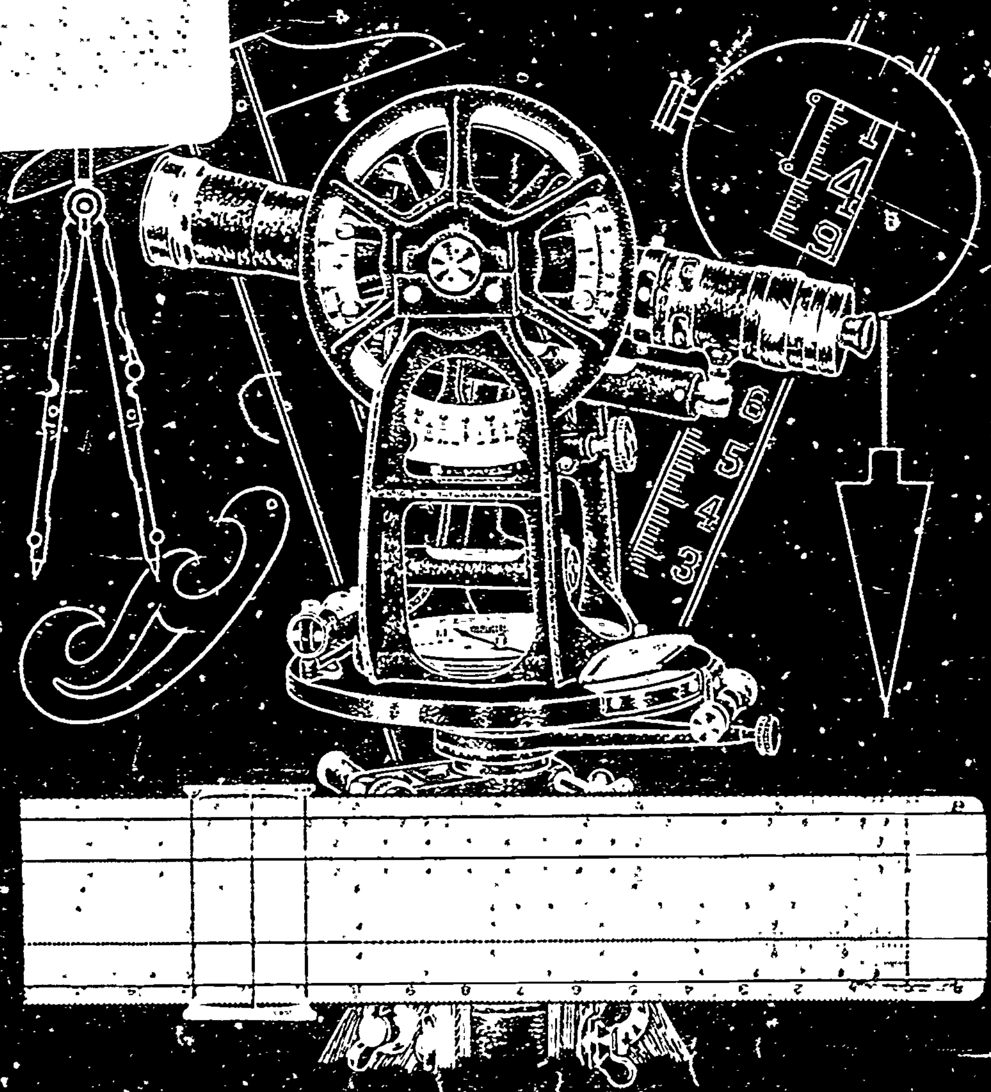
DOCUMENT RESUME

ED 105 121		CE 003 381

TITLE	Engineering Aid 1 & C. Rate Training Manual.
INSTITUTION	Naval Education and Training Command, Pensacola, Fla.
REPORT NO	NAVEDTRA-10635-B
PUB DATE	74
NOTE	513p.; 1964 edition revised
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 (Stock Number 0502-053-1760)
EDRS PRICE	MF-$ 0.92 HC-$26.02 PLUS POSTAGE
DESCRIPTORS	Administrativ Organization; Administrative Policy; Administrative Principles; Course Content; Engineering Education; *Engineering Technicians; *Engineering Technology; *Instructional Materials; Manuals; Military Personnel; *Military Training; Seamen; *Supervisory Training
IDENTIFIERS	Navy; *SEABEES

ABSTRACT

The manual is written primarily to aid in the training of personnel to meet the professional qualifications of the engineering aid, first class and chief. In chapter one, the trainee becomes familiar with the rewards and responsibilities of an engineering aid. Chapter two deals with principles of SEABEE administration, the organization and responsibilities of personnel in the Operations Department of a Naval Mobile Construction Battalion, safety responsibilities, and the principles of the Personnel Readiness Capability Program. Chapters 3 through 15 deal with the technical subject matter of the engineering and rating (geodesy and field astronomy; triangulation; level and traverse computations; construction and land surveys; topographic surveys; horizontal and vertical curves; adjustment and repair of surveying equipment; drafting layout, checking, and editing; planning and estimating, estimator's catalogs and specifications; scheduling; soil mechanics; and quality control). Finally, chapter 16 is concerned with the public works organization, responsibilities, and procedures. (A subject index is provided.) (Author/BP)



ENGINEERING AID 1 & C

PREFACE

The primary purpose of training is to produce a combat Navy which can ensure victory at sea. A victorious Navy is dependent upon the superior readiness of personnel. A superior quality of training will ensure superior readiness.

This Rate Training Manual provides the technical knowledge and skill requirements necessary to aid in preparing Engineering Aids to supervise personnel engaged in performing tasks involved in surveying, drafting, planning and estimating, construction scheduling, and quality control.

This training manual was prepared by the Naval Education and Training Program Development Center, Pensacola, Florida, for the Chief of Naval Education and Training. Technical assistance was provided by the Naval Facilities Engineering Command; the Naval Schools Construction, Port Hueneme, California; the Naval Schools Construction, Davisville, Rhode Island; and the Naval Construction Training Unit, Gulfport, Mississippi.

Stock Ordering No.
0502-053-1760

Original Edition 1964
Revised 1969
Revised 1974

Published by
NAVAL EDUCATION AND TRAINING SUPPORT COMMAND

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON, D.C.: 1974

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

CONTENTS

CREDITS

The illustrations listed below are included in this edition of *Engineering Aid 1 and C* through the courtesy of the designated sources. Permission to use these illustrations is gratefully acknowledged. Permission to reproduce illustrations and other materials in this publication must be obtained from the source.

Source	Material
Dyna Metric, Inc.	Figures 14-31, 14-32, 14-33, 14-34, 14-35, 14-36, 14-37, 14-38, 14-39, 14-40, 14-41 14-42, 14-43, and related textual material on seismic surveying.
Portland Cement Association	Figures 15-13, 15-14, 15-15, 15-16, 15-17, and Table 15-9. Also, textual material related to soil-cement construction.

CHAPTER 1

THE JOB AHEAD

If the Navy is to achieve Victory at Sea, each man must be well trained to ensure maximum performance of his assigned tasks. Adequate training requires every man to know his specific job and constantly keep abreast of new changes to his rating.

This manual is written primarily to aid in training personnel to meet the professional qualifications of the Engineering Aid, First Class and Chief.

In this chapter, you will become familiar with your increased responsibilities of the job ahead. Chapter 2 deals with principles of SEABEE administration, the organization and responsibilities of personnel in the Operations Department of a Naval Mobile Construction Battalion, safety responsibilities, and the principles of the Personnel Readiness Capability Program. Chapters 3 through 15 deal with the technical subject matter of the Engineering Aid rating. Chapter 16 is concerned with Public Works organization, responsibilities, and procedures.

It is strongly recommended that you study this chapter and chapter 2 carefully before beginning intensive study of the technical matter contained in the chapters that follow. In using this training manual, study the information from two points of view. First, what do you need to learn from it? And second, how would you go about teaching this information to others? Now that you have these two points in mind, let's add a little motivation.

As a SEABEE who gets ahead, you've done quite a bit of climbing. Not the mountain variety, but the kind that pays off in advancement. Yet, just like the mountain climber, you're not content with the halfway point. You don't want to remain motionless and become stagnant. You want to reach the top. Right now, you're climbing to the rate of Engineering Aid First Class or Chief. You realize, of course, that these are responsible positions–the type that require more than just an average amount of skill and ability, but you can qualify. It will mean additional hard work, study, training, and practice. But what of it? No worthwhile achievement ever comes easily.

Your new job ahead will bring you in constant contact with every phase of construction. Because the work is so varied, you will have to become thoroughly familiar with construction methods and the techniques involved in the Engineering Aid rating. This manual offers you the opportunity to gain a portion of the knowledge you will need. Further training and experience will be needed. Practice, study, and learn all you can about the equipment and techniques of your unique trade and you won't be left stranded at the halfway point.

REWARDS AND RESPONSIBILITIES

The job ahead will bring about both increased rewards and increased responsibilities. The time to start looking ahead and considering the rewards and the responsibilities is right now, while you are preparing to climb up the ladder.

By this time, you are probably well aware of many of the advantages of advancement–higher pay, greater prestige, more interesting and challenging work, and the satisfaction of getting ahead in your chosen career. You no doubt have also discovered that one of the most enduring rewards is the personal satisfaction you find in developing your skills and increasing your knowledge.

The Navy also benefits by your climb to higher success. Highly trained personnel are essential to the functioning of the Navy. By each advancement you increase your value to the Navy in two ways. First you become more valuable as a technical specialist in your own rating. Secondly, you become more valuable as a person who can supervise, lead, and train others and thus make far-reaching and long-lasting contributions to the Navy.

In large measure, the extent of your contribution to the Navy depends upon your willingness and ability to accept increasing responsibilities as you advance. When you assumed the duties of an EA3, you began to accept a certain amount of responsibility for the work of others. With each advancement, you accept an increasing responsibility in military matters and in matters relating to the occupational requirements of the Engineering Aid rating.

You will find that your responsibilities for military leadership are about the same as those of petty officers in other ratings, since every petty officer is a military leader as well as a technical specialist. Your responsibilities for technical leadership are special to your rating and are directly related to the nature of your work. The administration and organization of the enlisted personnel comprising the different divisions of the Operations Department is a job of vital importance, and it's a team effort that requires intelligent coordination by the senior petty officer in the Department. As you move ahead, you must continuously strive to improve your administrative ability, technical knowledge, and leadership potential. It requires a special kind of leadership ability that can be developed by personnel who have a high degree of technical competence and a deep sense of personal responsibility.

In a sense, you are an administrator, and as such, you must acquaint yourself thoroughly with the mission of your organization – be it a detached unit, Construction Battalion, or perhaps on the staff of a Regiment or Brigade. Make sure that you keep up-to-date on the status of all projects (underway and proposed) under the cognizance of your unit. Anticipate what role you and your men will play in the actual accomplishment of your mission. Plan ahead! At this point, let's consider some of the broader aspects of your increasing responsibilities for military and technical leadership.

YOUR RESPONSIBILITIES WILL EXTEND BOTH UPWARD AND DOWNWARD. Both officers and enlisted personnel will expect you to translate the general orders given by officers into detailed, practical on-the-job language that can be understood and followed even by relatively inexperienced personnel. In dealing with your juniors, it is your main responsibility to see that they perform their work properly. At the same time, you must be able to explain to officers any important needs or problems of the enlisted men.

YOU WILL HAVE REGULAR AND CONTINUING RESPONSIBILITIES FOR TRAINING. Even if you are fortunate enough to have a number of highly skilled and well trained Engineering Aids, you will still find that training is necessary. For example, you will always be responsible for training lower rated men for advancement. Also, some of your best workers may be transferred and inexperienced or poorly trained personnel may be assigned to you. A particular job may call for skills that none of your personnel have. These and similar problems require you to be a training specialist who can conduct formal and informal training programs to qualify personnel for advancement and who can train individuals and groups in the effective execution of assigned tasks.

YOU WILL HAVE INCREASING RESPONSIBILITIES FOR WORKING WITH OTHERS. As you advance to EA1 and then to EAC, you will find that many of your plans and decisions affect a large number of people, some of whom are not in the Engineering Division and some of whom are not even in the Operations Department. It becomes increasingly important, therefore, to understand the duties and responsibilities of personnel in other ratings. Every petty officer in the Navy is a technical specialist in his own field. Learn as much as you can about the work of other ratings, and plan your own work so that it will fit in with the overall mission of the organization.

AS YOUR RESPONSIBILITIES INCREASE, YOUR ABILITY TO COMMUNICATE CLEARLY AND EFFECTIVELY MUST ALSO INCREASE. The basic requirement for effective communication is a knowledge of your own language. Use correct language in speaking and in writing. Remember that the basic purpose of all communication is understanding. To lead, supervise, and train others, you must be able to speak and write in such a way that others can understand exactly what you mean.

A second requirement for effective communication in the Navy is a sound knowledge of the Navy way of saying things. Some Navy terms have been standardized for the purpose of ensuring efficient communication. When a situation calls for the use of standard Navy terminology, use it.

Still another requirement of effective communication is precision in the use of technical terms. Learn as much as possible about engineering terms, especially those related to construction. A command of the technical language of the Engineering Aid rating will enable you to receive and convey information accurately and to exchange ideas with others. A person who does not understand the precise meaning of terms used in connection with the work of his own rating is at a disadvantage when he tries to read official publications relating to his work. Although it is important for you to use technical terms correctly, it is particularly important when you are dealing with lower rated personnel to clarify further their meaning in the level of language that they can understand, sloppiness in the use of technical terms is likely to be very confusing to an inexperienced man.

YOU WILL HAVE INCREASED RESPONSIBILITIES FOR KEEPING UP WITH NEW DEVELOPMENTS. Practically everything in the Navy–policies, procedures, equipment, publications, systems–is subject to change and development. As an EA1, and even more as an EAC, you must keep yourself informed about all changes and new developments that might affect your rating and your work.

Some changes will be called directly to your attention, but others you will have to look for. Try to develop a special kind of alertness for new information. Keep up-to-date on all available sources of technical information. Above all, keep an open mind on the subject of surveying, drafting, construction methods and the associated instruments and equipment.

As the value of real estate, materials, and the cost of labor go higher and higher, scientists and engineers try to offset these trends economically by the introduction of improved survey methods, improved construction methods, and with the invention of more precise instruments and equipment. As an example, they have come up with various electronic distance measuring instruments, lightwave distance measuring devices, laser transits, and other laborsaving equipment. Keep yourself abreast of the latest developments relative to your rating, and disseminate your newly-acquired knowledge to your men the first opportunity you have after you become thoroughly familiar with the subject matter.

THE ENGINEERING AID RATING

Men holding the Engineering Aid rating plan, supervise, and perform tasks required in various engineering surveys, with more emphasis in construction surveying, construction drafting, planning and estimating, and quality control; prepare progress reports, presentation charts, time records, construction schedules, and material and labor estimates, establish and operate a basic quality control system for testing soils, bituminous materials, concrete, and other construction materials; prepare, edit, and reproduce construction drawings; devise and maintain up-to-date filing systems for drawings, field notes, and other engineering records, make reconnaissance and surveys for horizontal and vertical control network, performing such tasks as running and closing traverses, measuring horizontal/vertical distances and directions, staking out aboveground and underground excavations, collecting field data necessary for engineering designs, and obtaining and converting field notes into topographic maps.

Most Engineering Aid billets are allotted to Construction Battalions, staff duty, or other special duty assignments. In a battalion, an EA1 or EAC may serve as supervisor of field survey parties, as drafting room supervisor, as leader of a planning and estimating or quality control team, as an expediter (one who follows up requisitions to ensure adequate flow of construction materials), or as chief safety inspector.

In staff duty, an EAC may be assigned as administrative supervisor for the Engineering and Clerical Services Division, and serve as liaison between the battalion liaison officers in consolidating various progress reports required by higher authority. You might be assigned the task of assisting the staff operations officer in collecting data for the preparation of various studies and special reports—that is why thorough knowledge of your mission is important, so that you know just where to get the required information.

At shore stations, EAs may be assigned to Public Works offices, Engineering Field Divisions, recruiting duty, recruit training, and Naval Reserve training. A few Public Works office billets are also available overseas. A limited number of particularly well qualified EAs are given assignments to instruct in Navy schools; to assist in preparing the servicewide advancement examinations, Rate Training Manual (like this one), and other training materials at the Naval Education and Training Program Development Center, Pensacola, Florida; and to perform other highly specialized duties where their technical knowledge can be utilized effectively for the needs of the service.

REQUIREMENTS FOR ADVANCEMENT

In general, to qualify for advancement you must:

1. Have a certain amount of time in your present rate.

2. Complete the required professional and military training courses.

3. Demonstrate your ability to perform all the PRACTICAL requirements applicable to the rate for which you are seeking advancement and have them checked off on the Record of Practical Factors, NAVEDTRA 1414/1 (latest revision).

4. Be recommended by your commanding officer.

5. Demonstrate your KNOWLEDGE by passing written examinations based on the professional and military qualification standards.

FINAL MULTIPLE

Advancement is not automatic. Meeting all the requirements makes you eligible for advancement but does not guarantee your advancement. The number of men in each rate and rating is controlled on a Navy-wide basis. Therefore, the number of men that may be advanced is limited by the number of vacancies that exist. When the number of men passing the examination exceeds the number of vacancies, some system must be used to determine which men may be advanced and which may not. The system used is the "final multiple" and is a combination of three types of advancement systems:

Merit rating system
Personnel testing system
Longevity, or seniority system.

The Navy's system provides credit for performance, knowledge, and seniority, and, while it cannot guarantee that any one person will be advanced, it does guarantee that all men within a particular rating will have equal advancement opportunity.

A change in promotion policy, starting with the August 1974 examinations, changed the Passed-But-Not-Advanced (PNA) Factor to the High Quality Bonus Point (HQP) factor. Under this policy, a man that passed the examination, but was not advanced can gain points toward promotion in his next attempt. Up to three multiple points can be gained in a single promotion period. The points can then be accumulated over six promotion periods up to a maximum of 15. The addition of the HQP factor, with its 15-point maximum, raises the number of points possible on an examination multiple from 185 to 200. This gives the examinee added incentive to keep trying for promotion in spite of repeated failure to gain a stripe because of quota limitations.

The following factors are considered in computing the final multiple.

FACTOR	MAXIMUM POINTS	WEIGHT PAY GRADES					
		E4	E5	E6	E7	E8	E9
EXAMINATION	80	35	35	30	60	50	40
PERFORMANCE							
Leadership	50	0	10	15	40	50	60
All Other		30	20	20			
EXPERIENCE							
Awards & Medals	15	7.5	7.5	7.5			
Total Active Service (1 per yr)	20	10	10	10			
Time in Present Grade (2 per yr)	20	10	10	10			
HQP (maximum 3 per exam cycle)	15	7.5	7.5	7.5			
	200	100%	100%	100%	100%	100%	100%

All of the above information (except the examination score and the HQP factor) is submitted with your examination answer sheet. After grading, the examination scores, for those passing, and the HQP points (additional points awarded to those who previously passed the examination but were not advanced) are added to the other factors to arrive at the final multiple. A precedence list, which is passed on final multiples, is then prepared for each pay grade within each rating. Advancement authorizations are then issued, beginning at the top of the list, for the number of men needed to fill the existing vacancies.

KEEPING CURRENT ON ADVANCEMENT

Remember that the requirements for advancement may change from time to time. Check with your division officer or your training officer to be sure you have the most recent requirements when you are preparing for advancement and when you are helping lower rated men to prepare for advancement.

To prepare for advancement, you need to be familiar with (1) the military requirements and the occupational qualifications given in the *Manual of Qualifications for Advancement*, NAVPERS 18068-C (with changes); (2) the Record of Practical Factors, NAVEDTRA 1414/1; (3) appropriate Rate Training Manuals; and (4) any other material that may be required or recommended in the current edition of *Bibliography for Advancement Study*, NAVEDTRA 10052. These materials are discussed later in the section of this chapter that deals with sources of information.

SOURCES OF INFORMATION

It is very important for you to have an extensive knowledge of the references to use for detailed, authoritative, up-to-date information on all subjects related to the military requirements and to the occupational qualifications of the Engineering Aid rating. No single publication can give you all the information you need to perform the duties of your rate. You should learn where to find them when the need arises, as it is impossible to have everything in memory.

Some of the publications discussed here are subject to change or revision from time to time—some at regular intervals, others as the need becomes necessary. When using any publication that is subject to change or revision, be sure you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been entered.

Official publications and directives carry abbreviations and numbers which identify the source of the document and its subject matter. This training manual, for instance, is NAVEDTRA 10635-B, which means that it is a publication of the Naval Training Command, a Rate Training Manual in the Group VIII rating series. The letter following the numerals designates the edition Because you should always make it your responsibility to see that you are using the latest edition of any publication or directive, we do not usually show the final letter when referring to a publication or directive in this manual. ALWAYS USE THE LATEST EDITION.

NAVPERS, NAVTRA, OR NAVEDTRA PUBLICATIONS

The NAVPERS, NAVTRA, or NAVEDTRA publications described here include some which are absolutely essential for anyone seeking advancement and some which, although not essential, are extremely helpful.

THE QUALS MANUAL. The *Manual of Qualifications for Advancement*, NAVPERS 18068-C (with changes), gives the minimum requirements for advancement to each rate within each rating. The *Quals Manual* lists the military requirements which apply to all ratings and the occupational qualifications that are specific to each rating.

The *Quals Manual* is kept current by means of numbered changes. These changes are issued more frequently than most Rate Training Manuals can be revised, therefore, the training manuals cannot always reflect the latest qualifications for advancement. When preparing for advancement, you should always check the LATEST *Quals Manual* and the LATEST changes to be sure that you know the current requirements for advancement.

When studying the qualifications for advancement, remember these three things.

1. The quals are the MINIMUM requirements for advancement to each rate within each rating. If you study more than the required minimum, you will, of course, have a great advantage when you take the written examination for advancement.

2. Each qual has a designated pay grade—E-4, E-5, E-6, E-7, E-8, or E-9. You are responsible for meeting all quals specified for advancement to the pay grade to which you are seeking advancement AND all quals specified for lower pay grades.

3. The written examinations for advancement to E-6 and above contain questions relating to the practical factors and the knowledge factors of BOTH military/leadership requirements and occupational qualifications. Personnel preparing for advancement to E-4 or E-5 must pass a separate military/leadership examination prior to participation in the Navy-wide occupational examination. The military/leadership examinations for the E-4 and E-5 levels are given according to a schedule prescribed by the commanding officer. Candidates are required to pass the applicable military/leadership examination only once.

RECORD OF PRACTICAL FACTORS.—A special form known as the Record of Practical Factors, NAVEDTRA 1414/1, is used to record the satisfactory completion of the practical factors, both military and occupational, listed in the *Quals Manual.* Whenever a person demonstrates his ability to perform a practical factor, appropriate entries must be made in the DATE and INITIALS column. As an EA1 or EAC, you will often be required to check the practical factor performance of lower rated men and to report the results to your supervising officer. To facilitate record keeping, group records of practical factors are often maintained by each department. Entries from the group records must, of course, be transferred to each individual's Record of Practical Factors at appropriate intervals.

As changes are made periodically to the *Quals Manual*, new forms of NAVEDTRA 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the *Quals Manual*. The Record of Practical Factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating, but which are not identified as minimum qualifications for advancement. Keep this in mind when you are training and supervising lower rated personnel. If a man demonstrates proficiency in some skill which is not listed in the Engineering Aid quals but which falls within the general scope of the rating, report this fact to the supervising officer so that an appropriate entry can be made.

The Record of Practical Factors should be kept in each man's service record and should be forwarded with the service record to the next duty station. Each man should also keep a copy of the record for his own use.

NAVEDTRA 10052.–*Bibliography for Advancement Study*, NAVEDTRA 10052, is a very important publication for anyone preparing for advancement. This publication lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NAVEDTRA 10052 is revised and issued once each year by the Naval Education and Training Command. Each revised edition is identified by a letter following the NAVEDTRA number. When using this publication, be SURE you have the most recent edition.

The required and recommended references are listed by rate level in NAVEDTRA 10052. It is important to remember that you are responsible for all references at lower rate levels, as well as those listed for the rate to which you are seeking advancement.

Rate Training Manuals that are marked with an asterisk (*) in NAVEDTRA 10052 are MANDATORY at the indicated rate levels. A mandatory training manual may be completed by (1) passing the appropriate Nonresident Career Course based on the mandatory training manual, (2) passing locally prepared tests based on the information given in the mandatory training manual, or (3) in some cases, successfully completing an appropriate Navy school.

It is important to notice that all references, whether mandatory or recommended, listed in NAVEDTRA 10052 may be used as source material for the written examinations, at the appropriate levels.

RATE TRAINING MANUALS.–Rate Training Manuals are written for the specific purpose of helping to train personnel to meet job requirements. Some manuals are general in nature and are intended for use by more than one rating; others (such as this one) are specific to the particular rating.

Rate Training Manuals are revised from time to time to bring them up-to-date. The revision of a Rate Training Manual is identified by a letter following the NAVPERS or NAVEDTRA number. You can tell whether a Rate Training Manual is the latest edition by checking the NAVPERS or NAVEDTRA number and the letter following the number in the most recent edition of the *List of Training Manuals and Correspondence Courses*, NAVEDTRA 10061 (current edition).

Each time a Rate Training Manual is revised, it is brought into conformance with the official publications and directives on which it is based. During the life of any edition, discrepancies between the manual and the official sources are almost sure to arise because of changes to the latter which are issued in the interim. In the performance of your duties, you should always refer to the appropriate official publication or directive. If the official source is listed in NAVEDTRA 10052, and, therefore, is a source used by the Naval Education and Training Program Development Center in preparing the advancement examinations, they will resolve any discrepancy of material by using that which is most recent.

There are three Rate Training Manuals that are specially prepared to present information on the military requirements for advancement. These manuals are:

Basic Military Requirements, NAVEDTRA 10054 (current edition)

Military Requirements for Petty Officer 3 & 2, NAVEDTRA 10056 (current edition)

Military Requirements for Petty Officer 1 & C, NAVEDTRA 10057 (current edition).

Each of the military requirements manuals is mandatory at the indicated rate levels. In addition to giving information on the military requirements, these three books give a good deal of useful information on the enlisted rating structure; how to prepare for advancement; how to supervise, train, and lead other men; and how to meet your increasing responsibilities as you advance.

Some of the Rate Training Manuals that may be useful to you when you are preparing to meet the occupational qualifications for advancement to EA1 and EAC are discussed briefly in the following paragraphs. For a complete listing of Rate Training Manuals, refer to the *List of Training Manuals and Correspondence Courses*, NAVEDTRA 10061 (current edition).

Tools and Their Uses, NAVEDTRA 10085. Although this training manual is not specially required for advancement, you will find that it contains a good deal of useful information on the care and use of various types of handtools and portable power tools commonly used in the Navy.

Blueprint Reading and Sketching, NAVEDTRA 10077 This training manual contains information that may be of value to you as you prepare for advancement to EA1 and EAC.

Mathematics, Vol. 1, NAVEDTRA 10069 and *Mathematics*, Vol. 2, NAVEDTRA 10071. These two training manuals may be helpful if you need to brush up on your mathematics. Volume 1, in particular, contains basic information that is needed for using formulas and for making simple computations. The chapter which deals with trigonometry is of vital importance to surveying. The information contained in Volume 2 is more advanced, but you may occasionally find it helpful in Engineering Aid computations.

Engineering Aid 3 & 2, NAVEDTRA 10634-B. Satisfactory completion of this training manual is required for advancement to EA3 and EA2. If you have met this requirement by satisfactorily completing an earlier edition of *Engineering Aid 3 & 2*, you should at least glance through the -B revision (or latest edition) of the training manual. Much of the information given in this edition of *Engineering Aid 1 & C* is based on the assumption that you are familiar with the contents of *Engineering Aid 3 & 2*, NAVEDTRA 10634-B.

Rate Training Manuals prepared for other Group VIII (Construction) ratings are often a useful source of information. Reference to these training manuals will increase your knowledge of the duties and skills of other men in the SEABEES. The training manuals prepared for Builders, Steelworkers, Utilitiesman, and Equipment Operators are likely to be of particular interest to you.

CORRESPONDENCE COURSES.—Most Rate Training Manuals and Officer Texts are used as the basis for correspondence courses. Completion of a mandatory training manual can be accomplished by passing the correspondence course that is based on the training manual. You will find it helpful to take other correspondence courses, as well as those that are based on mandatory training manuals. For example, the completion of the correspondence courses based on drafting, general mathematics, and construction is strongly recommended for personnel preparing for advancement. Taking a correspondence course helps you to master the information given in the training manual or text and also gives you a pretty good idea of how much you have learned from studying the book. Both enlisted and officer correspondence courses are listed in the *List of Training Manuals and Correspondence Courses*, NAVEDTRA 10061 (revised).

NAVFAC PUBLICATIONS

A number of publications issued by the Naval Facilities Engineering Command (NAVFAC) which will be of interest to personnel in the Group VIII ratings are listed in the *NAVFAC Documentation Index*, NAVFAC P-349 (updated semi-annually). A publications program is one of the principal communications media used by NAVFAC to provide a ready reference of current technical and administrative data for use by its subordinate units. NAVFAC publications are listed in alphabetical and numerical order in NAVFAC P-349. copies of NAVFAC P-349 may be obtained through proper channels from the Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120. Technical publications that will be of value to Engineering Aids are those which deal with the subject of design, drafting, specifications and standards, which you will find very easily by simply going through the

Index once you know the particular subject matter you are after. When you are the senior EA in the Operations Department, by all means have an up-to-date copy of NAVFAC P-349 in the department's technical library at all times.

TRAINING FILMS

Training films available to naval personnel are a valuable source of supplementary information on many technical subjects. Films on various subjects that may be of interest are listed in the *United States Navy Film Catalog,* NAVAIR 10-1-777, published in 1969. Copies may be ordered in accordance with the *Navy Stock List of Forms and Publications,* NAVSUP 2002. Supplements to the *Film Catalog* are issued as appropriate.

When selecting a film, note its date of issue listed in the *Film Catalog.* As you know, procedures sometimes change rapidly. Thus some films become obsolete rapidly. If a film is obsolete only in part, it may sometimes be shown effectively if before or during its showing you carefully point out to trainees the procedures that have changed. For this reason, if you are showing a film to train other personnel, take a look at it in advance if possible, so that you may spot material that may have become obsolete and verify current procedures by looking them up in the appropriate sources before the formal showing.

TRAINING AIDS

In the course of training the men under you, it might be necessary at times to construct your own training aids to help present your subject matter vividly. Of course, you could use actual instruments or equipment for training purposes; however, there are functions or theories that are hard to describe only in words—and that is when you will have to improvise your training aids. Being an Engineering Aid, you are in a position to construct much better and more effective training aids than men in other ratings who do not have skill in drafting. The types and uses of training aids are explained in *Military Requirements for Petty Officer 1 & C,* NAVEDTRA 10057 (latest revision).

SCOPE OF THIS TRAINING MANUAL

Before studying any book, it is a good idea to know the purpose and the scope of the book. Here are some things you should know about this training manual:

- It is designed to give you information on the occupational qualifications for advancement to EA1 and EAC.

- It must be satisfactorily completed before you can advance to EA1 or EAC, whether you are in the regular Navy or in the Naval Reserve.

- It is NOT designed to give you information on the military requirements for advancement to PO1 or CPO. Rate Training Manuals that are specially prepared to give information on the military requirements are discussed in the section of this chapter that deals with sources of information.

- It is NOT designed to give you information that is related primarily to the qualifications for advancement to EA3 and EA2. Such information is given in *Engineering Aid 3 & 2,* NAVEDTRA 10634-B.

- The occupational Engineering Aid qualifications that were used as a guide in the preparation of this training manual were those promulgated in the *Manual of Qualifications for Advancement,* NAVPERS 18068-C, change 1. Therefore, changes in the Engineering Aid qualifications occurring after this change may not be reflected in this training manual. Since your major purpose in studying this training manual is to meet the qualifications for advancement to EA1 or EAC, it is important for you to obtain and study a set of the most recent Engineering Aid qualifications.

- This training manual includes information that is related to both the KNOWLEDGE FACTORS and the PRACTICAL FACTORS of the qualifications for advancement to EA1 and EAC. However, no training manual can take the place of actual on-the-job experience for developing skill in the practical factors. The training manual can help you understand some of the whys and wherefores, but you must combine knowledge with practical experience before you can develop the required skills. The Record of Practical Factors, NAVEDTRA 1414/1, should be utilized in conjunction with this training manual whenever possible.

- This training manual deals almost entirely with administration and the principles of higher surveying. If you would like to do some study on your own, additional technical knowledge will be gained if you refer to the latest edition of standard textbooks on surveying.

- Before studying this manual any further, study the table of contents and note the arrangement of information. Information can be organized and presented in many different ways. You will find it helpful to get an overall view of the organization of this training manual before you start to study it.

CHAPTER 2

ADMINISTRATION AND ORGANIZATION

The higher you ascend the enlisted rating ladder, the more valuable you will be to the Navy. This is understandable since you have more experience in your particular rating; you have probably been to several Navy schools; and your attitudes are generally 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 men under you. Your bearing, actions, and disposition will be under scrutiny not only by your seniors, but also by your subordinates.

This chapter discusses various principles of administration of primary concern to the EA. Special attention is given to factors that will be useful to you as a guide in the performance of your administrative and supervisory duties. We will point out major responsibilities of the EA groups in an NMCB Operations Department, and explain various functions of the Department. Among other things, we will also discuss major responsibilities of the supervisor of different divisions and sections within the Operations Department.

With each advancement in rate comes increased responsibilities connected with administration in the Navy. The job of supervising 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; interpretation and compliance with current directives; collecting engineering data; making progress reports; and carrying on a comprehensive and effective training program. It is important, therefore, that each senior petty officer understand just what "ADMINISTRATION" means to Navy personnel, and exactly what his administrative responsibilities encompass. In order to function efficiently (or perhaps even to function at all), any group of individuals engaged in a group endeavor must be ORGANIZED, TRAINED, and SUPERVISED. Being an EA1 or EAC, you will be more concerned with administration and human relations. You will accomplish your mission through the effective use of people.

ELEMENTS OF ADMINISTRATION

In the sense in which the term is used in this chapter, ADMINISTRATION means, basically, the intelligent utilization and division of labor.

One of the most important phases of administration is that of personnel matters. The basic objective of this phase is very broad; namely, to contribute to effective management wherever human relations are involved. The major operational objectives are threefold and as follows:

1. To obtain the best qualified people, and to ensure the best use of their capacities.
2. To establish working conditions which develop and maintain the best possible interest, satisfaction, and performance of personnel.
3. To assure that type and quality of performance is commensurate with cost of personnel; that is, the Navy gets a "day's work" for a "day's pay."

The success of any mission depends not only upon the equipment and facilities used, but also depends to a larger extent upon the personnel assigned. This makes the effective use of people imperative.

The elements of effective administration are PLANNING, ORGANIZING, SUPERVISING or DIRECTING, and CONTROLLING. In practice, these elements frequently fuse; therefore, one cannot deal with them in set order. For purposes of this discussion, however, planning comes first. These elements of administration illustrate the relationship of the EA1 or EAC to the proper administration of his unit.

PLANNING

Planning—the first element of administration—must answer the questions: Who? What? When? Where? How? and Why? A good plan has a well-defined objective, is simple but balanced and flexible, and provides standards for measuring action. It provides for use of all available resources before creation of new authorities and new resources. It specifies who is to carry out the plan and outlines responsibility in terms which avoid confusion.

Before making individual work assignments to personnel, much detailed information should be considered, including a statement showing all tasks to be done and the conditions under which they are to be accomplished. The consideration should show for each assigned task such information as the following:

1. Duties and responsibilities.
2. Knowledge required to do the work.
3. Skills required for proficient performance.
4. Training and experience necessary for proficiency.
5. Mental requirements.
6. Personal characteristics required by the work.
7. Physical demands—such as strength or stability.
8. Occupational relationship.
9. Tools, equipment, material, and publications used to work with.
10. Reports and records to be prepared.
11. Hazards and safety precautions.
12. The amount of supervision needed, and the nature of the supervision.
13. The relation of the job to subsequent operations.

The good administrator also anticipates the eventual loss of his most experienced workers through transfers, discharges, illness, or other unforeseeable circumstances. He offsets this loss by implementing an effective and continuing training program. In addition to raising the skill level of the division, this program ensures that personnel, when otherwise qualified, are ready for advancement examinations.

ORGANIZATION

Organization—the second element of administration—is the orderly arrangement of materials and personnel by functions. In charting a good organization, the following terms are used:

DUTY—the tasks which the individual is required to perform.

RESPONSIBILITY—the accountability for the performance of duties.

AUTHORITY—the right to make a decision in order to fulfill a responsibility, the right to require actions of others, or the right to discharge particular obligations of the individual himself.

ACCOUNTABILITY—the obligation of an individual to render an account of the proper discharge of his responsibilities. This accounting is made to the person to whom he reports. This means that along with responsibility and authority is associated the requirements that naval personnel must answer to their superiors for the success or failure in the execution of their assigned duties.

The most important consideration in organizing your work crew is the division of labor. Division of labor is best exemplified by the assembly-line methods used in the automobile and other industries. No single individual—probably no dozen individuals—could build as much as a single automobile in a year. By dividing the labor—that is, by assigning each subphase of auto construction to an individual who repeats this subphase on each car that comes along, the production of a number of complete cars a day by a relatively small number of workers is made possible.

You can see that the fundamental steps in organization are about as follows:

1. Breaking down the manufacture of a complete automobile into logical subphases capable of accomplishment by a single individual.

2. Arranging these subphases in logical order, from first to last. Obviously, for example, the frame must be made before the wheels can be

attached–and the wheels must be made and ready for attachment by the time the frame is made.

3. Selecting, assigning, and instructing the individuals who will perform the subphases of construction.

Organization for automobile manufacture is a pretty extensive operation, compared to the organization of a survey field party or a battalion drafting room crew. However, the organization of a field party or drafting room crew involves the same three fundamental steps. Now for the principles involved.

Homogeneous Assignments

HOMOGENEOUS means, in general, SIMILAR. The principle of homogeneous assignments means that workers performing similar functions should be grouped together, and that functions should be scheduled in logical sequence so that each operation performed is an additional step toward completion.

Also, if an individual is assigned more than one task, the second task should be one which employs, as nearly as possible, the same knowledge and skills required for the first; and the second should be a task to whose completion the first contributes.

The practice of assigning nonhomogeneous details as secondary duties is a common mistake.

Division of Labor

The division of labor has already been mentioned. We used as an example the division of labor practiced in the auto industry. This, however, is only one of three commonly used systems, as follows:

1. The SERIES (or ASSEMBLY-LINE) system. In this system, the structural materials flow from one person to another, each person performing a designated segment of the work. Individual jobs are usually simple, requiring relatively little training and skill. Disadvantages of the system include reduced worker interest, long transportation and cycle time, and lack of worker FLEXIBILITY (ability to transfer from one phase of construction to any other).

2. The PARALLEL system. In this system each worker performs a whole operation–that is, each worker, working independently, turns out a complete product by going through all the required production steps. This makes for a more flexible work force and much higher worker interest; but it requires workers with higher skills and therefore more training time. An additional disadvantage is the fact that some of the time of skilled workers is used for work which doesn't require skill.

3. The UNIT-ASSEMBLY system. In this system, several employees work together as a crew on one item from start to finish. The advantages and disadvantages are the same as those described for the series system. In addition, the unit-assembly system tends to produce an uneven distribution of work, which may result in idle on-the-job time for some individuals in the group. It takes careful planning to reduce this disadvantage to a minimum.

The unit-assembly system has only limited application in general productive industry. However, because of the special character of the work done by survey field parties, drafting-room crews, and planning and estimating or quality control groups, the unit-assembly system (combined occasionally with one or both of the others) is the one most frequently used in groups supervised by Engineering Aids.

SUPERVISION

The supervisor sets in motion the plan, schedules, and policies of his superiors. He is primarily concerned with seeing that the job is done, not necessarily performing the work himself. However, in the SEABEES, we are required to meet the scheduled deadline, so it may be necessary at times for the supervisor to give a hand while doing the supervision as well. The supervisor must know his men, assign them work to be done, train them to do the best job possible, direct them through the performance of the work, and assume responsibility for seeing that the job is done right. The primary objectives of a SEABEE supervisor are to operate with maximum efficiency and safety, to operate with minimum expense and waste, and to operate free from interruption and difficulty.

An Engineering Aid in charge of a field party, or in charge of a drafting room, is a SUPERVISOR rather than a MANAGER. The distinction lies in the fact that a supervisor is in direct contact with, and has direct control over, the individuals who do the actual work of production, whereas management is control once removed, as it were. To put it another way: management exercises control through supervisors, while supervisors exercise direct control.

Supervisory Duties and Responsibilities

The major duties and responsibilities of a supervisor may be broadly broken down as follows:

1. Production
2. Safety, health, and physical welfare of subordinates
3. Development of cooperation
4. Development of morale
5. Training of subordinates
6. Records and reports to management.

A detailed list of the techniques involved in carrying out these duties and responsibilities could be made only with regard to a particular supervisor; however, the following techniques have pretty general application:

1. Getting the right man on the job at the right time
2. Economical use and placement of materials
3. Attendance control
4. Accident prevention, by safety training and control of hazards
5. Keeping subordinates satisfied and happy on the job
6. Adjusting grievances
7. Maintaining discipline
8. Keeping records and making reports
9. Maintaining quality and quantity of production
10. Planning and scheduling work
11. Organized and unorganized training
12. Requisitioning tools, equipment, and materials
13. Inspection, care, and preservation of tools and equipment
14. Giving orders and directions
15. Developing and maintaining cooperation with other units
16. Checking and inspecting materials
17. Settling differences among subordinates
18. Planning and encouraging teamwork
19. Preparing and disseminating rules, organization charts, work procedures, and the like
20. Maintaining good job housekeeping

Supervisory Principles and Techniques

Supervision and leadership are to a large extent the same thing, and, therefore, the principles and techniques of leadership described in *Military Requirements for Petty Officer, 3 & 2*, NAVEDTRA 10056 (revised) and *Military Requirements for Petty Officer 1 & C*, NAVEDTRA 10057 (revised) have general application to the supervising EA. To the discussion contained in those works, the following discussion of some of the major supervisory duties and responsibilities may be added.

Production

The primary responsibility of every supervisor is PRODUCTION. This responsibility is carried out in three ways, as follows:

1. By planning and organizing the work to get maximum production with minimum effort and confusion.

2. By delegating as much authority as possible, while remaining responsible for the final product.

3. By continuous supervision and control to ensure that the work is done properly.

Safety, Health, and Physical Welfare of Subordinates

Safety and production go together, since the only efficient way to do anything is a safe way. When men are absent because of injury, production falls. Therefore, a good supervisor is a constant preacher of safety; he sets an example by observing all safety precautions himself; he teaches safety as an integral part of each training unit; and he plans every job with safety in mind.

Showing concern over the health and physical welfare of subordinates also pays off productionwise. It adds to a subordinate's self-esteem and increases his respect for the supervisor–in short, it is one of the elements of motivation.

Cooperation

The necessity for developing cooperation between the members of a supervisor's own unit goes without saying. Some supervisors, however, tend to overlook the necessity for cooperation in two other directions, which are:

1. Cooperation with management
2. Cooperation with the supervisors of other units.

The work of a survey field party, a drafting room crew, a planning and estimating section, or a quality control section is nearly always related to the work of all the other units in the battalion. It is particularly essential, therefore, that supervisors of these units develop the cooperation listed in (1) and (2) above.

Common Mistakes in Supervision

In learning any job, learning what NOT to do is often as important as learning what to do. The following are some common mistakes which new supervisors tend to make, and which a new supervisor should avoid.

1. "New broom" tactics, or going into the new billet with the loud assertion that "everything is going to be different around here from now on." This attitude overlooks a very potent human tendency called "resistance to change." There is no doubt that most people tend to resent and fear change. Therefore, a new supervisor should give the impression, not that everything will be different, but that everything will remain the same. Necessary changes should be made later, and gradually, after the initial change of a new supervisor has been accepted by subordinate personnel.

2. Conspicuous assertion of authority. This is resented at any time, but it is particularly watched for and resented in a new supervisor.

3. Playing favorites. A built-in sense of JUSTICE seems to be an innate human characteristic. Playing favorite outrages this sense of justice, and is one of the most common causes of resentment toward a supervisor.

CONTROLLING

Controlling, the fourth element of administration, includes all of the techniques that a supervisor uses to check on the work of his men. Probably no other task of the supervisor causes so much resentment as controlling. The possible reason is that indiscriminate controls frequently are casually administered and make no distinction concerning the reliability of subordinates. When one feels that he isn't trusted, the incentive to do well drops sharply.

Unity of Command

In order that a supervisor can control his subordinates, he must maintain a UNITY OF COMMAND. Unity of command may be defined as the principle which ensures that each individual in an organization is responsible to ONLY ONE superior. Each individual should be subordinate to, and should report to, only one superior. This principle should be applied in the following two ways:

1. Each man must know from whom he receives orders, and to whom he reports results.
2. Each man must know who the people are (if any) over whom he has control.

To achieve unity of command, lines of communication in the organization must be definite, clear cut, and SHORT. Organization charts should be prepared, as well as a list of the duties and responsibilities of each individual in the organization.

Limited Span of Control

The principle of LIMITED SPAN OF CONTROL means the confinement of the span of control of each supervisor within reasonable limits of personnel, distance, and time, while at the same time not reducing these limits below the supervisor's reasonable capacities.

The reasonable number of people supervised will vary, of course, with the nature of the activity; but the general average seems to be not fewer than three nor more than seven subordinates. A supervisor stationed over less than three subordinates is usually not making full use of his capacities; one supervising more than seven is often unable to supervise them all efficiently.

Similarly, it is unwise for a supervisor to locate a subordinate either too close or too far away. Having a subordinate too close usually results in oversupervision. Oversupervision means interference with the work of the subordinate, to the extent that he develops the habit of doing only what he is specifically told to do. Locating a subordinate too far away, on the other hand, may result in undersupervision, with the result that the subordinate begins to function too independently. The ideal distance is the one which minimizes both oversupervision and undersupervision; it is a matter which requires judgment rather than actual measurement of distance.

With regard to the time element involved in the principle of limited span of control, the four principal types of supervisory duties should be considered. These are ROUTINE, REGULAR, SPECIAL, and CREATIVE duties. Routine duties are those which a supervisor may assign to subordinates; the typing of notices is an example. Regular duties comprise the normal supervisory activities related to the mission of the unit. Special duties relate to special assignments, outside the regular run; these may be assigned by a superior, or they may be initiated by the supervisor himself. Creative duties involve actions taken on the supervisor's own initiative to improve the quantity and quality of the work.

TRAINING

The factors which contribute most to superior accomplishment of any mission are the training of personnel and the availability of materials and equipment; neither can be said to be more important than the other. Training challenges the ingenuity of, and requires enthusiasm from, all persons in the naval service. As a supervisor, you must always find time to train the men under you, in order to improve their skills, knowledge, and attitudes. You will accomplish various tasks through the effort and cooperation of your subordinates. It follows that each subordinate must be given the proper training required for the efficient performance of his own particular subphase of the overall task.

On-the-Job Training Methods

On-the-job training may be given in a variety of ways, among which are the following:

1. By giving orders. When a subordinate is given a new assignment, the supervisor tells him what to do, when, where, and perhaps how to do it; and why it should be done.
2. By giving PIECEMEAL instruction. The supervisor provides information to the subordinate at the latter's request, or he sees the subordinate doing something incorrectly and corrects him.
3. By the orientation and indoctrination of new subordinates.
4. By explaining rules and procedures to individuals or to groups on the job.

In brief, the supervisor carries out his training function by giving both organized and unorganized on-the-job instruction.

Job Breakdown

Your first approach to the training problem must be the JOB BREAKDOWN—that is, the analysis of each individual job to determine the steps it involves and the logical sequence in which these steps are performed. It is a good idea to prepare a LESSON PLAN, which is simply a list of the above-mentioned steps, arranged in order of performance.

Each of the steps should comprise a TEACHING UNIT, and each unit should be presented to the trainee in a way that shows its significance in the total task.

The lesson plan should show:

1. The name of the operation being taught, with the specific action specified, as "preparing," "checking," "determining," "recording," and the like.
2. Procedural steps, in order of performance.
3. Key points about each step. List here everything about each step which the trainee should know–including mistakes to be avoided, terms which should be learned, troublesome points, danger points, safety precautions, procedure for use and care of equipment, and methods of checking work.

Theory of Learning

The generally accepted theory of learning is the STIMULUS-RESPONSE theory, which holds that all learning is the result of a trainee's responses to external stimuli. External stimuli are things which affect the trainee's physical senses, the chief of which are the senses of SIGHT, HEARING, FEELING, TASTING, and SMELLING. There are two steps in the learning process: (1) the sensory stimulus, whatever it may be, and (2) the trainee's response to it. Response is not necessarily a consequence of stimulus, and part of an instructor's job is to ensure that the stimuli he provides produce the desired responses. This trainer activity is called MOTIVATION.

In the stimulus-response theory of learning there are two considerations of importance to an instructor, as follows:

1. The more senses stimulated, the better the chances of learning. The fact should be mentioned that about 75 to 80 percent of all learning takes place through the sense of hearing, which leaves only a small residue for feeling, tasting, and touching. Now, in telling you make use of only one trainee sense–hearing. But, if you combine telling with showing (by demonstration, visual aids, and the like), your instruction is a great deal clearer and more effective.
2. The more vivid the stimuli, the better the chances of learning. Colorful visual aids, striking demonstrations, dramatic presentations–these make for the best instruction.

Major Laws of Learning

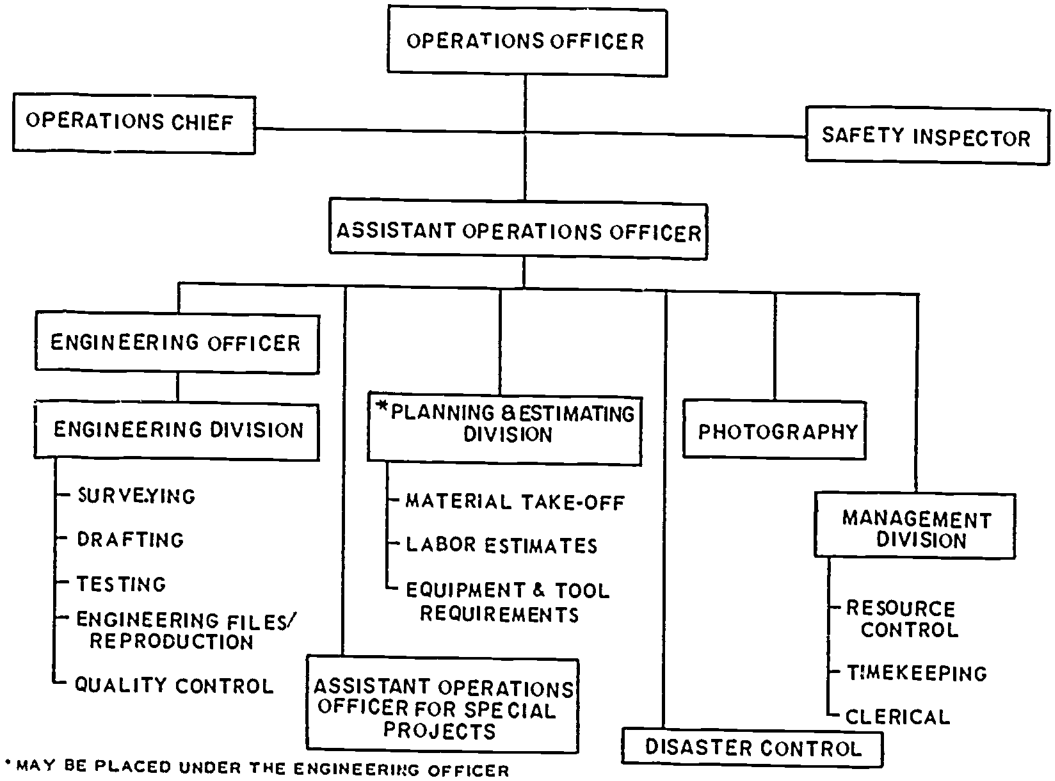
There are three training principles which have come to be called the MAJOR LAWS of learning, as follows:

1. The law of READINESS, which holds that a trainee learns easily when he is interested in the subject and desires to learn, but learns with difficulty or not at all otherwise. Instructor techniques relating to the law of readiness are to:
   a. Provide interest.
   b. Provide a proper background.
   c. Create a desire to learn, by calling attention to any incentives like pay increase, promotion, and recognition.
   d. Hold out hope of early success.
   e. See that the trainee has a knowledge of results.
2. The law of EFFECT, which holds that a trainee learns quickly when learning gives him a sense of satisfaction and accomplishment. The instructor, therefore, should make learning appear to be worthwhile, and should give praise and encouragement.
3. The law of EXERCISE, which holds that learning must be fixed by repetition.

OPERATIONS DEPARTMENT (S-3)

The following sections discuss the typical organizations and functions of EA groups in the Operations Department. The organization of a SEABEE Operations Department–be it in a staff, in a battalion, or any other detached unit–is similar in basic composition, with minor variations to suit the type of unit, its mission, and the prevailing conditions. Because of the great variety of missions, localities, and conditions under which the SEABEES operate, the general attitude of the Navy is to allow the CO more flexibility in the organization of the battalion under his command to permit the maximum utilization of his men and materials. The Operations Department, in turn, is organized along this line of thinking by the Operations Officer.

Figure 2-1 presents a typical organization chart of a Naval Mobile Construction Battalion



82.145(82B)

Figure 2-1.—Standard NMCB Operations Department Organization.

Operations Department. Due to rapid changes in technology and varied missions of the SEABEES, this functional chart will only serve as a guide for manning the NMCB Operations Department. This organizational chart could be expanded or modified to suit the mission of the unit and the availability of personnel to fill the billets. In this chapter, we will limit our discussion to the Operations Department of a U.S. Naval Mobile Construction Battalion. The information is taken mainly from *Naval Construction Forces Manual*, NAVFAC P-315, and some actual observations currently prevailing in the NMCBs of today.

OPERATIONS OFFICER

By this time, you should already be familiar with the various duties performed by the Operations Officer. By merely observing his daily activities in your unit, you should be in a position to enumerate his multitudinous duties and functions. As you already know, the Operations Officer is usually the third-ranking CEC officer in the battalion. He is responsible for coordinating the activities of elements of the battalion when they are engaged in performing task assignments under any type of mission, be it amphibious, construction, defense, or disaster control. These responsibilities include recommending the task organization, establishing priorities for allocation of resources, adjusting assignments to battalion units, and keeping the Commanding Officer informed of the situation as it develops.

As an EA1 or EAC, you should be aware of the Operation Officer's various responsibilities, for your knowledge of them will assist you in planning ahead and in accomplishing your tasks efficiently. The following are some of his specific duties:

1. Performs liaison on task assignments with the command having operational control over the battalion, and may assist higher commands in planning the work to be performed by the battalion.

2. Studies each Operation Plan or order directed to the battalion for execution and analyzes the arrangements for logistics support, requesting changes where necessary.

3. Determines status of drawings, specifications, area intelligence, etc., influencing each assignment and directs design and site adaptation for projects assigned to the battalion.

4. Determines specific camp facilities needed by the battalion for the deployment, and either arranges for accommodation of the battalion at existing bases or plans for the construction or improvement of the battalion camp.

5. Instructs battalion reconnaissance parties and advance parties, setting priorities for information to be gathered or indicating the work to be done before the main body arrives.

6. Supervises surveys, site adaptations, quantity takeoffs, bills of materials, labor and equipment estimates, shop drawings, and other engineering work assigned to the battalion.

7. Supervises the development of network analysis systems for all planned projects; estimates workload on each rating and class of equipment, recommending the distribution of personnel throughout the battalion, and requests extra manpower and equipment as needed.

8. Selects construction methods and issues job orders for all construction work to be performed by the battalion, keeping close check on the execution of these job orders from the standpoint of deadlines, manhours and machine-hour expenditures, safety, and quality of workmanship.

9. Reassigns work, reschedules work, or otherwise revises battalion job orders. maintains rapport with liaison officer from the higher echelon unit and advises the Commanding Officer on the effect of changes in any job order.

10. Coordinates the work of the battalion and arranges for the employment of local labor and use of local materials when approved.

11. Supervises compilation of manpower and equipment utilization records and drafts monthly operations reports, project completion reports, and other reports on operations for approval of the Commanding Officer; and, briefs visiting higher authorities or dignitaries when directed by the Commanding Officer

12. Coordinates the use of the teams in the engineer and transportation elements in disaster control operations.

13. Assists the Training Department (S-2) to devise the overall battalion training plan by providing guidance as to operational requirements and deficiencies.

After going through the above responsibilities of the Operations Officer, you may think that most of them do not really concern you; however, there is always the chance that you will get involved being the senior EA in the Operations Department. The Operations Officer needs various data, references, computations, and other information; you will be the collection point or monitor and in turn channel information to him or his assistants. It is important that you develop the ability to digest various data and convert them to intelligible materials that will best serve the purpose required by the Operations Officer.

SAFETY INSPECTOR

The Safety Inspector, or SAFETY CHIEF, is under the direct supervision and control of the Operations Officer, who is assigned the functional responsibility for the NMCB safety program. The safety program is of primary importance to the unit's mission, and is a full time responsibility. The Assistant Operations Officer or the Engineering Officer usually has the collateral duty of Safety Officer. The Safety Officer is assisted in his duties by the Safety Chief. The Safety Chief should be one of the top Chief Petty Officers in the unit, and one who will vigorously administer and supervise the unit's safety program.

The Safety Officer is responsible for the following:

1. Conducting a continuing and aggressive accident prevention program, both on and off the job.

2. Formulating a safety training program in coordination with the Training Officer.

3. Maintaining a safety library prescribed by COMCBPAC and COMCBLANT.

4. Maintaining cognizance of the procurement and maintenance procedures for required safety equipment.

5. Conducting jobsite inspections to ensure that proper safety precautions are being observed.

6. Investigating and analyzing all accidents so that measures can be taken to prevent their recurrence.

7. Compiling reports concerning accidents which occur at the jobsite.

The Safety Officer has the authority, delegated by the C.O., to stop work or practices involving an unsafe condition or a safety hazard. He directs an investigation of the hazardous situation and does not permit work to resume until it is safe to do so.

The Safety Chief has the authority to direct immediate correction of unsafe practices or conditions in the camp or at the jobsite when a safety hazard or violation is involved. He, too, has the authority to stop work due to unsafe practices or conditions, and should inform the Operations Officer and Company Commander of the situation.

OPERATIONS CHIEF

The OPERATIONS CHIEF is normally a senior enlisted man who serves in an advisory capacity to the Operations Officer. The position of Operations Chief is usually assigned to a Master Chief Constructionman (CUCM). The EA rating being a source of this compressed rate, you may eventually find yourself occupying this coveted position. The Operations Chief may also be an experienced Senior Chief Petty Officer. The position of Operations Chief requires a man of high calibe- and broad experience. He is a man who excels in leadership, human relations, ingenuity, resourcefulness, and initiative. Normal responsibilities of the Operations Chief are:

1. He is leading CPO of the Operations Department and is responsible for discipline and military duties of the department's enlisted personnel.

2. Keeping abreast of all assigned projects from the initial planning phase until the project's completion, and required reporting after customer acceptance.

3. Maintaining constant liaison with the Material Liaison Officer on project priorities to assure control of project materials.

4. Coordinating equipment assignment among various projects with Alfa Company as priorities dictate.

5. Approving field changes within the scope established by the Operations Officer.

6. Conducting customer and command liaison by project as prescribed by the Operations Officer.

7. Carrying out the construction quality control program responsibilities by constant inspection and testing.

8. Administering the battalion tool kit inventory and inspection program in accordance with COMCBPAC and COMCBLANT directives and local command implementing directives.

9. Coordinating and scheduling portland cement concrete and asphaltic concrete requirements.

10. Interviewing new personnel to determine training, experience, and construction skills; and recommending company, detail, or special assignments for approval of the Operations Officer.

MANAGEMENT DIVISION

The Management Division of the Operations Department may be headed by the Operations Chief, acting in an advisory capacity to the Operations Officer and the Operations Staff. The Management Division may also be headed by the Assistant Operations Officer. 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, the Monthly Operations Report, the Weekly Construction Status Report, and any other special reports which may be 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, and others may require special investigation and research.

For example, let us take the preparation of a Monthly Operations Report. Each battalion submits a monthly report of operations to either COMCBLANT or COMCBPAC (depending on what theater of operation it is in). Copies are sent to the Commander, NAVFAC, and to administrative, military, and operational commanders concerned. This report is a concise review of the battalion's activities during the month, regarding accomplishments, problems, and capabilities. It includes such information as planning, construction, welfare, morale, discipline, safety, training, and equipment. The numbers of officers and enlisted men are shown for the battalion, and for all detachments, specifying the method of movement.

Enclosures to the monthly report are specified by the Commander, Naval Construction Force. The following are generally included:

1. Progress and performance reports
2. Progress photographs
3. Labor distribution reports
4. Financial reports
5. Equipment status reports
6. Training reports
7. Summary of important events that occurred in the battalion during the reporting period.

There are detailed instructions covering the preparation of the Monthly Operations Report and other reports, so your only problem is the compilation of the data that will go with them.

Besides the aforementioned reports, the Management Division Head is responsible for.

1. Maintaining a complete status folder on each project.

2. Maintaining complete and accurate timekeeping records and labor analysis reports.

3. Maintaining and updating visual status boards required for effective construction management including. (a) company personnel strength, (b) project status, (c) labor analysis, and (d) project schedules.

4. Preparing project completion letters in accordance with applicable instructions from higher authority.

5. Maintaining constant liaison with the Material Liaison Officer.

The Management Division must maintain constant coordination and must work closely with the Planning and Estimating Division and the Deployment Planning Team. Depending upon the organizational structure, the Planning and Estimating Division may be under the Engineering Officer, or it may be under the direction of the Assistant Operations Officer or the Operations Chief. Regardless of the organization, the Management Division must be in constant contact with the Planning and Estimating Division on the technical aspects of the project, progress reports and master scheduling.

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 design necessary for the successful conduct of the construction program. Their specific responsibilities are as follows.

1. Providing guidance and support to the Deployment Planning Team.

2. Reviewing all plans for sound engineering practices and practicability of planning.

3. Resolving field problems relative to errors or revisions in design with the consent of the proper authority.

4. Briefing Company Commanders on engineering aspects of new projects.

5. Liaison with the customer concerning engineering and design.

6. Liaison with the Management Division and the Planning and Estimating Division, if they are

not organizationally under the Engineering Officer.

The Engineering Division is also responsible for, and renders technical support in, the following areas:

1. Provides construction inspection by the Engineering Officer to ensure that projects are built in accordance with the plans and specifications, and that quality workmanship prevails at all times. In this respect, the Engineering Officer is responsible for maintaining a continuing and aggressive quality control program. The responsibility for quality control is vested in every member of the construction organization, down to the man on the job.
2. Providing survey services for the companies as required.
3. Providing up-to-date drawings and specifications for projects in progress.
4. Providing soils and materials testing and evaluation services.
5. Maintaining as-built drawings and providing copies, as appropriate, to customer commands.

Engineering Chief

The EAC, when assigned to an NMCB, will normally have a wide range of duties and responsibilities, depending on the organization of the Operations Department. Usually he is directly under the Engineering Officer. He is responsible for the supervision of the drafting section and field surveying. In addition, the EAC may supervise either the Quality Control Section, the Planning and Estimating Section, or both sections. The EAC is usually assigned the responsibility of cleanliness and order of the Operations Department working spaces.

For military organization, Operations Department personnel, not assigned to the battalion staff, are assigned to Headquarters Company. Normally, if the EAC is senior CPO in the Operations Department, he will act as a Platoon Commander or Platoon Chief, with the Operations Department personnel organized into his platoon. Therefore, in any company matters, the EAC would be responsible for the actions of the entire Operations Department personnel.

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 non-standard materials, design new structures, and perform other design work. All major work designed by the NMCB must be approved by the command which exercises operational control. In nearly every case, the NMCB prepares "As-built" drawings of all constructions performed by the battalion.

Most of the above functions 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 such 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 desk job that requires a man of superior administrative and supervisory abilities. At times your workload might be piled up so high that you will never finish without working overtime, however, there are times that you might not have enough work to go around. These extreme situations may be avoided by proper planning and work distribution. The best method is to prepare a list of all major jobs to be done (preferably according to priorities), and another list of minor jobs. Naturally, you should try to channel most of your manpower in accomplishing the major jobs first, and during slack times, give out the minor jobs or fill-in jobs for accomplishment.

Drafting supplies and equipment must be inventoried periodically or from time-to-time, in order to maintain a reasonable supply level at all times. If possible, appoint one EA as your Supply PO in the section, who will perform such function as a collateral duty. He prepares requisitions for drafting supplies as needed, and keeps you informed of any breakdown in equipment that needs repairs or replacement. These drafting supplies and equipment are your primary tools for production, hence, they should be kept in proper level at all times to avoid delays.

For the reproduction machine (generally ozalid), it is a good idea to have some reserve spare parts for those parts that break down often, i.e., have a good supply of applicable fuses, roller guide plates, spare belts of right sizes, spare lamps, filters, and the necessary cleaning and lubricating substances for proper maintenance. Most of all, have 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. Fifty square feet of floor space per man, exclusive of storage space, is generally considered a minimum in most shops. A length-to-width ratio of about 2.1 is desirable for a drafting room, because this ratio facilitates the arrangement of drafting tables and provides for good lighting. North-exposure windows are best for admitting daylight in the northern hemisphere. It is important that the lighting in the room be adequate, both as to quality and intensity. However, take care to avoid placing working areas in positions where they will be subjected to the glare of direct sunlight.

An important factor to consider is the conservation of vision, since excessive light, as well as inadequate light, induces severe eyestrain. Usually excellent artificial lighting is achieved by the use of portable adjustable lamps, which can be clamped to the drawing table and moved so that the light falls in such a way as to minimize shadow and glare.

When you arrange the drafting room, try to separate work areas and storage space. Keep materials and instruments which are not in use in easily accessible cabinets, and see to it that it is not necessary for someone to walk around a man who is working in order to reach them. 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 which each man is trained to do all the different job phases, and the same man carries a drawing through from inception to finish. However, a senior man may occasionally be assigned as checker and editor, and routine tasks (such as lettering, tracing, and insertion of corrections) may be assigned to junior men and strikers. But for efficiency in training and to sustain interest and morale, you should maintain enough rotation to ensure that each man gets enough experience.

FILING 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. Below are a few suggestions.

Drawing numbers are assigned to drawings by various bureaus, each bureau assigning drawing numbers to those drawings for work over which it has cognizance. The only exceptions are drawings which have only a limited, local application.

Here are two file classification possibilities, then. by issuing agency and agency drawing number. However, this makes for rather large and unwieldy categories, since there are relatively few issuing agencies. Therefore, it is better to include with these two a third category, which might be a division into architectural, structural, mechanical, and electrical drawings. This is somewhat complicated by the fact that the same drawing is often both architectural and structural, or both mechanical and electrical; but you can take care of this in your card file.

The card file is the key to locating drawings in the drawing filing cases. A card file must be fully cross-referenced–meaning that for the same drawing there should be a card which lists the drawing by title, another which lists it by issuing agency and number, another which lists it by character (i.e., architectural, structural, and the like), another which lists it by job or project (if appropriate), and so on.

In addition to the general file, there should be a current file containing prints which are currently in actual use on current jobs. Obviously, this file will group prints by job category. Generally, they are kept on stick files and marked accordingly.

There should be an individual 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 never be removed from file except by specific order of the supervising EA. About the only time removal is necessary is for reproduction purposes.

Prints issued to constructors should be logged out, by recording the date of issue and the individual to whom issued. The principal purpose of this is to make it possible for you to inform constructors of any changes which must be made to prints they are using in the field.

REPRODUCTION ROOM.–Good ventilation is always a requirement for a room containing any type of reproduction equipment; for a room containing ammonia-vapor equipment, ventilation is of vital importance. The room must be free from dust and provisions must be initiated to maintain clean, dust-free surroundings. If possible, an air-conditioned room is highly recommended for this purpose.

Before a new reproduction machine is operated even before it is installed in place - the manufacturer's handbook must be studied carefully. The instructions it contains (both for safe and efficient installation and for safe and efficient operation) must be as carefully followed.

As stated previously, light-sensitive materials must be stowed in light-tight spaces. The original containers of such materials are light-tight - therefore, the materials should remain in these containers as long as possible.

DRAFTING ROOM LIBRARY. The Drafting Room Library should not be confused with the Engineering Technical Library. It is a part of the Engineering Technical Library. One of the EAs working in the drafting room may be assigned the responsibility of maintaining the complete Engineering Technical Library.

The procedures, practices, and conventions which must be followed by Engineering Aids are prescribed in NAVFAC publications and in Military Standards, and a collection of the appropriate publications and standards constitutes the Drafting Room Library. A NAVFAC publication may be designated as P (for "publication"), as TP (for "technical publication"), as MO (for "maintenance and operations manual"), or as DM (for "design manual"). Available publications are listed in the *NAVFAC Documentation Index*, NAVFAC P-349, (updated semiannually). A stock column gives you a symbol which, referred to a key on the inside cover, tells you the supply point from which you can order each publication.

Publications (minimum) which should be in the Drafting Room Library are as follows:

DM-6	*Drawings and Specifications*
P-74	*Instructions for Architect - Engineer Contractors in the Preparation of Drawings, Specifications, and Cost Estimates*
P-272	*Definitive Drawings for Naval Shore Facilities*
P-315	*Naval Construction Force Manual*
P-349	*NAVFAC Documentation Index*
P-357	*Abstracts - Design Manuals, MO Manuals and Related Publications*
P-385	*Planning Navy Advanced Bases*
P-405	*Seabee Planner's and Estimator's Handbook*
P-437	*Facilities Planning Guide*, Vol. 1 and Vol. 2 (supersedes P-140 and P-103)

Military Standards are procedural instructions published by the Department of Defense and required to be observed by all the Armed Services. Available standards are listed in the Department of Defense publication *Index of Specifications and Standards*, which consists of two basic parts (I and II), published annually in July and kept current by the periodical issuance of cumulative bimonthly supplements. The Index lists a vast number of specifications. The standards it lists are considerably fewer and rather difficult to find. Moreover, standards are frequently superseded by later standards, and you must know that the standard you are using is the one that is current. A superseding standard is given a letter in addition to the standard number, for example. MIL-STD-100, *Engineering Drawing Practices,* has been superseded by MIL-STD-100A, same title.

To determine whether or not a particular standard is current, proceed as follows: First look up the standard in the alphabetical listing of the current basic Part I or II of the *Index*. If the listed number (and letter, if any) is the same as the one on your standard, then the standard was current at the time of publication of the basic part. Next, look up the standard in each cumulative monthly supplement. If it doesn't appear there, there has been no change. If it does appear, the new letter will be shown, and you should at once order the new standard. Military standards may be ordered from the Commanding Officer, U.S. Naval Publications and Forms Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120.

A Drafting Room Library should contain the following Military Standards:

MIL-STD-12C	Abbreviations For Use On Drawings And In Technical-Type Publications
MIL-STD-14A	Architectural Symbols
MIL-STD-15-1A	Graphical Symbols For Electrical And Electronic Diagrams
MIL-STD-15-3	Electrical Wiring Symbols For Architectural And Electrical Layout Drawings (Part 3 of 15-1A)
MIL-STD-17B	Mechanical Symbols
MIL-STD-18A	Structural Symbols
MIL-STD-20	Welding Terms and Definitions
MIL-STD-100A	Engineering Drawing Practices

In addition to the above Military Standards, the Drafting Room Library should have the following standards:

AWS 2.0-61	*American Welding Society Standard Symbols.*
USASI Y14.5-66	*Dimensioning and Tolerancing for Engineering Drawings.*

Besides the aforementioned publications, the draftsman will have the entire Engineering Technical Library at his disposal. The Engineering Technical Library contains various commercial technical design manuals of interest to the draftsman, such as the *Architectural Graphic Standards,* current edition.

CHECKING AND EDITING (DRAFTING).--Every drawing prepared in the drafting room must be checked and edited, there is a space on every title block for the insertion of the name of the checker and editor. Checking means inspection to ensure that all data given in the drawing source of data (which may consist of sketches, written data, field survey notes, another drawing, or combinations of these) are correctly and accurately shown on the drawing. Editing means inspection to ensure that all the procedures and conventions prescribed in relevant NAVFAC publications and Military Standards are followed. It might be said that editing begins as soon as the drawing begins—meaning that you or a designated subordinate must maintain a constant editorship to ensure that proper procedures and conventions are followed at the time drawings are made.

A checker and editor must be thoroughly familiar with both drafting and structural practices. You may assign a capable subordinate to the job, but remember that the responsibility remains with you.

A draftsman who is capable of making a complete drawing from data is called a DETAIL draftsman—this distinguishes such a draftsman from less qualified members of the crew whose work must be confined (during training) to tracing, lettering, correction-making, reproduction-machine operating, and the like. When a detail drawing assignment is made, the draftsman may be given a sketch. Before drawing begins, the sketch itself should be checked, to ensure that it correctly shows everything needed to make the drawing.

A finished detail drawing is usually checked on a print of the same, on which the checker makes his corrections, if any; he may use red, yellow, or other colored pencil to indicate his corrections on the blueprint. When the detail draftsman has made the corrections indicated on the print, the checker compares the corrected original with the print to ensure that all corrections were made.

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

1. Will the drawing reproduce well meaning. are the line weights such as to satisfy the requirements of the reproduction process to be used?
2. Does the drawing meet Military Standard requirements as to format?
3. If references to other drawings are required, have these been set down?
4. Is the drawing number correct?

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

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, current Military Standards?
5. Is the drawing made to proper scale, and is the scale indicated?
6. Do the dimensions agree with those in the data source? And does the sum of partial dimensions equal the overall dimension?
7. Are all required dimensions shown?
8. Are all necessary explanatory notes given?
9. Are all figures and letters properly formed?
10. Do terms and abbreviations follow the requirements of Military Standards?

TRAINING DRAFTSMEN.–A detail draftsman must know just about all there is to know about prescribed conventions, procedures, and practices before he can be assigned to a detail (i.e., complete drawing) job. The best way to train new men 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. Basic procedures and conventions are covered in MIL-STD-100A, *Engineering Drawing Practices.* A study of typical drawings in P-437, *Facilities Planning Guide,* is particularly helpful, other typical drawings and conventions could be found in the *Architectural Graphic Standard.*

WORK ASSIGNMENTS AND WORK SCHEDULES. One of the most important responsibilities you will have as a drafting room supervisor is that of assigning the work to men who can do it. In order to be able to do this you must understand the work, you must know exactly what you are asking a man to do and how it should be accomplished. You must also know the man's capabilities.

A man may be proficient at one thing and not at another. He may be able to work well on a project that requires cooperation with others, or he may work best alone. The varied aspects of his responsibilities and character should be taken into consideration in assigning work.

As an EA1 or EAC, the chances are that you have had some experience with most of the work done by a SEABEE draftsman. At one time or another, you will have had to sit down and prepare a drawing similar to the one you will be assigning to a man under you. Or if you haven't had the experience yourself, you probably sat beside a man who did; and if you were alert to your opportunities, you profited by his experience.

But there is more to it than that. You must learn, as a supervisor, 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 to make sure that (1) you get all the information needed for the job from the person requesting it, and (2) you can pass this information on to the man to whom you assign the job.

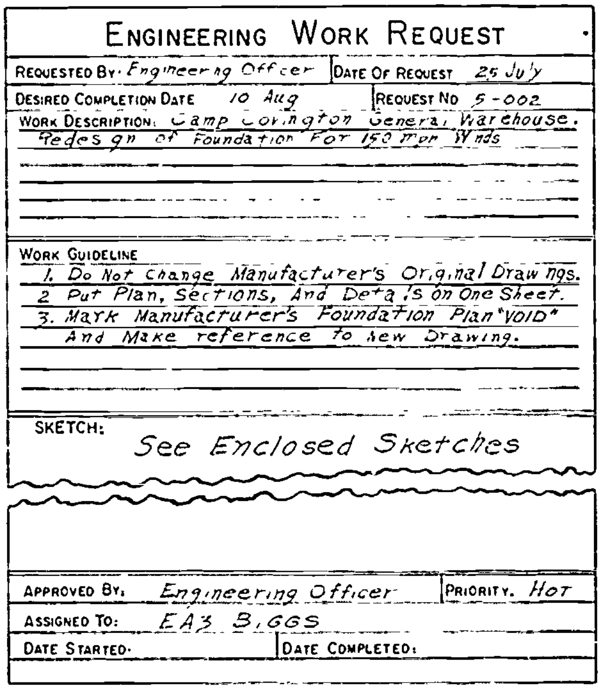
Suppose, for example, that the Operations Officer has tasked the Engineering Officer with the modification of a standard manufacturer's pre-engineered metal building foundation design to withstand wind forces of 150 mph. The Engineering Officer has prepared sketches from his calculations. He has given the sketches to you for preparation of construction drawings. You should first study his sketches to make sure you fully understand them. Ask the Engineering Officer to clarify anything you don't understand. Add notes to the sketch which will enable the man in the field to 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 man you are assigning the work is experienced, the sketches and a few guidelines will be sufficient. But if he 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. He must be encouraged to ask you questions and you must check his work as the drawing progresses. You must find his mistakes early to eliminate redoing the entire drawing. Mistakes, which are the fault of poor supervision, will greatly demoralize an inexperienced draftsman.

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 2-2. An ample supply of these request forms should be kept by the Engineering Officer and by you. This work request form could be used for work performed by all of the sections within the Engineering Division. 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 man assigned to accomplish 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 man assigned to do the work.

Work requests will 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 you, as the supervisor, will be held accountable for work progress by the Engineering Officer, who reports directly to the Operations Officer.


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 Briggs

DATE STARTED: | DATE COMPLETED:

5.144E1

Figure 2-2.—Typical Engineering Division work request.

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 2-3. This schedule will keep the Engineering Officer informed as to your workload and work progress. The work schedule will aid him in deciding on priorities for rush jobs.

Do not allow your men to assign priorities to work. Only you, the supervisor, should be responsible for assigning priorities, or the Engineering Officer when rush jobs or top priority jobs are requested.

Field Engineering Section

Under the Engineering Chief, the Field Engineering Section is generally supervised by an

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

82.217

Figure 2-3.—Typical drafting work schedule.

EA1. The Field Engineering Section performs such field engineering work as follows.

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 record (as-built) drawings.
5. Measurement and computation of earthwork quantities.
6. Reduction of survey notes.
7. Calculations for establishing line and grade.
8. Plotting survey data.
9. 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 Survey Party Chief, your responsibilities will include the formation of different survey parties. As you know, a survey party is organized and designated as to the type and purpose of the proposed survey. Whatever the scope and purpose of the survey, your main concern is to plan the job ahead.

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 if in a wartime situation?

A large construction project requires continuing survey activity—that is, the surveying can seldom be done in a single operation. Very often phases of construction surveying 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 task, 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 are probably already familiar with typical party organization, the following is merely a refresher.

RECONNAISSANCE PARTY: The manning level of a reconnaissance party is a very flexible one. The number of personnel will depend upon the purpose of the reconnaissance survey, engineering data required, terrain features, and mode of transportation. We have reconnaissance surveys for triangulation stations, routes, airfield, and base sites, each one of these should be treated independently in planning. One consideration that will also 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 men. instrumentman, head chainman, and party chief. The party chief is usually the notekeeper, and he may double as rear chainman, or there may be an additional rear chainman. The instrumentman operates the transit, the head chainman measures the horizontal distances, and the party chief directs the survey and keeps the notes. 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 when the dimension is called off to him.

STADIA PARTY. A stadia party should consist of three men. instrumentman, notekeeper, and rodman. However, two rodmen should be used if there are long distances between observed points, so that one can proceed to a new point while the other is holding on a point being observed. The notekeeper records the data called off by the instrumentman, and makes the sketches required.

PLANETABLE PARTY. A planetable party should consist of at least three men. instrumentman (sometimes called TOPOGRAPHER), notekeeper, and rodman. Again a second rodman may be used when there are long distances between observed points. The notekeeper records the data called off by the instrumentman and reduces the data to corresponding horizontal distances and elevations, on the basis of which the topographer does the plotting. The rodman must be trained to recognize and properly occupy the necessary control points.

LEVELING PARTY: Two men, 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 2-4 shows the type of information entered on the work assignment sheet. The party here was Field Party #3, consisting of an EA2, an EA3, and a CN. On 6 February and 7 February they were running profile levels on a project identified as "Hill Road," probably a highway construction project. On 6 February they were to begin at the intersection of Hill Road and By Road and proceed westerly; on the 7th they were to begin at Sta. 65 + 96.1.

On 8 February the party was assigned to building line layout on Bldg. #20, Aviations Operations Building, to be located approximately at Airstrip Sta. 30 + 00. On 9 February they were ordered back to the Hill Road job to take ditch cross-sections, beginning at Hill Road Traverse Station 15 + 09.61.

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

Work Assignment — Field Party # 3					
START: 3 AUG. 1972			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.6,1967	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.7,1967	"	"	"	Sta 65+96.1 ⊙#4	Continuing previous days work.
Feb.8,1967	Bldg #20 Aviation Operations	Bldg. Layout.	Base "S" Comm. Bldg	Approx. Airstrip Sta. 30+00	Includes staking out revetment around structure.
Feb.9,1967	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.

82.2

Figure 2-4.--Part of a surveying work assignment sheet.

sheets, CONTROL POINT sheets, TRAVERSE sheets, and BASE LINE sheets.

