13	73.78	43.98
50	76.74	42.25	75.25	43.16	73.73	44.01
52	76.69	42.28	75.20	43.18	73.68	44.04
54	76.64	42.31	75.15	43.21	73.63	44.07
56	76.59	42.34	75.10	43.24	73.58	44.09
58	76.55	42.37	75.05	43.27	73.52	44.12
60	76.50	42.40	75.00	43.30	73.47	44.15
C=0.75	0.66	0.36	0.65	0.37	0.65	0.38
C=1.00	0.88	0.48	0.87	0.49	0.86	0.51
C=1.25	1.10	0.60	1.09	0.62	1.08	0.64

APPENDIX III

SAMPLE SURVEY FIELD NOTES

The field notes contained in this Appendix are presented to show you, the EA2 survey party chief or the EA1 supervisor, how a series of notes are indexed and arranged in a field notebook For completeness, the field notes shown in appendix V of the EA3 TRAMAN are repeated in this Appendix.

The field notes in this Appendix are samples of the types of notes that are kept in surveying. They are not intended to describe how the notes should be kept. That is up to you. You are the one who decides what minimum information is necessary to achieve complete notes, and you are the one who decides how that information is to be recorded. As you are well aware, note keeping is not only an art that makes your notes clean and legible but it is also a science that makes your notes meaningful and correct.

Figures AIII-1 and AIII-2 are samples of the front page and index of a notebook. The front page should be filled out as required by your unit. A separate book should, when possible, be kept for each major project. The index should show all surveying projects by page number and must be kept up-to-date at all times.

An example of recording horizontal measurements is shown in figure AIII-3. To record taping problems, record distance measured (by parts of tapes, if measured) going from one station to the next. Record in the direction in which measured; that is, down for forward measurements, up for backward measurements.

A page check of a direct-level circuit is shown in figure AIII-4. As you recall, when page checking you are determining that the difference between the sum of the backlights and the sum of the forsights is equal to the difference in elevation between the initial benchmark or turning point and the final benchmark or turning point. For direct-level notes exceeding one page, the page check should always be made for each separate page of the notes. The final page should, in addition, show also a check from start to finish of the entire circuit. Remember, too, that when making a page check, you are checking only the accuracy of the arithmetic, not the accuracy of the level shots.

Figure AIII-5 shows horizon closure for a traverse station. In this example, each angle was repeated twice, once direct and once reverse, using the procedures you studied in chapter 13 of the EA3 TRAMAN for measuring angles by repetition.

Turn all angles, direct and reverse, to the right. Enter means, and if mean does not match single reading to ±30", reshoot the angles. Never proceed to the next station until horizon closure (360° ±30") has been achieved.

Figures AIII-6 and AIII-7 show, respectively, notes for a station-angle traverse and a deflection-angle traverse.

DEPARTMENT OF THE NAVY

THIRTY FIRST NAVAL CONSTRUCTION REGIMENT
NMCB FOUR

LEVEL, TRANSIT, AND GENERAL SURVEY
RECORD BOOK

PORT HUENEME, CALIFORNIA
LOCALITY

BLDG & ROAD LAYOUT, NORTH DRIVE
PROJECT

BOOK 2 OF 4

THEODOLITE WILD T 16
INSTRUMENT

EA2 W. J. BROWN
CHIEF OF PARTY

IMPORTANT
On the opposite page, print the address to which this book is to be returned, if lost.

Figure AIII-1.—Front page of a notebook.

INDEX

DESIGNATION ________ DATE ________ 19__

PAGE	PROJECT	DATE
6	HORIZONTAL TAPING - TRAV 27-A	16JAN84
10	DIRECT LEVEL CIRCUIT - BM61 TO BM63	12JAN84
11	HORIZON CLOSURE - TRAV #2	25JAN84
17	STATION ANGLE TRAV - TRAV #12	15FEB84
18	DEFL ANGLE TRAV - TRAV #12-A	17FEB84
19	TRIANGULATION - ELEV OF WATER TOW	13FEB84
20	TRIG ELEVATION - HT OF FLAG POLE	15FEB84
21	McCOY AVE EXT'D - HOR ∡ CONTROL	20FEB84
22	-"- HORIZ TAPING	22FEB84
23	-"- DIFF LEVELING	24FEB84
24	-"- HOR CURVE LAYOUT	20MAR84
25	-"- PROF & CR SECT LEVELS	21MAR84
26	-"- PROF LEV (SEWER LINE)	23MAR84
27	-"- SLOPE STAKES	30MAR84
28	BLDG T2855 - BLDG LAYOUT	1APR84
29	PLANETABLE MAPPING PROBLEM	10APR84

	LOCATION
S. DRIVE	PORT HUENEME, CALIFORNIA
PI AREA	-"-
AREA K	-"-
N. DRIVE	-"-
N. DRIVE	-"-
PI AREA	-"-
PI AREA	-"-
N. DRIVE	-"-
-"-	-"-
-"-	-"-
-"-	-"-
-"-	-"-
-"-	-"-
-"-	-"-
S. DRIVE	-"-
N. DRIVE	-"-

Figure AIII-2.—Index.

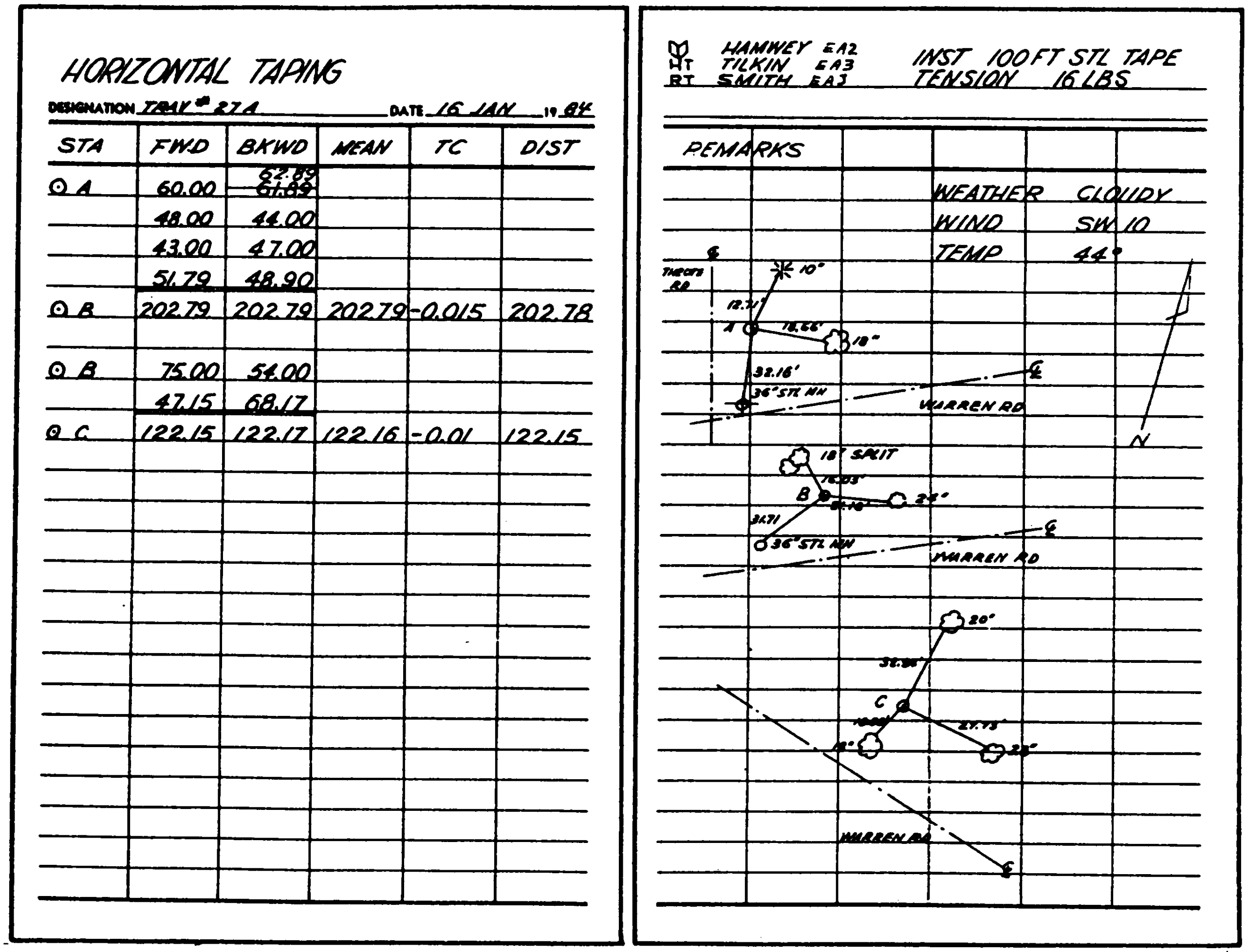
The set of horizontal angle control notes shown in figure AIII-8 indicates that the instrument was first set up over station 0 + 00 and indexed on point No. 1. The horizontal angle (to the right) to PI No. 1 was then turned, as well as the horizontal angle to a church steeple. This locates the traverse and ties it to a point that will not be disturbed The instrument was then moved to PI No. 1 and the deflection angle between 0 + 00 and PI No. 2 was turned (twice), making sure that the angle was recorded with its proper direction: right (R). The instrument was then moved to PI No. 2 and the procedures repeated

‘The set of horizontal taping notes in figure AIII-9 shows the proper way to tape and record distances between points. The line in question is taped in both directions, showing each distance and the mean distance. The mean distance must be within 1 in 5,000, or third-order accuracy. A good complete sketch is required.

Differential leveling notes are shown in figure AIII-10. When making the page check do not add the foresight for station 0 + 00, as it is a side shot. Also, note that the stadia distance to 0 + 00 has been omitted for the same reason. When making your sketch, you do not need to show the backsight and foresight distances on the sketch-only on the traverse points, and so forth, normally found on a sketch.

Horizontal curve notes (fig. AIII-11) should include all the curve data plus the deflection angles that are to be turned during the layout of the curve. The sketch should be as shown here. All stations that were staked out should be shown and labeled on the sketch.

Profile and cross-section level notes (fig. AIII-12) are best recorded from the bottom to the top of the page. The left-hand side of the notes should contain columns for stations, backsight (+), height of instrument (HI), foresight (-), and elevations. The right side, as shown, has left, center-line, and right columns. The top number



HORIZONTAL TAPING

DESIGNATION TRAV # 27A DATE 16 JAN 19 84

STA	FWD	BKWD	MEAN	TC	DIST
⊙ A	60.00	62.89 (61.89 crossed out)			
	48.00	44.00			
	43.00	47.00			
	51.79	48.90			
⊙ B	202.79	202.79	202.79	-0.015	202.78
⊙ B	75.00	54.00			
	47.15	68.17			
⊙ C	122.15	122.17	122.16	-0.01	122.15

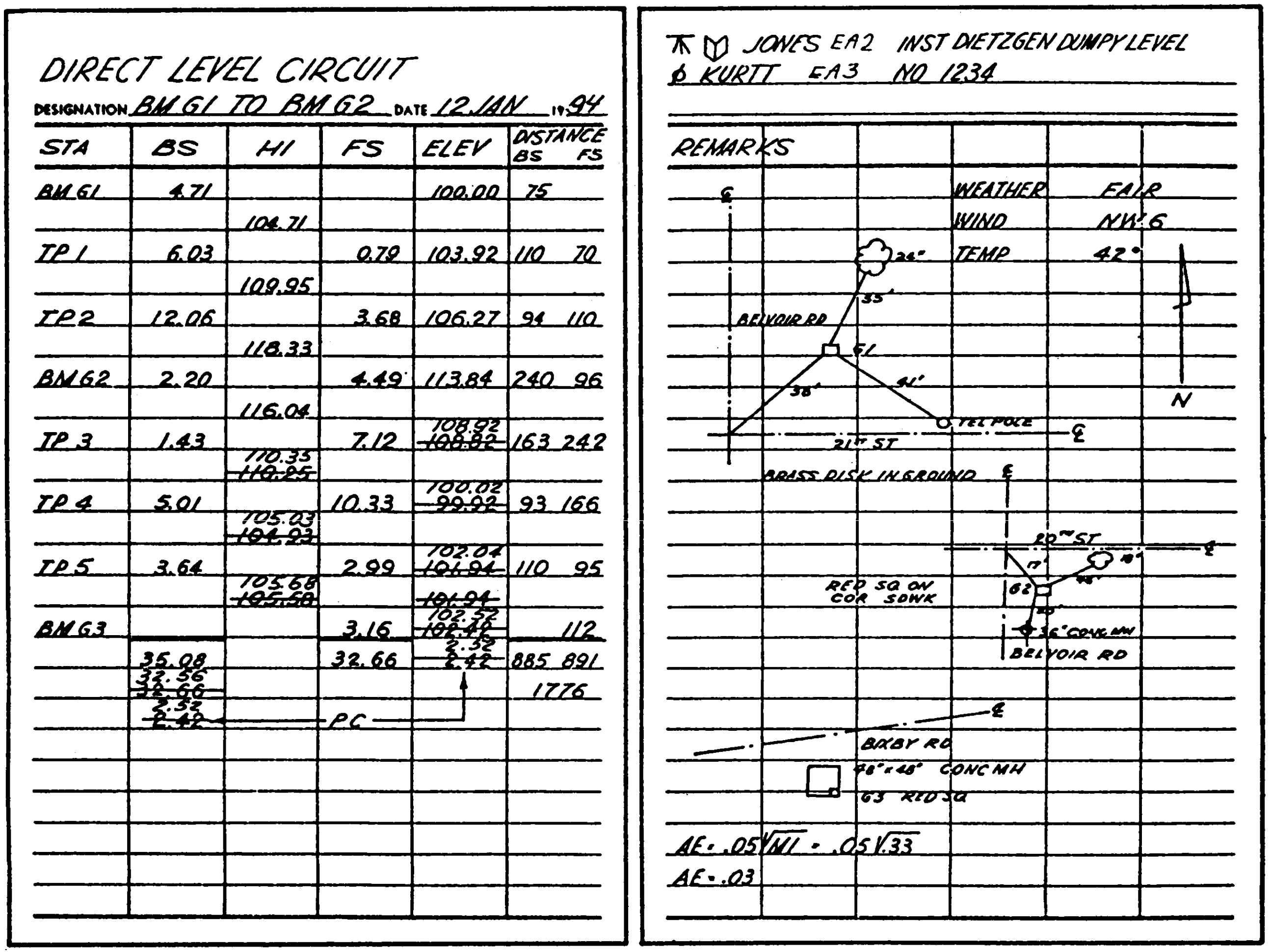
Figure AIII-3.—Horizontal taping.

is the ground elevation at that point, the center number is the rod reading, and the bottom number is the perpendicular distance to the centerline. An additional example of profile levels is shown in figure AIII-13.