Part of a bench mark sheet is shown in figure 2-5. 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 shown in figure 2-6. Traverse and base line sheets give the locations of traverse or base line stations, the latitude and departure of each course or base line, 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 (as described in chapter 5 of this training manual) usually provides a satisfactory abstract.

Part of a PILE LOCATION sheet is illustrated in figure 2-7. This sheet relates to the PILE LOCATION DIAGRAM shown in figure 2-8. This diagram shows the plotted locations of piles in a pier. You can see that 13 5-pile bents have been plotted in, identified by letters from A to M. Each pile is located by triangulation from a segment of a shoreside base line having end points at Control Sta. 6 + 00 and Control Station 9 + 02.15. The centerline of the pier runs from Sta. 7 + 51.08 on the base line, at an angle of 84° to the segment of the base line between the control stations.

The dotted lines from the control stations show how the piles in Bent M (piles 61 through 65) are located by triangulation. The location sheet shown in figure 2-7 shows the angle which should be turned at station 6 + 00 to locate each of these piles. The backsight station is Control Station 9 + 02.15, meaning that the transitman at Sta. 6 + 00 trains his telescope on Sta. 9 + 02.15 and then matches his zeros. To locate pile 61, he turns left to read 47° 08′, to locate pile 62, he turns left to read 48° 24′, to locate pile 63 he turns left to read 49° 39′, and so on. At the same time, a transitman at Sta. 9 + 02.15, using Sta. 6 + 00 as a backsight, is turning a determined angle for each of the same piles. For pile 61, for example, this man turns right to read 45° 00′. When he reads 45° 00′ as the other transitman reads 47° 08′, the lines of sight through the telescope intersect at the location of pile 61.

The surveyor, aside from positioning the piles, may also be required to record pile driving data, and mark piles for cut-off, as specified by the

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)

82.3

Figure 2-5.—Part of a bench mark sheet.

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°20'21" 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

82.4

Figure 2-6.—Part of a control point sheet.

PILE NO.	ANGLE READING AT TRANSIT SET-UP STATION		BENT NO.	DISTANCES		REMARKS
	CONTROL STA 6+00	CONTROL STA. 9+02.15		BENT	PILES	
61	47°08'	45°00'				CUT-OFF ELEV
62	48°24'	44°06'				30.00 ft THROUGHOUT
63	49°39'	43°02'	M	10 0'	5 0'	
64	50°55'	42°10'				
65	52°10'	41°00'				

82.5

Figure 2-7.—Part of a pile location sheet

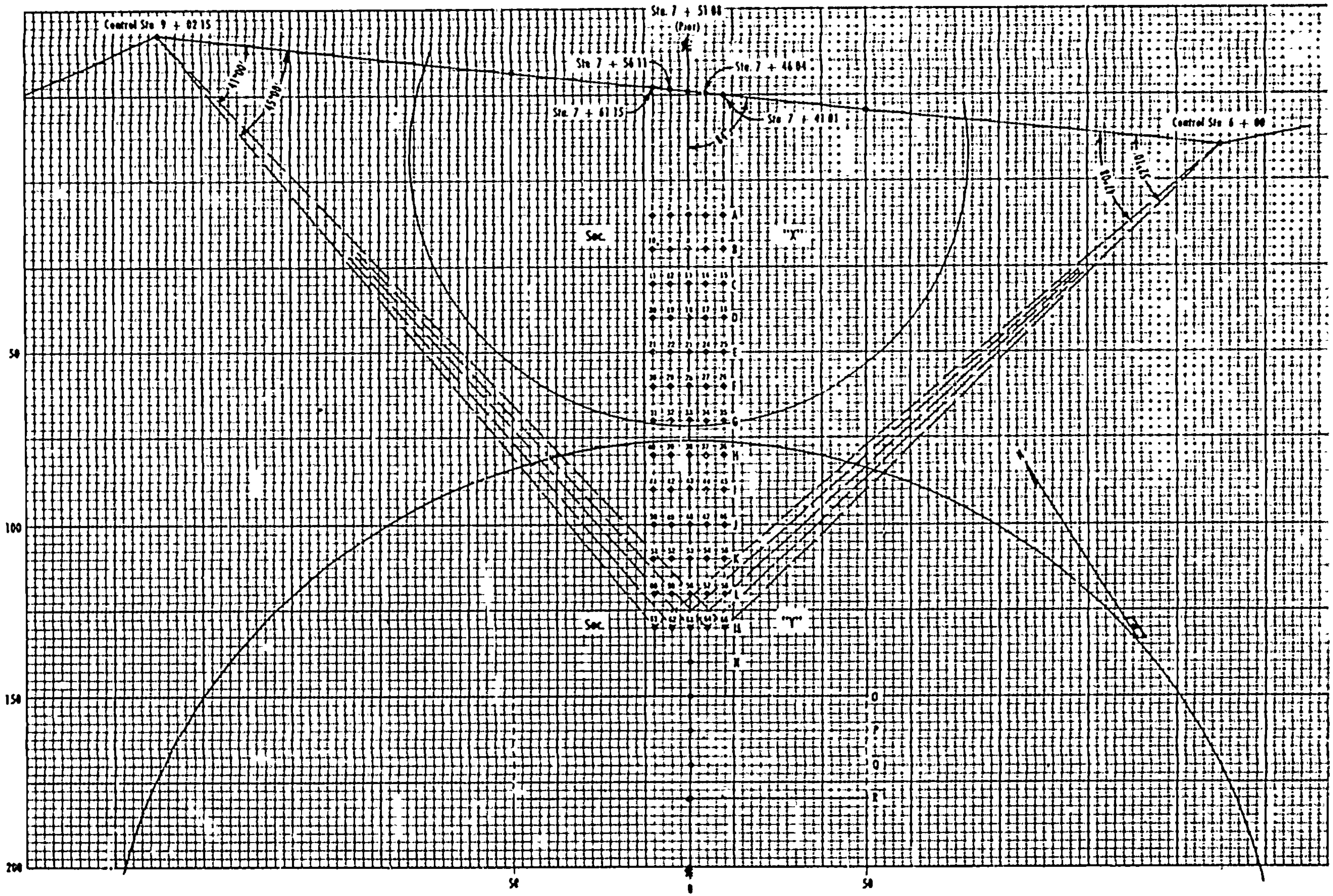
construction plans. During driving, a complete record is kept of the following: location and number of pile, dimensions, kind of pile, total penetration, average drop of hammer and average penetration under last five blows, penetration under last blow, and amount of cut-off. Elevations are marked on the two end piles of the bent and two 3-inch by 12-inch planks are nailed to guide the saw in cutting piles to the specified height. For clustered fender piles, make sure that cut-off points are marked distinctly, call this to the attention of the Builder supervisor to avoid mistakes.

CHECKING FIELD NOTES.–You are already familiar with field and office work, and therefore realize the extent to which the possibility of error is ever-present in surveying. As supervisor, 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 which 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 computing yourself. You can, however, require couputing procedures which will, if they are followed, reveal the existence of errors. For example, you can require that area 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 which 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 which 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 will often make it possible for you to spot a misdrawn contour line arrangement because the arrangement is inconsistent with real-life probability.

TRAINING SURVEY CREWS.–The techniques of the actual operation of surveying instruments are, for the most part, fairly easy to



82.6

Figure 2-8 —Pile location diagram.

learn, and a crewman learns these quickly in the field. However, these techniques are a very small part of the knowledge involved in the art/science of surveying. If a fieldman 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 of training.

The best way to train field men in the other things they need to know is to keep a crew constantly informed of the overall PURPOSE of what is being done. Suppose, for example, that the crew is setting offset grade hubs for a highway. Tell them, as you go along, the procedure by means of which the constructors will use these hubs to bring the subgrade to the desired elevation and to pour the highway surface concrete to the prescribed finished grade. Besides training the crew, this practice will make fieldwork a lot more interesting for everybody including yourself. Furthermore, the work of a field crew is bound to be better accomplished when the crew knows the ultimate purpose of what they are doing.

Another incentive is producing highly motivated field crews is by competition. 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. Naturally, you could determine how proficient they are on how close each crew arrived on the closing B.M. elevation and the time it took each crew to run the circuit. You can also utilize this method in transit work, like timing the setting up 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 on 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 are responsible for knowing the techniques of surveying And the EAs in the field should have a knowledge of drafting. Whenever the workload permits, the Engineering Chief should rotate a few men for short on-the-job training periods. If the men have working knowledge of both surveying and drafting it will create an interest in their work, besides help prepare them 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 intelligence is defined as. that knowledge of the enemy, weather, and geographical features (terrain) required by a commander in the planning and conduct of tactical operations. The objective of combat intelligence is to minimize the uncertainties of the effects which 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, condition, and load limits); existing roads (types, widths, and condition); and topographic mapping, including all pertinent natural and manmade features. In general, a rough reconnaissance survey is performed.

Methods for collecting engineering data will depend on the situation. You may be given a military map and told to take a reconnaissance patrol out to check the accuracy of the map. Or you may be tasked with obtaining data for establishing a suitable construction site for an entire advanced base, which might require the efforts of several survey 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 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*, NAVTRA 10479, chapter 8. The battalion operation order will specify combat intelligence procedures.

Planning and Estimating Section

The Planning and Estimating Section may be a branch of the Engineering Division headed by the Engineering Officer, or it may be a separate division headed by the Assistant Operations Officer or the Operations Chief. In any case, the Planning and Estimating Section functions solely to provide a planning and estimating capability of resources required for the construction mission. Planning and estimating personnel are taken from each of the Group VIII ratings, with exception of the Construction Mechanic rating. The responsibilities of the Planning and Estimating Section are as follows.

1. Preparing material "take-offs," or bills of materials, required for the construction mission.
2. Assisting in estimating tool and equipment requirements necessary to accomplish the construction mission.
3. Assisting in preparing and updating critical path charts and progress schedules for management of the construction mission.
4. Preparing manpower estimates for the construction mission.
5. Receiving and checking shop drawings.
6. Coordinating material requirements between the Material Liaison Officer and the construction companies.

In addition, the Planning and Estimating Section may be organized to operate as a Combat Operations Section and as a Control Plotting Team for emergency recovery operations.

PLANNING AND ESTIMATING SUPERVISOR.—Planning and estimating relates to QUANTITY CONTROL and to PROGRESS CONTROL. Quantity control means the determination of the quantities of materials, manhours, and equipment-hours required to do a job. Progress control means the scheduling of these material, manhour, and equipment-hour quantities—that is, the determination of the times when particular materials, men, and equipment will be required on the job—and the periodical reporting of construction progress.

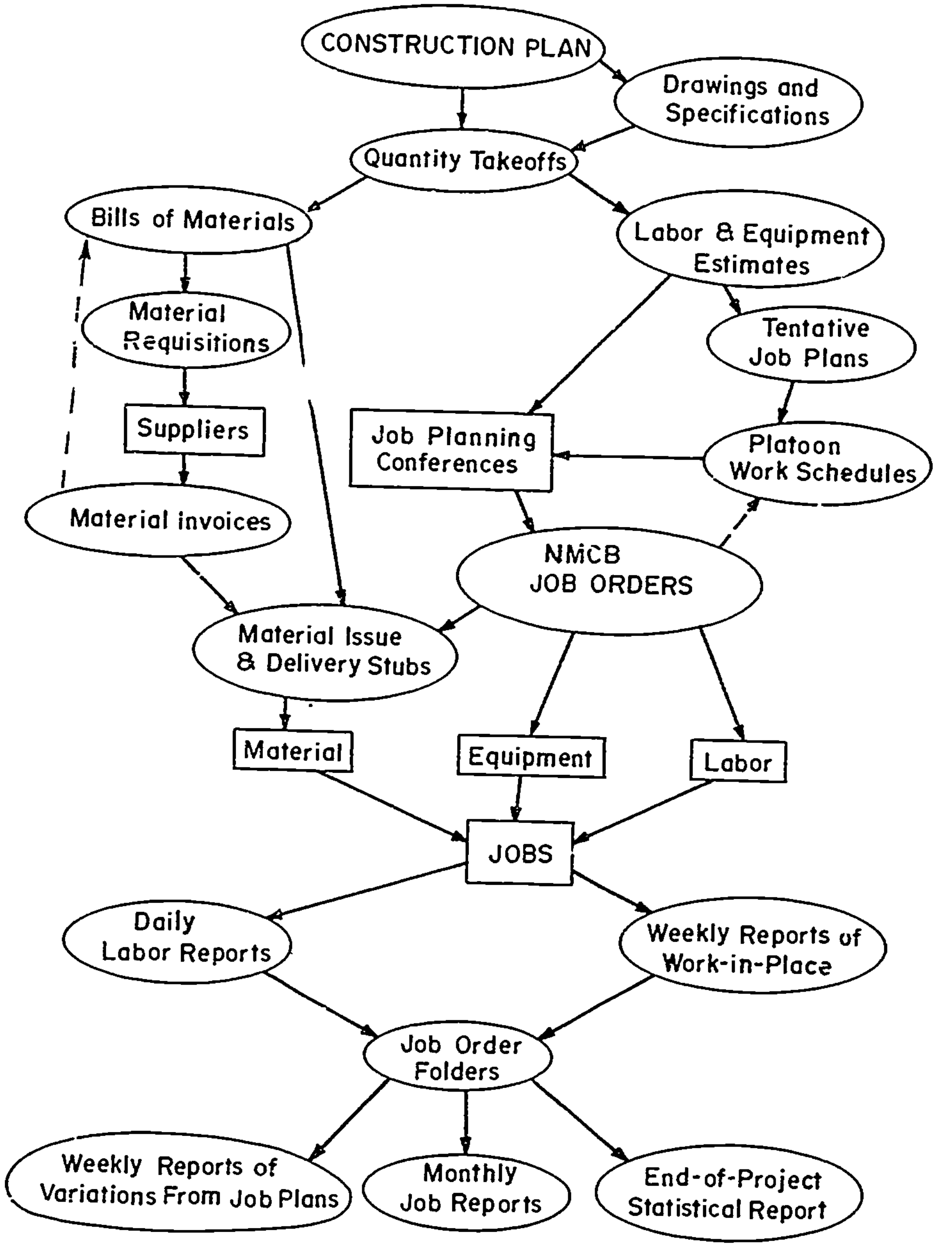
Under the P & E Officer, an EAC or BUC may be assigned as overall supervisor of the P & E Division. Senior rated EAs are sent through P & E schools (usually in their home bases), and are trained in the planning and estimating of materials, manpower and equipment. They are also trained in scheduling, which stresses the importance of the Network Analysis, and which will be explained in chapter 13 of this training manual.

As P & E supervisor, you should possess a broad knowledge of various construction works and methods, as well as be familiar with the use of references (such as estimator's manuals and other construction norms) for one of your responsibilities is to check the drawings and material takeoffs prepared by your men for accuracy and completeness. You should be an expert in blueprint reading and in the interpretation of specifications, for these are your main sources of information by which you will base your material and labor estimates, and your work schedule.

As an individual, you may have some doubts in the construction norms of certain jobs. If it is beyond your capability, do not hesitate to enlist the assistance of those who are in a better position to know. There are many instances where completion of the project is unreasonably delayed, because the estimator failed to include an inconspicuous structural member, but most critical for the completion of the job, and the checker failed to account for the missing item as well. Since lead time is the most important factor in ordering materials through the Navy Supply System, it is very imperative that material takeoffs and other estimates be complete in every respect.

CONSTRUCTION PLANNING AND CONTROL.—The duties of an EA group in a battalion usually relate to the entire construction project, rather than to any particular subphase, Consequently, a supervising EA must possess an overall view of the system of construction planning and control, from start to finish. Figure 2-9 is a chart which shows such an overall view. A brief explanation of the chart will be given here; many of the items it shows will be explained in further detail in a later chapter.

The procedure begins with the development of the overall CONSTRUCTION PLAN. Drawings and specifications are made, based on the structures and intent called for in the construction plan. From these drawings and specifications, material QUANTITY TAKEOFFS are



82.1

Figure 2-9.—Construction planning and control chart.

made, from which BILLS of MATERIALS and LABOR AND EQUIPMENT ESTIMATES are drawn up. On the basis of the bills of materials, MATERIAL REQUISITIONS (i. e., orders for materials) are sent to SUPPLIERS, who forward the requested materials to specified depots under MATERIAL INVOICES. A material invoice is simply a list of the materials in a shipment, together with the quantity of each material forwarded. The broken back-arrow running from "material invoices" back to "bills of materials" indicates a check, at the receiving depot, of the material shipment against the original amount of each material called for by the bill.

Shifting to the right-hand side of the chart, you see that, like the bills of materials, the initial labor and equipment estimates are based on the quantity takeoffs. The quantity takeoffs, for example, will reveal how much concrete must be mixed and poured. The labor and equipment estimate will determine approximately the number of manhours, the kind and quantity of equipment, and the number of equipment-hours required to form, mix, and pour that much concrete.

From the labor and equipment estimates, TENTATIVE JOB PLANS are drawn up, from which PLATOON WORK SCHEDULES are developed. JOB PLANNING CONFERENCES are then held, in which the whole construction effort is broken down into subphases called JOBS in the chart. You can see that, in drawing up the battalion job orders, the labor and equipment estimates are platoon work schedules are considered.

For each job, the project officer draws equipment, materials, and labor on the basis of the job order. He submits a DAILY LABOR report and a WEEKLY REPORT OF WORK IN PLACE. Copies of these are kept in a JOB ORDER FOLDER, and used as the basis for WEEKLY REPORTS OF VARIATIONS FROM JOB PLANS, MONTHLY JOB REPORTS, and the final END-OF-PROJECT STATISTICAL REPORT.

PERSONNEL ORGANIZATION.—Subordinates under the Planning and Estimating Supervisor are likely to be temporarily assigned individuals familiar with the various construction subphases that is, a BU may be assigned to assist with concrete, masonry, or structural members estimates, a SW to assist with rebars and steel frame estimates, a UT to assist with plumbing or heating estimates; a CE to assist with electrical estimates, and the like. These individuals are trained to estimate materials, labor, and equipment requirements in their own categories.

The function of the Planning and Estimating Supervisor is to organize and coordinate the work of the division by:

1. Providing each subordinate with the prints and specifications applicable to his construction category.

2. Instructing each subordinate in the procedures to be followed (i.e., forms to be filled out, accuracy desired, and the like), which are described in a later chapter.

3. Combining the estimates in the separate categories into a coordinated whole, and preparing material, equipment, and manpower schedules therefrom, as will be described also in a later chapter.

Quality Control Section

The Quality Control Section is established so that trained personnel are on hand to see that construction works are in accordance with the job specifications that is, the workmanship, the material used, prevailing conditions, and appearance of the finished structure are within the specified minimum standard. The only way to maintain these desired qualities is through constant and careful inspection and testing of materials used.

Inspection and testing relate to QUALITY control—meaning, steps taken to ensure that a structure will meet given minimum requirements as to strength, durability, safety, and appearance. Quality depends, broadly speaking, on two principal factors. (1) the inherent character of the materials used in the structure, and (2) the manner in which the materials are combined to make the structure. With regard to both of these considerations, DESIGN prescribes the minimum quality criteria which must be met. For example, design may prescribe that concrete ingredients be in the proportion of 1 cement to 2 sand to 4 coarse aggregate, or that studs be spaced 16 in. O.C. If the concrete ingredients were 1 cement to 4 sand to 8 coarse aggregate, and the spacing of studs 24 in. O.C., the strength quality of the structure would be considerably lower.

Quality control, then, consists of (1) the testing of materials to ensure that their inherent character meets minimum quality requirements, and (2) the inspection of structures to ensure that materials were installed (or, more frequently, are being installed) in the manner prescribed by design. The principal source of quality criteria are the specifications, however, much quality criteria (such as the spacing of studs, for example) appears on the drawings.

TESTING AND INSPECTION. Personnel assigned to the Quality Control Section assist the Engineering Officer in controlling the quality of construction work. With regard to the inspection, an enlisted man (usually an EAC or BUC) with a broad background in construction is assigned as Chief Inspector. In some areas he might have a civilian counterpart from the customer activity, usually a representative from the Resident-Officer-in-Charge of Construction (ROICC), or Public Works. Before the creation of the EA rating, the Chief Inspector was usually a BUC. At present the SEABEES have qualified EACs for this billet, although you will still find BUCs performing this function. To quality for Chief Inspector, you should have special training, either on-the-job training, civilian educational background, or attend special SEABEE Quality Control Inspectors schools. EAs may also attend the Army school for Testing Materials and Inspection at Fort Belvoir, Virginia.

Other inspectors are assigned according to the needs of the work. For inspection of specialized work, men familiar with the special area (such as BUs, UTs, or CEs) may be assigned to do the actual inspection under the Chief Inspector's supervision. Survey field parties form the Field Engineering Section may also do certain inspecting.

Inspectors also make soil tests as needed, and test and control all locally-produced materials, such as concrete, lumber, concrete block, crushed stone, sand, and gravel. For example, the inspectors may make tests of soil in place, take soil samples and make laboratory tests, and assist in determination and control of optimum moisture content and compaction of earthmoving operations. They measure the physical characteristics of aggregates used for concrete, such as size and gradation, moisture content, and hardness; calculate and control the proportioning of concrete mixes, and test concrete cylinders and beams.

TRAINING INSPECTORS AND TESTERS. Lower-rated men assigned as inspectors and testers should be given assignments for spare time reading of printed sources on inspection and testing procedures. Locally used inspection and data forms should be explained. New men should then be assigned to learning on-the-job procedures in the laboratory and at the jobsite under experienced men. Again, the PURPOSE of what is being done should be explained, for example, the ultimate effect of soil tests on the work of highway subgrading should be clearly shown.

There is relatively little routine, day-to-day work in inspecting and testing, since the work of the Inspection and Testing Section is keyed to whatever happens to be going on construction-wise at the moment. Therefore, it is difficult to make any suggestions about the organization of the section. A man who is making soil tests in the laboratory today may be making inspections at the jobsite tomorrow. The inspection and testing crew is usually small, and, therefore, each man in the crew must be trained to cope with all inspection and testing problems. In short, there is little specific organization, the main supervisory responsibility being to train inspectors and testers in all the functions of both categories.

CRITICAL ITEM INSPECTIONS.–As a guideline, the Quality Control Supervisor must be familiar with current COMCBPAC or COMCBLANT and battalion instructions pertinent to quality control. These instructions will state minimum requirements and stress CRITICAL ITEM inspections and tests which must be performed during construction. Critical items are those phases of construction which must be inspected or tested before the next phase of construction may proceed. For example, approval to pour concrete cannot be given until the forms, reinforcing steel, etc., have been inspected.

MATERIAL LIAISON OFFICER

Recently, in overseas deployment, there was a big increase in the need for a Material Liaison Officer (MLO) to assist the Supply Officer in the requisition and control of construction material. While the Supply Officer is responsible for the receipt of project materials, their stowage and issue, the Operations Officer also has a vital interest in the flow of project materials to the jobsite. Therefore, a good working relationship is essential. Most units assign a CEC officer to work for the Supply Officer as MLO; however, the Operations Officer may decide to retain the MLO in the Operations Department for administrative control. Liaison works both ways anyway, so the question on the administrative control will depend on the arrangement that will best serve the purpose.

The initiation of construction material procurement is usually supervised by a senior petty officer (generally a CPO) of one of the Construction ratings. Sometimes he has a handful of men working under him and the group is called the Construction Materials Procurement Section. The section maintains direct liaison with the Supply Department through the MLO, and assists the P&E Section when the battalion is responsible for preparing material takeoffs.

The Construction Materials Procurement Section or the Materials Liaison Officer is responsible for:

1. Preparing, logging, and following up on requisitions for building materials based on approved bills of materials.
2. Receiving construction materials and posting tickets against bills of materials.
3. Direct delivery (whenever feasible) of construction materials from ships to locations at the jobsites approved by the Operations Officer and field supervisor.
4. Keeping posted on job progress.
5. Close coordination with field supervisors.
6. Phased delivery of construction materials to jobsites.
7. Controlled issue of construction materials to authorized persons in authorized amounts.
8. Prompt notification of the Operations Officer and Supply Department of any anticipated shortages or delays.

On a deployment, the Materials Liaison Officer designates one of his men as the "Expediter"–he is usually a senior petty officer, generally a CPO of any of the ratings. As mentioned in chapter 1, an EA1 or EAC might be designated as Expediter. This assignment requires lots of legwork, tact and diplomacy, initiative and, above all, patience. The general impression attributed to a good expediter is to "Get the needed materials by whatever means and send them to the battalion as fast as you can".

Generally, in connection with this assignment, you will be issued TAD orders for temporary duty with a SEABEE unit nearest the supply point depot. Your main responsibilities are to follow-up requisitions for the battalion, receive the materials and ship them as soon as practicable to the battalion's jobsites. You will maintain constant communications with the battalion, or in most cases, with the Materials Liaison Officer. Generally, messages are sent to the Supply Depot on the status of requisitions and on materials under shipment; you will go through the message files each morning, so you will have the latest on your requisitions and perhaps intercept the materials you are interested in as soon as they arrive. You might also be given additional collateral duties by the Commanding Officer.

ADMINISTERING A COMPANY ACCIDENT PREVENTION PROGRAM

As mentioned earlier in this chapter, the safety program is under the direction of a Safety Officer designated by the commanding officer. Under the direction of the Safety Officer, and with the assistance of the Safety Chief, each company is required to administer a company accident prevention program. You, as an EAC, may be appointed to administer the Headquarter's Company accident prevention program. And as a supervisor in the Operations Department, you are responsible for the safety of the men under you, and for the reporting and investigating of accidents.

SAFEGUARDS AND SAFETY EDUCATION

Many supervisors feel that it is only necessary to provide safeguards and safety will then take care of itself. Provision of safeguards is a move in the right direction, but it alone will not get good results. To maintain a good safety record, you, as the supervisor, need to employ a combination of safety devices and safety training. If each man has had sound safety training, he will be able to guard against even those hazards where safety devices are impracticable. You must, however, train every man in the use of safeguards, explaining why, as well as how, they should be used. How many times have you seen a man shut off the power on a piece of machinery and then walk away from it before it has stopped running? Such a man uses a safeguard, but he does not know why he uses it. By providing the necessary training, you, as an alert supervisor, must make sure careless uses of safeguards do not happen.

Standup safety meetings should be held once every week. The meetings should be held at or near the work area. Instead of a routine safety lecture, it is much better to hold a group discussion on specific accidents that are to be guarded against or that may have happened in the unit. The men should be encouraged to express their ideas. A group conclusion as to how specific accidents can be prevented should be reached.

Another type of safety meeting is one in which the supervisor presents a safety problem that has developed because of new work or new equipment. Again, the men should be encouraged to express their ideas.

A third type of safety meeting is one in which actual demonstrations and practice by the group are carried out. You might demonstrate how to lift, and then have the men practice lifting.

Making these meetings interesting is of the utmost importance. The supervisor should not complain or scold, and the meetings should be limited in time. The subject matter should be thought out carefully in advance and it should be timely. Considerable ingenuity is required to keep these meetings from becoming dull routine affairs. You should have the men themselves rotate as leaders of the safety meetings; this is an excellent way to maintain interest Hundreds of good motion pictures and other visual aids are available on safety subjects. Consult with the Safety Chief. He will be able to suggest different topics for your safety meetings. And often, he will, upon request, conduct safety meetings for your men.

As company safety administrator, you are required to submit safety meeting reports periodically to the Safety Chief. You must keep a record of all meetings conducted within the company. Information required for this report will include the topics discussed, the number of men attending, and the length of the meeting.

SAFETY INSPECTIONS

Safety inspections are a never-ending responsibility of the supervisor. The supervisor does not follow a strict schedule of safety inspections; instead he maintains a continual alertness for all potential safety hazards around him. He ensures that all safeguards in the work areas are being adhered to and that all protective equipment is being used when required. For example, if a survey party is performing survey operations along a busy highway, the party chief must make sure that every man is wearing a brightly colored vest and that flagmen are provided to control traffic.

ACCIDENT REPORTING

When an accident occurs, the immediate supervisor or crew leader of the person involved must fill out an OPNAV Form 5100/1, Accidental Injury/Death Report (see figs. 2-10 through 2-13). This form provides a method of recording the essential facts concerning an accident, from which data for use in accident prevention can be compiled. Item 27—"Corrective action taken/recommended"—is the most important part of this report. The manner in which this question is answered provides a clue to the attitude of the supervisor. Too many supervisors answer this question with, "The man had been warned to be more careful." This type of answer does not mean a thing. The answer to this question should tie in with the rest of the report. If an unsafe working condition is the cause of the accident, the supervisor cannot correct it by warning the man to be more careful. The supervisor should study the report, analyze it, then take the proper corrective action. This report is one of the best accident prevention tools if properly used. In many cases, the difference between a minor accident and a major one is a matter of luck. Do not ignore the small cuts and bruises; investigate the reasons for them and correct the causes. If you do this, you will have a safe working crew and an efficient one.

ACCIDENTAL INJURY/DEATH REPORT
OPNAV FORM 5100/1 (5-69) S/N-0107-776-0010
SPECIAL HANDLING REQUIRED IN ACCORDANCE WITH OPNAVINST 5100.11

FOR OFFICIAL USE ONLY
REPORT SYMBOL OPNAV 5100-3

TO COMMANDER NAVAL SAFETY CENTER NAVAL AIR STATION NORFOLK VA 23511

1 REPORTING COMMAND

2A COMMAND AUTHORITY EXERCISED BY

2B GCM AUTHORITY EXERCISED BY

3 REPORT NUMBER

4. NAME OF PERSON INJURED/KILLED (FIRST, MIDDLE, LAST

5A SERVICE/BADGE NO

5B SOCIAL SECURITY NO

6. RANK & DESIGNATOR/RATE AND NEC/CIVILIAN OCCUPATION

7 SEX

8 AGE

9A TIME IN SERVICE (MIL ONLY)

9B YEARS EXPERIENCE (CIV ONLY)

10A MIL ☐ USN ☐ USNR ☐ OTHER

10B CIV: ☐ EMPLOYEE ☐ DEPENDENT ☐ OTHER

11A DUTY STATUS
MIL ☐ EXT ACT DU ☐ ACDUTRA ☐ DRILL ☐ TRAVEL
☐ LV/LIB ☐ UA ☐ OTHER

11B DUTY STATUS
CIV: ☐ REG ☐ TEMP ☐ TRAVEL
☐ UNAUTH WORK ☐ OTHER

12. DATE AND TIME OF INJURY

HOUR	DATE	MONTH	YEAR	DAY OF WEEK

13 PLACE OF OCCURRENCE
☐ ABOARD SHIP ☐ ASHORE
DESCRIBE LOCATION

14 DAYS LOST/CHARGED

15 WEATHER/NATURAL DISASTER

16 LIGHT CONDITIONS AT SITE

17 DESCRIPTION OF EVENTS (DESCRIBE THE CONTRIBUTING EVENTS LEADING UP TO THE INJURY/DEATH SO THAT THE REVIEWING OFFICIAL WILL HAVE A CLEAR PICTURE OF WHAT CAUSED THE INJURY/DEATH. SELECT THE APPROPRIATE ENTRY FROM EACH MAJOR FACTOR CATEGORY LISTED ON BACK OF INSTRUCTION SHEET AND ENTER IT WITH AMPLIFYING DETAIL IN BOXES 18 THROUGH 25 BELOW.)

WITNESSES NAME, RANK/RATE, ADDRESS

18. KIND OF INJURY

19 BODY PART INJURED

20 SOURCE OF INJURY (OBJECT, SUBSTANCE, ETC WHICH CONTACTED THE BODY AND INJURED PERSON):

21. KIND OF ACCIDENT (FALL, CRUSHED, STRUCK BY, ETC):

22. HAZARDOUS CONDITION (WHAT CONDITION CAUSED, PERMITTED, CONTRIBUTED TO ACCIDENT WHICH RESULTED IN INJURY): ☐ NOT APPLICABLE

23 AGENCY (AND AGENCY PART) OF ACCIDENT (OBJECT, SUBSTANCE, ETC TO WHICH THE HAZARDOUS CONDITION APPLIED): ☐ NOT APPLICABLE

24. UNSAFE ACT (WHAT PERSONAL ACTION CAUSED OR ALLOWED ACCIDENT TO OCCUR):
☐ BY INJURED MAN ☐ BY ANOTHER ☐ NOT APPLICABLE

25 UNSAFE PERSONAL FACTOR (MENTAL OR PHYSICAL CONDITION WHICH RESULTED IN OR CONTRIBUTED TO THE UNSAFE ACT):

26. REASON FOR BEING ON GOVERNMENT PROPERTY (REGULAR DUTY ASSIGNMENT, CIV EMP, PATIENT, VISITOR, BUSINESS, ETC):

0.33890

29.52.1(2D)

Figure 2-10.—Accidental Injury/Death Report, OPNAV Form 5100/1 (front).

OPNAV FORM 5100/1 (5-69) (BACK)

27 CORRECTIVE ACTION TAKEN/RECOMMENDED (WHAT ACTION WILL HELP PREVENT ANOTHER ACCIDENT OF THIS TYPE?)

28. SIGNATURE OF PERSON PREPARING REPORT	29. TITLE AND GRADE	30. DATE

31. REVIEW AND COMMENTS OF SAFETY OFFICER OR COMMANDING OFFICER

32. SIGNATURE	33. TITLE AND GRADE	34. DATE

ADDITIONAL INFORMATION WHEN REQUIRED BY JAG

35. CONDITION OF INDIVIDUAL AT TIME OF THIS OCCURRENCE·
UNDER THE INFLUENCE OF: ☐ ALCOHOL ☐ NARCOTICS ☐ BARBITURATES ☐ OTHER (SPECIFY) ______ ☐ NOT APPLICABLE
☐ UNABLE TO DETERMINE DUE TO PHYSICAL CONDITION
EXAMINER ______

36. BASIS FOR ABOVE OPINION:
A. CLINICAL FINDINGS: ______
B. BIOLOGICAL SPECIMEN TAKEN: ☐ NO ☐ YES TIME ______ LABORATORY TO WHICH SPECIMEN SENT ______
TYPE OF TEST RESULT OTHER TESTS/RESULTS

37. MEDICAL OFFICER'S FINDINGS RELATIVE TO NATURE AND EXTENT OF INJURY·

38 WAS SUBJECT HOSPITALIZED AS A RESULT OF THIS OCCURRENCE? ☐ YES ☐ NO	39. IF THE SUBJECT WERE ALREADY ON THE SICKLIST FOR OTHER REASONS AT TIME OF INJURY WOULD THIS INJURY IN ITSELF HAVE REQUIRED HOSPITALIZATION? ☐ YES ☐ NO ☐ NOT APPLICABLE
40 IT IS POSSIBLE THAT THE FOLLOWING DISABILITY MAY RESULT: ☐ PERMANENT PARTIAL ☐ PERMANENT TOTAL	41. DATE OF EXPIRATION OF ENLISTMENT/TERM OF OBLIGATED SERVICE

42. IF DECEASED, WAS AUTOPSY CONDUCTED? ☐ YES ☐ NO IF YES, ATTACH COPY OF AUTOPSY PROTOCOL

43 ADDITIONAL INFORMATION FOR RESERVISTS: IF RESERVIST WAS ENGAGED IN ACTIVE-DUTY TRAINING OR INACTIVE DUTY (DRILL) SUPPLY THE FOLLOWING INFORMATION:

MEMBER REPORTED FOR DUTY OR DRILL		DISMISSED FROM DUTY OR DRILL		INJURY	
DATE	TIME	DATE	TIME	DATE	TIME

44. MEDICAL OFFICER'S SIGNATURE	45. GRADE	46. DATE

47 IT IS THE OPINION OF THE UNDERSIGNED THAT THE INJURY/DEATH IN QUESTION WAS INCURRED IN THE LINE OF DUTY AND NOT AS THE RESULT OF THE SUBJECT MAN'S OWN MISCONDUCT. ☐ YES ☐ NO

COMMANDING OFFICER (OR ONE AUTHORIZED TO SIGN BY HIS DIRECTION · IF LATTER SO INDICATE)

48. SIGNATURE	49. TYPED NAME AND GRADE	50. DATE

51. ACTION OF OFFICER EXERCISING GENERAL COURT-MARTIAL JURISDICTION:

DATE: ______

FROM:

TO: JUDGE ADVOCATE GENERAL OF THE NAVY

______
SIGNATURE AND TYPED NAME OF OFFICER EXERCISING GCM AUTHORITY (OR ONE AUTHORIZED TO SIGN BY DIRECTION)

0-33880

29.52.2(2D)

Figure 2-11.—Accidental Injury/Death Report, OPNAV Form 5100/1 (back).

ACCIDENTAL INJURY/DEATH REPORT
OPNAV FORM 5100/1 (5-69)

Print with pencil or type, items not applicable or [illegible] to the injury death will be marked NA

INSTRUCTIONS FOR ACCIDENTAL INJURY DEATH REPORT

Block 1 Reporting Command Self explanatory

Block 2A Command Activity Exercising [illegible] In the case of ships and [illegible] units this is the Type Commander. For shore activities this is the command [illegible] (e.g. [illegible] SERVLANT in the case of NAVSTA, [illegible] COMNAVSHIPSYSCOM in the case of a ship yard, etc.)

Block 2B [illegible] Self [illegible] the report is required by [illegible]

Block 3 Report Number [illegible] serially numbered [illegible] by each reporting command [illegible] during the fiscal year [illegible] as the second report of fiscal year 1969

Block 4 Name of Person Injured/Killed Self explanatory

Block 5A Service Badge Number Self explanatory

Block 5B Social Security Number Self explanatory

Block 6 Rank & Designator Rate & NEC Civilian Occupation Self explanatory

Block 7 Sex Self-explanatory

Block 8 Age Self explanatory

Block 9A Time in Service (Mil Only) Indicate in years only

Block 9B Years Experience (Civ Only) Indicate number of years experience in present occupation including years of experience gained in that occupation in other government or private industry employment. In cases of injury or death to civilians other than employees of the Department of the Navy mark "NA"

Block 10 Employment Status In the event the line "Other" is selected for either military or civilian specify as contract employee, visitor, Army, Air Force, etc

Block 11 Duty Status For either military or civilian check all applicable boxes

Block 12 Date and Time of Injury Give the hour on the basis of the 24 hour clock using four digits. Use two digits each for the date, month and year

Block 13 Place of Occurrence In describing the location enter paint locker, weather deck, flight deck, machine shop, galley, etc as appropriate

Block 14 Days Lost Charged For fatal injury or missing persons enter 6000 days. For all other injuries enter the number of calendar days of disability or time charges using the schedule of charges Table 1 Appendix I. Wherever the schedule of charges is used the actual number of calendar days of disability is not entered

Block 15 Weather Natural Disaster If a factor describe weather conditions or natural disaster which contributed to the injury

Block 16 Light Conditions at Site Describe outside or internal lighting conditions as applicable existing at the immediate site and time of accident

Block 17 Description of Events Enter narrative description of circumstances and events which directly or indirectly led to the injury physical impairment or death. Include sufficient information to clarify or expand upon the character and scope of data to be entered in blocks 18 through 25 of the report. Accidental injury death reports in all cases resulting from a ship accident will reference the applicable ship accident report serial in this block. Include in this block as appropriate, comments on the following

a. Time injured person first seen by medical officer representative
b. Disposition of injured person, i e treated and retained aboard or transferred to another ship (military personnel) or transferred to a hospital for treatment (military and civilian personnel)
c. In cases of exposure to toxic fumes chemical poisons describe type of substance concentration and type of exposure
d. Describe additional causative contributing factors not described in blocks 20 through 25 and indicate (D) for a definite cause (S) for a suspected cause and (P) for condition present but not a factor. Enter name rank/rate or grade and address of witnesses to the accident. If none, so indicate

Block 18 Kind of Injury Enter words from Block 18 (on reverse side of this sheet) which best describes nature of injury

Block 19 Body Part Injured Enter word(s) from block 19 (on reverse side of this sheet) which best describes body part affected by nature of injury

Block 20 Source of Injury Enter object or environment from block 20 (on reverse side of this sheet) which best describes source of injury (NOTE A direct logical relationship between "Source of Injury" and "Kind of Injury" must be established)

Block 21 Kind of Accident Enter action motion or type of contact from block 21 (on reverse side of this sheet) which best describes means by which injured person came in contact with previously selected "Source of Injury" (NOTE A direct logical relationship between the "Source of Injury" and "Kind of Accident" must be established)

Block 22 Hazardous Condition Enter the condition from Block 22 (on reverse side of this sheet) which best describes the hazardous condition which permitted or occasioned occurrence of previously selected "Kind of Accident" (NOTE A direct logical relationship between "Kind of Accident", "Hazardous Condition" and "Agency of Accident", which is to follow, must be established)

Block 23 Agency (and Agency Part) of Accident Enter the object or environment from Block 20 (on reverse side of this sheet) which best describes the agency to which the hazardous condition applies. In addition describe the part of the agency which is unsafe. For instance if the agency is a table saw from which the blade guard has been removed, enter the words "cross cut saw - blade." In some agencies such as a length of pipe, rope, lumber, etc., no agency part is required to be named. The rule for agency part is - if corrective or preventive action for the part involved is different from the action on any other part of the agency, name the agency part involved (NOTE A direct logical relationship between "Hazardous Condition" and "Agency of Accident" must be established) If there is no hazardous condition there can be no agency or agency part of accident, and all three items shall be described as "Not Applicable"

Block 24 Unsafe Act Enter the act or omission from Block 24 (on reverse side of this sheet) which best describes unsafe act which permitted or caused occurrence of previously named kind of accident (NOTE A direct logical relationship between "Unsafe Act" and "Kind of Accident" must be established)

Block 25 Unsafe Personal Factor Enter the reason from Block 25 (on reverse side of this sheet) which best describes the unsafe personal factor which led to the "Unsafe Act" or contributed to the injury (NOTE If there was an unsafe act committed, an unsafe personal factor should always be selected. If no unsafe act was committed there may still, however, be an unsafe personal factor which contributed to the accident)

Block 26 Reason for Being on Government Property Self-explanatory

Block 27 Corrective Action Taken Recommended List specific remedial actions which have been or should be taken to prevent recurrence of similar injury. If an entry of "unknown" or "none" seems appropriate, an explanation shall be given as to why corrective action can not be recommended. Specify whether actions have been taken or are only recommended. If the latter what action is expected?

Blocks 28 through 30 First Signature Line Report is to be signed and dated by the individual who prepared the report to this point

Block 31 Review and Comments of Safety Officer or Commanding Officer Additional recommendations may be made if appropriate

Blocks 32 through 34 Second Signature Line Self-explanatory

The remainder of the report form will only be filled out in those instances where the injury death to the military member is reportable to JAG

a. Blocks 1 34 Prepared in accordance with above instructions
b. Blocks 35 50 Self-explanatory
c. Blocks 35 through 40 42 and 44 through 46 shall be completed and signed by the medical officer on the basis of his observation or examination of the injured or deceased member and information then available to him
d. Blocks 41, 43 and 47 through 50 shall be completed and signed by the commanding officer on the basis of his investigation (or by an officer authorized and directed by the commanding officer to investigate the incident and sign the report by direction)

29.52.3(127E)

Figure 2-12.—Instructions for Accidental Injury/Death Report (front).

BLOCK 18 KIND OF INJURY

AMPUTATION OR ENUCLEATION
ASPHYXIA, STRANGULATION
BURN OR SCALD (THERMAL)
BURN (CHEMICAL)
CAISSON DISEASE BENDS
CONCUSSION, BRAIN
CONTUSION, CRUSHING, BRUISE
CUT, LACERATION, PUNCTURE, OPEN WOUND
DISLOCATION
DROWNING
ELECTRIC SHOCK, ELECTROCUTION
FOREIGN BODY LOOSE (DUST, RUST, SOOT)
FOREIGN BODY, RETAINED OR EMBEDDED
FRACTURE
FREEZING, FROSTBITE
HEARING LOSS, OR IMPAIRMENT
HEAT STROKE, SUNSTROKE, HEAT EXHAUSTION
HERNIA
*INJURIES INTERNAL
*POISONING, SYSTEMIC
RADIATION IONIZING
RADIATION, NONIONIZING
RADIATION ACT NEC
SCRATCHES, ABRASIONS
SPRAINS, STRAINS
SUBMERSION, NONFATAL
*MULTIPLE INJURIES
UNDETERMINED
*OCCUPATIONAL DISEASE, NEC
*OTHER INJURY, NEC

BLOCK 19 BODY PART INJURED

*HEAD (INCLUDING FACE)
*NECK
*UPPER EXTREMITIES
*TRUNK
*LOWER EXTREMITIES
*MULTIPLE PARTS
*BODY SYSTEM
*BODY PARTS, NEC

BLOCKS 20 & 23 SOURCE OF INJURY AND AGENCY OF ACCIDENT

*AIR PRESSURE
*ANIMALS
*BODILY MOTION
*BOILERS PRESSURE VESSELS - PARTS
*BOXES, BARRELS, CONTAINERS, PACKAGES (EMPTY OR FULL, EXCEPT GLASS)
*BUILDINGS & STRUCTURES - PARTS
*CHEMICALS & CHEMICAL COMPOUNDS
*CLOTHING, APPAREL, SHOES
*COAL AND PETROLEUM PRODUCTS
*CONSTRUCTION MATERIALS (NOT PART OF A STRUCTURE)
*CONVEYORS, GRAVITY OR POWERED (EXCEPT PLANT & INDUSTRIAL VEHICLES)
*DRUGS AND MEDICINES
*ELECTRIC & ELECTRONIC APPARATUS, NEC
*FLAME, FIRE, SMOKE
*FOREIGN BODIES OR UNIDENTIFIED ARTICLES
*FURNITURE, FIXTURES, FURNISHINGS
*GLASS & CERAMIC ITEMS, NEC
*HAND TOOLS (NOT POWERED, WHEN IN USE, CARRIED BY A PERSON)
*HAND TOOLS (MECH & ELEC MOTOR POWERED, IN USE, CARRIED AND HELD BY A PERSON)
*HEATING EQUIPMENT, NEC (NOT ELEC) WHEN IN USE (FOR ELEC FURNACES SEE ELECTRONIC APPARATUS)
*HOISTING APPARATUS
*ELEVATORS
*HUMAN BEING
*INSTRUMENTALITIES OF WAR
*MACHINES (PORTABLE & FIXED, EXCEPT WHEELED VEHICLES)
*METAL ITEMS, NEC
*MINERAL ITEMS, NEC
*NATURAL POISONS AND TOXIC AGENTS, NEC
NOISE
*PERSONNEL SUPPORTING SURFACES (DECK, LADDER, STAGE, BROW, PLATFORM)
*PLASTIC ITEMS, NEC
*PUMPS, ENGINES, TURBINES (NOT ELEC)
*RADIATING SUBSTANCES AND EQUIPMENT (USE ONLY FOR RADIATION INJURIES)
*SCRAP, DEBRIS, WASTE MATERIAL, ETC , NEC (EXCEPT RADIOACTIVE)
*SHIP STRUCTURE - PARTS
*SPORTS
*TEMPERATURE (ATMOSPHERIC, ENVIRONMENTAL)
*TEXTILE ITEMS, NEC
*VEHICLES, (AIR, LAND, SEA) INCLUDING MILITARY AND INDUSTRIAL
WATER AND STEAM
*WOOD ITEMS, NEC
*MISCELLANEOUS, NEC
UNDETERMINED
*OTHER, NEC

BLOCK 21 KIND OF ACCIDENT

*STRUCK AGAINST
*STRUCK BY
*FALL OR JUMP FROM ELEVATION
*FALL OR JUMP ON SAME LEVEL
*CAUGHT IN, UNDER, OR BETWEEN
BITE OR STING, VENOMOUS AND NON-VENOMOUS
*RUBBED, ABRADED, PUNCTURED OR CUT
BODILY REACTION OR MOTION
*OVEREXERTION
*CONTACT WITH
UNDETERMINED
*OTHER, NEC

BLOCK 22 HAZARDOUS CONDITION

*DEFECT OF THE AGENCY OF ACCIDENT
*DRESS OR APPAREL HAZARD
*IMPROPER ILLUMINATION
*IMPROPER VENTILATION
* ENVIRONMENTAL HAZARD, NEC
* HAZARD OF OUTSIDE WORK ENVIRONMENT - OTHER
* INADEQUATELY GUARDED
* PLACEMENT HAZARD
* PUBLIC HAZARD
UNDETERMINED
NO HAZARDOUS CONDITION
* HAZARDOUS CONDITION, NEC

BLOCK 24 UNSAFE ACT

* WORKING ON MOVING OR DANGEROUS EQUIPMENT
* DRIVING ERRORS BY VEHICLE OPERATOR
* FAILURE TO USE PERSONAL PROTECTIVE EQUIPMENT
FAILURE TO WEAR SAFE PERSONAL ATTIRE
* FAILURE TO SECURE OR WARN
HORSEPLAY AND SKYLARKING
QUARRELING OR FIGHTING
* IMPROPER USE OF EQUIPMENT
* IMPROPER USE OF HANDS OR BODY PARTS
INATTENTION TO FOOTING OR SURROUNDINGS
* FAILURE TO USE SAFETY DEVICES
* OPERATING OR WORKING AT UNSAFE SPEED
* TAKING UNSAFE POSITION OR POSTURE
* UNSAFE PLACING, MIXING, COMBINING, ETC
* USING UNSAFE EQUIPMENT
* OTHER UNSAFE ACTS, NEC
UNDETERMINED
NO UNSAFE ACT
NEC - NOT ELSEWHERE CLASSIFIED

BLOCK 25 UNSAFE PERSONAL FACTOR

UNDER INFLUENCE DRUG/ALCOHOL
FATIGUE
ILLNESS
* IMPROPER ATTITUDE
* LACK OF KNOWLEDGE OR SKILL
* BODILY DEFECTS
UNDETERMINED
NO UNSAFE PERSONAL FACTOR
*OTHER UNSAFE PERSONAL FACTOR, NEC

* SPECIFY/DETAIL

D-13890

29.52.4(127E)

Figure 2-13.—Instructions for Accidental Injury/Death Report (back).

ACCIDENT INVESTIGATION

To fill out the OPNAV Form 5100/1, shown in figures 2-10 and 2-11, an accident investigation must be conducted. The following important factors should be considered when conducting an accident investigation:

1. Unsafe conditions. Was the equipment improperly guarded, unguarded, or inadequately guarded? Was the equipment or material rough, slippery, sharp-edged, decayed, worn, or cracked? Was there a hazardous arrangement, such as congested work space, lack of proper lifting equipment, or unsafe planning? Was there proper illumination and ventilation? Was the man dressed properly for the job? Was the man provided with proper respirator, goggles/gloves?
2. Type of Accident. Was the man struck by some object? Did the man fall at the same level or to a different level? Was he caught in or between objects? Did he slip (not fall) or overexert himself?
3. Unsafe Act. Was the man operating a machine without proper authorization? Was he working at an unsafe speed, too fast or too slow? Was any safety device made inoperative or removed? Was any load made unsafe, or were tools or equipment put in an unsafe place where they would fall? Did someone fail to wipe up oil, water, grease, paint, etc., on working surfaces? Did the injured man take an unsafe position of posture? Did he lift with a bent back or while in an awkward position? Did he lift jerkily? Was he riding in an unsafe position on a vehicle? Was he using improper means ascending or descending? Was the injury caused by failure to wear the provided safe attire or personal protective devices such as goggles, gloves, masks, or safety shoes?
4. Unsafe Personal Factor. Was the man absent-minded or inattentive? Did he fail to understand instructions, regulations, and safety rules? Did he wilfully disregard instructions or safety rules? Was he unaware of safe practices, or unskilled? Was he unable to recognize the hazards? Did he have a bodily defect, such as poor eyesight, defective hearing, or a hernia?
5. Type of Injury. Did he sustain a cut, bruise, sprain, strain, hernia, or fracture? Generally, you should get this information from a doctor, because it is often difficult for a layman to diagnose injuries.
6. Part of Body Affected. Did the injury involve arm, leg, ribs, feet, fingers, head, etc.? This information should also be obtained from the doctor.

The factors cited above will give you an idea of some of the things a supervisor must investigate and report when accidents occur. Each accident is different, and each should be investigated and judged on its own. Do not jump to conclusions. Start each investigation with an open mind. The most important factor in any accident investigation is to determine how to prevent a similar accident.

THE PERSONNEL READINESS CAPABILITY PROGRAM

The Personnel Readiness Capability Program (PRCP) is a management tool which was developed in the mid-1960's by the staff of the Commander, Construction Battalion, U.S. Atlantic Fleet and subsequently implemented throughout the active and reserve Naval Construction Force (NCF). Its purpose is to provide management at all levels of the NCF with personnel information in a timely manner, to increase their capabilities in the areas of planning, decision making, and control.

Prior to the implementation of the PRCP, personnel information was kept on an "as required" basis by various members of the unit in personal notebooks, files, and records. As management required this information to determine military and construction capabilities, training requirements, logistics support, etc., it was collected. This collecting of information was usually a time-consuming, laborious task requiring a piecemeal inventory of the command's capabilities and/or requirements, or was obtained through the use of rough estimates. These methods, however, did not produce the accuracy or rapid response desired. Implementation of the PRCP helped solve these problems by establishing standard procedures for identifying, collecting, processing, and utilizing this needed information.

The Personnel Readiness Capability Program requires each participating command to gather, and continuously update, information on each member of their unit Most of this information concerns skills acquired through actual job experience or through some type of training program. Other information such as expiration of enlistment, rotation date, etc., is required for accurate planning. The gathering of this type of information is called a SKILL INVENTORY.

SKILL INVENTORY

An accurate and current skill inventory is the "backbone" of the PRCP. Without it, the reliability of any planning based on information stored in the PRCP DATA BANK is questionable. Presently, all PRCP skills and other data are based on requirements established by COMCBPAC and COMCBLANT and promulgated in their joint instruction of the 1500.20 series. Additionally, these skills have been conveniently classified into five major categories:

1. Individual General Skills. These are essentially non-manipulative (knowledge) skills related to two or more ratings, such as Construction Inspection, Planning & Estimating, and Safety Inspection.
2. Individual Rating Skills. This is the largest and perhaps most significant category. These skills are all primarily manipulative skills associated with one of the seven Group VIII (Construction) ratings. Some examples are. Surveying for Engineering Aid, Cable Splicing for Construction Electrician, and Shore-Based Boiler Operation for Utilitiesman.
3. Individual Special Skills. This category contains technical skills which are performed by several ratings, including Non-Group VIII's. For example: Forklift Operation, Ham Radio Operation, and Typing.
4. Military Skills. This is the second largest category. It is divided into two sub-categories: General Military Requirements and Seabee Combat Readiness. Respectively, examples are Disaster Recovery Training and Mines & Booby Traps.
5. Crew Experience (Skills). This category comprises experience gained by working with others on specific projects. Most of these projects are related to advanced-base construction, such as Steel Tank Erection, Pile Driving, and SATS Installation.

A skill inventory has three principal steps. First, a clear definition of each skill must be prepared so that each person will give it the same meaning. Second, a standard procedure for obtaining the information must be developed. This helps to ensure that the information, regardless of where it is collected or by whom, will meet certain standards of acceptability. The third and last step is the actual collection of the skill data, and this includes the procedures for submitting it to the data bank.

Skill Definitions

A book of standard SKILL DEFINITIONS, called *Book 1 - PRCP Skill Definitions*, has been prepared, which contains a definition for every skill identified in the Personnel Readiness Capability Program. These definitions have been jointly approved by COMCBLANT, COMCBPAC, and CNRT (Chief of Naval Reserve Training) and they are applicable to the entire Naval Construction Force.

Each definition consists of one, two, or three SKILL LEVELS, depending upon the complexity and number of the various TASKS which make up the skill. Each level within a given skill is more difficult to attain than the previous one, however, it has no relationship to another skill.

Figure 2-14 illustrates an individual rating skill definition. Its significant features are. a standard numerical designation and title (420--Drafting), a statement of tasks to be performed at each level, and the identification of training whereby the tasks may be learned.

Data Collection Procedure

The skill definitions alone do not contain sufficiently detailed information to accurately classify people, nor do they provide any classification procedures. Recognizing this, special SEABEE workshops were conducted by the Civil Engineering Support Office (CESO) and, under their guidance, the *PRCP Interviewer's Standards and Guides* were developed. These

SKILL DEFINITION

420 — Drafting

Skill Level 1: Individual must be a Skill Level 1 in 400—Applied Mathematics plus he must identify, use, and care for all items in the NMCB Draftsman Kit; draw freehand sketches from objects, notes, and verbal descriptions; letter freehand in single stroke Gothic; trace and revise drawings, charts, and maps; "construct" various plane figures, circular curves, and non-circular curves; use standard drawing conventions to make oblique and orthographic projections and multiview orthographic projections, including auxiliary and section views; operate and perform operator's maintenance on ammonia vapor reproduction machines and file drawings and fold prints.

Applicable Training: "A" School
420.1 — Drafting I

Skill Level 2: Skill Level 1 plus be a Skill Level 2 in 400—Applied Engineering Mathematics; layout and make construction drawings, including electrical and mechanical layouts from engineering sketches; make electrical schematics and isometrics of piping and ductwork; use standard architectural, structural, electrical, and mechanical symbols; make prespective drawings; and layout and draw topographic maps.

Applicable Training: 420.2—Drafting II

Skill Level 3: Not applicable.

82.218

Figure 2-14.—Individual rating skill definition for drafting from PRCP Interviewer's Standards and Guides.

"guides" contain a detailed TASK ANALYSIS of each skill definition as well as standard procedures for their use. The *PRCP Interviewer's Standards and Guides* are the principal tools used in collecting skill data. They can be used two ways. (1) By following the interviewing procedures in each guide, a trained interviewer is able to classify people to a predetermined skill level within an acceptable degree of uniformity; and (2) anyone so authorized can, by having a thorough knowledge of the tasks required of each skill, classify others to an appropriate skill level by actually observing the men performing the tasks, either in training or on the job.

Skill information obtained from interviewing or observing is submitted to the Facilities Systems Office (FACSO). Port Hueneme, California, on a special form known as a TRANSCRIPT MASTER. This form, which consists of multiple sheets of carbon sensitive paper, is pre-printed with every skill identified in the PRCP. Normally, it is only necessary to mark the appropriate skill levels attained, send a copy to FASCO where the data bank is maintained and retain a designated copy at the unit level. Complete instructions and information for using the Transcript Master, as well as other PRCP data processing information, can be obtained from the training officer of units participating in the program.

As an EA1 or EAC, you are directly responsible for using the *PRCP Interviewer's Standards and Guides* to interview your men (or others) and to provide the initial information for the PRCP data bank. Subsequent UPDATING of this initial information will be based on your observance of the man performing on the job or upon his performance at a school. New men, however, and others returning from long periods of certain types of shore duty, may require interviews.

PRCP INTERVIEWS

There are two types of PRCP interviews. The first and most important is the INDIVIDUAL RATING SKILL INTERVIEW. The second type is simply called OTHER INTERVIEWS. Both types require the use of the *PRCP Interviewer's Standards and Guides.*

Rating Skill Interviews

The individual rating skill interviews require an experienced and knowledgeable tradesman. In these, a discussion technique is used by the interviewer to classify other SEABEES in the skill levels of the various individual rating skills. This technique requires a thorough understanding of the skills and tasks explained in the interviewing guides. It is recognized that few individuals possess the exceptional knowledge required to interview in all the skills of their rating. In this case, the interviewer must be mature enough to recognize his own limitations and be willing to seek assistance from others in his rating.

Other Interviews

The "other" interviews are used to classify people into the individual general and special skills, military skills, and crew experience. With only a few exceptions, these skills do not require an experienced interviewer, and in many cases, skill levels can be assigned without talking to the individual concerned by looking through the man's service or training record. Those skills requiring the man to be present can usually be assigned after a simple "Yes" or "No" answer. Administrative personnel, including company clerks, are ideal for conducting these "other" interviews.

USING THE INDIVIDUAL RATING SKILL GUIDES

The following information, taken from the *PRCP Interviewer's Standards and Guides,* is intended only as general guidance. When assigned as an interviewer, it is mandatory that you obtain, read, understand, and use the respective interviewing guides. Each of the "guides" is assembled in a standard format. First is a TITLE PAGE. This is followed by the SKILL DEFINITION, then comes the various TASKS which are broken down into several TASK ELEMENTS. (See figs. 2-15, 2-16, and 2-17.)

Title Page

The title page serves to identify the skill and the pages which follow. For example, the SAMPLE GUIDE in figure 2-15 identifies the Individual Engineering Aid Skill of 410 Surveying. The number 410 is a numerical code which identifies this particular Engineering Aid skill.

The CONTENTS can be used to ensure that there are no missing pages in your guide. The respective skill definition will always be listed

INTERVIEWER'S

STANDARDS AND GUIDE

for the

INDIVIDUAL ENGINEERING AID SKILL

of

410—Surveying

CONTENTS

82.219

Figure 2-15.—Title page of the PRCP Interviewer's Standards and Guides for the individual Engineering Aid skill of surveying.

SKILL DEFINITION

410 — Surveying

Skill Level 1: Individual must be a Skill Level 1 in 400—Applied Engineering Mathematics plus he must identify, use, and care for all items in the NMCB Surveyor's Kit; demonstrate use of standard arm and hand signals; perform as chainman using pins, tape spring balance, range pole, and plumb bob; perform as rodman, using level and stadia rods; take soundings with lead line or rod; setup level (dumpy and self leveling) and perform differential leveling; setup transit and read horizontal and vertical angles and stadia distances; determine azimuths and bearings with a surveyor's compass; set, mark and survey construction reference and control points; record and reduce level and traverse notes; read and interpret topographic maps; plot survey data to scale, using graph paper and letter freehand in single stroke style.

Applicable Training: "A" School
410.1 — Surveying I

Skill Level 2: Skill level 1 plus be a Skill Level 2 in 400—Applied Engineering Mathematics; use plane table with alidade; read and interpret construction drawings required of a "party chief;" perform duties of "party chief" for topographic, land, and construction (engineering) surveys, including selection of Horizontal and vertical reference and control points, determination of measuring techniques, verification of survey accuracy by field checks, and computation of data required for laying out vertical and horizontal curves; measure construction items for progress reports and "as-built" drawings; compute and distribute error of closure for traverse and level nets; convert field survey data into information required for engineering studies and material quantity estimates, using surveying and math tables, calculator, and slide rule; and determine the need for and make field adjustments to transits, levels, and alidades.

Applicable Training: "B" School
410.1 — Surveying II

Skill Level 3: Not applicable.

82.220

Figure 2-16.—Individual rating skill definition for surveying from PRCP Interviewer's Standards and Guides.

410.1.01 TASK: Perform as chainman.

.00 For the TASK ELEMENTS listed below:

	VALUE
A. Describe the sequence of steps of this procedure and explain the reasons for each.	3
B. List significant tools and materials used in this procedure.	2
C. Describe principal materials used in this procedure.	2
D. Discuss the parameters of this procedure.	2
E. Describe assistance required while performing this procedure.	1
F. Explain results if this procedure is not performed properly or it is neglected.	4
G. Perform the steps of this procedure when practical.	5

TASK ELEMENTS:	A	B	C	D	E	F	G	T
.01 Perform as head chainman:								
a. Select and set traverse station.	3	2			1	4	5	15
b. Horizontal chaining using plumb bob.	3	2		2		4	5	16
c. Break chaining using locke hand level	3	2		2		4	5	16
d. Slope chaining using clinometer.	3	2		2		4	5	16
e. Keep control point notes.	3					4	5	12
f. Give and set foresight for angle turning.	3	2		2		4	5	16
.02 Perform as rear chainman:								
a. Give backsight for alignment.	3	2		2		4	5	16
b. Hold tape or chain.	3	2				4	5	14
c. Drive and mark stakes.	3	2				4	5	14
d. Clear line of sight.	3	2				4	5	14
.03 Transport, clean and store:								
a. Chains.	3		2			4	5	14
b. Range poles.	3		2			4	5	14
c. Plumb bobs.	3		2			4	5	14
d. Cutting tools.	3		2			4	5	14
							Possible	205
							Qualifying	105

82.221

Figure 2-17.—Typical task analysis with task elements and related action statements.

first. Directly under this will be .1, Skill Level 1. Beneath each of the applicable skill levels are the "tasks" for which you must interview each candidate to see if he is qualified to that level.

Skill Definition

The skill definition for 410 - Surveying is shown in figure 2-16. Its purpose in the guide is to introduce the skill material to the interviewee. For example, you can begin your interview by reading the skill definition to the man. If he says he can do the related work, you may continue with the interview for that skill level, however, if he says he can't do the work, it is obvious that you should go on to some other skill.

Tasks and Task Elements

A task is a specific portion of the overall skill level. Many tasks cover relatively broad areas. Others may be quite specific and brief. Each task is further broken down into several smaller jobs called task elements.

A TASK ELEMENT is a basic part of each task. When interviewing, you will use the task elements and their related ACTION STATEMENTS to determine the interviewee's qualifications. Action statements tell you the type of information you should get from the man being interviewed. Each action statement is identified in the "guides" by a capital letter (A, B, C, etc.). They are listed near the top and the number used varies from task to task. The first action statement in figure 2-17 is:

A. Describe the sequence of steps of this procedure and explain the reasons for each.

Note that each action statement is assigned a numerical VALUE. The value of each ranges from one (1) to five (5), depending on the relative importance to the discussion it will produce during the interview. The TOTAL value of all action statements applied to a particular task is called the POSSIBLE (score) and the total required to qualify an interviewee is called the QUALIFYING (Score).

STEPS FOR INTERVIEWING

When interviewing, the first thing you should do is to attempt to put the interviewee at ease. A good way of doing this is by explaining the purpose of the interview. For example the interview will:

1. Let the man know what he is actually expected to know and to do.
2. Determine what the man can actually do so that he is assigned to the right job.
3. Determine the man's deficiencies so that he will be programmed to receive proper training.

Next, explain to the interviewee that he should discuss what he knows of the skill honestly and that he should not be embarrassed if he doesn't know every item covered in the "guides".

Tell the interviewee what skill and skill level he is being interviewed for. Read the skill definition, as was suggested previously, to see if the man is knowledgeable of the subject.

Many skill levels require that the man hold a specific NEC (Navy Enlisted Classification). For example, Skill Level 2 of Planning, Estimating, and Scheduling requires the individual to have an NEC of EA 5515 – Construction Planner and Estimator Specialist. If the man has such an NEC, he should immediately be assigned the applicable skill level without being interviewed for any lower skill level.

Task Interviewing

Begin interviewing by reading the task. This helps the man to concentrate in the right area. This should be rephrased:

"The first thing we will discuss in surveying is the performance of the chainman."

Then read the first TASK ELEMENT (.01 Perform as head chainman). By applying it through ACTION STATEMENT "A" (Describe the sequence of steps of this procedure and explain the reasons for each), it would sound something like this:

"Describe the sequence of steps when performing as head chainman in selecting and setting traverse stations, and explain the reasons for each step."

As you can see, this is not a question. It is a statement which tells the man that you want him to tell you what he knows about performing the steps of the pre-start check and the reasons for performing them. There are no questions in the *PRCP Interviewer's Standards and Guides*, therefore, no answers are provided. The "guides" point out the areas to be discussed (in terms of TASK ELEMENTS AND ACTION STATEMENTS), and the interviewee's replies are evaluated by the interviewer on the basis of his own personal experience, knowledge, and judgment.

It should be obvious now why all rating skill interviewers MUST be experienced in the skill for which they will interview. The only way you can determine that the interviewee knows the task element is to thoroughly know it yourself. If you are unfamiliar with, or "rusty" in, any tasks in the "guides", you must study these areas thoroughly before attempting to interview anyone. Also, if you do not understand how a particular action statement is used with a task element, you must resolve this before interviewing. Discuss the problem with others who are familiar with the skill.

ONLY discuss the task element with the action statements indicated in the columns to their right by the numerical value. For example, in figure 2-17, only action statements A, B, D, F, and G are used with task element .02. And, in task element .03, only action statements A, C, F, and G are applied. As an expert in the skill, you will probably have a desire to "ask questions" in tasks not covered by the "guides". This must be avoided as then there will be no standard. If you feel strongly that the "guides" can be improved, discuss your recommendation with the PRCP coordinator.

Scoring Interviews

If the interviewee discusses the task element to your satisfaction, he is awarded the numerical value of the applicable action statement. The interviewee is not awarded any partial values. He either knows that part of the task element to which the action statement is applied - or he doesn't know it.

Continue to discuss all the task elements and action statements with the interviewee where indicated and award values for those you judge he is qualified in. When a task is completed, total up the values awarded, and if they exceed or are equal to the qualifying score, certify the man as qualified. The same procedure is followed for the remaining tasks at that level.

A man must qualify in each task of a given skill level in order to qualify for that level. Once a man has been assigned a Skill Level 1, he may then be interviewed for Skill Level 2, and so on.

The scores, as such, are only used to determine whether or not the man is qualified to a given level, and only the actual level received is entered on the TRANSCRIPT MASTER mentioned earlier.

Scoring should be done as the interview proceeds, and the man should be told how he is doing. If time permits, go over weak points with him and recommend how he can improve his technique or knowledge. A record of the interview provides a good basis for local training programs.

CHAPTER 3

GEODESY AND FIELD ASTRONOMY

Surveying which covers a small part of the earth's surface and ignores the correction for curvature in the computation of distances is called PLANE surveying, that which covers a vast area of the earth's surface and its curvature is taken into account is called GEODETIC surveying. Most of the surveying you do in the Seabees will be plane surveying. There are times, however, when your job may involve geodetic surveys. On an advanced base the engineering officer may require precise control points as a tie-in for more detailed surveys. In this connection you must have some knowledge of the basic principles of geodetic surveying. You must also have some knowledge of practical astronomy, the curvature of the earth, and the problem of projecting all or part of the curved surface of the earth onto the flat plane of a map or chart.

This chapter provides information that will aid you in carrying out your duties involving geodesy and field astronomy. We will discuss map and chart projection and describe the characteristics and development of various types of projection. We will explain the use of different kinds of time such as solar time, zone time, and Greenwich mean time in determining direction from celestial observations. Some of the basic elements of field astronomy also are taken up, for instance, celestial coordinates, local hour angle, polar distance, and so on. Instructions are provided on determining latitude by use of a transit. We will also explain the procedure used to determine true azimuth of a line on the ground from a celestial observation.

TYPES OF MAP AND CHART PROJECTIONS

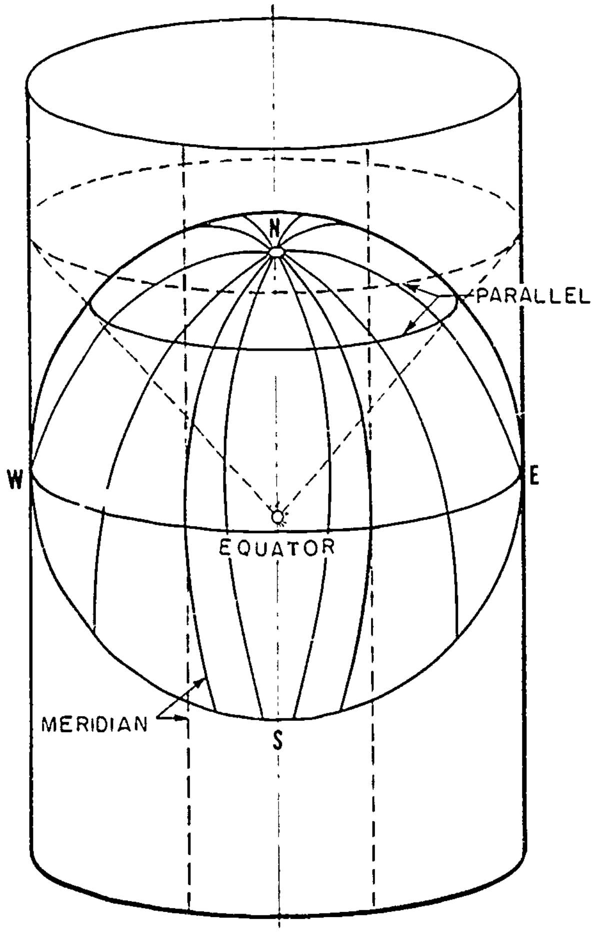
A paper cylinder (without ends) and a paper cone can be cut along the side and flattened out without distortion. For this reason, the two most common basic projection methods are the MERCATOR, in which the earth's surface is projected onto a cylinder, and the CONIC, in which the surface is projected 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

The concept of Mercator projection can be grasped if you imagine the earth to be a glass sphere, with the geographical meridians and parallels occurring at a given interval (for example, every 15°) inscribed as lines on the sphere, and with a strong light at the center. Now imagine a paper cylinder placed around the sphere, tangent to the Equator, as shown in figure 3-1. The shadow images of the meridians will appear on the paper as equispaced, parallel, vertical lines. The shadow images of the parallels will likewise appear as straight lines, running perpendicular to the shadow images of the meridians, but instead of being equispaced, the distance between adjacent parallels will progressively increase as latitude (distance N or S of the Equator, the line of tangency) increases.

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 together so as to meet at a point 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 which 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,

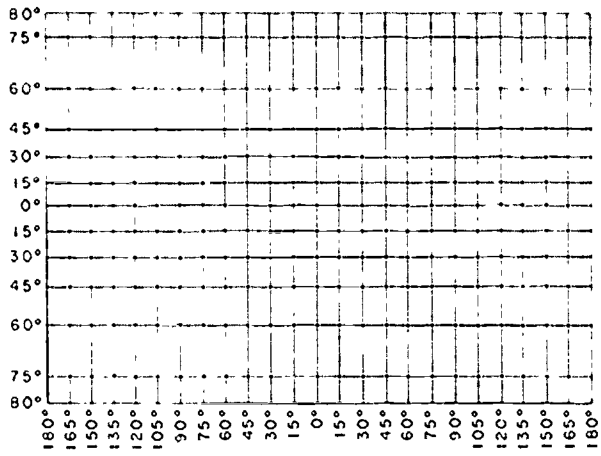


45.422

Figure 3-1.—Mercator projection.

which has an area (exclusive of Alaska) of about 2,973,776 sq miles.

Figure 3-2 shows the appearance of the meridians and parallels, at 15-degree intervals, on a Mercator projection of the world, when the cylinder is flattened out. Note that the parallels extend only to 80 degrees N and S because the cylinder has no ends, Mercator projection of regions in latitudes higher than about 80° is impossible. Note, too, that although the distance along a meridian between (for example) 15° N and 30° N and 60° N and 75° N is the same on the ground, these distances are very different on Mercator projection. Still another characteristic to note is the fact that a meridian is perpendicular to all the parallels it intersects, and that



45.422(65)2

Figure 3-2.—Meridians and parallels on a Mercator projection.

all the meridians are parallel to each other. This last feature means that direction on a Mercator projection (as indicated by the N-S direction of the meridians) is everywhere the same.

Transverse Mercator Projection

On a Mercator projection the cylinder is placed tangent to the earth's central parallel, the Equator. On a TRANSVERSE Mercator projection the cylinder is rotated 90° from this position, so as to bring it tangent to a meridian. Figure 3-3 shows the appearance of the meridians and parallels on a transverse Mercator world projection when the cylinder is flattened out. In this case the cylinder was placed tangent to the meridian running through 0° and 180° longitude.

You can see that distortion is, in general, less in amount than it is in a Mercator projection. You can also see that, unlike a Mercator projection, distortion on a transverse Mercator increases with longitude away from the meridian of tangency, as well as with latitude. This is indicated by the shaded areas shown in figure 3-3 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 is larger.

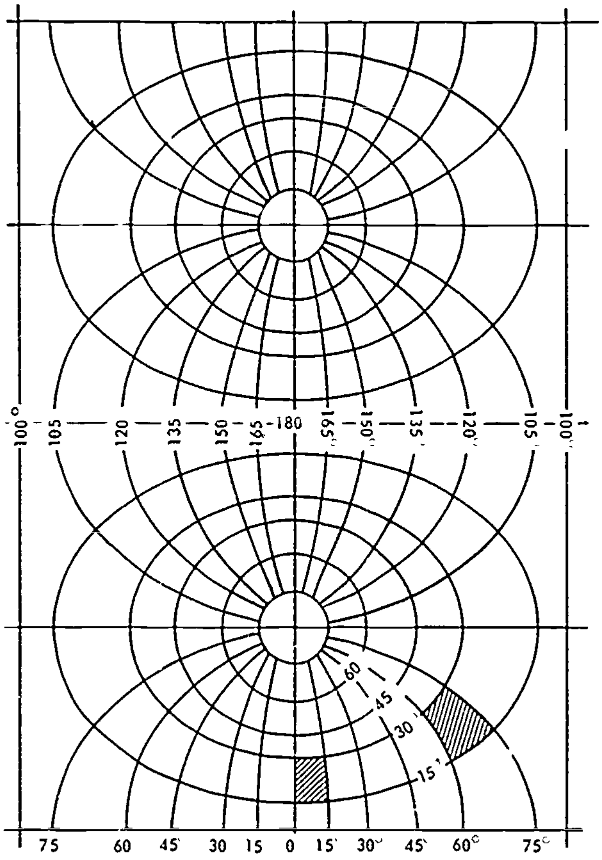


Figure 3-3.—Meridians and parallels on a transverse Mercator projection.

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 which makes the transverse Mercator the most feasible projection for use with the military grid reference system described in the next section.

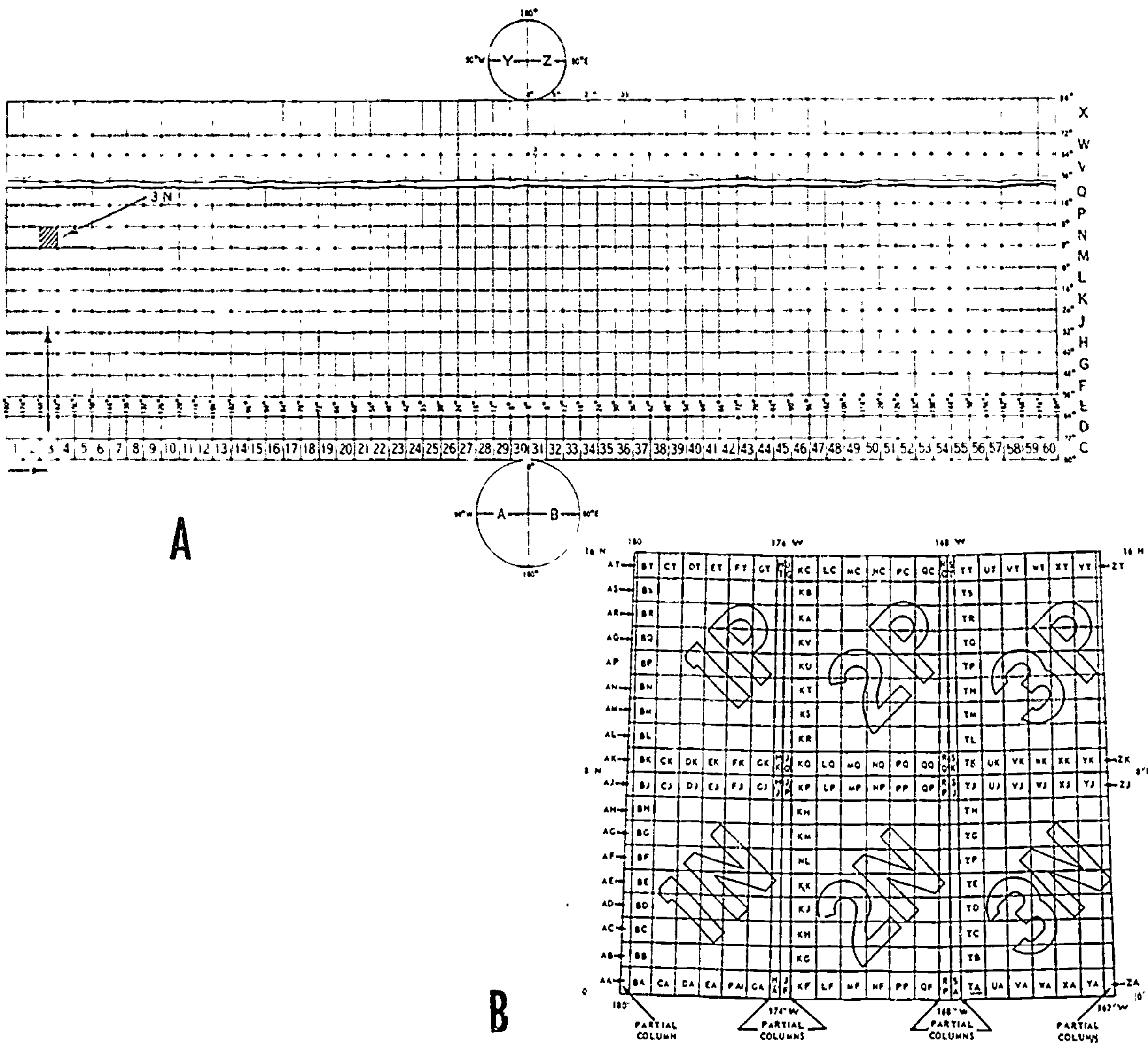
Actually, it is not proper to visualize Mercator projections (Mercator or transverse Mercator) as a direct geometrical projection because of the distance between the points in the axis from which the various parallels or longitudes are projected. In a sense, the nearest geometrical semblance to the Mercator projection as shown in figure 3-1 is still applicable, except that the projection is set back almost 3/4 of the diameter (on the polar or equatorial axis). The tangent cylinder concept is discussed here only to show the nearness of this concept to the mathematical method used in actual practice. The Mercator projection was not derived from the projection of the globe upon a cylinder, but it is a modification from that idea.

A mathematical navigational devise to make the rhumb line a right line on the chart, preserving the same angle of bearing with respect to the intersected meridians as does the track of a vessel under a true course, was developed to plot the Mercator-projected maps. 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 all equally long. This means that any parallel is increased by $\frac{1}{\cos\theta}$ or $\sec\theta$, where θ is the latitude in degrees. In order to have the same scale along the parallels as along the meridians, each degree of latitude must also be increased 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 can refer to special publications on the subject, published by the U.S. Coast and Geodetic Survey.

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 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 arrangement of transverse Mercator Projections for the grid system is as follows. See figure 3-4A.

Starting at the 180th meridian and progressing eastward by the compass, the earth's surface is divided into a succession of N-S 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 E-W ROWS, each containing 8 degrees of latitude, with the



82.52

Figure 3-4.—(A) Grid zone designations of the military grid reference system. (B) 100,000-meter square designations in the UTM military grid system.

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 most southerly row and proceeds N. For a particular zone-row area, the designation is first the zone number, next the row letter, as. 16S, which means row S in zone 16.

For the Polar regions (that is, the areas above 84° N and below 80° S) there are only two zones in each area. These lie on either side of the 0° - 180° meridian. In the North Polar region the half of the region which contains the W longitudes is zone Y, that containing the E longitudes is zone Z. No numbers are used with these designations. Similarly, in the South Polar region the half containing the W longitudes is zone A; that containing the E longitudes zone B.

A particular point on the earth is further identified in the Universal Transverse Mercator

Military Grid System by the 100,000-METER SQUARE it happens to lie in. Each of the 6° longitude by 8° latitude zone-row areas in the system is subdivided into squares measuring 100,000 meters (about 63 miles) on a side. Each N-S column of 100,000-meter squares is identified by letter as follows. Beginning at the 180th meridian and proceeding eastward, there are six columns of full squares in each 6-degree zone. Besides the full columns, there are usually also partial columns, running 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 three zones the lettering system begins over again.

Observe, for example, figure 3-4B. 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 E of 180° is the partial column A. Next come six full columns. B, C, D, E, F, and G. Then comes partial column H, to the W of the zone meridian 174°W. The first column to the E of zone meridian 174°W is partial column J, then come the six full columns K, L, M, N, P, and Q, followed by partial column R. To the E of zone meridian 168°W the first column is partial column S, then come the six full columns T, U, V, W, X, and Y, and the partial column Z to the W of zone meridian 162°W.

The E-W 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 N of the Equator has the letter designation A, for columns in the even-numbered zones the first row of squares N of the Equator has the letter designation F. Rows above and below this row are designated in due alphabetical accord. The first row S of the Equator in the odd-numbered zones, for example, has the letter designation V, while the first row S 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 E of the 180th meridian and N of the Equator (square BA) in zone-row 1N, as shown in figure 3-4B.

If you know the latitude and longitude of a point on the earth you can determine tne designation of the 100,000-meter square in which the point lies. Take Fort Knox, Kentucky, for example, which lies approximately 38° 00'N, longitude 86° 00'W. You will find this latitude and longitude in figure 3-5, the point lies in column 16, row S, and 100,000-meter squares 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. To avoid the use of W or negative E-W coordinates, a FALSE EASTING of 500,000 meters, instead of a value of 0 meters, is assigned to the central meridian. To avoid the use of S or negative N-S coordinates, for points in the earth's southern hemisphere, the Equator is assigned a FALSE NORTHING of 10,000,000 meters, 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 point of origin. For example. for the bullion depository at Fort Knox, Kentucky, the coordinates of the 10-meter square in which the depository is located are. easting 590,990 meters, northing 4,193,150 meters. However, since the grid zone-row designation pin 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 3-6. The grid squares on this map measure 1,000 meters on a side. Note that the easting grid lines are identified by printed coordinates in which only the principal digits are

BEST COPY AVAILABLE

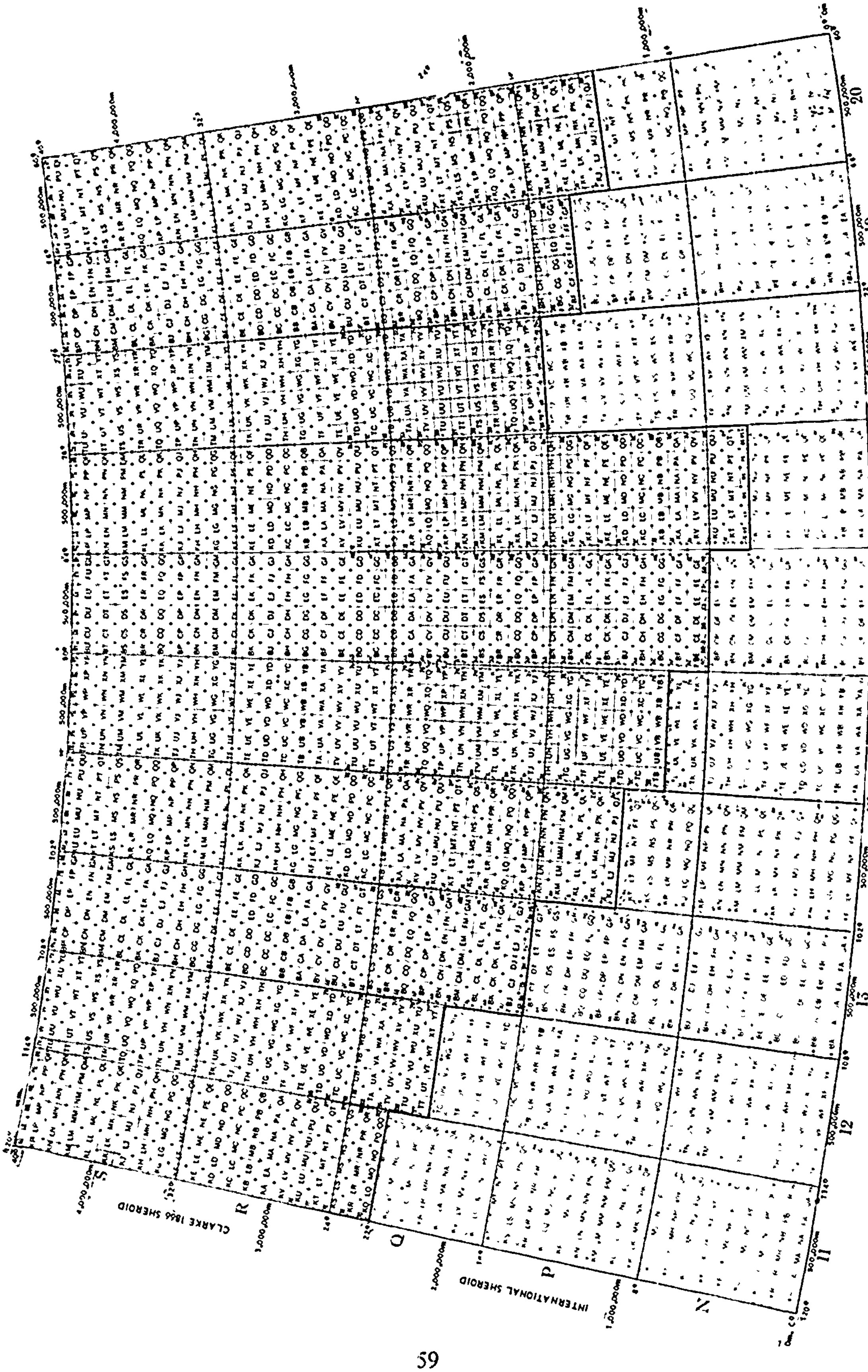
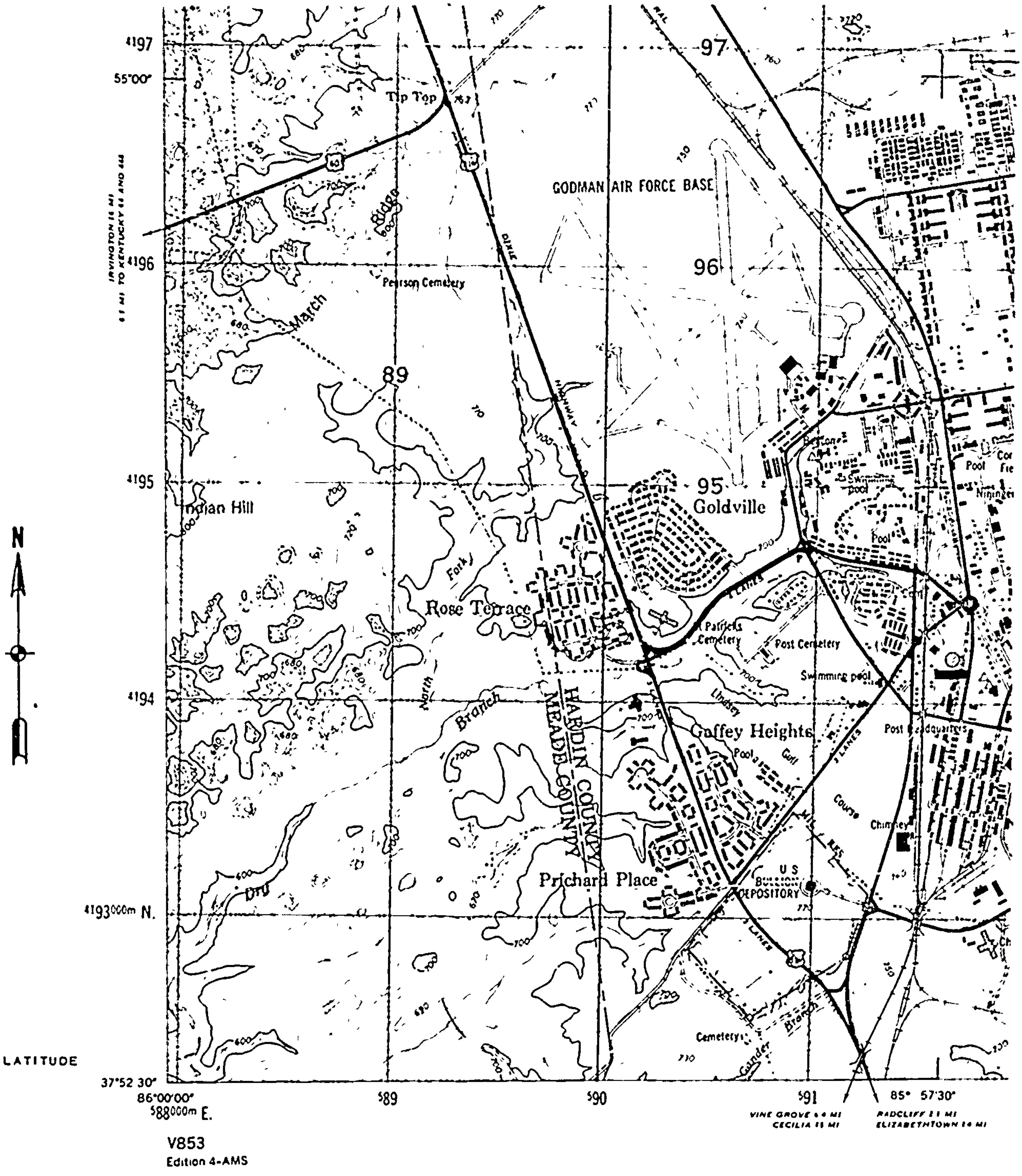


Figure 3-5.—100,000-meter square identifications for the military grid reference system.

82.52(82A)



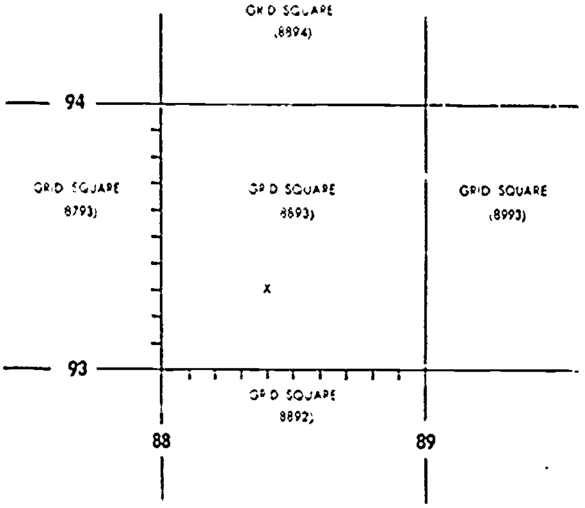
65.138

Figure 3-6.—Portion of a military map.

shown, and of these even the initial 5 is in small type. For 589, the value 589,000 meters is understood, and in setting down the coordinate for this line, even the 5 would 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 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, easting 9099, northing 9315. Actually, the easting 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 3-7, 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, another digit would have to be added to each coordinate element. The X lies four-tenths of 1,000 meters between line 88 and line 89; therefore, the easting 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, another pair of digits would be added these being determined by scale measurement on the map. It follows from all this that the coordinate previously given for the bullion depository at Fort Knox (90999315) locates this building with reference to a particular 10-meter square.



45.407(65)F
Figure 3-7.—Division of a grid square.

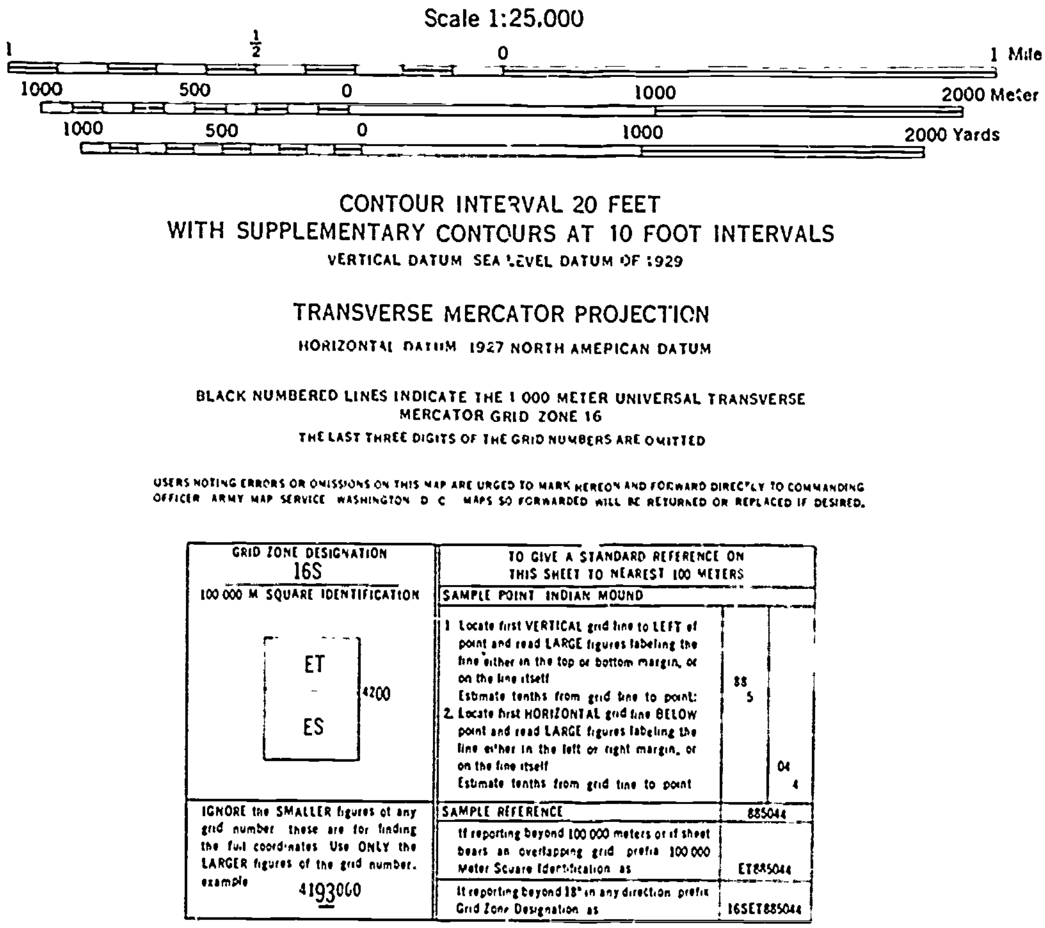
Figures 3-8 and 3-9 show the marginal information usually given on a UTM grid military map. Note the reference box which gives the grid zone-row and 100,000-meter square designation. The two squares indicate that the map covers parts of both. Note, too, that the direction of GRID NORTH (that is, the direction of the N-S grid lines on the map) varies from that of true N by 0° 39′ E, and from magnetic N by 1° 15′ W.

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, imagine a paper cone, placed over the northern hemisphere tangent to a parallel as shown in figure 3-10. The North Pole will be projected as a point at the apex of the cone. The meridians will radiate outward from the 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 3-11. 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.

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. Again the Pole will project as a point, from which the meridians will radiate away as straight lines; and again the parallels will appear as concentric circles, growing progressively smaller as latitude increases. The difference between this and a conic 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



65.124D

Figure 3-8.—Marginal information on a military map (1).

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 area.

Figure 3-12 shows the theory of gnomonic projection. Figure 3-13 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 E-W direction) must be both parallel to each other and perpendicular to the meridians.

2. It must be a projection on which the distance scale N and S is the same as the distance scale E and W.

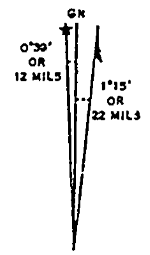
Obviously, none of the projections which we have described possesses both of these characteristics. The only one which possesses char-

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		
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		
Improved light duty road, street		
Unimproved dirt road		
Trail		
Route markers: Federal; State		
Barns, sheds, greenhouses, stadiums, etc.		
Bench mark, monumented	BM X 792	
Bench mark, non-monumented	X 431	
Spot elevations in feet: Checked; Unchecked	× 168	× 168
Light, lighthouse; Windmill, wind pump; Water mill		
Woods or brushwood	GREEN	
Vineyard; Orchard	GREEN	
Intermittent lake	BLUE	
Intermittent stream; Dam	BLUE	
Marsh or swamp	BLUE	
Rapids; Falls	BLUE	Falls, Rapids
Large rapids, Large falls	BLUE	

SERIES V853
SHEET 3859 IV NW
EDITION 4-AMS

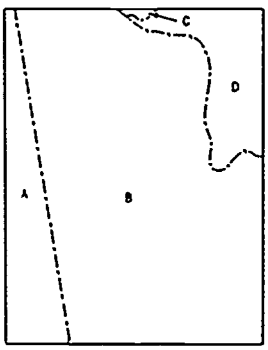


APPROXIMATE MEAN DECLINATION 1950
FOR CENTER OF SHEET
ANNUAL MAGNETIC CHANGE 1' EASTERLY

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.

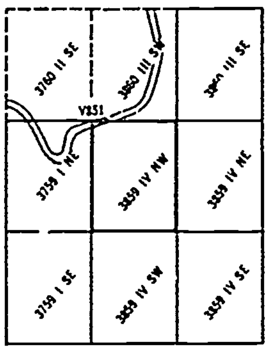
SX 11-61 PRINTED BY ARMY MAP SERVICE CORPS OF ENGINEERS

INDEX TO BOUNDARIES



A. Meade County
B Hardin County
C Jefferson County
D Bullitt County

INDEX TO ADJOINING SHEETS

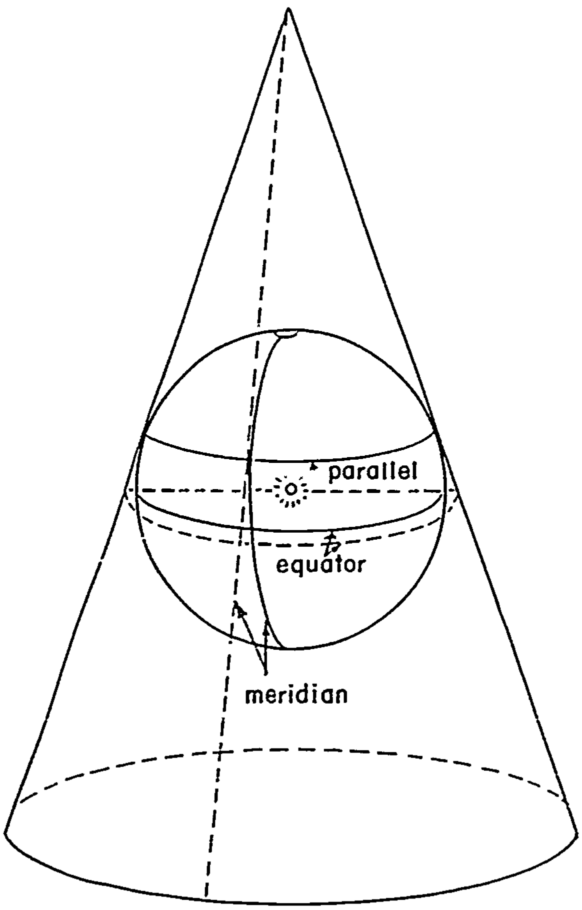


Sheet 3859 IV NW falls within NJ 16-9, V501, 1:250,000

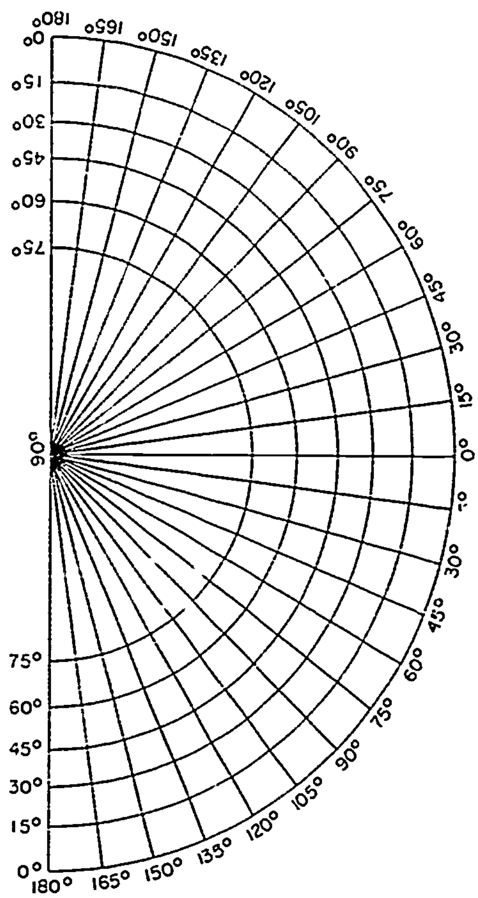
FORT KNOX, KENTUCKY

65.124E

Figure 3-9.—Marginal information on a military map (2).



45.423
Figure 3-10.—Conic projection.

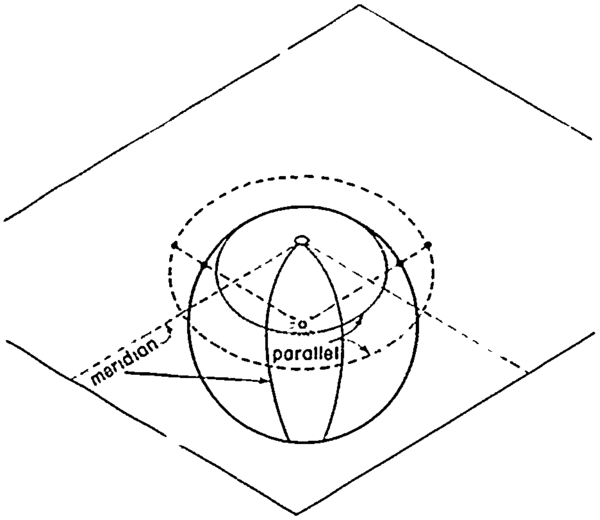


82.53
Figure 3-11.—Appearance of meridians and parallels on a conic projection.

acteristic number 1 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 N or E is the same anywhere on the map. With regard to 2, however, a distance of (for example) 15° is longer in any part of the map N-S than a distance of 15° (even in the same part) E-W.

As for the transverse Mercator, the conic, and the gnomonic projections, a glance at the appearance of meridians and parallels on one of these indicates, not only that direction is different in different parts of the map, but that direction of (for example) N in one part of the map may be precisely opposite to what it is 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 his ship's geographical location, and the principal disadvantage of Mercator projection—the N-S as against E-W 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° latitude) is impossible.



45.424
Figure 3-12.—Gnomonic projection.

For surveying and other purposes in which distance measurement must be consistent in any 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 which are virtually conformal, both direction-wise and distance-wise.

POLYCONIC PROJECTION

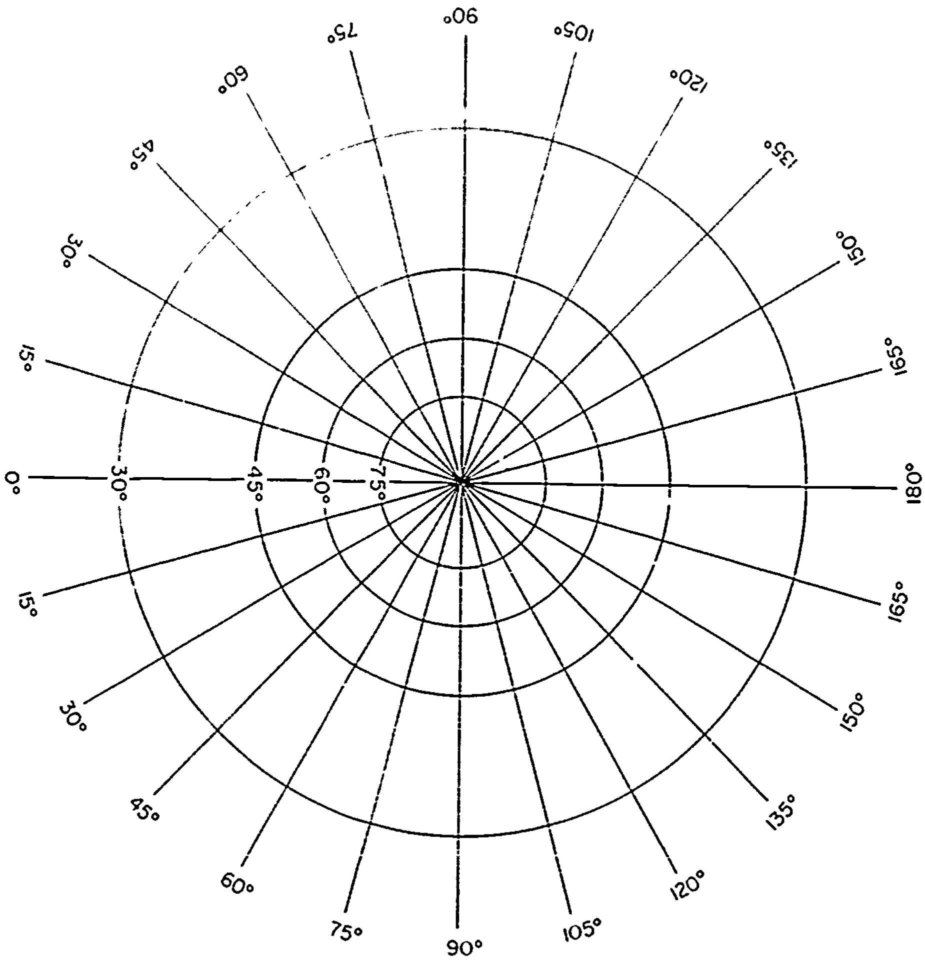
In POLYCONIC PROJECTION a near approach to directional conformality is obtained in relatively small-area maps by projecting the area in question onto more than one cone. A central meridian on the map is straight, all the others are very slightly curved and not quite parallel. Similarly, the parallels 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 3-14.

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 scale 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 which 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 which is square on the ground, is oblong rather than square. The vertical or latitude length of the map is always greater than the horizontal or longitude length. The reason is the fact 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 chart projection. A great circle is any line on the earth's surface (not necessarily a meridian or the Equator) which lies in a plane which 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 which 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 which 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.



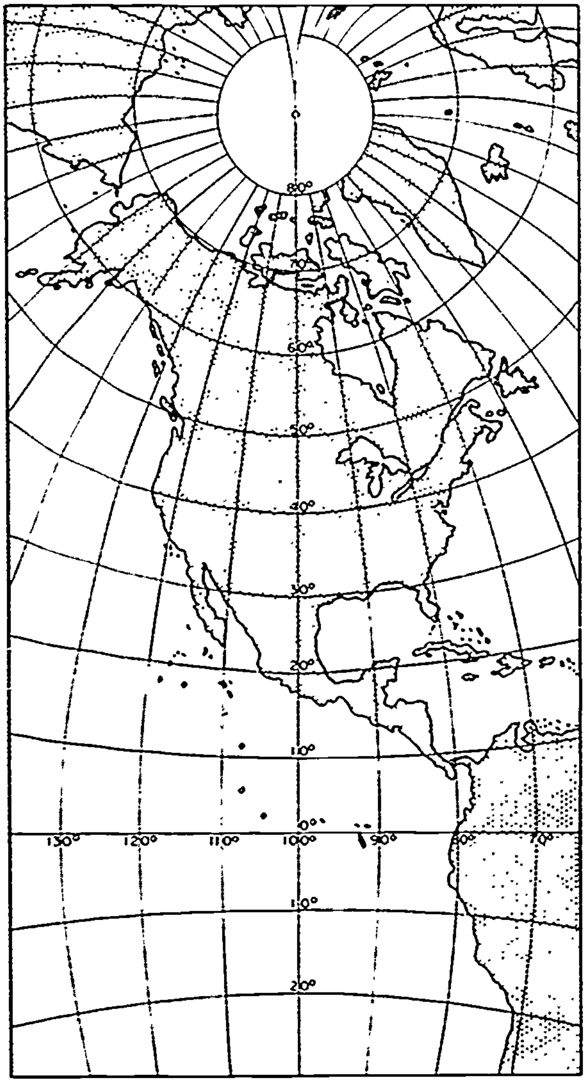
82.54

Figure 3-13.—Meridians and parallels on a polar gnomonic projection.

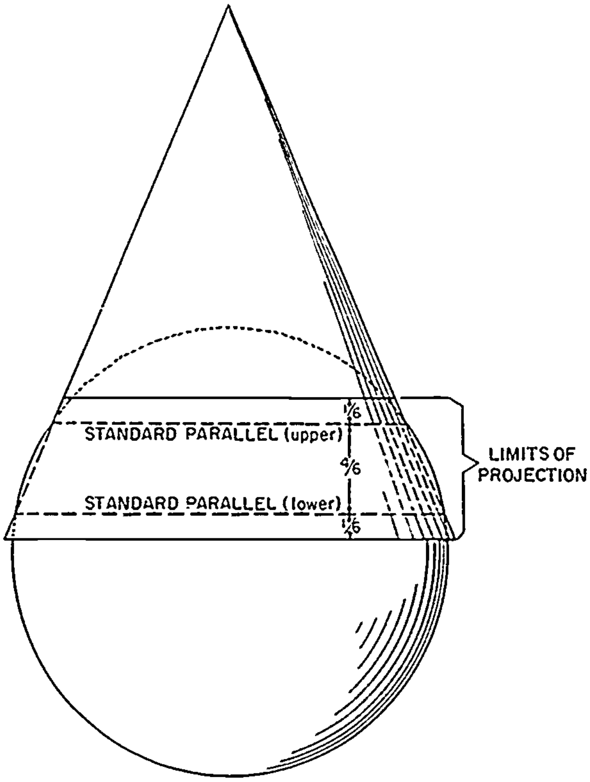
LAMBERT CONFORMAL CONIC PROJECTION

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 3-15. 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 directions. However, the distance scale applying to the whole map is exact only at the standard parallels, as shown in figure 3-16. 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 which 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 N-S, the Survey uses the transverse Mercator projection.



45.423(82B)A
Figure 3-14.–Polyconic projection of North America.



45.423(65)
Figure 3-15.–Lambert conformal conic projection.

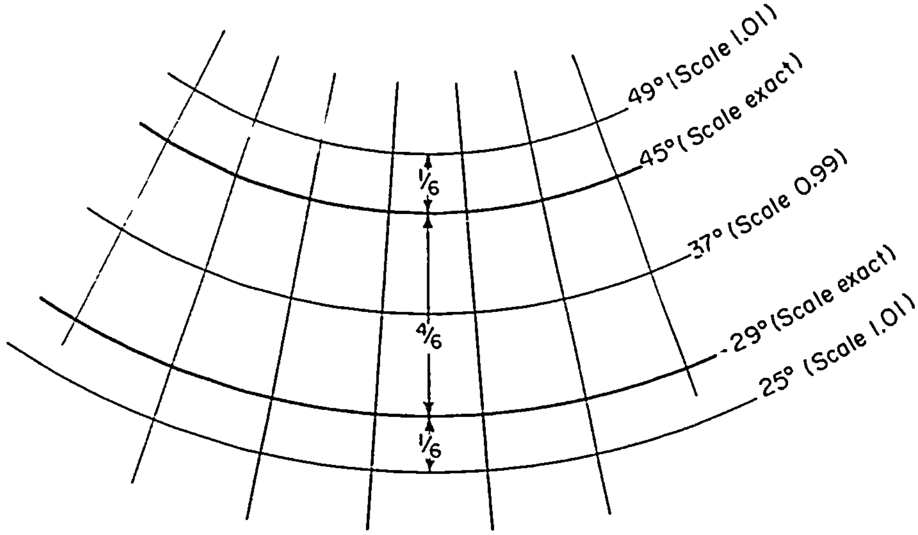
DIRECTION FROM CELESTIAL OBSERVATIONS

Occasions may occur when you must determine direction (that is, the location of true meridian) in an area where no practically located station monuments exist. In a case like this, you must rely on an observation taken on one of the celestial bodies, such as the sun or a star. Before you can understand the procedure involved, you must have some knowledge of different designations of time and FIELD ASTRONOMY.

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 in accordance with 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 one, 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



45.423(82B)B

Figure 3-16.—Scale distortion of the Lambert conformal conic projection with the standard parallels at 29° and 45°.

(that is, by the position of the actual sun) vary slightly in length. To avoid this difficulty, time is reckoned in accordance with a MEAN position of the sun, and this is called MEAN (or CIVIL) time. By mean time the interval from noon to noon along any meridian is always the same 24 hours.

As the sun moves along its course (we know that it's actually the earth, not the sun, that moves, but for purposes of explanation we assume that the earth is motionless, with the heavenly bodies moving to the westward around it), it takes noontime with it, so to speak. To put this another way: when the mean sun is on a particular meridian, it is noontime along that meridian, but it is not yet noon at any point to the westward and already past noon at any point of the eastward, by local mean time.

This means that, by local mean time, the time is different at any two points lying in different longitude. To avoid the obvious disadvantages of a system in which the time is different at the opposite ends of a short street running E-W, ZONE or STANDARD time has been established by general agreement among the nations of the earth.

ZONE TIME

Under this system the earth has been divided, along meridians, into 24 time zones. The starting point is the Greenwich meridian, lying in 0° longitude. Every meridian E or W of Greenwich which is numbered 15° or a multiple of 15° (such as 30° E or W, 45° E or W, 60° E or W, 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 either side of the meridian. In each zone the time is the same throughout the zone.

There is one hour's difference in time between the time in a particular zone and the time in an adjacent zone. In this connection, remember that IT IS LATER TO THE EASTWARD. If it is 1200 in your zone, it is 1300 in the next zone to the E, 1100 in the next zone to the W.

ZONE TIME AND GREENWICH MEAN TIME

The time listed in most of the computational tables used in celestial observations is GREENWICH MEAN TIME—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 which is called the ZONE DESCRIPTION. The Greenwich zone is number 0. The others are numbered from 1 through 12, E or W of Greenwich. To determine the zone description for any point on the earth, you divide the longitude by 15. If the remainder is less than 7° 30', the quotient PLUS ONE is the zone description.

Suppose, for example, that the longitude of the point of observation is 142° 19'W. Divide this by 15 and you get 9, with 7° 19' left over. This remainder is less than 7° 30', therefore, the zone description is 9. But suppose now that the longitude is 142° 41'W. Divide this by 15 and you get 9, with 7° 41' left over. This remainder is greater than 7° 31', therefore, the zone description is 9 + 1, or 10.

Zones E of Greenwich are minus, zones W of Greenwich are plus. To convert the zone time of an observation to the corresponding Greenwich mean time, you apply the zone description ACCORDING TO ITS SIGN to the zone time. For example, suppose the longitude of your point of observation is 75° 15' 37" E. Divide this by 15 and you get 5, with less than 7° 30' left over. The longitude is E, therefore, the zone description is -5. Suppose the zone time of the observation was 16h 23m 14s - 5h, or 11h 23m 14s.

Suppose now that the longitude of the point of observation was 68° 19'22"W and the ZT of the observation was 10h 15m 08s. 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 was 10h 15m 08s + 5h, or 15h 15m 08s.

ZONE TIME AND THE 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 ZT of your observation is 16h 24m 11s. The ZD is + 12. GMT of the observation was therefore 16h 24m 11s + 12, or 28h 24m 11s. However, 28h 24m 11s, 1 May, means 04h 24m 11s 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 ZT of the observation is 02h 15m 27s. The ZD is -3. You can't subtract 3h from 02h 15m 27s, but 02h 15m 27s 1 May can be considered as 26h 15m 27s 30 April. Therefore, GMT for the observation was 26h 15m 27s - 3h, or 23h 15m 27s, but on date 30 April rather than 1 May.

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 or 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. The best arrangement is an accurate ordinary watch plus a stop watch. The ordinary watch should be set to exact time shortly before the time of observation–by time signal, if possible. Time signals from the Naval Observatory at Washington are sent by telegraph throughout the country; many local radio stations re-broadcast a signal at noon ZT, and many telegraph stations provide time-signal service. The signal begins at 5 minutes before the hour. There is a tick for every second except the 51st second of the 1st minute, the 52nd second of the second minute, the 53rd second of the 3rd minute, the 54th second of the 4th minute, the 29th second of each minute, the last 4 seconds of each of the first 4 minutes, and the last 9 seconds of the last minute before the hour. After this long pause, the hour signal is an extra-long tick.

If a radio time signal is not available ashore, you may be able to get an exact time set from a sea-going ship in the vicinity. Such a ship maintains a running, constant correction for its chronometer through time signal.

Just before the observation is made, the stop watch should be started on an even minute indicated by the ordinary watch. If a long interval has elapsed since the ordinary watch was set by time signal, another signal should be obtained after the observation. If this signal shows that the watch has developed an error, the size of the error at the time of observation should be determined (by proportional equation) and applied to the observed time of observation.

ELEMENTS OF FIELD ASTRONOMY

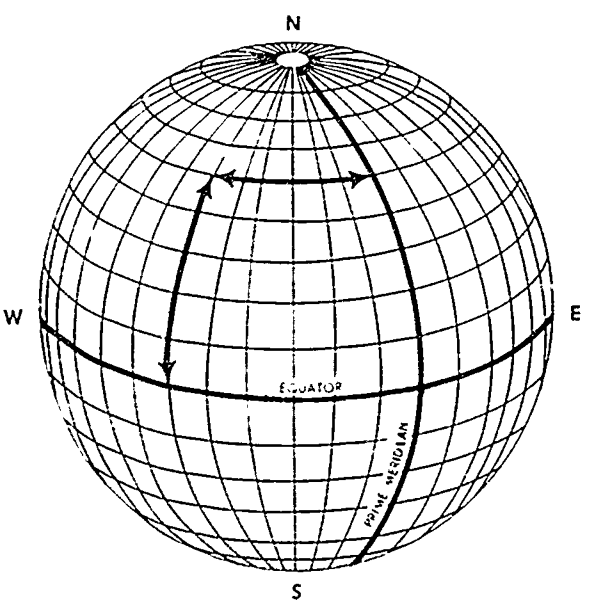
Although the earth is not actually a true sphere, it is presumed to be such for the purpose of astronomy. Astronomic determinations are based on the relations that exist among sets of coordinates the TERRESTRIAL SYSTEM stated in latitude and longitude, the CELESTIAL SYSTEM of right ascension and declination, or its subsidiary system of hour angle and declination, and the HORIZON SYSTEM in terms of altitude and azimuth.

Terrestrial Coordinates

In figure 3-17, the fundamental REFERENCE LINES of this system 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. 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.

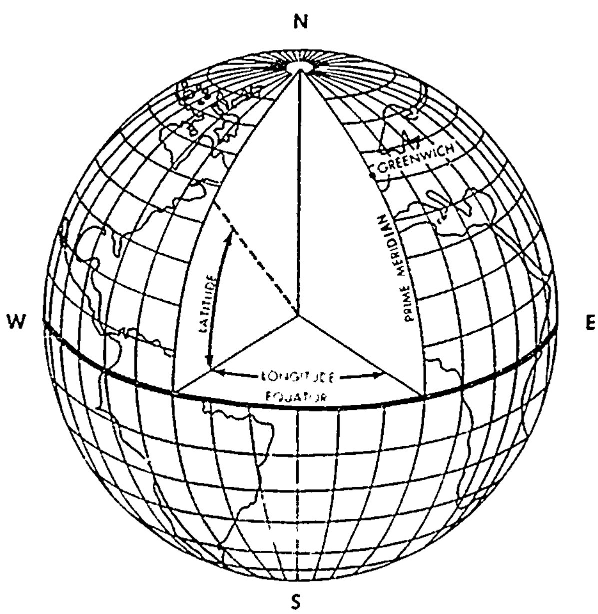
Note that in figure 3-18 the angle between the normal to the spheroid through a point and the plane of the Equator is the geodetic LATITUDE. Latitudes are expressed in degrees from 0° to 90° north and south from the Equator. The conventional symbol for latitude used in computation is the Greek letter ϕ (phi).

Observe, for example, in figure 3-18 that the LONGITUDE is the angular distance measured at the rotational axis of the earth between the plane through a chosen meridian of reference and the plane of the meridian through a required point. The meridian chosen as the origin of longitude is known as the prime meridian. Longitude is measured in degrees from 0° to



65.116E

Figure 3-17.—Refer e lines.



65.116F

Figure 3-18.—Latitude, longitude, and reference lines.

180° both west and east from the prime meridian. The conventional symbol for longitude is the Greek letter λ (LAMBDA).

Celestial Coordinates

The reference lines of the celestial system are the prolongation of the earth's axis of rotation and the plane of the Equator extended to intercept the celestial sphere. Assume again that the earth is a glass sphere, with meridians and parallels traced in black and a light placed at the center. Suppose this sphere is placed at the center of another infinitely larger sphere. This one is the imaginary CELESTIAL SPHERE, on which all the heavenly bodies are presumed to be located. The celestial sphere is a mathematical device, or concept, of a sphere of infinite radius whose center is at the center of the earth. The points where the earth' prolonged axis 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, similar 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 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 patl or motion, it is this apparent motion that is intended.

DECLINATION.–The declination of a celestial body (star, sun, or planet) is its angular distance north or south from the celestial equator measured along the hour circle. Declinations are measured in degrees from 0° to 90° from the equator: north and south values are given the signs, plus and minus, 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 a selected point on the celestial sphere where the apparent path of the sun, ECLIPTIC, crosses the Equator from south to north. There is no physical marking of this point visible in the sky. The vernal equinox moves westward along the Equator about 50 seconds of arc per year. This is known as the precession of the equinoxes. The right ascension is the angular distance measured eastward (opposite to the star's apparent motion) along the celestial equator from the vernal equinox to the hour circle passing through any celestial body. Right ascension is normally expressed in units of time from 0 to 24 hours, although it can be expressed in degrees, one hour of time corresponding to 15 degrees. The conventional symbol for right ascension is the Greek letter α (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. It is the angle between celestial meridians, or hour circles, but its origin is the meridian which passes through the observer's zenith. The HOUR ANGLE is defined as the angular distance, measured at the observer's position, westward along the celestial equator from the observer's meridian passing through the observer's zenith to the hour circle passing through the body. This angle is often called the LOCAL HOUR ANGLE (LHA), which will be discussed latter.

GREENWICH HOUR ANGLE.–The coordinate which corresponds to longitude is, for a heavenly body, called GREENWICH HOUR ANGLE (GHA). Greenwich hour angle is the distance of the body's hour circle W of the projected Greenwich meridian, in degrees, minutes, and seconds of arc, measured from the projected Greenwich meridian along the circle of equal declination which the body happens to be on at the given instant. Longitude is measured E or W from Greenwich through 180°; GHA, however, is measured only to the W from Greenwich, through 360°. Another point to remember is that, while the longitude of a point on the earth remains always the same, the GHA of the celestial object is constantly increasing as the body moves westward on the celestial sphere.

AZIMUTH. 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.

Horizon Coordinates

In order to connect the celestial and terrestrial coordinates, a third system, descriptive of the observer's position, is necessary. The fundamental reference of this system is the observer's horizon. The HORIZON is a plane through the observer's position perpendicular to the direction of gravity at that point and which intercepts the celestial sphere in a great circle. The direction of gravity is commonly called the direction of the plumb line, and 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 star observations, the distance from this plane to the center of the earth is too small to affect the computations. However, observations on 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. That vertical circle whose plane is at right angles to the plane of the observer's meridian and passes through his zenith is known as the PRIME VERTICAL.

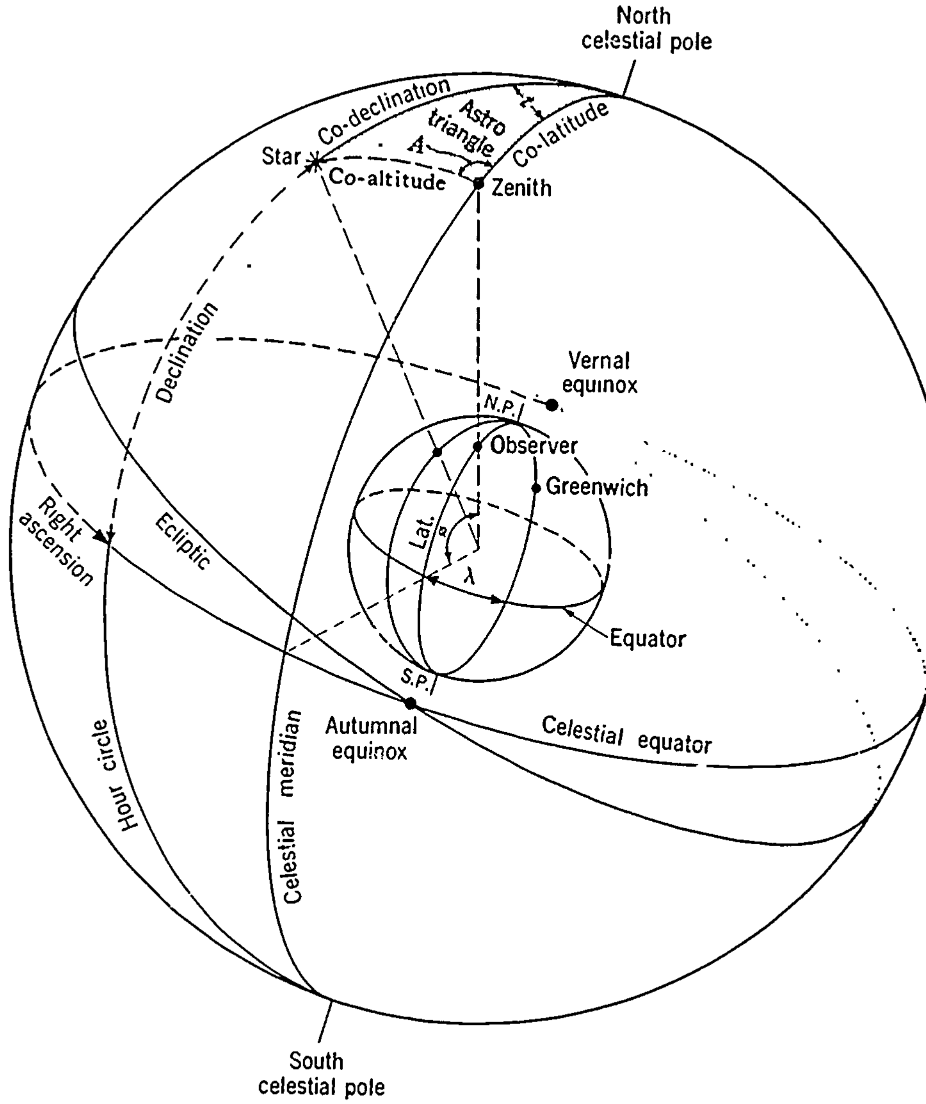
The Astronomic Triangle

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 which lies on the celestial sphere, and whose vertices are the pole, the zenith, and the celestial body involved. This is known as the ASTRONOMIC or the PZS (pole-zenith-star) triangle. The ASTRONOMIC TRIANGLE is shown in figure 3-19. 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 astronomic triangle, the side between the pole and the zenith is $90° - \phi$ or the co-latitude, between the pole and star is $90° - \delta$ or the co-declination, and between the zenith and the star is the zenith distance (z) or co-altitude (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 side 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.

The Solar Ephemeris and Nautical Almanac

The declination and Greenwich hour angle of the sun and of five planets (the Moon, Venus, Mars, Jupiter, and Saturn) are given for every even hour of GMT for every day in the year in the daily pages of the *Solar Ephemeris* or the *Nautical Almanac*, publications prepared by the Naval Observatory and available for sale at the U. S. Government Printing Office, Washington D.C. Suppose that you want to determine the GHA and declination of the sun for an observation made at ZT 10h 23m 18s on 7 May 1972 in longitude 79° 37′ 12″ W. The ZD is + 5; therefore, GMT of the observation was 15h 23m 18s.

Table 3-1 shows the relevant daily page of the 1972 *Nautical Almanac.* You can see that for 15h 00m 00s on 7 May the GHA listed for the sun is 45° 52′.7. For the extra 23m 18s you turn to a TABLE OF INCREMENTS AND CORRECTIONS in the back of the book. Table 3-2 shows



82.147

Figure 3-19.–Terrestrial and celestial coordinate systems.

the relevant page of the table. Under 23m and beside 18s 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° 52′.7 + 5° 49′or 51° 42′. 2.

On the daily page for 7 May (ɔle 3-1) the *Almanac* gives a sun declination 15h 00m 00s GMT of N 16° 57′.3. At th ot of the column you see a small d and the figure 0.7. In the increments and corrections table (Table 3-2) you see a column of "v" or "d" corrections for declination. You go down this column to the figure 0.7, where you find that the "d" correction in this case is 0′ .3. Whether you add this or subtract it depends upon whether the sun's declination 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 N 16° 57′.3 + 0′.3, or N 16° 57′.6.

On an opposing daily page of the *Nautical Almanac* the declinations of a select list of 57

Table 3-1.—Sun and Moon Daily Page from the Nautical Almanac

1972 MAY 6, 7, 8 (SAT., SUN., MON.)

G.M.T.	SUN G.H.A.	SUN Dec.	MOON G.H.A.	v	Dec.	d	H.P.
d h	° ′	° ′	° ′	′	° ′	′	′
6 00	180 51·0	N16 30·2	272 27·5	11·6	S17 02·9	11·3	56·8
01	195 51·1	30·9	286 58·1	11·7	16 51·6	11·4	56·9
02	210 51·1	31·7	301 28·8	11·6	16 40·2	11·4	56·9
03	225 51·2	· · 32·4	315 59·4	11·7	16 28·8	11·6	56·9
04	240 51·2	33·1	330 30·1	11·7	16 17·2	11·7	57·0
05	255 51·3	33·8	345 00·8	11·7	16 05·5	11·8	57·0
06	270 51·3	N16 34·5	359 31·5	11·8	S15 53·7	11·8	57·0
07	285 51·4	35·2	14 02·3	11·7	15 41·9	12·0	57·1
S 08	300 51·4	35·9	28 33·0	11·8	15 29·9	12·0	57·1
A 09	315 51·4	· · 36·6	43 03·8	11·9	15 17·9	12·1	57·1
T 10	330 51·5	37·3	57 34·7	11·8	15 05·8	12·2	57·2
U 11	345 51·5	38·0	72 05·5	11·9	14 53·6	12·3	57·2
R 12	0 51·6	N16 38·6	86 36·4	11·9	S14 41·3	12·4	57·2
D 13	15 51·6	39·3	101 07·3	11·9	14 28·9	12·5	57·3
A 14	30 51·7	40·0	115 38·2	11·9	14 16·4	12·6	57·3
Y 15	45 51·7	· · 40·7	130 09·1	11·9	14 03·8	12·6	57·3
16	60 51·8	41·4	144 40·0	12·0	13 51·2	12·7	57·4
17	75 51·8	42·1	159 11·0	12·0	13 38·5	12·8	57·4
18	90 51·9	N16 42·8	173 42·0	12·0	S13 25·7	12·9	57·4
19	105 51·9	43·5	188 13·0	12·0	13 12·8	13·0	57·5
20	120 51·9	44·2	202 44·0	12·0	12 59·8	13·0	57·5
21	135 52·0	· · 44·9	217 15·0	12·1	12 46·8	13·1	57·6
22	150 52·0	45·6	231 46·1	12·0	12 33·7	13·2	57·6
23	165 52·1	46·3	246 17·1	12·1	12 20·5	13·3	57·6
7 00	180 52·1	N16 47·0	260 48·2	12·1	S12 07·2	13·4	57·7
01	195 52·2	47·7	275 19·3	12·1	11 53·8	13·4	57·7
02	210 52·2	48·4	289 50·4	12·1	11 40·4	13·5	57·7
03	225 52·2	· · 49·1	304 21·5	12·1	11 26·9	13·6	57·8
04	240 52·3	49·7	318 52·6	12·1	11 13·3	13·6	57·8
05	255 52·3	50·4	333 23·7	12·1	10 59·7	13·8	57·8
06	270 52·4	N16 51·1	347 54·8	12·2	S10 45·9	13·7	57·9
07	285 52·4	51·8	2 26·0	12·1	10 32·2	13·9	57·9
08	300 52·4	52·5	16 57·1	12·2	10 18·3	13·9	58·0
S 09	315 52·5	· · 53·2	31 28·3	12·1	10 04·4	14·0	58·0
U 10	330 52·5	53·9	45 59·4	12·2	9 50·4	14·1	58·0
N 11	345 52·6	54·6	60 30·6	12·1	9 36·3	14·1	58·1
D 12	0 52·6	N16 55·2	75 01·7	12·2	S 9 22·2	14·2	58·1
A 13	15 52·6	55·9	89 32·9	12·1	9 08·0	14·2	58·1
Y 14	30 52·7	56·6	104 04·0	12·2	8 53·8	14·4	58·2
15	45 52·7	· · 57·3	118 35·2	12·2	8 39·4	14·3	58·2
16	60 52·8	58·0	133 06·4	12·1	8 25·1	14·5	58·3
17	75 52·8	58·7	147 37·5	12·2	8 10·6	14·5	58·3
18	90 52·8	N16 59·4	162 08·7	12·1	S 7 56·1	14·5	58·3
19	105 52·9	17 00·0	176 39·8	12·2	7 41·6	14·6	58·4
20	120 52·9	00·7	191 11·0	12·1	7 27·0	14·7	58·4
21	135 53·0	· · 01·4	205 42·1	12·1	7 12·3	14·7	58·4
22	150 53·0	02·1	220 13·2	12·1	6 57·6	14·8	58·5
23	165 53·0	02·8	234 44·3	12·1	6 42·8	14·8	58·5
8 00	180 53·1	N17 03·4	249 15·4	12·1	S 6 28·0	14·9	58·6
01	195 53·1	04·1	263 46·5	12·1	6 13·1	14·9	58·6
02	210 53·1	04·8	278 17·6	12·1	5 58·2	15·0	58·6
03	225 53·2	· · 05·5	292 48·7	12·1	5 43·2	15·0	58·7
04	240 53·2	06·2	307 19·8	12·0	5 28·2	15·1	58·7
05	255 53·2	06·8	321 50·8	12·0	5 13·1	15·1	58·7
06	270 53·3	N17 07·5	336 21·8	12·0	S 4 58·0	15·2	58·8
07	285 53·3	08·2	350 52·8	12·0	4 42·8	15·2	58·8
08	300 53·3	08·9	5 23·8	12·0	4 27·6	15·3	58·9
M 09	315 53·4	· · 09·5	19 54·8	11·9	4 12·3	15·3	58·9
O 10	330 53·4	10·2	34 25·7	12·0	3 57·0	15·3	58·9
N 11	345 53·4	10·9	48 56·7	11·9	3 41·7	15·4	59·0
D 12	0 53·5	N17 11·6	63 27·6	11·9	S 3 26·3	15·4	59·0
A 13	15 53·5	12·2	77 58·5	11·8	3 10·9	15·4	59·0
Y 14	30 53·5	12·9	92 29·3	11·8	2 55·5	15·5	59·1
15	45 53·6	· · 13·6	107 00·1	11·8	2 40·0	15·5	59·1
16	60 53·6	14·3	121 30·9	11·8	2 24·5	15·6	59·2
17	75 53·6	14·9	136 01·7	11·7	2 08·9	15·5	59·2
18	90 53·7	N17 15·6	150 32·4	11·7	S 1 53·4	15·6	59·2
19	105 53·7	16·3	165 03·1	11·7	1 37·8	15·7	59·3
20	120 53·7	16·9	179 33·8	11·7	1 22·1	15·6	59·3
21	135 53·8	· · 17·6	194 04·5	11·6	1 06·5	15·7	59·3
22	150 53·8	18·3	208 35·1	11·5	0 50·8	15·7	59·4
23	165 53·8	19·0	223 05·6	11·6	0 35·1	15·3	59·4
	S.D. 15·9	d 0·7	S.D. 15·6		15·8		16·1

Lat.	Twilight Naut.	Twilight Civil	Sunrise	Moonrise 6	Moonrise 7	Moonrise 8	Moonrise 9
°	h m	h m	h m	h m	h m	h m	h m
N 72	////	////	00 46	04 17	03 19	02 43	02 13
N 70	////	////	01 53	03 35	03 00	02 35	02 13
68	////	////	02 29	03 06	02 45	02 28	02 13
66	////	01 12	02 54	02 44	02 32	02 22	02 13
64	////	01 56	03 13	02 27	02 22	02 18	02 13
62	////	02 24	03 29	02 13	02 13	02 13	02 13
60	01 04	02 45	03 42	02 00	02 06	02 10	02 13
N 58	01 44	03 02	03 53	01 50	01 59	02 06	02 13
56	02 10	03 16	04 03	01 40	01 53	02 04	02 14
54	02 30	03 29	04 12	01 32	01 48	02 01	02 14
52	02 46	03 39	04 19	01 25	01 43	01 59	02 14
50	03 00	03 49	04 26	01 18	01 38	01 56	02 14
45	03 26	04 08	04 41	01 04	01 29	01 52	02 14
N 40	03 47	04 23	04 53	00 52	01 21	01 47	02 14
35	04 03	04 36	05 03	00 41	01 14	01 44	02 14
30	04 16	04 47	05 12	00 32	01 07	01 41	02 14
20	04 37	05 04	05 28	00 17	00 5[illegible]	01 36	02 14
N 10	04 53	05 19	05 41	00 03	00 4[illegible]	01 31	02 14
0	05 06	05 31	05 53	24 39	00 39	01 26	02 15
S 10	05 18	05 43	06 05	24 30	00 30	01 22	02 15
20	05 29	05 55	06 18	24 20	00 20	01 17	02 15
30	05 39	06 08	06 33	24 09	00 09	01 12	02 15
35	05 44	06 14	06 41	24 03	00 03	01 08	02 16
40	05 50	06 22	06 51	23 56	25 05	01 05	02 16
45	05 55	06 31	07 02	23 47	25 01	01 01	02 16
S 50	06 02	06 40	07 15	23 37	24 56	00 56	02 16
52	06 04	06 45	07 22	23 32	24 53	00 5[illegible]	02 16
54	06 07	06 50	07 29	23 27	24 51	00 [illegible]	02 17
56	06 10	06 55	07 36	23 21	24 48	00 48	02 17
58	06 14	07 01	07 45	23 15	24 45	00 45	02 17
S 60	06 17	07 08	07 55	23 07	24 41	00 41	02 17

Lat.	Sunset	Twilight Civil	Twilight Naut.	Moonset 6	Moonset 7	Moonset 8	Moonset 9
°	h m	h m	h m	h m	h m	h m	h m
N 72	23 27	////	////	08 09	10 49	13 07	15 25
N 70	22 06	////	////	08 50	11 06	13 12	15 19
68	21 28	////	////	09 17	11 19	13 16	15 15
66	21 02	22 49	////	09 37	11 29	13 19	15 12
64	20 42	22 02	////	09 53	11 38	13 22	15 09
62	20 26	21 32	////	10 07	11 45	13 24	15 06
60	20 13	21 10	22 56	10 18	11 52	13 26	15 04
N 58	20 01	20 53	22 13	10 28	11 57	13 28	15 02
56	19 51	20 38	21 46	10 36	12 02	13 30	15 00
54	19 43	20 26	21 26	10 44	12 07	13 31	14 58
52	19 35	20 15	21 09	10 51	12 11	13 33	14 57
50	19 28	20 06	20 55	10 57	12 14	13 34	14 56
45	19 13	19 46	20 28	11 10	12 22	13 36	14 53
N 40	19 01	19 31	20 07	11 20	12 29	13 38	14 50
35	18 50	19 18	19 51	11 29	12 34	13 40	14 48
30	18 41	19 07	19 38	11 37	12 39	13 42	14 47
20	18 26	18 49	19 17	11 51	12 47	13 45	14 43
N 10	18 13	18 34	19 00	12 03	12 55	13 47	14 41
0	18 00	18 22	18 47	12 13	13 01	13 49	14 38
S 10	17 48	18 10	18 35	12 24	13 08	13 51	14 35
20	17 35	17 58	18 24	12 36	13 15	13 54	14 33
30	17 20	17 45	18 14	12 49	13 23	13 56	14 30
35	17 12	17 38	18 08	12 56	13 28	13 57	14 28
40	17 02	17 31	18 03	13 05	13 33	13 59	14 26
45	16 51	17 22	17 [illegible]7	13 15	13 39	14 01	14 23
S 50	16 37	17 12	17 51	13 27	13 46	14 03	14 21
52	16 31	17 07	17 48	13 32	13 49	14 04	14 19
54	16 24	17 02	17 45	13 38	13 52	14 05	14 18
56	16 16	16 57	17 42	13 45	13 56	14 06	14 16
58	16 07	16 51	17 39	13 52	14 01	14 08	14 15
S 60	15 57	16 44	17 35	14 01	14 05	14 09	14 13

Day	SUN Eqn. of Time 00h	SUN Eqn. of Time 12h	SUN Mer. Pass.	MOON Mer. Pass. Upper	MOON Mer. Pass. Lower	Age	Phase
	m s	m s	h m	h m	h m	d	
6	03 24	03 26	11 57	06 02	18 26	23	
7	03 28	03 30	11 56	06 50	19 14	24	
8	03 32	03 34	11 56	07 38	20 02	25	

69.146(82B)

Table 3-2.–Page from Nautical Almanac. Table of Increments and Corrections

22ᵐ INCREMENTS AND CORRECTIONS 23ᵐ

22	SUN PLANETS	ARIES	MOON	v or d	Corr	v or d	Corr	v or d	Corr
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

23	SUN PLANETS	ARIES	MOON	v or d	Corr	v or d	Corr	v or d	Corr
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

82.56(82B)

prominent stars are given. Instead of the GHA's of these stars, however, the SIDEREAL ANGLE of each star is given, as shown in Table 3-3. The sidereal angle of a star is its arc distance westward from the hour circle of a point on the celestial sphere called the 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 3-2 and 3-3. You then add this to the SHA of the star, as given in the daily page of the *Almanac* (Table 3-3). 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, for any time of the day.

Identifying Stars

You can learn to identify at sight a number of useful stars from their positions in or near well-known constellations. A few that are easy to identify in this fashion are as follows:

POLARIS—This is the North star, which can be located by following a line through the POINTERS. The POINTERS are the two stars which form the leading edge of the bucket of the BIG DIPPER.

DUBHE is the pointer star in the BIG DIPPER which is nearer to POLARIS.

ALKAID is the end star in the handle of the BIG DIPPER.

ALIOTH is the star in the BIG DIPPER handle which is nearest to the bucket.

ARCTURUS is a bright star near the BIG DIPPER, found by following a line through the DIPPER handle away from the bucket.

The following stars are in the constellation ORION, the HUNTER:

ALNILAM is the middle star in ORION's belt.

BETELGEUSE is the forward, brighter shoulder of ORION.

BELLATRIX is the rear, dimmer shoulder of ORION.

RIGEL is the rear, brighter knee of ORION. The following stars are near ORION.

ALDEBARAN is above ORION, on a line from the star in the forward, lower end of the belt through BELLATRIX.

PROCYON is in front of ORION, on a line from BELLATRIX through BETELGEUSE.

POLLUX is above PROCYON, on a line from BELLATRIX through BETELGEUSE.

SIRIUS (brightest of all the stars) is below ORION, on a line from BELLATRIX through the star in the forward, lower end of the belt.

The constellation CASSIOPEIA is shaped like a chair with a broken back. SCHEDAR, a star in this constellation, is located at the back end of the chair seat.

You will not be able to learn to recognize at sight more than a few of the 57 stars listed in the *Nautical Almanac*, and your observation may be taken in a latitude and/or at a time when few or none of the stars you know by sight are visible. For identification, at any time, of the prominent stars visible in any latitude, the RUDE STAR FINDER, H.O. 2102-D, is invaluable The star finder is available for sale at the U. S. Navy Oceanographic Office and its branches.

The star finder contains elements as follows:

1. A circular opaque white plastic disk, showing a star map of prominent stars visible in N latitudes on one side and those visible in S latitudes on the other. The edge of the disk is graduated on both sides from 0° through 360°, the 0 graduation representing the hour circle of the FIRST POINT OF ARIES.

2. Transparent circular templates, one for every 10° of latitude, each having N latitude on one side and S latitude on the other. On each template there is a grid which can be read for altitude (vertical angle above the observer's horizontal plane) and azimuth.

Complete instructions for the use of the star finder are provided with it. The procedure is as follows:

Suppose you want to know what prominent stars will be visible in latitude about 35°N on a certain night at a certain time, and the ap-

Table 3·3.–Star and Planet Daily Page from the Nautical Almanac

1972 MAY 6, 7, 8 (SAT., SUN., MON.)

G.M.T.		ARIES	VENUS −4·2		MARS +1·8		JUPITER −2·0		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.
		° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′		° ′	° ′
6	00	223 56·8	136 55·9	N27 37·2	138 34·2	N24 31·8	305 06·6	S 22 54·8	158 47·9	N19 52·6	Acamar	315 42·0	S 40 24·8
	01	238 59·3	151 56·6	37·2	153 34·9	31·9	320 09·1	54·8	173 50·1	52·7	Achernar	335 50·0	S 57 22·4
	02	254 01·8	166 57·3	37·2	168 35·6	32·0	335 11·7	54·8	188 52·2	52·7	Acrux	173 43·6	S 62 57·1
	03	269 04·2	181 58·0 ..	37·2	183 36·3 ..	32·0	350 14·2 ..	54·9	203 54·4 ..	52·8	Adhara	255 37·0	S 28 56·2
	04	284 06·7	196 58·7	37·2	198 37·0	32·1	5 16·8	54·9	218 56·5	52·8	Aldebaran	291 25·1	N 16 27·3
	05	299 09·1	211 59·4	37·2	213 37·7	32·1	20 19·4	54·9	233 58·6	52·9			
	06	314 11·6	227 00·1	N27 37·2	228 38·4	N24 32·2	35 21·9	S 22 54·9	249 00·8	N19 53·0	Alioth	166 47·0	N 56 06·6
	07	329 14·1	242 00·8	37·3	243 39·1	32·2	50 24·5	54·9	264 02·9	53·0	Alkaid	153 22·5	N 49 27·0
S	08	344 16·5	257 01·5	37·3	258 39·8	32·3	65 27·0	54·9	279 05·1	53·1	Al Na'ir	28 22·3	S 47 05·5
A	09	359 19·0	272 02·2 ..	37·3	273 40·5 ..	32·4	80 29·6 ..	54·9	294 07·2 ..	53·1	Alnilam	276 17·9	S 1 13·1
T	10	14 21·5	287 03·0	37·3	288 41·2	32·4	95 32·2	54·9	309 09·3	53·2	Alphard	218 26·4	S 8 32·4
U	11	29 23·9	302 03·7	37·3	303 41·9	32·5	110 34·7	54·9	324 11·5	53·2			
R	12	44 26·4	317 04·4	N27 37·3	318 42·6	N24 32·5	125 37·3	S 22 54·9	339 13·6	N19 53·3	Alphecca	126 36·7	N 26 48·2
D	13	59 28·9	332 05·1	37·3	333 43·3	32·6	140 39·8	54·9	354 15·8	53·4	Alpheratz	358 15·8	N 28 56·2
A	14	74 31·3	347 05·9	37·3	348 44·0	32·6	155 42·4	55·0	9 17·9	53·4	Altair	62 38·2	N 8 47·5
Y	15	89 33·8	2 06·6 ..	37·3	3 44·7 ..	32·7	170 45·0 ..	55·0	24 20·0 ..	53·5	Ankaa	353 46·2	S 42 27·2
	16	104 36·2	17 07·3	37·3	18 45·4	32·7	185 47·5	55·0	39 22·2	53·5	Antares	113 03·8	S 26 22·5
	17	119 38·7	32 08·1	37·2	33 46·1	32·8	200 50·1	55 0	54 24·3	53·6			
	18	134 41·2	47 08·8	N27 37·2	48 46·8	N24 32·8	215 52·6	S 22 55·0	69 26·5	N19 53·6	Arcturus	146 23·5	N 19 19·4
	19	149 43·6	62 09·5	37·2	63 47·5	32·9	230 55·2	55·0	84 28·6	53·7	Atria	108 33·0	S 68 58·8
	20	164 46·1	77 10·3	37·2	78 48·2	32·9	245 57·8	55·0	99 30·7	53·8	Avior	234 30·9	S 59 25·5
	21	179 48·6	92 11·0 ..	37·2	93 48·9 ..	33·0	261 00·3 ..	55·0	114 32·9 ..	53·8	Bellatrix	279 05·4	N 6 19·6
	22	194 51·0	107 11·8	37·2	108 49·6	33·0	276 02·9	55·0	129 35·0	53·9	Betelgeuse	271 34·9	N 7 24·2
	23	209 53·5	122 12·5	37·2	123 50·3	33·1	291 05·5	55·0	144 37·1	53·9			
7	00	224 56·0	137 13·3	N27 37·2	138 51·0	N24 33·1	306 08·0	S 22 55·0	159 39·3	N19 54·0	Canopus	264 10·2	S 52 41·0
	01	239 58·4	152 14·0	37·2	153 51·7	33·2	321 10·6	55·1	174 41·.	54·0	Capella	281 20·5	N 45 58·4
	02	255 00·9	167 14·8	37·2	168 52·4	33·2	336 13·2	55·1	189 43·6	54·1	Deneb	49 52·5	N 45 10·6
	03	270 03·4	182 15·6 ..	37·2	183 53·1 ..	33·3	351 15·7 ..	55·1	204 45·7 ..	54·2	Denebola	183 04·8	N 14 43·5
	04	285 05·8	197 16·3	37·2	198 53·8	33·3	6 18·3	55·1	219 47·8	54·2	Diphda	349 27·0	S 18 08·2
	05	300 08·3	212 17·1	37·1	213 54·5	33·4	21 20·9	55·1	234 50·0	54·3			
	06	315 10·7	227 17·9	N27 37·1	228 55·2	N24 33·4	36 23·4	S 22 55·1	249 52·1	N19 54·3	Dubhe	194 28·8	N 61 54·2
	07	330 13·2	242 18·6	37·1	243 55·9	33·5	51 26·0	55·1	264 54·2	54·4	Elnath	278 51·9	N 28 35·2
	08	345 15·7	257 19·4	37·1	258 56·6	33·5	66 28·6	55·1	279 56·4	54·4	Eltanin	91 00·1	N 51 29·2
S	09	0 18·1	272 20·2 ..	37·1	273 57·3 ..	33·6	81 31·1 ..	55·1	294 58·5 ..	54·5	Enif	34 17·4	N 9 44·7
U	10	15 20·6	287 21·0	37·1	288 58·0	33·6	96 33·7	55·1	310 00·7	54·6	Fomalhaut	15 58·0	S 29 46·0
N	11	30 23·1	302 21·7	37·0	303 58·7	33·7	111 36·3	55·1	325 02·8	54·6			
D	12	45 25·5	317 22·5	N27 37·0	318 59·4	N24 33·7	126 38·8	S 22 55·2	340 04·9	N19 54·7	Gacrux	172 35·1	S 56 57·8
A	13	60 28·0	332 23·3	37·0	334 00·1	33·8	141 41·4	55·2	355 07·1	54·7	Gienah	176 23·9	S 17 23·6
Y	14	75 30·5	347 24·1	37·0	349 00·8	33·8	156 44·0	55·2	10 09·2	54·8	Hadar	149 31·4	S 60 14·7
	15	90 32·9	2 24·9 ..	37·0	4 01·5 ..	33·9	171 46·5 ..	55 2	25 11·3 ..	54·8	Hamal	328 36·0	N 23 19·9
	16	105 35·4	17 25·7	36·9	19 02·2	33·9	186 49·1	55·2	40 13·5	54·9	Kaus Aust.	84 24·4	S 34 24·0
	17	120 37·9	32 26·5	36·9	34 02·9	33·9	201 51·7	55·2	55 15·6	55·0			
	18	135 40·3	47 27·3	N27 36·9	49 03·6	N24 34·0	216 54·2	S 22 55·2	70 17·8	N19 55·0	Kochab	137 17·1	N 74 16·0
	19	150 42·8	62 28·1	36·9	64 04·3	34·0	231 56·8	55·2	85 19·9	55·1	Markab	14 09·2	N 15 03·3
	20	165 45·2	77 28·9	36·8	79 05·0	34·1	246 59·4	55 2	100 22·0	55·1	Menkar	314 47·7	N 3 59·0
	21	180 47·7	92 29·7 ..	36·8	94 05·7 ..	34·1	262 02·0 ..	55·2	115 24·2 ..	55·2	Menkent	148 43·7	S 36 14·3
	22	195 50·2	107 30·5	36·8	109 06·4	34·2	277 04·5	55·2	130 26·3	55·2	Miaplacidus	221 46·6	S 69 36·5
	23	210 52·6	122 31·3	36·8	124 07·1	34·2	292 07·1	55·3	145 28·4	55·3			
8	00	225 55·1	137 32·1	N27 36·7	139 07·8	N24 34·2	307 09·7	S 22 55·3	160 30·6	N19 55·3	Mirfak	309 25·2	N 49 45·9
	01	240 57·6	152 32·9	36·7	154 08·5	34·3	322 12·3	55·3	175 32·7	55·4	Nunki	76 36·3	S 26 20·0
	02	256 00·0	167 33·7	36·7	169 09·2	34·3	337 14·8	55·3	190 34·9	55·5	Peacock	54 07·4	S 56 49·3
	03	271 02·5	182 34·6 ..	36·6	184 09·9 ..	34·4	352 17·4 ..	55·3	205 37·0 ..	55·5	Pollux	244 05·5	N 28 05·7
	04	286 05·0	197 35·4	36·6	199 10·6	34·4	7 20·0	55·3	220 39·1	55·6	Procyon	245 32·1	N 5 17·8
	05	301 07·4	212 36·2	36·6	214 11·3	34·4	22 22·5	55·3	235 41·3	55·6			
	06	316 09·9	227 37·0	N27 36·6	229 12·0	N24 34·5	37 25·1	S 22 55·3	250 43·4	N19 55·7	Rasalhague	96 34·8	N 12 34·5
	07	331 12·3	242 37·9	36·5	244 12·7	34·5	52 27·7	55·3	265 45·5	55·7	Regulus	208 16·2	N 12 06·1
	08	346 14·8	257 38·7	36·5	259 13·4	34·6	67 30·3	55·3	280 47·7	55·8	Rigel	281 42·0	S 8 14·0
M	09	1 17·3	272 39·5 ..	36·5	274 14·1 ..	34·6	82 32·8 ..	55·3	295 49·8 ..	55·9	Rigil Kent.	140 33·4	S 60 43·5
O	10	16 19·7	287 40·4	36·4	289 14·8	34·6	97 35·4	55·4	310 51·9	55·9	Sabik	102 47·6	S 15 41·7
N	11	31 22·2	302 41·2	36·4	304 15·5	34·7	112 38·0	55·4	325 54·1	56·0			
D	12	46 24·7	317 42·1	N27 36·3	319 16·2	N24 34·7	127 40·6	S 22 55·4	340 56·2	N19 56·0	Schedar	350 16·4	N 56 23·0
A	13	61 27·1	332 42·9	36·3	334 16·9	34·8	142 43·2	55·4	355 58·4	56·1	Shaula	97 03·5	S 37 05·2
Y	14	76 29·6	347 43·8	36·3	349 17·6	34·8	157 45·7	55·4	11 00·5	56·1	Sirius	259 01·1	S 16 40·8
	15	91 32·1	2 44·6 ..	36·2	4 18·3 ..	34·8	172 18·3 ..	55·4	26 02·6 ..	56·2	Spica	159 03·5	S 11 01·3
	16	106 34·5	17 45·5	36·2	19 19·0	34·9	187 50·9	55·4	41 04·0	56·3	Suhail	223 15·3	S 43 19·5
	17	121 37·0	32 46·3	36·2	34 19·7	34·9	202 53·5	55·4	56 06·9	56·3			
	18	136 39·5	47 47·2	N27 36·1	49 20·4	N24 34·9	217 56·0	S 22 55·4	71 09·0	N19 56·4	Vega	80 59·6	N 38 45·1
	19	151 41·9	62 48·0	36·1	64 21·1	35·0	232 58·6	55·4	86 11·2	56·4	Zuben'ubi	137 39·3	S 15 55·9
	20	166 44·4	77 48·9	36·0	79 21·8	35·0	248 01·2	55·5	101 13·3	56·5			
	21	181 46·8	92 49·8 ..	36·0	94 22·5 ..	35·0	263 03·8 ..	55·5	116 15·4 ..	56·5			
	22	196 49·3	107 50·6	35·9	109 23·2	35·1	278 06·4	55·5	131 17·6	56·6			
	23	211 51·8	122 51·5	35·9	124 23·9	35·1	293 08·9	55·5	146 19·7	56·6			
Mer. Pass.	h m	8 58·8	v 0·8	d 0·0	v 0·7	d 0·0	v 2·6	d 0·0	v 2·1	d 0·1			

	S.H.A.	Mer. Pass.
	° ′	h m
Venus	272 17·3	14 50
Mars	273 55·0	14 44
Jupiter	81 12·1	3 35
Saturn	294 43·3	13 19

82.57(82B)

proximate altitude and azimuth of each of them. You first select the template which includes latitude 35° N. and set it on the disk using the side of the disk which shows N-latitude stars. You then compute the LOCAL HOUR ANGLE of the FIRST POINT OF ARIES for the time of observation, by the procedure explained in the next section.

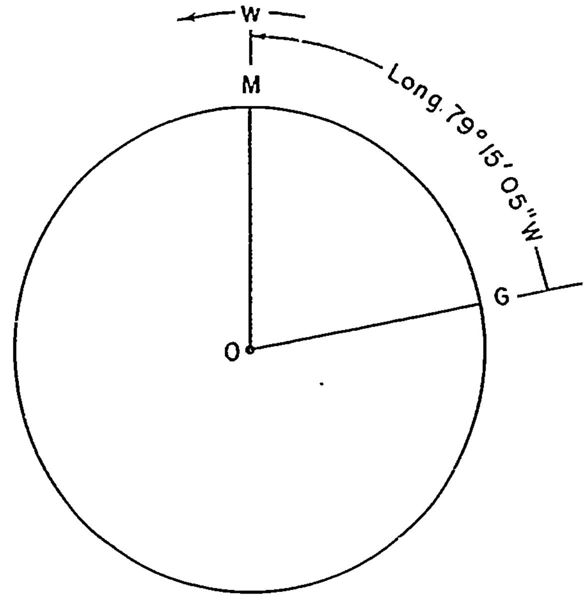
Suppose that LHA ARIES comes to about 168°. You set the 0° azimuth arrow on the template to the 168-degree graduation on the edge of the disk. The stars which will be visible at the time of observation will appear under the grid on the template. The star ARCTURUS (for example) will appear under the grid at about the point of intersection between the 100-degree azimuth line and the 48-degree altitude line. This means that at the time of observation ARCTURUS will be visible at azimuth 100°, altitude 48°. It therefore also means that a prominent star, visible at the time of observation at that azimuth and altitude, must be ARCTURUS.

POLARIS, by the way, is not shown on the star finder, the reason being the fact that POLARIS is so near the North Pole as to have its position covered by the central axis of the disk. Furthermore, the azimuth of POLARIS from any point from which the star is visible is very nearly 0°, and the altitude very nearly 90°. Neither is POLARIS listed in the daily pages of the *Nautical Almanac*, the reason being the fact that the extremely high declination of POLARIS (approximately 89° 5′) puts observations on that star in a separate category. These observations will be described later in this discussion.

Time Diagram

Before we go into field astronomy any further, you should learn the use of the TIME DIAGRAM (also called the DIAGRAM ON THE PLANE OF THE CELESTIAL EQUATOR). The diagram consists essentially of a circle representing the celestial equator as it would appear on a plane passed through the celestial sphere perpendicular to the axis of the sphere and midway betweed the celestial poles. The observer is presumed to be looking up from S; therefore, counterclockwise direction on the time diagram is W.

The first thing you locate on the time diagram is the celestial meridian of the point of observation that is, the terrestrial meridian of the point of observation as that is projected on the celestial sphere. You draw this from the circumference of the time diagram to the center (representing the point of observation), as shown by the line MO in figure 3-20.