Slope-stake notes (fig. AIII-14), as with profile notes, are best recorded from the bottom to the top of the page. As you see in the figure, in addition to grade rod, the right-hand page of the notes has left, center-line, and right columns. In these columns the amount of cut or fill, ground rod, and the distance of the slope stakes from the center line are recorded for each station.

Notes for a building layout are shown in figure AIII-15. Building corner numbers on the sketch must agree with the designation on the left-hand side of the notes. Grade rod setting is computed in the field. Batter elevations are entered in the first column on the right-hand side of the notes—after having been computed at the jobsite. The sketch must show all pertinent data for locating the building.

Typical notes for a plane-table survey are shown in figure AIII-16.



DIRECT LEVEL CIRCUIT

DESIGNATION BM 61 TO BM 62 DATE 12 JAN 19 94

STA	BS	HI	FS	ELEV	DISTANCE BS	DISTANCE FS
BM 61	4.71			100.00	75	
		104.71				
TP 1	6.03		0.79	103.92	110	70
		109.95				
TP 2	12.06		3.68	106.27	94	110
		118.33				
BM 62	2.20		4.49	113.84	240	96
		116.04				
TP 3	1.43		7.12	108.92 ~~108.82~~	163	242
		110.35 ~~110.25~~				
TP 4	5.01		10.33	100.02 ~~99.92~~	93	166
		105.03 ~~104.93~~				
TP 5	3.64		2.99	102.04 ~~101.94~~	110	95
		105.68 ~~105.58~~		~~101.94~~		
BM 63			3.16	102.52 ~~102.42~~		112
	35.08		32.66	2.52 ~~2.42~~	885	891
	32.56 ~~32.66~~				1776	
	2.52 ~~2.42~~ ←	P.C.				

Figure AIII-4.—Page check.

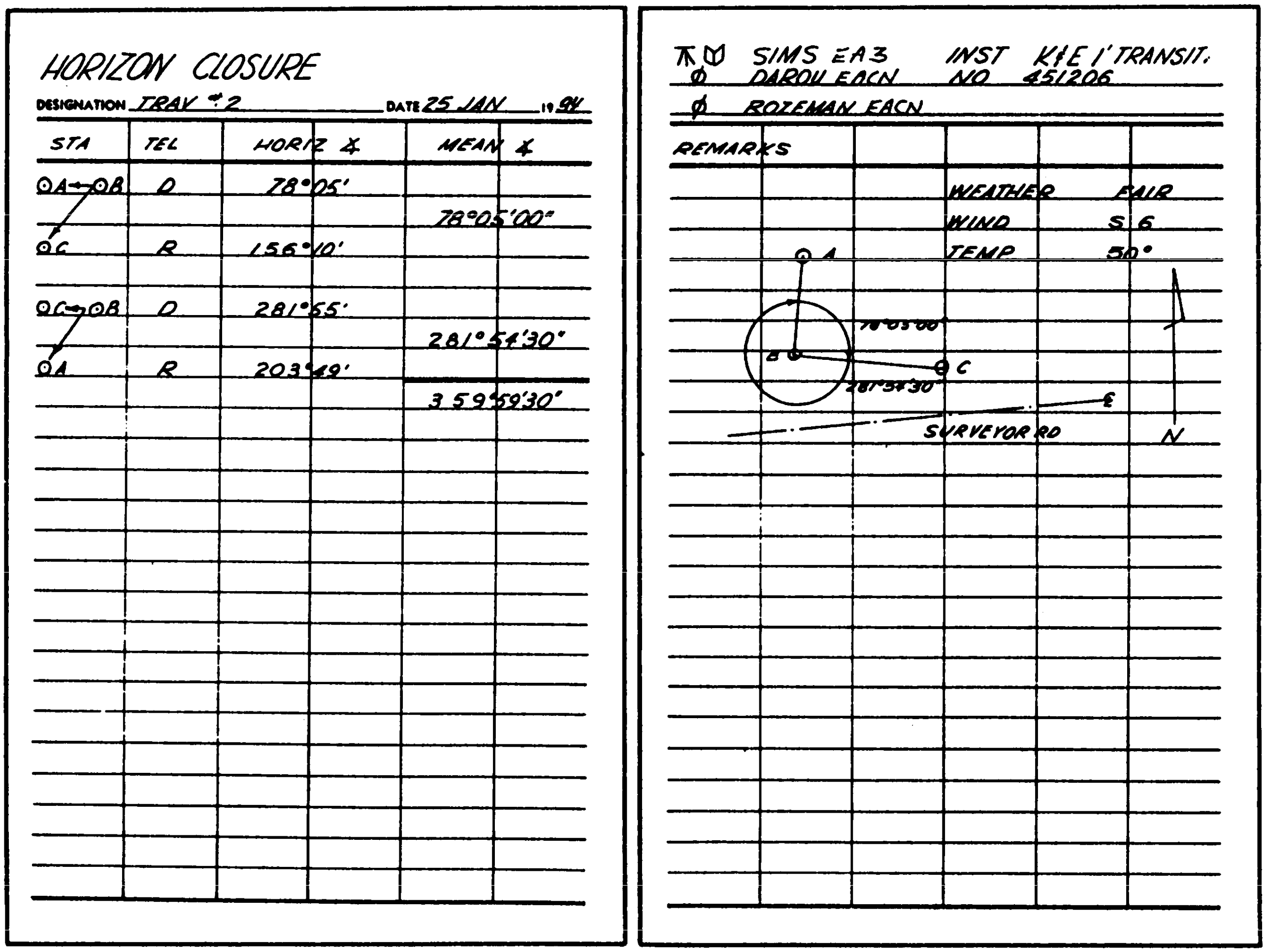
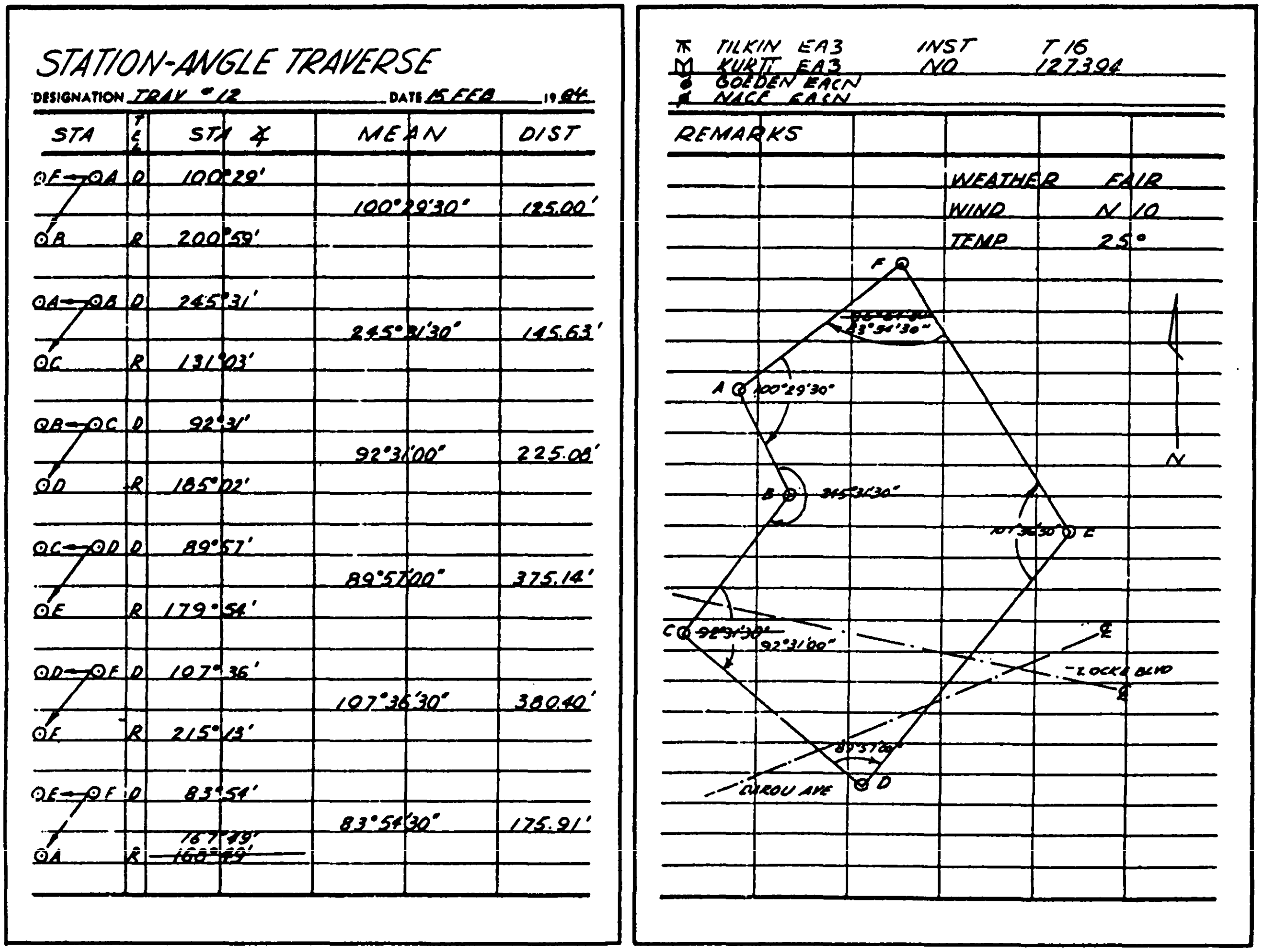


Figure AIII-5.—Horizon closure.

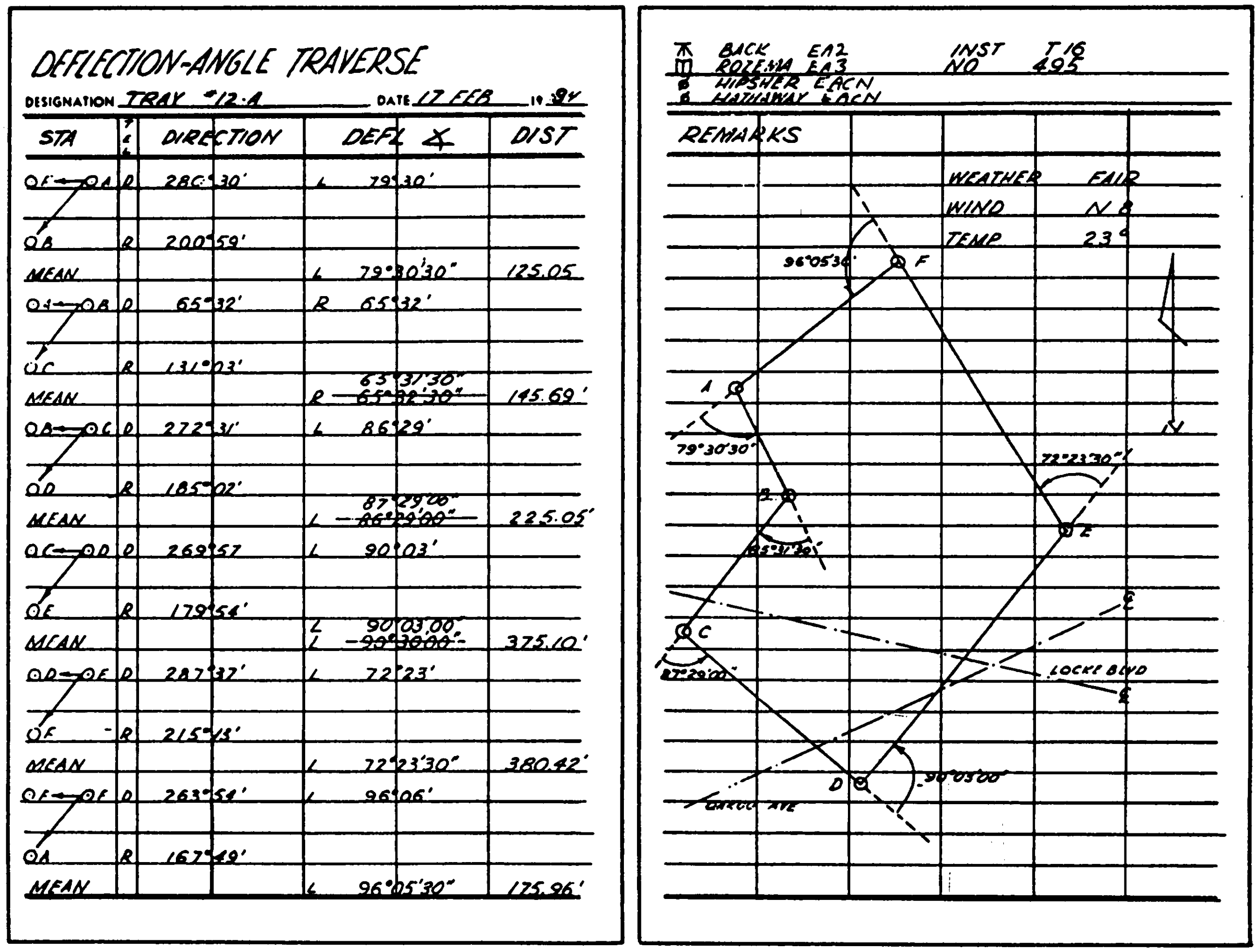


STATION-ANGLE TRAVERSE

DESIGNATION TRAV #12 DATE 15 FEB 19 84

STA		STA ∡	MEAN	DIST
⊙F→⊙A	D	100°29'		
			100°29'30"	125.00'
⊙B	R	200°59'		
⊙A→⊙B	D	245°31'		
			245°31'30"	145.63'
⊙C	R	131°03'		
⊙B→⊙C	D	92°31'		
			92°31'00"	225.08'
⊙D	R	185°02'		
⊙C→⊙D	D	89°57'		
			89°57'00"	375.14'
⊙E	R	179°54'		
⊙D→⊙F	D	107°36'		
			107°36'30"	380.40'
⊙F	R	215°13'		
⊙E→⊙F	D	83°54'		
			83°54'30"	175.91'
⊙A	R	167°49' (168°49' struck out)		

Figure AIII-6.—Station-angle traverse.



DEFLECTION-ANGLE TRAVERSE

DESIGNATION TRAV #12-A DATE 17 FEB 19 84

STA		DIRECTION	DEFL ∡	DIST
⊙F—⊙A	D	280°30'	L 79°30'	
⊙B	R	200°59'		
MEAN			L 79°30'30"	125.05
⊙A—⊙B	D	65°32'	R 65°32'	
⊙C	R	131°03'		
MEAN			R 65°31'30" ~~65°32'30"~~	145.69'
⊙B—⊙C	D	272°31'	L 86°29'	
⊙D	R	185°02'		
MEAN			L 87°29'00" ~~86°29'00"~~	225.05'
⊙C—⊙D	D	269°57	L 90°03'	
⊙E	R	179°54'		
MEAN			L 90°03'00" L ~~90°30'00"~~	375.10'
⊙D—⊙E	D	287°37'	L 72°23'	
⊙F	R	215°15'		
MEAN			L 72°23'30"	380.42'
⊙E—⊙F	D	263°54'	L 96°06'	
⊙A	R	167°49'		
MEAN			L 96°05'30"	175.96'

Figure AIII-7.—Deflection-angle traverse.

HORIZONTAL ANGLE CONTROL

DESIGNATION MC COY AVE EXTENDED DATE 20 FEB 1984

STA	BS	FS	1st ∡	2nd ∡	MEAN ∡
0+00	#1				00°00'
		PI #1	87°16'	174°32'	87°16'
0+00	#1				00°00'
		CHURCH STEEPLE	61°37'	123°14'	61°37'
PI #1	0+00				00°00'
		PI #2	R 16°10'	R 32°20'	R 16°10'
PI #2	PI #1				00°00'
		POT #2	L 18°41'	L 37°22'	L 18°41'

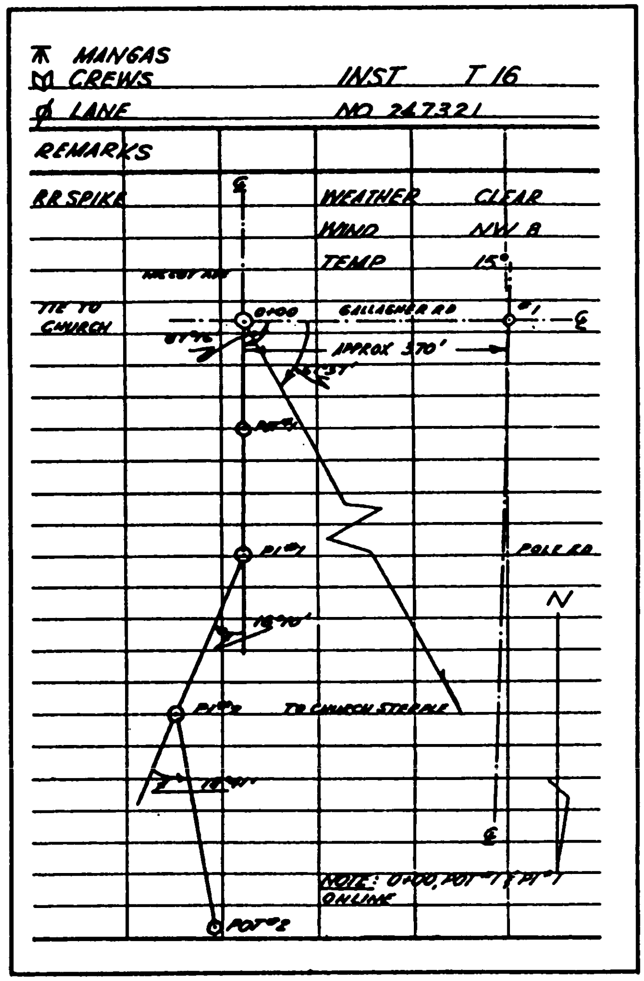


Figure AIII-8.—Horizontal angle control.

HORIZONTAL TAPING

DESIGNATION MC COY AVE EXTENDED DATE 22 FEB 19 84

STA	FWD	BKWD	MEAN		
0+00	62.86'	86.21'			
	71.43'	48.06'			
POT #1	134.29'	134.27'	134.28		
POT #1	96.84'	79.78'			
	92.71'	100.00'			
	100.00'	86.19'			
	73.86'	97.42'			
PI #1	363.41'	363.39'	363.40 ~~363.39'~~		
PI #1	100.00'	94.23'			
	85.41'	97.18'			
	96.20'	90.20			
PI #2	281.61'	281.61'	281.61'		
PI #2	100.00'	98.10'			
	97.00'	66.50'			
	54.65'	88.03'			
POT #2	251.65'	251.63'	251.64'		

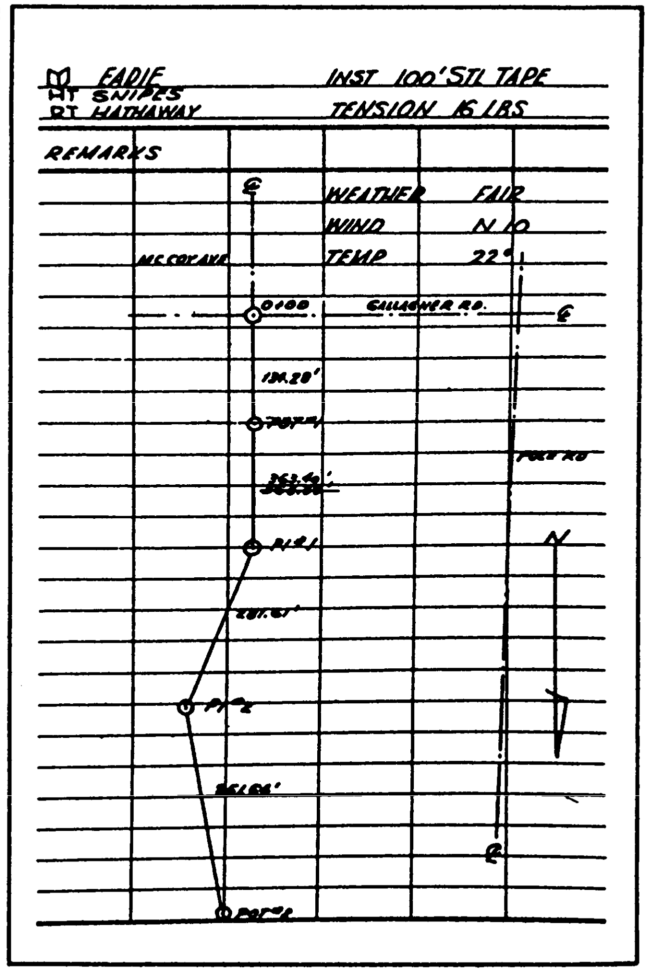


Figure AIII-9.—Horizontal taping between stations.

DIFFERENTIAL LEVELING

DESIGNATION MC COY AVE EXTENDED DATE 24 FEB 19 84

STA	BS	HI	FS	ELEV	DISTANCE BS FS
BM #1	3.68	89.82		86.14	70
0+00			4.16	85.66	
POT #1	4.68	88.63	5.87	83.95	156 71
TP #1	2.06	84.51	6.18	82.45	173 156
PI #1	1.16	79.95	5.72	78.79	208 171
TP #2	3.18	78.98	4.15	75.80	243 207
PI #2	4.86	77.11	6.73	72.25	178 241
TP #3	5.96	77.90	5.17	71.94	142 180
POT #2	4.17	77.96	4.11	73.79	196 143
BM HILL			2.37	75.59	193
	29.75		40.30	10.55	1366 1362
			29.75	PC	2728
			10.55		
			10.52		
		ERROR	+ .03		
BM #1	86.14				
BM HILL	75.62				
DE (TRUE)	10.52				

$AE = .05\sqrt{\frac{2728}{5280}} = .05\sqrt{.52} = .05 \times .7$

$AE = .035$

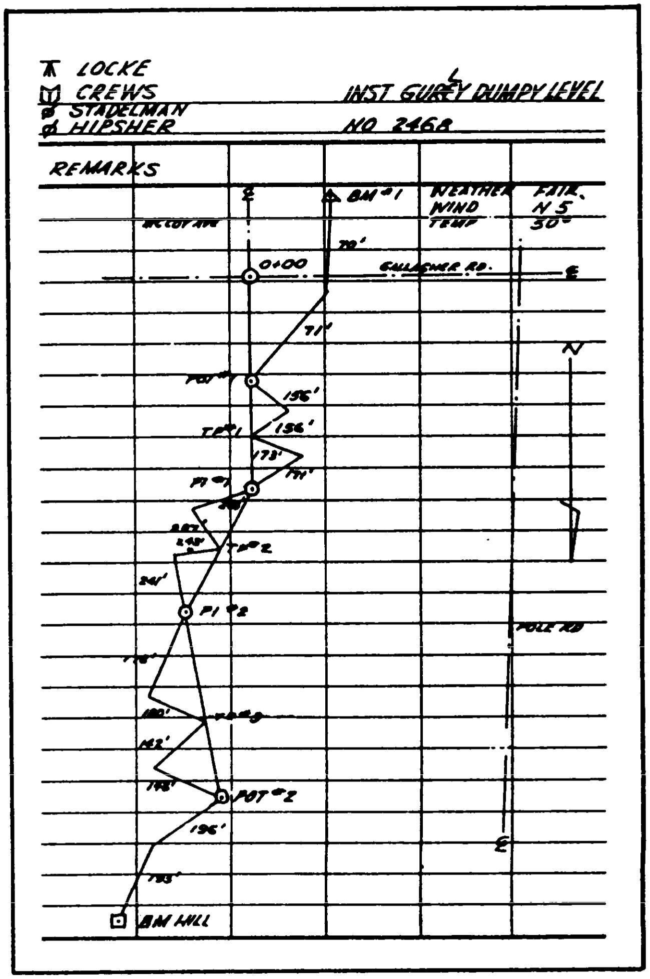


Figure AIII-10.—Differential leveling.

HORIZONTAL CURVE LAYOUT

DESIGNATION MC COY AVE EXTENDED DATE 20 MAR 19 84

STA	CHORD	DEFL ∢		DESCRIPTION OF CURVE	
PC 6+09.22	—	0°00'		I	= 21°28'
+50		1°38'		D	= 8°
7+00		3°38'		PI	= 7+45.00
+50		5°38'		T	= 135.78'
8+00		7°38'		PC	= 6+09.22
+50		9°38'		L	= 268.33
PT 8+77.55		10°44'		PT	= 8+77.55
				R	= 716.25'
				E	= 12.75'
				M	= 12.52'
				C_1	= 40.78'
				C_2	= 27.55'
				d_1	= 1°38'
				d_2	= 1°06'

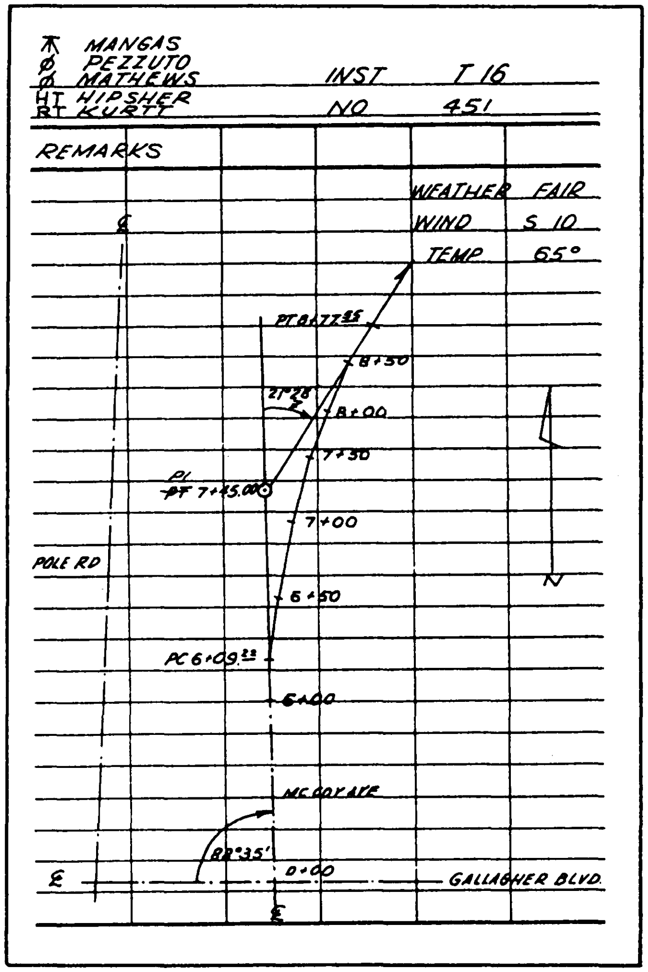


Figure AIII-11.—Horizontal curve layout.

PROFILE & CROSS-SECTION LEVELS

DESIGNATION MC COY AVE EXTENDED DATE 21 MAR 19 94

STA	+	HI	−	ELEV	
TP #1			6.08	132.10	
7+50					
7+00					
6+50					
PC 6+09.22					
6+00					
	3.02	138.18			
BM #4				135.16	

T CORNETT
Ø ROZEMA
Ø NACE INST GURLEY DUMPY LEVEL
Ø LUFKIN NO 12345

	LEFT	℄	RIGHT	
		WEATHER	FAIR	
		WIND	S 10	
		TEMP	62°	
135.0 3.2/50		133.7 4.5/0		132.0 6.2/50
137.1 1.1/50		135.9 2.3/0	134.6 3.6/20	134.3 3.9/50
135.1 3.1/50		134.1 4.1/0		133.6 4.6/50
132.3 6.9/50		134.6 3.6/0		133.2 5.0/50
134.7 3.5/50		134.6 3.6/0		134.6 3.6/50

NAIL IN TREE 60' LEFT OF ℄ STA 0+50

Figure AIII-12.—Profile and cross-section levels.