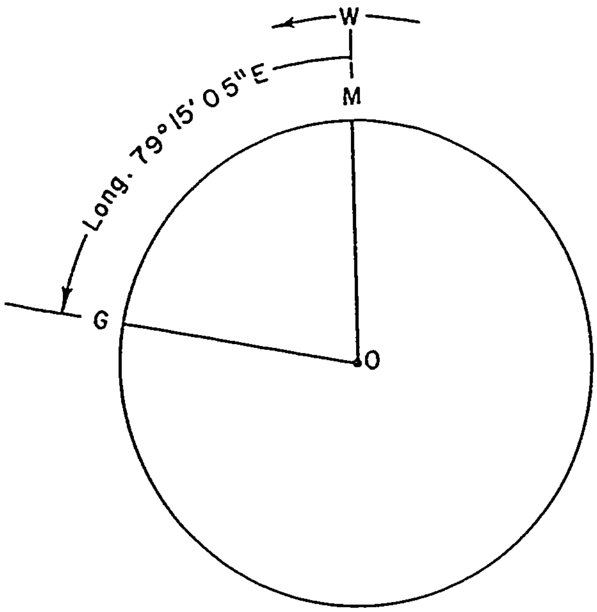


45.426

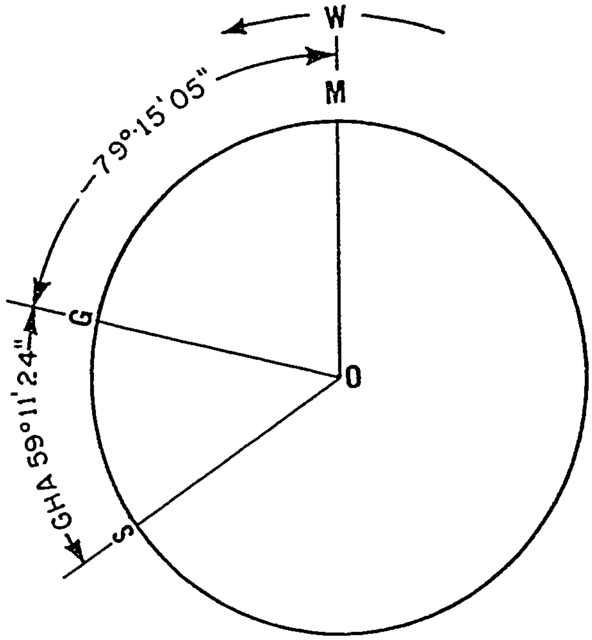
Figure 3-20.—Locating projected observer's meridian and Greenwich meridian on time diagram—longitude W.

Next you locate the projected Greenwich meridian on the time diagram in accordance with the longitude of the point of observation. Suppose this longitude is 79° 15′05″W. In this case you will measure 79° 15′05″ to the East, that is, clockwise direction from MO, and draw in the projected Greenwich meridian (GO in fig. 3-20). But if your longitude was 79° 15′05″E, you would measure counterclockwise from MO, as shown in figure 3-21. You simply remember that, if the longitude is W, Greenwich must be E of the observer's meridian, if the longitude is E, Greenwich must be W of the observer's meridian.

The next thing you locate on the time diagram is the hour circle of the observed body,



45.427
Figure 3-21.—Locating projected observer's meridian and Greenwich meridian on time diagram—longitude E.



45.428
Figure 3-22.—Locating hour circle of observed body on time diagram.

in accordance with the GHA of the body at the instant of observation. Suppose that for an observation made in longitude 79° 15'05"E the GHA of the sun was 59° 11' 24" at the instant of observation. GHA is measured W (counterclockwise on the time diagram) from Greenwich through 360°. So you would measure off 59° 11' 24" W (counterclockwise) from Greenwich on the time diagram and draw in the sun's hour circle (SO in figure 3-22).

Local Hour Angle

Local Hour Angle (LHA) is expressed in degrees of arc from 0° to 360°. Often, it is more convenient in computations to measure the hour angle towards the east to avoid angles over 180°. In this case, it is called the negative hour angle. Some texts call this negative hour angle "the meridian angle," although this term may be confused with the azimuth angle.

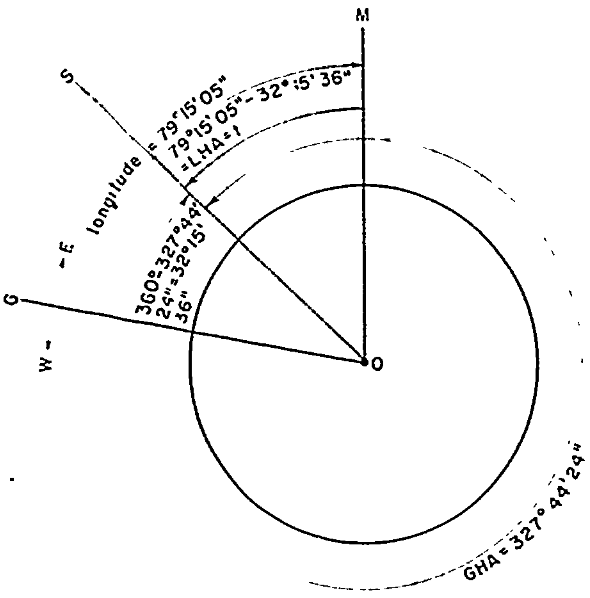
We now come to one of the principal purposes of the time diagram, which is to ensure that you determine the value of LOCAL HOUR ANGLE correctly. Local hour angle is measured W, through 360°, from the observer's celestial meridian to the observed body's hour circle. A glance at figure 3-22 tells you that in this case LHA amounts to the sum of the longitude plus GHA, or 79° 15' 05" + 59° 11' 24", or 138° 26' 29".

Suppose now that at the instant of observation, in the same longitude, GHA of the sun was 327° 44' 24". The time diagram for this situation is shown in figure 3-23. You must study the diagram a little to realize that in this case LHA amounts to the longitude minus the difference between 360° and the GHA, or 79° 15' 05" - (360° - 327° 44' 24"), or 79° 15' 05" - 32° 15' 36", or 46° 59' 29".

Another way of finding the values of an hour angle is by the following method:

(1) GHA = LHA - λ W - used when longitude λ is W
(2) GHA = LHA + λ E–used when longitude λ is E

If the total value of an hour angle is greater than 360°, subtract 360° from it and use the



45.430

Figure 3-23.—Locating local hour angle (LHA) of observed body on time diagram.

remainder. To illustrate this, GHA of the sun was 327° 44′ 24″ and the longitude is 79° 15′ 05″ E. So you use formula (2). Transposing to solve for LHA, you have

$$LHA = GHA + \lambda E$$
$$= 327^\circ 44' 24'' + 79^\circ 15' 05''$$
$$= 406^\circ 59' 29''$$

It is over 360°, so subtract 360° from the 406° 59′ 29″ and the result is 46° 59′ 29″.

Meridian Angle

MERIDIAN ANGLE, like LHA, is measured between the observer's celestial meridian and the observed body's hour circle. Meridian angle, however, is measured E or W from the celestial meridian to the hour circle, through a maximum of 180°, instead of being measured always to the W, like 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 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 which 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 pin-point 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 crosshair accurately on the center. To get an accurate setting, you must line the crosshair 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, is 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 observed the lower limb, you add the semidiameter correction to the observed altitude: if you observed 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 (that is, the corrected) altitude of the body. The letter z is the conventional symbol used to represent zenith distance.

DETERMINING LATITUDE

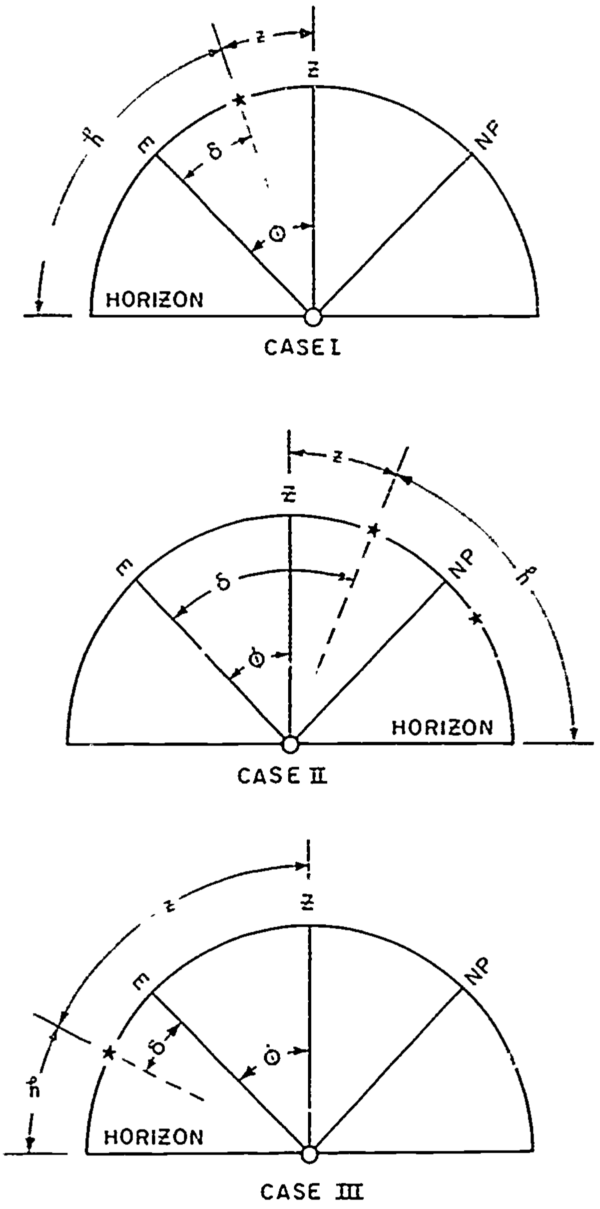
To determine the true azimuth of a line on the ground from a celestial observation, you must know the latitude of the point from which the celestial observation is made. If you can locate the point of observation accurately on an accurate map (such as a C. & G.S. quad sheet), you can determine the latitude 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 when it crosses your celestial meridian. At this instant, the body will be at the maximum altitude observable from your position.

In applying a meridian altitude to get the latitude, there are three possible situations, each illustrated in figure 3-24 and explained below.

CASE I. When the body observed is toward the equator from the zenith. You can derive this formula to get latitude:



82.148

Figure 3-24.—Three possible situations in determining latitude by meridian altitude observation.

$$\phi = \delta + z$$
$$= \delta + (90^\circ - h)$$

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. To get the latitude of the place of observation, use these formulas.

$\phi = \delta - z$
$= \delta - (90° - h)$ pr
$\phi = h \pm p$ - use this formula only for circumpolar star observations, where p is the polar distance $(90° - \delta)$.

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 ϕ and δ are positive when they are located at the north of the equator and negative when south of it.

LATITUDE BY ALTITUDE OF SUN AT NOON

You can observe the altitude of the sun by two methods. (1) Set the line of sight of the transit in the plane of known meridian and wait for the sun to cross the line of sight, and then take the reading of the vertical angle at this instant, (2) Follow the sun just before it is about to cross the approximate meridian. In either method our main objective is to measure the sun's altitude accurately. Time should be known closely, so that the instant of local apparent noon can be computed, 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 crosshair tangent to the lower edge of the sun's disk. When observing for maximum altitude, the sun is followed through until it no longer rises. The moment the sun starts going down, the vertical angle is recorded and the index error should be determined. In the first method referred to above, the setting of the sun's disk is similar, except that you get the reading at the instant that the sun crosses your known meridian. In either method, 1 or 2 above, the altitude observed in the field is corrected for index error, semi-diameter, parallax and refraction. Index error could be eliminated in the first 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 the table of the *Nautical Almanac*, the *Solar Ephemeris*, or *The Ephemeris*. The table for May 1969, 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 Observatory, is shown in table 3-4. The *Solar Ephemeris* is issued (on request) each year by major engineering instrument makers, such as K & E, Gurley, and C. L. Berger & Sons.

Find the sun's declination as follows:

1. Accepting the observation as having been made at the meridian, the local apparent time is 12^h.
2. Add the longitude equivalent time to obtain Greenwich apparent time (GAT).
3. Subtract the Equation of Time from GAT to obtain GCT (Greenwich civil time). (Eq. T = App. T - Mean T). 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 GCT from 0^h.
5. In case the local standard time of the observation is recorded, the GCT is found at once by simply adding the time zone difference. Then, after all the necessary corrections are made, just substitute the values to one of the formulas enumerated above, analyzing carefully, to see which case it fits in.

EXAMPLE: Suppose now that on May 28, 1969 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. Now the computation to get the corrected declination will appear as follows:

Table 3-4.—Solar Ephemeris for May 1969

		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, 1969									
Thur.	1	N15 06 30.8	+45.29	15 53.78	66	2 56.47	11 24.0 A.M.	E.E. 5 28.0 A.M.	22.70
Fri.	2	15 24 30.3	44.66	15 53.54	66	3 03.61	11 20.0	5 24.1	22.38
Sat.	3	15 42 14.6	44.02	15 53.31	66	3 10.22	11 16.1	5 20.2	22.09
Sun.	4	15 59 43.4	43.37	15 53.07	66	3 16.27	11 12.2	5 16.3	21.82
Mon.	5	16 16 56.3	42.71	15 52.84	66	3 21.75	11 08.3	5 12.3	21.59
Tues.	6	16 33 53.3	42.03	15 52.61	66	3 26.65	11 04.4	5 08.4	21.36
Wed.	7	16 50 33.8	41.34	15 52.38	67	3 30.97	11 00.4	5 04.5	21.14
Thur.	8	17 06 57.7	40.64	15 52.15	67	3 34.71	10 56.5	5 00.6	20.91
Fri.	9	17 23 04.5	39.92	15 51.92	67	3 37.86	10 52.6	4 56.6	20.66
Sat.	10	17 38 53.9	39.19	15 51.69	67	3 40.42	10 48.7	4 52.7	20.39
Sun.	11	17 54 25.8	38.45	15 51.47	67	3 42.38	10 44.7	4 48.8	20.10
Mon.	12	18 09 39.7	37.70	15 51.26	67	3 43.75	10 40.8	4 44.9	19.80
Tues.	13	18 24 35.2	36.93	15 51.05	67	3 44.53	10 36.9	4 40.9	19.50
Wed.	14	18 39 12.3	36.15	15 50.84	67	3 44.74	10 33.0	4 37.0	19.20
Thur.	15	18 53 30.5	35.36	15 50.63	67	3 44.36	10 29.0	4 33.1	18.91
Fri.	16	N19 07 29.4	+34.55	15 50.43	67	3 43.42	10 25.1 A.M.	E.E. 4 29.2 A.M.	18.63
		° ′ ″	″	′ ″	s	m s	h m	h m	° ′ +89 07 ″
Fri.	16	N19 07 29.4	+34.55	15 50.43	67	3 43.42	10 25.1 A.M.	E.E. 4 29.2 A.M.	18.63
Sat.	17	19 21 [illegible]	33.74	15 50.24	67	3 41.90	10 [illegible]	4 25.3	18.38
Sun.	18	19 34 20.8	32.91	15 50.05	67	3 39.83	10 17.[illegible]	4 21.4	18.15
Mon.	19	19 47 28.6	32.07	15 49.86	67	3 37.22	10 13.4	4 17.4	17.93
Tues.	20	20 00 08.2	31.22	15 49.68	68	3 34.06	10 09.5	4 13.5	17.72
Wed.	21	20 12 27.2	30.36	15 49.50	68	3 30.38	10 05.5	4 09.6	17.52
Thur.	22	20 24 25.4	29.49	15 49.33	68	3 26.18	10 01.6	4 05.7	17.32
Fri.	23	20 36 02.6	28.61	15 49.16	68	3 21.47	9 57.7	4 01.8	17.11
Sat.	24	20 47 18.5	27.71	15 48.99	68	3 16.26	9 53.8	3 57.8	16.89
Sun.	25	20 58 12.9	26.81	15 48.83	68	3 10.56	9 49.9	3 53.9	16.66
Mon.	26	21 08 45.6	25.90	15 48.67	68	3 04.39	9 46.0	3 50.0	16.42
Tues.	27	21 18 56.3	24.98	15 48.52	68	2 57.76	9 42.0	3 46.1	16.17
Wed.	28	21 28 44.8	24.06	15 48.36	68	2 50.67	9 38.1	3 42.2	15.92
Thu.	29	21 38 11.1	23.13	15 48.21	68	2 43.14	9 34.2	3 38.3	15.68
Fri.	30	21 47 14.9	22.19	15 48.06	68	2 35.18	9 30.3	3 34.4	15.46
Sat.	31	N21 55 56.0	+21.24	15 47.92	68	2 26.79	9 26.4 A.M.	E.E. 3 30.4 A.M.	15.28

EXAMPLE

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}.

For time of Western Elongation of Polaris for any date after April 21st, add $5^h 55.9^m$ to the time of Upper Culmination of the same date.

82.149

Local Apparent Time		12^h
Longitude Equivalent Time	+(+)	$5^h44^m32^s$
Greenwich Apparent Time		$17^h44^m32^s$
Equation of Time	−(+)	2^m57^s
Greenwich Civil Time (GCT)		$17^h41^m35^s$ ($=17.7^h$)
Declination at 0^h (table 3-4)	+	21°28′44″.8
Correction for elapsed time $(577.4 \times \frac{17.7}{24})$		7′ 06″

NOTE: $\frac{577.4}{12 \text{ hr.}}$ = Diff. for 1 hr. (table 3-4) x

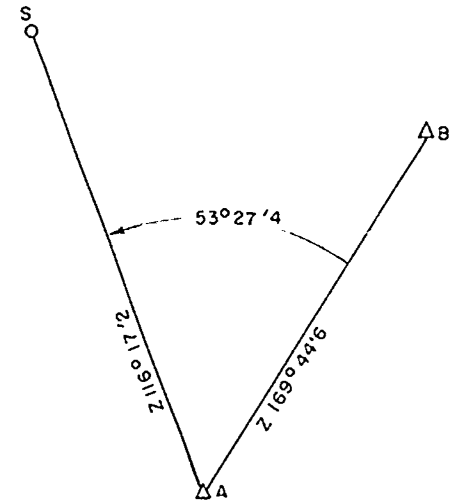
Corrected declination	21° 35′ 50″.8

From the above computation, you see that the declination is positive, so it is a N declination. Then the transit was pointed S, so this is a case where the body observed was between the zenith and the equator. This is then, a Case I situation, where the latitude equals declination plus zenith distance (90° - 67° 37′ 06″ or 22° 22′ 54″). Therefore, the latitude is equal to 21° 35′ 50″.8 + 22° 22′ 54″ or 43° 58′ 44″.8.

TRUE AZIMUTH FROM CELESTIAL OBSERVATION

Figure 3-25 illustrates the procedure that is followed in determining the true azimuth of a line on the ground from a celestial observation. The true azimuth of the line AB is desired. The transit is set up at A and trained on B, the horizontal limb is then set at 0 and the lower motion is locked The telescope is then trained on S, a heavenly body. The altitude of S, and the horizontal angle SAB, are read at a carefully timed instant. Actually, several readings are taken, direct and reversed, and the averages of the horizontal and vertical angles are used, together with the average of the time of observation, as explained later.

From the body's corrected altitude, its declination, and the latitude of the point of observation, the body's true azimuth from the point of observation at the instant of observation can be computed. In this case the true azimuth was 116° 17′.2. The true azimuth of the line AB, then, is obviously 116°17′.2+53°27′.4, or 169°44′.6. If it is a bearing that is desired, you know that an azimuth of 169° 44′.6 means a bearing of S 10° 15′.4 E.



45.432

Figure 3-25.—True azimuth of a line from celestial observation.

All that remains for you to learn about this operation is the commonly used methods of computing the azimuth of a heavenly body from its corrected altitude, its declination, and the latitude of the point of observation. First, however, something should be said about semidiameter correction as it is applied to the horizontal angle observation. You remember that you line the horizontal crosshair up with the sun's upper or lower limb, and apply semidiameter correction to get the altitude of the center. Similarly, you line the vertical crosshair up with the left or right edge of the disk in the type of observation now being described, and this means that you must apply the sam semidiameter correction to the horizontal angle (SAB in fig. 3-25). The direction in which you apply it depends on which edge of the disk you line up with the vertical crosshair. In figure 3-25 you can se that if the right edge of the disk was used, semidiameter correction would be added, if the left edge were used, it would be subtracted.

AZIMUTH OF BODY OTHER THAN POLARIS

To compute the azimuth of a body other than POLARIS, you apply the following formula:

$$\cos Z = \frac{\sin \delta}{\cos \phi \cos h} - \tan \phi \tan h$$

The symbol δ in this formula means declination; ϕ means latitude of the point of observation: and h means the corrected altitude. Z stands for AZIMUTH ANGLE, and it is important to remember that the numerical value of this angle is not necessarily the same as that of the azimuth itself. To determine the value of the azimuth, measure off the azimuth angle (Z) either E or W of either N or S according to the following rules:

1. If the value of cos Z is positive, Z is measured from N; if the value of cos Z is negative, Z is measured from S.
2. If the observed body was E of the observer's meridian, Z is measured to the E; if the observed body was W of the observer's meridian, Z is measured to the W.

Suppose that cos Z worked out to be −0.867476 (which means an azimuth angle of 29° 50′) for a sun shot made at ZT 10h 12m 06s. Cos Z is negative, therefore, the angle is measured from S. The shot was made in the morning, so the sun was E of the observer's meridian, and the angle is measured to the E. Therefore, the bearing of the sun was S 29° 50′ E, and the azimuth was 150° 10′.

Suppose now that for a sun shot taken at ZT 15h 12m 18s cos Z worked out to be + 0.863249, which means an azimuth angle of 30° 19′. Cos Z is positive; therefore, the angle is measured from N. The shot was made in the afternoon; therefore, the sun was W of the observer's meridian, and the angle is measured to the W. The bearing of the sun at the time of observation was therefore N 30° 19′ W, and the azimuth was 329° 41′.

Suppose now that for an observation of the sun, made at ZT 10h 15m 12s on 25 May 1962 in latitude 38° 50′ 24″ W, the average corrected altitude of the sun was 60° 20′ 24″. The ZD is + 5; therefore, GCT at the time of observation was 15h 15m 12s. The sun's declination for this GCT was (from the *Nautical Almanac*) N 20° 56′ 12″.

For the azimuth angle the formula is:

$$\cos Z = \frac{\sin \delta}{\cos \phi \cos h} - \tan \phi \tan h$$

A table of natural functions shows that the required functions are as follows.

$$\begin{aligned}
\sin \delta &= \sin 20° 56' 12'' = 0.357335 \\
\cos \phi &= \cos 38° 50' 24'' = 0.778901 \\
\cos h &= \cos 60° 20' 24'' = 0.494852 \\
\tan \phi &= \tan 38° 50' 24'' = 0.805170 \\
\tan h &= \tan 60° 20' 24'' = 1.756034
\end{aligned}$$

Substituting these values in the formula, we have:

$$\cos Z = \frac{0.357335}{(0.778901)(0.494852)} - (0.805170)(1.756034)$$

$$= \frac{0.357335}{0.385441} - 1.413906$$

$$= 0.927080 - 1.413906$$

$$= -0.466826$$

This cosine means an azimuth angle of 60° 54′ 56″. Cos Z is negative, therefore, the angle is measured from S. The sun was E of the meridian, therefore, the angle is measured to the E. The bearing of the sun at the time of observation was therefore S 60° 54′ 56″ E, the azimuth was 119° 05′ 04″.

For a planet or a star other than POLARIS, the method would be the same.

AZIMUTH OF POLARIS

POLARIS is not listed in the daily pages of the *Nautical Almanac*. However, most of the prominent manufacturers of surveying instruments provide, free of charge, handbooks (usually called EPHEMERIS or SOLAR

EPHEMERIS) containing tables which give the GHA and the polar distance (90° - declination) of POLARIS. Knowing the GHA of POLARIS, you can compute the meridian angle (t), and knowing the meridian angle, the polar distance, and the corrected altitude, you can compute the azimuth angle from the following formula:

$$Z = \frac{\sin t}{\cos h} p$$

Z is again the azimuth angle; for POLARIS it is always measured from N. If the LHA of POLARIS at the time of observation was from 0° to 180°, you measure Z to the W; if the LHA was from 180° to 360°, you measure it to the E. As for the other symbols in the formula, t means meridian angle, h means corrected altitude, and p means polar distance.

Suppose now that in latitude 38° 50′ 24″ N, longitude 77° 06′ 42″ W, at ZT 20h 16m 09s, on 28 May 1962, the average corrected altitude for POLARIS was 37° 59′ 36″. The ZD is +5; therefore, GMT for the observation was 01h 16m 09s, 29 May.

Tables in the Keuffel & Esser publication *Solar Ephemeris*, 1962, give the following information. Table 1 gives the GHA of POLARIS for 0h 0m 0s GMT, 29 May, as 216° 54′. Table 5 gives the amount to be added to this for 1h 16m 09s, which is 19° 5′.4. LHA POLARIS is the GHA minus the longitude W, or 235° 59′ .4 - 77° 06′.7, or 158° 52′.7, which is W 158° 52′ 42″. Table 3 in the K & E *Ephemeris* gives polar distances for POLARIS. Interpolating for 29 May, the polar distance comes to 54′.97.

The formula for the azimuth angle is as follows:

$$Z = \frac{\sin t}{\cos h} p$$

A table of natural functions gives the relevant functions as follows:

Sin t = sin 158° 52′ 42″ = 0.360350
Cos h = cos 37° 59′ 36″ = 0.788082

The polar distance (p) is 0° 54′.97. Substituting these values in the formula, we have:

$$Z = \frac{0.360350}{0.788082} 54'.97$$

$$= \frac{19.808439}{0.788082}$$

$$= 2.5134 = 0° 25' 08''$$

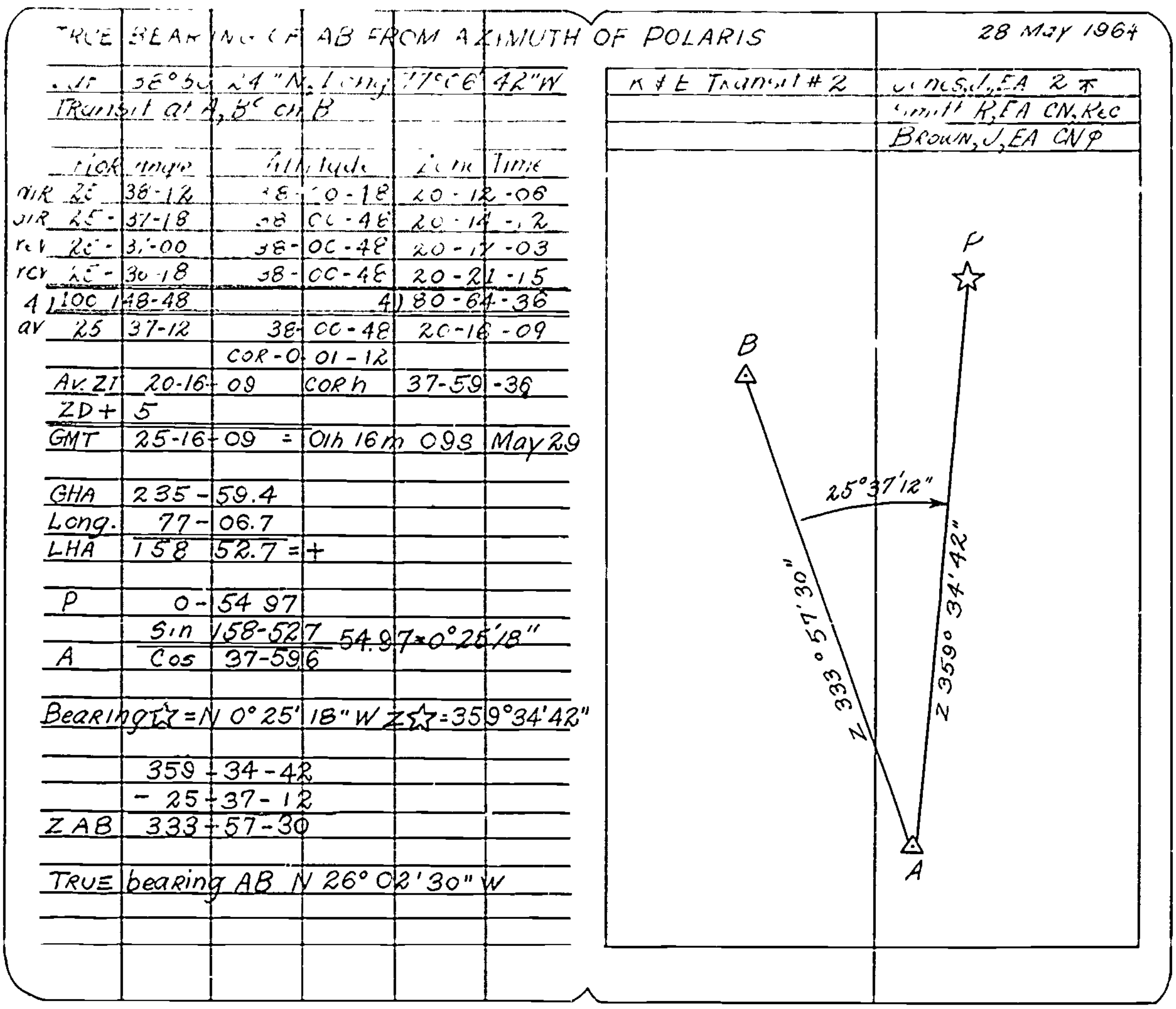
LHA is between 0° and 180°; so Z is measured to the W. Therefore, the bearing of POLARIS at the time of observation was N 0° 25′08″ W, the azimuth was 359° 34′ 52″.

FIELD NOTES FOR CELESTIAL OBSERVATION

Figure 3-26 shows field notes for the observation on POLARIS described in the preceding section. It is assumed that this observation was made to determine the true bearing of the line AB shown in the sketch.

On the data side you see that four observations were made, two direct and two reversed, at intervals of from about 2 to about 4 minutes. The A vernier was set at 0 and a backsight was taken on B using the lower motion. The lower motion was then clamped, and the four observations of POLARIS were made without using the lower motion—that is, without resetting the vernier at 0 for each observation. For the direct observations the horizontal angle was read on the A vernier. For the reversed observations the A vernier was again read, but this time with 180° added to the reading, and 360° subtracted from a reading larger than 360°. Note that the horizontal angle was increasing slightly with time, while the altitude did not change perceptibly during the observation period. The average observed altitude was 38° 00′48″; the correction was - 0°01′12″; therefore, the corrected average altitude was 37°59′36″.

The time to the nearest second and the horizontal angle to the nearest 0′.10 (06″) were recorded for each observation. The average angle and average time were then worked out as shown. The rest of the data page shows the computational steps involved in determining the azimuth of POLARIS at the average time of observation, and in determining the azimuth and bearing of AB from the azimuth and horizontal angle of POLARIS.



45.7.15

Figure 3-26.–Field notes for celestial observation.

CHAPTER 4
TRIANGULATION

In triangulation surveys, the duties of the EA1 or EAC 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 a side of an adjacent triangle, two sides of a triangle may form sides of adjacent triangles. By using the triangulation method of control, the length of every line need not be measured. 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 is an example of extensive high order triangulation network to establish control across the United States.

This chapter contains information on the three types of triangulation systems. We will also cover primary and secondary triangulation stations and types of signals which are used in marking triangulation stations. The usual procedure for conducting a triangulation survey is also discussed. Finally, information is provided on checking for precision and locations of points.

In addition to triangulation, another principal method of locating points in horizontal control is by traversing. Information on the traverse method is given in chapter 5 of this text. At this point, however, note that in traverse the distance and the angle are measured at each station, while in triangulation the distance is measured only at the beginning, at specified intervals, and the end of a survey. 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 that each is employed. 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 base line, 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 possible; therefore, triangulation is used to establish horizontal control in large-area surveys.

In some large-area surveys conducted by triangulation, it will be necessary to consider factors involving the curvature of the earth; hence, in such cases, GEODETIC triangulation will be 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 from ignoring 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 planetriangulated without significant error. In this discussion we are concerned with plane triangulation only.

TYPES OF TRIANGULATION SYSTEMS

In triangulation there are three types of triangulation systems: chain of single triangles, chain of polygons, and chain of quadrilaterals. Each of these systems is discussed in this chapter.

CHAIN OF SINGLE TRIANGLES

The simplest type of triangulation system is the CHAIN OF SINGLE TRIANGLES shown in figure 4-1. Suppose AB to be the base line, and that it measures 780.00 ft. 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.

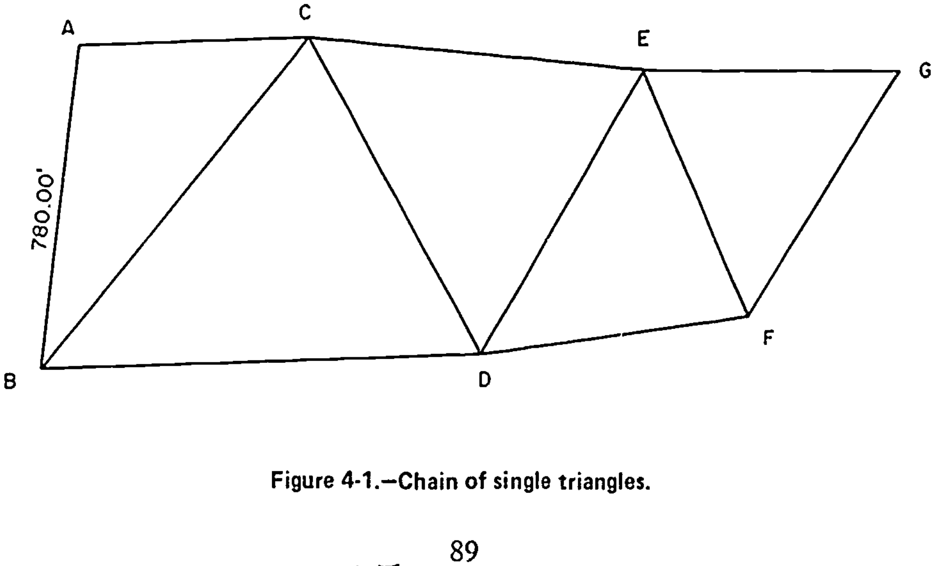
By the law of sines, BC = AB sin A/sin C, or 780.00 sin 98°54′/sin 48°24′, or 780.00 (0.987960)/0.747798, or 1030.50 ft. By the same law, AC = AB sin B/sin C, or 780.00 sin 32°42′/sin 48°24′, or 780.00 (0.540240)/0.747798, or 563.50 ft.

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. This method should be used only when locating inaccessible points, not when a side of the triangle is to be used to extend control.

In comparison with the other two 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 by computations made by a different route. In figure 4-1, 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 may be computed by solving more than one series of triangles.

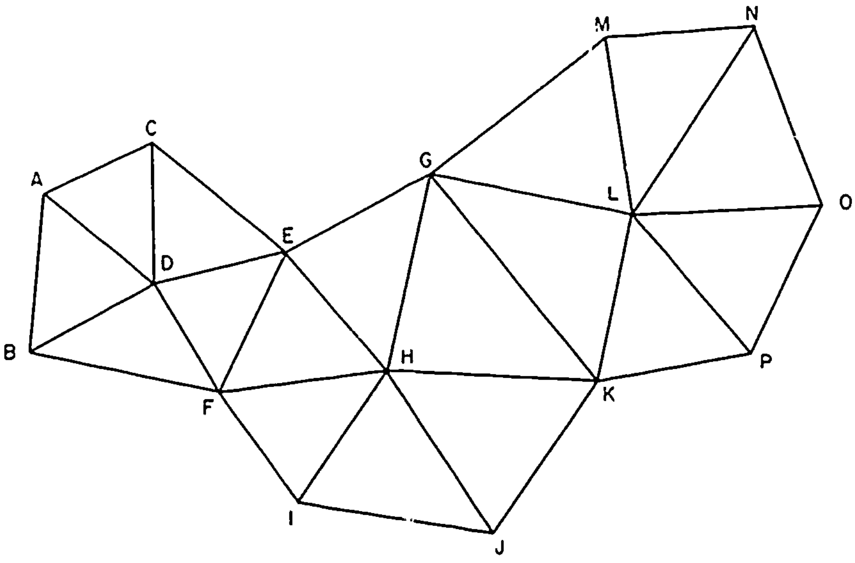
CHAIN OF POLYGONS

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 means a system in which a number of adjacent triangles are combined to form a polygon as shown in figure 4-2.



82.9

Figure 4-1.—Chain of single triangles.



82.10

Figure 4-2.—Chain of polygons.

Within each polygon the common vertex of the triangles which 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 consider the length of line EF. You can compute this length by solving 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, extending up to approximately 25,000 yards in length or breadth.

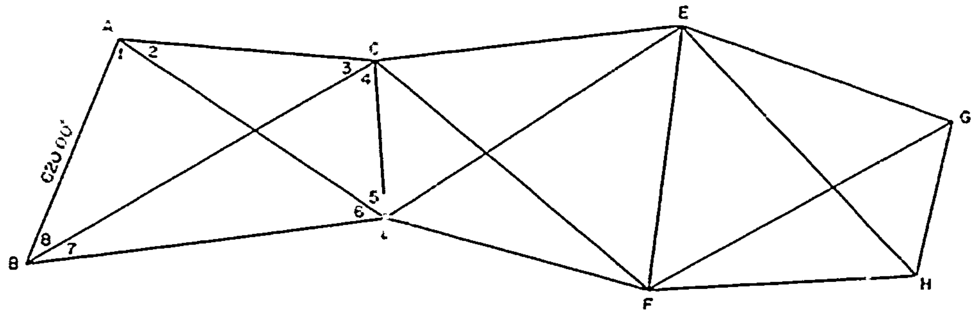
CHAIN OF QUADRILATERALS

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 a chain of quadrilaterals means a figure arrangement like that shown in figure 4-3. 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.

Take, for example, the quadrilateral ACDB. We'll call the angle BAC, the whole angle at a corner 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 which make up each of the four overlapping triangles, together with their natural sines, are as follows:



82.11

Figure 4-3.—Chain of quadrilaterals.

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. We'll solve each of the overlapping triangles by the law of sines. beginning with triangle ABC. Solving for AC. we have AC = 620.00 sin 8/sin 3, or 620.00(0.612907)/0.560639, or 677.80 ft. Solving for BC. we have BC = 620.00 sin A/sin 3, or 620.00(0.950516)/0.560639, or 1051.16 ft.

In triangle ABD, solving for BD, we have BD = 620.00 sin 1/sin 6, or 620.00(0.981959)/0.648120, or 939.35 ft. For AD we have AD = 620.00 sin B/sin 6, or 620.00(0.870356)/0.648120, or 832.59 ft.

In triangle ADC we have AC = AD sin 5/sin C, or 832.59 sin 5/sin C, or 832.59(0.803857)/0.991445, or 675.06 ft. For CD we have CD = AD sin 2/sin C, or 832.59 sin 2/sin C. or 832.59(0.484810)/0.991445. or 407.13 ft.

In triangle BCD we have BD = BC sin 4/sin D. or 1051.16 sin 4/sin D. or 1051.16 (0.894154)/0.997684. or 942.08 ft. For CD we have CD = BC sin 7/sin D. or 1051.16 sin 7/sin D, or 1051.16(0.385906)/0.997684. or 406.59 ft.

Summarizing the solutions. we have:

Triangle	Side	Length '
ABC	AC	677.80
	BC	1051.16
ADB	BD	939.35
	AD	832.59
ADC	AC	675.06
	CD	407.13
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 AND SIGNALS

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 *Engineering Aid 3&2*. 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 which is sighted from primary stations, but 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 which 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, bipods, and pole, all of which may incorporate variations. The targets are constructed of wood or metal frameworks with cloth covers.

Size of Targets

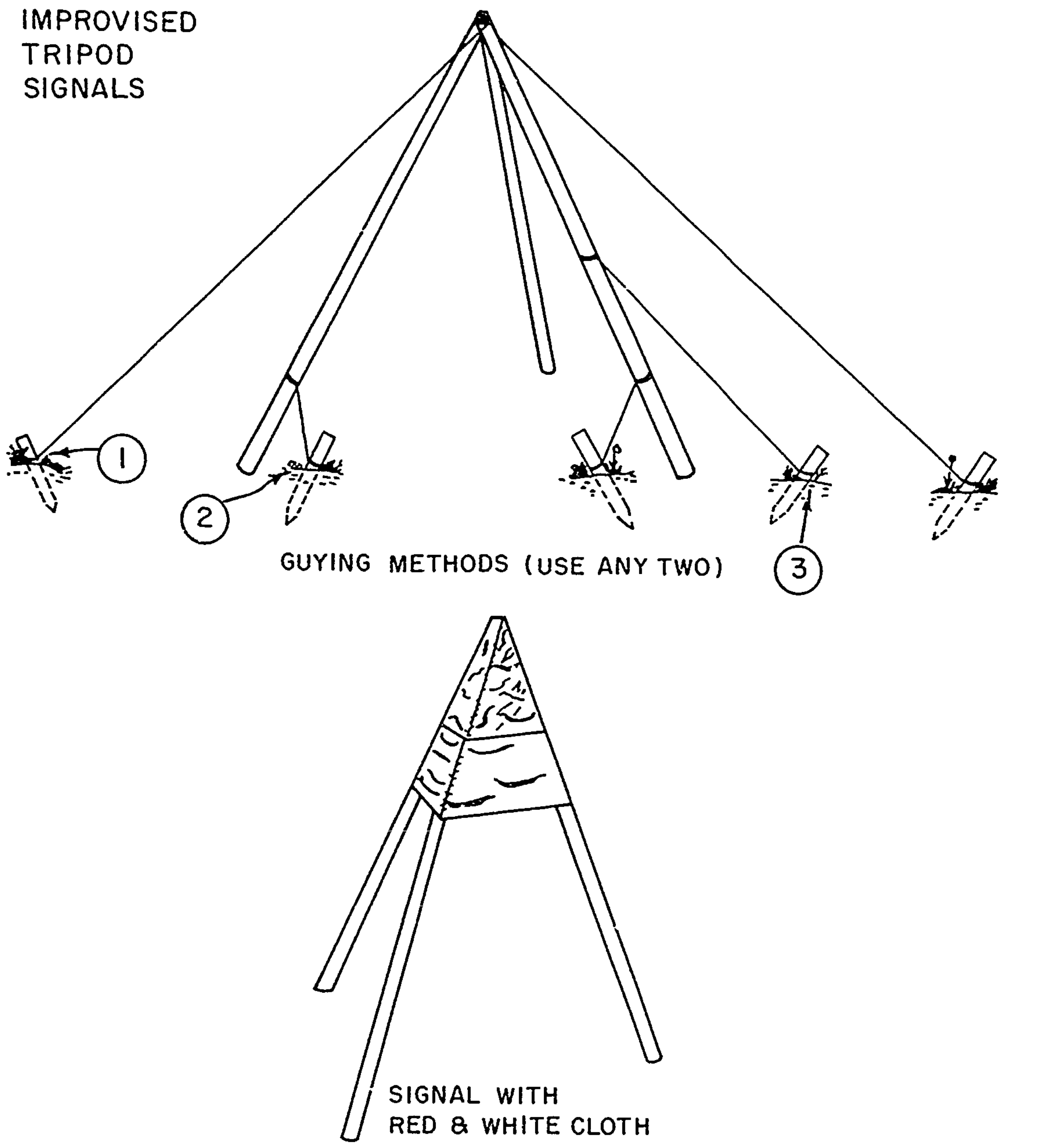
To make a target easily visible against both light and dark backgrounds, it should be constructed in alternating belts of red and white or red and yellow. For ready bisection, it should be as narrow as possible without sacrificing distinctness. A target which subtends an angle of 4 to 6 seconds of arc will fulfill this purpose. Since 1 second of arc equals 0.5 centimeter at a kilometer distance, an angle of 6 seconds requires a target 3 centimeters wide at that distance, 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 type 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, pipe, poles, or bamboo joined at one end by wire or bolts threaded through drilled holes. The tripod must be well guyed and plumbed (fig. 4-4) 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 lower order (4th order) work, as it is almost impossible to make it symmetrical around the station.

Bipod Target

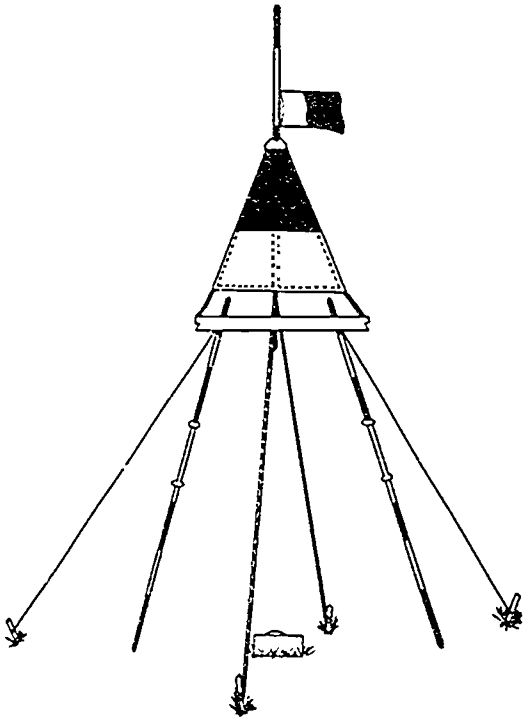
Bipod targets are more simply constructed than tripods, but are less stable and must be strongly guyed. Figure 4-5 shows a standard surveying bipod target. It is carried disassembled in a canvas case about 53 inches long. It can be



45.61(82C)

Figure 4-4.—Tripod targets.

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 at each end of the crossbar. In soft ground the pointed legs will sink unevenly because of wind action and rain, and 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.



82.222

Figure 4-5.—Bipod target.

Pole Targets

Pole targets (fig. 4-6) are seldom used because the station cannot be occupied while the target is in place In certain cases, as when a picture point is to be intersected or an unoccupied station must be used and cutting of lines of sight is difficult or impossible, a pole target which can be seen above the medium size trees may be 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 4-6. 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.

Centering and Plumbing Targets

When setting a target, whether lights, cloth, or wood, it is very important that it be plumbed exactly over the station. A target is said to be eccentric when its center is not in the vertical line passing through the point to which the observations are referred. The proper correction can always be made for eccentricity if the distance and direction to the true station are recorded. The observer can make an estimate of the error introduced by eccentricity by remembering the approximation "a second is a foot at 40 miles" (actually 39.065 miles), or that an inch represents about 3-1/4 seconds at a distance of 1 mile. Always check a target or signal that has been observed, for eccentricity. Any eccentricity found must be recorded in such a manner that the computer can be certain of the facts when correcting the observations.

Locating of Targets

The locating of targets by observers is sometimes a. difficult and tedious task, dependent upon the type of terrain and foliage in the area. In jungle type areas where the targets are not profiled or silhouetted, they are very difficult to locate without direct sunlight shining on them. To expedite the location of targets it sometimes becomes necessary to use a method of illuminating the target area. Four of the generally accepted methods are: the lighting of highway type flares, the use of a handheld flashing mirror, if available a strobe flashing unit, or the use of colored smoke grenades during daylight hours. Once the area of the target is located, it becomes a simple task to find the exact location of the target. The use of iridescent cloth on the target in place of regular signal cloth is recommended, especially in jungle type areas.

Phase

When observations are made on targets in the daylight, errors in the horizontal angle measurements due to unequal lighting of a target are referred to as phase (fig. 4-7). When one side is brightly illuminated by the sun and the other side is in shadows, the observer tends to favor the sunlit side. Sometimes, with a skylined white

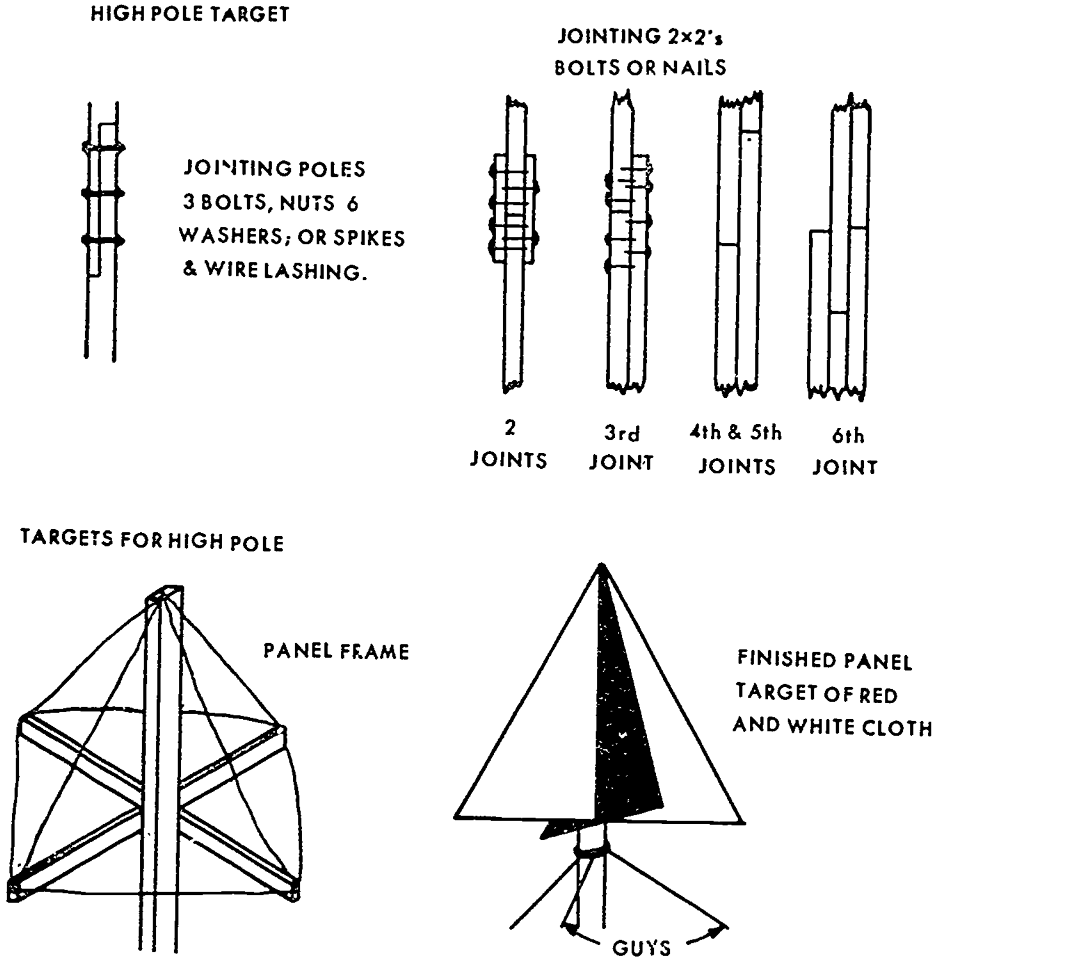
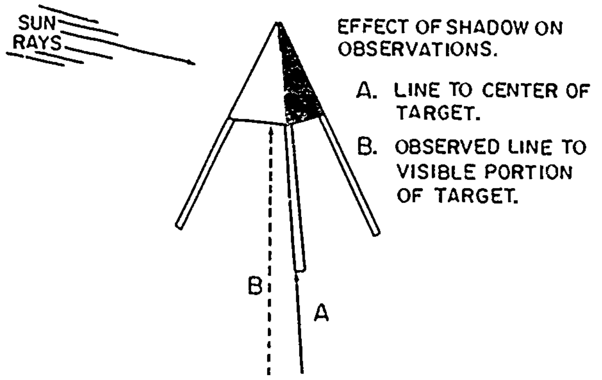


Figure 4-6.—Pole targets.

target, the reverse is true, and the dark side is favored. In effect, it is an eccentricity which could be corrected for if its exact amount were known. The difficulty lies in the inability of the observer to measure its amount accurately, for it depends upon factors which change rapidly. The angle of the sun with the line of sight, the opacity of the signal, the shape of the object sighted upon, and the intensity of the sunlight, will each have its effect on the appearance of the signal. Trigonometric formulas for the correction of phase have appeared in some textbooks. These are based upon the direction of the sun and are not usually practicable to apply because of the other factors that enter into phase. The apparent penumbra zone lying between the surface having full illumination and that having no direct sunlight upon it will vary in width with the intensity of the light. The formulas would also apply only to cylindrical or spherical objects, whereas many observations are made upon square targets. A target made of signal cloth will show a different phase from one made of lumber of the same shape and dimensions. For these reasons, the best rule, when the outline of a signal can be seen, is for the observer to make a close examination of the signal through the telescope and decide upon what part of the illuminated surface it is necessary to observe in order to eliminate errors due to phase. However, it is usually best



82.224
Figure 4-7.—Phase.

to delay observations until poor conditions improve or no longer exist.

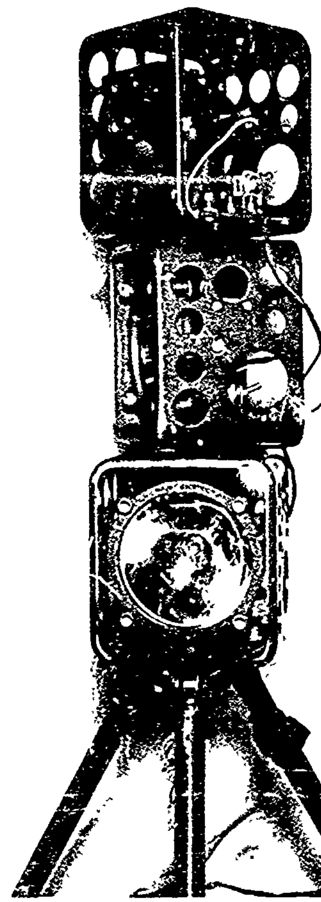
SIGNALS

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 may be made during daylight hours using lights, but for high accuracy surveys this is done only under extreme conditions.

Signal Lights

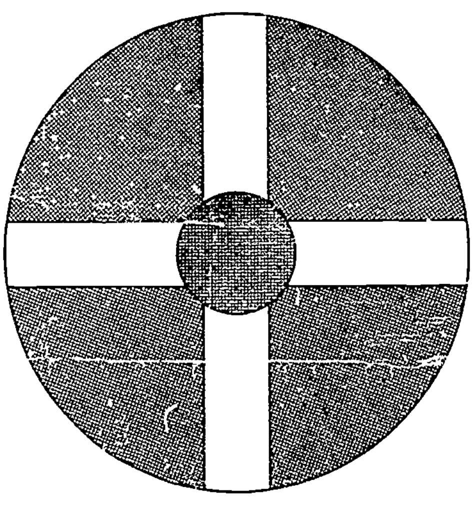
The most commonly used signal light has a 5-inch reflector. A group of 5-inch signal lights is used as illustrated in figure 4-8 for lines of sight in excess of 8 kilometers, but by masking the face of the lights they can be used for shorter lines of sight.

The exact horizontal and vertical POINTING of the light is very important. If the light is not pointed exactly toward the instrument, only a portion of the reflector will be observed and this portion will not, in some cases, be plumb over the station mark. The instrumentman must check the pointing prior to starting the observations, by viewing the light through the telescope. During hazy weather and especially on long sights, the view through the telescope may appear as a bright spot surrounded by a flare. The instrumentman should request the lightkeeper to swing the light slightly in a horizontal and vertical arc while it is being viewed through the instrument until the best pointing can be determined. The best pointing will be when the light is brightest. The light is then stopped and locked into position. The bottom light must be pointed first when lights are stacked as shown in figure 4-8. The light can be adjusted for brightness by adding or removing batteries. The light should never be turned to reduce its brilliance as this will create an eccentric light.



82.225
Figure 4-8.—Stacking of 5-inch lights.

The light can be MASKED to reduce the size and brilliance by covering an equal portion on both sides of the glass face. When masking a light, opposite sides of the glass must be masked equally to eliminate eccentricity, that is, not being in the same vertical line with the station which it represents. One method of masking a light is shown in figure 4-9. This type of masking is very good for distances between 6 to 10 kilometers on normal night . A sheet of orange scribe paper is required, but any other color would work almost as well. When using the orange paper as a masking material, the light will present an orange glow with a brilliant white cross for pointing on by the observer. At maximum ranges the orange glow is practically invisible through the telescope and at minimum ranges the glow will help in identification of the light.



82.226

Figure 4-9.—Masking of signal light.

The light is FOCUSED by means of a screw at the rear of the bulb socket. By turning this screw, the position of the bulb is changed in relationship to the reflector. If the light is not properly focused, it will appear as a fuzzy ball in the telescope. The light may be focused at night by shining it on a flat surface about 50 meters away, and adjusting until the beam is slightly larger than the light. When no distant object is available, a field expedient is to hold your hand about 6 inches in front of the light and adjust until a *dark* spot the size of a quarter appears in the center of the beam.

The BRILLIANCE of the light is determined by the type of bulb and the amount of voltage being used. The light is issued with two different bulbs, the standard 3.7-volt and a 6.0-volt bulb. The amount of voltage needed will vary with the lighting requirements. The various battery arrangements are shown in figure 4-10. If dry cell batteries are not available or too weak, a field expedient is to connect two lights with 6-volt bulbs in series and then connect to a 12-volt wet cell battery. Never apply more voltage to the bulbs than their rated value.

When lights to several observers from the same station are needed, the lights are STACKED, generally on a range pole tripod as shown in figure 4-8. If lights are stacked over a station, they must be leveled and plumbed over the station mark. The first (lowest) light must be leveled and plumbed, then the other lights are attached and individually checked for level.

Target Set

The target set is a precise survey lighting device generally used for short traverse lines. The target set assembly (fig. 4-11) consists of a lower and upper group. The lower group is a tribrach with a three screw leveling head, circular bubble, and optical plumbing device; the upper group contains a plate with three triangles, a long level vial and a lighting attachment.

In traversing where continual backsights and foresights are needed, and where distances are not excessive, the target sets can be used in a leapfrog technique. The actual distance the target set can be seen depends on weather conditions.

Extreme care must be taken in the pointing of this device. The lighting attachment must be pointed directly at the observer in order to eliminate the appearance of uneven lighting of the target's triangles. A disadvantage of the target set is that only one at a time may be set at a station.

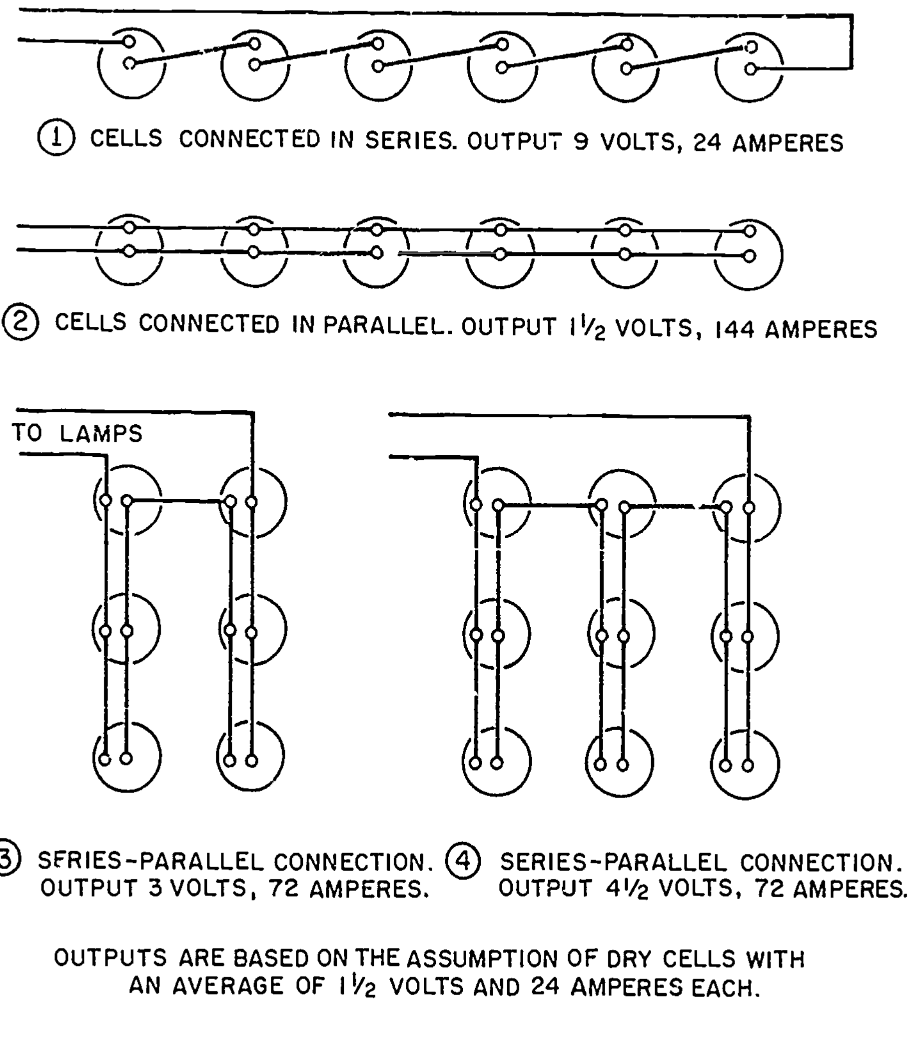
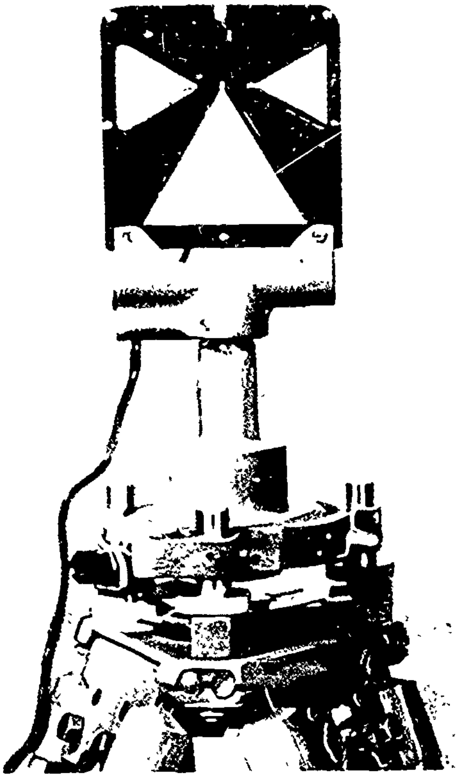


Figure 4-10.—Battery wiring diagram for signal lights.

Heliotropes

The heliotrope is a device which reflects the sun's rays through a pair of mirrors set over a point and toward an observer on another station.

The heliotrope consists of a flat base to which are attached two plane mirrors and a pair of sights (fig. 4-12). The base may be mounted on a theodolite or range pole tripod and plumbed directly over a point. One mirror is fixed to the base, though it may be rotated and tilted, and directs the reflected rays of the sun through the sights to the observing instrument. If the sun is in the direction of the observer, the fixed mirror is all that is needed. The second mirror is on a movable arm for use when the sun is shining toward the observer. It serves to direct the light into the fixed mirror, and hence to the observer. No provision is made for adjusting the pointing in a vertical plane, but flat wood chips or folded cardboard shims between the base and the tripod head will solve this problem. The main point to remember is that all fittings must be tight, as any play or looseness will cause trouble. Whichever mirror is receiving the direct rays of



82.228

Figure 4-11.–Target set.

the sun MUST BE CONSTANTLY ATTENDED and moved with the movement of the sun. The sun mirror should be just tight enough so that light taps with the fingernail or a pencil will maintain the correct angle. The TWO SIGHTS ARE SELDOM ALIGNED perfectly with the light apertures, and tests should be made prior to use so that the proper allowances can be made.

The heliotrope's use is limited by, first, necessity for sunlight, second, difficulty to use it as a target while making simultaneous observation from the same ground station, and third, difficulty of lining in without radio communications. The second difficulty can be solved by placing the heliotrope to one side of the station and making careful measurements of its eccentricity. It can also be used in this position for simultaneous vertical angle measurements by measuring the difference of elevation from the true station. The third difficulty is not often present as most parties are equipped with radios, but faulty pointing technique can cause much fumbling. After communicaions and identifications have been established, the observer, with his eye at the telescope and radio in hand, gives a running stream of one-way directions to the heliotrope attendant until the observer has a steady light in his telescope. At that time, the heliotrope attendant needs only to note the position of the sun's image on the sights and periodically adjust the sun mirror. Many surveyors tend to shy away from using the heliotrope because they have not been able to get good results due to faulty pointing techniques. There are times when use of this instrument is the only way to solve a line of sight problem. The intense rays of the reflected sunlight are visible through hazy or smoky atmosphere when no other signals can be detected.

Expedient Lights

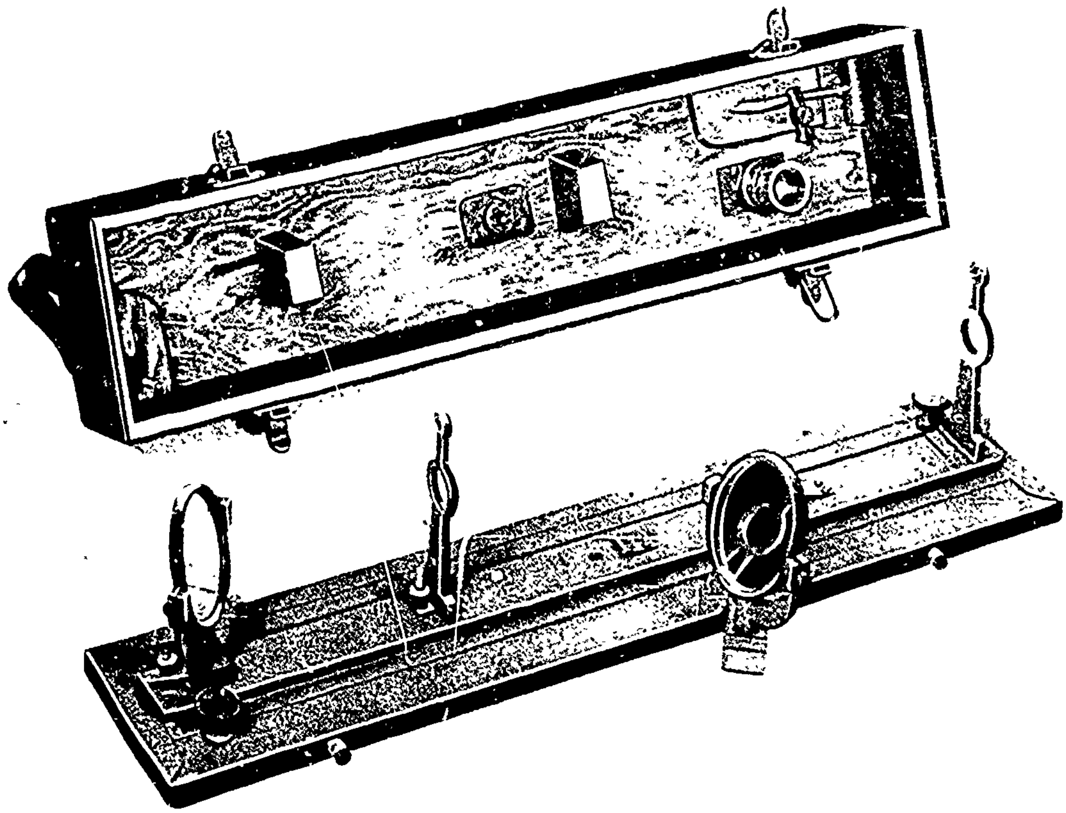
There are many types of expedient lights or signals that can be used when standard equipment is nonavailable or inoperative. No attempt will be made here to list or illustrate all the different types of expedient lights or signals that are or can be used. These include the headlights of vehicles, a masked lantern, or a boxed light bulb. The survey party chief must use his own experience and ingenuity to determine the proper expedient for the particular conditions and/or problems.

Light Keeping

When doing triangulation, it occasionally becomes necessary to have a station occupied by only lights and this necessitates the use of a lightkeeper. The duties of the lightkeeper are to correctly and accurately point all lights and/or heliotropes being observed and to maintain their operation. When occupying a station with a heliotrope, he must continually readjust the mirrors to maintain a steady light.

TOWERS

It becomes necessary to build towers on some stations in order to raise the lines of sight to



82.229

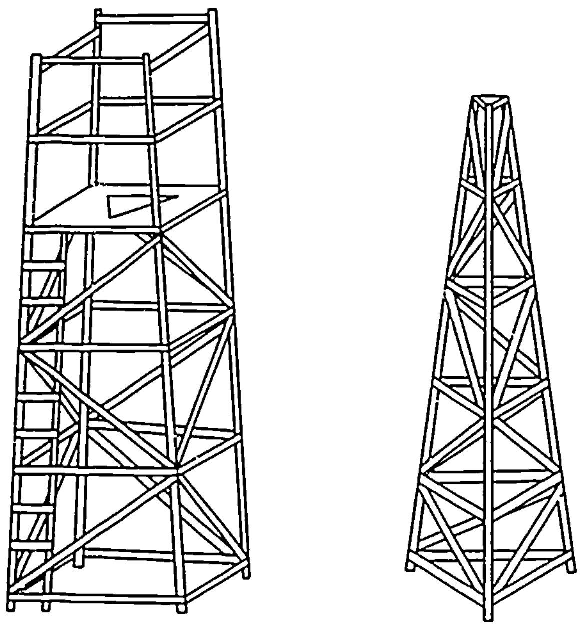
Figure 4-12.—Heliotrope.

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.

Wooden Towers

The wooden towers are usually built on the station site using lumber or natural forest materials. It is not considered practical to build wooden towers higher than 25 feet, except in extreme cases.

When building lumber towers, one side is cut and fastened on the ground. This is used as a pattern for the other sides. The inner tower is always a tripod, but the outer tower may have four sides. The legs on the instrument stand must be leveled at the point where they receive the cross and diagonal bracing. All diagonal bracing must be cut so the ends butt firmly against the edges of the crossmembers (fig. 4-13); the lowest bracing must be as near to the ends of the legs as possible without touching the ground, to reduce the unbraced length. A hole should be dug for each leg and clean dirt replaced, tamping until it is very firm. The tops of the legs are sawed off even with the upper edge of the top crossmember or collar, and a facing of



82.230
Figure 4-13.–Wooden tower framing details.

1-inch board is nailed firmly to the legs and collar, cutting off the projecting corners.

The instrument stand is not guyed during observations, but it may be weighted with rocks or other weights to increase stability. It may be guyed when not in use to prevent damage from high winds. Care should be taken when guying the instrument stand so as not to pull it off plumb.

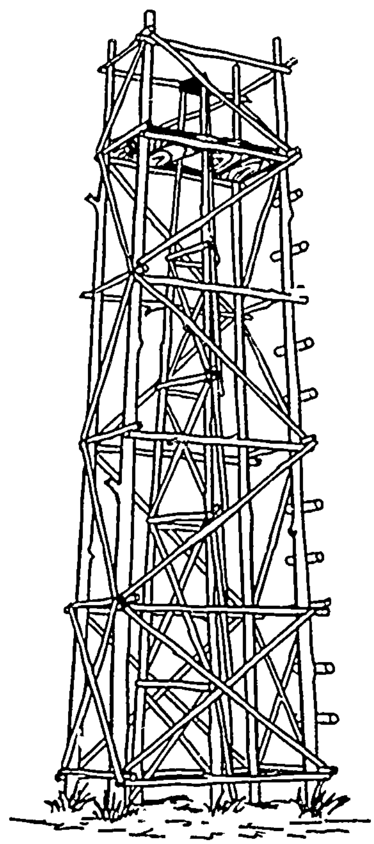
The outer tower must be strong enough to be safe and must not touch the inner tripod at any point. It should be provided with a hand railing in any case, as the observer often loses his sense of balance momentarily when he takes his eyes away from the telescope. The observer's tower is usually constructed with four legs and is guyed at all corners.

Natural Material Towers

When working in an area where there is an abundance of trees, such as jungles and tropical islands, it is sometimes more feasible to build towers at the station site using the natural material. When working in this type of environment, the construction party should be equipped with bolts, nuts, large washers, and a brace and bit, because nails are sometimes unsatisfactory, especially when the wood has been freshly cut. Two types of natural wood towers are: pole towers and tree towers.

The POLE tower is built in the same manner as the lumber tower, except that freshly cut trees are used in place of the standard lumber (fig. 4-14). Usually this type of tower is built using nuts, bolts, and washers in place of nails. However, fairly satisfactory results can be obtained by notching the members at each joint, tacking with a large nail or spike, and lashing tightly with steel wire or natural vines.

A TREE tower is sometimes used in a dense jungle, where high stands of timber are prevalent. The tower consists of a large tree, topped the required height above the ground. This is



82.231
Figure 4-14.–Pole tower.

used as the instrument stand, and a scaffold is constructed around the tree to be used as the observing platform. The scaffold should be constructed in the same manner as the outer tower of a pole tower. The height of this type should be limited to less than 60 feet.

Expedient Tower

The expedient tower is usually a high structure that is already in the area. The fire lookouts in forests, lighthouses along seacoasts, and cornices of tall buildings or water towers in or near cities and towns are some examples of the expedient tower. When using this type of tower, care must be exercised to keep the instrument level and plumb over the exact point at all times. These towers are generally used as eccentric stations or points; therefore, care must be taken in the measurements of all directions and distances to the true stations.

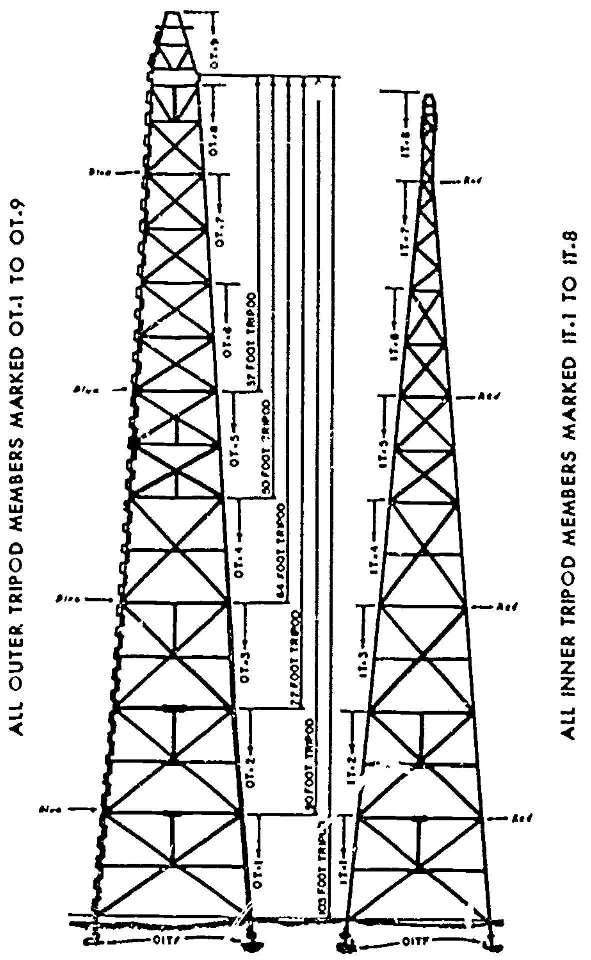
Aluminum and Steel Towers

When heights of greater than 25 feet are needed the aluminum or steel tower is usually used. The standard height of this type of tower is 103 feet, but intermediate heights of 37, 50, 64, 77, and 90 feet can be obtained by omitting lower sections (fig. 4-15). Heights of greater than 103 feet can be reached by adding supplementary sections. The light stand on top of the outer tower is 10 feet higher than the instrument stand. Due to greater stability the steel tower is preferred over the aluminum tower.

A construction party of five men, consisting of a crew leader and four riggers, is needed to erect this type of tower.

Plumbing Towers

Towers may be plumbed with a 1-second theodolite, or a 32-ounce plumb bob if the wind does not interfere. An accessory kit is available for the 1-second theodolite containing a right angle eyepiece that can be used for accurately plumbing towers. The methods used with the 1-second theodolite, with or without the right angle eyepiece and depending upon whether the stations are being established or recovered, are as follows:



82.232

Figure 4-15.—Aluminum or steel tower.

RECOVERED STATIONS.—Stations that have been recovered from previous surveys require that the tower be erected and then plumbed over the station mark. When erecting the tower over a station, there are certain procedures that must be followed in the placing of the tower footings. These procedures are found in the tower erection manual for the particular tower that is to be erected. There are many ways of plumbing a tower over a station mark, but the following two methods are the generally accepted methods.

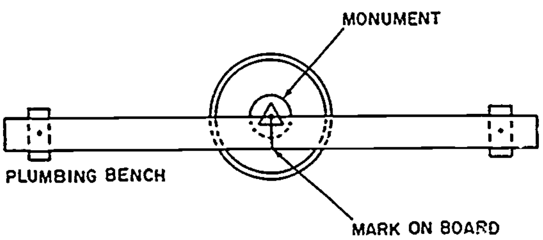
THEODOLITE WITH RIGHT ANGLE EYEPIECE. When using the theodolite, plumb and level the instrument over the station mark on its own tripod, then attach the right angle eyepiece and point the telescope straight up. Set the horizontal plates at approximately 0° and the vertical circle on exactly 0°. Tape a piece of cardboard flat to the underside of the tower instrument stand. Level the vertical circle bubble and have an assistant on the tower mark the center of the reticle (crosshairs) on the cardboard. Turn the instrument 180° in azimuth, relevel circle bubble, and mark a second point. Connect the two points with a straight line. Repeat this procedure with a horizontal reading of 90° and 270°. Connect these two points with a straight line. The intersection of these straight lines on the cardboard will be the desired center point. Without disturbing the cardboard, attach and center the instrument base plate over the center point on the cardboard. To determine the exact center of the base plate, place three strings along the base plate grooves and either glue or wax (sealing type) them in place, then extend them over the opening of the base plate and glue or wax the other ends to the plate. The junction of these three strings is the center of the base plate. After the base plate is centered over the point on the cardboard, clamp the plate securely to the tower instrument stand. If observations are conducted over a period of days the position of the base plate must be checked occasionally to assure that no change in the position has occurred.

THEODOLITE WITHOUT A RIGHT ANGLE EYEPIECE. When the building party is without a right angle eyepiece, a method commonly known as the "90° method" is used to plumb the tower over the existing station mark. This method is not as convenient or as easily accomplished as with the eyepiece, but with proper care and careful measurements the tower can be plumbed to within the accuracy requirements. Set a theodolite up at a distance away from the tower, where both the underside of the instrument stand and the station mark can be seen. Tape a piece of cardboard to the underside of the tower instrument stand. Make a pointing on the center of the station mark. To make this pointing hold a sharp pencil or similar object in the center of the station mark, and point on the lowest visible part of the object. Then point the telescope up to the cardboard and make two marks on the cardboard, coinciding with the vertical crosshairs of the instrument, one on the near side toward the instrument and one on the far side. Reverse the telescope, rotate the instrument 180° around its vertical axis, make a new pointing on the station mark, and again point the telescope up to the cardboard. If the vertical crosshair does not coincide with the two marks on the cardboard, two new marks are made to define the second sighting. Then draw a line at the mean position of the two lines. Do not disturb the cardboard. Move the instrument to a point about 90° around the tower and repeat the above procedure. The intersection of the two mean positions of the sighting will be the center point. Attach the base plate to the tower instrument stand as in the preceding procedure using the right angle eyepiece.

ESTABLISHING STATIONS.—When stations are to be established and the station mark is to be constructed by the construction party, it is easier and more convenient to build the tower and then plumb the station mark under the tower. The following two methods will plumb the station mark within the required accuracy.

THEODOLITE WITH RIGHT ANGLE EYEPIECE. After the tower has been constructed, the theodolite is set up under the tower at the approximate center between the three legs of the tower instrument stand. Level the instrument and attach the right angle eyepiece. Set the horizontal plates at approximately 0° and the vertical circle at exactly 0°. Level the vertical circle bubble and sight through the telescope. If the line of sight passes through the opening in the tower instrument stand, the theodolite is positioned right, but if the line of sight misses the opening, reposition the theodolite and repeat until the line of sight does pass through the opening. After the theodolite is in the right position, tape a piece of cardboard to the underside of the tower instrument stand, determine the center point, and attach the base plate as in the procedure for recovered stations. After the base plate has been attached, plumb the station mark under the instrument tripod using either the optical plumb or a plumb bob hung from the instrument center. After the station mark is set, a check must be made to determine if the mark and base plate are still in line. Periodic checks must be made to assure that the tower remains plumb over the station mark if observations take place over a period of days.

THEODOLITE WITHOUT A RIGHT ANGLE EYEPIECE. The procedure for this method is exactly the same as in the procedure for recovered stations using a theodolite without a right angle eyepiece, except that a board is placed on the ground in the approximate position where the station mark is to be constructed. The base plate is first attached to the tower instrument stand and its center is transferred to the board. After a center point has been established on the board, a plumbing bench is constructed and the center point is marked on the bench. The monument is constructed and the station mark is plumbed under the center point on the bench as shown in figure 4-16.



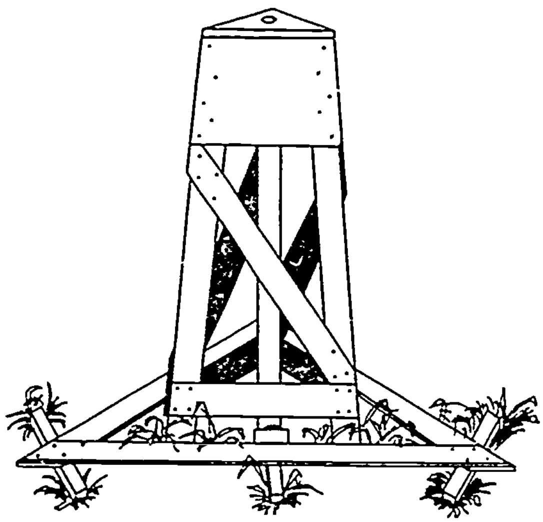
82.233
Figure 4-16.—Top view of a monument and plumbing bench.