PROFILE LEVELS (SEWER LINE)

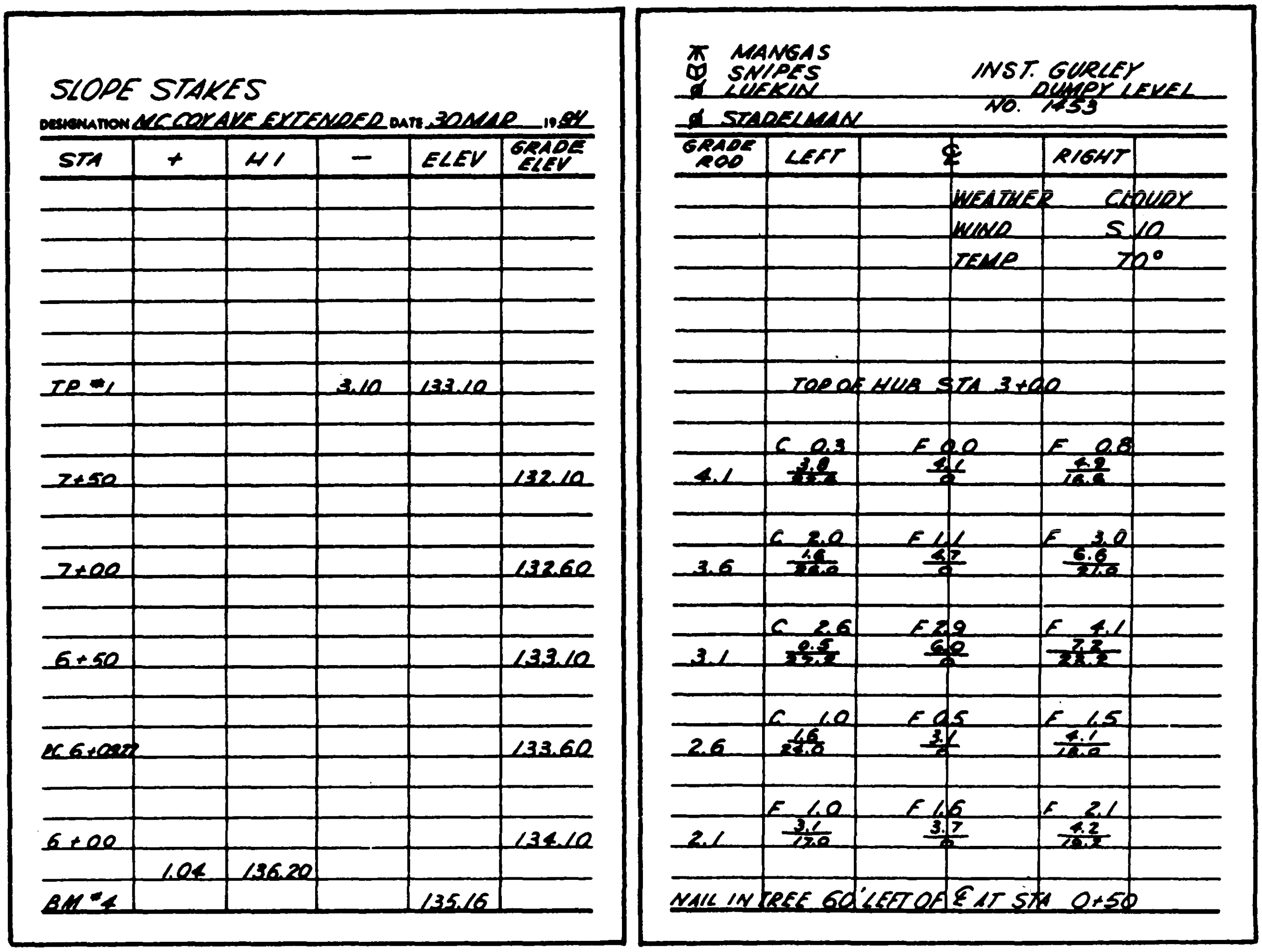
DESIGNATION MC COY AVE EXTENDED DATE 23 MAR 19 94

⊼ BACK
Ʊ SNIPES
ϕ KURTT
ϕ MATHEWS

INST GURLEY DUMPY LEVEL
NO 123

STA	+	HI	—	ELEV	TP ELEV	REMARKS
BM #4	3.02	138.18			135.16	NAIL IN TREE 60' LEFT OF ℄ NEAR 0+50
0+00			3.6	134.6		℄ OF ROUTE 611
+21			5.1	133.1		BOTTOM OF DITCH
+50			3.6	134.6		
1+00			4.1	134.1		
+50			2.3	135.9		
+78			4.6	133.6		
2+00			4.5	133.7		WEATHER FAIR
+50			6.1	132.1		WIND S5
3+00			5.8	132.4		TEMP 60
4+00			5.7	132.5		
+10			5.0	133.2		
+60			6.0	132.2		
+76			5.9	132.3		
5+00			6.0	132.18		
TP #1	1.79	133.29	6.68		131.50	TOP OF HUB @ STA 6+00
6+00			2.3	131.0		
TP #2			4.76		128.53	ON STONE

Figure AIII-13.—Additional example of profile levels.



SLOPE STAKES

DESIGNATION MC COY AVE EXTENDED DATE 30 MAR 19 84

STA	+	HI	—	ELEV	GRADE ELEV
TP #1			3.10	133.10	
7+50					132.10
7+00					132.60
6+50					133.10
PC 6+08.77					133.60
6+00					134.10
	1.04	136.20			
BM #4				135.16	

MANGAS
SNIPES
LUEKIN
STADELMAN

INST. GURLEY DUMPY LEVEL NO. 1453

GRADE ROD	LEFT	℄	RIGHT
		WEATHER	CLOUDY
		WIND	S 10
		TEMP	70°
	TOP OF HUB STA 3+00		
4.1	C 0.3 3.8 / [illegible]	F 0.0 4.1 / 0	F 0.8 4.9 / 16.8
3.6	C 2.0 1.6 / [illegible]	F 1.1 4.7 / 0	F 3.0 6.6 / 21.0
3.1	C 2.6 0.5 / [illegible]	F 2.9 6.0 / 0	F 4.1 7.2 / [illegible]
2.6	C 1.0 1.6 / [illegible]	F 0.5 3.1 / 0	F 1.5 4.1 / 18.0
2.1	F 1.0 3.1 / 17.0	F 1.6 3.7 / 0	F 2.1 4.2 / [illegible]

NAIL IN TREE 60' LEFT OF ℄ AT STA 0+50

Figure AIII-14.—Slope-stake notes.

BUILDING LAYOUT

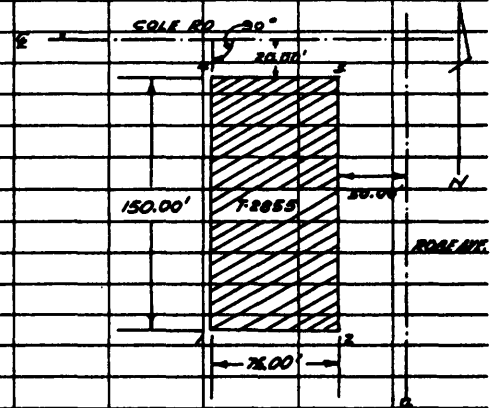
DESIGNATION BLDG T-2855 DATE 1 APR 19 94

STA	BS	HI	FS	ELEV	GRADE ROD
BM 18	5.22	35.22		30.00	
1			4.26	30.96	
2			4.14	31.08	
3			4.68	30.54	
4			4.52	30.70	
1					2.64
2					2.64
3					2.64
4					2.64

⊼ SNIPES
Ⴔ TILKIN
ϕ LUEKIN
ϕ COWART

INST K&E LEVEL / K&E 1' TRANSIT
NO 451206/4219

BATTER ELEV	REMARKS			
		WEATHER		FAIR
		WIND		S 8
		TEMP		52°
32.58				
32.58				
32.58				
32.58				



NOTE : BATTERBOARD ELEVATION 1.5' ABOVE HIGHEST CORNER.
BATTERBOARD ELEVATION IS TOP OF FOUNDATION.

Figure AIII-15.—Building layout.

PLANE TABLE MAPPING PROBLEM

DESIGNATION AREA K   DATE 10 APR 19 94

STA	CORR H DIST	H SCALE	RI	V SCALE	PRODUCT ±
A					
1	625	100	6.25	55	+ 31.25
2	160	100	1.60	48	- 3.2
3	199	97	2.05	68	+ 36.9
4	368	98	3.75	62	+ 45.0
5	105	100	1.05	54	+ 4.2
6	425	100	4.25	47	- 12.8
7	240	98	2.45	37	- 31.8
8	255	100	2.55	50	0
9		100	3.65	52	
10		99	0.85	58	
11		99	4.55	61	
12		100	2.20	50	
13		97	2.85	33	
14		100	6.70	54	
15		99	3.35	40	
16		99	1.70	38	
17		100	5.10	47	
18		100	4.40	55	

⊼ LOCKE
⊻ SNIPES
Ø SMITH
Ø JONES

INST K&E ALIDADE
NO 6666
WEATHER CLEAR
WIND N 10
TEMP 75°

RC	DE ±	HI	ELEV	REMARKS
	+ 4.3	116.7	112.4	ELEV STA B
- 4.6	+ 26.6		143.3	TOP OF SLOPE
- 2.8	- 6.0		110.7	BOTTOM OF SLOPE
- 8.4	+ 28.5		145.2	℄ ROAD
- 7.2	+ 37.8		154.5	℄ ROAD
- 3.9	+ 0.3		117.0	SPOT ELEV
- 4.4	- 17.2		99.5	SPOT ELEV
- 7.5	- 39.3		77.4	M.H.
- 5.4	- 5.4		111.3	POWER POLE
- 6.7				18" CULVERT
- 4.3				WATER VALVE
- 7.6				EDGE ROAD
- 3.1				EDGE ROAD
- 8.4				EDGE ROAD
- 5.2				COR PARK LOT
- 6.4				COR PARK LOT
- 4.1				EDGE ROAD
- 8.2				18" CULVERT
- 5.6				POWER POLE

Figure AIII-16.—Plane-table notes.

APPENDIX IV

OTHER USEFUL REFERENCES

NOTE: Listed in this Appendix are a few references that you may find useful when assigned to duty outside the Naval Construction Force. They are NOT required study for advancement. Following each reference is a brief description of its purpose.

***Facilities Planning Criteria for Navy and Marine Shore Installations* (NAVFAC P-80)**

This publication provides planning criteria for determining the requirements for shore-based facilities needed to support Fleet and Marine Corps Operations. In addition, these criteria are used to evaluate the adequacy of existing facilities, to identify facility deficiencies or excesses, and to validate construction project submittals.

***Facilities Projects Manual* (OPNAVINST 11010.20 SERIES)**

This instruction provides detailed guidance for the administration of facilities projects at naval shore activities. It includes definitions of the various typesof special projects and the preparation and submittal procedures for special projects.

***Naval Mobile Construction Battalion Facilities* (NAVFAC P80.2)**

This publication is similar in purpose to NAVFAC P-80, described above; however, it is tailored specifically to facilities needed to support Naval Mobile Construction Battalion Operations.

***Shore Facilites Planning Manual* (NAVFACINST 11010.44 SERIES)**

T'his instruction explains the process for the planning of shore facilities. It provides guidance on the preparation of Military Construction (MILCON) and Nonappropriated Funded (NAF) project documentation, and for the preparation of site approval documentation required for MILCON, NAF, and special projects.

APPENDIX V

UNIFIED SOIL CLASSIFICATION SYSTEM

The figure and tables in appendix V relate to identification and classification of soil.

Table AV-1 presents useful information concerning the Unified Soil Classification System.

Figure AV- 1 concerns the classification of soil after the soil has been visually identified as coarse grained, fine grained, or highly organic.

Table AV-2 shows soil characteristics pertinent to roads and airfields.

Table AV-3 shows soil characteristics pertinent to embankments and foundations.

ALL FOLDOUTS REMOVED
from APPENDIX V

APPENDIX VI

ANSWERS

NOTE: This appendix provides answers to the review questions found at the end of each chapter of this TRAMAN. When a question was drawn from a source other than this TRAMAN, the reference source is included with the answer.

Chapter 1

A1. Footing abutment, pile abutment, and concrete abutment.

A2. The numbers of rows of piles. A bent has one row of piles; a pier has two or more rows.

A3. Foundation bed, footing, and foundation wall.

A4. A sheet pile.

A5. A mole.

A6. The W12 x 50 wide flange shape. Because it has a greater cross-sectional area.

A7. The type of construction that uses masonry walls to support floor and roof loads.

A8. According to Steelworker 3 &2, NAVEDTRA 10653-G, page 12-10, girts are used primarily as attachment members for the metal siding.

Chapter 2

A1. The transmission system and the distribution system.

A2. The radial distribution system.

A3. To step down primary voltage to utilization level.

A4. On a crossarm or spool rack located below the primary mains.

A5. When they are shown to be more economical or when special circumstances warrant the use of concrete poles.

A6. Number size, type, voltage, and location.

A7. The level of underground water that has collected over an impervious stratum.

A8. Water quantity, reliability, and quality.

A9. NEVER. Water distribution and sewage collection piping must always be separated.

A10. To pump sewage from a lower level to a higher level because gravity flow is no longer possible or practical at the lower level.

Chapter 3

A1. (A) Traveled way, (B) shoulder, (C) crown, (D) base course, (E) subbase course, (F) surface or surface course.

A2. Superelevation.

A3. Final cross sections.

Chapter 4

A1. (A) Architectural, (B) civil (C) mechanical, (D) structural.

A2. D.

A3. The roles of the condenser and evaporators can be reversed so that the heat pump can be used for both heating and cooling.

A4. Temperature, humidity, and air motion. (Source: Utilitiesman 3, NAVEDTRA 12532, page 10-41.)

A5. Policy and Procedures for Project Drawing and Specification Preparation, MIL-HDBK-1006/1.

A6. Centimeter. (Source: MIL-HDBK-1006/1.)

A7. Vertical.

A8. The letter P. (Source: MIL-HDBK-1006/1.)

A9. Never.

A10. To make sure the drawing can be clearly reproduced.

Chapter 5

A1. NAFACENGCOM guide specifications.

A2. Specifications take precedence over drawings.

A3. 16.

A4. Division 2: Site Work

A5. Part 3: Execution.

A6. Seabee Planner's and Estimator Handbook, NAVFAC P-405.

A7. 94 cubic meters.

A8. 5 percent. (Source: Seabee Planner's and Estimator's Handbook, NAFAC P-405, appendix C.)

A9. Facilities Planning Guide, NATFAC P-437.

A10. Volume II, Part 3 (Assemblies).

Chapter 6

A1. The vertical axis.

A2. Three times.

A3. To make the line of sight parallel to the horizontal axis of the instrument so that the line of sight will generate a true horizontal plane when the instrument is rotated about the vertical axis.

A4. To enable you to use any point on the vertical cross hair when you are measuring angles or running lines.

A5. Only when a low degree of accuracy can be tolerated and an adjustment cannot be made immediately.

Chapter 7

A1. Barometric leveling and trigonometric leveling.

A2. (A) 398.303 meters, (B) –46.506 meters. (If your answer to Part A is incorrect, then you should review Engineering Aid 3, pages 12-18 and AIII-13.)

A3. (A) 0.08 feet, (B) no.

A4. (A) –0.21 feet, (B) +23.02 feet.

A5. 0 feet.

A6. 1/959 (or 1/1,000).

A7. N47°45´E.

A8. 8,520 square feet.

Chapter 8

A1. Topographic control is the establishment of the horizontal and vertical control points from which the location and elevation of all topographic details are determined.

A2. 0.05 distance in miles. No.

A3. (A) 243 feet, (B) +28.1 feet, (C) 202.4 feet.

A4. (A) 566 feet, (B) 327.3 feet.

A5. The vertical distance between adjacent contour lines.

A6. Either a summit or a depression.

Chapter 9

A1. Wingnut B. (Source: Engineering Aid 3, NAVEDTRA 10696.)

A2. Inside the triangle of error.

A3. Progression or plane-table traverse.

A4. Correct H-Dist = 365; Product = + 7.3; DE = +0.6; Elev = 117.3.

A5. For any given area distortion is nearly the same in all directions.

A6. 3MTV.

A7. 1,174 miles.

Chapter 10

A1. Reconnaissance, preliminary, and final-location survey phases.

A2. To make installation, inspection, and maintenance of the line easier and to lessen the requirement for tree trimming.

A3. The water remaining after absorption, evaporation, and transpiration.

A4. 95.92 feet.

A5. (A) 233.3 square feet, (B) 480.7 cubic yards.

A6. A distance at which the cost of haul equals the cost of excavation.

A7. (C) The degree of accuracy required.

A8. 25 feet.

A9. 0.27974.

A10. Interior angles.

Chapter 11

A1. Station at PC_1: 19 + 11.71

Station at PI_1: 23 + 84.28

Station at PCC: 27 + 68.85

Station at PI_2: 29 + 66.62

Station at PT_2: 31 + 43.85

A2. d_1 = 1052.1´, d_2 = 2°37.9´, d = 6°, C_1 = 31.13fi, C_2 = 43.84ft, C = 99.81 ft.

A3. 6 stations (600 feet).

A4. (A) 124.80 feet, (B) 128.00 feet, (C) 128.80 feet, (D) 128.25 feet, (E) Station 14 + 67, elevation on tune equals 129.0 feet.

A5. (A) 652.00 feet, (B) 624.00 feet, (C) 636.67 feet, (D) 643.20 feet, (E) Station 11 + 00, elevation = 652.00 feet. (The turning point is the high or low point on a vertical curve. When the tangent grades are equal, the high or low point will be at the center of the tune. When the tangent grades are both plus, the low point is at the PVC and the high point is at the PVT. When both tangent grades are negative, the high point is at the PVC and the low point is at the PVT. When unequal plus and minus tangent grades are encountered, the high or low point will fall on the side of the curve that has the flatter gradient.)

Chapter 12

A1. Electromagnetic EDMs and electro-optical EDMs.

A2. 729.35 meters.

A3. Electronic positioning systems.

A4. The lock mode.

Chapter 13

A1. To determine the moisture content at which the maximum density for a given compactive effort occurs.

A2. (A) Proctor, (B) 25.

A3. To ensure that densities obtained in the field conform to the project specification requirements.

A4. The bulk density can change due to varying temperature and humidity conditions.

A5. Shear.

A6. Type V (sulphate-resistant portland cement).

A7. The aggregate contains exessive organic material.

A8. Hairline cracking.

A9. Water that is in excess of the amount needed for a saturated, surface-dry condition.

A10. For improved watertightness and increased resistance to frost action.

A11. The chemical reaction between cement and water that causes a concrete to harden.

A12. When the test specimen breaks outside the middle third of span length by less than 5 percent.

A13. By heating, dissolution, and emulsifiication.

A14. The volubility test.

A15. A distillation test.

Chapter 14

A1. 75 man-days.

A2. Indirect labor.

A3. 61 percent. (Source: NMCB Operations Officer's Handbook, COMSECOND/COMTHIRDNCBINST 5200.2A, Section IV.)

A4. 150 man-days. (Source: NMCB Operations Officer's Handbook, COMSECOND/THIRDNCBINST 5200.2A, appendix I.)

A5. Commander, THIRD Naval Construction Brigade.

A6. So that you can (1) get all of the information needed for the job from the person requesting it and (2) pass this information on to the person to whom you are assigning the job.

Chapter 15

A1. 24.

A2. 0600.

A3. The angular distance of a celestial body measured north or south of the celestial equator along the hour circle of the body.

A4. Over the south celestial pole.

A5. N43°03´.

A6. S76°55´00.1"E.

A7. The calculation of the length of the sides can be cross-checked using different routes.

A8. A primary triangulation station is used as an instrument station and a sighted station. A secondary station is used only for sighting.

A9. 38°22´18.25".

Chapter 16

A1. 4.

A2. True.

A3. 4.

A4. (A) 21.18 ercent, (B) 74.25 percent, (C) 4.57 percent, (D) SP.

A5. (A) LL = 43, (B) PI = 18, (C) CL.

A6. 4.

Chapter 17

Al. (A) 1 1/2 inches, (B) 33.0 gallons, (C) 860 pounds, (D) 1,848 sacks, (E) 333.9 tons.

Chapter 18

A1. Lime.

A2. Clayey soils.

A3. Sieve analysis, Atterberg limits test, moisture-density test, and freeze-thaw test.

A4. A CBR mold. (Source: NAVFAC MO-330, chapter 5.)

INDEX

V

W

Z

Assignment Questions

Information: The text pages that you are to study are provided at the beginning of the assignment questions.

COMMANDING OFFICER
NETPDTC
6490 SAUFLEY FIELD RD
PENSACOLA, FL 32509-5237

ERRATA #1 03 Feb 98

Specific Instructions and Errata for
Nonresident Training Course

ENGINEERING AID 1

1. No attempt has been made to issue corrections for errors in typing, punctuation, etc., that do not affect your ability to answer the question or questions.

2. To receive credit for deleted questions, show this errata to your local course administrator (ESO/scorer). The local course administrator is directed to correct the course and the answer key by indicating the question(s) deleted.

3. Assignment Booklet

Delete the following questions, and leave the corresponding spaces blank on the answer sheets:

Questions

1-52

2-25

2-26

ASSIGNMENT 1

Textbook Assignment: "Technical Administration and Supervision." Pages 14-1 through 14-14.
"Field Astronomy and Triangulation." Pages 15-1 through 15-24.

Learning Objective: Identify the duties and responsibilities of the EA supervisor in providing assistance to the management division of a battalion operations department.

1-1. Which of the following responsibilities applies to you, a supervisor, in an engineering department?

1. Making progress reports
2. Performing PRCP interviews
3. Carrying on a comprehensive training program
4. Each of the above

1-2. The management division of the operations department is also known as the

1. engineering division
2. administration division
3. quality control division
4. operations staff

1-3. Labor reports are used to accomplish which of the following purposes?

1. To compare actual performance with the estimated standards
2. To determine the effectiveness of labor utilization
3. To determine labor expenditures on projects
4. Each of the above

1-4. Man-days are computed on what time standard?

1. An 8-hour day
2. A 12-hour day
3. A 10-hour day
4. The scheduled battalion workday

1-5. Productive labor includes which of the following labor categories?

1. Overhead
2. Direct
3. Indirect
4. Both 2 and 3 above

1-6. Which of the following tasks is considered indirect labor?

1. Preparation of as-built drawings
2. Transit time to and from the jobsite
3. Concrete testing
4. Each of the above

1-7. The SITREP is transmitted in what format?

1. NAVGRAM
2. Message
3. Memorandum
4. Marsgram

1-8. What reference should you use for the SITREP format?

1. COMSECOND/COMTHIRDNCBINST 3121.1
2. COMSECOND/COMTHIRDNCBINST 5100.1
3. COMSECOND/COMTHIRDNCBINST 5200.2
4. COMSECOND/COMTHIRDNCBINST 6260.4

Learning Objective: Identify the duties and responsibilities of an EA supervisor for coordinating and supervising the activities of the engineering division of a battalion operations department.

1-9. In the absence of an EAC, the EA1 assumes which of the following responsibilities?

1. The duties of the engineering chief
2. The manager of the radiation safety program
3. Both 1 and 2 above
4. The duties of the training chief

1-10. What is the recommended interval for performing an inventory of the drafting kit?

1. Once a month
2. Twice a month
3. Every 3 months
4. Every 2 weeks

1-11. What person is normally held accountable for the tool kits?

1. The drafter
2. The engineering officer
3. The drafting supervisor
4. The supply petty officer

1-12. According to NAVFAC P-80, the drafting office should have what minimum space per drafter?

1. 75 square feet, including storage
2. 75 square feet, excluding storage
3. 90 square feet, including storage
4. 90 square feet, excluding storage

1-13. Whenever possible, the drafting equipment and reproduction equipment should be located in the same room.

1. True
2. False

1-14. What is the purpose of logging out prints?

1. To keep an accurate account of what project is using the most paper
2. To ensure unnecessary prints are not reproduced
3. To inform cognizant personnel of changes made to the drawings
4. All of the above

1-15. Which of the following considerations must be addressed first when setting up a reproduction room?

1. Storage
2. Air conditioning
3. Ventilation
4. Lighting

1-16. The publications required for the engineering technical library are listed in what reference?

1. NAVFAC P-315
2. NAVFAC P-437
3. NAVFAC P-349
4. TOA

1-17. NAVFAC publications and military handbooks are the only publications required for the engineering technical library.

1. True
2. False

1-18. When checking and editing drawings, what standard, if any, establishes the procedures that you should follow?

1. NAVFAC P-272
2. MIL-HDBK-1006/1
3. ANSI Y14 series
4. None

1-19. You should consult with the appropriate Seabee ratings when you encounter problems while reviewing drawings.

1. True
2. False

1-20. A newly reported EA should study which of the following publications to be proficient as a drafter?

1. NAVFAC P-437
2. MIL-HDBK-1006/1
3. MIL-STD-100E
4. All of the above

1-21. Which of the following supervisory responsibilities should be considered in making work assignments?

1. Awareness of the OCCSTDs for each paygrade
2. Knowledge of how the task is to be accomplished
3. Knowledge of each person’s capabilities
4. Both 2 and 3 above

1-22. The degree of explanation required for a work assignment depends on the experience of the drafter.

1. True
2. False

1-23. A work request serves which of the following purposes?

1. To account for requested work
2. To track work progress
3. To identify personnel shortages
4. To reflect priorities assigned by shop personnel

1-24. Which of the following engineering duties is performed by the field engineering section?

1. Obtaining as-built information
2. Making field compaction tests
3. Directing earthwork operations
4. Reproducing field prints

1-25. What is the first concern of a survey party chief when organizing survey crews?

1. The availability of transportation
2. The job completion deadline
3. The formulation of a job plan
4. The capabilities of personnel assigned

1-26. Of the following survey parties, which one affords the greater flexibility as to the number of personnel required?

1. Plane table
2. Stadia
3. Leveling
4. Reconnaissance

1-27. what type of sheet is used to record reduced field note data?

1. Bench mark
2. Abstract
3. Traverse
4. Base line

1-28. What person is responsible for error-free computations in field notes?

1. The party chief
2. The engineering officer
3. The supervisor
4. The note keeper

1-29. Which of the following methods helps to ensure that the calculations of the crew are correct?

1. Recheck all calculations
2. Spot-check calculations
3. Compute data by two different methods
4. Observe all calculations being performed

1-30. As a survey crew party chief, you must develop which of the following skills for use when checking field notes?

1. Weighing the results for the probability of error
2. Weighing the results for possible errors
3. Avoiding mistakes when you are making calculations
4. Spot-checking the calculations made by your crew members

1-31. To increase the motivation of a field crew, you must employ what technique?

1. Offer job rotation for the crew
2. Reduce competition among the crew
3. Keep the crew informed of the purpose of the task
4. Give them more free time to study the job assigned

1-32. When is the best time for a supervisor to conduct training for personnel assigned?

1. At the beginning of the workday
2. At the end of the workday
3. During designated training periods
4. Whenever the work load permits

1-33. What is the definition of combat intelligence?

1. Knowledge of the enemy, weather, and terrain necessary to plan and conduct tactical operations
2. Knowledge of enemy troop movements
3. A battalion operation order
4. Information about battalion capabilities

1-34. The materials testing section provides support for what division in the operations department?

1. Management
2. Field engineering
3. Quality control
4. Design

1-35. All work requests for the materials testing section are generated outside of the engineering department.

1. True
2. False

1-36. You are reviewing an in-place density test result. A great difference exists between the results and the expected results. What action should you take?

1. Have the EA that performed the test review the procedures as the test was obviously performed wrong
2. Rerun the test
3. Review the procedures and attempt to determine the cause of the discrepancy
4. Replace the EA assigned to the soils lab

1-37. Part of trainínq new personnel should encompass which of the following examples?

1. Have them work with experienced personnel
2. Explain the forms used locally
3. Have them practice the difficult tests under supervision
4. Each of the above

Learning Objective: Identify the systems of time used in field astronomy.

1-38. When the sun is in exact alignment with a particular meridian, what is the local apparent time?

1. 0600
2. 1200
3. 1600
4. 1800

1-39. What meridian is used as the center line of each time zone?

1. Meridians that are multiples of 7°30′
2. Meridians that are multiples of 15°
3. Longitudes that are multiples of 15°30′
4. Longitudes that are multiples of 7°30′

1-40. GMT is located

1. 0°
2. 15°E
3. 30°E
4. 60°W

1-41. When the time is 1220 at your location of 47°W, what is the time 44° west of you?

1. 0620
2. 0920
3. 1520
4. 1820

1-42. If you record the time incorrectly by 2 minutes, what type of plotting error is created?

1. 15´ in latitude
2. 15´ in longitude
3. 30´ in latitude
4. 30´ in longitude

1-43. If you are taking star shots in an area that is using daylight saving time, what compensation, if any, must be made?

1. Add 1 hour to your time
2. Deduct 1 hour from your time
3. Deduct 1 hour if it is a sun shot
4. None

Learning Objective: Identify given elements of field astronomy. Identify elements of the astronomical triangle.

1-44. Which of the following systems use astronomic determinations based on hour angle and declination?