Instrument Stands

When observations of second order or higher are required, it is desirable that wooden or aluminum instrument stands or concrete piers be used instead of the issued tripods. The stands are usually 4-foot tripods.

WOODEN STANDS.–The stand is constructed with commercial lumber, two-by-fours are used for the legs and one-by-fours for the crossmembers and diagonals (fig. 4-17). It is advantageous to make up a pattern and cut the lumber to size in the base camp and assemble at the station sites.

Holes should be dug for the legs of the stand whenever possible. The tops of these holes are left open to avoid transmitting surface disturbances to the stand. The stand must be secured in place by weighing it down with large rocks or sandbags.



82.234
Figure 4-17.—Wooden instrument stand.

Footboards or a platform for the observer should be placed around the stand. This should be supported as far away as practicable from the legs of the instrument stand.

ALUMINUM STAND.—The aluminum stand is constructed in much the same manner as the wooden stand, using portions of a salvaged aluminum tower for the legs and crossmembers and turnbuckles for the diagonals. Care must be taken when tightening the turnbuckles to ensure that they are all uniformly tight to prevent straining or warping the stand. The head of this type of stand can be constructed of wood or any other type of material that will dampen vibration. This type of stand is portable and durable, and can be used many times without excessive maintenance in damp and rainy parts of the world. A platform for the observer must be built around the stand in the same manner as for the wooden stand.

PIERS.–In special geodetic surveys, it sometimes becomes necessary to construct a concrete pier to be used as an instrument stand. The dimensions of this type of stand will vary with the type of survey being accomplished. When observing for high order astronomic latitude and longitude a pier is required. The dimensions of an astronomic pier are usually, 18 inches square, extending 3 feet above the ground and 3 feet below the ground. Under no circumstances are any metal reinforcing rods used in these concrete piers. A platform must be built around the pier as a walkway in the same manner as for the wooden stand.

TRIANGULATION PROCEDURE

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 course, INTERVISIBILITY. An observation between two stations which are not intervisible is impossible. Next comes ACCESSIBILITY. Obviously again, a station which is inaccessible cannot be occupied, and between two stations otherwise equally feasible, the one which 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. The 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, stations should be selected which 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/signals, the most important thing is that these stations 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. Information on types of signals and towers was presented earlier in this chapter.

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 Av. 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 6 times. As explained in *Engineering Aid 3 & 2*, 6 repetitions with a 1-minute transit measures angles to the nearest 05 seconds. To ensure elimination of certain possible instrumental errors, half of the repetitions should be made with telescope erect and half with telescope reversed. In each case, the horizon should be closed around the station.

DETERMINATION OF DIRECTION

As you learned from chapter 3, 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, and 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 N-S meridian running through the point of origin. Whereas, the departure of the traverse line means the length of the line as projected on the E-W parallel running through the point of origin. Latitudes and departures will be discussed in detail in chapter 5.

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 transitman is required to give precise alignment while measuring a base line. For third-order triangulation measurement with the steel tape, it is required to incorporate all the tape corrections described in *Engineering Aid 3 & 2.* 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 set up 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 tensionometer (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 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, it may be the case that, after a few tape intervals have been laid off, the end of the tape will begin to lie slightly off the metal marking strip on the buck. To take care of this situation, the head chainman carries a finely divided (to 0.001 ft.) pocket scale. With this scale he measures the distance which 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 notes, and deducted from or added to the tape length for that particular interval.

Figure 4-18 shows field notes for a base line measurement. In this case the tape was supported on stakes, driven at full-tape 100-ft. intervals. With the exception of the interval between stake 5 and stake 6, the horizontal distance between each adjacent pair of stakes will amount 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 stake 5 and stake 6 (where there is, as you can see, a forward set), the horizontal distance will amount to the standard tape length plus 0.104 ft., 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 to a small extent 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.

COMPUTATIONS

In triangulation of ordinary precision or higher, the observed angles are ADJUSTED

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	735	730		
4	5	725	725		
5	6	72 5	73.0	0.104	
6	7	73.0	73.5		
7	8	735	73.5		
8	9	73.5	73.0		

3 June 1963	Smith, J, EA1 Recorder
Cloudy, Warm	Jones, R, EA 3 Marker
Measuring Forward	Brown, B, CN, HChnmn
100-Ft tape #2	Adams, G, CN, R.Chnmn
Tensionometer #4	
Tape Supported at	0 & 100 Ft.
Thermometers #1 & #2	

82.7.34

Figure 4-18.—Field notes for base line measurement.

before the lengths of the triangle sides are computed. 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)180°, n representing the number of sides of the polygon.

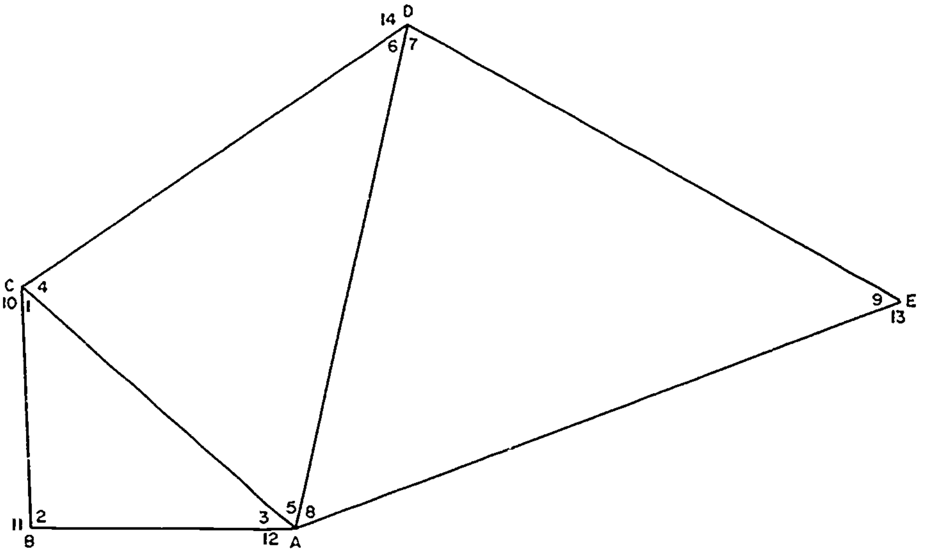
Adjusting a Chain of Triangles

In station adjustment you compute the sum of the 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 4-19 shows a chain of triangles. Station adjustment for this chain of triangles is given in table 4-1.

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, came to 360° 00′ 25″. This differed from 360° by 25″. The number of angles around the station was 4; therefore, the correction for each angle was one-fourth of 25, or 6 seconds, with 1 second left over. The sum of the observed angles was 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,



82.14

Figure 4-19.—Chain of triangles.

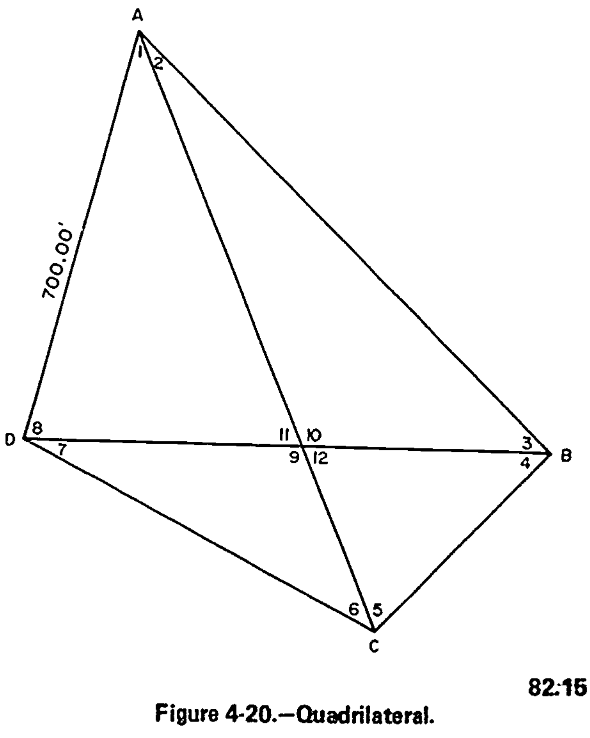
the sum of the interior angles is 180°. The figure adjustment for each of the three triangles illustrated in figure 4-19 is shown in table 4-2.

As you can see, the sum of the three observed interior angles in triangle ABC (angles 1, 2, and 3) came to 179° 59′ 40″. This is 20 seconds less than 180°, or 20/3, or 6 seconds for each angle, with 2 seconds over. Therefore, 6 seconds was added to the station adjusted value of angle 1 and 7 seconds each 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, with the exception, of course, of the fact 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 4-20. The diagonals in this quadrilateral intersect to 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



82:15

Figure 4-20.—Quadrilateral.

Table 4-1.–Station Adjustment For Chain of Triangles, Figure 4-19

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

82.131

Table 4-2.–Figure Adjustment For Chain of Triangles, Figure 4-19

Triangle	Angle	Value after Station Adjustment °	′	″	Value after Figure Adjustment °	′	″
ABC	1	46	10	10	46	10	16
	2	92	47	34	92	47	41
	3	41	01	56	41	02	03
	Sum	179	59	40	180	00	00
ACD	4	75	31	00	75	31	02
	5	61	10	35	61	10	37
	6	43	18	20	43	18	21
	Sum	179	59	55	180	00	00
ADE	7	74	43	05	74	43	10
	8	56	08	42	56	08	47
	9	49	07	58	49	08	03
	Sum	179	59	45	180	00	05

82.132

the angles in any triangle is 180°, it follows that, for any pair of vertically opposite angles in figure 4-20 the sums of the other two angles in each of the corresponding triangles must be equal.

For example. In figure 4-20, 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, are as 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 employs 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 4-20, AB is the base line 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:

$$AB\,\frac{\sin 1 \sin 3}{\sin 6 \sin 8} = AB\,\frac{\sin 2 \sin 4}{\sin 5 \sin 7}$$

Cancelling 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 logarithm, 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 sin 7) - (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 4-20 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	9.648478-10	8	9.985354-10
Sum	9.243395-10	Sum	9.243442-10
			- 9.243395-10
	Difference		0.000047

The difference in the sums of the log sines is 0.000047. Since there are 8 angles, this means an average difference for each angle of 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 8 angles involved. This is determined from the "D" values given in the table, for each of the angles shown in figure 4-20, 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 is greater than that of angles 1, 3, 5, and 7. Therefore, 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 in accordance with (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 4-20, the values of the angles in the quadrilateral, after station adjustment, were 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 which make up each of the overlapping triangles within the quadrilateral is as follows:

Triangle		Angles °	′	″	Triangle		Angles °	′	″
ABC	2	23	44	38	ABC	1	38	44	06
	3	42	19	09		2	23	44	38
	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
		179	59	59			180	00	01

The sum of the closing errors for the 4 triangles is (09 + 01 + 07 + 01), or 18 seconds. The average triangle closure for the 4 triangles, then, is 18/4, or 04.5 seconds. For third-order triangulation the maximum average triangle closure is 06 seconds, therefore, for third order work this closure would be acceptable.

BASE LINE DISCREPANCY

If AD is the base line in figure 4-20, then BC would be the adjacent base line. Let's assume that the base line AD measures 700.00 ft, 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 by (2) solving triangle ACD for DC and triangle DBC for BC.

Solving ABD for AB, we have AB = AD sin 8/sin 3, or 700.00(0.966837)/0.673256, or 1005.243 ft. Solving ABC for BC, we have BC = AB sin 2/sin 5, or 1005.243(0.402627)/0.934035, or 433.322 ft.

Solving ACD for CD, we have CD = AD sin 1/sin 6, or 700.00(0.625727)/0.637824, or 686.724 ft. Solving DBC for BC, we have BC = DC sin 7/sin 4, or 686.724(0.445130)/0.705449, or 433.315 ft.

Thus we have, by computation by 2 routes, values for BC of 433.322 ft and 433.315 ft. There is a discrepancy here of 0.007 ft. 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 ft) 433.32 ft.

Suppose, now, that the precision requirements for 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 ft. 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 ft. The error here is (433.32 - 433.25), or 0.07 ft, which is within the allowable limit.

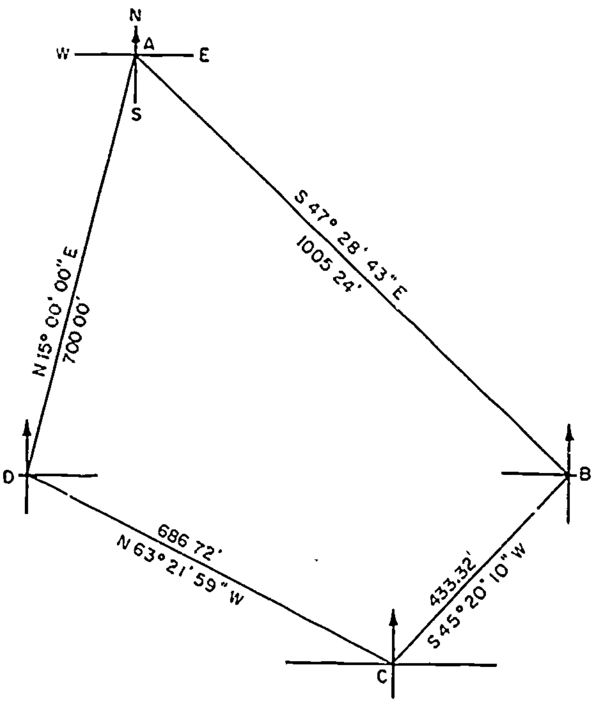
LOCATIONS OF POINTS

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/interior angles are described in *Engineering Aid 3 & 2*; the following is how to determine the bearing of lines of a quadrilateral.

BEARING AND DISTANCE

Figure 4-21 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 N 15°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, N 15°,00′ 00″ E. Now draw your meridian through point A. From figure 4-21 you can see that the line AB bears SE, and you could 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 could recall from figure 4-8. The bearing angle of AB is (62°28′ 43″-15° 00′ 00″) 47°28′ 43″. Therefore, the complete bearing of line AB is S 47° 28′ 43″ E.

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 reckoned always from N or S direction. To find the bearing of BC you have to get the sum of angle B (Angles 3 and 4, figure 4-20) plus the bearing angle of AB, then subtract it from 180°; you could see that it bears SW, so just add this



82.16

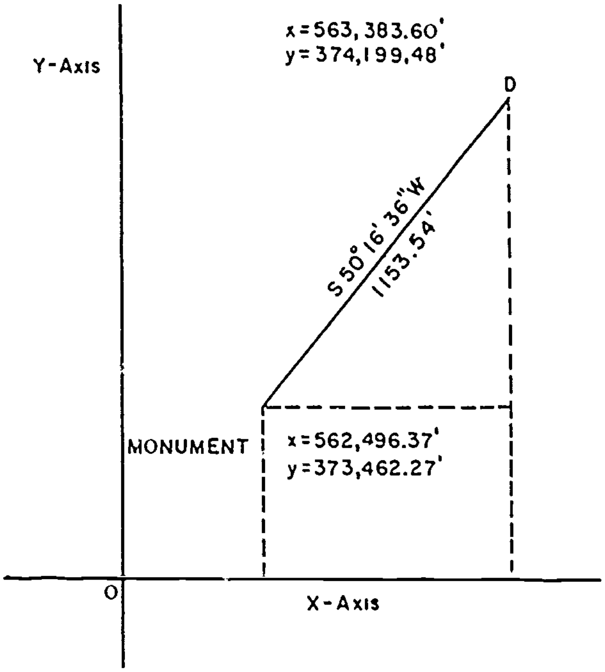
Figure 4-21.—Bearing and distances of a quadrilateral.

designation to the proper place in the bearing angle for BC. In this case the bearing of BC will be (180°00′00″ minus (42°19′08″ + 44° 51′ 59″ + 47° 28′ 43″) or S 45° 20′ 10″ W. The bearing of CD is equal to angle C minus the bearing angle of BC.

COORDINATES

Suppose that you are tying this quadrilateral in figure 4-21 into a state grid system. The nearest monument in this system lies 1153.54 ft from station D, bearing S 50°16′ 36″ W from D as shown in figure 4-22. This means that the bearing from the monument to D is N 50° 16′ 36″ E. Suppose that the grid coordinates of the monument are y = 373,462.27 ft., x = 562,496.37 ft.

The latitude of the line from the monument to station D is 1153.54 cos 50°16′ 36″, or 1153.54(0.639081), or 737.21 ft. The departure of the same line is 1153.54 sin 50° 16′ 36″, or 1153.54(0.769139), or 887.23 ft.



82.150

Figure 4-22.—Coordinates.

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 ft. 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 ft.

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 700.00(0.965926), or 676.15 ft. The departure of DA is 700.00 sin 15°00′ 00″, or 700.00(0.258819), or 181.17 ft. The y coordinate of station A is equal to the y coordinate of station D plus the latitude of DA, or 374,199.48 + 676.15, or 374.875.63 ft. 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. The coordinates of the other stations can be similarly determined.

CHAPTER 5

LEVEL AND TRAVERSE COMPUTATIONS

This chapter provides information on procedures used in making level and traverse computations. We will take up 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. We will explain methods of computing areas by double meridian distance, double parallel distance, and multiplication of coordinates. Computations of areas of parcels which include curves and irregular figures are also covered. In addition, several methods of plotting horizontal control, which may be used in determining the bearing of traverses, are described. These methods include plotting angles by protractor and scale, plotting angles from tangents, and plotting by coordinates. Some of the common types of mistakes that the EA may encounter in making or checking computations are pointed out, and information is given on locating mistakes.

PRELIMINARIES TO COMPUTATIONS

Prior to computations, a close check on the field data for completeness and accuracy is required. This includes checking the field notes to ascertain that they accurately reflect what was actually measured. For example, a deflection-angle note 78° 61′ R must be checked to ensure that the angle actually measured 78° 61′ (by ascertaining that the sum of the angle and the closing angle is 360° or within allowable difference), 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 2-time, 4-time, or 6-time angles. Each of these must be "reduced" to the mean angle, as explained in *Engineering Aid 3 & 2*. 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 which are within the maximums specified for, or implied from the nature of the survey.

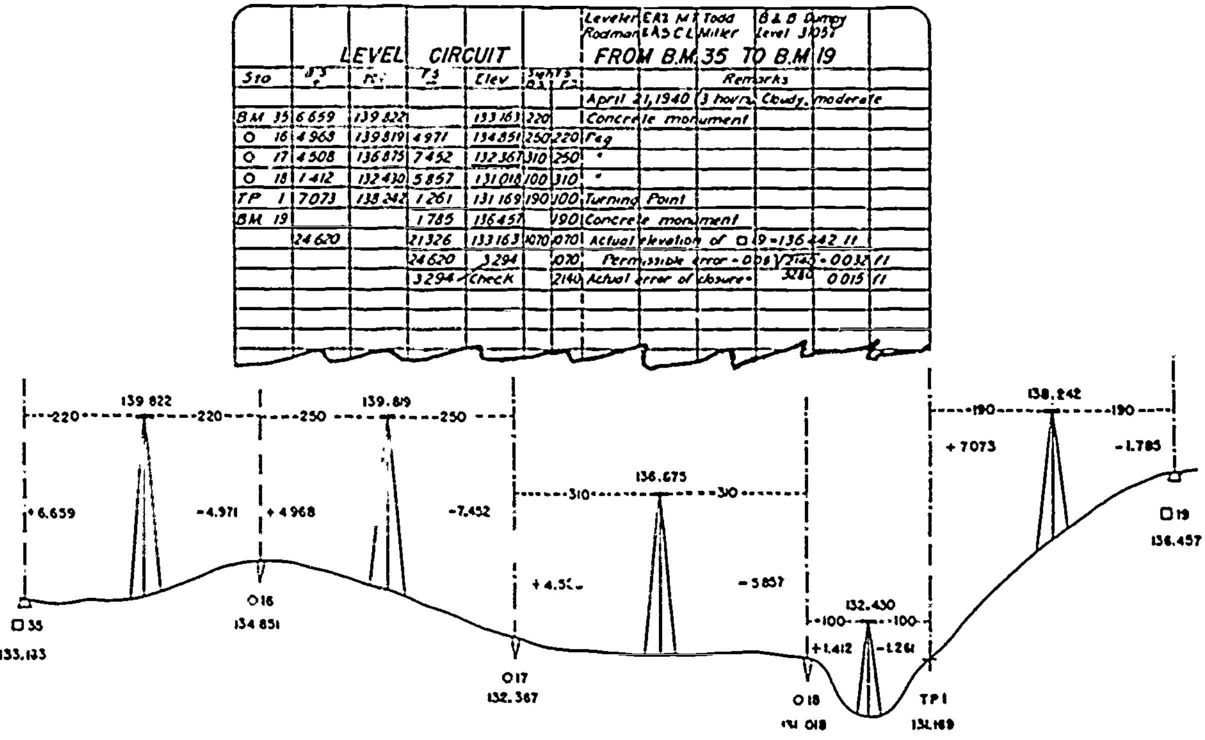
An error which is within the maximum allowable is eliminated by adjustment. Adjustment means the equal distribution of a sum total of allowable error over the separate values which contribute to the total. Suppose, for example, that for a triangular closed traverse with interior angles about equal in 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 and check on the notes for a level run by verifying the beginning BM that is, by determining that the correct BM was used and its correct elevation duly recorded.

Then, check on the arithmetical accuracy with which you added backsights and subtracted foresights. The difference between the sum of the foresights taken on BM's or TP's and the sum of the backsights taken on BM's or TP's should equal the difference in elevation between the initial BM or TP and the final BM or TP. This fact is illustrated in figure 5 1.

You must remember that this checks the arithmetic only. It doesn't indicate anything about how accurately you made the vertical distance measurements.



45.778

Figure 5-1.—Differential-level circuit, and notes for differential leveling.

ADJUSTMENT OF INTERMEDIATE BENCH MARK ELEVATIONS

Level lines which begin and end on points which have fixed elevations, such as bench marks, 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 will seldom be 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 5-1 indicates that the actual elevation of BM 19 is known to be 136.442 feet. The elevation found through differential leveling was 136.457 feet. The error of closure of the level circuit is 136.457-136.442 = 0.015 foot.

It is assumed that errors have occurred progressively along the line over which the leveling was accomplished, so adjustments for these errors are distributed proportionally along the line as shown by the following example. Referring to figure 5-1, you will notice that total distance between BM 35 and BM 19, over which the line of levels was run, was 2,140 feet. The elevation on the closing BM 19 was found to be 0.015 feet 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:

$$\text{Correction} = \begin{matrix}\text{Error}\\ \text{of}\\ \text{closure}\end{matrix} \left[\frac{\text{distance between the starting BM and the intermediate BM}}{\text{distance between the starting and closing BM}}\right]$$

BM 16 is 440 feet from the starting BM. The total length distance between the starting and closing BMs is 2,140 feet. The error of closure is 0.015 foot.

$$\text{Correction} = -0.015 \times \frac{440}{2140} = -.003$$

The adjusted elevation of BM 16 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 which can be allowed depends on the precision required (first, second, or third order). The permissible error of closure in accuracy leveling is expressed in terms of a coefficient and 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 old bench mark 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:

$$0.050 \text{ ft} \sqrt{\text{length of the level circuit in miles}}$$

By adding the sight distances in the sixth and seventh columns of figure 5-1, you will find that the length of the level circuit is 2,140 feet. The length in miles is 2140 ÷ 5280 = 0.405. The allowable error of closure is:

$$0.050 \sqrt{0.405} = 0.050\,(0.64) = 0.032 \text{ feet}$$

Since the actual error is only 0.015 feet, the results are sufficiently accurate.

First- and second-order levels usually close on themselves, that is, the leveling party runs a line of levels from an old bench mark 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:

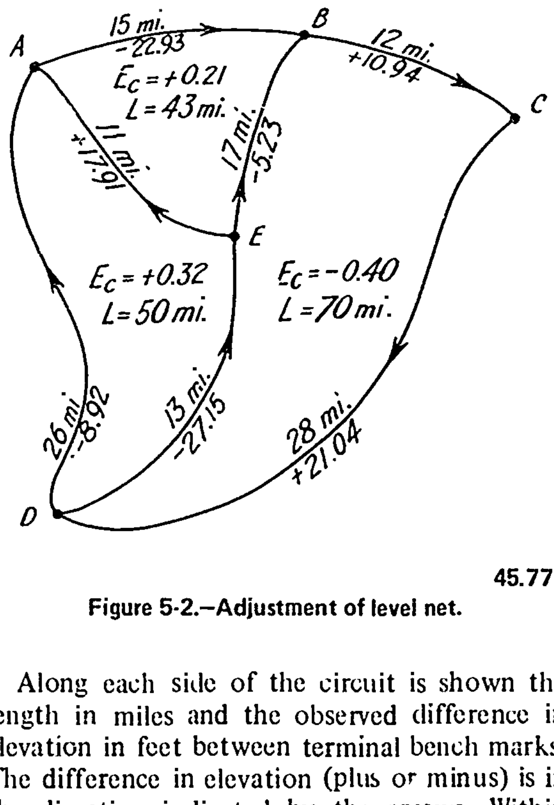
$$0.035 \text{ ft} \sqrt{\text{the length of the level circuit in miles}}$$

First-order leveling is still more precise. The allowable error cannot be greater than

$$0.017 \text{ ft} \sqrt{\text{the length of the level circuit in miles}}$$

ADJUSTMENT OF LEVEL NETS

When a level survey system covers a large area, you will 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 5-2 represents a level net made up of circuits BCDEB, AEDA, and EABE.



45.779

Figure 5-2.–Adjustment of level net.

Along each side of the circuit is shown the length in miles and the observed difference in elevation in feet between terminal bench marks. The difference in elevation (plus or minus) is in the direction indicated by the arrows. Within each circuit is shown its length (L), and the error of closure determined by summing up the differences in elevation in a clockwise direction. Figure 5-3 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 (D.E.) are listed.

For circuit BCDEB, the error of closure is -0.40 foot. This is distributed among the lines in proportion to their lengths. Thus, for the line BC, the correction is

$$0.40 \times \frac{12}{70} = +0.07 \text{ foot.}$$

(17% of 0.40 = +0.07) with the sign opposite to that of the error of closure. The correction of +0.07 foot 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 line 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, always listing 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

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	......	......

45.782

Figure 5-3.—Computations required to balance the level net.

military post or an 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.

CHECKING AND REDUCING ANGLES

Begin traverse computations by checking to ensure that all the required angles (including closing angles) were turned, and that the notes correctly indicate their sizes. For deflection angles, check to ensure that angles marked L or R were actually turned, and should have been turned, in those directions. Check your sketches and be sure they are in agreement with your field notes.

Next, reduce repeated angles to mean angles.

CHECKING AND REDUCING DISTANCES

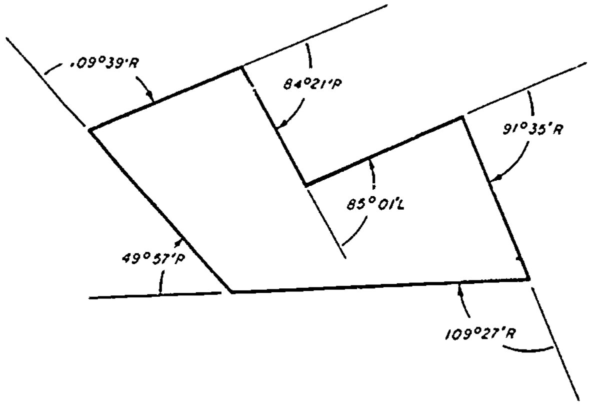
Check to ensure that all required linear distances have been chained. Reduce slope distances as required. If you broke chain on the slopes, check to ensure that sums of break distances were correctly added.

Finally, apply standard error, tension, and temperature corrections as required.

ADJUSTING ANGLES

In a closed traverse, the theoretical or geometrical sum of the interior angles is 180° x (n-2) where n = number of angles measured; the sum of the exterior angles is 180° x (n + 2) where n = number of angles measured; and 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 which is within the allowable maximum equally among the angles. Figure 5-4 shows a traverse in which one of the deflection angles was turned to the left, all others to the right. The sum of the right deflection angles is 444°59', the deflection angle turned to the left is 85° 01'. The difference is 359° 58', therefore, there is an angular error of closure of 02'. If all the deflection angles were right, you would adjust by adding one-sixth of 02', or 20", to each angle. Here, however, you adjust by adding 20" to each right deflection angle, but SUBTRACTING 20" from the left angle. If you do this, the sum of the adjusted angles to the right will be 445° 00' 40", the sum of the left angles (of which there is only one) will be 85° 00' 40", and the difference between sums of adjusted angles will be 360° 00' 00", as it should be.



45.310

Figure 5-4.—Closed traverse by deflection angle method.

Remember, then, that in adjusting the angles in a deflection-angle traverse, you apply the adjustments to right and left angles in opposite directions.

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 the procedure, you must have a knowledge of "latitude" and "departure."

Latitude and Departure

Latitude and departure are values which 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 selected according to convenience. The location of a point is given in terms of its distance N or S, and its distance E or W, of the point of origin. The plane coordinate system will be further explained later in this chapter.

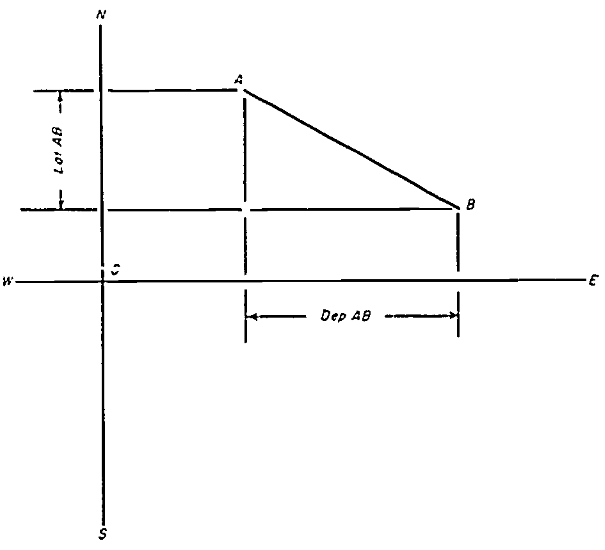
The "latitude" of a traverse line means the length of the line as projected on the N-S meridian running through the point of origin. The "departure" of a traverse line means the length of the line as projected on the E-W parallel running through the point of origin. To clarify this, examine figure 5-5. The point of origin is at 0. 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 N and S the latitude would equal the length of the line and the departure would be zero, while for a line running due E and W the departure would equal the length of the line and the latitude would be zero.

Now, for a line running other than N-S or E-W, you can determine the latitude or departure by simple triangle solution. Figure 5-6 shows a traverse line 520.16 ft long bearing S 61° 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′. The cosine of 61° 25′ is 0.47944; therefore, AC (that is, the latitude) = 520.16 x 0.47944, or 249.38 ft.

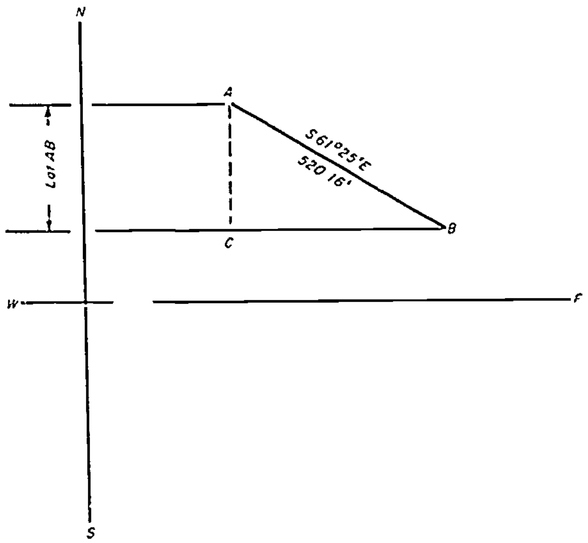
The latitude of a traverse line, then, equals the product of the length of the line times the COSINE of the angle of bearing.

To determine the departure, you solve the triangle for the length of the side CB shown in figure 5-7. CB = 520.16 sin 61° 25′. The sine of 61°25′ is 0.87812; therefore, CB = 520.16 X 0.87812, or 456.76 ft.

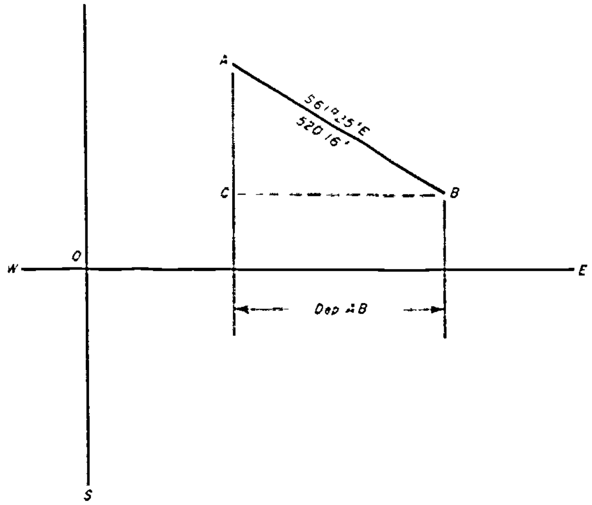
The departure of a traverse line, then, equals the length of the line times the SINE of the angle of bearing.



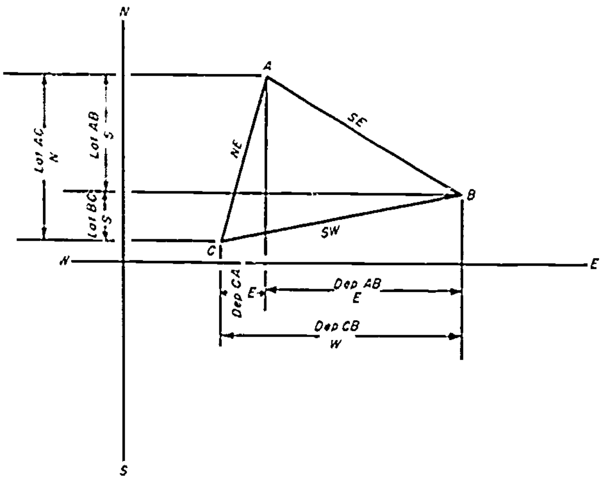
45.312
Figure 5-5.—Latitude and departure.



45.313
Figure 5-6.—Latitude equals length of traverse line times cosine of angle of bearing.



45.314
Figure 5-7.—Departure equals length of traverse line times sine of angle of bearing.



45.315
Figure 5-8.—Graphic solution of a closed traverse by latitude and departure.

The latitude of a traverse line is designated N or S, and the departure is designated E or W, according to the compass direction of the bearing of the line. A line bearing NE, for example, has a N latitude and E departure. In computations, N latitudes are designated plus and S latitudes minus; E departures are designated plus and W departures minus.

Figure 5-8 is a graphic demonstration of the fact that, in a closed traverse, the algebraic sum of the plus and minus latitudes is 0, and the algebraic sum of the plus and minus departures is 0. The plus latitude of CA is equal in length to the sum of the two minus latitudes of AB and BC; the minus department of BC is equal in length to the sum of the two plus departures of CA and AB.

Linear Error of Closure

The above is the case geometrically speaking, as it were, or only when perfect "linear closure" is obtained. In practical fact, the sum of the N latitudes usually differs from the sum of the S latitudes, and the difference is called the "error of closure in latitude". Similarly, the sum of the E departures usually differs from the sum of the W departures, and the difference is called the "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", which 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.

Suppose, for example, that you come up with an error of closure in latitude of 5.23 ft and an error of closure in departure of 3.18 ft. 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 the square root of $5.23^2 + 3.18^2$, or about 6.12 ft. Suppose the total length of the traverse was 12,000.00 ft. Then your ratio of linear error of closure would be

$$\frac{6.12}{12{,}000.00}, \text{ or about } \frac{1}{2{,}000}.$$

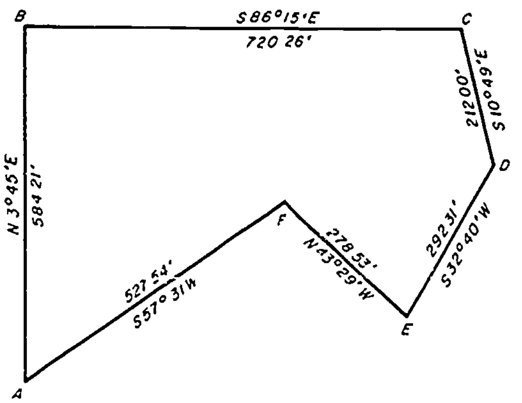
Closing a Traverse

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, the one with the most general application is based on the so-called "compass rule". By this rule you adjust the latitude and departure of each traverse line as follows:

Correction in latitude = total correction in latitude times length of traverse line over total length of traverse.

Correction in departure = total correction in departure times length of traverse line over total length of traverse.

Figure 5-9 shows a closed traverse with bearings and distances inscribed. Figure 5-10 shows the computation of the latitudes and departures for this traverse, done on the type of form commonly used for the purpose. As you can see, the error in latitude is +0.33 ft and the error in departure +2.24 ft. The linear error of closure, then, equals the square root of $(0.33^2 + 2.24^2)$, or 2.26 ft. The total length of the traverse is 2614.85 ft, therefore, the ratio of error of closure is $\frac{2.26}{2614.85}$, or about $\frac{1}{1157}$.



45.316

Figure 5-9.—Closed traverse by bearings and distances.

We'll assume that this ratio of error 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 5-11, 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.

Next use the compass rule to determine the latitude correction and departure correction for each line. For AB, for instance, the latitude correction equals $0.33 \times \frac{584.21}{2614.85}$, or 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 in departure; the corrections, however, are opposite in sign to the error of closure.

Finally, enter the adjusted latitudes and adjusted departures in the last two columns, determined 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, indicating that the errors of closure have been entirely distributed.

Adjusting Bearings and Distances

With the adjusted latitudes and departures, you can now adjust the original bearings and distances by the procedure 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 5-12 shows traverse line AB with adjusted latitude and departure inscribed. To determine the adjusted angle of bearing, solve the triangle AA′B for angle A′AB as follows:

$$\tan A'AB = \frac{37.70}{582.88} = 0.06468$$

$$A'AB = 3^\circ\ 42'$$

The adjusted bearing of AB, then, is N 3° 42′ E. For the adjusted distance, solve the triangle for AB as follows:

$$AB = \frac{37.70}{\sin 3^\circ\ 42'} = \frac{37.70}{0.06453} = 584.22 \text{ ft.}$$

The adjusted length of AB, then, is 584.22 ft.

COMP. BY EAY DATE 11 OCT.

STATION	BEARING	DISTANCE	FUNCTION		LATITUDE		DEPARTURE	
			COSINE	SINE	NORTH	SOUTH	EAST	WEST
A								
	N 3° 45′ E	584.21	.99786	.06540	58295		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	20209			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	

45.317

Figure 5-10.—Form for computing latitudes and departures.

PLANE COORDINATES

The location of a point by "plane coordinates" means to describe the point's location in terms of its distance N or S from, and its distance E or W from, a point of origin.

Figure 5-13 shows how coordinate distances are measured on an axis running N-S through the point of origin and called the "Y" axis; E-W coordinates are measured on an axis running E-W through the point of origin and called the "X" axis. Values on the Y axis N of the point of origin are plus, values S of the point of origin are minus. Values on the X axis E of the point of origin are plus, values W of the point of origin are minus.

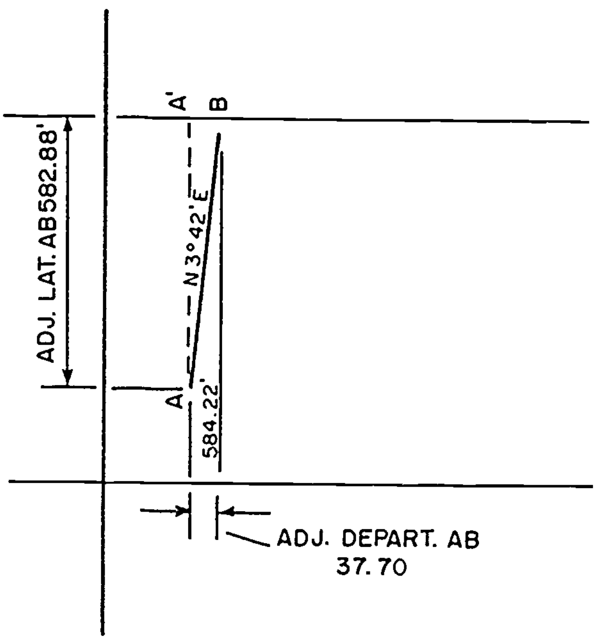
Plane Coordinates From Latitude and Departure

Figure 5-13 also illustrates 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 ft) equals the latitude of AB, and that the difference between the X coordinate of A and the X coordinate of B (which is 600.00 ft) equals the departure of AB. It follows that 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 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

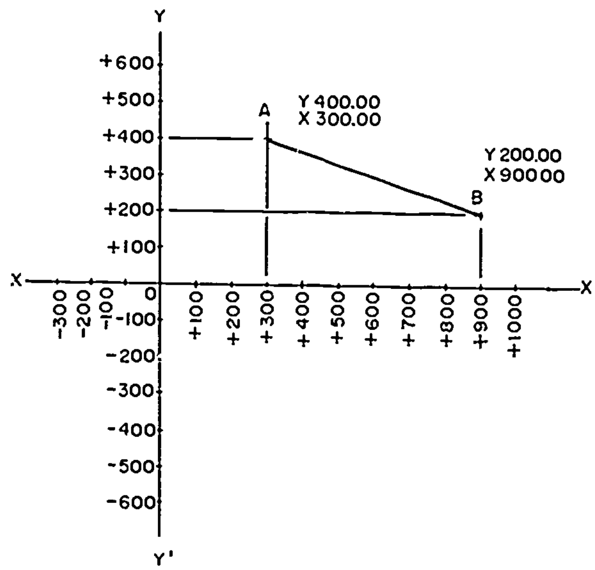
45.318

Figure 5-11.—Form for adjusting latitudes and departures.



45.682

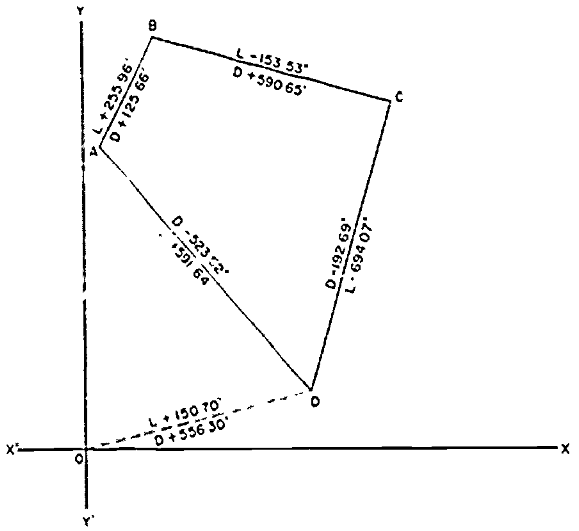
Figure 5-12.—Adjusted bearing and distance from adjusted latitude and departure.



45.686

Figure 5-13.—Location by plane coordinates.

Figures 5-14 shows a closed traverse with adjusted latitudes and departures inscribed. 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 0 which is west of the most westerly traverse station and south of the most southerly traverse station.



45.322

Figure 5-14.—Closed traverse with adjusted latitudes and departures.

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 ft, and that the X coordinate of D must equal the departure of OD, or 556.30 ft.

The Y coordinate of station A equals the Y coordinate of D plus the latitude of AD, or 150.70 + 591.64, or 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, or 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, or 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, or 158.34 ft.

The Y coordinate of station C equals the Y coordinate of station B minus the latitude of BC, or 998.30 - 153.53, or 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, or 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, or 150.70 ft. The coordinate of station D equals the X coordinate of station C minus the departure of CD, or 748.99 - 192.69, or 556.30 ft. These are the same coordinates you originally computed for station D, a fact which serves as a check on your accuracy.

You enter these values on a form like the one shown in figure 5-15. In actual practice, you will use a wide 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 thus computed is positive or negative, the best thing to do 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 NE, the latitude is positive or N and the departure is positive or E. If the line bears SW, both latitude and departure are negative.

TRAVERSE TABLES

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

STATION	LATITUDE		DEPARTURE		COORDINATES	
	NORTH	SOUTH	EAST	WEST	Y	X
A					74234	32.68
	25596		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		

45.323

Figure 5-15.—Form for computing coordinates.

distance can be determined mostly by inspection.

Table 5-1 shows sample pages from a table which 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 ft. 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 ft long, bearing N 15°30′ E. To get the latitude, proceed as follows. In the latitude column under 15 1/2°, look up the latitude for 70 ft. You read 67.45 ft. If the latitude for 70 ft is 67.45 ft, the latitude for 700 ft is 674.50 ft. Set that down.

Next, look up the latitude for 25 ft under the same 15 1/2° latitude column, which is 24.09 ft. The latitude for 725.00 ft, then, equals 674.50 + 24.09, or 698.59 ft.

Finally, for the 0.32 ft, look up the latitude for 32 ft, which is 30.84 ft. If the latitude for 32 ft is 30.84 ft, it follows that the latitude for 0.32 ft must be 0.3084 ft, which rounds off at 0.31 ft.

The numerical value of the latitude, then, is 698.59 + 0.31, or 698.90 ft. Because the line AB bears NE, the latitude is positive.

You get the departure in the same way, using the departure column.

METHODS OF COMPUTING AREAS

Various methods are used in computing areas. Some of the common methods with which the EA should be familiar are discussed below.

AREA BY DOUBLE MERIDIAN DISTANCE

The MERIDIAN DISTANCE of a traverse line is equal to the length of a line running E-W from the midpoint of the traverse line to a reference meridian, the reference meridian being the

Table 5-1.—Sample Pages From Traverse Table

Distance.	15°.		15¼°.		15½°.		15¾°.		Distance.
	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	Lat.	Dep.	
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	44.32	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	48.19	13.36	48.12	13.57	50
Distance.	Dep.	Lat.	Dep.	Lat.	Dep	Lat	Dep.	Lat.	Distance.
	75°.		74¾°.		74½°.		74¼°.		

Distance.	15°.		15¼°.		15½°.		15¾°.		Distance
	Lat.	Dep	Lat	Dep	Lat	Dep	Lat	Dep	
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	61.60	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	79.89	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	Dep	Lat.	Dep	Lat.	Dep	Lat.	Dep	Lat.	Distance
	75°.		74¾°.		74½°.		74¼°.		

45.45.12

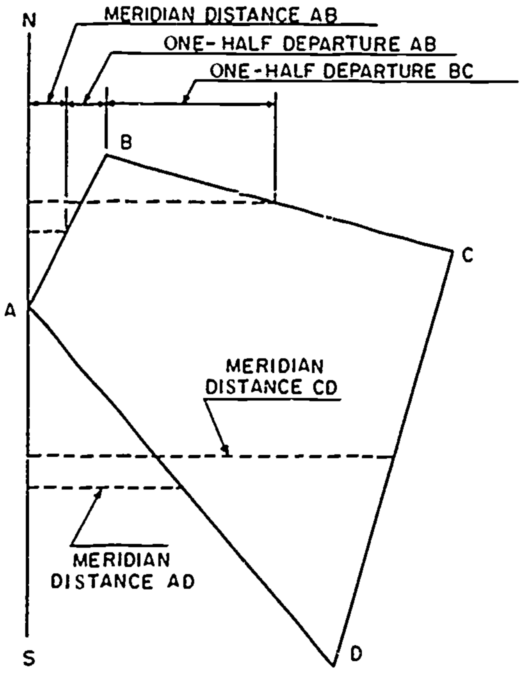
meridian which passes through the most westerly traverse station.

In figure 5-16, the dotted lines indicate the meridian distances of the traverse lines to which they extend from the reference meridian NS. 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 sum of the meridian distance of AB, plus one-half the departure of AB, plus one-half the departure of BC.

You can also see that the meridian distance of CD equals the sum of the meridian distance of BC, plus one-half the departure of BC, MINUS one-half the departure of CD. Similarly, the meridian distance of AD equals the meridian distance of CD, MINUS one-half the departure of CD, MINUS one-half the departure of AD.

You should now be able to perceive 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 the departure.



45.324

Figure 5-16.—Meridian distances.

2. For each subsequent traverse line, the meridian distance equals the sum of the meridian distance of the preceding line, plus one-half the departure of the preceding line, plus one-half the departure of the line itself. However, it is the ALGEBRAIC sum that is meant meaning that plus departures are added, but minus departures are subtracted.

For reasons of convenience, it is customary to use DOUBLE MERIDIAN DISTANCE, (DMD for short), rather than meridian distance, in calculations. Now, if meridian distance of the initial traverse line in a closed traverse equals one-half the departure of the line, it follows that the DMD of this line equals its departure. It follows again, from the rule for meridian distance of the next line, that 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 it is the algebraic sum that is meant. 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 N latitude, you get a plus result which you add. If you multiply a positive meridian distance by a minus or S latitude, however, you get a minus result which you subtract.

It follows from the above that 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 two.

Figure 5-17 shows form entries for the double-meridian-distance computation 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 ft. 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

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	+309794.54	
						341958.47	989865.86
							341958.47
						2)	647907.39
							323953.69
			AREA = 323,953.69 SQ. FT. = 7.44 ACRES				

45.327

Figure 5-17.—Area from double meridian distances.

subtracted), or 1239.93 ft. 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 ft. Note that the DMD of this last traverse line equals the departure of the line, but with opposite sign. This fact serves as a check on the computations.

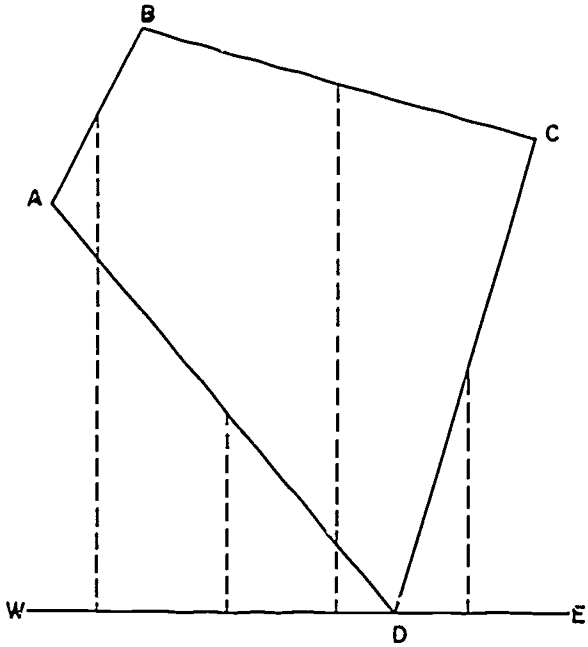
The double area for AB equals the DMD times the latitude, or 125.66 x 255.96, or 32163.93 sq ft. The double area for BC equals 841.97 (the DMD) times MINUS 153.53 (the latitude), or MINUS 129267.65 sq ft. The double area of CD equals 1239.93 x (-694.07), or -860598.21 sq ft. The double area of DA equals 523.62 x 591.64, or 309794.54 sq ft.

The difference between the sum of the minus double areas and the sum of the plus double areas is the double area, which is 647907.39 sq ft. The area is one-half of this, or 323953.69 sq ft. Land area is generally expressed in acres. There are 43,560 sq ft in 1 acre; therefore, the area in acres equals $\frac{323953.69}{43560}$, or 7.44 acres.

AREA BY DOUBLE PARALLEL DISTANCE

You can check the accuracy of a double-meridian-distance area computation by computing the same area from "double parallel distances".

As indicated in figure 5-18, the parallel distance of a traverse line is the N-S distance from the midpoint of the line to a reference parallel, the reference parallel being the parallel passing through the most southerly traverse station.



45.326

Figure 5-18.—Parallel distances.

You can see that the solution for parallel distance is the same as the one for meridian distance, except that for 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 the latitude. The parallel distance of the next line, AB, equals the parallel distance of the preceding line, DA, plus one-half the latitude of the preceding line, DA, plus one-half the latitude of the line AB itself.

It follows from the above that the DOUBLE parallel distance of the initial traverse line DA equals the latitude of the line. The double parallel distance of the next line, AB, equals the double parallel distance 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 it is for area by meridian distance, except that for the double area of each traverse line you multiply the double parallel distance by the departure instead of multiplying the double meridian distance by the latitude.

Figure 5-19 shows entries for double-parallel-distance area computation for the traverse we are working on. Note that the result is identical with that obtained by double-meridian-distance computation.

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'll 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 5-20.

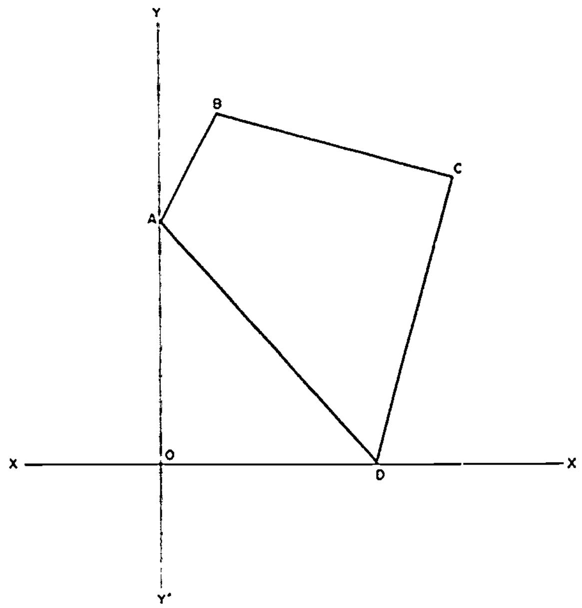
Figure 5-21 shows the coordinate entries. You can see that the Y coordinate of A equals the latitude of DA, or 591.64 ft, while the X coordinate of A is O. The Y coordinate of B equals the Y coordinate of A plus the latitude of AB, or 591.64 + 255.96, or 847.60 ft. The X coordinate of B equals the departure of AB, or 125.66 ft. The Y coordinate of C equals the Y coordinate of B MINUS the latitude of BC, or 847.60 - 153.53, or 694.07 ft. The X coordinate of C equals the X coordinate of B plus the departure of BC, or 125.66 + 590.65, or 716.31 ft. The Y coordinate of D obviously is O, however, it computes as the Y coordinate of C minus the latitude of CD, or 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, or 523.62. This is the same as the departure of DA, but with opposite sign - a fact which serves as another check.

Figures 5-22 and 5-23 illustrate the method of determining the double area from the coordinates. First, muitiply pairs of diagonally opposite X and Y coordinates as shown in figure 5-22, and determine the sum of the products. Then, multiply pairs diagonally in the opposite

COURSE	LATITUDE		DEPARTURE		DPD	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	

45.692

Figure 5-19.—Area from double parallel distances.



45.331
Figure 5-20.—Computations of closed traverse by coordinate method.

direction as shown in figure 5-23, and determine the sum of the products. The difference between the sums (which in this case is 1,044,918.77 - 397,011.37, or 647,907.40) equals the double area.

This method of computing area is one which lends itself to the use of a desk calculator. The arrows indicate that the upper Y coordinate is multiplied by the second X coordinate, and this product then added to the product of the second Y coordinate times the third X coordinate, and so on. The same procedure is then carried out beginning with the upper X and second Y coordinates. This accumulation of products may be carried along with the multiplication on a calculating machine. On some machines you lock the dial in which a product appears, so that the product is "held" when you clear for the next multiplication. More automatic machines have a special keyboard button called "cumulative multiply" or "multiply and add".

The symbol shown beside the coordinate product sums is the capital Greek letter (Σ) "sigma." In this case it simply means "sum".

STATION	LATITUDE		DEPARTURE		COORDINATES	
	+	−	+	−	Y	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

45.321
Figure 5-21.—Coordinate entries for computation of figure 5-20.

STATION	COORDINATES	
	Y	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 X 125.66 = 74,345.48

847.60 x 716.31 = 607,144.36

694.07 X 523.62 = 363,428.93

0 X 0 = 0

Σ → 1,044,918.77

45.695

Figure 5-22.—First step for tabulated computation of figure 5-20.

STATION	COORDINATES	
	Y	X
A	591.64	0
B	847.60	125.66
C	694.07	716.31
D	0	523.62
A	591.64	0

0 X 847.60 = 0

125.66 X 694.07 = 87,216.83

716.31 X 0 = 0

523.62 X 591.64 = 309794.54

Σ ← 397,011.37

45.696

Figure 5-23.—Second step for tabulated computation of figure 5-20.

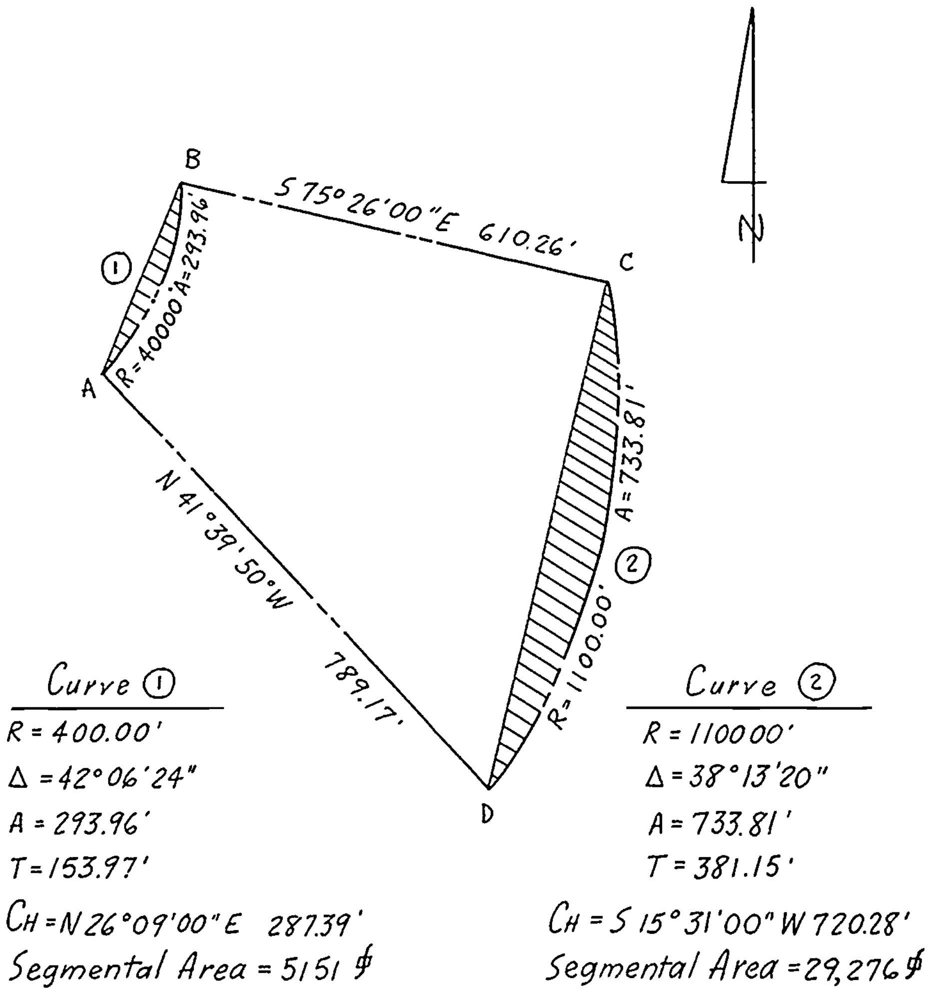
The slanted arrow after the sigma indicates which of the product sums is here represented.

PARCELS WHICH INCLUDE CURVES

Not all parcels of land are bounded entirely by straight lines. You may be required to compute the area of a construction site which is bounded in part by the centerlines or edges of curved roads or the right-of-way lines of curved roads.

Figure 5-24 shows a construction site with a shape for the most part similar to that of the parcel we have been considering in previous examples. In this case, 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 involved is inscribed on figure 5-24—that is, the radius R, the central angle Δ, the arc length A (based on the arc definition of degree of curvature), the tangent length T, and the chord bearing and distance C_H.



45.697

Figure 5-24.—Area within straight-line and curved-line boundaries (curved segments).

The cross-hatched areas lying between chord and arc are called "segmental areas". To determine the area of the parcel, you must (1) determine the area lying within the straight-line and chord (also straight-line) boundaries, (2) determine the segmental areas, and (3) subtract the segmental area for Curve 1 from, and add that for Curve 2 to, the straight-line boundary area.

The method of determining a segmental area was explained in *Engineering Aid 3 & 2*. The straight-line area may be determined by the coordinate method, as explained in this chapter. For figure 5-24, the segmental area for Curve 1 works out to be 5,151 sq ft, for Curve 2, it is 29,276 sq ft.

Figure 5-25 shows a typical computation sheet for the area problem shown in figure 5-24. Included with the station letter designations in the "station" column are indications ("chord #1" and "chord #2") showing which of the bearings and distances 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 area from difference between sums of N and sums of E coordinates, and area from half of double area. From this area, segmental area #1 is subtracted. To this remainder, segmental area #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 according to whether the particular area in question lies inside or outside of the actual curved boundary. In figure 5-24, 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 sq ft, or 8.01 acres.

STATION	BEARING	DIST	FUNCTION		LAT.	DEP	COORDINATES	
			COS	SIN	N+; S-	E+; W-	NORTH	EAST
A							740 33	31 68
Chord #1	N 26°09'00"E	287 39	89764	44072	+257 97	+126.66		
B							998 30	158 34
	S 75°26'00"E	610 26	25151	96786	-153 49	+590 65		
C							844 81	748 99
Chord #2	S 15°31'00"W	720 28	96355	26752	-694 03	-192 69		
D							150 78	556 30
	N 41°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

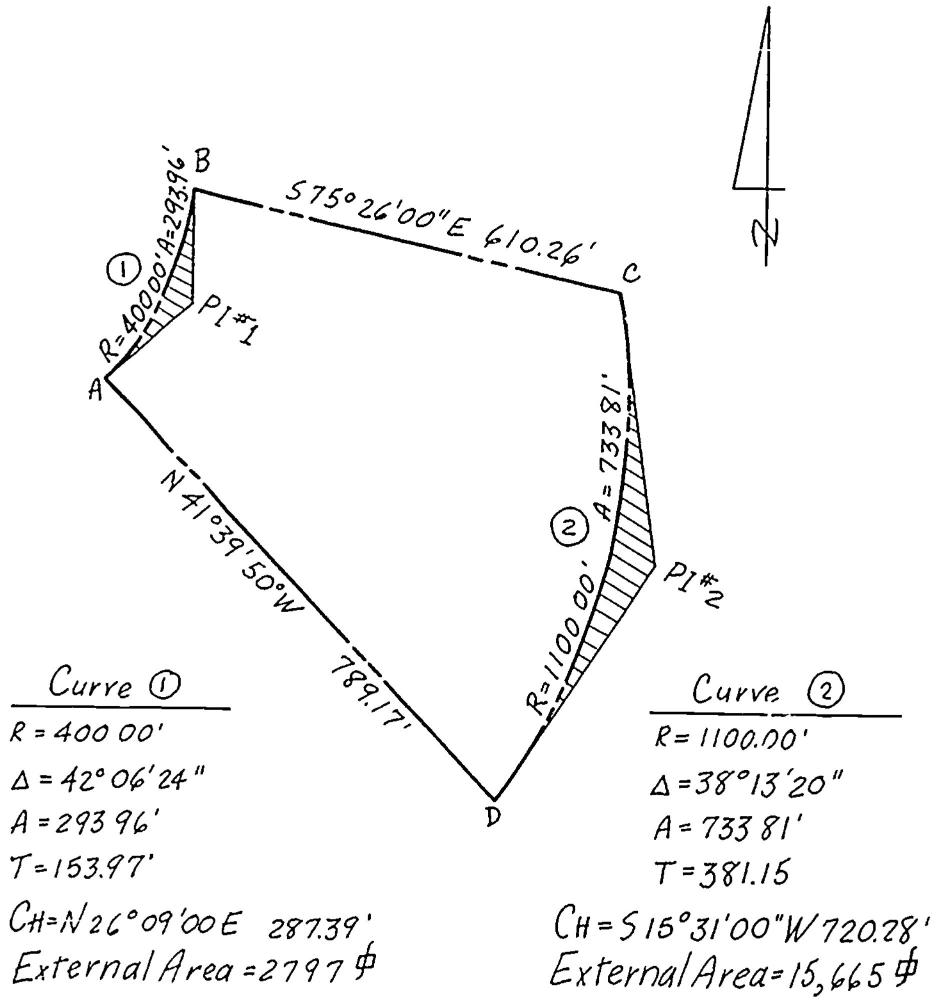
45.698

Figure 5-25.—Computation of area which includes curve segments.

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 5-26. 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 as a check on the result obtained by the chord method.

The computation sheet shown in figure 5-27 follows the same pattern as that of the one shown in figure 5-25. However, there are two more straight-line boundaries 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 previous example, but the coordinates of the P.I.'s 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 5-27. When you have only the chord bearing, you can compute the tangent bearing by adding or subtracting one-half delta as appropriate. The angle between the tangent and the chord equals one-half delta.



45.699

Figure 5-26.–Area within the curve and its tangents.

STATION	BEARING	DIST	FUNCTION		LAT	DEP	COORDINATES	
			COS	SIN	N+;S−	E+;W−	NORTH	EAST
A							74033	3168
tangent	N 47°12'12" E	15397	67940	73377	+10461	+11298		
PI #1							84494	14466
tangent	N 5°05'48" E	15397	99605	08884	+15336	+1368		
B							99830	158.34
C							84481	74899
tangent	S 3°35'40" E	38115	99803	06269	−38040	+2389		
PI #2							46441	772.88
tangent	S 34°37'40" W	38115	82286	56824	−31363	−21658		
D							15078	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		

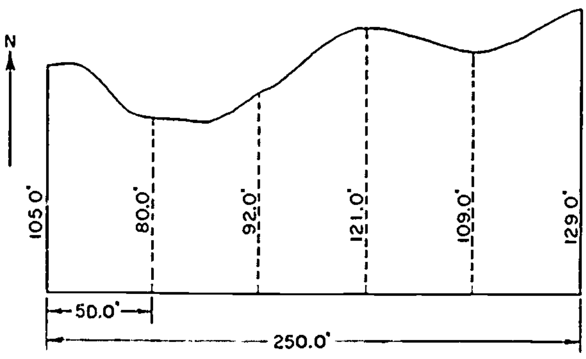
45.700

Figure 5-27.—Computation of area which includes external area of curves.

After setting coordinates on the P.I.'s, 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 5-26, 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 sq ft, which is an acceptable check on the area obtained by using the segmental areas.

AREA BY TRAPEZOIDAL FORMULA

It is often necessary to compute the area of an irregular figure, one or more of whose sides



45.54

Figure 5-28.—Area of irregular figure by trapezoidal rule.

do not form a straight line. Figure 5-28 shows a figure of this kind, representing a lakeside lot in which the S, E, and W boundaries are straight lines perpendicular to each other, but the N boundary is the irregular lake shoreline.

To determine the area of this figure, first lay off convenient equal intervals (in this case, 50.0-ft intervals) from the W boundary, and erect perpendiculars as shown. Measure the perpendiculars. Let the equal interval be called d, and let the perpendiculars (beginning with the W boundary and ending with the E boundary) be called h1 through h6.

Now, you can see that for any segment lying between two perpendiculars, the approximate area, by the rule for determining area of a trapezoid, equals the product of d times the average between the perpendiculars. For the most westerly segment, for example, the area equals $d \times \frac{h1 + h2}{2}$ 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.

$$A = d\left(\frac{h1 + h2}{2} + \frac{h2 + h3}{2} + \frac{h3 + h4}{2} + \frac{h4 + h5}{2} + \frac{h5 + h6}{2}\right)$$

However, this works out to:

$$A = d\left(\frac{h1 + 2h2 + 2h3 + 2h4 + 2h5 + h6}{2}\right)$$

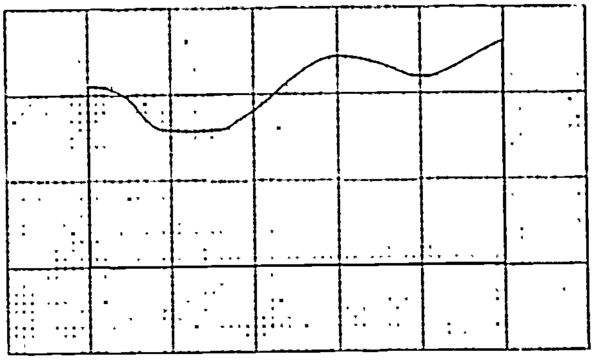
And this in turn reduces to:

$$A = d\left(\frac{h1 + h6}{2} + h2 + h3 + h4 + h5\right)$$

Substituting in the formula the data from figure 5-28, you have:

$$A = 50\left(\frac{105 + 129}{2} + 80 + 92 + 121 + 109\right)$$

If you work this out, you'll find that it comes to 25,950 sq ft.



45.55

Figure 5-29.–Computing area by counting the squares.

AREA BY COUNTING THE SQUARES

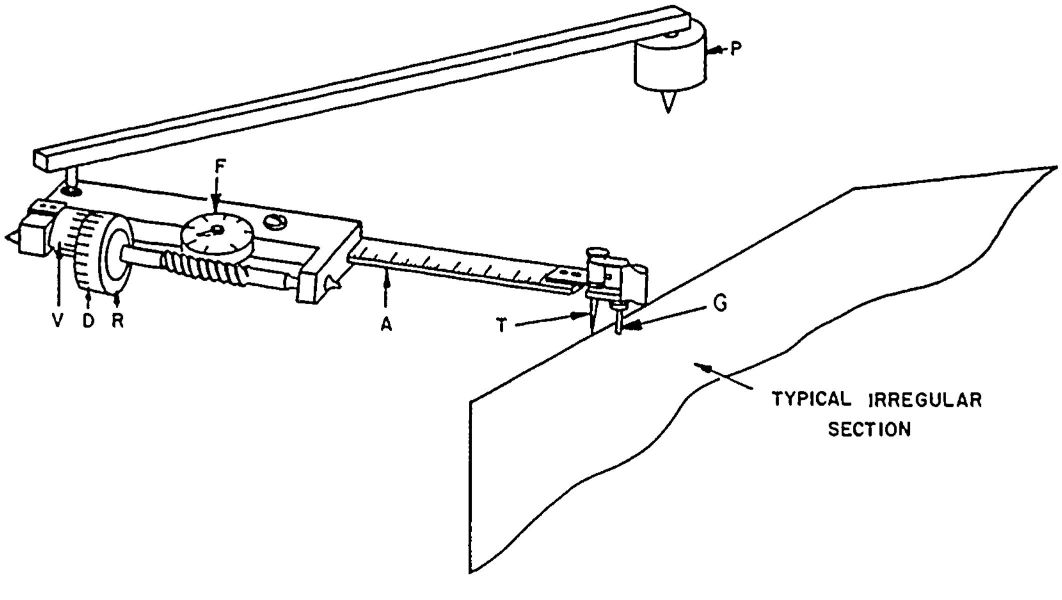
Another method of computing the area of an irregular figure is to plot the figure on a sheet of graph paper (plotting is explained later in this chapter), and then determine the area by counting the squares within the figure outline and multiplying the result by the area represented by each square.

Figure 5-29 shows the same figure shown in figure 5-28, but plotted to scale on a sheet of graph paper on which each of the small squares indicates 5 ft x 5 ft, or 25 sq ft. If you count the squares within the outline, you will find that they total 1,038 squares, which means 1,038 x 25, or 25,950 sq ft.

You do not usually need to go through the tedious process of counting all the individual squares one by one. In figure 5-29, for example, you can see that the outline encloses 7 of the larger squares on the paper, plus another large square which is only 2 squares less than complete. There are 100 small squares in one of the large squares; you, therefore, have 798 of the small squares quickly accounted for. In counting the remaining squares, it is helpful to remember that each horizontal or vertical row of smaller squares within a large square contains 10 squares.

AREA BY PLANIMETER

A "planimeter" is a mechanical device by means of which you can compute the area of an



45.56(82A)

Figure 5-30.—Polar planimeter.

irregular figure after tracing the perimeter of a scaled drawing of the figure with a "tracing point" on the planimeter. The most commonly used instrument is called the "polar planimeter."

Let's take a look at the polar planimeter in figure 5-30. Its parts include an anchor point, P, a tracing point, T, with 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 tenths, the drum, in hundredths, and the vernier, in thousandths.

The planimeter is used as follows:

1. Determine the "planimeter constant," meaning the ratio between the area traced by the tracing point on the paper and the number of revolutions of the roller. Mathematically, we can write it this way:

$$C = \frac{A}{n}$$

Where. C is the planimeter constant,
A is the area traced by the tracing point, and
n is the number of revolutions

It can be shown that the value of C is equal to the product of the length of the tracing arm and the circumference of the roller. If the length of the arm is fixed and not variable, the usual ratio between revolutions of the roller and square inches on the paper is 1 to 10–meaning that if you pass the tracing point around a 1-in. x 1-in. square on the paper, the roller dial will record 0.10 revolution. The area of the figure on the paper equals the number of revolutions multiplied by 10, in this case, the planimeter constant is therefore 10.

2. Check the accuracy of the planimeter as a measuring device to guard against errors due to temperature changes and other noncompensating factors. A simple method of testing its consistency of operation is to trace an area of one square inch with the arm set for 1:1 ratio. The disk, drum, and vernier combined should read 1.000 for this area.

3. Before measuring the specific area determine the scale of the drawing and set the adjustable arm of the planimeter according to the chart in the planimeter case. Check the setting by carefully tracing a known area, such as five large squares, on the cross-section paper, and verifying the reading on the disk, drum, and vernier. If the reading is inconsistent with the known area, readjust the arm setting until a satisfactory reading is obtained.

4. To measure an area, set the anchor point of the adjusted planimeter outside the plotted area, place the tracing point on the selected point on the perimeter of the figure, take an initial reading from the disk, drum, and vernier; continue by tracing the perimeter clockwise, keeping the tracing point carefully on the line being followed, and, when the tracing point closes on the initial point, again take a reading from the disk, drum, and vernier. The difference between the initial reading and the final reading gives a value proportional to the area being measured.

5. Make two independent measurements to ensure accurate results. The first is performed as discussed above; the second measurement is made with the anchor point again placed outside the area being measured, but on the opposite side of the area from its position in the first measurement. This procedure gives two compensating readings, the mean of which is more accurate than either.

6. To measure plotted areas larger than the capacity of the planimeter, divide the area into sections and measure each separately as outlined above.

The average planimeter can be set for any scale from about 1 in. = 20 ft to about 1 in. = 200 ft. Suppose your drawing scale is 1 in. = 20 ft. You set this scale on the planimeter. A linear scale of 1 in. = 20 ft means an area scale of 1 sq in.=400 sq ft.

Instead of recording the initial reading, you can set the roller dial at 0, place the tracing point on a suitable starting point on the figure, and trace all the way around the figure. Suppose that you now read 7.50 revolutions on the roller dial. Because the planimeter constant is 10, the actual area covered by the outline on the paper is 7.50 x 10, or 75. Because the scale of the drawing is 1 sq in. = 400 sq ft, the actual area on the ground is 400 x 75, or 30,000 sq ft.

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 you are working on. 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 which are given in feet and decimals of feet, you use the appropriate scale on an engineer's or chain 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.

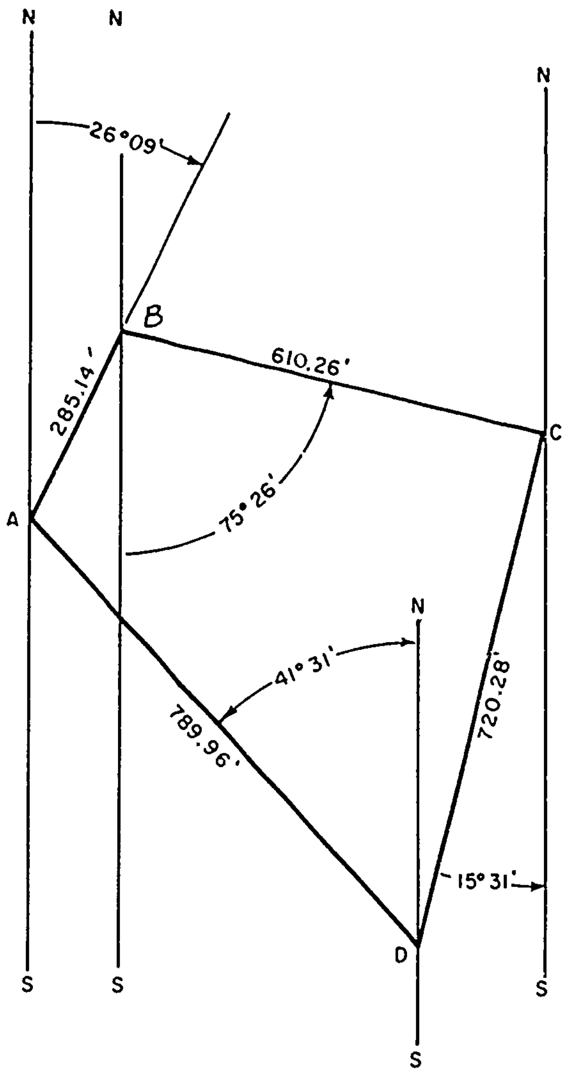
PLOTTING ANGLES BY PROTRACTOR AND SCALE

For the traverse we have been working on, the adjusted bearings and distances are as follows:

Traverse Line	Bearing	Distance
AB	N 26° 09′ E	285.14 ft
BC	S 75° 26′ E	610.26 ft
CD	S 15° 31′ W	720.28 ft
DA	N 41° 31′ W	789.96 ft

Figure 5-31 illustrates the procedure for plotting this traverse with chain scale and protractor. Select first a scale on the chain scale which will conform the size of the plot to the size of your paper. Select a convenient point on the paper for station A and draw a light line NS, representing the meridian through the station.

AB bears N 26° 09′ E. Set the protractor with the central hole on A and the OO line on NS, and lay off 26° 09′ (you'll have to estimate the minutes as best you can, remembering that 10 minutes equals one-sixth of a degree) to the E. Draw a line in this direction from A, and on the line measure off the length of AB (which is 285.14 ft) to scale.



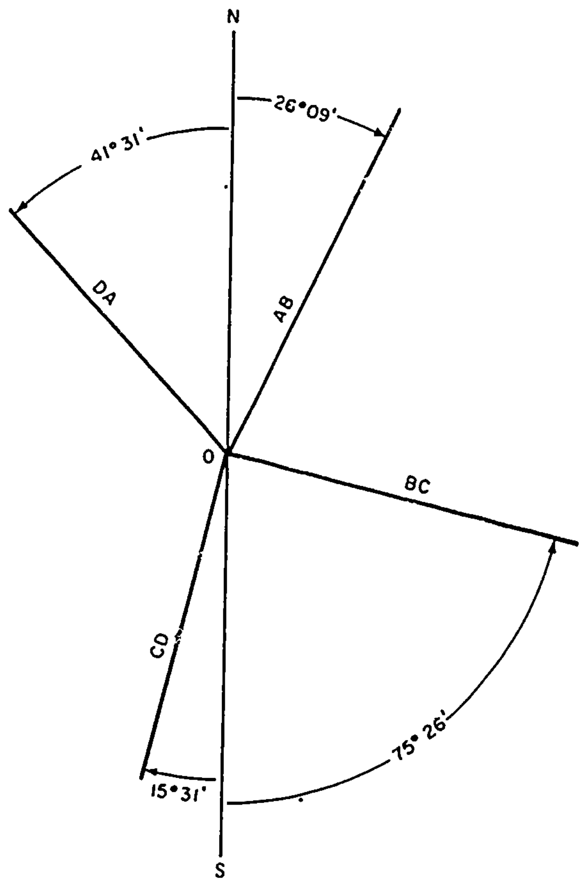
45.701
Figure 5-31.—Traverse plotted by protractor and scale method.

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 S 75° 26′ E. Set the protractor with the central hole on B and the OO 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 ft) to scale to 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 which eliminates these lines is illustrated in figure 5-32. 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 0, lay off each of the traverse lines in the proper direction. You can then transfer these directions to the plot by one of the procedures for drawing parallel lines.

PLOTTING ANGLES FROM TANGENTS

It could be the case that, instead of having bearing angles to plot from, you might want to plot the traverse from deflection angles turned



45.702
Figure 5-32.—Plotting traverse lines by parallel method from a single meridian.

in the field. The deflection angles for the traverse we 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

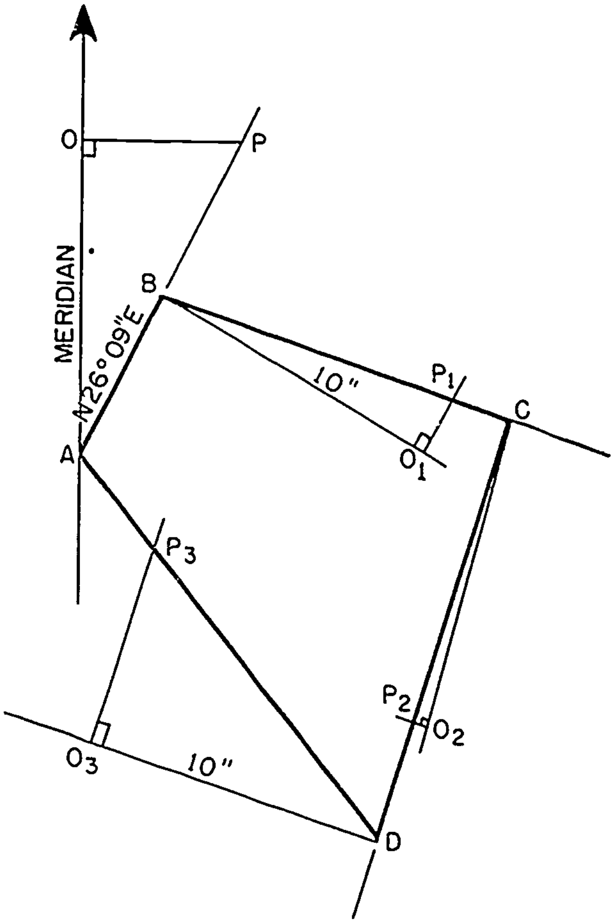
You could plot from these angles by protractor, by laying off one of the traverse lines to scale, laying off the direction of the next line by turning the deflection angle to the right of the first line extension by protractor, and so on.