1. Terrestrial
2. Horizon
3. Celestial
4. Lunar

1-45. The longitude of a point is the angular distance between the meridian at the point and the prime meridian.

1. True
2. False

1-46. Projections through the poles comparable to the meridians are known as

1. great circles
2. declinations
3. ascensions
4. hour circles

1-47. What is the declination of a celestial body?

1. The angular distance north or south from the celestial meridian
2. The angular distance north or south from the celestial equator
3. The angular distance east or west from the celestial meridian
4. The angular distance east or west from the celestial equator

1-48. Right ascension is normally expressed in

1. hours
2. minutes
3. degrees
4. miles

1-49. The correction for parallax, which must be made for precise computations, accounts for the

1. refraction of the rays of the sun
2. gravitational differential created by the direction of the plumb line
3. displacement of the horizon plane
4. elliptical variation of the surface of the earth

1-50. The side of the astronomical triangle between the pole and the star is known as the

1. colatitude
2. coaltitude
3. parallactic
4. codeclination

Learning Objective: Determine the celestial coordinate when given meridian altitude observation.

IN ANSWERING QUESTIONS 1-51 AND 1-52, REFER TO TABLES 15-1 AND 15-2 IN YOUR TEXTBOOK.

1-51. What was the GHA of the sun at zone time $09^h22^m14^s$ on 16 May 1986 in longitude 79°37′12"W?

1. 293°51.9′
2. 97°47.6′
3. 94°51.2′
4. 36°28.7′

1-52 What was the declination of the sun at the time and place in question 1-51?

1. S 8°59.2′
2. N 19°07.1′
3. N 19°07.9′
4. N 19°08.1′

1-53 What is the polar distance, measured from the elevated north pole of the celestial body whose declination is 20°S?

1. 20°
2. 70°
3. 110°
4. 200°

1-54 In a time diagram, the observer is located at what point?

1. Over the north celestial pole
2. On the celestial equator
3. On the Greenwich meridian
4. Over the south celestial pole

1-55. The GHA of a star is measured in what manner?

1. Counterclockwise from Greenwich to the star only
2. Clockwise from Greenwich to the star only
3. The same direction from Greenwich to the star
4. The same direction from the star to Greenwich

1-56. LHA is always measured from the local meridian in what direction?

1. Northward
2. Southward
3. Eastward
4. Westward

1-57. What method is used to obtain the LHA when the GHA and longitude are known?

1. Always add the longitude to the GHA
2. Always subtract the longitude from the GHA
3. Subtract an eastern longitude from the GHA and add a western longitude to the GHA
4. Add an eastern longitude to the GHA and subtract a western longitude from the GHA

1-58 What is the polar distance of a heavenly body?

1. The declination at that instant
2. 90° minus the declination
3. 180° minus the declination
4. 270° minus the declination

1-59 The difference between the surface-plane altitude value and the center-of-the-earth-plane altitude value is what type of correction?

1. Semidiameter
2. Refraction
3. Parallax
4. Upper limb

Learning Objective: Identify methods, procedures, and calculations required to determine latitude and azimuth.

1-60. To determine the true azimuth of a line, you must know which of the following data?

1. Longitude of the point from which the observation is made
2. Latitude of the point from which the observation is made
3. The polar distance
4. The meridian angle

1-61. An object is observed in the direction of the equator from the zenith of the observer's position. What is the latitude of the observer's position if the object's declination is S15°10′ and the corrected meridian altitude is 62°07′?

1. 17°32′
2. 28°42′
3. 36°22′
4. 43°03′

1-62. You are determining latitude by the altitude of the sun at noon. If the exact meridian is unknown, the vertical angle of the position of the sun is recorded when the sun

1. has crossed the line of sight
2. begins to cross the line of sight
3. is on a known meridian
4. reaches its zenith

1-63. If the transit used in determining latitude by altitude of the sun at noon is not equipped with solar attachment, what action should you take?

1. Use No.10 welder's glasses for sighting
2. Set the vertical cross hair tangent to the left edge of the sun's disk
3. Set the horizontal cross hair tangent to the lower edge of the sun's disk
4. Set the horizontal cross hair tangent to the upper edge of the sun's disk

1-64. What two methods are commonly used to determine an azimuth by sun observation?

1. Altitude and latitude
2. Altitude and longitude
3. Hour angle and longitude
4. Hour angle and altitude

1-65. Which of the following methods for determining an azimuth by sun observation is the fastest and most accurate?

1. Hour angle
2. Altitude
3. Latitude
4. Longitude

1-66. In what direction is the azimuth of the sun measured?

1. Clockwise from the meridian
2. Clockwise from the north
3. Counterclockwise from the meridian
4. Counterclockwise from the north

1-67. When you obtain the correct time from radio station WWV, what is the maximum correction you will make by counting the double ticks after the minute tone?

1. 1.0 second
2. 0.9 second
3. 0.7 second
4. 0.1 second

1-68. For a morning observation in the Western Hemisphere and an afternoon observation in the Eastern Hemisphere, Greenwich and local dates are NOT the same.

1. True
2. False

1-69. When you obtain a negative declination for the sun, what does this indicate?

1. An error in your calculations
2. The sun is east of the 0° meridian
3. The sun is north of the equator
4. The sun is south of the equator

1-70. What alternate method can be used to observe the sun with a telescope that does not have a special eyepiece or a lens filter?

1. Project the image onto a black piece of paper 1 foot behind the eyepiece
2. Project the image onto a black piece of paper 6 inches behind the eyepiece
3. Project the image onto a white piece of paper 1 foot behind the eyepiece
4. Project the image onto a white piece of paper 6 inches behind the eyepiece

1-71. By computing an azimuth for each sighting and averaging the azimuths, you eliminate what type of error?

1. Parallax
2. Instrument
3. Systematic
4. Human

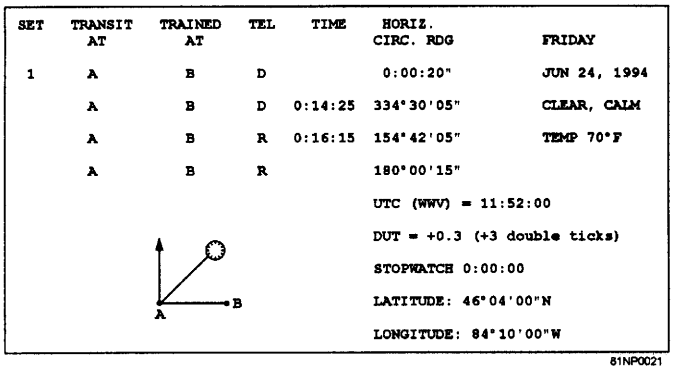


Figure 1A

IN ANSWERING QUESTIONS 1-72 AND 1-73, REFER TO FIGURE 1A.

1-72. What is the computed declination of the sun from the point of observation?

1. 25°24'35.5"
2. 23°25'13.7"
3. 23°25'15.7"
4. 23°25'51.7"

1-73. What is the azimuth of the line AB?

1. 17°58'18.4"
2. 77°56'13.7"
3. 103°04'53.7"
4. 167°56'35.2"

1-74. The Doppler positioning system works on what basis?

1. Counting radio waves
2. Constant changing radio frequency
3. Counting light waves
4. Measuring time intervals between beams of light

1-75. To determine a location with the GPS, you must know which of the following data?

1. Your position at the time of the reading
2. The satellites location at the time of observation
3. The distance from your position to the satellite
4. Each of the above

ASSIGNMENT 2

Textbook Assignment: "Field Astronomy and Triangulation." Pages 15-24 through 15-41. "Soils: Surveying and Exploration/Classification/Field Identification." Pages 16-1 through 16-4.

Learning Objective: Identify the principles and practices used in the triangulation method of surveying.

2-1. What is the major difference between traversing and triangulation?

1. Distances must be measured from each station in triangulation but not in traversing
2. Distances must be measured from each station in traversing but not in triangulation
3. Angles must be measured from each station in triangulation but not in traversing
4. Angles must be measured from each station in traversing but not in triangulation

2-2. What condition requires the triangulation method to be used?

1. When a high degree of precision is required
2. When EDMs are being used
3. When chaining is not possible due to terrain
4. When angles cannot be turned at each station due to obstructions

2-3. Which of the following duties should the party chief perform during a triangulation survey?

1. Head chainman
2. Rear chainman
3. Note keeper
4. Instrumentman

2-4. Who should perform the computations to determine horizontal locations of the points in the triangulation system?

1. Rear chainman
2. Instrumentman
3. Office personnel
4. Party chief

2-5. In a triangulation system, the beginning and ending distances are measured for what purpose?

1. To establish base lines for determining the distances of the other lines
2. To begin and close the triangulation net accurately
3. To establish base lines for checking the computed distances of the other lines
4. To provide the only distances required for the survey

2-6. What is one of the disadvantages of using the chain of single triangles?

1. Cannot be used for narrow areas
2. Provides no means of cross-checking computed distances
3. Cannot be used for inaccessible points
4. Requires the most calculations of any method

2-7. When discussing triangulation figures, to what does a chain of polygons refer?

1. A single chain of triangles
2. A chain of quadrilaterals
3. Both 1 and 2 above
4. A system of triangles forming a polygon

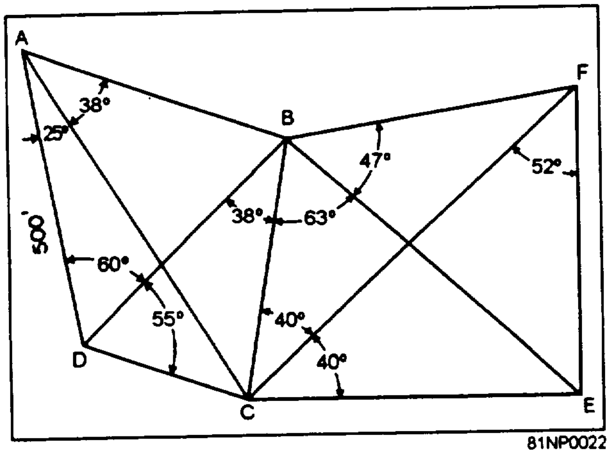


Figure 2A

IN ANSWERING QUESTIONS 2-8 THROUGH 2-11, USE THE CHAIN OF QUADRILATERALS IN FIGURE 2A AND THE TABLES IN APPENDIX II.

2-8. The size of the angle ABD is

1. 37°
2. 51°
3. 57°
4. 60°

2-9. What is the length of the line DB?

1. 500 ft
2. 531 ft
3. 548 ft
4. 554 ft

2-10. What is the length of line CE?

1. 646 ft
2. 608 ft
3. 697 ft
4. 709 ft

2-11. What is the length of line BF?

1. 452 ft
2. 487 ft
3. 520 ft
4. 561 ft

Learning Objective: Identify the construction and uses of various targets and signals as related to triangulation.

2-12. What minimum number of reference markers must be used for triangulation stations of first-order precision?

1. One
2. Two
3. Three
4. Four

2-13. What is the difference between a primary triangulation station and a secondary triangulation station?

1. The secondary station is used as a control point; the primary station is not
2. The secondary station is an instrument station; the primary station is not
3. The primary station is an instrument station; the secondary station is not
4. The primary stations are set up on monuments only; the secondary stations can use any point

2-14. A tripod target is the most satisfactory target to use because of which of the following qualities?

1. Its accuracy
2. Its durability
3. Its ease of construction
4. Each of the above

2-15. One of the disadvantages of using a bipod target is that it

1. is difficult to transport
2. must be strongly guyed
3. is extremely difficult to construct
4. cannot be used when first- or second-order precision is required

2-16. For accuracy, you should perform first- and second-order triangulation surveys (a) during what time of day and (b) using what type of signals?

1. (a) At night
   (b) signal lights
2. (a) At night
   (b) heliotropes
3. (a) In daylight
   (b) target sets
4. (a) In daylight, while overcast
   (b) nonilluminating bipod signals

Learning Objective: Identify the procedures used in triangulation surveying and recognize their importance.

2-17. Which of the following considerations must be made when selecting stations for triangulation?

1. Ease of signal erection
2. Size of the angles to be turned
3. Transit time between instrument setups
4. Direction of the sightings

2-18. After the stations have been selected and you begin to erect the towers, what must you consider regarding the targets?

1. How to light
2. The size
3. Color contrast of the target and background
4. Both 2 and 3 above

2-19. When you are using a 1-minute how many times must the angles be repeated to obtain third-order precision?

1. 20
2. 12
3. 3
4. 6

2-20. To compute the coordinates of triangulation stations, you must have what data?

1. Latitude and departure of the point of origin
2. The true meridian and azimuths for all lines
3. Latitude and departure of the lines between the stations
4. All of the above

2-21. You have measured a few tape intervals in a base line and the tape doesn't quite reach the metal strip on the buck. The head chainman measures the distance the chain must be set (a) in what direction? He then records this information in the field book and (b) takes what action concerning the measurement?

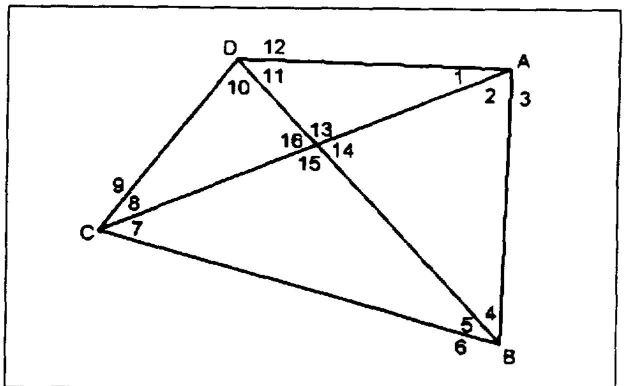
1. (a) Forward
   (b) adds the measurement to the tape length
2. (a) Forward
   (b) subtracts the measurement from the tape length
3. (a) Back
   (b) adds the measurement to the tape length
4. (a) Back
   (b) subtracts the measurement from the tape length

2-22. Figure adjustment uses what data for adjustment?

1. The sum of the exterior angles
2. The sum of the interior angles
3. The Pythagorean theory
4. The 360° theory

2-23. When adjusting a chain of triangles, what type of adjustment should you perform first?

1. Figure
2. Station
3. Side
4. Log-sine



ANGLE NO.	MEASURED VALUE	ANGLE NO.	MEASURED VALUE
1	30°57'05"	7	42°01'18"
2	61°07'50"	8	29°14'38"
3	267°54'59"	9	288°44'22"
4	38°28'37"	10	70°21'55"
5	38°22'22"	11	49°26'17"
6	238°09'10"	12	240°11'36"

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Figure 2B

IN ANSWERING QUESTIONS 2-24 THROUGH 2-28, USE THE QUADRILATERAL AND ANGLE VALUES SHOWN IN FIGURE 2B.