However, the fact that you can read a protractor directly to only the nearest 30 minutes presents a difficulty in this case. 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 5-33 shows the procedure of plotting deflection angles larger than 45°. The direction of the starting line is referred to as meridian, following a conventional procedure, that the N-side of the figure being plotted is situated on top of the drawing paper. In doing this, you might have to plot the traverse approximately to a small scale using a protractor and an engineering scale, just to have a general idea where to start. Make sure that the figure will fit-in proportionately on the paper in accordance with the desired size. Starting at point A, you draw the meridian line lightly. Then lay off Ao, 10 inches (or any convenient round-figured length) along the referenced meridian. Now, from o, 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° 09′, which is equal to 0.49098. Find the distance op as follows:

$$\begin{aligned} op &= Ao \tan 26^\circ\, 09' \\ &= 10'' \times 0.49098 \\ &= 4.9098 \text{ or } 4.91 \text{ inches} \end{aligned}$$

Now we know that op is equal to 4 91 inches Draw Ap extended, then lay off the distance AB



45.332(82A)
Figure 5-33.—Plotting by tangent offset method from deflection angles larger than 45°.

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 5-33, 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′ or 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.

$$o_1p_1 = Bo_1 \tan 11° 35'$$
$$= 10'' \times 0.20497$$
$$= 2.0497 \text{ or } 2.05 \text{ inches}$$

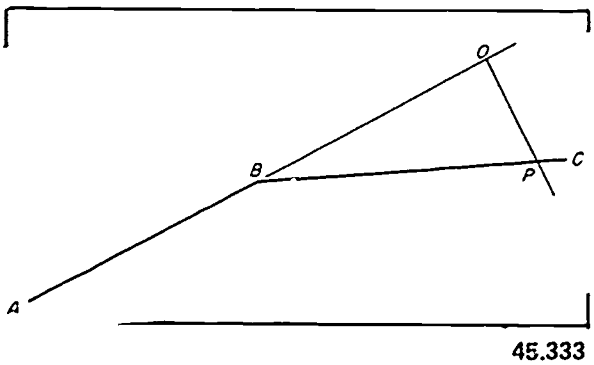
Now check the distance o_1p_1 which is equal to 2.05 inches. Draw a line from B through p_1 extended, lay off the distance BC to scale along this line. The remaining sides, CD and DA, are plotted the same way. Make sure that the angles used for your computations are the correct ones. A rough sketch of your next line will always help to avoid major mistakes.

When the deflection angle is less than 45°, the solution by tangent for plotting is as illustrated in figure 5-34. Here you measure off a convenient round-figure length (say 500.00 ft) 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, in this case, the deflection angle. Assume that this is 23° 21′. The formula for the length of OP is

$$OP = BO \tan 23° 21' = 500 \times 0.43170 = 215.85 \text{ ft.}$$

PLOTTING BY COORDINATES

A common and accurate method of plotting is by coordinates, as illustrated in figure 5-35. Here you simply locate each station by its coordinates and have no angular measurement to bother about. To plot station B, for instance, you would lay off from O on the Y axis a distance equal to the Y coordinate of B (847.60 ft), erect a light line from this point perpendicular to the Y axis, and measure off on this line from the Y axis a distance equal to the X coordinate of B (125.66 ft). The remaining points are plotted the same way.



45.333

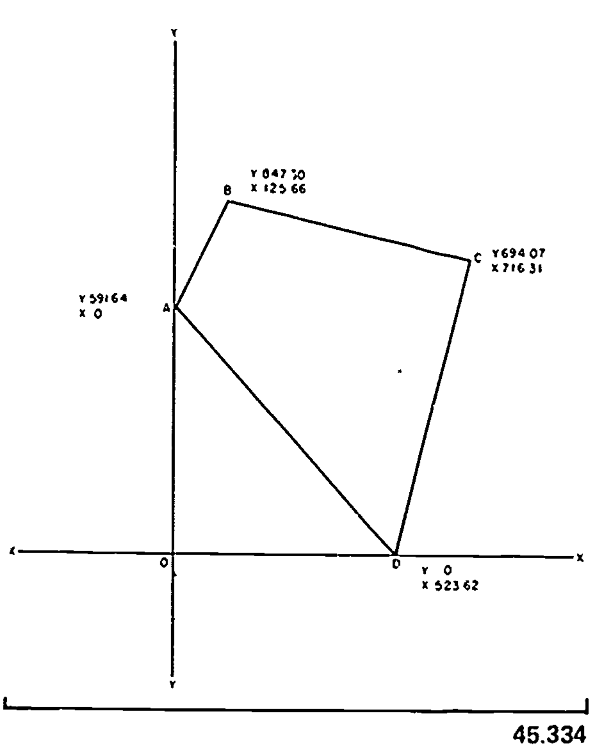
Figure 5-34.—Plotting by tangent offset method from deflection angle smaller than 45°.

MISTAKES IN COMPUTATIONS

An involved computation such as determining an area by DMD's involves a considerable number of calculations which present a large scope for 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



45.334

Figure 5-35.—Plotting by coordinates.

in addition, subtraction, multiplication, and division. The matter of signs is such a fertile field for mistakes that it is a good idea never to write a value without including the sign. The practice of omitting plus signs is a recognized 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 minus as plus.

WRONG COLUMN

A "wrong column" mistake may be an entry made in a wrong column or it may be a reading taken from a wrong column. To avoid such mistakes, make both entries and readings with DELIBERATION; that is, without undue haste and WITH close attention always to which column you should be entering in or reading from.

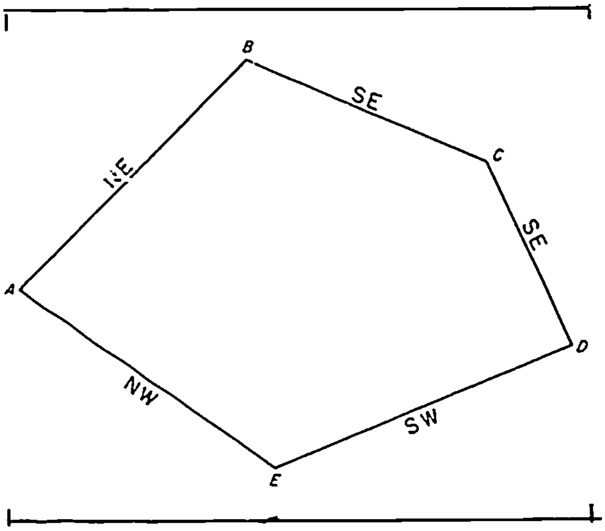
WRONG QUADRANT

When you miscue as to the quadrant in which a line lies, you get a bearing which may have the correct angular value but which has the wrong compass direction. The usual mistake of this kind is to set down the compass direction of the back bearing rather than that of the front bearing.

A common cause of this mistake is viewing the direction of a line from the wrong station. In figure 5-36, the direction of AB is NE, but the direction of BA is SW. AB and BA are, however, the same traverse line. But if you are determining the direction of AB, that direction is NE. If you are determining the direction of BA, that direction is precisely the opposite, or SW. To minimize directional error, arrows may be placed 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 5-36 is N 46° E. Then the azimuth of AB is (measured from N) 46°. BA is the same traverse line, but the azimuth of BA is definitely not 46°, but 226°.



45.335

Figure 5-36.—Proper compass direction of a closed traverse.

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 the computational procedure. If you get an out-sized angular and linear error of closure, check first to ensure that you haven't "dropped" one of the traverse lines.

WRONG DECIMAL PLACE

Wrong placement of a decimal point is a mistake which is particularly liable to occur when you are using the slide rule. Suppose, for example, you are determining an approximate double area by multiplying a DMD of +841.97 ft by a latitude of -153.53 ft by slide rule. A common and usually satisfactory method of placing the decimal point in multiplication is to move the point in one value to the left or right until you get a number between 1 and 10, and then move the decimal point in the other value the same number of places in the opposite direction.

In this case, you might move the decimal point in -153.53 two places to the left, and the one in +841.97 two places to the right. The result would be 84197 x 1.5353. But if you mentally multiply +80,000 x -1 to place the decimal point, you will give your answer by slide rule only 5 places before the decimal, and your slide rule answer will be 12,900, which is a long way off. Actually, you should multiply +80,000 x -1.5, which would give you 6 places before the decimal, for a slide-rule product of -129,000. Actually the product of +841.97 x -153.53 is -129,267.65.

Another method of locating the correct decimal point of results from slide rule computations is by using the general rule in slide rule operations, wherein you keep track of the movement of the slide (left or right). For example, in multiplication, if the slide was moved to the left, you simply take the sum of the number of decimal places in both the multiplicand and the multiplier to the left of their decimal points, and that w.. be the number of decimal places in your answer, you subtract 1, if the slide was moved to the right Anyway, this procedure is described fully in the brochure that comes with any slide rule, if by now, you are not fully aware of this, make arrangements to get one, and study the correct procedure and practice it.

LOCATING MISTAKES

If you can't locate and correct a particular mistake, you must rerun the whole traverse to find it This can often be avoided, however, if you know a few tricks for locating mistakes.

OUT-SIZED ANGULAR ERROR OF CLOSURE

The size of an out-sized angular error of closure may be a clue as to the location of the particular mistake. Suppose, for example, that for a 6-sided closed traverse you got interior angles as follows:

90° 18′
118° 48′
154° 42′
147° 18′
101° 12′
612° 18′

The interior angles in a 6-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 an angle measuring about 107° 42′ was "dropped" somewhere along the line, and you should look for an angle of about this size in the traverse.

Suppose that in a 4-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 4-sided traverse, this difference should be 360°. The large 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.

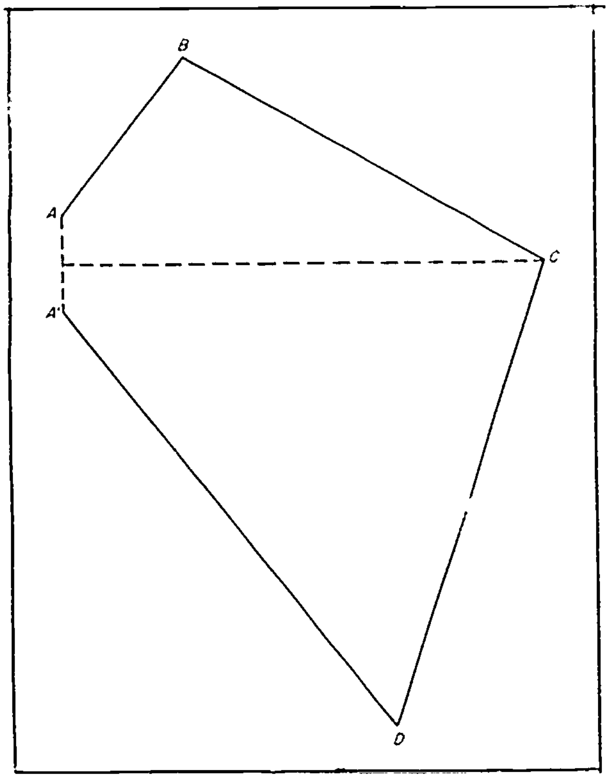
If you haven't dropped an angle, a large interior-angle error of closure probably means a large mistake in measuring, or in recording the measurement of one of the angles. You may be able to locate the doubtful angle by plotting the traverse from the measured angles, drawing in the line of the linear error of closure, and erecting a perpendicular bisector from this line. The bisector may point to the dubious angle.

For example: in figure 5-37, all the bearings are correct except the bearing of CD, which should be S 15° 31′ W for closure, but inadvertently you made a mistake and have S 05° 31′ W. As a result 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 beginning of the traverse. In figure 5-38, the bearings of all lines are correct for closure except that of the initial line AB, which should be N 26° 09′ E for closure but was plotted N 16° 09′ E. A perpendicular from AA′ does not point at any angle in the traverse.

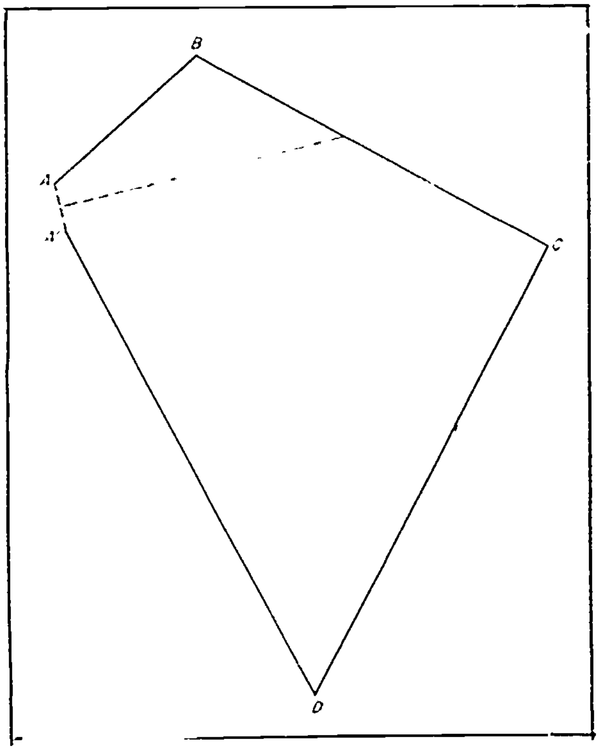
OUT-SIZED LATITUDE AND/OR DEPARTURE ERROR OF CLOSURE

If both the latitudes and departures fail to close by large amounts, there is probably a mistake in an angle or a distance. If one closure is satisfactory and the other isn't, however, it is probably that a computational mistake is the cause of the out-sized closure error.



45.336

Figure 5-37.—Graphical method to locate angular mistake in a closed traverse (see angle C).



45.337

Figure 5-38.—Graphical method to locate angular mistake in a closed traverse (see angle A).

OUT-SIZED LINEAR ERROR OF CLOSURE

If angular error of closure is within allowable limits and there is an out-sized linear error of closure, check for mistakes as follows.

1. Ascertain that you haven't 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 haven't accidentally 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. Ensure 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. Ensure that you copied all bearings and distances correctly.
6. Ensure that you copied all cosines and sines correctly, or set them correctly on the slide rule. If you used the slide rule, ensure that you also set distance values correctly, and placed all decimal points correctly.
7. Ensure 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. It is often the case that the traverse line which contains the mistake is parallel to this line. If there is a line which is thus parallel, start your rerun with this one.

CHAPTER 6

CONSTRUCTION AND LAND SURVEYS

This chapter describes important factors involving route surveys, stakeout and as-built surveys, airfield surveys, waterfront surveys, earthwork computations, and land surveys. Construction surveys were discussed in *Engineering Aid 3&2*, and they are presented here from the viewpoint of the party chief.

Land surveying, as described in this chapter, is intended to acquaint the EA with procedures and legal aspects involved in this special type of survey. Land surveying includes reestablishing original land boundaries, establishing new boundaries, and preparation of legal property descriptions.

Technically speaking. construction surveying is engineering surveying. Its primary concern is the orderly process of obtaining data for the various phases of construction activities. As explained in *Engineering Aid 3 & 2*, construction surveying is divided into (1) the "layout" or "stakeout" survey, and (2) the "as-built" survey. The layout or stakeout survey includes the reconnaissance survey, the preliminary survey and the location survey. The as-built survey consists simply of determining horizontal and vertical locations of points as they were actually constructed.

The objectives of construction (or engineering) surveying include:

1. The obtaining of reconnaissance information and preliminary data required by engineers for selecting suitable routes and sites, and for preparing structural designs.
2. The defining of selected locations by establishing a system of reference points.
3. The guidance of construction forces by setting stakes or otherwise marking lines, grades, and principal points, and by giving technical assistance.
4. The measuring of construction items in place for the purpose of preparing progress reports.
5. The dimensioning of structures for preparation of as-built plans.

There are a great many different types of man-made structures, only a few of the most common can be discussed in this chapter. Those discussed are roads, highways, utilities (that is, sewer, power, gas, water, and fuel lines), airfields and waterfront structures. Building and bridge layout survey has been adequately covered in *Engineering Aid 3 & 2*.

For a structure which follows a specified route, the construction survey must usually be preceded by a ROUTE survey.

ROUTE SURVEYS

The term ROUTE, like many other terms, has more than one meaning, but the first definition given in most dictionaries is: "The course or way which is followed, or which is to be followed." A ROUTE SURVEY, then, is one which deals with the route (that is, the course or way) which a structure will follow.

Of the structures discussed in this section, two follow routes; these two are utilities lines and roads/highways. The route survey for a road or highway differs in important respects from that for a utilities line, and the survey for one type of utilities line may differ considerably from that for another. However, in general it may be said that the principal purposes of any route survey are:

1. To select one or more tentative GENERAL routes for the structure.

2. To gather enough information about the area covered by each general route to make it possible for designers to pinpoint the specific FINAL LOCATION of the route finally selected.

3. To mark this final location.

Consistent with these principal purposes, a route survey is usually broken down into three phases, as follows:

1. The RECONNAISSANCE survey (purpose 1).
2. The PRELIMINARY survey (purpose 2).
3. The FINAL LOCATION survey (purpose 3).

With regard to terminology, the route survey is not a part of, but is preliminary to, the construction survey. However, the two are interconnected to the extent that a discussion of construction surveying would be unintelligible without an understanding of the previous route survey.

The amount of detail involved in a route survey will vary, of course, in accordance with the type of structure and many other circumstances. Obviously, a route survey for a line of telephone or power poles requires less detail than a route survey for a superhighway. However, the primary purpose of any route survey is to select the route that will satisfy the requirements of the project with maximum economy and advantage.

HIGHWAY ROUTE SURVEY

Highway route surveys for construction involve considerations of curvatures, gradients, drainage, soil conditions, sight distance, safety, width, and roadside safeguards and surfaces to withstand the impact of traffic.

Reconnaissance Survey

The minimum information with which a highway reconnaissance party enters the field is the specified CONTROL POINTS–that is, the points which must be connected by the highway. If the highway is to follow the route of an already existing road, little–perhaps no–reconnaissance will be necessary. For a new highway, the entire area between the control points must be examined for possible routes.

A reconnaissance party usually functions under the direction of an officer acting as LOCATION ENGINEER; however, the enlisted party chief, in order to assist the location engineer intelligently, must know something about the general principles and practices of reconnaissance.

The first requirement is a mental picture of the general landscape of the area. Here, maps are of great importance especially contour maps or composite aerial photographs (mosaic) of the surrounding area. After a thorough study of all available maps, the reconnaissance party should go over the ground–both by plane and by ground travel, if both are possible. The ground party will examine the natural features of the proposed route, see if the existing soil is stable for a normal roadway, and take note of approximate locations of available sources of construction materials (quarry sites and borrow pits) in the immediate vicinity.

Enough approximate elevations and distances are obtained to convey an idea of the grading, earthwork,. and other construction problems along the different routes. The locations and descriptions of streams, ridges, existing man-made features, and other obstacles are set down, as well as the locations of any objects which may offer advantages, such as existing bridges or low points on ridges.

Approximate methods are used for distance, direction, and elevation measurements. Distances may be scaled from available maps or, in the absence of maps, measured approximately by one of the approximate methods described in *Engineering Aid 3 & 2.* Elevations may be taken from contour maps or, in the absence of these, measured by altimeter or computed from vertical angles measured by clinometer. Directions (horizontal angles) may be measured by hand compass.

The reconnaissance report contains a summary of the information gathered. It usually also includes a description of alternative routes considered feasible by the location engineer, and a discussion of the controlling elements, economic considerations, and recommendations pertaining to each alternative route. All available maps, sketches and aerial photographs applying to the area are submitted with the report.

Preliminary Survey

A study of the reconnaissance report may indicate that only one of the suggested alternative routes is feasible, or the report may itself indicate only a single feasible route. If this is the case, the preliminary survey will be omitted and the next step will be the final location survey.

If alternatives exist, a narrow strip along each alternative route is surveyed and a PRELIMINARY MAP and a PROFILE of the strip are prepared. A transit party runs an open traverse approximately along the middle of the strip, setting stakes at every full station and setting hubs and stakes wherever the traverse changes direction. A level party follows the transit party, establishing bench marks and taking profile elevations along the traverse. The level party may also take cross-section elevation, or these may be left for the topographic party.

Finally, a topographic survey party locates all relevant details on the strip, such as buildings, property lines, streams, fences, bridges, and any other features, either natural or artificial, which may influence the selection of the final location.

If the route runs through wooded country, the traverse must usually be run by transit-tape, with a separate party running the levels as described. However, in open country all three preliminary survey operations (running line, running levels, and locating details) may be done at the same time, by a single party using transit-stadia. The party, set up on the traverse, first measures the horizontal angles, vertical angles, and stadia distances applying to the traverse ahead, then takes side shots applying to the cross-section elevations and details.

As the preliminary survey proceeds, each day's work is plotted on a preliminary PROFILE and a preliminary MAP. The profile shows the plotted elevations of existing ground along the traverse line, the map shows the topography and other detail along the line, including contours. A commonly used scale for highway preliminary profiles is horizontal 1 in. = 100 ft, vertical 1 in. = 10 ft. The contour interval for a highway preliminary map varies according to the slope or irregularity of the ground, the average for ordinary country is 5 ft, but in level country it may be 2 ft or even 1 ft, and in rough country may be 10 ft or more.

Final Location Survey

From the preliminary survey data, one of the alternative routes suggested by reconnaissance is selected and the others are eliminated. Along the selected route, a tentative location for the highway centerline (including curves) is chosen. This location is still tentative, because circumstances which develop in the course of the final location survey may require departures. Usually the tentative horizontal location is drawn in on the preliminary map, and the tentative vertical location on the preliminary profile. In this case these are familiarly called the PAPER locations.

A number of considerations influence the selection of the horizontal location and grade of a highway. Some of the most important are.

1. Keeping changes in direction at a minimum, and making unavoidable changes in direction as gradual as possible.
2. Keeping changes in elevation at a minimum, and making unavoidable changes in elevation as gradual as possible.
3. Making total volumes of cut and fill as small as possible.
4. Minimizing haul expense by making the distance from borrow pit to cut in each case as small as possible and using as little borrow as possible. An attempt is made to set line and grade in a manner which will best facilitate the filling of hollows with fill taken from nearby high points along the traverse.
5. Providing for adequate drainage slopes.

The first task of the final location survey field party might be described as the task of adjusting the preliminary traverse to fit the requirements of the paper location traverse. The paper location traverse may, for parts of its length, coincide with the preliminary traverse, for these sections, no adjustment is necessary. For those sections along which the two do not coincide, the field party has the problem of locating, on the ground, the paper location traverse so that its ground location will bear the same relation to that of the preliminary traverse that the two bear to each other on the preliminary map.

This relation may be determined by any of the methods of tying in points described in *Engineering Aid 3 & 2*. Consider figure 6-1, for example. In this figure the line through stations C, D, and E represents the preliminary traverse. The paper location traverse coincides with the preliminary traverse to station C′, but then runs S 73°30′ E, 580.36 ft, to station D′, and thence to rejoin the preliminary traverse at station E.

One way of locating station D′ on the ground would be by perpendicular offset from the preliminary traverse, as indicated by the dotted line SD′. A right triangle solution will locate S on the preliminary traverse, and determine the length of SD′. The bearings of C′S and C′D indicate that angle A must measure 29°42′. The length of C′S amounts to 580.36 cos 29°42′, or 580.36(0.868632), or 504.12 ft. Therefore, point S will be located 504.12 ft from station C′, or at station 18 + 29.16.

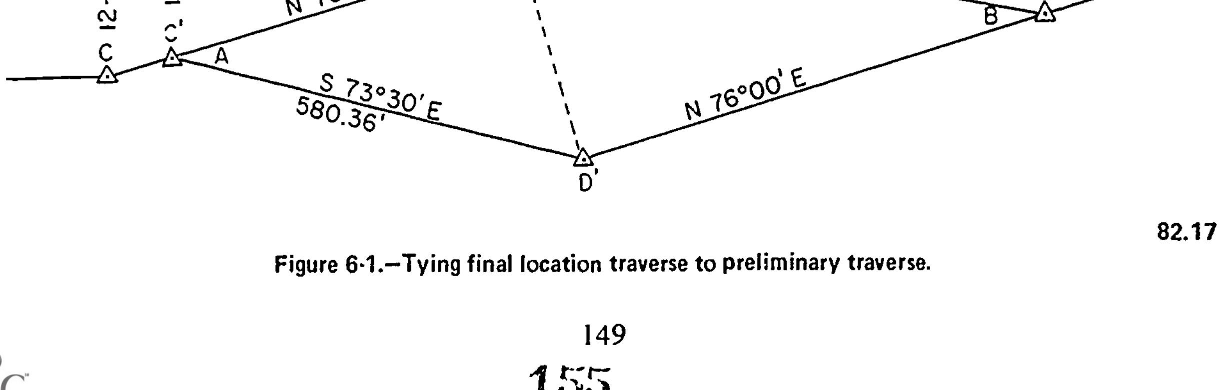
The length of SD′ amounts to 580.36 sin 29°42′, or 580.36(0.495459), or 287.54 ft. Therefore, to locate station D′ you would set up a transit at station 18 + 29.16 on the preliminary traverse, turn 90°, and lay off 287.54 ft from S.

Another way to locate station D′ would be by triangular intersection from stations C′ and E. The bearings indicate that the size of angle B is 26°54′. Angle A measures 29°42′. Set one transit up at C′, backsight on D, and turn 29°42′ to the right. Set up another transit at E, backsight on D, and turn 26°54′ to the left. A range pole sighted through both telescopes will be located on station D′. Measure the distance C′D′ to check if it measures 580.36 ft–the paper distance.

Stakes are usually set at all full stations, and at all P.I.'s, P.C.'s, and P.T.'s. In general, stakes are set at 50-ft stations on horizontal curves. Where the location traverse diverges from the preliminary traverse, profile levels and cross-sections for this portion are taken. Then, a corrected location plan is prepared; in most cases this correction is just integrated to the existing plan. As a result of a study of these departures from the preliminary traverse, further adjustments in line or grade may be ordered. When these have been made in the field, and on the location plan and profile, the final location survey is completed.

OTHER ROUTE SURVEYS

Other structures which follow routes are utilities lines, which may be broadly divided into OVERHEAD power and communications lines and UNDERGROUND power/communications lines; sewerlines; and water, gas, and fuel lines. The character of the route survey for a utility will vary, of course, with the circumstances. A sanitary sewer, for example, will follow the streets on which the buildings it serves are



82.17

Figure 6-1.—Tying final location traverse to preliminary traverse.

located, consequently, reconnaissance and preliminary surveys are seldom necessary for one of these. The same applies, in general, to the DISTRIBUTION part of a power, gas, water, or fuel line. The location of one of these is controlled by the locations of the buildings it serves.

If utilities lines already exist in an area, they are shown on UTILITIES MAPS. A separate map is generally used to show the principal features of each utility. Small-scale maps show locations, materials, pipe sizes, and other information relating to the main transmission, collection, and distribution systems. Minor construction details and service connections are shown on larger-scale detail plans.

A utilities project often involves extending an existing line -as, for example, tying in a line from new housing to an existing sanitary sewer. The first requirement in a case of this kind is a study of the existing utilities maps.

ABOVEGROUND UTILITIES ROUTE SURVEYS

Aboveground utilities are usually electrical power or communications lines, strung on poles or towers. The location of the DISTRIBUTION (service) part of one of these is usually controlled by the locations of the buildings it serves meaning that the service or distribution line will usually follow the streets on which the buildings are located. For the TRANSMISSION part, however, judgment in the selection of a route is usually required. By transmission part we mean that part of a line which carries (for example) high-voltage electrical power from the power plant to points from which the power is distributed to consumer outlets.

The route survey for a power transmission line, then, may be divided, like that for a highway, into reconnaissance, preliminary, and final location surveys. Controlling considerations are, of course, different from those for a highway. For a tower line, construction economy requires that changes in direction be kept at a minimum, for the reason that a tower located where a line changes direction must stand a higher stress than one located in a straight-line part of the line. In general, tower construction in level country is cheaper than construction in broken country, however, the line may be run over broken country to minimize changes in direction, or to make it shorter, or to follow a line where the cost of obtaining right-of-way is cheap. To facilitate access for construction and future maintenance, it is desirable that lines be located adjacent to existing roads.

When running the preliminary survey, incorporate all pertinent topographic information into the field notes. Note particularly any existing overhead or subsurface lines and indicate whether they are power or communications lines. Locate such features as marshes, streams, forests, roads, railways, power plants, laboratories, and adjacent military camps or bases.

Pole Line Surveys

When the route has been selected on the basis of the reconnaissance data, a plan and profile are plotted. The plan shows the route the line will follow and the significant topography adjacent thereto. The profile shows the ground elevation along the line and the top elevations of the poles. These are generally set in accordance with a specified minimum allowable clearance between the ground line and the top of a pole. In open country the minimum clearance for a line crossing roads, railroads, or waterways is usually 14 ft, in built-up country it is usually 18 ft. Minimum allowable clearance between two crossing powerlines is usually 4 ft, for two communications lines it is usually 2 ft apart.

When a power or communication line crosses a highway or railroad, poles adjacent to the highway or road are usually required to be set a minimum of 12 ft back from the highway shoulders or railroad rails.

Poles are numbered consecutively in accordance with a specified theoretical span between adjacent poles -regardless of whether or not there is actually a pole set at each of these intervals. Theoretically, the spacing is usually 150 ft. The line might cross a stream wide enough to cause the span between adjacent poles to be say 400 ft. Suppose the pole number on one side of the stream was 65. The next adjacent pole on the other side would be, not #66, but #68.

Each pole location 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. This is usually simply designated as a plus, as: +25 ft.

Tower Line Surveys

High voltage lines are often supported by TOWERS, a tower being a broad-based steel structure 35 ft or more in height. When a change in direction in a tower line is unavoidable, it is made gradually, in as small angular increments as possible. Suppose, for example, a change in direction of 90° was required. Instead of an abrupt change in direction of 90°, towers would be set so as to cause the line to follow a gradual curve in a succession of chords around an arc of 90°.

Each tower in a curve of this kind must be placed at an angle which will balance the lateral pull of the cables in and out of the tower. This is done by locating the centerline of the tower so as to bisect the angle between the lines as shown in figure 6-2.

BELOWGROUND UTILITIES ROUTE SURVEYS

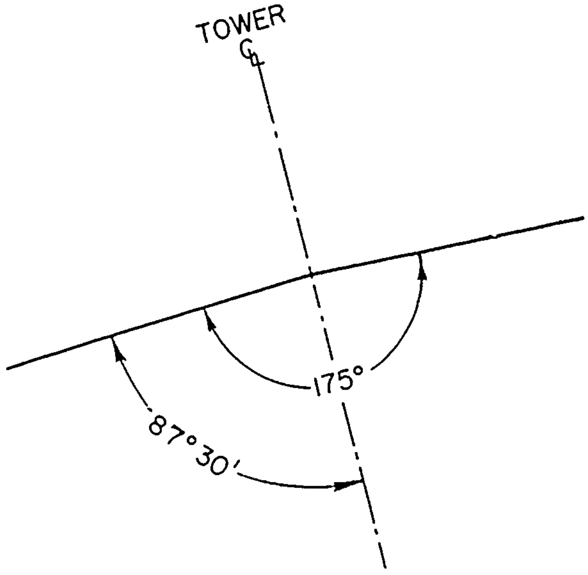
When man-made structures are erected in a certain area, it is necessary to plan, design, and construct an adequate drainage system. Generally, an underground drainage system is the most desirable means in removing surface water effectively from operating areas. An open drainage system, like a ditch, 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 sufficiently 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 what might be called the mechanics of water drainage from the earth's surface.



82.18

Figure 6-2.—Balancing the stresses on a tower.

When rainwater falls on the earth's surface, some of it is absorbed in the ground. The amount thus 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, on the other hand, absorption will be negligible.

Of the water which is not absorbed in the ground some will evaporate, and some, absorbed through the roots and exuded onto the leaves of plants. will additionally dissipate through a process called TRANSPIRATION.

The water which 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, will make its way (i.e. "run-off") through natural channels to the lowest point it can attain. To put this in terms of a general scientific principle, water will, whenever it can, seek its own level. The general, final level which unimpeded water on the earth's surface will seek 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 land-locked 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 gulley, 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 other inland body of water.

The natural channels through which this runoff passes will generally contain and dispose of all the runoff in normal weather circumstances. However, it is commonly the case that during the winter in the high mountains runoff is interrupted by snow conditions—that is, instead of running off, the potential runoff accumulates in the shape of snow. When this accumulated mass melts in the spring, the runoff often attains proportions which 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, much water which was previously absorbed will now present drainage problems.

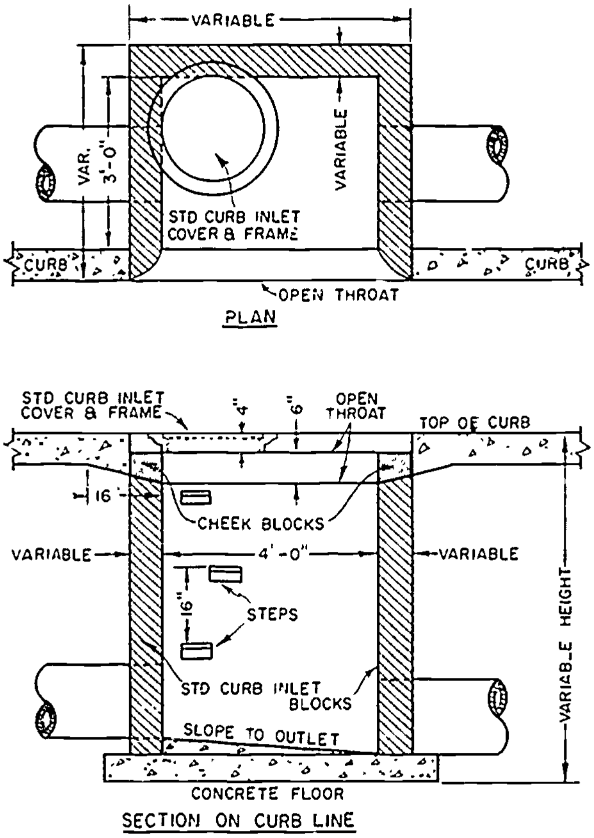
In short, when man-made structures such as bridges, buildings, etc. are erected in an area, it is usually necessary to design and construct an artificial drainage system to offset the extent to which the natural drainage system has been upset. Storm sewers are usually the primary feature of an artificial drainage system; however, there are other features, such as drainage DITCHES. Both storm sewers and ditches carry surface run off. 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 below the surface.

Similarly it might be said that 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.

Parts of an Artificial Drainage System

A surface drainage system consists principally of DITCHES, which 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.

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 which admits the surface water runoff, and an inner chamber called a BOX (sometimes a CATCH BASIN). A box is usually rectangular, but may be cylindrical. An inlet with surface opening in the side of a curb is called a CURB inlet, a working drawing of a curb inlet is shown in figure 6-3. An inlet with a horizontal surface opening covered by a grating is called a GRATE



82.19

Figure 6-3.—Working drawing for typical curb inlet.

(sometimes a DROP) inlet. A general term applied in some areas to an inlet which is neither a curb nor a grate inlet is YARD inlet.

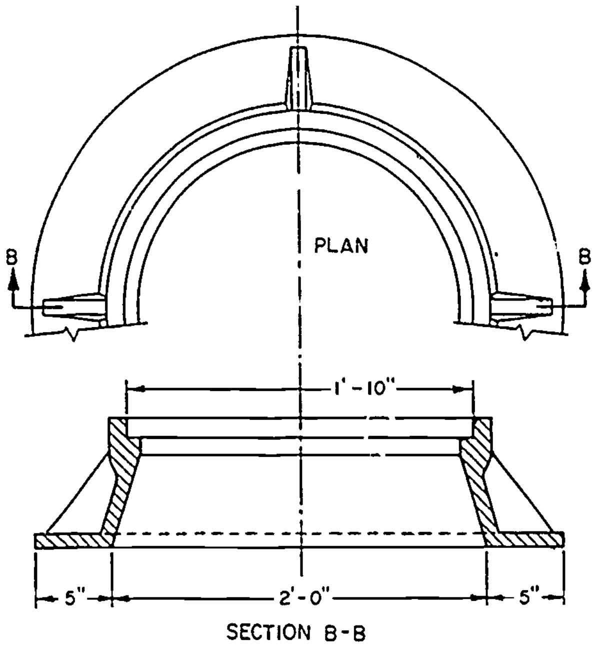
Technically speaking, the term "storm sewer" applies to the pipeline; the inlets are called APPURTENANCES. There are other appurtenances, the most common of which are MANHOLES and JUNCTION BOXES. A manhole is a box which is installed, of necessity, at a point where the trunk changes direction, gradient, 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; that on a junction box a junction box opening. Distances between manholes are normally 300 ft, but this distance may be extended to a maximum 500 ft if the specification requires it.

The structure at an access opening consists of the manhole (or curb inlet, or junction box) COVER and a supporting metal casting called the FRAME. A frame for a circular cover is shown in figure 6-4. 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 may be constructed of special concrete masonry units or of cast-in-place concrete. The bottom consists of a formed slab, sloped in the 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.

Drainage Design

A complete description of the many problems involved in drainage design cannot be given in this course. We can only discuss enough of the



82.20
Figure 6-4.—Frame for an access opening.

highlights to make it possible for you, as field party chief, to assist the design officer intelligently. In drainage design, the topography of the whole area concerned is closely studied. If satisfactory topographic maps do not exist, such must be made. Obviously, of course, both the existing terrain and the terrain as it will exist after construction are considered.

The first consideration with regard to the drainage problem at a particular point is the maximum quantity of runoff which may be expected at that point. This maximum quantity is familiarly called the "Q". The point in question is called the POINT OF CONCENTRATION. A study of the map (particularly of the relief) determines the limits of the CONTRIBUTING AREA for that point—that is, the boundaries of the area around the point from which water will drain toward the point of concentration. Next, the runoff for this area is determined. The quantity of this runoff will depend upon a number of factors, one of which is the INTENSITY of the rainfall in the contributing area UNDER DESIGN CONDITIONS.

The term "intensity" signifies a RATE of rainfall: a 10-minute cloudburst which dumps 1 inch of water on an area means a rate of 6 inches per hour, there being six 10-minute intervals in an hour. The numerical value of intensity for a given contributing area is affected by (1) the duration of the storm, and (2) the design frequency of the storm. The duration of the storm is presumed to be equal to the length of time it takes a drop of water at the outermost limit of the contributing area to reach the point of concentration; it is assumed that at this time the entire area is contributing runoff to the point of concentration. Design frequency refers to how bad a storm the system can carry without flooding—for example, a storm that can be expected only once in 2 years, or in 5 years, or in 10 years. It is seldom economical to design for the worst possible storm; the design frequency selected will vary according to the extent to which occasional flooding of the system will cause damage. Obviously, occasional flooding of the ground floor of a shop containing valuable articles would be more serious than occasional flooding of, say, a tennis court.

The system, then, may be designed for the type of storm which occurs only every 2 years, or every 10 years—this is familiarly called "designing for a 2-year storm" or "for a 10-year storm." If weather records exist, design intensity can be based on these. If they don't, estimates must be based on the experience of inhabitants, on judgment, or on both.

Now, the product of the design intensity times the area (in acres) of the contributing area gives the amount of water which would accumulate as runoff at the point of concentration if all this water ran off. However, some of the water will be absorbed, some will evaporate, and some will dissipate through transpiration. Therefore, the product of the contributing area (A), times the design intensity (i), is reduced by multiplying by a factor called the RUNOFF COEFFICIENT (C). The result is the amount of the product of A times i which will remain as runoff after absorption, evaporation, and transpiration. In general, to get the runoff coefficient you refer to tables similar to the one shown table 6-1. Such tables are based upon studies made in the past with regard to the perviousness or imperviousness of various types of surfaces, and apply the table values to estimates of the proportion of pervious to impervious areas in the contributing area.

Table 6-1.—Surface Runoff Factors

Types of surface	*Coefficients*
Pavements (concrete or asphalt)	0.70 to 0.95.
Gravel or macadam pavements	0.35 to 0.70.
Impervious soils [1]	0.40 to 0.65.
Impervious soils, with turf [1]	0.30 to 0.55.
Slightly pervious soils [1]	0.15 to 0.40.
Pervious soils [1]	0.01 to 0.10.
Wooded areas depending on surface slope and soil cover	0.01 to 0.20.

[1] For slopes from 1 to 2 percent.

Note. The figures given are for comparatively level ground. For slopes greater than 1 in 50 (2%) the coefficient should be increased by 0.2 for every 2 percent of slope, but coefficient cannot exceed 1.0.

82.153

In sum, then, the Q (quantity of runoff, in cu ft per second, accumulating at the point of concentration during the design storm) is determined from the formula ACi, A being the area of the contributing area in acres, C being the runoff coefficient expressed as a percentage (as, 0.40), and i being the intensity of rainfall, in inches per hour, in the contributing area during the design storm.

You may note that in this formula acres is multiplied times inches per hour and the answer is reported in cubic feet per second—an apparent inconsistency in units. The use of these units is possible because the flow of 1 inch of water from 1 acre in 1 hour is almost equal in numerical value to the flow of 1 cubic foot of water in 1 second. This fact may be demonstrated by assuming an area of 1 acre, a coefficient of runoff of 1, and a rainfall intensity of 1 inch per hour.

$$Q = ACi = 1 \text{ acre} \times 1 \times \frac{1 \text{ inch}}{1 \text{ hour}}$$

$$Q = \frac{43560 \text{ sq ft} \times 1/12 \text{ foot}}{3600 \text{ seconds}} = \frac{3630 \text{ cu ft}}{3600 \text{ seconds}}$$

$$Q = 1.008 \text{ cubic feet per second}$$

Generally, the first point of concentration is the highest point on or near the structure where runoff will accumulate, under design conditions, to an extent requiring artificial drainage. Therefore, the system will begin at this point. The next point of concentration will be the next adjacent point where runoff thus accumulates. Between the first and second points the system will be designed to carry the Q which accumulates at the first point. Between the second and the third point, it must be designed to carry the Q which accumulates at the first two points. Thus, as the system proceeds along its course, the Q it must be designed to carry increases, which means that the carrying capacity of the system must progressively increase as well. The nature of the structure may require branching trunks, converging at various points; in a case of this kind, of course, the pipe beyond a junction box must be designed to carry the Q brought into the junction box by the contributing trunks above it.

The maximum quantity of water which will flow at a given rate through a drain pipe is controlled by (1) the size of the pipe, (2) the gradient (slope) of the pipe, and (3) the classification or type of the pipe. Item 3 is principally a matter of friction; everything else being equal, water will flow more rapidly through smooth-walled concrete pipe (for example) than it will through corrugated metal pipe. If the system contains the same type of pipe throughout, the roughness coefficient will remain the same for all sections. This coefficient can be found in tables for pipe made of all the commonly used materials.

Drain water will flow faster through a steeply sloped pipe than it will through a pipe that is nearly horizontal. Therefore, when Q increases to the point where the flow capacity of the system must be increased, this may be accomplished by increasing the slope. The extent to which this can be done, however, depends on the circumstances. If the ground is level and the line is long, a large slope percentage will soon carry the pipe too far down into the ground. But if the ground itself slopes downward, the pipe can be carried indefinitely at the same downslope.

The flow capacity of pipe increases with the inside diameter of the pipe. Therefore, the flow capacity may also be increased by using larger pipe. If the alternative exists of increasing either the slope or the diameter of the pipe, the alternative selected will be, of course, the one which is cheaper in view of all the long-run circumstances.

All of these considerations influence the selection of pipe sizes, gradients, and elevations. The route followed by the trunk line is also affected. Normally this route would follow, more or less, the course from one point of concentration to the next. However, it is often necessary or desirable to diverge from this route, to avoid structures, to take advantage of sloping ground, to avoid areas of difficult excavation, or for some other reason. When this is the case, runoff from inlets not located over the trunk is carried to the trunk by LATERAL or BRANCH pipelines. A common use of laterals or branches is to carry runoff from an inlet on one side of a highway to a trunk located along the opposite side.

Design Computations

The flow capacity, in cu ft per second, of a given section of pipeline is determined from the formula aV, a being the section area in sq ft of the flowing stream and V the velocity of speed of flow in fps. If it is assumed that the pipe will flow full, a is the section area inside the pipe wall. For a 24-in. pipe a is π times R^2, or π times 1^2, or 3.14 sq. ft.

To determine V you use another formula, as follows:

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

The symbol n in this formula is the roughness coefficient, usually obtained from tables based on the character and size of the pipe. R (which stands for HYDRAULIC RADIUS) is determined by dividing a by the length of the WETTED PERIMETER. The wetted perimeter is the portion of the inner circumference of the pipe which is under water when the stream is flowing at design maximum. If the pipe is presumed to flow full, the wetted perimeter is equal to the circumference. Therefore, for a 24-in. pipe, flowing full, the wetted perimeter is 2 ft $\times\ \pi$, or 6.28 ft. R is $\frac{a}{6.28}$ or $\frac{3.14 \text{ sq ft.}}{6.28 \text{ ft}}$, or 0.50 ft. R to the 2/3 power means the cube root of R^2, or the cube root of 0.25, or 0.63.

S in the formula means the gradient of the pipe IN FEET PER FOOT. A 2 percent gradient means a drop of 2 ft in 100 ft, which in turn means a drop of 0.02 ft in 1 ft. S to the 1/2 power means the square root of S, which in this case is the square root of 0.02, or 0.14.

Assume that the roughness coefficient (n) is 0.013. Substituting the known values in the formula for V (velocity), we have.

$$V = \frac{1.486}{0.013} \times 0.63 \times 0.14$$

If you work this out, you will find that V comes to 10.01 fps. The flow capacity, then, is a x V, or 3.14 sq ft x 10.01 fps, or 31.43 cfps.

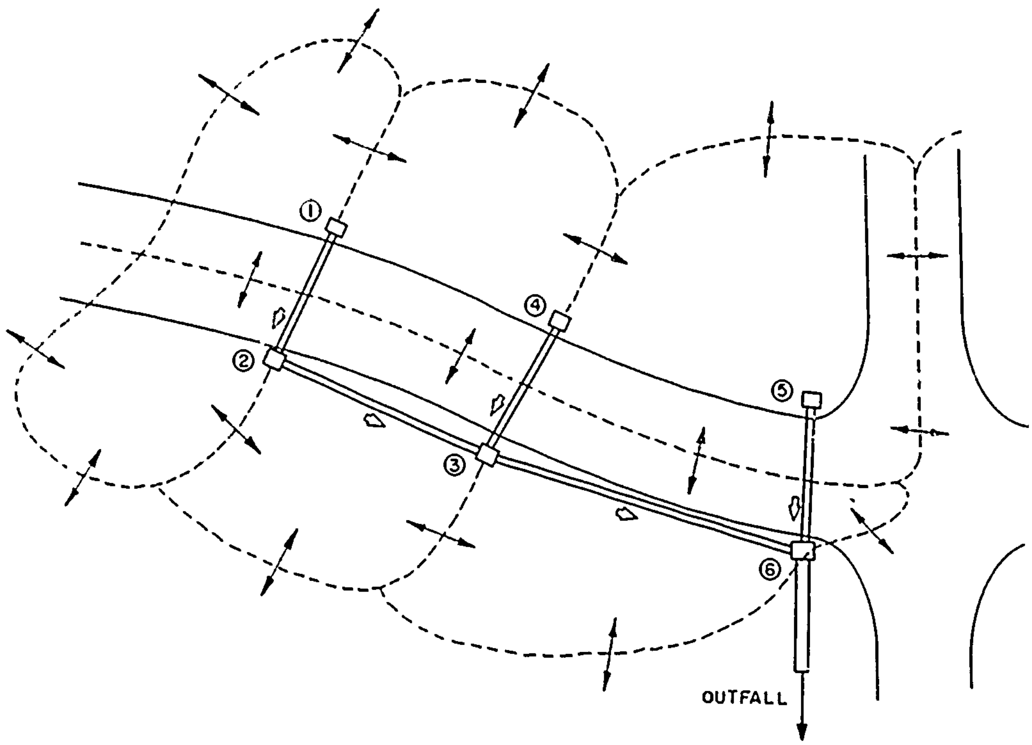
This is the flow capacity of a section in which the gradient and the size of the pipe are given. The design problem, however, is more likely to involve determining the gradient and size of the pipe for handling a predetermined quantity of runoff. One way of doing this is by first determining the minimum slopes required for pipe through a range of sizes, as follows.

Figure 6-5 shows a flow diagram of a storm sewerline running along a highway. The trunk begins at inlet 2 and runs through inlets 3 and 6 to the outfall. Inlets 4 and 5 admit runoff to laterals connected to the boxes at 3 and 6.

The dotted lines show the limits of the contributing areas for each of the inlets. Suppose, now, that the Q for each area, under design conditions, is as follows:

Inlet No.	Q (cfs)
1	4.5
2	3.6
3	3.0
4	2.7
5	3.0
6	3.0

The total Q at the outfall is the sum of these, or 19.8 cfs. The next problem is to determine the Q which must be handled by each of the separate sections (called LINES) in the system. The line from 1-2 will handle only the Q from contributing area 1, or 4.5 cfs. The line from 2-3, however, will carry the sum of the Q's from areas 1 and 2, or 4.5 plus 3.6, or 8.1 cfs. The line from 4-3 will carry only the Q from area 4,



82.21

Figure 6-5.—Flow diagram inlet of a storm sewerline system.

or 2.7 cfs. But the line 3-6 will carry the Q's from areas 1, 2, 3, and 4, or 4.5 + 3.6 + 3.0 + 2.7, or 13.8 cfs. The line 5-6 will carry only the Q from area 5, or 3.0 cfs.

If you add these together, you will find that the sum is again 19.8 cfs equal, as it should be, to the previously determined total Q at the outfall.

The next step is to determine, for each line, the MINIMUM slope required for pipe ranging through all the sizes considered feasible. Drain pipe is made in sizes from 4 in. to about 108 in. in diameter. As a rule the use of pipe smaller than a certain minimum size (usually about 12- or 15-in.) is not permitted for storm sewers, because of the possibility of clogging with debris. Also, for pipe of a given size and character, there is usually a maximum permissible velocity of flow, beyond which the pipe would be seriously eroded by the velocity of the flowing stream. This means that for a pipe of a given size and character, the maximum feasible slope is the slope which permits the maximum permissible velocity of flow.

The largest pipe to be considered would be the largest required to carry the total Q at the outfall at the minimum permissible slope. In working these design calculations, engineers use various types of circular slide-rule or graphic calculators called NOMOGRAPHS, from which formula solutions may be obtained by inspection. If you enter one of these with the roughness coefficient, the size of the pipe, and the Q for the line, you can determine the minimum slope for that Q, size of pipe, and roughness coefficient by inspection.

Assuming now a roughness coefficient of 0.013 and a total Q at the outfall of 19.8 cfs, then a nomograph calculation indicates that a 27-in. pipe will carry this Q at a slope of 0.41 percent. Assuming the minimum specified slope to be 0.5 percent, then 27-in. will be adequate for this minimum specified slope, and is the largest pipe that needs to be considered. Assume that the smallest permissible pipe is 15-in. Pipe in ranges from 15-in. to about 30-in. is usually available in sizes 3-in. apart that is, 15-in., 18-in., 21-in., and so on. Beyond 30-in. the sizes usually increase in 6-in. increments.

We are going to determine the minimum slopes required for pipe from 15-in. to 27-in. for each of the lines in the system. This data is entered in a form as follows.

		Minimum slope (%) for Following Sizes				
Line	Q (cfs)	15″	18″	21″	24″	27″
1-2	4.5	0.5	--	--	--	-
2-3	8.1	1.6	0.6	0.26	-	-
4-3	2.7	0.17	--	-	—	—
3-6	13.8	4.6	1.7	0.76	0.38	—
5-6	3.0	0.22		—	-	-
6 Out	19.8	9.3	3.5	1.6	0.77	0.41

This tabulation indicates that, for the Q for line 1-2, a 15-in. pipe at the flattest permissible slope is sufficiently large. Therefore, there is no point in calculating the minimum slope for larger pipe for this line.

For line 2-3, on the other hand, a 15-in. pipe would have to be placed at a slope of at least 1.6 percent. If the character of the ground were such as to make this too steep a slope (taking the pipe too far down in the ground), it might be more economical to use 18-in. pipe, which would carry the Q at a slope of only 0.6 percent. In deciding between these alternatives, the excavating cost would be weighed against the increase in price for larger pipe. There are similar alternatives for line 3-6 and for the outfall line.

In general, a design engineer determines by studying the profile, what the maximum possible economically feasible slope is for each line in the system. For a long line running in relatively level ground, the slope is obviously more limited that it is for a line running in ground which slopes in the direction of the line. However, even when the ground slopes radically downward, there is a limit beyond which the pipe may not be economically sloped. A slope of more than this causes the water to attain a velocity which rapidly erodes concrete pipe. When the engineer has determined the maximum slope which is economically feasible for each line, he selects from the table the smallest pipe capable of handling the Q for that line at that slope.

For the determination of required cross-sectional areas and capacities of culverts for most Theater of Operations roads and outlying areas of an airfield, where accurate computation of runoff is impracticable, Talbot's formula can be used. This formula is an approximate method for computing the cross-sectional area of the proposed pipe or culvert. It is stated as:

$$A = C\sqrt[4]{D^3}$$

where. A = area of waterway opening in square feet

C = a coefficient that depends upon the slope, shape, and character of area to be drained

D = drainage area in acres.

This formula is recommended only for small structures requiring a waterway opening not greater than 400 sq ft. In addition, the formula is intended only for a rainfall intensity of 4 inches per hour for 1 hour or less. For locations having greater intensities than this, the required opening may be computed by dividing the area of the drainage structure obtained from the formula by 4, then the result is multiplied by the intensity of rainfall to be expected at the given location. The key to the use of the formula is the judgment exercised by the engineer in the choice of a value for the coefficient "C". Normal values for C are as follows:

C = 0.2 flat areas not affected by cumulated snow, and where the length of the valley drained is several times the width.

C = 0.35 for gently rolling farmland, where the length of the valley is about 3 or 4 times the width.

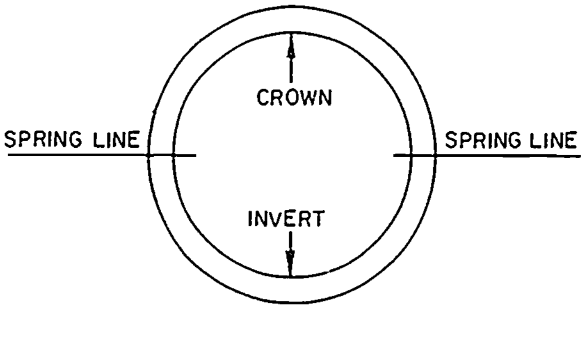
C = 0.7 for rough hilly areas having moderate slopes.

C = 1.0 for steep barren areas having abrupt slopes, and for moderately mountainous areas.

The value of the coefficient C is influenced by the shape of the drainage area, the side slopes, the length of the valleys, and the character and culture of the ground. All of these factors affect the proportion of runoff and its time of concentration at the culvert. Therefore, the engineer must adjust the value of C to suit each case. The value of C should be increased as the lengths of the valleys decrease in proportion to their widths, and vice versa. As side slopes steepen, C also should increase. Heavy shrub growth would decrease the value of C over cultivated farmland, whereas rocky or barren slopes would increase the value of C. Predominately sandy or gravelly soils tend to decrease C, whereas heavy clay soils tend to increase C. A value of 1.0 is satisfactory for moderately mountainous terrain, or for reasonably steep barren areas with abrupt slopes up to 10 percent. The formula should not be used for precipitous rocky mountain areas where C would be greater than 1.0. The drainage areas may be obtained from the map of the area involved by planimeter, or by dividing the area into several triangles and/or rectangles.

Transition Loss

As shown in figure 6-6, the line connecting the lowest inside points on a pipe in place is called the INVERT; that connecting the highest inside points is called the CROWN. The SPRING LINE lies halfway between the invert and the crown.



82.22

Figure 6-6.—Cross-section view of a storm sewer pipe.

A point where a sewerline changes pipe size, direction, or gradient is called a TRANSITION. A point where two or more lines converge is also a transition. Now, at any transition point there is a loss of energy in the stream flow. Turbulence in the box caused by a change in direction (either horizontal or vertical) and by the box structure itself cuts down the rate of flow, to the extent that the outflowing pipe will not flow to design capacity.

This type of transition loss is estimated, as well as it can be, and is usually taken into account in the design of the outflowing line. Another type of transition loss is easier to determine. Figure 6-7 illustrates this type. This figure shows a section through a manhole. Notice first that the pipe is presumed to run to the manhole centerline, it is actually, of course, cut off in line with the inner wall of the box.

The specified elevation for a pipe is the elevation of the invert, and the elevation at a box means the invert elevation AT THE CENTERLINE OF THE BOX. Now, at the manhole shown in figure 6-7, the inflowing and outflowing pipes are the same size (18-in.). However, because of an increase in slope in the outflowing pipe, that pipe, flowing full, allows the stream to flow at a higher velocity. You can see that V for the inflowing pipe is 5 fps, while V for the outflowing pipe is 8 fps.

If the stream, when it reaches the outflowing pipe, is still flowing at only 5 fps, the outflowing pipe will not flow full. Therefore, the box is designed to step up the flow to the velocity of which the outflowing pipe is capable. This is accomplished by DROPPING THE INVERTS—that is, by placing the invert out at a lower elevation than that of the invert in.

The amount of the drop can be calculated, by determining the difference in the respective VELOCITY HEADS of the two pipes. Velocity head can be determined from the formula $\frac{V^2}{2g}$. V in this formula is the velocity of which the pipe, flowing full, is capable; this is determined by formula as previously explained, or from a nomograph. The symbol g in the formula means the force of gravity, which is 32 ft/sec^2.

For the pipes shown in figure 6-7 then, the velocity heads are as follows:

Inflowing pipe $= \frac{25}{64} = 0.39$ ft.

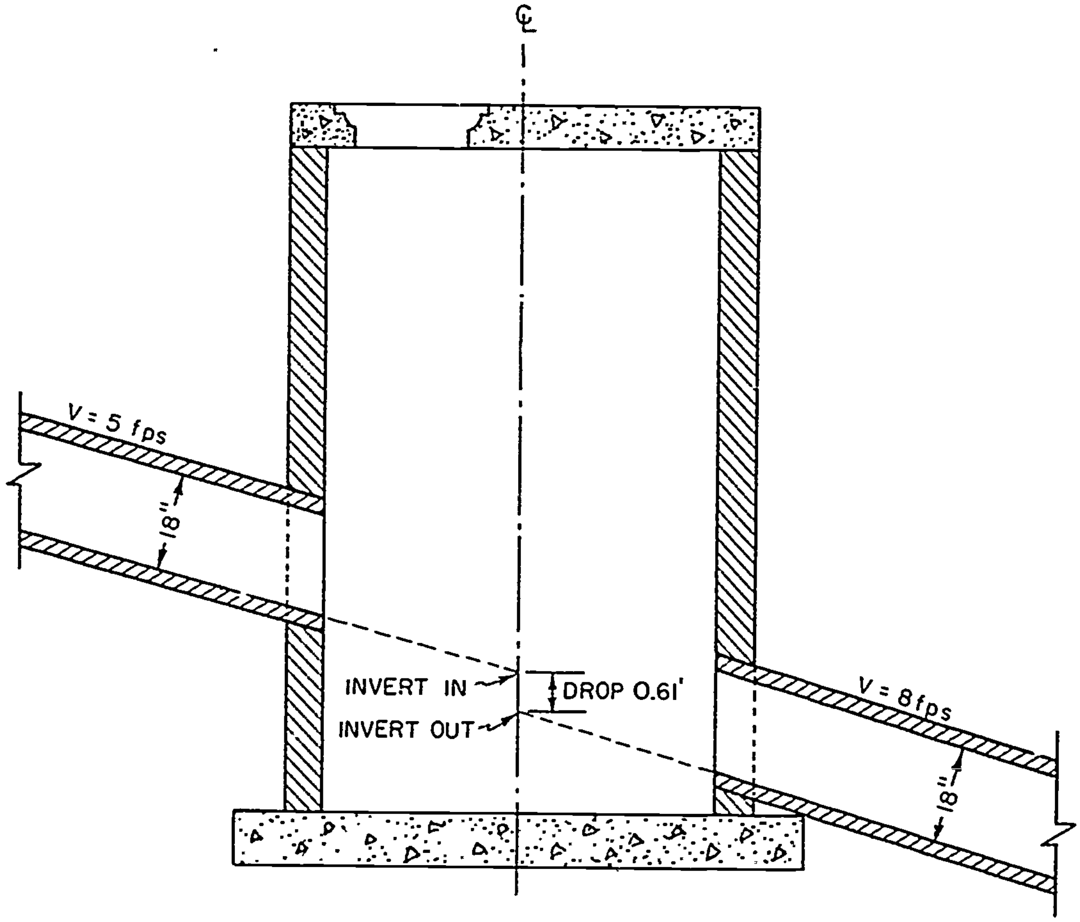
Outflowing pipe $= \frac{64}{64} = 1.00$ ft.

The amount of the drop is the difference between these two, or 0.61 ft. The bottom of the box would, of course, be filled with cast concrete or rubble pargetted with mortar, to channel the stream smoothly from the inflowing pipe to the outflowing pipe, for the sake of clearness, this material is omitted in figure 6-7.

The computation just described gives you the amount of invert drop WHEN THE PIPES ARE OF THE SAME SIZE. When the outflowing pipe is LARGER than the inflowing pipe, you ADD the difference in diameters of the pipe to what the drop would be for pipe of the same size. Suppose, for example, that in figure 6-7 the outflowing pipe was 24-in. instead of 18-in. The difference in diameters here is 6 in., or 0.50 ft, and the invert drop would be 0.61 ft plus 0.50 ft, or 1.11 ft.

When the outflowing pipe is SMALLER than the inflowing pipe, you SUBTRACT the difference in diameters of the pipe from what the drop would be for pipe of the same size. Suppose that in figure 6-7 the outflowing pipe was 15-in. instead of 18-in. The difference in diameters is 3 in., or 0.25 ft, and the invert drop would be 0.61 minus 0.25, or 0.36 ft.

It may occasionally happen that the difference in diameters is larger than what the drop for pipe of the same size would be, thus



82.23

Figure 6-7.—Dropping inverts.

requiring, by computational theory, a rise rather than a drop for the outflowing pipe invert. In a case of this kind (which is rare), you follow a general rule to the effect that an invert out is never placed at a higher elevation than an invert in.

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 which 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 might be said to be done on paper.

It is often the case, on the other hand. that a line or parts of it 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 this data has 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 6-8 shows a storm sewer plan and profile. The project here is the installation of 230 ft of 18-in. 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.

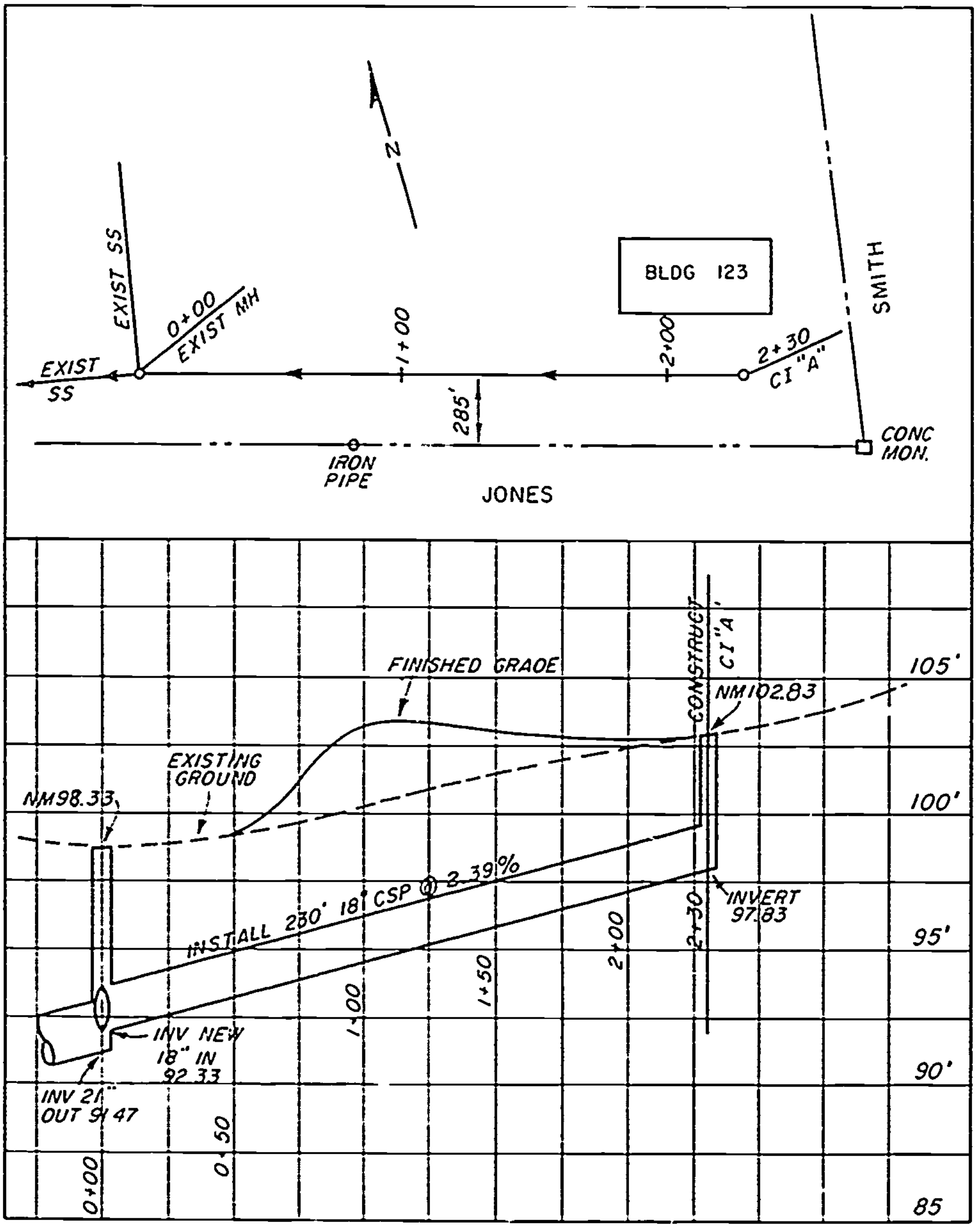
The pipe in figure 6-8 is to run downslope from a curb inlet to a manhole in an existing sewerline. The reason for the distorted appearance of the curb inlet and manhole, which look much narrower than they would in their true proportions, is due to the exaggerated vertical scale of the profile. The appearance 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-in. pipe at the manhole is 91.47 ft; that of the inflowing 18-in. pipe is to be 92.33 ft. Obviously there is a drop here of 0.86 ft. Of this drop, 0.25 ft is due to the difference in diameters; the other 0.61 ft is probably due to 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 centerline 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-ft stations in 230 horizontal feet), or 5.50 ft. Therefore, the invert elevation at the curb inlet will be 92.33 ft (invert elevation at the manhole) plus 5.50 ft, or 97.83 ft. The invert elevation at any intermediate point along the line can be obtained by similar computation.

The plan shown in figure 6-8 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 and the new line is tied to the paper location as previously described for a highway. 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



82.24

Figure 6-8.—Storm sewer plan and profile.

rather than the route survey) in the same operation.

Sanitary Sewer Systems

A sanitary sewer, like a storm sewer, flows "downhill," and design for a sanitary system is similar to design for a storm system. Only points in which the systems differ will be mentioned here.

First, let's trace the course of a system from the outfall end up to the input end. There are still many places where the sanitary sewer outfall is simply a point where raw sewage flows into a stream, but this situation is being replaced, as rapidly as possible, by one in which inland systems outfall into sewage disposal or treatment plants. Systems in coastal communities frequently outfall into the ocean.

The outfall is, of course, the lowest point in the system, and the outfall pipe is the pipe of largest flow capacity. Following this pipe up, we come to many other pipes, branching off the main trunk in all directions, and called by various names, such as subtrunks, branch trunks, or branches. These frequently follow the courses of streams, because the course of a stream is always a downhill course.

Branching off from the subtrunks we find the street sewerlines, running along the streets on which the buildings the line serves are located. The street lines are connected to the buildings by BUILDING SEWERS, which in turn are connected to the WASTE STACKS and SOIL STACKS in the buildings. A stack is a vertical line of soil or waste piping, into which a building's soil or waste BRANCHES (pipes running from lavatory drains, shower drains, water closets, and other waste sources) convey liquid and semiliquid waste. A waste stack is one which conveys waste not containing human excrement; a soil stack is one which conveys waste containing human excrement.

Once the Q for a sanitary system has been determined, the pipe is sized and graded much as storm sewer pipe is sized and graded. A sanitary system designer is usually dealing with smaller pipe, however, and there are, of course, no storm water inlets in a sanitary system.

To help prevent clogging and to facilitate maintenance, a minimum pipe size is usually specified which may be larger than is necessary to carry the design flow at the upper ends of the system. Typical mi. num sizes are 6, 8 and 10 in., and the recommended minimum velocity of sanitary sewers should be 2 ft per sec (sewer flowing full).

As the area and number of building FIXTURES (water closets, urinals, etc.) served by a system increase, the chance of all the fixtures being in use at the same time decreases, therefore, some averaging system is needed to achieve an economical design.

The design engineer bases his design on the average daily consumption of water per person in the area to be served. A typical value is 100 gals per person per day. But the use is not constant, consumption 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 flow (based on the average consumption) is multiplied by a PEAK FLOW FACTOR to obtain the design flow. The peak flow factor is sometimes varied as the size of an area increases, because the larger the area, the greater the tendency for the flow to average out.

Typical peak flow factors might range from 4 to 6 for small areas down to 1.5 to 2.5 for larger areas. An allowance for infiltration of subsurface water into the lines is sometimes added to the peak flow to obtain the design flow. A typical infiltration allowance is 500 gals per inch of pipe diameter per mile of sewer per day.

Other Underground Utilities

More and more the advanced bases of the U.S. Armed Forces are using underground systems for distribution of water, power and communication lines. There are several reasons for this:

1. In areas subject to high winds and storms, overhead lines can present quite a problem.
2. Landing fields need a clear area without poles and overhead lines.
3. Areas used for handling and storing of materials need open spaces for cranes and other equipment.
4. In case of an enemy attack, the underground lines would be subject to far less damage compared to overhead lines.

UNDERGROUND WATERLINES. An underground waterline flows under pressure, rather than "downhill" like a storm sewer or sanitary sewer. Therefore, the matter of gradient is not relevant to the design problem. Usually a waterline is simply placed at a uniform average distance below the surface, called under so many feet of "cover." However, it may be the case that, to avoid other utilities lines in an area, the vertical distance of a waterline below the surface may vary. When this is the case, the system is both planned and profiled, otherwise it is only planned.

As a rule there are no manholes or similar boxes in a waterline. There are usually, however, subsurface meter boxes, valve boxes, and the like. All of these are shown in the plan.

The Q for a waterline is the sum of the Q's required at the consumer end that is, at the fixtures (such as fire hydrants and faucets) which convey water for consumption. The factors considered in determining pipe sizes include the Q's needed, the pressures desired, and the friction losses, which vary with the size, type, and length of the line. Formulas which incorporate these factors are available in engineering handbooks, and are referred to in sizing the pipe for a water system.

Water is carried from the source of supply across country by a TRANSMISSION MAIN, from which DISTRIBUTION MAINS branch off to the streets where consumer outlets exist. A building is connected to the distribution main by a BUILDING SUPPLY LINE. Fire hydrants on a street are connected directly to the distribution main. The pipe in a main is usually much larger than would be required to provide buildings with required amounts of water at desired pressure; this is because mains must be sized to provide water, not only for domestic use, but also for fire protection, industrial use, and waterfront berthing spaces. The fire demand is usually the determining factor in sizing. As a general rule, the pipe in a main serving fire hydrants is not less than 6 in.

UNDERGROUND POWERLINES. Gradient is also, of course, not a factor in an underground powerline. One of these lines does, however, have manholes, in which adjacent sections of power cable are spliced together. Cable comes on reels, and the maximum length available on a reel is 600 ft; therefore, power manholes are usually located not more than 500 ft apart. The box on a power manhole is constructed to provide a minimum of 6 ft of head room, and usually measures 7 ft long (dimension running with the cable) by 5 ft wide.

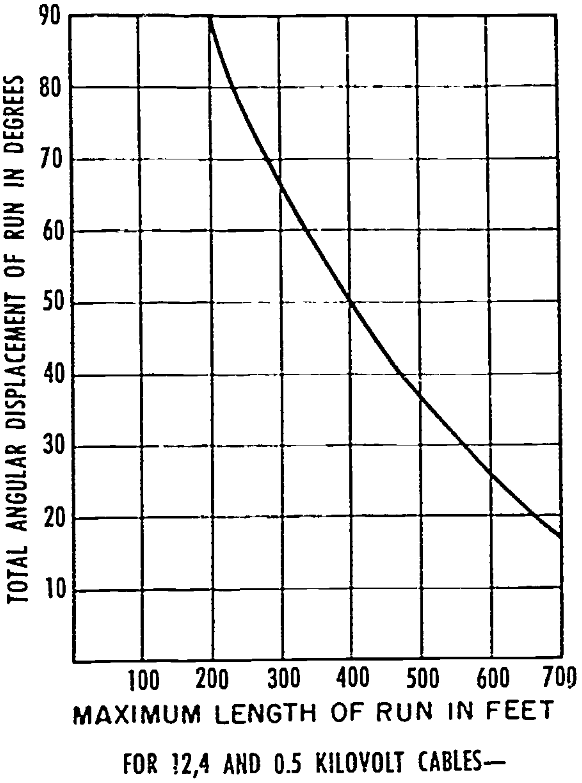
The cable running from one manhole to the next is passed through a cylindrical, pipe-like container called a CONDUIT. The inside diameter of conduit runs from 4 in. to about 6 in. Until recently the type most frequently used was FIBER conduit (familiarly called ORANGEBURG), made of pressed wood pulp and available in 8-ft lengths, equipped with PRESSED SLEEVE COUPLINGS for joining together. Similar conduit, but made of plastic, is now coming into use. There is also IRON PIPE conduit, in 10-ft lengths with threaded joints and asbestos composition conduit (commonly refered to as TRANSITE), in 10-ft lengths with pressed sleeve couplings.

Conduit may be designed for encasement in concrete (about 3 in. minimum cover usually specified), or for laying directly in earth without encasement. A small-diameter wire is threaded through the sections, from one manhole to the next, as the conduit is laid in the trench. Later, when the cable is to be run through the conduit, the small wire is used to pull a larger PULL WIRE or PULL ROPE through. The cable is then pulled through with this one, either by hand with block-and-tackle or by a power winch on a truck.

Conduit is designed to be as watertight as possible. Still, however, there is a possibility that subsurface water may penetrate to the cable, and some water accumulates inside through condensation. Therefore, drainage must be provided for by a downslope, usually specified at a minimum of 1 percent. This may be a downslope from manhole to manhole, or it may be toward the manholes from an intermediate high point in the conduit. The bottom of a manhole is constructed to drain into a gravel bed, drain tile, or other suitable arrangement.

Conduit may be laid in a horizontal curve, from one manhole to the next, to avoid obstructions or for some other reason. Because of the fact that a curve in the conduit increases pull friction, however, the radius of such a horizontal curve must be not less than about 40 percent of the straight-line distance between the manholes. A double-slope duct (one that drains from the center toward the manholes) is laid in a vertical curve, for a curve of this kind, the radius should equal the length of the straight-line run.

Angular displacement (for curves) limits the total length of the run between manholes, because of pull friction. Graphs like the one shown in figure 6-9 give the maximum runs for various total angular displacement. Suppose, for example, that a conduit run has three horizontal displacements of 8°, 20°, and 12°, and two vertical displacements of 5° and 7°, as indicated by the chords of horizontal and vertical curves. The total angular displacement is the sum of all these, or 52°, the graph indicates that in this case the maximum conduit run would be 390 ft.



82.25

Figure 6-9.–Maximum conduit runs for total angular displacements.

UNDERGROUND COMMUNICATIONS LINES.–Underground communications lines do not carry the high voltages of underground powerlines, therefore, the conduit for these does not need to be as substantial. Underground com munications lines are usually laid in duct made of fiber, asbestos composition, or plastic.

The character of the route survey for underground water, power, or communications will depend on the circumstances. The route to be followed by the distribution part of an underground powerline will follow the streets on which the consumer outlets (buildings, street lights, traffic lights, etc.) are located -therefore, no reconnaissance or preliminary location survey is likely to be necessary. A final location survey (probably combined with stakeout) will be run from a paper location. For the transmission part of a powerline, however, reconnaissance and preliminary location surveys may be required if the line runs for a considerable distance over rough, irregular country. The same is true, generally speaking, of an underground communications line.

STAKEOUT AND AS-BUILT SURVEYS

You know that construction surveys include (1) marking points in the field to guide the crews who do the work of construction, and (2) determining the actual horizontal and/or vertical locations of points as built. We'll call these operations the STAKEOUT survey and the AS-BUILT survey, respectively.

The as-built survey consists simply of determining horizontal and vertical locations of points, and there should be little about this which you don't already know. Also, there is little to be said about building stakeout which hasn't already been said in *Engineering Aid 3 & 2*. Therefore, this section will be confined to the structures which have been mentioned in this chapter. Here again, the stakeout for an aboveground utility line (which consists simply of running a traverse and marking pole or tower locations thereon) involves nothing new to you.

There is an aspect of as-built and stakeout surveys which is of particular significance to the party chief. he 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, gathering engineering data, and so on. But in stakeout, the survey party is an integral part of the construction team. Timing and scheduling are important, if line and grade stakes have not been set at the right place and at the right time, the work of entire construction crews will be delayed. The party chief must also be constantly aware of the need for replacing stakes which have been knocked out by design or accident. 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; the press of further construction may prevent a timely return to the job to obtain the as-built data, and users of the plans may be seriously misled in supposing that the construction conformed to the original drawings.

SEWER STAKEOUT

To stake out a sewer, you obtain data from a plan and profile which show (1) the horizontal location of each line in the system, (2) the horizontal location and character of each appurtenance, (3) the invert elevations at each appurtenance, and (4) the gradient of each line. You will also have detail drawings of each type of appurtenance. If appurtenances 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 centerline 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 centerline 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 batte oards or various types of offset string lines was described in *Engineering Aid 3 & 2*.

If the survey party stakes only the offset hubs, then the construction crew usually sets centerline 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 of and the availability of personnel, and the workload. In any case, hubs and/or stakes are generally set at 25-ft intervals, though 50-ft and even 100-ft intervals have been known to suffice.

Sewer hubs are usually offset from 5 to 8 ft from the centerline. Before you enter the field, you compute from the profile the invert elevation at every station where you will set a hub. Consider figure 6-10, 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 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 appurtenances are given on the profile. Suppose that the invert out at CI "A" #2 is 122.87 ft. 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 ft minus (0.50 X 2.18), or 122.87 ft minus 1.09, or 121.78 ft. 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 centerline 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 ft. This presumes that, if the ground slopes across the line, the high side is the side on which the hubs are placed in figure 6-10. Hubs are always placed on the high side, the reason being to prevent them from being covered by earth dozed off to form a bench for the trench-digging rig.

You drive a hub 8 ft offset from station 9 + 00, and determine the elevation of the top of the hub. The vertical distance from the top of

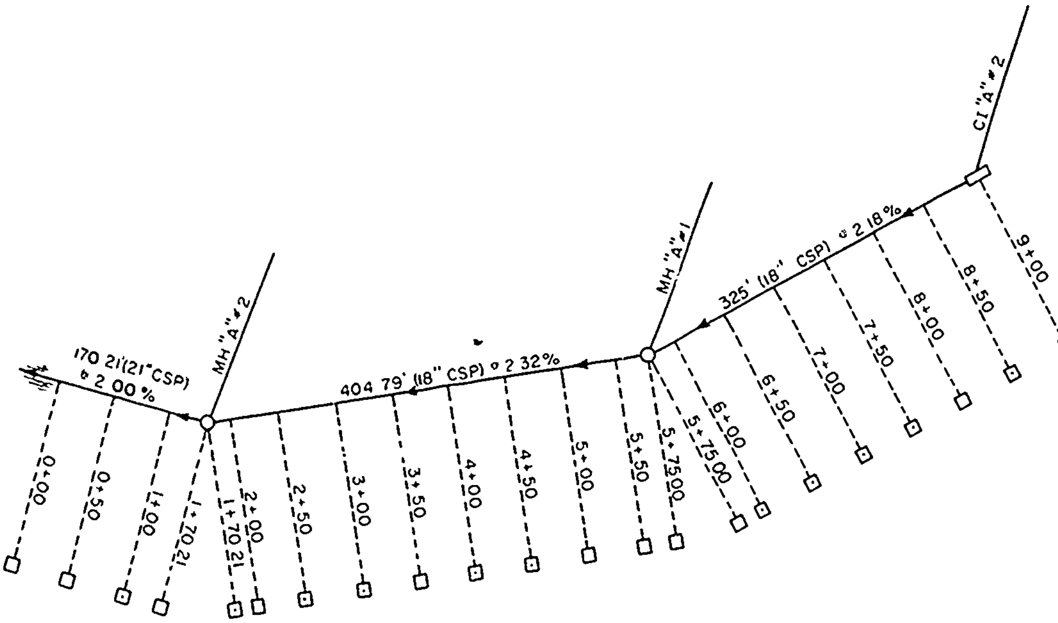


Figure 6-10.–Sewer stakeout plan.