2-24. After point A is adjusted by the station adjustment method, what is the corrected value angle 1?

1. 30°59'07"
2. 30°59'05"
3. 30°57'08"
4. 30°57'07"

2-25. What correction must be applied to the station adjusted value of angle 5 for the first figure adjustment?

1. 00.00”
2. 00.25”
3. 00.50”
4. 01.00”

2-26. After the quadrilateral is figure adjusted for the first time, the value of angle 7 is

1. 42°00'00.0"
2. 42°01'12.0"
3. 42°01'12.5"
4. 42°07'12.5"

2-27. What pairs of angles equals the sum of angles 5 and 7?

1. 1 and 11
2. 2 and 4
3. 8 and 10
4. 6 and 12

2-28. What is the average triangle closure?

1. 01”
2. 02”
3. 03”
4. 04”

2-29. Which of the following factors are used to determine the precision of a triangulation survey?

1. The maximum angle size measured during the survey
2. The average triangle closure
3. The difference between any measured line and the computed value of that line
4. The average log-sine difference

2-30. The average triangle closure is checked at what point of your adjustments?

1. Before the station adjustment
2. After the first figure adjustment
3. After the second figure adjustment
4. After the station adjustment

A. $$\frac{\log \sin 2 \times \log \sin 4 \times \log \sin 7 \times \log \sin 11}{\log \sin 1 \times \log \sin 5 \times \log \sin 8 \times \log \sin 10} = 1$$

B. $$(\log \sin 2 + \log \sin 4 + \log \sin 7 + \log \sin 11) - (\log \sin 1 + \log \sin 5 + \log \sin 8 + \log \sin 10) = 0$$

C. $$(\log \sin 1 + \log \sin 4 + \log \sin 7 + \log \sin 10) - (\log \sin 2 + \log \sin 5 + \log \sin 8 + \log \sin 11) = 0$$

D. $$(\log \sin 1 \times \log \sin 4 \times \log \sin 7 \times \log \sin 10) - (\log \sin 2 \times \log \sin 5 \times \log \sin 8 \times \log \sin 11) = 0$$

Figure 2C

IN ANSWERING QUESTION 2-31, REFER TO FIGURE 2C.

2-31. Which equation, from figure 2C, properly represents the log-sine relations of the angles?

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

2-32. You have computed the length of a line in two ways by solving the appropriate triangles. Which, if any, of the following values should you select for the line?

1. The larger value
2. The smaller value
3. The average of the two values
4. None of the above, you must rerun the survey to obtain the same value each way

2-33. What is the desired results of a triangulation survey?

1. To determine the area of the property surveyed
2. To determine the horizontal location of points by bearing and distance
3. To determine vertical location of points by bearing, distance, and elevation
4. To determine the equipment error for future maintenance

2-34. When you have the coordinates of a monument, how do you determine the coordinates of the triangulation points?

1. By measuring the bearing and distance to your starting point
2. By measuring the bearing and distance to all points
3. By measuring the bearing to your starting point
4. By measuring the distance to your starting point

Learning Objective: Identify the purpose, methods, and requirements of geological and pedological surveys.

2-35. The purpose of a geological survey is to obtain which of the following data?

1. To locate rock formations in the field and determine their physical characteristics
2. To determine rock age and distribution
3. To determine the types of rocks and their mineral content
4. All of the above

2-36. How can a geologist determine the approximate age of a rock formation?

1. By examining the sequence of rock units
2. From data obtained by seismic surveys
3. By the presence of certain organic particles
4. From data obtained by nuclear density surveys

2-37. Which of the following survey methods might a geologist use in plotting features on a field map?

1. Reference an outcrop to a relief feature
2. Reference an outcrop by establishing direction with a compass
3. Measure the difference in elevation with an altimeter
4. Each of the above

2-38. The surveyor supports the geologist by performing which of the following tasks?

1. By examining the borehole samples
2. By plotting the results of the geological surveys
3. By preparing the basic topographic map
4. Both 2 and 3 above

2-39. To establish your base direction, you should take which of the following steps?

1. Perform a triangulation survey
2. Run a control traverse
3. Begin from an established monument
4. Use an established base line from a triangulation net

2-40. Distance measurements should be obtained as accurately as possible for a base map survey.

1. True
2. False

2-41. Measurements made by stadia during a geological survey must be accurate to 1 part in

1. 200
2. 300
3. 500
4. 1,000

2-42. What is the maximum allowable error in elevation when plotting data for a geological map?

1. One half of the contour interval
2. One contour interval
3. Two contour intervals
4. 25 feet

2-43. Horizontal angles, other than traverse angles, that are plotted on a geological topography map should be read to the nearest

1. 1 minute
2. 15 minutes
3. 30 minutes
4. 1 degree

2-44. Aerial photographs may be used in place of a base map that will be used for engineering purposes.

1. True
2. False

2-45. Which of the following topographic features are more clearly shown on aerial photographic maps?

1. Intermittent streams
2. Sinkholes
3. Abrupt contour changes
4. Heavily wooded swamp areas

2-46. The plotted elevations of the intersection of core borings and the surface of the earth should be accurate to the nearest

1. 0.1 ft
2. 0.5 ft
3. 1.0 ft
4. 5.0 ft

2-47. Geological surveys should conform to what degree of precision?

1. First order
2. Second order
3. Third order
4. Fourth order

2-48. What type of drawing is prepared for a pedological survey?

1. Mosaic
2. Base map
3. Plan and profile
4. Preliminary survey map

2-49. Pedological surveys should conform to what degree of precision?

1. Low order
2. Second order
3. Third order
4. Fourth order

2-50. In the absence of known bases, what should be used for the established base direction?

1. Railroad tracks
2. Magnetic north
3. Highway center lines
4. True north

2-51. To reduce the time of the survey, you should measure distances in what manner?

1. Pacing
2. Rough chaining
3. Stadia
4. EDM

2-52. When you are not given specific instructions for the preparation of sketches of the pedological survey, what scale should you use?

1. 1 in. = 200 ft
2. 1 in. = 300 ft
3. 1 in. = 400 ft
4. 1 in. = 500 ft

ASSIGNMENT 3

Textbook Assignment: "Soils: Surveying and Exploration/Classification/Field Identification." Pages 16-4 through 16-23.

Learning Objective: Identify the purpose of soil exploration. Identify reference sources and their uses in planning soil exploration.

3-1. Soil surveys of a proposed construction site provide which of the following information about the soil conditions of that site?

1. The condition of the soil layers
2. The drainage characteristics
3. The source of possible construction materials
4. All of the above

3-2. Which of the following types of soil has better internal drainage?

1. Well-graded gravel
2. Inorganic clay
3. Silty sand
4. Organic clay

3-3. When you discover that a proposed grade line is below the groundwater table, which of the following actions must be taken?

1. Change the location
2. Lower the grade line
3. Lower the water table by mechanical means
4. Install a water barrier during the construction

3-4. At what time interval should the measurement for the groundwater table be taken in a test hole?

1. As soon as water is located
2. At high tide
3. 24 hours after the hole is bored
4. 36 hours after the highest water level is reached

3-5. A soil profile provides which of the following information?

1. Location of ledge rock
2. Location of the water table
3. Identification of the soil layers
4. All of the above

3-6. The soil profile does NOT provide information that is useful in determining the finished grade location.

1. True
2. False

3-7. Which of the following sources of information would provide you with a location of construction materials, as well as locations of sand and gravel pits?

1. Intelligence reports
2. Topographic maps
3. Agricultural maps
4. Geologic maps

3-8. An agricultural soils map provides a variety of information on soils to what maximum depth?

1. 72 inches
2. 36 inches
3. 12 inches
4. 6 inches

3-9. When reviewing aerial photographs, you observe areas with smoothly rounded slopes. What type of soil does this indicate?

1. Granular
2. Plastic
3. Bedrock
4. Silt deposits

3-10. When reviewing aerial photographs, you notice a drainage area. What is indicated by a sudden change in grade or direction of that drainage area in the photograph?

1. Diversion ditches
2. Rock formations
3. Sand deposits
4. All of the above

3-11. With proper study of maps and photographs, there should be no need for any field investigation.

1. True
2. False

3-12. Which of the following requirements is true of a test pit excavation?

1. Must be large enough for a man to enter
2. Must be made with power-driven equipment
3. Must be below the water table
4. Load-bearing tests must be performed on soil samples taken every 18 inches

3-13. Test holes are best performed on what type of soil?

1. Cohesiveless soil below the water table
2. Cohesiveless soil above the water table with large aggregate
3. Cohesive soil
4. Bedrock

3-14. Soil samples obtained by digging test holes are used for which of the following test purposes?

1. Soil classification
2. Compaction
3. Moisture Content
4. Each of the above

3-15. What method is commonly used commercially to make deep test holes?

1. Wash boring
2. Core boring
3. Drilling
4. Auger boring

3-16. Undisturbed samples are used to test which of the following qualities of the soil?

1. Saturation point
2. Cohesiveness
3. Shear strength
4. Load-bearing strength

3-17. You must determine subgrade conditions for construction of a new road. What is the next step once the field reconnaissance has been completed?

1. Develop soil profiles
2. Classify the soil
3. Obtain samples for laboratory testing
4. Perform preliminary borings at appropriate locations

3-18. When performing soils investigation on possible borrow areas, you should make borings to what depth?

1. 10 feet
2. The depth of planned excavation
3. 2 - 4 feet below anticipated excavation
4. Same depth as all other borings

3-19. When performing soils surveys, which of the following sources should you use to obtain information pertinent to the area?

1. Local contractors
2. Existing mine shafts of earth cellars
3. Eroded slopes
4. All of the above

3-20. Detailed soil explorations should be performed at what type of site?

1. Proposed center line
2. Proposed large cut location
3. Extreme grade shift
4. Proposed pavement location

3-21. What minimum spacing, if any, is required between boring holes?

1. 25 feet
2. 50 feet
3. 100 feet
4. None

Learning Objective: Identify the classification of soils according to the Unified Soil Classification System and solve mathematical problems related to soil classification.

3-22. Highly organic soil is identified by what manner?

1. More than 50 percent passing a No. 200 sieve
2. 50 percent or more retained on a No. 200 sieve
3. Determining that the sample is neither a fine-grained nor coarse-grained soil
4. Visual inspection

3-23. The Unified Soil Classification System uses what number of groups for soil classification?

1. Five
2. Seven
3. Fifteen
4. Thirty

3-24. Coars-grained sils are divided into what divisions?

1. Silt and sand
2. Clay and gravel
3. Sand and gravel
4. Clay and silt

3-25. To classify a coarse-grained soil, you would use what sieve?

1. 1/4 inch
2. No. 4
3. No. 50
4. No. 200

3-26. Coarse-grained soils with more than 12-percent fines are classified by what characteristic(s)?

1. Cohesiveness
2. Liquid limit
3. Plasticity index
4. Both 2 and 3 above

3-27. For a soil sample to be classified as silty gravel, the plasticity index should be

1. more than 7
2. between 4 and 7
3. less than 4
4. unmeasurable

3-28. Coarse-grained soils with between 5- and 12-percent fines are classified in what manner?

1. By dual symbols
2. As clayey silts
3. As nonplastic, nonliquid soils
4. As silty clays

3-29. A borderline soil may meet more than one zone requirement.

1. True
2. False

3-30. Fine-grained soils are classified based on what requirement?

1. Plasticity index
2. Grain-size distribution
3. Percentage of organic material
4. Liquid limit

3-31. Plastic silts have what group designation?

1. MH
2. ML
3. MP
4. MW

3-32. Peat is identified in what manner?

1. By grain-size distribution
2. By liquid limit determination
3. By odor
4. By plasticity index determination

3-33. C_c is defined as the coefficient of

1. uniformity of the grain-size curve
2. gradation
3. curvature of the gradation curve
4. distribution

3-34. To determine the coefficient of uniformity, you must have what information?

1. Percent retained on the No. 10 and No. 60 sieves
2. Percent passing the No. 10 and No. 60 sieves
3. Grain size, in centimeters, at 10- and 60-percent passing levels on the gradation curve
4. Grain size, in millimeters, at 10- and 60-percent passing levels on the gradation curve

YOU HAVE COMPLETED A SIEVE ANALYSIS WITH THE FOLLOWING RESULTS:

SIEVE SIZE	PERCENT PASSING
1/2 IN.	100
1 IN.	74
3/4 IN.	57
1/2 IN.	40
NO. 4	27
NO. 10	22
NO. 40	14
NO. 60	8
NO. 100	5
NO. 200	3.8

Figure 3A

IN ANSWERING QUESTIONS 3-35 THROUGH 3-39, USE THE INFORMATION FROM FIGURE 3A.

3-35. What is the value of D_{60} for this soil sample?

1. 7.2 mm
2. 20.0 mm
3. 29.6 mm
4. 37.3 mm

3-36. What is the coefficient of uniformity (C_U) of this soil sample?

1. 18.1
2. 32.7
3. 48.9
4. 66.7

3-37 What is the value for D_{30} for this soil sample?

1. 3.0
2. 4.8
3. 5.6
4. 6.2

3-38 What is the coefficient of curvature (C_c) of this soil sample?

1. 5.6
2. 12.7
3. 21.9
4. 52.0

3-39 What is the classification of this soil sample?

1. GW
2. GP
3. SW
4. SP

Learning Objective: Identify the test procedures used in the field to identify soil characteristics.

3-40. Why is it also necessary to perform field identification tests on soils even when laboratory tests are required during soil explorations?

1. To determine which laboratory tests will be omitted
2. To minimize the duplication of laboratory tests samples
3. To provide duplicate results for positive identification
4. To ensure there are no errors in the laboratory tests

3-41. What is the best way to gain the necessary skills required for field testing?

1. By working with experienced technicians
2. By receiving formal soils training
3. By getting the "feel" of the soil during the laboratory tests

3-42. What is the most useful tool for performing field identification tests?

1. A hand auger
2. A scale or balance
3. A No. 40 sieve
4. A No. 200 sieve

3-43. When identifying soils in the field, which of the soil properties should you include in the description of the soil?

1. Color
2. Percentage of sand
3. Maximum particle Size
4. Particle shape

3-44. Visual examination is used to establish which of the following properties of the soil?