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 ft. Suppose the elevation of the top of the hub is 126.94 ft. 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 was 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 constructors will use these hubs to g 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 ft. Figure 6-11 illustrates this method.

Take station 9+00 in figure 6-10, for example. The elevation of the top of the hub is 126.94 ft and the invert elevation is 122.87 ft. To be 10 ft above invert elevation, the top of the batter board must be placed on the post 5.93 ft above the top of the hub. To get this distance the field constructor would simply subtract the specified

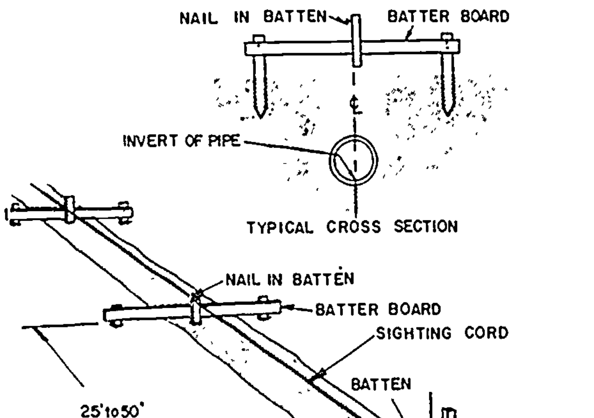


Figure 6-11.–Setting sewerline to grade.

cut from 10 ft. 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 ft.

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 centerline alignment. A string is stretched and tacked along these battens; this string indicates the horizontal location of the line, and it follows the gradient of the line, but at a distance of 10 ft 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 ft, for example, another 1.5 ft of cut must be taken out.

Corners of rectangular appurtenance 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 centerline of the box bisect the angle between the lines, as described for a tower. 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.

UNDERGROUND DUCT SYSTEM STAKEOUT

The stakeout for an underground powerline is similar to that for a sewer. For the ducts, cuts are 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 ft below the bottoms of the incoming and outgoing ducts. Power and communications manholes are often combined, figure 6-12 shows plan and section views of a standard 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 6-13 shows plan and section views of a handhole.

AIRFIELD SURVEYS

Airfield construction is of a special kind, for this reason, it is discussed here under separate heading.

AIRFIELD TERMINOLOGY

It is advisable at first to present a list of definitions of some of the terms frequently used in this highly specialized work. Figure 6-14 is a plan view of a small advanced-base field. A field 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 are defined as follows:

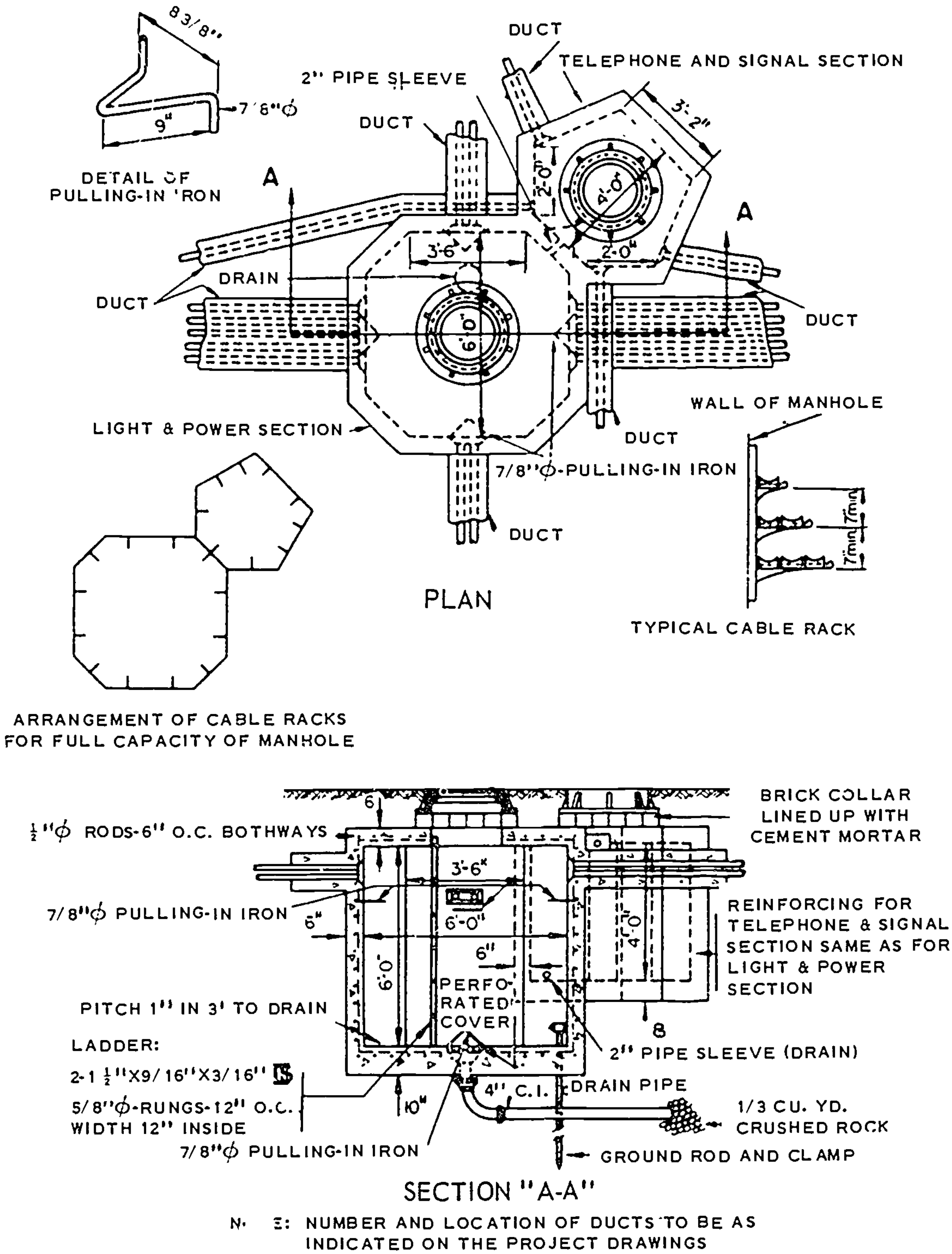
APPROACH ZONE is a trapezoidal area established beyond the end zone at each end of a runway. The approach zone must be free of obstructions on the plane of a specific GLIDE ANGLE.

APRON is a stabilized, paved or metal plank-surfaced area, designed for the temporary parking of aircraft other than at hardstands. Aprons are classified as SERVICE, WARM-UP, and PARKING.

END ZONE is 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.

GLIDE ANGLE is 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.

HARDSTAND is a stabilized, paved or metal plank-surfaced parking area, of sufficient size and strength to accomodate a limited number of aircraft. Hardstands 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.



82.27

Figure 6-12.—Standard combination power and communication manhole.

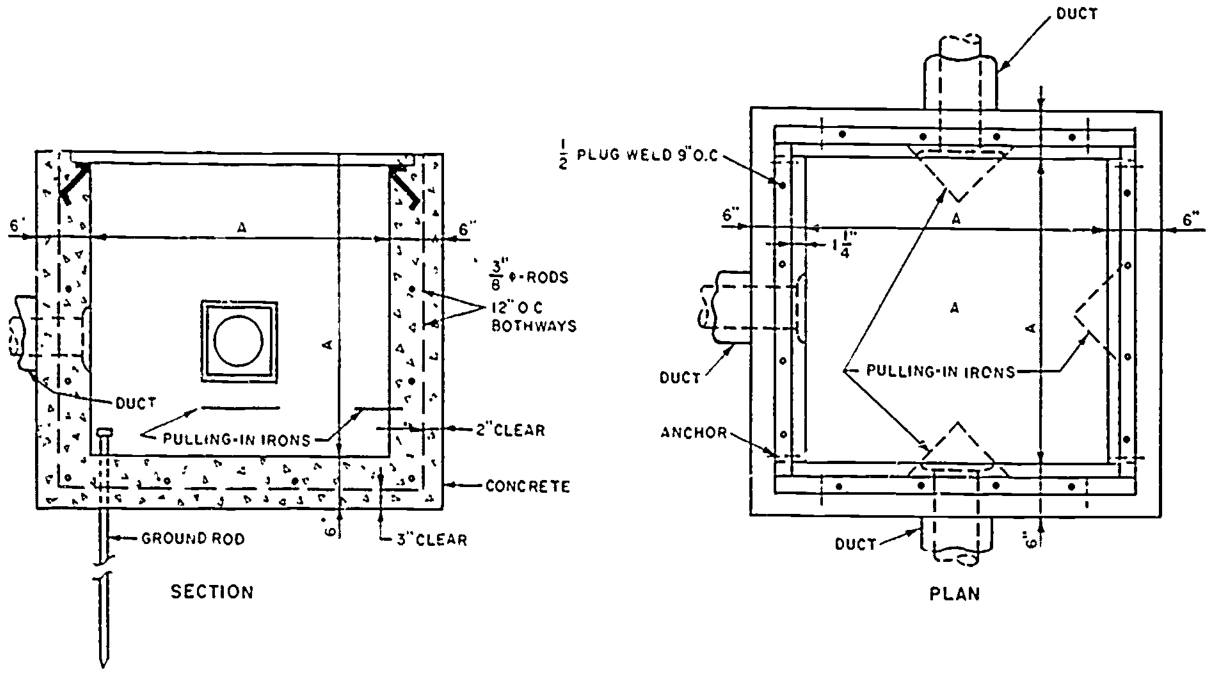


Figure 6-13.—Handhole.

LANDING AREA is the paved portion, or runway, 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, the end zones, the shoulders, and cleared areas.

REVETMENT is a protective pen usually made by excavating into the side of a hill or by constructing an 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 not well concealed.

RUNWAY is that portion of the landing strip, usually paved, where the aircraft actually land and take off.

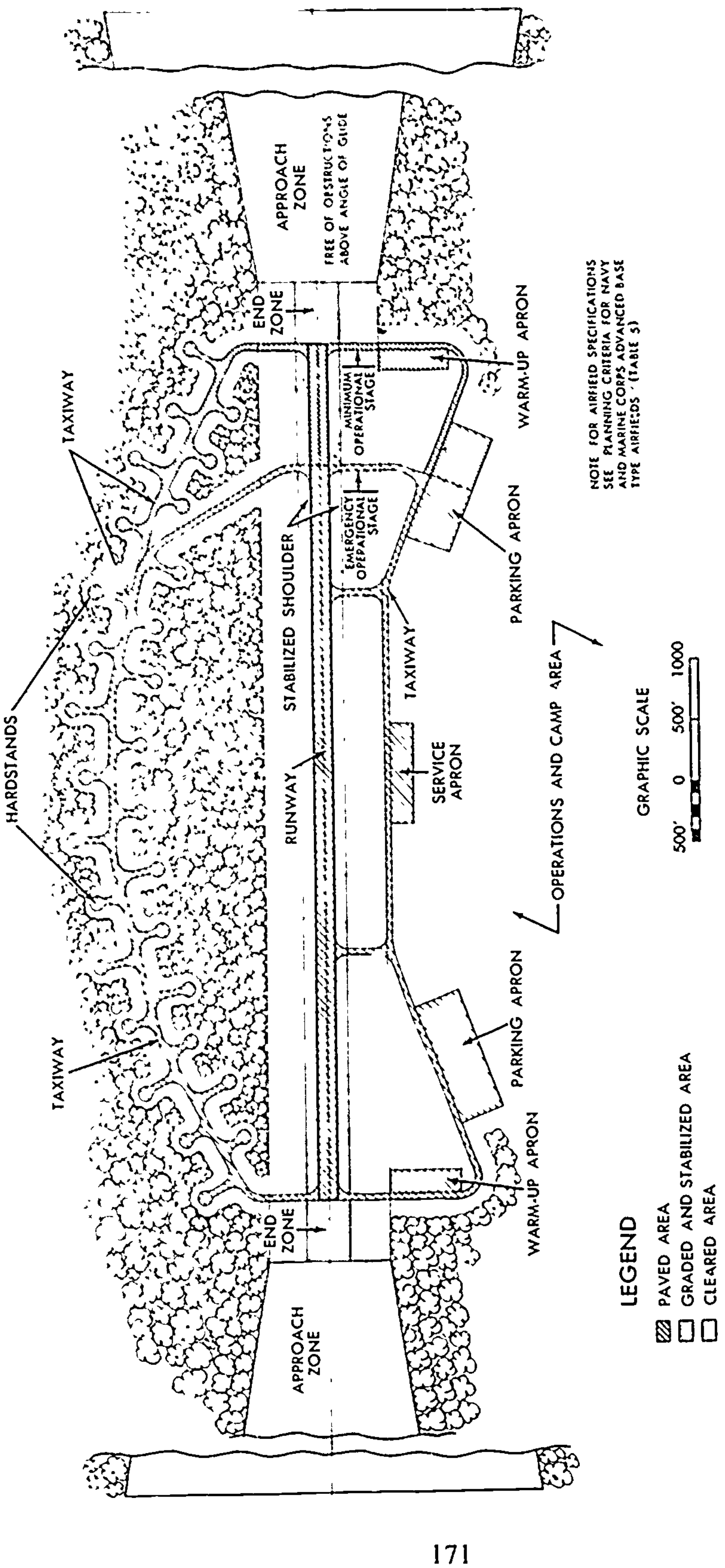
SHOULDER is the graded and stabilized area adjacent to the runway or taxiway. Although it is made capable of supporting aircraft and auxiliary equipment (such as crash trucks) in emergencies, its principal function is to facilitate surface drainage.

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

TRANSITION SURFACE is a sloping plane surface (about 1 rise to 7 run) at the edge of a landing strip. Its function is to provide lateral safety clearance for planes which accidentally run off the strip.

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 of construction materials; safety factors such as approach zone obstructions and traffic control, the provision for expansion, and defense. Under wartime conditions, there are also tactical considerations. All of these factors affect the number, orientation, and dimensions of runways, taxiways, aprons, hardstands, hangars, surfacing materials, and other facilities.



82.29

Figure 6-14.—Plan view of advanced base airfield.

AIRFIELD ROUTE SURVEY

The "route" for an airfield is the horizontal location of the runway centerline; if there is more than one runway, there is, of course, more than one "route." The principal consideration with regard to the direction of a runway centerline is the average direction of the prevailing wind in the area, since planes must take off into the wind. The azimuth of the centerline 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) includes 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 centerlines 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 centerline. In a case of this kind, 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.

You recall that an approach zone is a trapezoidal area beyond the end zone at each end of a runway, to be free of obstruction on 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 ft long, with a width of 1,500 ft at the outer end. For purposes of explanation only, we'll 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 6-15 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:

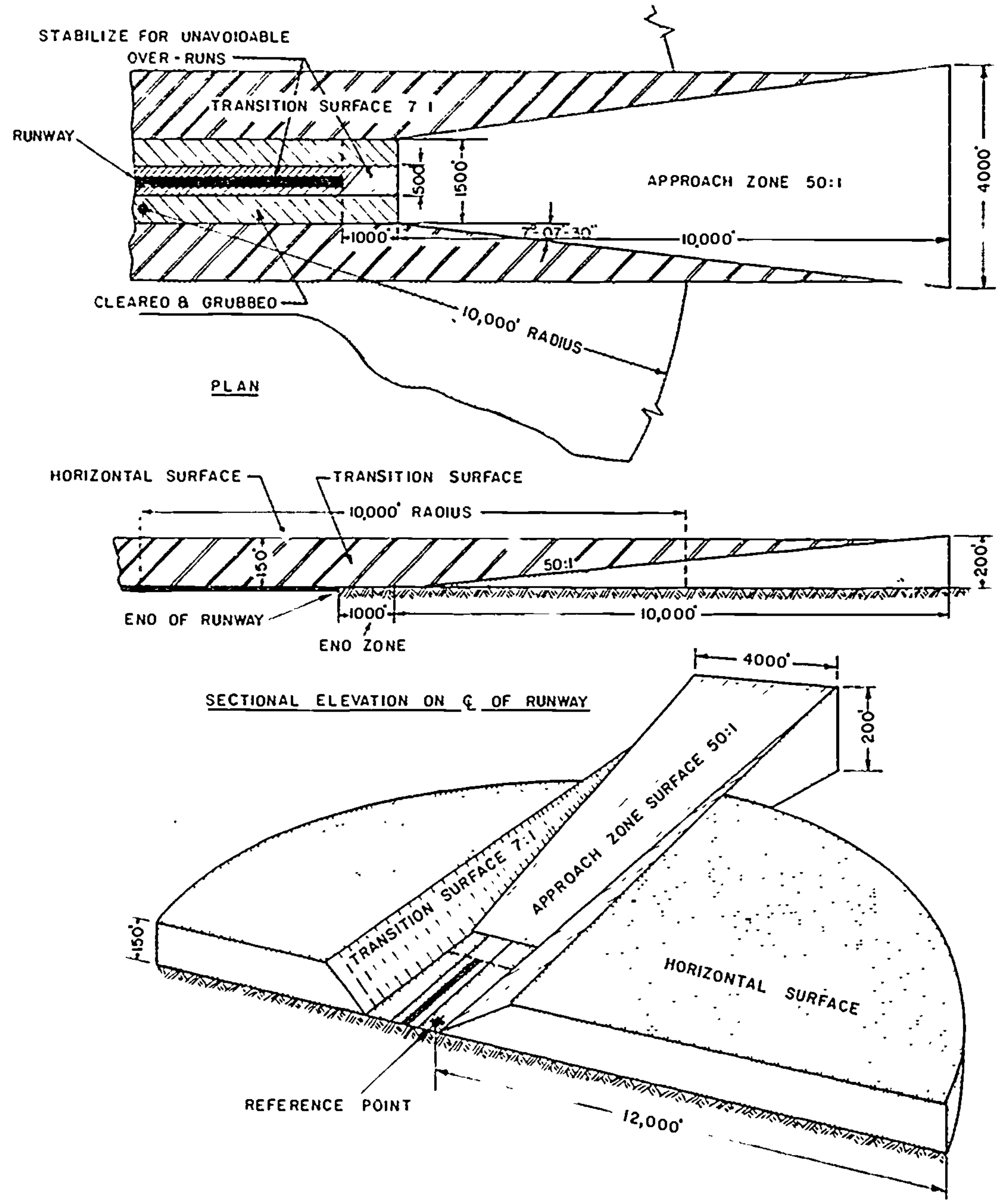
Figure 6-16 shows the approach zone in plan. The dotted line BC lies 750 ft from the centerline. The angle at B can be determined by solving the triangle CBD; tan B = 1250/10,000, or 0.125000; therefore, angle B measures 7°7'30". Determining the distance from the dotted line to the edge of the approach 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 100 (0.125), or 12.5 ft. Therefore, the distance between the centerline and the edge of the approach zone at this station is 750 + 12.5, or 762.5 ft.

To check for obstructions, you must set up a transit at the narrow end of the approach zone, set the telescope at a vertical angle equal to that which the glide plane makes with the horizontal, and take observations over the whole approach zone as indicated in figure 6-17. 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°8'50".

Figure 6-17 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 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



82.30

Figure 6-15.—Runway approach zone.

offshore points there must usually be coordination between a survey party on the beach and a party afloat.

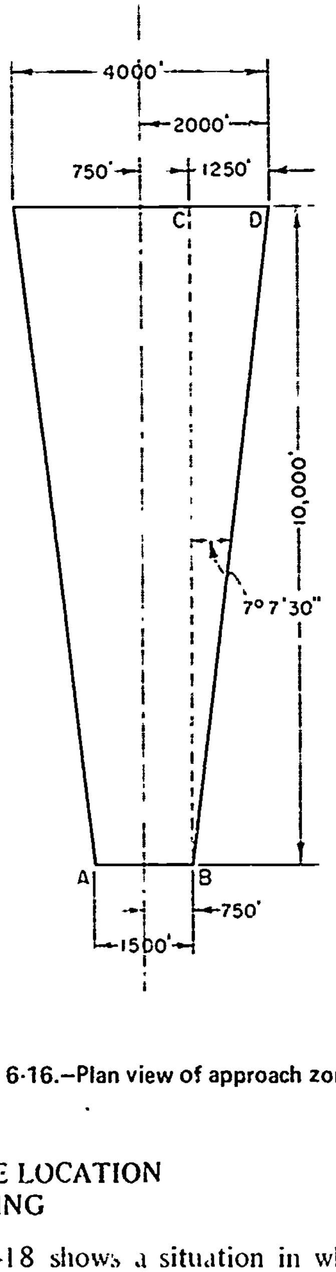


Figure 6-16.—Plan view of approach zone.

OFFSHORE LOCATION BY CHAINING

Figure 6-18 shows a situation in which offshore locations of piles for a wharf were determined by chaining. We'll 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 6-18 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.

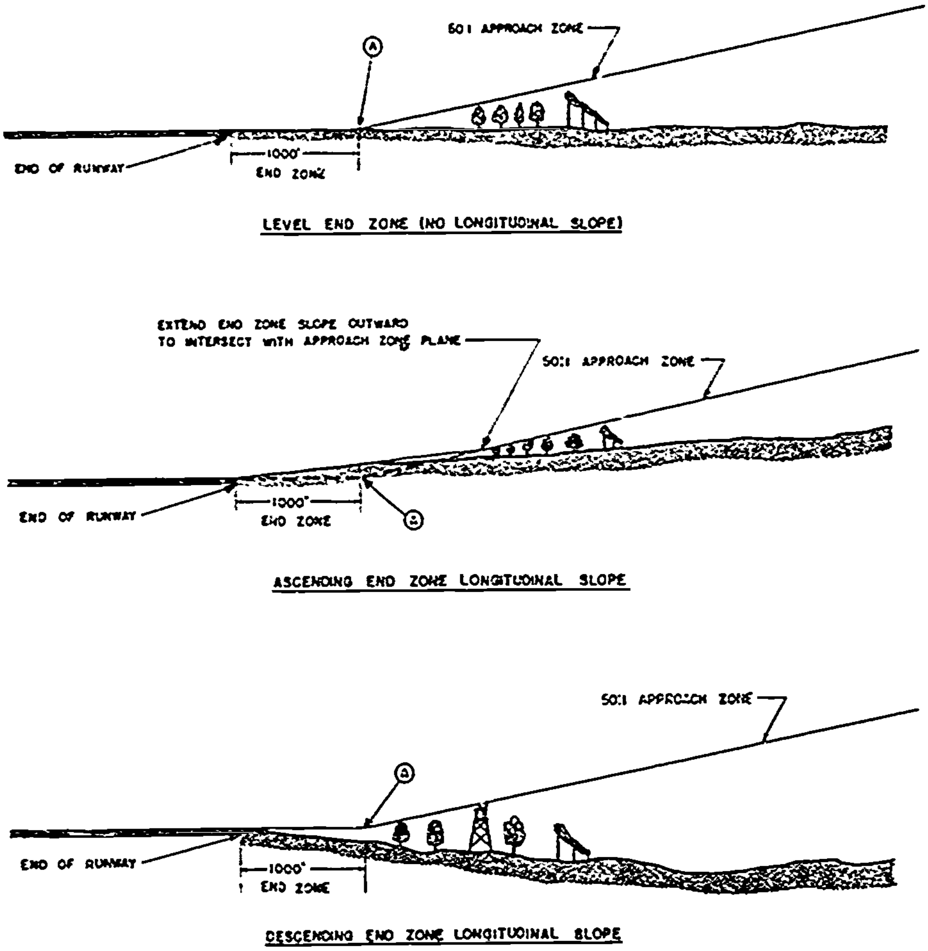
Consider figure 6-19, for example. Here the angle between each line and the base line (either as prescribed or as measured by protractor on a plan) is 60°40′. You can determine the distance between transit setups by solving the triangle JAB for AB, JA being drawn from transit setup B perpendicular to the line from transit setup A through piles 1, 2, 5, 10, 16, and 25. AB measures 50/sin 60°40′, or 50/0.87178, or 57.35 ft. 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 may also be determined by right-triangle solution. For pile #1 this distance is prescribed as 50 ft. For piles 2, 3, and 4, first solve the triangle A2L for 2L, which is 100/tan 29°20′, or 100/0.56193, or 177.95 ft. The distance from 2 to Q is 150 ft; therefore, QL measures 177.95 - 150, or 27.95 ft. QD amounts to 27.95/tan 60°40′, or 27.95/1.77955, or 15.71 ft. Therefore, the distance from transit setup D to pile #8 is 50 + 15.71, or 65.71 ft. Knowing the length of QL and the distance from 3 to Q, you can determine the distance from 3 to Q, you can determine the distance from setup point B to pile 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 I123 by solving the right triangle AN10 and proceeding as before. For pile #24 the distance I24 amounts to 50 tan 29°20′, or 50(0.56193), or 28.10 ft.

OFFSHORE LOCATION BY TRIANGULATION

For piles located farther offshore, the triangulation method of location is preferred. A pile



82.32

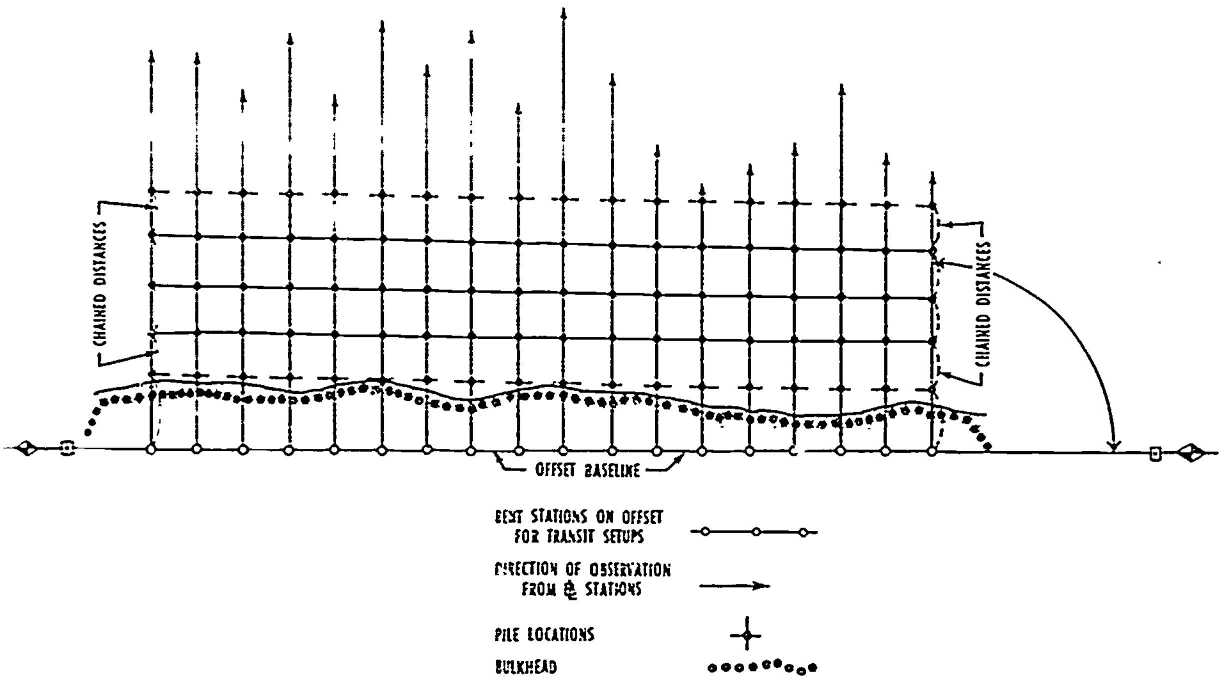
Figure 6-17.–Approach clearance for different types of end zones.

location diagram is shown in figure 6-20. 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 (1038.83 - 443.27), or 595.56 ft, 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 in each bent are 10 ft 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 10/0.994522, or 10.05 ft.

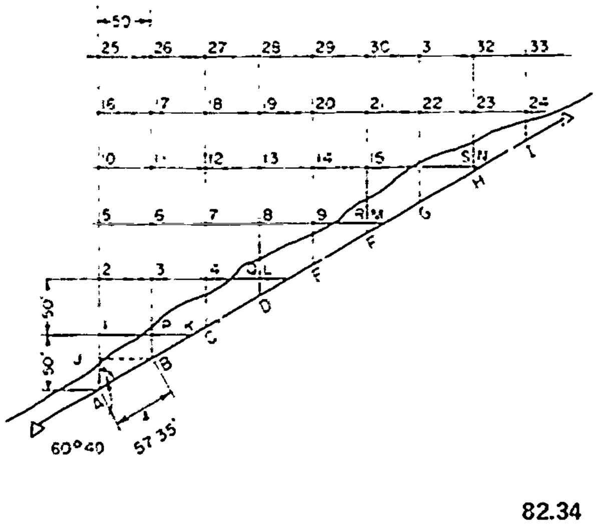
Bents are located 20 ft apart. The distance from the centerline base line transit setup at station 7 + 41.05 to pile #3 is 70 ft. The distance from station 7 + 51.10 to pile #2 is 70 + 10 tan 6°, or 70 + 10(0.105104), or 70 + 1.05, or 71.05 ft. The distance from station 7 + 61.15 to pile #1 is 71.05 + 1.05, or 72.10 ft. The distance from station 7 + 31.00 to pile #4 is 70-1.05, or 68.95 ft, that from station 7 + 20.95 to pile #5 is 68.95 - 1.05, or 67.90 ft.

You can determine the angle you turn, at a control station, from the base line to any pile location, by triangle solution. Consider pile #61, for example. This pile is located (240 + 72.10), or 312.10 ft from station 7 + 61.15 on the base line. Station 7 + 61.15 is located (1038.83 - 761.15), or 277.68 ft from control station 10 + 38.83. The angle between the line from station 7



82.33

Figure 6-18.—Offshore location by chaining.



82.34

Figure 6-19.—Offshore locations in line oblique to the base line.

+ 61.15 through pile #61 and the base line measures (180° - 84°), or 96°. Therefore, you are dealing with the triangle shown in figure 6-21. You want to know the size of angle A.

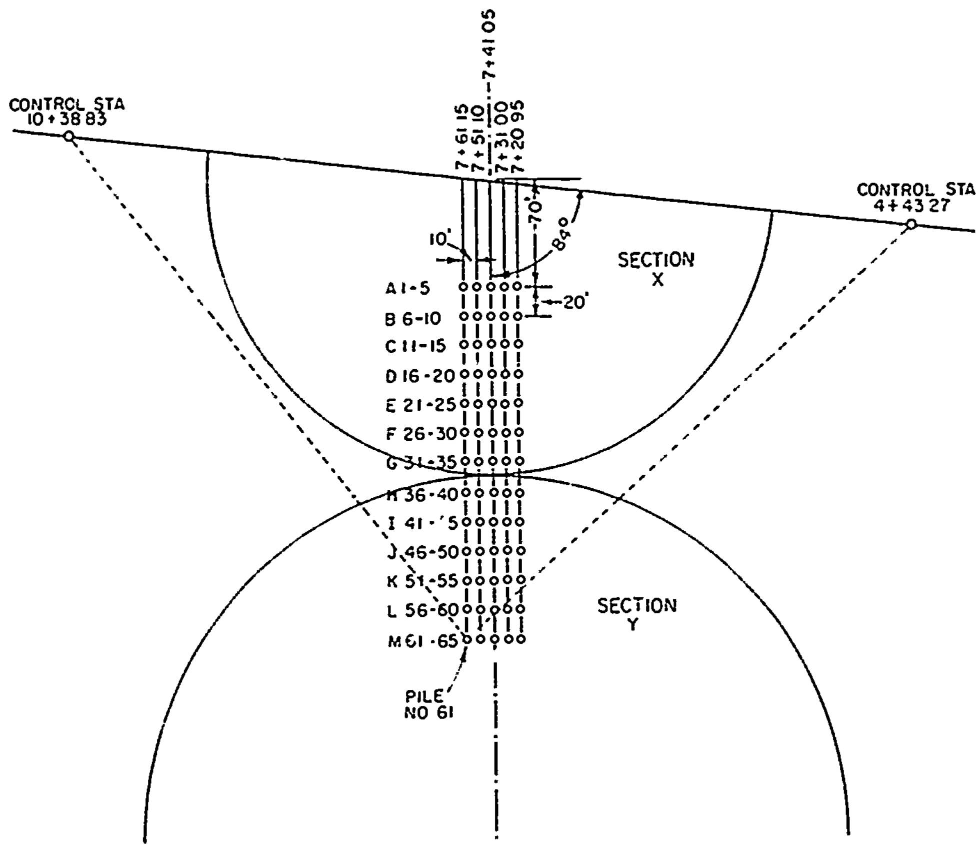
First solve for b by the law of cosines, in which $b^2 = a^2 + c^2 - 2ac \cos B$, as follows:

$$b^2 = 312.10^2 + 277.68^2 - 2(312.10)(277.68) \cos B$$

The cosine of an angle larger than 90° is the same as minus the cosine of its supplement; therefore, the cosine of 96° is the same as minus the cosine of 84°, or - 0.10453. So now we have:

$$b^2 = 312.10^2 + 277.68^2 - 2(312.10)(277.68)(-0.10453)$$
$$b^2 = 97406.41 + 77106.18 + 18117.96$$
$$b^2 = 192630.55$$
$$b = \sqrt{192630.55} = 438.89 \text{ ft.}$$

Knowing the length of b, you can now determine the size of angle A by the law of sines. Sin A = 312.10 sin 84°/438.89, or 312.10 (0.99452)/438.89, or 0.70699. This means that angle A measures, to the nearest minue, 45°.



82.6

Figure 6-20.—Pile location diagram.

To determine the direction of this pile from control station 4 + 43.27, yc.. would solve the triangle shown in figure 6-21. The length of side c equals the distance along the base line from control station 4 + 43.27 to station 7 + 61.15; the length of side a equals the distance from station 7 + 61.15 to pile #61. You would solve for side b as follows:

$b^2 = 312.10^2+317.88^2-2(312.10)(317.88)(\cos 84°)$

$b^2 = 97406.41 \quad 101047.69-(198357.12)(0.104523)$

$b^2 = 198454.10 - 20733.87$

$b^2 = 177720.23$

$b = \sqrt{177720.23} = 421.56$ ft.

You would solve for angle D as follows:

$\sin D = \frac{312.10 \sin 84°}{421.56} = \frac{312.10(0.99452)}{421.56} = 0.73646$

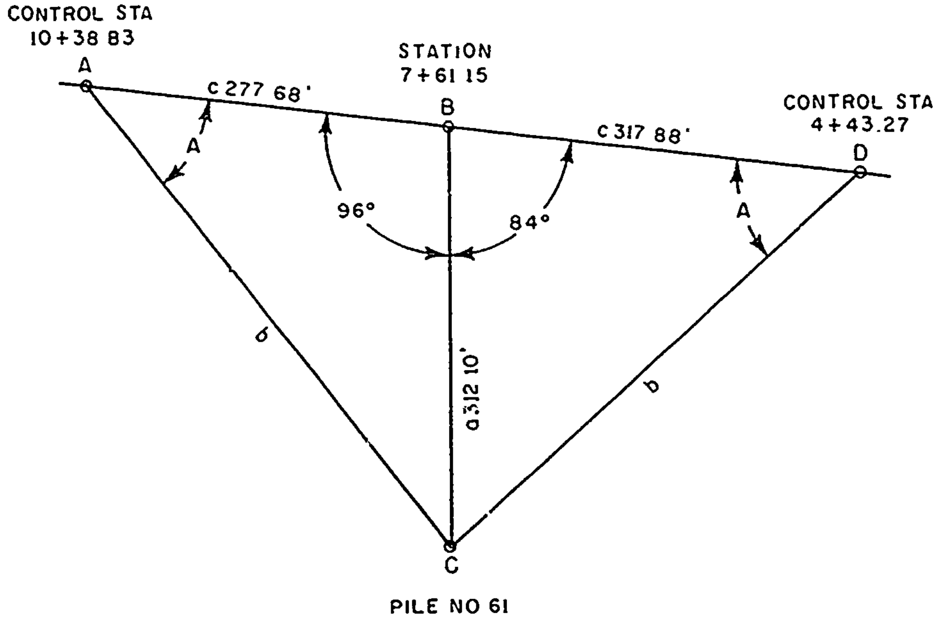
Angle D, then, would measure 47°26′. It would probably be necessary to locate in this fashion only the two outside piles in each bent; the piles between these two could be located by measuring off the prescribed spacing on a tape stretched between the two. For the direction from control station 10 + 38.83 to pile #65 (the other outside pile in bent M) you would solve the triangle shown in figure 6-22 as follows:

$b^2=307.90^2+317.88^2-2(307.90)(317.88)(-0.10453)$

$b^2 = 94802.41 + 101047.69 + 20461.80$

$b^2 = 216311.90$

$b = \sqrt{216311.90} = 465.09$ ft.

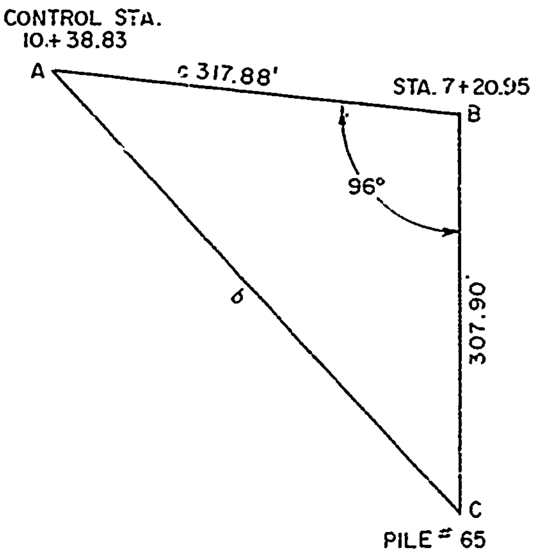


82.151

Figure 6-21.—Trigonometric solution for pile #61.

$$\sin A = \frac{307.90(0.994522)}{465.09} = 0.658388$$

Angle A = 41°10′



82.38

Figure 6-22.—Trigonometric solution for pile #65.

For each control station a PILE LOCATION SHEET like the one shown in figure 6-23 would be made up. If desired, the direction angles for the piles between #61 and #65 could be computed and inserted in the intervening spaces.

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

TRANSIT AT CONTROL STA 10+38.83				
BENT	PILE #	BS STATION	ANGLE FROM BS	REMARKS
M	61	7+61.15	45° 00'	∠ RIGHT
	62			
	63			
	64			
	65	7+61 15	41° 10'	∠ RIGHT

82.39

Figure 6-23.—Pile location sheet.

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.

EARTHWORK COMPUTATIONS

The computation of earthwork volumes is a feature in nearly all construction surveys especially in highway and airfield construction. The computation of earthwork for airfield construction is similar to that of a highway. The earthwork procedures for highways were discussed in *Engineering Aid 3 & 2*; the computation of volumes by the average-end-area method, the contour method, and the prismoidal method were explained.

A highway designer's concern 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. The technique for balancing cut and fill, and determining the economical haul distance, is by the MASS DIAGRAM method.

MASS DIAGRAM METHOD

The 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. See table 6-2 of soil conversion factors. These factors should be used when 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

Table 6-2.—Soil Conversion Factors (Conversion Factors for Earth-Volume Change)

Soil Type	Soil condition initially	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

143.117

adjacent hollow with material taken from a nearer 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.

There exists what is called a FREE-HAUL distance—that is, a distance over which it is considered that haul involves no extra cost. This distance is usually taken to be about 500 ft—meaning that it is only for hauls longer than 500 ft that the limits of economic haul need to be considered.

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 6-3. Under "End Areas" you put the cross-section area at each station—sometimes this is cut, sometimes fill, and sometimes (as at station 9 + 00 and 15 + 00) part cut and part fill. Under "Volumes" you put the volumes of cut and/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, 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 6-24 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 cu yds. The horizontal coordinates are the stations, each vertical line representing a full 100-ft station.

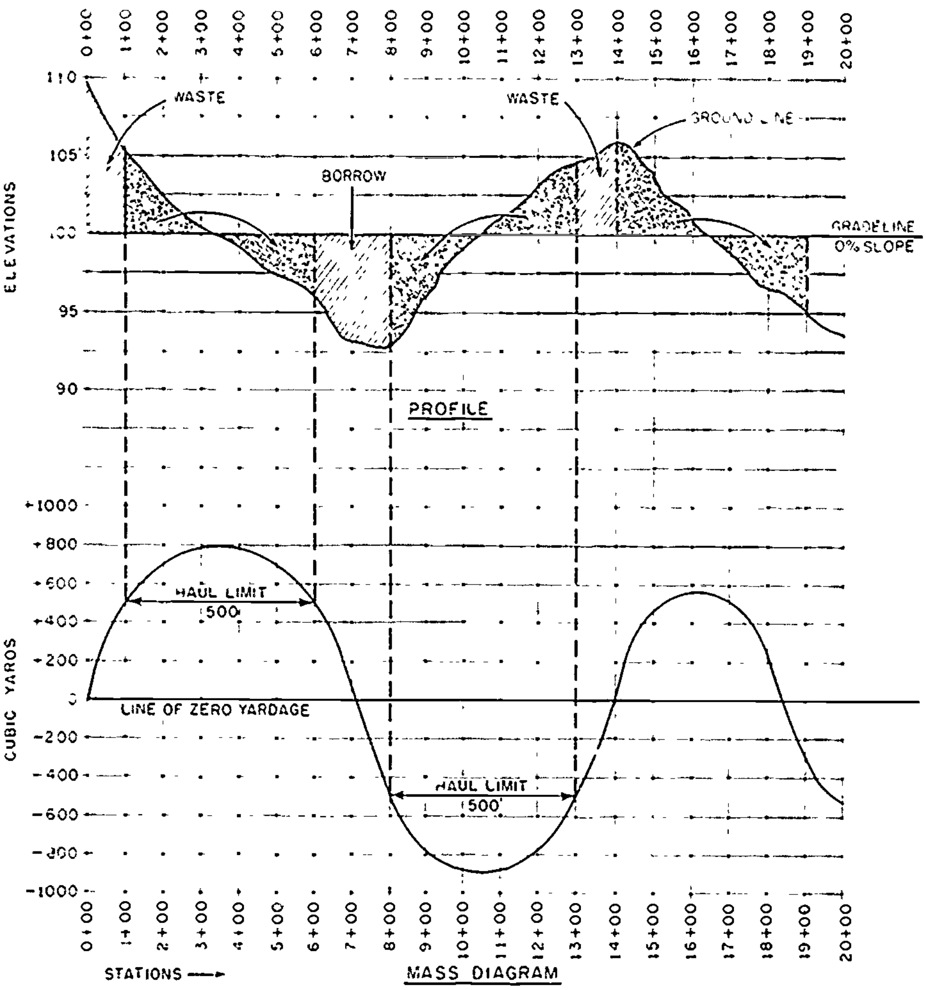
As you can see, the mass diagram makes it possible for you to determine, by inspection, the yardage of cut or fill lying between any pair of stations. Between station 0 + 00 and station 3 + 50, for example, there are about 800 cu yds of cut. Between station 3 + 50 and station 7 + 00 there are about 800 cu yds of fill (descending curve). Between station 7 + 00 and station 10 + 50 there are about 850 cu yds of fill (curve still descending), and so on.

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, which represent the maximum or minimum yardage, occur at, or near, the gradeline 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 us examine figure 6-24. Here the profile of a road, 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 6-24, a 500-ft haul limit line has been inserted into the mass diagram curve above and below the lines of zero yardage (the 500-ft 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



82.152

Figure 6-24.–Profile and mass diagram.

stations 13 + 00 and 14 + 00, and the fill between stations 19 + 00 and 20 + 00.

As indicated in figure 6-24, 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 stations 10 + 50 and 13 + 00, and the space between stations 16 + 50 and 19 + 00 would be filled with 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 is also 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 6-24 is only about 400 ft, 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

Table 6-3.—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

82.47

cut remaining would naturally be wasted after allowing for shrinkage in the filled spaces.

LAND SURVEYS

Land surveying includes surveys to locate and monument 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 which 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 of the Union. 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 ownership in 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. The EA1, as survey team or crew leader, must have a knowledge of the principles of land surveys in order to plan his 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

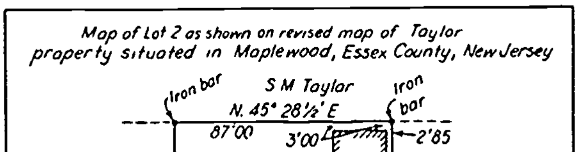
When a tract of land is defined by giving the bearings and lengths of all boundaries it is said to be described by METES and BOUNDS. This is an age-old method of describing land and still forms the basis for the majority of deed descriptions in the eastern states of the U.S., and in many foreign lands. A good metes-and-bounds description starts at a point of beginning which 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 co. r 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 boundries in the U.S. if often difficult is tl e fact that early surveyors often confined themselves to MINIMAL descriptions that is, to a bare statement of the METES AND BOUNDS, COURSES AND DISTANCES. Nowadays 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 6-25 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 herein distant along same line four hundred and thirty-one feet and seventy-one 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 H. L. Coombs one hundred and fifty-six feet and thirty-two one-hundredths of a foot to an iron bar; thence turning and running (2) North forty-five degrees twenty-eight and one-half minutes East along land of S. M. Taylor eighty-seven feet to an iron bar; thence turning and running (3) South forty-four degrees and thirty-one and one-half minutes East along land of B. A. Toler one hundred and fifty-six feet and thirty-two one-hundredths of a foot to an iron bar in a north-westerly line of Maplewood Avenue; thence turning and running (4) South forty-five degrees twenty- eight and one-half minutes West along said line of Maplewood Avenue eighty-seven feet to the point and place of beginning; all bearings being true and the lot containing a calculated area of thirteen thousand six hundred square feet. This description has been prepared from a survey made by R.F. Jones, Licensed Land Surveyor, New Jersey



45.803

Figure 6-25.—Lot plan by metes and bounds.

No. 4411, said survey being dated December 11, 1944."

Another form of a lot description may be 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 S 6°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 S 83°30′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 . . . etc."

You will notice that in the above example, interior angles were added to the bearings of the boundary lines, which will be another help in retracing lines.

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 connecting 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, etc."

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 which 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 73 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, etc."

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 lacking 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 which 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. What distinguishes land surveying from other types of surveying is the fact 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 which is described in a deed as running, from a described point of beginning marked by a described object, N 26°15′E, 216.52 ft. 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 which 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 N 26°14′E, 215.62 ft.

You can see that there is conflicting evidence here. By deed evidence the boundary runs N 26°15′E, 216.52 ft, but the evidence on the ground seems to indicate that it runs N 26°14′E, 215.62 ft. 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 which 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 N 26°15′E, 216.52 ft", and you found the remains of an ancient fence on a line bearing N 26°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 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 procedure. 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 which 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 which purport to describe the same property, but which 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 which goes to the effect than an ambiguous document should be given the sense which 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 locations exists in the field. Physical evidence means for the most part MONUMENTS. In land-surveying parlance, the term MONUMENT applies to any identifiable object which 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 which decays easily.

3. The location, in the field, of the existing physical evidence of the boundaries.

4. The establishment of the boundary. This involves those decisions previously mentioned as to the best evidence. It also involves the setting, referencing, and marking of points which should have been marked in previous surveys but weren't, or which were marked with markers which 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 practicable, 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 6-26 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" X 24" in trimmed dimensions, for convenience in filing. The usual scale is 1" = 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 equals 20 chains or 1 inch equals 10 chains may be used. A detail of a small area may be shown (fig. 6-25), as an inset on the main plat. Larger details are drawn on separate sheets. When the drawing is simple, with few topographic or hydrographic features or works of man to be shown, the entire drawing is in black ink. When, as in figure 6-26, the features other than the survey lines are quite extensive, color printing is

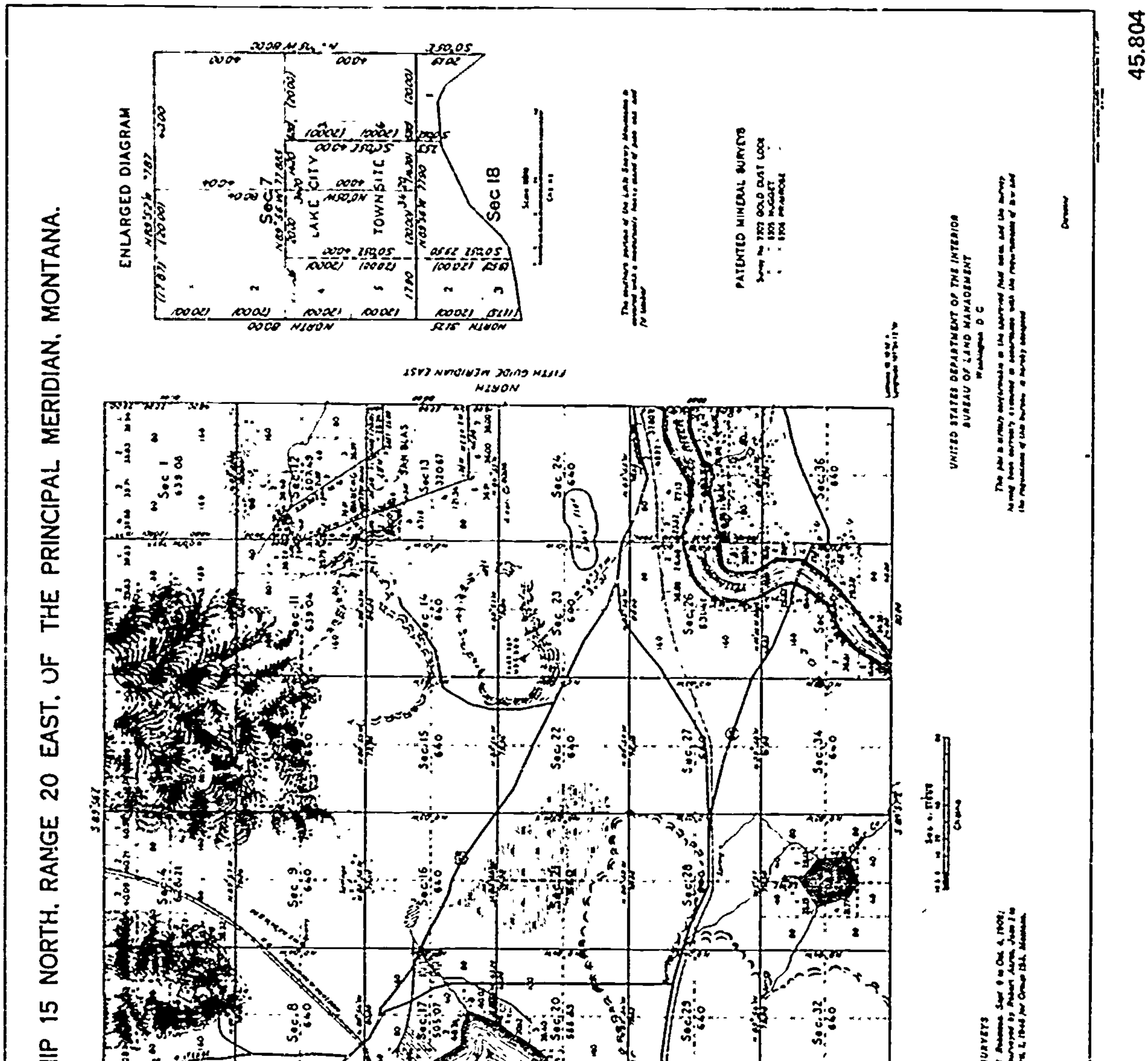


Figure 6-26.—Typical township plat.

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. 6-26). These several colors are not shown on the reproduction of the plat presented in fig. 6-26, although the various features are indicated in appropriate colors on the original map where this figure was reproduced.

A property plat plan must contain the following:

1. Directional orientation, usually indicated by 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 which 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 which appear on the plat (such as the name of a stream), or the character (such as "10-in. oak tree") of any natural monuments which 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 which 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, corner 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 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 transit-tape. For a large tract, however (such as a large Government reservation), corners 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 a million dollars per acre) would be surveyed with a considerably higher precision than would be used for surveying 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 to transfer chained distances to the ground.
2. Tape leveled by Locke level.
3. Tension applied by spring balance.
4. Temperature correction.
5. Angles turned 4 times.

If you turn angles 4 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 ft. Four-time angles might be precise enough for lines up to 500.00 ft long. For longer lines, a higher angular precision (obtained by repeating 6 or 8 times) might be advisable.

CHAPTER 7

TOPOGRAPHIC SURVEYS

Topographic surveys are made to obtain field data from which topographic maps may be made, indicating the relief, or the configuration of the earth's surface, and the location of natural and man-made objects.

The objectives of topographic surveying include:

1. Establishing horizontal control.
2. Determining vertical control.
3. Determining horizontal location and elevation of a sufficient number of ground points to provide data for the map.
4. Locating such other natural or man-made details as required.
5. Calculating angles, distances, and elevations.
6. Plotting and finishing the topographic map.

To accomplish the forementioned objectives, various methods are employed to produce topographic maps. The location (both horizontal and vertical) of topographic details by transit stadia from traverse stations is described in *Engineering Aid 3 & 2*. In this chapter the general approach to the mapping problem, from the party chief's viewpoint, will be described with detailed reference to the planetable methods of locating details.

This chapter also contains a section devoted to surveys in support of geology and pedology, which are related to the use of topographic maps.

TOPOGRAPHIC SURVEYS

The procedures to be used in producing a topographic map depend on the use to which the map is to be put and the time and facilities available. Under some circumstances it is more economical to use aerial photogrammetry, in these cases the fieldwork is limited to establishing horizontal and vertical control, checking, and perhaps picking up some extra details. Some of the factors which affect the decision as to whether topo should be flown or shot in the field are the size of the site, the purpose of the map as reflected in the scale and contour interval needed, the denseness of the underbrush (which obscures the bottoms of swales and ravines), the types of trees and the time of the year as reflected in whether or not leaves are on the trees.

The methods to be used in a field topo survey depend largely on the purpose of the map. For example, the horizontal and vertical control may not have to be as precise, and the detail as extensive, for a 1″ = 200′ and 5′ contour interval map to be used for preliminary planning as for a 1″ = 50′ and 2′ contour interval map to be used for design of streets, utilities, and site grading.

DEVELOPMENT OF TOPOGRAPHIC MAPS

Typical steps in the development of a map at the latter scale might be as follows. First, gather all available maps, plats, survey data, and utilities data which 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 is 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 on the datum and bench marks to be used, consider previous local surveys, USC&GS monuments, sanitary sewer inverts (not rims they are frequently adjusted) and assumed datum. Determine whether or not there is a coordinate system in the area monumented sufficiently for your use, if not, plan on using assumed coordinates. In the latter case, decide on the source of the meridian adjacent surveys, magnetic, assumed, or shooting the sun or Polaris.

Next, perform a reconnaissance survey. Observe the vegetation and decide how many men you will need to cut brush. Select main control traverse stations at points appropriate for planetable setups. Decide on the number and location of cross ties 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, checking its directions from time to time where necessary on long traverse. Checks could be done by astronomical methods, by cut-off lines, or by connecting the traverse with established points. Then run the levels, turning on all traverse stations. Close, balance, and coordinate the main traverse. Then adjust the cross ties into the main traverse. Balance the levels. Plot the traverse stations by coordinates on the planetable sheets (milar or stabilene sheets are ideal). Be sure there is sufficient overlap of all sheets. 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.

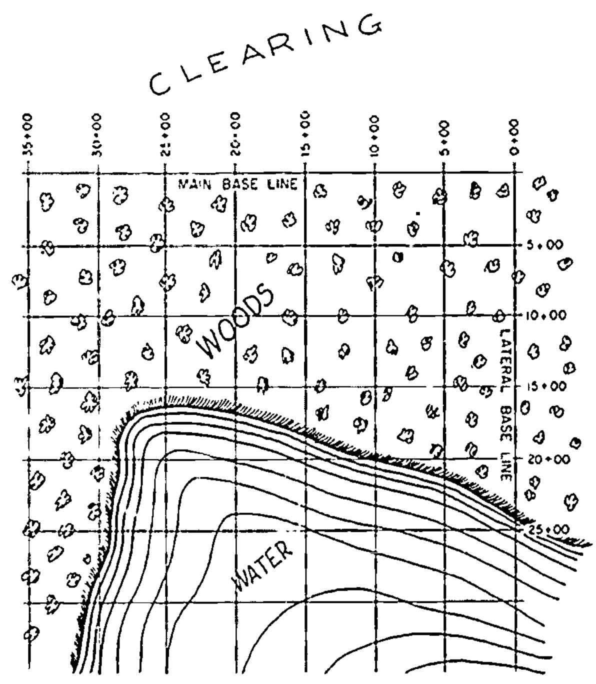
The planetable work is the final big step of the fieldwork. But some transit and level work may still need to be done. The location of some details (such as street centerlines or buildings) may be needed to a precision greater than that obtainable with the planetable; tie such details to the traverse by transit tape survey. For design purposes, the elevation of some points (such as the inverts of culverts, paved flumes, and sewers, and the tops of curbs and gutters) may be needed to a precision greater than that obtainable with the planetable. 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 planetable sheets onto the final drawing.

Random traversing, as described in the foregoing, 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 used in the example described in the following paragraphs.

Suppose that a site chosen through reconnaissance for an advanced base with airstrip facilities is as shown in figure 7-1. Here 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.

Topographic data for a map of this area might be gathered by three field parties, two of them transit-level parties and the third a planetable party. The transit-level parties would operate in the wooded and the water areas, the planetable party in the clear area.

Basic horizontal control is the MAIN BASE LINE, run along the edge of the wooded area as shown. Topographic details in the clearing will be plotted from planetable stations tied to the



82.40

Figure 7-1.—Advanced base site.

main base line. Details in the wooded area and offshore will be plotted from stations on a grid tied to the main base line.

Transit-level party #1 runs the main base line from station 0 + 00, located at random, setting hubs at every 500-ft station. Transit-level party #2 runs a LATERAL base line from 0 + 00, perpendicular to the main base line, and sets hubs at every 500-ft station. From every 500-ft station on the main base line, party #1 will run a LATERAL, perpendicular to the main base line (and therefore parallel to the lateral base line, party #2 will run a LONGITUDINAL, perpendicular to the lateral base line (and therefore parallel to the main base line).

You can see that the coordinates of a point of intersection between a longitudinal and a lateral are the designations of the longitudinal and the lateral-similarly. The coordinates of any point in the grid area are the main base line station and the lateral base line station of lines perpendicular to the main base line and the lateral base line passing through the point. You designate any point by its grid coordinates, expressed in fractional form, one over the other. You must decide which coordinate you will place on top, and then BE SURE TO STICK TO YOUR RULE. We'll place the lateral coordinate (that is, the main base line station) on top. For the point of intersection between lateral 15 + 00 and longitudinal 10 + 00, for example, our designation will be 1500/1000.

With regard to the vertical control situation, it may be the case that there are no established bench marks in the area. If this is so, the level group from party #2 should take a series of rod readings, over a succession of high and low tides, or on the high-water mark wash line along the beach. The average of all these readings may be used as a temporary vertical control datum, until a more accurate datum is obtained from tide gage readings. From a temporary BM 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 in 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 500-ft points of the intersection on the grid.

DETAIL BY PLANETABLE

The planetable party will be engaged in the process of locating detail and drafting a map of the clear area in a single operation.

A planetable field party for a large survey should consist of an instrumentman or topographer, a notekeeper or computer, and one or more rodmen. The instrumentman operates the planetable and alidade, making the observations and performing the plotting and sketching. He reads off the rod readings and vertical angles to the notekeeper, who records and reduces the field notes. The notekeeper computes the elevations and the horizontal distances. The rodman's job is to occupy the minimum number of points required to give an adequate representation of the ground being surveyed.

Planetable Equipment

For regular topographic mapping, a 24" X 30" planetable is generally employed. An alidade and stadia rod or Philadelphia rod are used in combination with the planetable. With these instruments, the direction, the distance, and the difference in elevation can be measured, computed, and plotted directly in the field. The planetable operation produces a completed sketch or map without need for further plotting or computing. Mistakes are easily recognized and corrected right in the field.

A small table called a traverse table, about 18" X 24", is often used for reconnaissance sketching and small-scale mapping. Some traverse tables are equipped with a ruler sight alidade with hinged sights similar to those on a surveyor's compass. Others merely contain a scale, the edge of which is used for sighting. A trough compass is countersunk along one edge of most traverse tables to facilitate orientation.

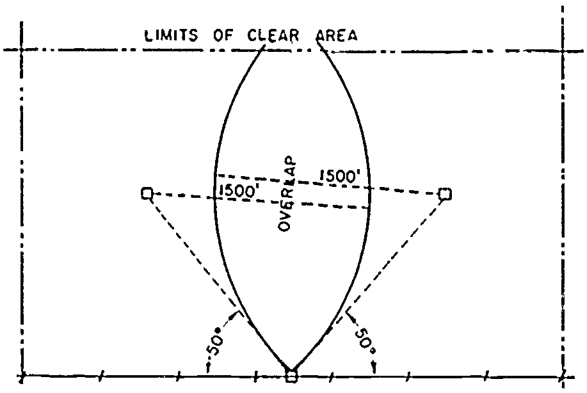
Special weather-resistant drawing paper is available for planetable work. The paper should be attached before the board is oriente.' and leveled.

Planetable Methods

There are four common methods of orienting the planetable, they are radiation, progression, intersection, and resection. Each of these methods is discussed separately below.

RADIATION.–In this method the detail in a circular area around the planetable is plotted from a single setup. Select a point on the drawing paper to represent the point on the ground. The planetable is set up over the point on the ground whose position has been previously plotted, or will be plotted, on the planetable sheet during the operation. The board is oriented either by using a magnetic compass for north-south orientation, or by sighting on another visible point whose position is plotted. The board is clamped and the alidade is pointed toward any new desired point using the plotted position of the setup ground station as a pivot. A line drawn along the straightedge, which is parallel to the line of sight, will give the plotted direction from the setup point to the desired point. Once the distance between the points is determined, it is plotted along the line to the specified scale. The plotted position represents the new point at the correct distance and direction from the original point. By holding the planetable orientation and pivoting the alidade around the setup point, the direction to any number of visible points can be quickly drawn. The distances to these points, determined by any convenient method as prescribed by the desired accuracy, can be plotted along their respective rays from the setup point. Thus, from one setup, the positions of a whole series of points can be established quickly. For mapping, the difference in elevation is also determined and plotted for each point. The map is completed by subdividing the distances between points with the correct number of contours spaced to represent the slope of the ground.

In clear, level country, detail within a radius of about 1500 ft can be located with reasonable accuracy. This means that, from four setups, an area of about a square mile can be covered. The clear area shown in figure 7-1 measures 3500 by about 2000 ft, or just about one-third square mile. Figure 7-2 shows how this rectangular clear area could be covered, with considerable overlap to spare, from two instrument points tied to the midpoint of the main base line.



82.41

Figure 7-2.—Planned planetable stations to cover a rectangular area.

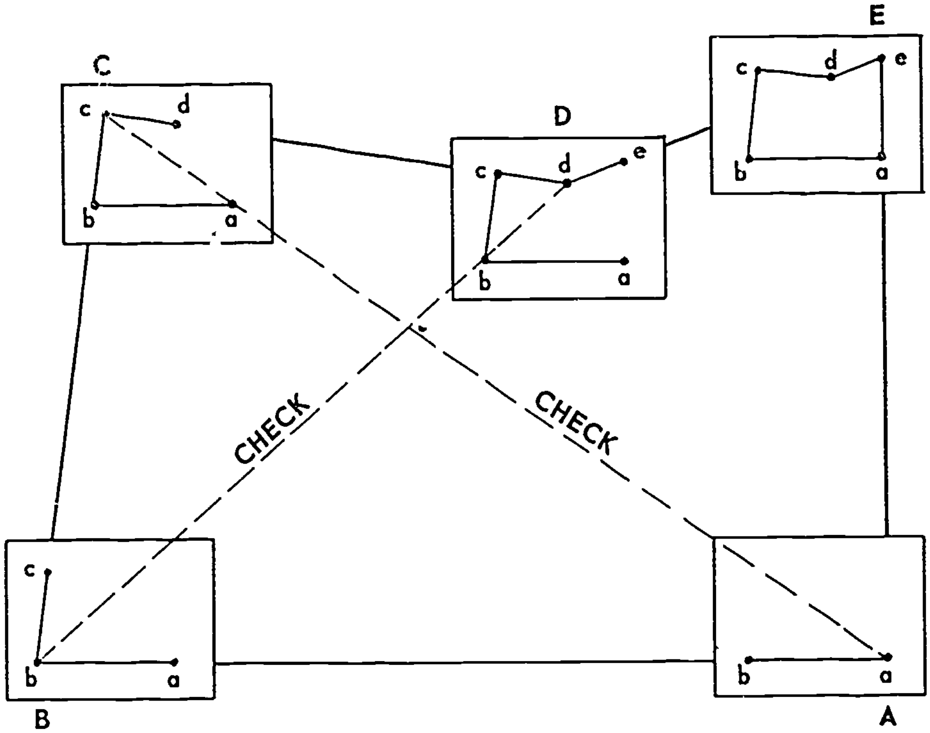
PROGRESSION.–In radiation, as you can see, successive planetable instrument points are located by triangulation. In progression, the planetable might be said to generate a traverse as it moves along. Figure 7-3 illustrates the method. Here the planetable progressed from station A through B, C, and D to E, thus plotting the closed traverse ABCDE. You locate your starting point on the paper so as to ensure that all the other stations on the traverse will lie within the margins of the paper, which of course involves selecting an appropriate distance scale as well.

Set up the table so that starting point a on the paper is directly over station A on the ground. Orient the board by aligning the edge of the blade with point a, sighting through the telescope on station B, and then pivoting the board so as to bring line ab (to be drawn along the edge of the blade) where you want it to come on the paper.

Determine the horizontal distance from station A to station B, and lay off ab to scale. Then shift to station B, plumb b on the paper over B on the ground, set the edge of the blade on b, backsight on station A, and bring ba in line with the edge of the blade. Then proceed with station C as you previously did with B.

INTERSECTION.—When two points which can be occupied by the planetable have already been plotted on the paper, the location of a third point can be plotted by determining the point of intersection of lines of direction from the already plotted points. This method, known as intersection, is illustrated in figure 7-4.

You wish to locate point X, and you have A and B plotted. Plumb point A on the paper over

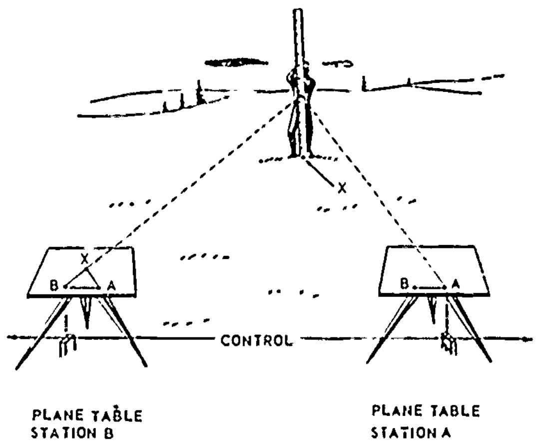


82.42

Figure 7-3.—Progression.

station A on the ground, set the edge of the blade on A, and line up the edge with line AB, as indicated in figure 7-4. Then revolve the board until the telescope is trained on point B on the ground. Now, keeping the edge of the blade on A on the paper, train the telescope on point X on the ground. The edge of the blade is now on the line from A on the ground to X on the ground; draw a line along the edge from A toward X.

Now shift the planetable to B on the ground, and repeat the procedure you carried out at A. You will wind up with two lines on the paper, one from A, the other from B, toward X. The point where these two lines intersect is the plotted location of X.

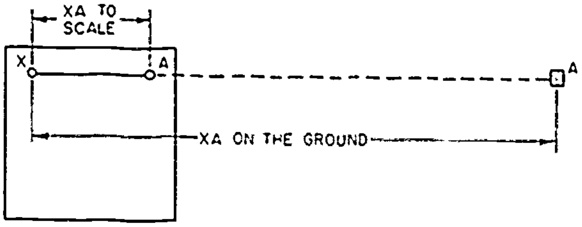


82.43

Figure 7-4.—Intersection.

RESECTION.—This method, like intersection, is one in which you have two points plotted and desire to locate a third. It varies from intersection in that, instead of occupying the already plotted points with the planetable, you occupy instead the point whose location is being sought.

Figure 7-5 illustrates the method. This figure shows one-point resection. Here you have a point of known location, A, and a point, X, whose location is desired. First measure the



82.44
Figure 7-5.—One point resection.

horizontal distance between A and X by an appropriate method. Then set up the planetable at X, train the telescope on A, orient the board so that XA will lie where you want it on the paper, and draw a line along the blade from A toward X. Lay off AX to scale on this line.

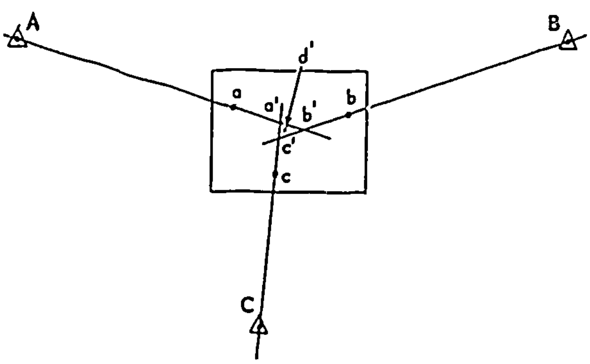
In THREE-POINT resection (familiarly called the THREE-POINT problem) you determine the location of a point with reference to three points of known location. The method is frequently used to locate minor triangulation stations with reference to major stations. Two common solutions are the LEHMANN TRIANGLE OF ERROR solution and the TRACING CLOTH or MECHANICAL solution.

Figure 7-6 illustrates the Lehmann solution. The figure shows three located points: A, B, and C. The planetable is set up over D, a point whose location is desired, and oriented as closely as possible, either by compass or by eye.

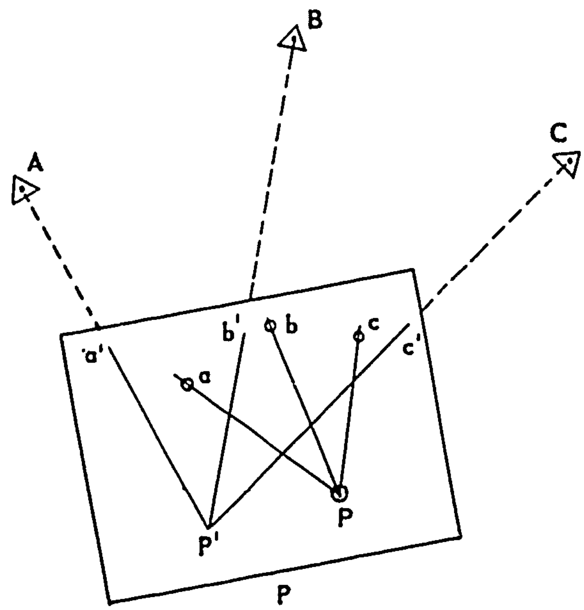
If the table were oriented correctly, resection lines from A, B, and C would intersect only at a point, d. In most cases, however, these lines intersect to form a small triangle (a′b′c′ in fig. 7-6), called the TRIANGLE OF ERROR. The correct location of d is at the center of this triangle.

In figure 7-6 the planetable is set up over a point which is inside the triangle formed by stations A, B, and C. Therefore, the plotted position d lies at the center of the triangle of error, and it is fairly easy to estimate where this center is. However, it could be the case that the point whose location is sought may lie outside of the triangle formed by the three located points. In a case of this kind you would use the tracing-cloth solution.

Observe figure 7-7, which illustrates the tracing-cloth solution. Here there are three located points, A, B, and C, and a point, P, whose location is desired, lying outside the triangle formed by A, B, and C. First, set up the planetable, on which is mounted the paper with a, b, and c plotted thereon, over P, and orient it as closely as possible. Then fasten a sheet of tracing cloth or transparent paper over the board, and locate P′ by sighting on A, B, and C. Draw in P′a′, P′b′, and P′c′.



82.45
Figure 7-6.—Triangle of error.



82.46
Figure 7-7.—Tracing cloth solution.

Now unfasten the tracing cloth, and move it into a position where these three lines pass through plotted points a, b, and c. P' on the tracing cloth will now be located at the correct location of point P.

Values of Planetable Method

Advantages of the planetable 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 minimize the overlooking of important data. Errors in measurement may be 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. The planetable method greatly reduces the number of field notes required, and consequently the number of computations. This in turn reduces the number of opportunities for errors and mistakes.
3. The graphic solutions of the planetable 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 planetable 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.

Disadvantages of the planetable method are as follows:

1. The planetable 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 planetable work impossible.
3. The use of the planetable is limited to relatively level, open country.

SURVEY SUPPORT FOR GEOLOGY AND PEDOLOGY

This section discusses surveys in support of geology and pedology. In essence, it is a topographic survey, however, you must be aware of the other specialized data that may be included as required by the Geologist or the Soil Engineer when collecting data for engineering studies for naval construction projects.

SURVEY SUPPORT FOR GEOLOGY

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 topographic 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 ground water and mineral resources that the rock 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 geologic 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 Forces planning and operations. Construction Forces requirements may necessitate regional geologic study and mapping, surveys of more limited areas, or the development of detailed geologic data at a construction site.

Methods of Geologic Surveying

Most geologic 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, whether 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 rock bedding, and development of joints or fractures. In addition, the age of the rock is determined 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. To amplify 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 the results of geologic investigations are plotted and by making such tie measurements to geologic features as the geologist may require.

The geologist uses simple survey methods in plotting geologic 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 relation of a geologic 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 geologic survey is keyed to a large-scale plan, the geologist generally uses a planetable and data is plotted with accuracy commensurate with the accuracy of the base plan.

Base Map Surveys

The survey for the base map should precede the geologic 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 geologic survey, since the geologist can use the aerial photograph as a plotting base and later transfer the data to a base map. However, where possible, the base map should be prepared in advance as the number of aerial photographs needed to cover an area is generally too large to be handled in the field.

Planetable 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 planetable traverses run in closed circuits or between known control stations of a higher order of accuracy, or locate planetable 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, stadia or graphical triangulation to locate points and station. 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. Sideshot points located by pacing or other rough measurements should be accurate to within 25 ft. Sights for traverse lines or graphical triangulation should be taken 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 planetable, 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 which will be plotted by protractor to the nearest quarter-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, planetable or compass traverses are suitable.

Use of Aerial Photographs

If aerial photographs are available, the geologist generally uses them in the field in lieu 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 forms 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 detail from an uncontrolled mosaic with spot elevations added from field surveys. Use of contact prints of aerial photographs by the geologist in place of the base map is satisfactory, 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 geologic data commensurate with the accuracy of the final plan.

Map Bases for Detailed Geologic Surveys

Detailed geologic 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 PROFILES.–Geologic data affecting foundation design 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. Planetable 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 it is better to locate points which are actually on the contours or to determine elevations at the intersection of closely spaced grid lines staked out on the site rather than to use the method of contouring specified earlier in this section. 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 geologic survey is a complete topographic map or plan with relief expressed by contours. Colors and symbolization of basic details are simple so that they will not conflict with the overlay of geologic information that is shown by colors and symbols. Published topographic maps are used where suitable. The geologic 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 are generally used to satisfy this requirement, rather than using other maps of a larger scale. This permits the direct reduction of geologic data to the scale of the final map with a minimum amount of drafting.

When no topographic map is available or if 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 using precise instrument methods, such as multiplex, 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 half-foot.

SURVEY IN SUPPORT FOR PEDOLOGY

If 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, the pedological survey is conducted under the direction of the soils engineer, and the surveyors mission is 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 outcroppings on maps, overlays, and sketches for subsequent engineering uses. The following approaches may be used in conjunction with soils survey operation.

1. Aerial photography may be used when an extensive area is to be surveyed. Usually there are no survey measurements required in this case.

2. Maps of an area of several square miles in extent 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 analysts 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 facilitates 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. The survey party chief prepares, according to the soils analyst's instructions, maps or overlays upon which are plotted the control and ties to pedological features. The pedological interpretation of aerial photographs is the responsibility of the terrain analysts.

Planetable Traverse

The planetable 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 a telescopic alidade.

4. DISTANCE MEASUREMENTS. Pace or rough tape. When a telescopic alidade is available, use stadia measurements where possible with a view to reducing the time required for the survey rather than increasing 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, then 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 with care to maintain directions of an accuracy comparable to distances.

9. TOPOGRAPHY. 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, rough topography, obtained by clinometer, pocket transit, or sta-

dia, may be required to facilitate the location of a favorable route.

Compass Traverse

The compass traverse is more convenient in heavily wooded areas although more time is required for plotting than is the case with planetable traversing. Traverse lines between stations should be long in order 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 it is necessary to retrace the traverse. In the absence of detailed instructions from the soils engineer, the basic guides for planetable traverse apply.

Field Sheets and Site Plans

The survey engineer must furnish the soils analysts 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 analysts 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 tying 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.

CHAPTER 8

HORIZONTAL AND VERTICAL CURVES

The surveyed centerline of a road or highway consists of a series of straight lines and curves. Many people may rate a highway as smooth or bumpy; however, surveyors and engineers will be concerned about its physical and safety features. When you consider its horizontal alignment or changes in horizontal direction, you will be concerned with HORIZONTAL CURVES, when you think about slopes (the rise and fall), you will be concerned with VERTICAL CURVES. It is the introduction of these curves that makes modern travel more comfortable and enjoyable.

As an EA1 or EAC you might have to design these curves yourself, 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 employed 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.

HORIZONTAL CURVES

When a highway changes horizontal direction, it is not feasible to make the point where it changes direction a point of intersection between two straight lines. The change in direction would be too abrupt for the safety of modern, highspeed 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 modern highways, the curves are CIRCULAR curves; that is, curves which form circular arcs. The smaller the radius of a circular curve, the sharper the curve. For modern, high-speed highways the curves must be very flat, rather than sharp, meaning that they must be large-radius curves.

COMPUTATION OF HORIZONTAL CURVES

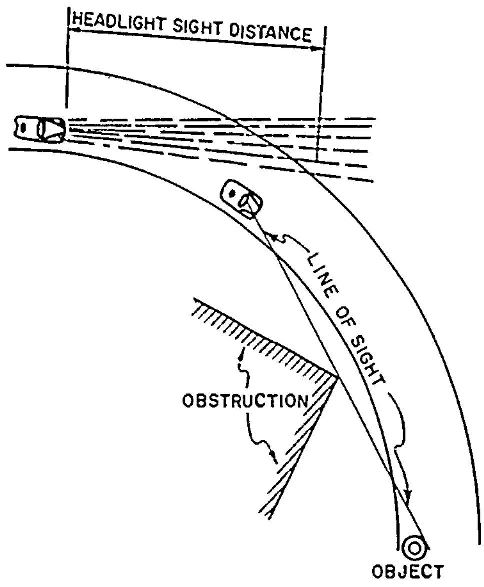
In highway work, the curves needed for the location of improvement of small secondary roads may be worked out in the field. Usually, however, the horizontal curves are computed after the route has been selected, the field surveys have been done, and the survey base line and necessary topographic features 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 purpose of the design; but in urban work the streets and their curves are of secondary importance, and the best utilization of the building sites is of primary importance.

The design of the curve consists principally of selecting the length of the radius (or "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 (see fig. 8-1). Typical radii which 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.

ELEMENTS OF A CURVE

Refer to figure 8-2, which shows some of the elements of a circular curve.

P.C. Point of curvature. Also designated B.C. (beginning of curve) or T.C. (tangent to curve).



45.339

Figure 8-1.–Lines of sight.

P.I. Point of intersection of tangents. Also designated designated V (vertex).

P.T. Point of tangency. Also designated E.C. (end of curve) or C.T. (curve to tangent).

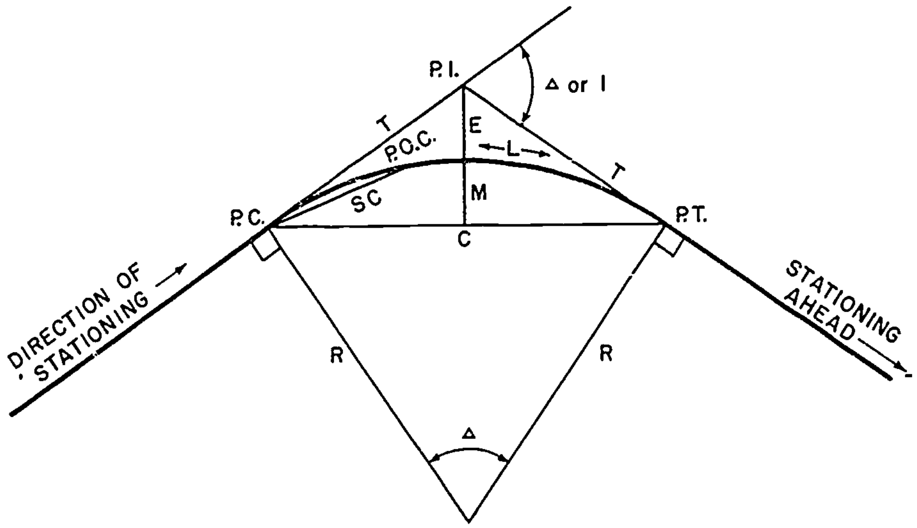
Δ (I) (Greek letter delta). Central angle; that is, the angle which subtends the total arc of the curve. Is always equal to the deflection angle at the P.I. Also designated I (intersection).