1. Color
2. Grain distribution
3. Cohesiveness of the soil
4. Grain shape of the fines

3-45. When the color of a soil has been identified through a visual examination, what other data should you note regarding the soil condition at the time of identification?

1. Temperature
2. Maximum particle size
3. Chemical content
4. Moisture content

3-46. During visual examination of a soil sample, you notice a yellow color. What can you conclude about the soil from this observation?

1. Organic material is present
2. Iron oxides are present
3. The soil has poor drainage capabilities
4. Aluminum compounds are present

3-47. What is the first step in approximating grain-size distribution in field identification?

1. Separating the larger particles
2. Examining the coarse-grained soil for gradation distribution
3. Estimating the percentage of fine-grained soil
4. Performing the sieve sampling

3-48. You have determined the soil to be coarse-grained and estimated the fines to be 4 percent. What is the soil classification of the soil?

1. GW-GM
2. SW-SM
3. GC
4. Gravel or sand, depending on additional information

3-49. Which of the following field tests can be used to determine the cohesiveness of a soil?

1. Ribbon
2. Roll
3. Breaking
4. Each of the above

3-50. The breaking, ribbon, and wet-shaking tests are performed on material passing the

1. No. 40 sieve
2. No. 60 sieve
3. No. 100 sieve
4. No. 200 sieve

3-51. You have performed the dry-strength test. The sample cannot be powdered but will break with difficulty. What is the classification of the soil?

1. CL
2. CH
3. ML
4. MH

3-52. What tests complement each other in giving a clearer picture of the plasticity of the soil?

1. Wet shaking and roll
2. Ribbon and breaking
3. Roll and ribbon
4. Wet shaking and breaking

3-53. What is the size of the sample used for the wet-shaking test?

1. A roll of soil 1/2 inch in diameter and 3 inches long
2. A pat of soil 1/2 inch thick and 1 1/2 inches in diameter
3. A ball of soil 3/4 inch in diameter
4. A ball of soil 1 3/4 inches in diameter

3-54. A mall amount of clay present in your sample will affect your shaking test in what manner?

1. Causes no reaction
2. Causes a sudden reaction
3. Retards the reaction
4. Assists in identifying the sands and silts

3-55. The odor test is effective in identifying what type of soils?

1. Organic
2. Cohesive
3. Clayey
4. Oily

3-56. What field test can readily identify soil as containing sand, silts, or clay?

1. Acid
2. Feel
3. Bite
4. Shine

3-57. To prevent a false test result when performing the acid test, you should prepare your sample in what manner?

1. By heating
2. By wet-sieve washing
3. By adding moisture
4. By adding lime

3-58. A positive result of the shine test indicates the

1. lack of clay in the soil
2. presence of highly plastic clay
3. presence of peat
4. lack of plasticity of the sample

3-59. To determine the texture of the soil, it is recommended you rub the soil

1. on the back of your hand and allow the sample to dry
2. on a tender skin area, such as the wrist
3. between dry fingers
4. between slightly oiled fingers

ASSIGNMENT 4

Textbook Assignment: "Mix Design: Concrete and asphalt." Pages 17-1 through 17-22. "Soil Stabilization." Pages 18-1 through 18-9.

Learning Objective: Identify the methods and procedures used in the design of concrete mixtures.

4-1. Concrete mixture proportions are determined by which of the following factors?

1. Anticipated weather conditions at the time of placement
2. Anticipated weather conditions during the entire curing process
3. Size and shape of the structure
4. Quantity to be placed

4-2. What factor determines the strenqth and durability of the concrete?

1. Volume of water
2. Volume of cement
3. Water-cement ratio
4. Compressive strength

4-3. When considering the exposure conditions and strength requirements using tables 17-1 and 17-2, what water-cement ratio should you use?

1. Higher ratio
2. Lower ratio
3. Average of the appropriate ratios
4. Laboratory obtained ratio

4-4. A concrete wall is 10 inches thick. What is the maximum size of the coarse aggregate that can be used in the mix?

1. 2.0 in
2. 3.5 in
3. 5.0 in
4. 7.5 in

4-5. Fine aggregate is used in a mix for which of the following purposes?

1. To increase the strength of the mix
2. To absorb excess water
3. To increase the workability of the mix
4. To accelerate the hydration process

4-6. Regardless of weather conditions, entrained air should always be used in concrete for which of the following purposes?

1. Precast
2. Paving
3. Drainage
4. Foundation

4-7. Concrete that is exposed to moisture or free water before freezing is classified as what type of exposure?

1. Mild
2. Moderate
3. Severe
4. Harsh

4-8. What method measures the consistency of the concrete mix?

1. Trial batch
2. Workability test
3. Proportions and ratio
4. Slump test

4-9. The size of your trial batch should be determined by which of the following factors?

1. Size of the placement
2. Equipment available for placement
3. Number of test samples required
4. Size of the coarse aggregate

4-10. The aggregates for your test batch should be in what condition?

1. Oven-dried
2. Saturated, surface-dry
3. Saturated
4. Super saturated

4-11. To determine the amount of mixing water needed for a trial batch, you must determine which of the following information?

1. Amount of cement required
2. Water-cement ratio
3. Desired slump
4. All of the above

4-12. Your coarse aggregate has a maximum size of 2 inches and a fineness modulus of 3.00. What quantity of coarse aggregate is required for a 1-cubic-yard trial batch?

1. 1,944 lb
2. 2,000 lb
3. 19.44 cu ft
4. 20.00 cu ft

4-13. You are preparing a l-cubic-foot trial batch with a water-cement ratio of 0.50. The quantity of cement to be used is 23.5 pounds. What is the required quantity of water?

1. 23.50 lb
2. 11.75 lb
3. 0.50 cu ft
4. 0.25 cU ft

4-14. You mix a 1-cubic-yard trial batch and the slump is 2 inches more than the desired slump. What action must you take?

1. Add 10 gal of water
2. Decrease your water by 10 lb
3. Decrease your water by 20 lb
4. Add more cement

4-15. To determine the absolute volume of coarse aggregate, which of the following information do you require?

1. Maximum aggregate size
2. Specific gravity
3. Dry-rodded weight
4. All of the above

4-16. When the fineness modulus is not in the tables, what must you do to determine the volume for the coarse aggregate?

1. Use the value that is higher than the aggregate
2. Use the value that is lower than the aggregate
3. Use the average value from the tables
4. Interpolate to obtain the value

4-17. How do you determine the absolute volume of fine aggregate?

1. (Percents of fine aggregate) x (total cement)
2. 27 - (Total absolute volume of all other materials)
3. (Absolute volume of coarse aggregatea)-(absolute volume of concrete)
4. (Total volume of all material) x (specific gravity of fines) x 62.4

4-18. What is the percentage of free-surface moisture in sand that is squeezed and clings together but contains no excess water?

1. 0% to 2%
2. 2% to 4%
3. 5% to 8%
4. 8% to 12%

4-19. What is the maximum FSM of gravel?

1. 1%
2. 2%
3. 3%
4. 4%

4-20. When you are batching the concrete mix by weight, how do you account for the weight contributed by the FSM?

1. Increase the total weight for the coarse aggregate only by the FSM
2. Decrease the total weight for the fine aggregate only by the FSM
3. Increase the total weight for the aggregates per cubic yard by the FSM
4. Decrease the total weight for the aggregates by the FSM

4-21. What adjustment, if any, should be made to water requirements to account for FSM of the aggregates?

1. Increase the amount of water by the FSM
2. Decrease the amount of water by the FSM
3. Decrease the amount of water by the FSM of the fine aggregates only
4. None

4-22. The FA has a 4 percent FSM and the CA has a 2 percent FSM. The original mix design called for the FA to be 1,050 pounds per cubic yard. What is the adjusted weight of the FA for the actual concrete mix?

1. 1,008 lb/cu yd
2. 1,050 lb/cu yd
3. 1,092 lb/cu yd
4. 1,113 lb/cu yd

4-23. You should monitor the moisture content of the aggregates and make appropriate adjustments under which of the following conditions?

1. After periods of dryness
2. After rains
3. After new material is delivered
4. All of the above

4-24. What waste factor, if any, should be applied to a concrete estimate of 220 cubic yards?

1. 5%
2. 10%
3. 15%
4. None

4-25. Determine the total number of sacks of cement required for a design project that uses a total volume of 180 cubic yard of concrete? (Use 6.5 sacks per cubic yard.)

1. 1,000
2. 1,170
3. 1,240
4. 1,287

Learning Objective: Identify methods and procedures used in the design of bituminous mixtures.

4-26. The objective of bituminous mix design is to determine which of the following factors?

1. The most durable mix possible
2. The most workable mix
3. The most economical blend that will meet all specified requirements
4. The most stable mix with the ability to withstand all possible traffic loads

4-27. The aggregate blend must achieve a specified gradation. Your trial batches are based on selected percentages from what source?

1. Project specifications
2. TM 5-337
3. NAVFAC MO-330
4. U. S. Army Corps of Engineers Pavement Design Manual

4-28. The specification limits for the gradation blend are established by what authority or publication?

1. By project specifications
2. By TM 5-337
3. By NAVFAC MO-330
4. U. S. Army Corps of Engineers

4-29. The final bitumen mix design is affected by all of the following variables except the

1. use of mix
2. minimum aggregate size
3. binder
4. loading

4-30. Which of the following data is required to prepare the test specimens?

1. Flow
2. Percentage of voids
3. Specific gravity of the aggregates
4. Total mix unit weight

IN ANSWERING QUESTION 4-31, REFER TO TABLE 17-7 IN YOUR TEXTBOOK.

4-31 What flow rate is acceptable for a surface course that serves as a high-pressure tire pavement?

1. 16 or less
2. 20 or less
3. 2% - 4%
4. 5% - 7%

4-32 When verifying the test results with the criteria for a particular property, you should use the OAC from that particular test only.

1. True
2. False

4-33 The Marshall test method requires no special modification until the 1-inch plus aggregate exceeds what percentage of the total aggregate?

1. 5%
2. 7%
3. 10%
4. 12%

4-34. You have determined the optimum bitumen content to be 5.5 percent. The aggregate will be what percentage of the mix?

1. 100.0%
2. 97.8%
3. 94.5%
4. 89.0%

4-35. When you perform the tests for cold-mix asphalts, what is the maximum moisture content of the aggregate by weight?

1. 1%
2. 2%
3. 5%
4. 7%

Learning Objective: Identify the general methods of soil stabilization.

4-36. Which of the following methods is a general method used for soil stabilization?

1. Modification
2. Additive
3. Cementing
4. Bituminous

4-37. The method of soil stabilization to be used is determined by which of the following factors?

1. Soil description
2. Soil classification
3. Amount of required stabilization
4. Each of the above

4-38. The mechanical method of soil stabilization is accomplished by mixing what materials?

1. Soils of different gradations
2. Cement and soil
3. Bituminous products and soil
4. Each of the above

4-39. Additives are used for what primary purpose?

1. To improve soil strength only
2. To improve soil durability only
3. To reduce the thickness required only
4. To improve soil quality

4-40. When stabilization is achieved by cementing, the final strength depends on which of the following factors?

1. Amount of cement used
2. Density achieved during curing
3. Density achieved during compaction
4. Both 2 and 3 above

Learning Objective: Identify types of stabilizers and the methods used for determining the type and the amount of stabilizer required.

4-41. Which of the following tests must be performed before a stabilizer can be selected?

1. Moisture content
2. Sieve analysis
3. Specific gravity
4. Bearing tests

4-42. Cement can be used with coarse-grained soils that meet what criteria?

1. At least 45% retained on a No. 4 sieve
2. At least 45% passing a No. 4 sieve
3. At least 45% retained on a No. 40 sieve
4. At least 45% passing a No. 40 sieve

4-43. Plasticity index should meet what criteria when you use a bituminous material for soil stabilization?

1. Greater than 30
2. Less than 30 but greater than 10
3. Equal to 25
4. Less than 10

4-44. When you choose a stabilizer additive, which of the following factors must be considered?

1. Environmental conditions
2. Cost
3. Type of soil quality improvement desired
4. Each of the above

4-45. Plastic soil-cement is used for which of the following purposes?

1. Road repairs
2. Erosion prevention
3. Paving ditches
4. Each of the above

4-46. When you add cement to the soil, which of the following properties increases ?

1. Plasticity
2. Water-holding capacity
3. All properties
4. Bearing capacity

4-47. Water is used in soil-cement for what purpose?

1. For hydration of the cement
2. To obtain maximum compaction
3. Both 1 and 2 above
4. To increase the weight

4-48. Soils used for soil-cement must be well graded to provide proper aggregate cohesion.

1. True
2. False

4-49. Which of the following soils is the most desirable for soil-cement construction?

1. Silty and clayey soil that contains a relatively high percentage of clay
2. Sandy soil that is deficient in fines
3. Sandy and gravelly soil with more than 55% passing a No. 4 sieve
4. Sandy and gravelly soil that contains 10% to 35% silt and clay

4-50. What is the first requirement for quality soil-cement?

1. Proper moisture content
2. Adequate cement content
3. Density of the soil
4. Proper compacting equipment

4-51. When you perform laboratory tests, composite samples should not be used because they could provide misleading and inaccurate results.

1. True
2. False

4-52. The required cement content for nonfrost areas is determined by which of the following tests?

1. Moisture-density
2. Freeze-thaw
3. Wet-dry
4. Both 2 and 3 above

4-53. The wet-dry test takes approximately how long to complete?

1. 1 day
2. 2 days
3. 24 days
4. 108 days

4-54. Your sample is classified as a gravelly soil. What is the passing criteria for this type of soil when the freeze-thaw test has been performed on the sample?

1. At least 7% weight loss
2. Not more than 7% weight loss
3. At least 14% weight loss
4. Not more than 14% weight loss

4-55. The principle requirement of a soil-cement mixture is to withstand exposure to the weather. By meeting this requirement, another requirement is also met. What is that other requirement?

1. Strength
2. Moisture content
3. Plasticity

4-56. The use of bitumen has which of the following effects on the soil?

1. Decreases the load-bearing capacity
2. Decreases cohesion
3. Increases the resistant to water action
4. Each of the above

4-57. In frost areas, tar is the recommended bituminous binder.

1. True
2. False

4-58. When pollution control concerns exist, what type of bituminous product is recommended?

1. Asphalt cement
2. Asphalt emulsion
3. Tar
4. Cutback asphalt

4-59. For a well-graded aggregate with little to no mineral filler, which of the following bituminous materials should you use?

1. MC-3000
2. MC-250
3. SS-1h
4. SC-70