R Length of the radius. The radius is always perpendicular to the back tangent at the P.C. and to the tangent ahead at the P.T.

L Length of the curve. Also designated A (arc).

T Tangent distance. The distance from the P.I. to the P.C., or the distance from the P.I. to the P.T. Said distances are always equal.

P.O.C. Any point on the curve.



45.340

Figure 8-2.–Curve elements.

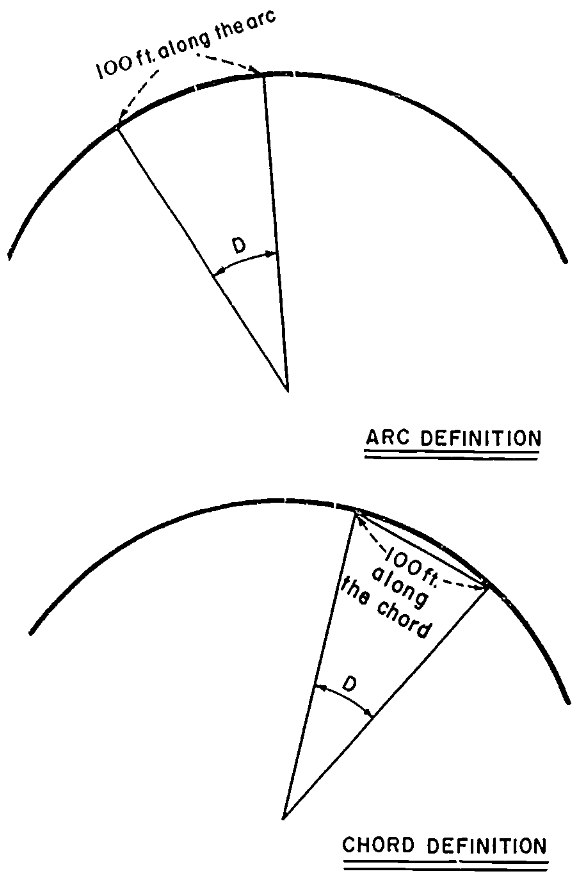
C Chord distance. The straight line distance from the P.C. to the P.T. Called the LONG CHORD (L.C.) to distinguish it from any other shorter chord, such as the one labeled SC in the illustration.

E External distance: from the P.I. to the midpoint of the curve. Also called the external secant.

M Middle ordinate. Distance from the midpoint of the curve to the midpoint of the long chord.

DEGREE OF CURVATURE

An element of a curve that deserves separate attention is the DEGREE OF CURVATURE (D). Curvature may be identified by simply stating the length of the radius of the curve; this was done earlier in the chapter when typical radii for various roads were cited and is commonly done in land surveying, and in the design of urban streets. But in highway and railroad work, the curvature is defined by the degree of curvature. There are two definitions of the degree of curvature; both are illustrated in figure 8-3. According to the ARC DEFINITION, the degree of curvature is the central angle which subtends 100 feet measured along the ARC of the curve. According to the CHORD DEFINITION, the degree of curvature is the central angle which subtends a portion of the curve which has a CHORD of 100 feet. 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 for that portion is 12°, then you have a curve for which the degree of curvature (arc definition) is 12° or, as commonly stated, you have a "12° curve". If you take a flat curve, mark a 100-foot CHORD, and determine the central angle to be 0°30′, then you have a "thirty-minute curve, chord definition." The chord definition is used in railraod practice and in some highway work. The chord definition was adopted because of its practical application in the field. When you measure around a curve with a 100-foot tape, you are measuring a series of 100-foot chords. The arc definition is widely used in highway practice because it facilitates the complex computations needed for modern highway design.

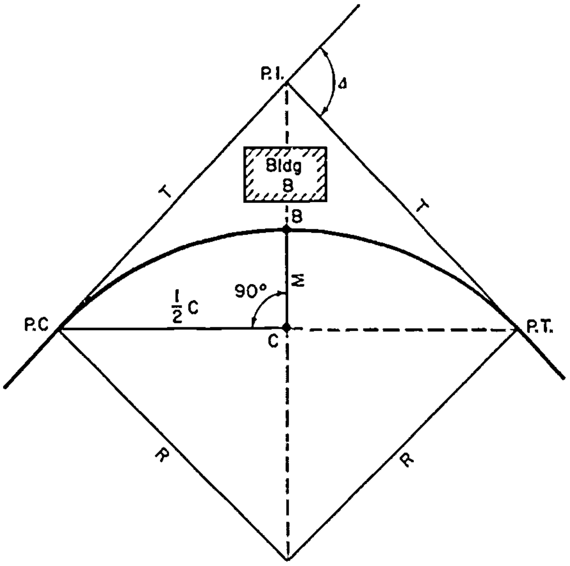


45.341

Figure 8-3.—Degree of curvature.

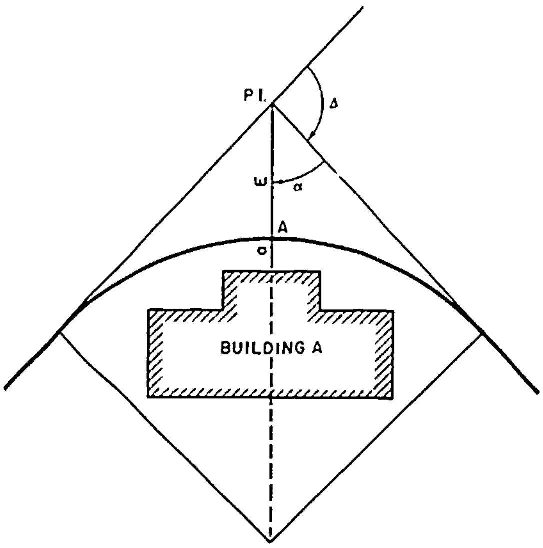
CURVE FORMULAS

The relationship between the elements of a curve are expressed in a variety of formulas. Generally, if you know two elements, you can compute the other elements. This is not true, however, in the case of R and D, because as explained before, they are both expressions of curvature. Which factors are given will vary with the job. On a highway project, the Δ at the P.I. (or I) will have been measured in the field and then the design criteria will indicate the required D (or R). On urban streets, the Δ might be protracted from the preliminary plan and the T or R measured on the plan. The T and L must be computed in most cases so that you may properly station the curve (explained later.) The M or E may control the design of a curve or provide a check on the design of a curve to meet field conditions. Suppose that the alignment of a road is being established in the field, and that the location of the tangents has been decided upon (fig. 8-4). Therefore the Δ may be measured in the field, providing one given element for the computations. Suppose it is decided that the curve should be distance "a" off the center front of building A. Turn angle α (alpha), which is $\frac{180° - \Delta}{2}$, at the P.I. and measure down to point A; the measured distance is the E of the curve. Thus a second element is provided, permitting the complete computation of the curve. Or suppose, in another case as shown in figure 8-5, that the alignment of the tangents has been determined, Δ measured, and a tentative P.C., P.T., and T selected. Suppose further that it is desired to check whether the resulting curve clears building B. Using the formulas presented in this section, compute C and M. Lay off 1/2 C, occupy point C, turn 90° and lay off M, setting point B. Then observe whether or not the clearance of building B is satisfactory. Of the many curve formulas that may be developed, the formulas in this section are a few that are commonly used in practice.



45.343

Figure 8-5.–Checking by use of M.



45.342

Figure 8-4.–Measuring E.

Radius and Degree of Curvature

In the case of the arc definition, figure 8-6, the ratio between D (the angle subtended by 100 ft of arc) and 360° (angle subtended by a complete circle) is the same as the ratio between 100 ft of arc and the circumference of a circle having the same radius. Circumference equals 2πR; therefore,

$$\frac{D}{360} = \frac{100}{2\pi R}$$

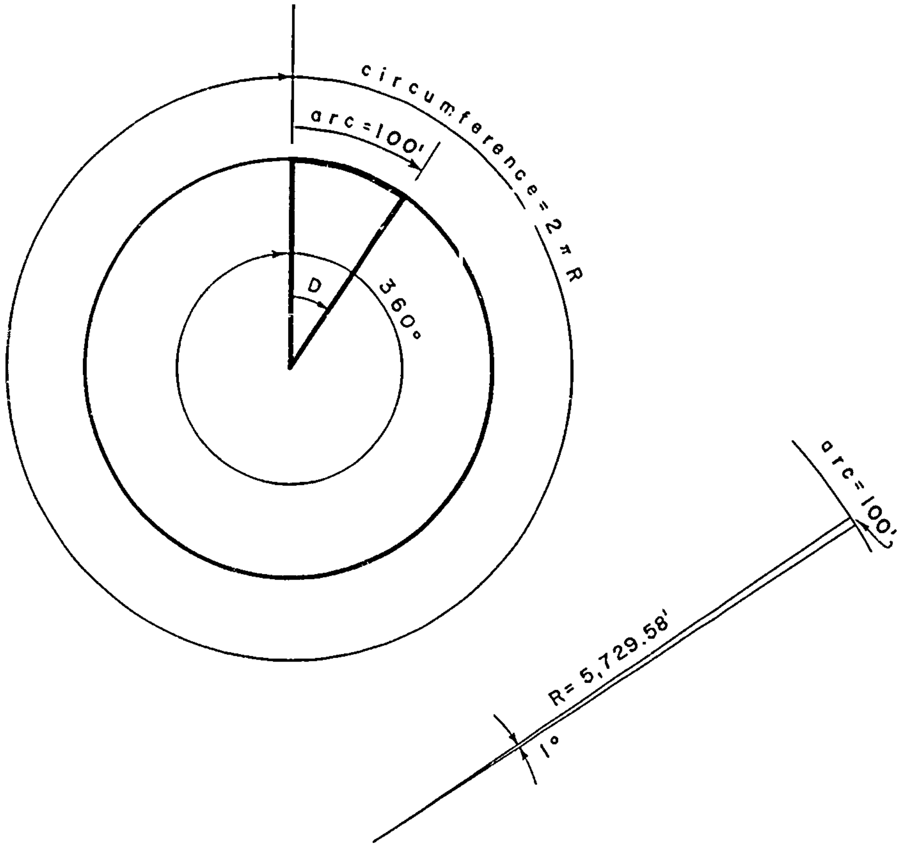
solving for R:

$$R = \frac{100 \times 360}{2\pi D}$$

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

and also:

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



45.344

Figure 8-6.—R and D, arc definition.

For a 1° curve, D = 1, therefore R = 5,729.58 ft.

In the case of the chord definition, figure 8-7, D subtends a 100-ft chord. In the right triangle,

$$\sin \frac{D}{2} = \frac{50}{R}$$

solving for R:

$$R = \frac{50}{\sin \frac{D}{2}}$$

For a 1° curve, D/2 is 0°30′, and the value for R computes to be 5,729.65 ft.

You will notice that the radii for 1° curves by the two definitions have very nearly the same value: 5,729.58 as opposed to 5,729.65. For some calculations not requiring great precision, the rounded-off value of 5,730 feet is used for the radius of a 1° curve.

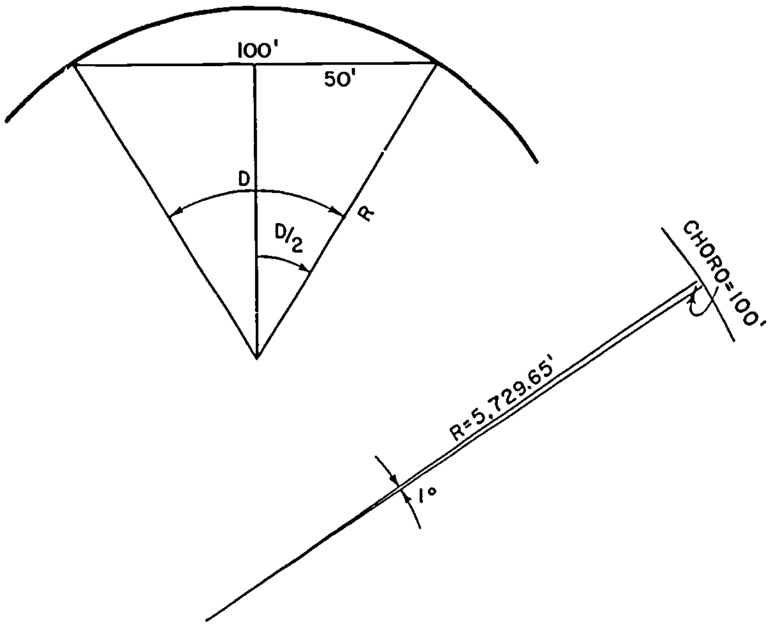
Tangent Distance

If you study figure 8-8, you will see that the solution for T (tangent distance from P.C. or from P.T. to P.I.) is a simple right-triangle solution. T is one of the shorter sides of a right triangle; R is the other shorter side. T is the side opposite an angle which measures $\frac{\Delta}{2}$. Therefore,

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

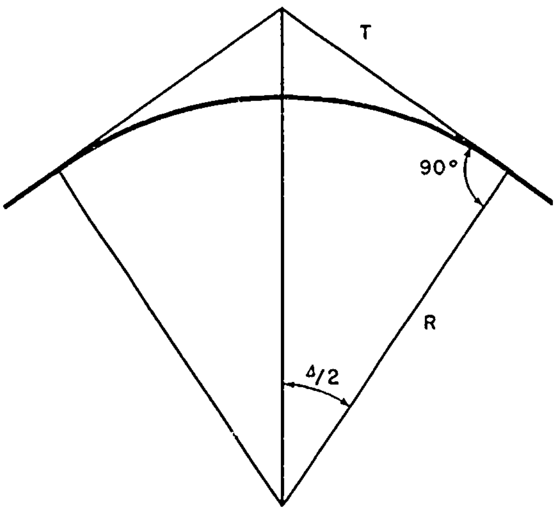
and solving for T,

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



45.345

Figure 8-7.–R and D, chord definition.



45.346

Figure 8-8.–Tangent distance.

Chord Distance

The solution for the length of C is again a simple right-triangle solution. (See fig. 8-9.) One-half of C is one of the shorter sides of a right triangle; R is the hypotenuse of the same triangle. One-half C is the side opposite an angle equal to $\frac{\Delta}{2}$.

Therefore,

$$\sin \frac{\Delta}{2} = \frac{C/2}{R}$$

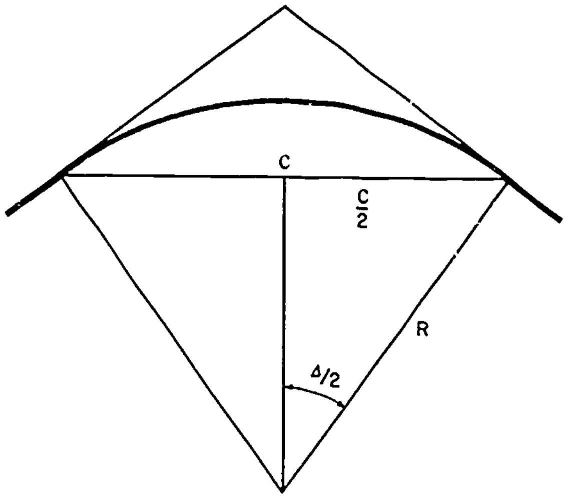
Solving for C:

$$C/2 = R \sin \Delta/2$$
$$C = 2R \sin \Delta/2$$

Middle Ordinate and External Distance

Two commonly used formulas for M and E are:

$$M = R\,(1 - \cos \Delta/2)$$
$$E = T \tan \Delta/4$$



45.347
Figure 8-9.—Chord distance.

Length of Curve

In the arc definition of the degree of curvature, length is measured along the arc. The relationship between L and a complete circle of the same radius, and Δ and the central angle of a complete circle (360°), may be expressed as (see fig. 8-10A)

$$\frac{L}{2\pi R} = \frac{\Delta}{360}$$

from which

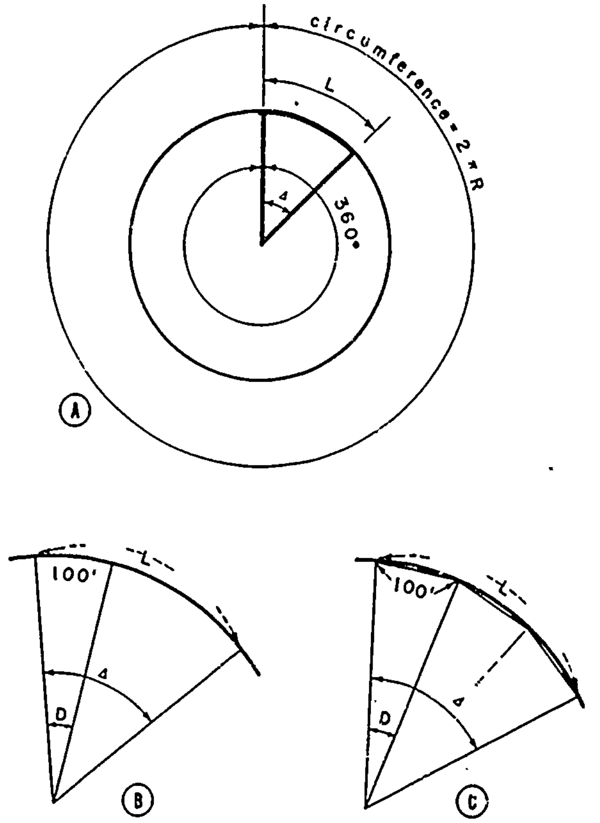
$$L = \frac{2\pi R\Delta}{360}$$

Since there are 2π radians in a circle the number of radians corresponding to a given Δ are:

$$\frac{\Delta}{360} \times 2\pi$$

Note that in the equation $L = \frac{2\pi R\Delta}{360}$, the R is the only factor not included in the expression above for the number of radians. Therefore, the arc length may be expressed:

$$L = R \times \Delta \text{ in radians.}$$



45.348
Figure 8-10.—Length of curve.

This expression is frequently used to compute A by referring to a table of radians (sometimes called a "table of arc lengths for unit radius").

The relationship between D (see fig. 8-10B) and Δ and L and a 100-foot arc length may be expressed:

$$\frac{L}{100} = \frac{\Delta}{D}$$

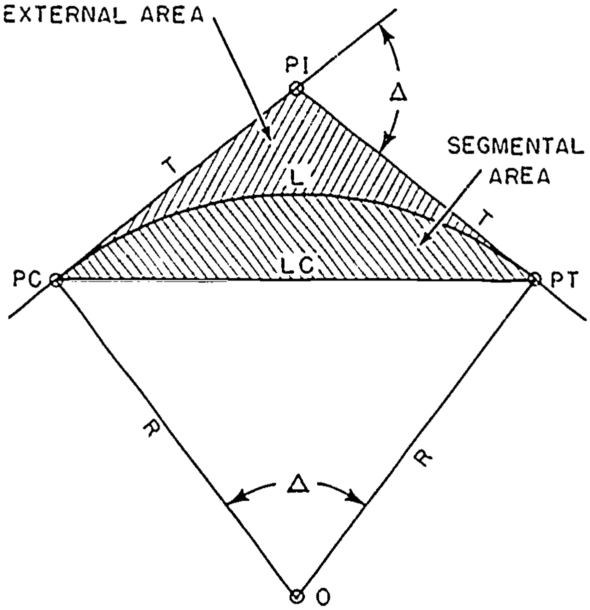
from which

$$L = 100\frac{\Delta}{D}$$

This expression is also applicable to the chord definition (see fig. 8-10C). But L in this case is not the true arc length, because, in the expression $L = 100\ \frac{\Delta}{d}$ ' $\frac{\Delta}{D}$ indicates the number of 100-foot CHORD lengths and not the number of 100-foot ARC lengths.

Curve Areas

It is frequently necessary, whe computing land areas, to determine certain areas bounded by elements of the curve. Two of these areas, which may be called the SEGMENTAL AREA (SA) and the EXTERNAL AREA (EA), are shown in figure 8-11.



82.172

Figure 8-11.—Curve areas.

Formulas which may be used to compute these areas are:

$$SA = R/2\,(A - R \sin \Delta)$$
$$EA = R\,(T - A/2)$$

A computational check may be made by comparing the sum of these two computations against the value determined by using the formula

$$SA + EA = C/2 \times C/2 \times \tan \Delta/2.$$

In order to get an exact check on your computations, you may have to use, for computational purposes, a greater number of significant digits for the elements (A, C, T, etc.) than you would normally need for stakeout.

An example of a computation of the areas follows.

GIVEN:
$R = 400.00$ ft.
$\Delta = 42°06'24''$
$C = 287.39$ ft.
$T = 153.973$ ft.
$L = 293.960$ ft.

TO FIND: EA, SA, and SA + EA

SOLUTION:
$SA = R/2\,(A - R \sin \Delta)$
$SA = 400.00/2\,(293.960 - (400.00 \times 0.670513)$
$SA = 200.00\,(293.960 - 268.205)$
$SA = 200.00\,(25.755)$
$SA = 5{,}151$ sq. ft.
$EA = R(T - L/2)$
$EA = 400.00\,(153.973 - (293.960/2))$
$EA = 400.00\,(153.973 - 146.980)$
$EA = 400.00\,(6.993)$

$EA = 2{,}797$ sq. ft.

The sum of the two computations above is:

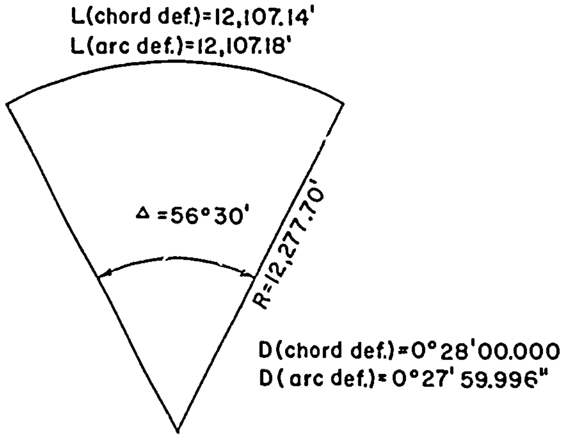
$$SA + EA = 5{,}151 + 2{,}797 = 7{,}948 \text{ sq. ft.}$$

To check the above:

$SA + EA = C/2 \times C/2 \times \tan \Delta/2$
$SA + EA = 287.39/2 \times 287.39/2 \times \tan 21°03'12''$
$SA + EA = 143.695 \times 143.695 \times 0.394932$
$SA + EA = 2064.825 \times 0.384932$
$SA + EA = 7.948$ sq. ft.

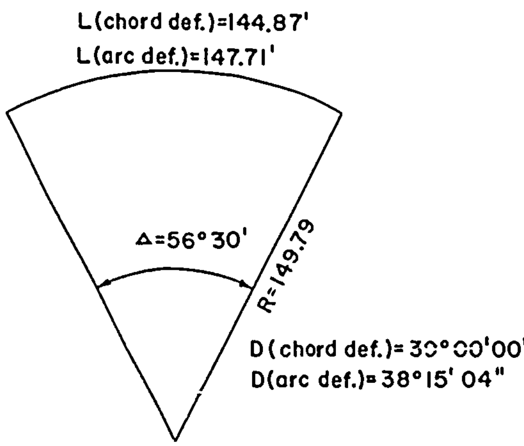
DEGREE OF CURVATURE COMPUTATIONS

The magnitude of the numerical differences between the arc and chord definitions of the degree of curvature is indicated in figures 8-12 and 8-13. In figure 8-12 you are given a curve of 12,277.70 ft. radius with a Δ of 56°30′. From tables (discussed later) you find that the D (chord def.) is 0°28′00″, which is 0.46666667° in terms of decimals of a degree. From before,



45.349.1

Figure 8-12.—Example 1: Degree of curvature computations.



45.349.2

Figure 8-13.—Example 2: Degree of curvature computations.

$L = 100\frac{\Delta}{D}$. Substituting, $L = \frac{100 \times 56.500000}{0.46666667} =$ 12,107.14 ft. (chord def.). For the length by the arc definition you may use $L = \frac{2\pi R\Delta}{360}$. Using the given radius, L computes to be 12,107.18 feet (arc def.). To find D (arc def.), you may use the relationship $L = 100\frac{\Delta}{D}$, which may be arranged $D = \frac{100\Delta}{L}$. Since you know Δ and L, you may substitute and find that D (arc def.) = 0.46666543° or 0°27′59.996″. As you can see, there is very little difference between the L's and D's for a curve of such long radius.

Now refer to figure 8-13. Again you are given a Δ of 56°30′. But you are now given a short radius of 149.79 feet. From tables based on the chord definition, you may determine that D (chord def) = 39°00′00″. Using $L = 100\frac{\Delta}{D}$, you find L (chord def.) = 144.87 feet. Using the same procedures as for the long radius curve, you find D (arc. def.) = 38°15′04″ and L (arc def.) = 147.71 feet. Compare the D's and L's and you will see that there is a marked difference.

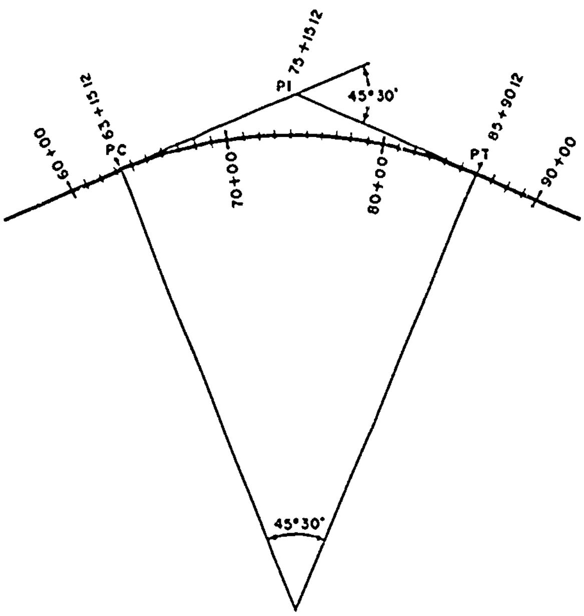
In these examples, the Δ and R were held in each case, and the D and L computed for each definition. The same magnitude of differences may be shown by holding any two of the elements (except, of course, R and D) and computing the others. From this demonstration you should learn two important facts. First, that you must always determine whether arc or chord definition is intended when D is specified. Second, that the numerical differences between the arc and chord definitions are much more significant on short radius curves than on long radius curves.

PLOTTING AND STATIONING A CURVE

You now have all the formulas you need to make a basic analysis and a plot of a horizontal curve. The data you have given is the location of the P.I., the size of Δ (the central angle), and the degree of curvature (D). We'll assume that the degree of curvature (arc definition) is 2°00′, that the location of the P.I. is station 75 + 15.12, and that the size of Δ is 45°30′.

Begin by plotting the tangents from the P.I. as illustrated in figure 8-14. Draw one of the tangents at a convenient angle on the paper, and draw the other at a deflection angle of 45°30′. Mark the point of intersection (P.I.) with the station (75 + 15.12).

The next step is to locate the P.C. and the P.T. by computing T. To compute T, you must first compute R, which is 5,729.58/D, or 5,729.58/2, or 2,864.79 ft. T equals 2,864.79



45.350

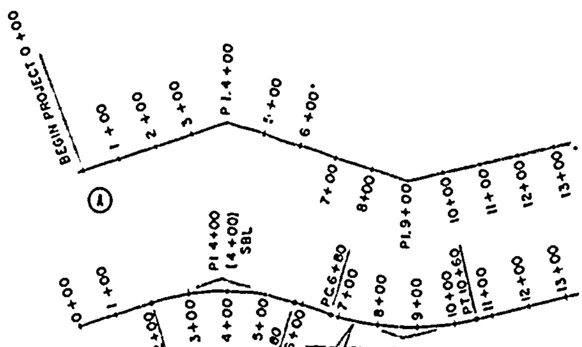
Figure 8-14.—Plotting a curve.

tan 1/2 Δ, or 2,864.79 tan 22.75°, or (by slide rule) 1200 ft. For more precise values, you will have to use logs or a calculating machine.

Select a suitable scale on the engineer's scale, and measure off 1200 ft on the tangents from the P.I. This locates the P.C. and the P.T. Draw the radii from the P.C. and the P.T. by erecting perpendiculars to the tangents. Each radius should scale 2,864.79 ft. and the angle between them should measure 45°30′. If this is not the case, you have made a mistake somewhere.

Compute and set down the stations of the P.C. and P.T. The station of the P.C. is (7515.12 - 1200), or 6315.12, or 63 + 15.12. The station of the P.T., however, is DEFINITELY NOT (7515.12 + 1200), or 8715.12, or 87 + 15.12, and you must avoid the common mistake of assuming that it is. The distance from the P.C. to the P.T. is the LENGTH OF THE CURVE or L. To compute the station of the P.T., you must compute L and add it to the station of the P.C. L equals 100 Δ/D or 100 x 45.5/2 or 2275.00 ft. The station of the P.T., then, is (6315.12 + 2275.00), or 8590.12, or 85 + 90.12.

In highway work, the SURVEY BASE LINE, which is run in the field before the curves are designed, is generally stationed as shown in figure 8-15, example A. After the curves are computed, new stationing is set on the centerline, using the lengths of the curves in the manner just described. The new P.I. stations are based on stationing back, not ahead. Reference may be made on the plans to the original SBL stations of the P.I.'s as shown in figure 8-15, example B. In some cases, where there are few curves, for example, you may find it desirable to use the original stationing on the tangents and establish an EQUALITY at the P.T., as shown in figure 8-15, example C. At an equality, the stationing value for the line back is different from the stationing value of the line ahead. In the illustration, the difference between the L and the sum of the T's is reflected in the difference of the stationing back and ahead. Equalities are also used to correct for revisions to the centerline alignment after the final stationing has been set, and also to correct for errors or mistakes in fieldwork or computations. An equality is sometimes marked on the plan with a distinctive symbol to help direct attention to the change in stationing.



45.351

Figure 8-15.—Stationing curves.

TABLES OF CURVE FUNCTIONS

Many of the elements of curves you have computed may be obtained more easily, particularly in the field, from tables.

Radii

Figure 8-16 shows a page from a table of RADII AND THEIR LOGARITHMS. This table contains the radii and their logarithms for curves of every degree of curvature, chord definition, to the nearest minute, from 0° to 40°. As you can see, the radius for the 2-degree curve used in the last section is listed as 2864.93 ft; for the arc definition, we got 2864.79 ft. Next to the radius is the log of the radius.

Functions of a 1° Curve-Arc Definition

Figure 8-17 shows a page from a table of FUNCTIONS OF A 1° CURVE, arc definition, using R = 5730. This table lists, under central angles to the nearest minute from 0° to 106°, the L.C., M, E, and the T of a 1° curve. To get the L.C., M, E, or T for a curve other than a 1° curve, you divide the listed value by D, the degree of curvature. For us, D equals 2°. Under 45° and beside 30′ the listed T is 2402.8. This is T for a 1° curve with a Δ of 45°30′. For our 2° curve, T equals 2402.8/2, or 1201.4 ft.

The explanation of why dividing a tabular value by your given degree of curvature (D) will give you the value for that particular curve is as follows. You know that, for any given horizontal curve, T = R tan 1/2 Δ, and R = 5730/D. Therefore, substituting 5730 for R in the first equation, $T = \frac{5730 \times \tan 1/2\Delta}{D}$. The values given for T in the table are derived from this formula, with a D in each case of 1°. For example. for a curve with a central angle (Δ) of 5°, the listed value of T is 250.17. If you work out the formula $\frac{5730 \tan 2.5^\circ}{1}$ you will find that the result is 250.17. You can see that, to get the value for a D of other than 1°, you would simply substitute that D for the 1 in the formula. To divide the result of the formula by the specific D amounts to the same thing.

The explanation with regard to the L.C. is similar. For any horizontal curve, L.C. = 2R sin 1/2 Δ. Substituting 2(5730/D) for 2R, L.C. = $\frac{11460 \sin 1/2\Delta}{D}$ The values in the table are derived from this formula, with a D in each case of 1°. To convert a tabular value to a value for a D of other than 1°, you simply divide the tabular value by the specific D.

The procedure for the determination of M and E are, again, similar. For a curve of given Δ, divide the tabular M or E by the given D to obtain the final value of M or E.

Precision of Computations

The values in the table of functions of a 1° curve shown in figure 8-17 are based on a 1° curve having a radius of the rounded-off value of 5730 feet instead of the more precise value of 5729.58 feet (arc definition) presented earlier in the chapter. This difference won't matter for many types of computations, but there are times when you may be using numbers with so many significant figures that the table will not provide the proper precision. For example, the curve in figure 8-12 has a radius of 12,277.7 feet (to six significant figures) and a Δ of 56°30′ Using the formula L.C. = 2R sin Δ/2 you get L.C. = 11,622.6 feet. But, using the table, you enter under Δ = 56°30′ (not shown in the figure) and get L.C. = 5424.1 for the 1° curve (based on an R rounded off at the fourth significant figure). Divide by D (which is 0.466665°) and you get L.C. = 11,623.1 feet; a difference from using the formula of 0.5 foot too much for some types of computations. This example points out the necessity of being aware of the number of significant figures involved in your calculations. For most fieldwork, however, tables such as those shown will give you answers of sufficient precision.

Functions of a 1° Curve—Chord Definition

In the table shown in figure 8-17, the values of L.C., M, E, and T are exact for the arc definition only, not the chord definition. This is

Deg. D.	Radius R.	Log. R.	Deg. D.	Radius R.	Log. R.	Deg. D.	Radius R.	Log. R.
° ′			° ′			°		
0 0	∞	∞	1 0	5729.65	3.758128	2 0	2864.93	3.457115
1	343774.68	5.536274	1	5635.72	.750950	1	2841.26	.453511
2	171887.34	.235244	2	5544.83	.743888	2	2817.97	.449937
3	114591.56	.059153	3	5456.82	.736939	3	2795.06	.446392
4	85943.67	4.934214	4	5371.56	.730100	4	2772.53	.442876
5	68754.94	4.837304	5	5288.92	3.723367	5	2750.35	3.439388
6	57295.79	.758123	6	5208.79	.716737	6	2728.52	.435928
7	49110.68	.691176	7	5131.05	.710206	7	2707.04	.432495
8	42971.84	.633184	8	5055.59	.703772	8	2685.89	.429089
9	38197.20	.582031	9	4982.33	.697432	9	2665.08	.425710
10	34377.48	4.536274	10	4911.15	3.691183	10	2644.58	3.422356
11	31252.26	.494881	11	4841.98	.685023	11	2624.39	.419029
12	28647.90	.457093	12	4774.74	.678949	12	2604.51	.415727
13	26444.22	.422331	13	4709.33	.672959	13	2584.93	.412449
14	24555.35	.390146	14	4645.69	.667051	14	2565.65	.409197
15	22918.33	4.360183	15	4583.75	3.661221	15	2546.64	3.405968
16	21485.94	.332154	16	4523.44	.655469	16	2527.92	.402763
17	20222.06	.305825	17	4464.70	.649792	17	2509.47	.399582
18	19098.61	.281002	18	4407.46	.641489	18	2491.29	.396424
19	18093.43	.257521	19	4351.67	.638656	19	2473.37	.393289
20	17188.76	4.235244	20	4297.28	3.633194	20	2455.70	3.390176
21	16370.25	.214055	21	4244.23	.627799	21	2438.29	.387085
22	15626.15	.193852	22	4192.47	.622470	22	2421.12	.384016
23	14946.75	.174547	23	4141.96	.617206	23	2404.19	.380969
24	14323.97	.156064	24	4092.66	.612005	24	2387.50	.377943
25	13751.02	4.138335	25	4044.51	3.606866	25	2371.04	3.374938
26	13222.13	.121302	26	3997.48	.601787	26	2354.80	.371954
27	12732.43	.104911	27	3951.54	.596766	27	2338.78	.368990
28	12277.70	.089117	28	3906.64	.591803	28	2322.98	.366046
29	11854.33	.073877	29	3862.74	.586896	29	2307.39	.363122
30	11459.19	4.059154	30	3819.83	3.582044	30	2292.01	3.360217
31	11089.54	.044914	31	3777.85	.577245	31	2276.84	.357332
32	10743.00	.031125	32	3736.79	.572499	32	2261.86	.354466
33	10417.45	.017762	33	3696.61	.567804	33	2247.08	.351618
34	10111.06	.004797	34	3657.29	.563160	34	2232.49	.348789
35	9822.18	3.992208	35	3618.80	3.558564	35	2218.09	3.345979
36	9549.34	.979973	36	3581.10	.554017	36	2203.87	.343187
37	9291.25	.968074	37	3544.19	.549517	37	2189.84	.340412
38	9046.75	.956492	38	3508.02	.545063	38	2175.98	.337655
39	8814.78	.945212	39	3472.59	.540654	39	2162.30	.334915
40	8594.42	3.934216	40	3437.87	3.536289	40	2148.79	3.332193
41	8384.80	.923493	41	3403.83	.531968	41	2135.44	.329488
42	8185.16	.913027	42	3370.46	.527690	42	2122.26	.326799
43	7994.81	.902808	43	3337.74	.523453	43	2109.24	.324127
44	7813.11	.892824	44	3305.65	.519257	44	2096.39	.321471

45.45.4

Figure 8-16.—Sample page from table of radii and their logarithms.

	44°				45°				
	L. C.	M.	E.	T.	L. C.	M.	E.	T.	
0	4293.0	417.2	450.0	2315.1	4385.5	436.2	472.1	2373.4	0
2	4296.1	417.8	450.7	2317.0	4388.6	436.8	472.9	2375.4	2
4	4299.2	418.4	451.5	2319.0	4391.7	437.5	473.6	2377.3	4
6	4302.2	419.1	452.2	2320.9	4394.7	438.1	474.4	2379.3	6
8	4305.3	419.7	452.9	2322.8	4397.8	438.8	475.1	2381.2	8
10	4308.4	420.3	453.7	2324.8	4400.9	439.4	475.9	2383.2	10
12	4311.5	421.0	454.4	2326.7	4404.0	440.0	476.6	2385.2	12
14	4314.6	421.6	455.1	2328.7	4407.0	440.7	477.4	2387.1	14
16	4317.7	422.2	455.9	2330.6	4410.1	441.3	478.1	2389.1	16
18	4320.7	422.9	456.6	2332.6	4413.2	442.0	478.9	2391.0	18
20	4323.8	423.5	457.3	2334.5	4416.3	442.6	479.6	2393.0	20
22	4326.9	424.1	458.1	2336.4	4419.3	443.2	480.4	2394.9	22
24	4330.0	424.8	458.8	2338.4	4422.4	443.9	481.1	2396.9	24
26	4333.1	425.4	459.5	2340.3	4425.5	444.5	481.9	2398.8	26
28	4336.2	426.0	460.3	2342.3	4428.6	445.2	482.6	2400.8	28
30	4339.2	426.7	461.0	2344.2	4431.6	445.8	483.4	2402.8	30
32	4342.3	427.3	461.7	2346.1	4434.7	446.4	484.2	2404.7	32
34	4345.4	427.9	462.5	2348.1	4437.8	447.1	484.9	2406.7	34
36	4348.5	428.6	463.2	2350.0	4440.9	447.7	485.7	2408.6	36
38	4351.6	429.2	463.9	2352.0	4444.0	448.3	486.5	2410.6	38
40	4354.7	429.8	464.7	2353.9	4447.0	448.9	487.2	2412.6	40
42	4357.7	430.5	465.4	2355.9	4450.1	449.5	488.0	2414.5	42
44	4360.8	431.1	466.2	2357.8	4453.2	450.2	488.7	2416.5	44
46	4363.9	431.7	466.9	2359.8	4456.3	450.8	489.5	2418.5	46
48	4367.0	432.4	467.7	2361.7	4459.3	451.5	490.3	2420.4	48
50	4370.1	433.0	468.4	2363.7	4462.4	452.1	491.0	2422.4	50
52	4373.2	433.6	469.1	2365.6	4465.5	452.7	491.8	2424.4	52
54	4376.2	434.3	469.9	2367.6	4468.6	453.4	492.5	2426.3	54
56	4379.3	434.9	470.6	2369.5	4471.6	454.1	493.3	2428.3	56
58	4382.4	435.6	471.4	2371.5	4474.7	454.8	494.1	2430.2	58
60	4385.5	436.2	472.1	2373.4	4477.8	455.5	494.8	2432.2	60

45.45.5

Figure 8-17.—Sample page from table of functions of a 1° curve.

because in the case of the arc definition, R varies inversely as D, and you reflect this relationship when you divide the tabular values (which are functions of R) by D. But for the chord definition, R varies inversely with the sin D/2 instead of with D. The net result is, that for the chord definition, a small correction must be applied to the tabular values obtained. Figure 8-18 shows a table which provides such corrections for T and E. Note that the corrections become larger as both Δ and D increase.

The differences involved may be demonstrated by assuming D = 30° for both an arc definition curve and a chord definition curve. Using the formulas $R = \frac{5729.58}{D}$ and $R = \frac{50}{\sin D/2}$ or tables based on these formulas, you may determine that R for the arc definition is 190.99 feet and R for the chord definition is 193.19 feet, all as shown in figure 8-19. Now assume that Δ is 45° in both cases. Using the formula T = R tan Δ/2, you get T (arc def.) = 79.11, and T (chord def.) = 80.02. Now compare these values with those determined by using the table shown in figure 8-17. Under T for 45°00′ you will find the value 2373.4 ft. for the 1° curve. Divide the 2373.4 by 30 (which is D) and you get 79.11 feet. Note that this agrees with the value for T

Corrections To Be Added to Tangents and External Distances for Curves Laid Out by Chord Definition

FOR TANGENTS ADD

Central angle (degrees)	Degree of curve								
	5°	10°	15°	20°	25°	30°	40°	50°	60°
10	0.03	0.06	0.09	0.13	0.16	0.19	0.25	0.31	0.38
20	.06	.13	.19	.26	.32	.39	.51	.65	.79
30	.10	.19	.29	.39	.49	.59	.79	.99	1.20
40	.13	.26	.40	.53	.67	.80	1.06	1.34	1.64
50	.17	.34	.51	.68	.85	1.02	1.36	1.72	2.10
60	.21	.42	.63	.84	1.05	1.27	1.71	2.17	2.60
70	.25	.51	.76	1.02	1.28	1.54	2.06	2.60	3.16
80	.30	.61	.91	1.22	1.53	1.84	2.46	3.10	3.78
90	.36	.72	1.09	1.45	1.83	2.20	2.94	3.70	4.50
100	.43	.86	1.30	1.74	2.18	2.62	3.50	4.40	5.37
120	.62	1.25	1.93	2.52	3.16	3.81	5.11	6.44	7.80

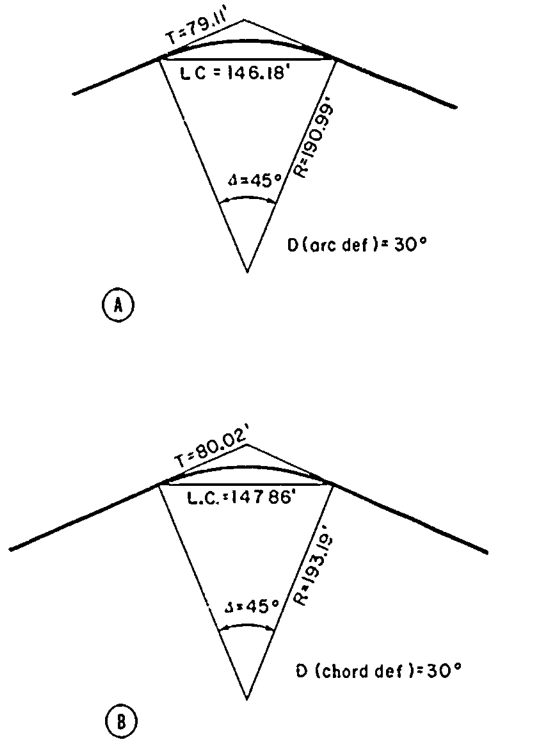
FOR EXTERNALS ADD

Central angle (degrees)	Degree of curve								
	5°	10°	15°	20°	25°	30°	40°	50°	60°
10	0.001	0.003	0.004	0.006	0.007	0.008	0.011	0.014	0.017
20	.006	.011	.017	.022	.028	.034	.045	.057	.070
30	.013	.025	.038	.051	.065	.078	.103	.129	.170
40	.023	.046	.070	.093	.117	.141	.203	.265	.290
50	.037	.075	.116	.151	.189	.227	.305	.384	.467
60	.056	.112	.168	.225	.283	.340	.457	.575	.697
70	.080	.159	.240	.321	.403	.485	.652	.819	.994
80	.110	.220	.332	.445	.558	.671	.903	1.13	1.38
90	.149	.299	.450	.603	.756	.910	1.22	1.54	1.87
100	.200	.401	.604	.809	1.01	1.22	1.64	2.06	2.50
120	.360	.721	1.08	1.45	1.82	2.19	2.95	3.72	4.50

45.45.6

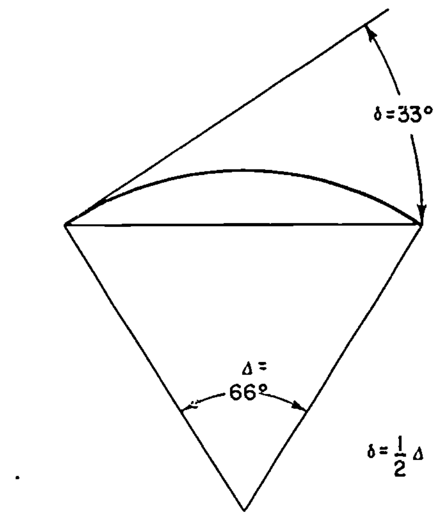
Figure 8-18.—Table of corrections to be added to tangents and external distances for curves laid out by chord definition.

(arc definition) worked out from the formula. This value must be corrected if you are using the chord definition, so enter the table in figure 8-18 under a 30° curve and opposite the 40° and 50° angles. Interpolate (for the 45° Δ assumed in this case) between the values 0.80 and 1.02 shown, and you get 0.91 ft. correction. Add this correction to the 79.11 feet you get from the table in figure 8-17, and your answer is 80.02. This agrees with the values determined from the formula. To work out the values for L.C. you may use the formula L.C. = 2R sin Δ/2, using the R computed for each definition. The results are shown in figure 8-19. Now compare these with the L.C. computed by using the table in figure 8-17. Under 45°00′ you will find L.C. for the 1° curve is 4385.5 feet; divide by 30 (which is D) and you get 146.18 feet. This agrees with the value shown in 8-19 for the arc definition. Figure 8-18 shows corrections for E as well as T; the procedure for computing E is the same as that described for computing T.



45.352

Figure 8-19.—Curve computations: arc definition versus chord definition.



45.353

Figure 8-20.—Angle between tangent and chord equals one-half of central angle.

PLOTTING BY DEFLECTION ANGLES

You could plot in the curve in figure 8-14 by compass, providing you had a compass large enough to be spread to the radius of the curve. However, we'll plot the curve in by the DEFLECTION ANGLE method, because this is the method most frequently used to stake out a curve in the field.

First, consider figure 8-20. This figure shows an arc, a tangent drawn at one end of the arc, and the chord of the arc. The arc subtends an angle (the one we call the central angle, or Δ) of 66°. The angle between the tangent and the chord (called δ, or little delta) measures one-half of that, or 33°. The deflection-angle method of curve layout is based on the fact that the angle formed by a tangent drawn at one end of an arc and the chord of the arc (that is, the deflection angle of the chord from the tangent) is one-half the size of the angle subtended by the arc.

We'll apply that fact, now, to plot a series of points along the arc of the curve illustrated in figure 8-21. You are given D = 20° (arc def.) and Δ = 80°. First draw a line for the back tangent, select a point on the line for the P.I., protract the Δ of 80°, and draw the tangent ahead. Next, determine T using a table or formula. To use the formula you need R:

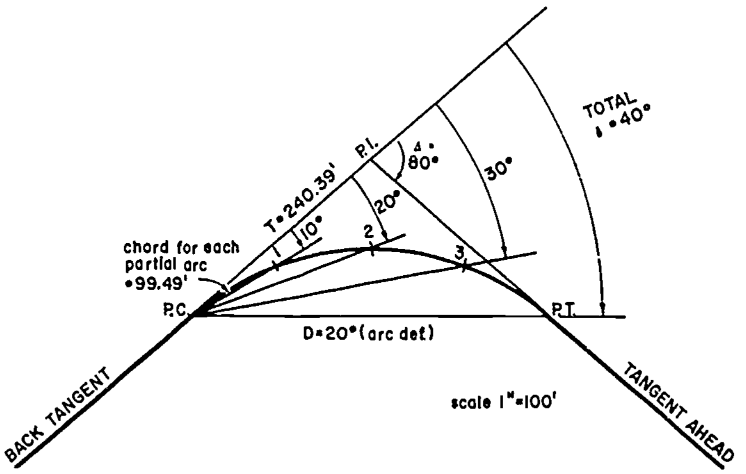
$$D = 20° \text{ (arc def.)}$$
$$R = 5729.58/D$$
$$R = 5729.58/20$$
$$R = 286.48 \text{ ft.}$$

Using R, you may compute T:

$$T = R \tan \Delta/2$$
$$T = 286.48 \times \tan (80°/2)$$
$$T = 286.48 \times \tan 40°$$
$$T = 286.48 \times 0.83910$$
$$T = 240.39 \text{ ft.}$$

Scale T back from the P.I. and mark the P.C.; scale T ahead of the P.I. and mark the P.T.

Now assume that you decide to plot three points on the curve between the P.C. and the P.T., dividing the arc into four equal segments. The Δ for the total curve is 80°, each segment is 1/4 of the total arc; therefore the Δ for each



45.354

Figure 8-21.—Plotting a curve by drawing a succession of chords.

partial arc is 80°/4 or 20°. Since the deflection angle is 1/2 80° or 40°, and δ for each segment is 1/2 20° or 10°. Set the center of your protractor at the P.C. with 0° on the line through the P.I.; mark off deflections of 10°, 20°; 30°; and 40°; then draw four rays from the P.C. The three intermediate points on the curve will be on the first three rays; and the last ray, passing through the P.T., marks the long chord of the whole curve. The final step in locating the P.O.C.'s is to set your compass point at the P.C. and mark an arc (numbered 1 in figure 8-21) across the first ray; the intersection of the arc and the ray is the first P.O.C. Then shift your compass point to the first P.O.C. and swing arc 2, marking the second P.O.C. Swing arc 3 from the second P.O.C. in the same manner. The last arc, swung from the third P.O.C., should intersect the P.T. BUT, what length do you set your compass to when you swing the arcs? You use the chord which subtends each partial arc. In this case you divided the curve into four equal parts, each with a Δ of 20°. The chord distance to which you set your compass, then, is:

$$\text{chord} = 2R \sin \Delta/2$$
$$\text{chord} = 2(286.48) \times \sin (20°/2)$$
$$\text{chord} = 572.96 \times \sin 10°$$
$$\text{chord} = 572.96 \times 0.17365$$
$$\text{chord} = 99.49 \text{ ft.}$$

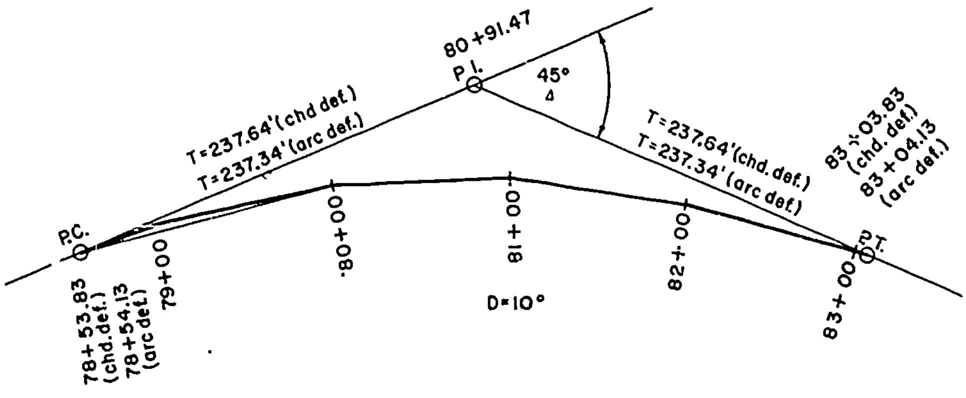
After you have located the P.O.C.'s you can draw in the line of the arc with a railroad curve or a spline.

CURVE STAKEOUT IN THE FIELD

The foregoing is, basically, the method used to stake out a curve in the field. The transit is used to turn the deflection angles, and the steel tape is generally used to lay off chords. Field stakeout, however, is complicated by the fact that the curve must be correctly stationed along its length, and the lengths of the chords laid out in the field are selected to meet the requirements of the job. Also, it may not be possible to turn all the deflection angles from the setup at the P.C., so you may have to move ahead on the curve.

Staking the P.C. and P.T.—Arc Definition

Suppose that you are setting the alignment and staking the centerline of a road in the field, that you have set a P.I. at station 80 + 91.47 and established a Δ of 45°, and that you have decided upon a 10° curve (arc definition); all as shown in figure 8-22. Reference to a table of functions of a 1° curve shows that, for a Δ of 45°, T is 2373.4 for a 1° curve Divide by 10 (since D is 10°) and you find that T is 237.34 ft. Subtract T from the station of the P.I. and you get the station of the P.C.: 78 + 54.13.



45.355

Figure 8-22.—Staking a curve.

The next step is to determine L, so that you may station the P.T. Since $L = 100 \frac{\Delta}{D}$ L in this case is $100 \times \frac{45}{10}$ or 450.00 feet. Add 450.00 feet to the station of the P.C. (78 + 54.13) and you get the station of the P.T.: 83 + 04.13.

Measure 237.34 feet back from the P.I. and mark the P.C.; measure 237.34 feet ahead from the P.I. and mark the P.T. Staking the P.T. gives you a point to check in to when you perform the final operation, that is, staking the points on the curve.

Staking the P.C. and P.T.—Chord Definition

If you had selected a 10° curve, chord definition (instead of arc definition) in the preceding example, you would follow exactly the same procedure in computing and staking the P.C. and P.T. But the T is somewhat different for the chord definition since the correction must be applied. The table in figure 8-18 indicates, under a 10° curve and interpolating for the 45° central angle between the values opposite 40° and 50°, a correction of 0.30 ft. Therefore, the T for the chord definition is 237.34 ft plus 0.30 ft or 237.64 ft. Subtracting T from the station of the P.I. (80 + 91.47) you get station 78 + 53.83 for the P.C. (See fig. 8-22.) The length is still 450.00 ft, but for the chord definition it represents the distance along a series of 100-foot chords instead of the distance along the arc. The procedure for stationing the P.T. is the same as before: add the L (450.00 ft) to the station of the P.C. (78 + 53.83) and you get 83 + 03.83, the station of the P.T.

Staking the P.O.C.'s

After the P.C. and P.T. have been staked, the next step is to stake the selected stations on the curve. The usual procedure is to occupy the P.C. and turn the deflection angles to successive stations while the chords are laid off from one station to the next. Set up at the P.C., set the plate at zero, back sight at a point on the back tangent, plunge the scope, and turn the deflections. Or, if it will give you a longer backsight, use the P.I. as the backsight. To set the first P.O.C., one chainman holds the end of the tape at the instrument (at the P.C.) while the second chainman holds the appropriate chord distance on the tape and swings the tape until he intersects the line of sight of the first deflection angle, he then marks a stake with the station number and drives a hub and/or stake at the point established. Next, the instrumentman turns the second deflection, the chainmen move ahead to the second P.O.C., and the second station is marked, the process is repeated at each point until the P.T. is reached – the last angle and distance should check in to the previously-staked P.T.

The stations may be staked at intervals of 100, 50, 25, or sometimes 10 feet, depending on the type of construction and the degree of curvature. The intervals are marked at full stations and fractions thereof, such as 9 + 00, 9 + 25, 9 + 50, 9 + 75, 10 + 00, and so on. If a curve were to begin and end at full stations, and you were staking it on 100-foot stations, the computations would be simple; the chords would all be the same, and deflections would all be the same (each angle would be D/2, because δ is 1/2 Δ, and Δ is D for a 100-foot length). But P.C.'s and P.T.'s almost always fall at odd pluses, that is, beyond a station at a plus distance other than the specified interval. Therefore, you will usually have to figure an irregular deflection and chord for the first length past the P.C. and for the last length before the P.T.

Chords—Arc Definition

When the arc definition of the degree of curvature is specified, the length of a curve is stationed along the arc; but, in the field, you must measure chords, and not arcs, with the tape. The chord is always shorter than the arc, and the problem created by this fact may be solved in either of two ways. First, you may use chords that are short enough so that the difference between the arc and chord lengths is insignificant, or second, you may determine and measure the actual chord length which corresponds to the arc length being stationed.

To eliminate corrections by using short chords, you must consider the degree of curvature. The sharper the curve, the shorter the chords must be to obtain the precision appropriate to the given job. For work of ordinary precision, a typical guide which might be established for a job is:

For D of less than 2°, use 100-ft chords
For D from 2° to 7°, use 50-ft chords
For D from 7° to 18°, use 25-ft chords
For D greater than 18°, use 10-ft chords.

To determine the chord length for a given arc length, you may either compute the chord using the formulas presented earlier in this chapter, or refer to tables which show chord lengths for arc definition curves. Figures 8-23 and 8-24 show such tables. one is for curves defined by D, and the other for curves defined by R.

Now apply the foregoing information to the 10° curve shown in figure 8-22. Remember that

Degree of curve (degrees)	Radius = 5,729.58 $\frac{(I)}{D}$	Chord for 25 feet of arc	Chord for 50 feet of arc	Chord for 100 feet of arc
1	5, 729. 58	25. 00	50. 00	100. 00
2	2, 864. 79	25. 00	50. 00	100. 00
3	1, 909. 86	25. 00	50. 00	99. 99
4	1, 432. 40	25. 00	50. 00	99. 98
5	1, 145. 92	25. 00	50. 00	99. 97
6	954. 93	25. 00	50. 00	99. 95
7	818. 51	25. 00	50. 00	99. 94
8	716. 20	25. 00	49. 99	99. 92
9	636. 62	25. 00	49. 99	99. 90
10	572. 96	25. 00	49. 98	99. 87
12	477. 46	25. 00	49. 98	99. 82
14	409. 26	25. 00	49. 97	99. 75
16	358. 10	25. 00	49. 96	99. 68
18	318. 31	24. 99	49. 95	99. 59
20	286. 48	24. 99	49. 94	99. 49
22	260. 44	24. 99	49. 92	99. 39
24	238. 73	24. 99	49. 91	99. 27

45.45.7

Figure 8-23.—Table of chord lengths (for degree of curve by arc definition).

Radius	Chords for 25' arcs	Radius	Chords for 100' arcs
100	24.93	600	99.88
150	24.97	700	99.91
200	24.98	800	99.93
		900	99.95
	Chords for 50' arcs	1,000	99.96
		1,500	99.97
		2,000	99.98
250	49.92	2,500	99.99
300	49.94	3,000	100.00
350	49 96		
400	49.97		
450	49.97		
500	49.98		

45.45.8

Figure 8-24.—Table of lengths of chords for even radius curves (arc definition).

Curve Stakeout Table
(Arc Definition)

D=10° L=450.00 Δ=45°

Station	Arc	Δ	δ	Total Deflection	Chord
P.C.-78+54.13					
	45.87	4°35'	2°17'30"		46.85
79+00				2°17'30"	
	100.00	10°00'	5°00'00"		99.87
80+00				7°17'30"	
	100.00	10°06'	5°00'00"		99.87
81+00				12°17'30"	
	100.00	10°00'	5°00'00"		99.87
82+00				17°17'30"	
	100.00	10°00'	5°00'00"		99.87
83+00				22°17'30"	
	4.13	0°25'	0°12'30"		4.13
P.T.-83+04.13				22°30'00"	
	450.00	45°00'	22°30'		

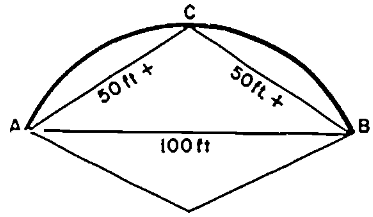
45.356

Figure 8-25.—Curve stakeout table (arc definition).

you are using the arc definition for this first example. You may find it convenient to tabulate the stakeout information as shown in figure 8-25. The first column shows the stations. The second shows the arc lengths between the stations, these are found by subtracting one station from the next. The totals at the bottom of three of the columns are a check on your arithmetic. The third column shows the central angle for each arc length. By definition, the Δ for a 100-foot length is 10° because D is 10°. The other central angles are proportional. the Δ for 45.87 ft is $\frac{45.87}{100} \times 10°$ or 4.587° or 4°35′; the Δ for 4.13 ft is $\frac{4.13}{100} \times 10°$ or 0.413° or 0°25′. The deflection angles in the fourth column are as previously explained, one-half the central angles. The fifth column shows the total of the deflection angles to the station indicated, these are the values which you will set on your instrument as the chainmen progress from one station to the next along the curve. The last column shows the chords which the chainman will measure from one station to set the next. Reference to the table in figure 8-23 shows that the chord for a 50-foot arc of a 10° curve is 49.98, that is, a 0.02 ft correction. The first arc length in the table (45.87 ft) is sufficiently close to 50 ft, so the same correction is reasonable, therefore, the first chord is 45.87 minus 0.02 or 45.85 ft. The reasonableness of this procedure may be shown by using the formula C = 2R sin Δ/2 and a more precise value of Δ C = 2(572.96) (sin 2° 17′36″) = (1145.92) (0.040016) = 45.855 ft; sufficiently close to 45.85 ft for most work. The chords for the 100-foot arcs are 99.87 ft, from the table. The last arc, 4.13 ft, is so short that no correction is needed.

Chords—Chord Definition

When the chord definition of the degree of curvature is specified, the length of the curve is stationed along a series of 100-foot chords, which is what you may be actually measuring in the field. But when the P.C. and P.T. fall at odd pluses, and when the curve is sharp, you will be laying off chords of less than 100 ft, and these subchords will be LONGER than their nominal proportion of the standard 100-foot chord. This fact may be readily seen by studying the simplified example shown in figure 8-26. Let AB be a 100-foot chord of the curve. Assume that you decide to set one more point, C, on the



45.357

Figure 8-26.—Subchords by chord definition.

middle of the curve. The two chords AC and CB are, nominally, "50-foot chords", but, since there are two equal sides opposite the 100-foot hypotenuse in triangle ABC, they obviously have to be longer than 50 ft.

Methods which may be used to determine actual subchord length include (1) the use of a formula, (2) the use of tables of excess of arc and ratio of correction, and (3) the use of a table of corrections for subchord lengths.

Let c be the actual length of a subchord. Let d be the central angle subtended by c. As shown before (see fig. 8-7):

$$\sin\frac{D}{2} = \frac{50}{R}$$

Therefore $$\sin\frac{D}{2} = \frac{100}{2R}$$

Similarly, $$\sin\frac{d}{2} = \frac{c}{2R}$$

Since they are proportional,

$$\frac{\sin\frac{D}{2}}{\sin\frac{d}{2}} = \frac{\frac{100}{2R}}{\frac{c}{2R}}$$

Cross multiplying and solving for c:

$$\left(\sin\frac{D}{2}\right)\left(\frac{c}{2R}\right) = \left(\sin\frac{d}{2}\right)\left(\frac{100}{2R}\right)$$

$$\left(\sin\frac{D}{2}\right)(c) = \left(\sin\frac{d}{2}\right)(100)$$

$$c = 100\frac{\sin\frac{d}{2}}{\sin\frac{D}{2}}$$

This last expression is a formula you may use to compute the actual length of c.

The actual arc length is always greater than the chord; the amount of excess increases as the curvature (D) increases. Figure 8-27 shows a sample page from a table of long chords and actual arcs. As you can see from the table, the excess of arc for one station is 0.127 ft for a 10° curve and 0.326 ft for a 16° curve. Now let us call the amount by which an actual subchord length exceeds the nominal length the "correction" of the subchord. This correction for any subchord bears an almost constant ratio to the excess of arc per station, whatever the degree of curvature might be. Figure 8-28 shows this ratio for various nominal subchords. To determine the actual subchord length in a given case, multiply the excess of arc per station for the given degree of curve (fig. 8-27) times the ratio of correction (fig. 8-28) for the given subchord nominal length.

The third method of determining the actual subchord length is to interpolate from a table of corrections for subchord lengths. Figure 8-29 shows such a table, together with an explanation and an example.

Now apply these methods of computing subchords to the curve shown in figure 8-22. Set up a curve stakeout table (fig. 8-30) similar to the one prepared for the arc definition curve. As before, the first column shows the stations. The second column is headed "length" instead of "arc" in this case, because the length of the curve is measured along the 100-foot chord lengths and the nominal subchord lengths. The third, fourth, and fifth columns, showing the Δ, the deflection angle, and the total deflection angle, are computed in exactly the same manner as for the arc definition example. The first chord length in the last column is the actual length of the nominal 46.17-foot chord. You may use the following formula to compute it:

$$c = 100\frac{\sin\frac{d}{2}}{\sin\frac{D}{2}} = 100\ \frac{\sin\ 2°18'30''}{\sin\ 5°00'00''}$$

$$= 100\ \frac{.040277}{.087156} = 46.21$$

Degree of curve	Actual arc, 1 station	Long chords 2 sta.	3 sta.	4 sta.	5 sta.	6 sta.	7 sta.	8 sta.	Degree of curve
10 0	100.127	199.2	297.0	392.4	484.9	573.7	658.1	737.5	10 0
10	131	99.2	96.9	92.2	84.4	72.8	56.7	35.5	10
20	136	99.2	96.8	91.9	83.9	71.9	55.3	33.4	20
30	140	99.2	96.7	91.7	83.4	71.0	53.9	31.3	30
40	145	99.1	96.5	91.4	82.8	70.1	52.4	29.1	40
50	149	99.1	96.4	91.1	82.3	69.2	51.0	27.0	50
11 0	100.154	199.1	296.3	390.8	481.8	568.2	649.5	724.8	11 0
10	158	99.1	96.2	90.6	81.2	67.3	48.0	22.5	10
20	163	99.0	96.1	90.3	80.7	66.3	46.5	20.3	20
30	168	99.0	96.0	90.0	80.1	65.3	44.9	18.0	30
40	173	99.0	95.9	89.7	79.5	64.3	43.3	15.7	40
50	178	98.9	95.7	89.4	78.9	63.3	41.8	13.3	50
12 0	100.183	198.9	295.6	389.1	478.3	562.3	640.1	710.9	12 0
10	188	98.9	95.5	88.8	77.7	61.3	38.5	08.5	10
20	193	98.8	95.4	88.5	77.1	60.2	36.9	06.1	20
30	199	98.8	95.3	88.2	76.5	59.2	35.2	03.7	30
40	204	98.8	95.1	87.9	75.9	58.1	33.5	01.2	40
50	209	98.7	95.0	87.6	75.3	57.0	31.8	698.6	50
13 0	100.215	198.7	294.9	387.2	474.6	555.9	630.1	696.1	13 0
10	220	98.7	94.7	86.9	74.0	54.8	28.3	93.5	10
20	226	98.6	94.6	86.6	73.3	53.7	26.5	90.9	20
30	232	98.6	94.5	86.3	72.7	52.5	24.8	88.3	30
40	237	98.6	94.3	85.9	72.0	51.4	22.9	85.7	40
50	243	98.5	94.2	85.6	71.3	50.2	21.1	83.0	50
14 0	100.249	198.5	294.1	385.2	470.6	549.1	619.3	680.3	14 0
10	255	98.5	93.9	84.9	70.0	47.9	17.4	77.5	10
20	261	98.4	93.8	84.5	69.3	46.7	15.5	74.8	20
30	267	98.4	93.6	84.2	68.6	45.5	13.6	72.0	30
40	274	98.4	93.5	83.8	67.8	44.2	11.7	69.2	40
50	280	98.3	93.3	83.4	67.1	43.0	09.8	66.3	50
15 0	100.286	198.3	293.2	383.1	466.4	541.7	607.8	663.5	15 0
10	293	98.3	93.0	82.7	65.7	40.5	05.8	60.6	10
20	299	98.2	92.9	82.3	64.9	39.2	03.8	57.7	20
30	306	98.2	92.7	81.9	64.2	37.9	01.8	54.8	30
40	312	98.1	92.6	81.5	63.4	36.6	599.8	51.8	40
50	319	98.1	92.4	81.2	62.6	35.3	97.8	48.8	50
16 0	100.326	198.1	292.3	380.8	461.9	534.0	595.7	645.8	16 0
10	332	98.0	92.1	80.4	61.1	32.6	93.6	42.8	10
20	339	98.0	91.9	80.0	60.3	31.3	91.5	39.7	20
30	346	97.9	91.8	79.6	59.5	29.9	89.4	36.6	30
40	353	97.9	91.6	79.1	58.7	28.6	87.3	33.6	40
50	361	97.8	91.4	78.7	57.9	27.2	85.1	30.4	50
Degree	Actual arc	2 sta.	3 sta.	4 sta.	5 sta.	6 sta.	7 sta.	8 sta.	Degree

45.45.9

Figure 8-27.—Sample page from table of long chords and actual arcs (chord definition).

Nominal Length of Subchord	Ratio	Nominal Length of Subchord	Ratio
0	0.000	55	0.383
5	0.050	60	0.383
10	0.099	65	0.374
15	0.147	70	0.356
20	0.192	75	0.327
25	0.234	80	0.287
30	0.273	85	0.235
35	0.307	90	0.169
40	0.336	95	0.092
45	0.358	100	0.000
50	0.374		

45.45.10

Figure 8-28.—Table of ratio of correction of subchords to the excess of arc per station (chord definition).

Or, you may determine the excess per station (0.127) for a 10° curve from figure 8-27; then multiply the excess by the ratio of correction (0.36) interpolated for 46.17 feet from figure 8-28. The correction to be added to 46.17, then, is (0.127) X (0.36) or 0.046, which you may call 0.05. The actual chord, then, computes to be 46.17 plus 0.05 or 46.22 ft. Or, to apply the third method, you may interpolate in figure 8-29 opposite 10° between 25 ft and 50 ft, and determine a correction of 0.045 (which you may call either 0.04 or 0.05) to be added to 46.17, giving you either 46.21 or 46.22. Note that all methods provide answers within a few thousandths of a foot of one another, such differences are not significant for most fieldwork. If a more exact value were needed, however, you could use a more precise value of d/2 in the equation and get your answer to the thousandth. The remaining chords in the last column of figure 8-30 require no correction, the 100-foot chords are exact because you are using the chord definition of degree of curvature, and, as before, the last chord is small enough to need no correction.

Intermediate Set-up

In the foregoing examples, the assumption was made that the entire curve could be staked out with the instrument set up on the P.C. This is not always possible; there may be obstructions on the line of sight, or the curve may be so long that it isn't practical to keep the instrument at the P.C. In these cases, it is necessary to move ahead on the curve and set up at an intermediate point on the curve. Assume that, in figure 8-22 station 80 + 00 has been staked from the P.C., that obstructions prevent your sighting station 81 + 00, and that you must move ahead to station 80 + 00.

To understand the method of training the telescope from one station to a subsequent station, study figure 8-31. This figure shows a semicircular curve, running from A to D, and a tangent at A. The curve is divided into three intervals of arc, and the stations are connected by three equal chords: AB, BC, and CD. The chord from A to B is chord AB; chords from A to C and from A to D are indicated by the dotted lines AC and AD.

The deflection angle between AB and the tangent is 30°; this is the COMPUTED DEFLECTION ANGLE for station B. Then the computed deflection angle for station C is 2 X 30°, or 60°; and the computed deflection angle for station D is 3 X 30°, or 90°. Remember that the computed deflection angle for any station is the angle between the tangent at the P.C. and the chord running from the P.C. to the station.

The deflection angle between chord BC and chord AB (extended) measures TWICE the size of the deflection angle between chord AB and the tangent. If you were set up at station B, you could turn this deflection angle by plunging the telescope, sighting back on A, setting the vernier at 0, replunging, and turning 60° to the right. That is, you could turn the deflection angle from station B to station C by backsighting on A, setting the computed deflection angle of station A (which is 0°) on the vernier, and then turning (to the right, in this case) an angle equal in size to the computed deflection angle for station C.

Similarly, if you were set up at station C, you could train the telescope on station D as follows: Backsight on station B, and set the computed deflection angle of station B (30°) on the vernier. Then plunge the telescope, and turn right until you read the computed deflection angle for station D (90°) on the vernier. Or, backsight on station A and set the computed

CORRECTIONS FOR SUBCHORD LENGTHS

(CHORD DEFINITION)

For setting stakes for sharp curves it is often necessary to use chord lengths less than 100 feet. The most common chord lengths are 50, 25, 20, and 10 feet, in order as the degree of curvature increases. Common and accepted practice prescribes that the length of a curve be measured in chords 100 feet long and fractions thereof. The arc of a curve corresponding to a 100-foot chord is greater than 100 feet. Similarly the sum of 2, 4, 5, or 10 equal subchords which subtend the arc measured by a 100-foot chord is greater than 100 feet. The nominal lengths of these subchords are 50, 25, 20, or 10 feet, respectively. To these nominal lengths add the corrections shown in the table to give the actual lengths of the subchords. *Example.* Suppose it is desirable to set stakes by subchords of 25-foot nominal length on a 20° curve. Enter the table for $D = 20°$. On this line, in the column headed 25, is found the correction .119. To 25 add .119. This gives 25.119 feet as the actual length of the subchord whose nominal length is 25 feet.

D.	50′	25′	20′	10′	D.	50′	25′	20′	10′
°					°				
3	.004	.003	.002	.001	27	.349	.218	.179	.092
4	.008	.005	.004	.002	28	.376	.235	.192	.099
5	.012	.008	.006	.003	29	.403	.252	.206	.106
6	.017	.011	.009	.005	30	.431	.270	.221	.114
7	.023	.015	.012	.006	31	.461	.288	.236	.122
8	.030	.019	.016	.008	32	.491	.307	.252	.130
9	.039	.024	.020	.010	33	.523	.327	.268	.138
10	.048	.030	.024	.013	34	.555	.347	.285	.147
11	.058	.036	.030	.015	35	.589	.368	.302	.156
12	.069	.043	.035	.018	36	.623	.390	.320	.165
13	.081	.050	.041	.021	37	.659	.412	.338	.174
14	.093	.058	.048	.025	38	.695	.435	.356	.184
15	.107	.067	.055	.028	39	.733	.458	.376	.194
16	.122	.076	.063	.032	40	.771	.483	.396	.204
17	.135	.086	.071	.036	41	.811	.507	.416	.214
18	.155	.097	.079	.041	42	.851	.533	.437	.225
19	.172	.108	.088	.045	43	.893	.559	.458	.236
20	.191	.119	.098	.050	44	.936	.586	.480	.248
21	.211	.132	.108	.056	45	.980	.613	.502	.259
22	.231	.144	.118	.061	46	1.024	.641	.525	.271
23	.253	.158	.130	.067	47	1.070	.670	.549	.283
24	.275	.172	.141	.073	48	1.117	.699	.573	[illegible]
25	.299	.187	.153	.079	49	1.165	.729	.598	.308
26	.323	.202	.166	.085	50	1.214	.760	.623	.321

45.45.11

Figure 8-29.—Table of corrections for subchord lengths (chord definition).

deflection angle for station A (0°) on the vernier. Then plunge the telescope and turn right until you read the computed deflection angle for station D (90°) on the vernier.

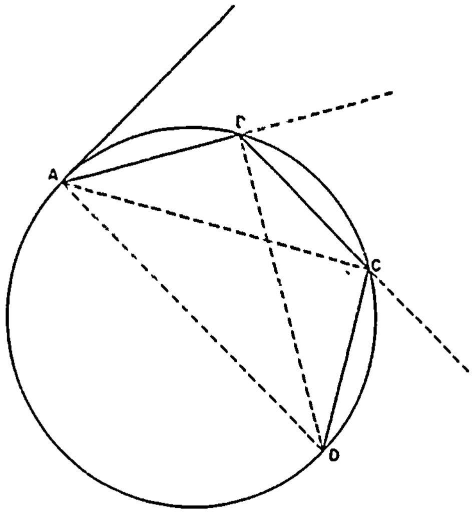
Suppose you wanted to shoot station D from station B. The chord from station B to station D is the dotted line BD. You can see that the deflection angle between chord AB and this chord measures 90°, and you can see that the same rule applies. Backsight on A, and set the computed deflection angle for A (0°) on the vernier. Then plunge the telescope, and turn until you read the computed deflection angle for D (90°) on the vernier.

Curve Stakeout Table
(Chord Definition)
D=10° L=450.00 Δ=45°

Station	Length	Δ	δ	Total Deflection	Chord
PC=78+53.83					
	46.17	4°37'	2°18'30"		46.21
79+00				2°18'30"	
	100.00	10°00'	5°00'		100.00
80+00				7°18'30"	
	100.00	10°00'	5°00'		100.00
81+00				12°18'30"	
	100.00	10°00'	5°00'		100.00
82+00				17°18'30"	
	100.00	10°00'	5°00'		100.00
83+00				22°18'30"	
	3.83	0°23'	0°11'30"		3.83
P.T.=83+03.83				22°30'00"	
	450.00	45°00'	22°30'		

45.358

Figure 8-30.—Curve stakeout table (chord definition).



45.359

Figure 8-31.—Deflection angles on a semicircle.

The rule, then, for turning the deflection angle between any two adjoining chords is this:

1. Plunge the telescope, backsight on the appropriate station, and set the vernier to read the computed deflection angle of that station.
2. Replung the telescope, and turn until you read the computed deflection angle of the other appropriate station.

Let's go back, now, and compute the deflection angles for the curve (arc definition) shown in figure 8-22. The computed deflection angle for station 79 + 00 is 2°17'30"; you have already turned that one. The computed deflection angle for station 80 + 00 is 7°17'30". These and the deflection angles for the other stations on the arc are shown in figure 8-25.

You are set up at station 80 + 00. To turn the deflection angle between the chord from the P.C. to 80 + 00 and the chord from 80 + 00 to 81 + 00, backsight on the P.C. and set the vernier to read the computed deflection angle of that station, which is 0°. Then plunge the telescope, and turn until you read the computed deflection angle of station 81 + 00 (which is 12°17'30") on the vernier. When you have turned the angle, measure off a full chord (99.87 ft) from station 80 + 00 along the line of sight. This locates station 81 + 00.

You can go ahead and locate station 82 + 00 with the transit still at station 80 + 00, or you can shift to station 81 + 00 if field conditions so demand. If you stay at station 80 + 00, you locate station 82 + 00 as follows: turn right until you read the computed deflection angle of station 82 + 00 (17°17'30") on the vernier. When you have turned the angle, measure off one full chord (99.87 ft) from station 81 + 00 to locate station 82 + 00. Follow the same procedure to set 83 + 00 and to check in to the P.T.

In addition to being staked out from the P.C. and from intermediate stations, a curve may be staked out with the instrument set up at the P.T. If you want the chainmen to chain ahead from the P.C. to the P.T., set the circle at 0°, back sight on the P.C., and lay off the same deflection angles you would use if the transit were at the P.C. If you want the chainmen to chain back from the P.T. to the P.C., set the circle at the total deflection (Δ/2), back sight on the P.I., and turn in succession (toward the P.C.) to each deflection angle (computed for each station) from the P.T. back to the P.C., when you make the last setting, your plate should read 0° and you should be sighting the P.C.

Field Notes for Curve Layout

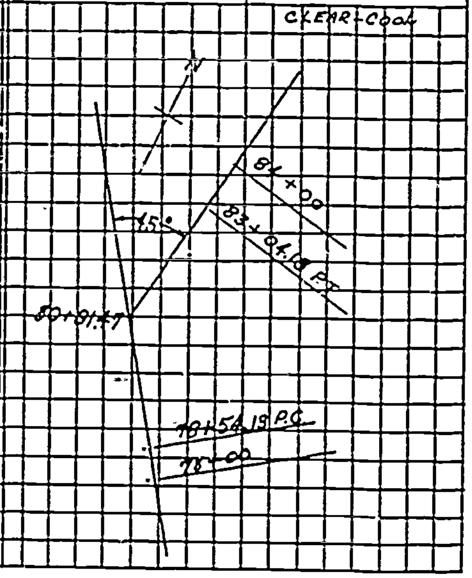
Figure 8-32 shows field notes for the curve you staked out in figure 8-22. On the remarks

ALINEMENT OF HIGHWAY NO. 7

TRANSIT #7
100' STEEL TAPE #2

Smith, R, EAS2
Jones, A., CNEAS
Brown R., CNEAS
Nov. 3, 1972
CLEAR-COOL

Station	Point	Comp. Defl. A	Bearing	Curve Data	
				Δ	45°00'
84+00					
			N8°45'E	D	10°00'
83+04.13	P.T.	22°30'		L	450.00'
				T	237.34'
83+00	P.O.C	22°18'			
82+00	P.O.C	17°18'			
81+00	P.O.C	12°18'			
80+00	P.O.C.	7°18'			
79+00	P.O.C.	2°18'			
78+54.13	P.C.	0°00'			
			N36°15'W		
78+00					



45.7.11

Figure 8-32.—Field notes.

page, make a sketch, to a suitable scale, of the tangents, and locate and mark such points as the last full station before the P.C., the P.C., the P.I., the P.T., and the first full station after the P.T.

In the two right-hand columns of the data page, set down the curve data, such as the central angle (Δ), the degree of curvature (D), the length of the curve (L), and the tangent (T).

In the first column on the data page, under "Station," list the stations—not only those which appear in the sketch, but also those full stations which lie on the curve. Since the sketch reads from the bottom up (so that data will be presented as it appears in the field as you look ahead on line), you list your stations from the bottom up on the page.

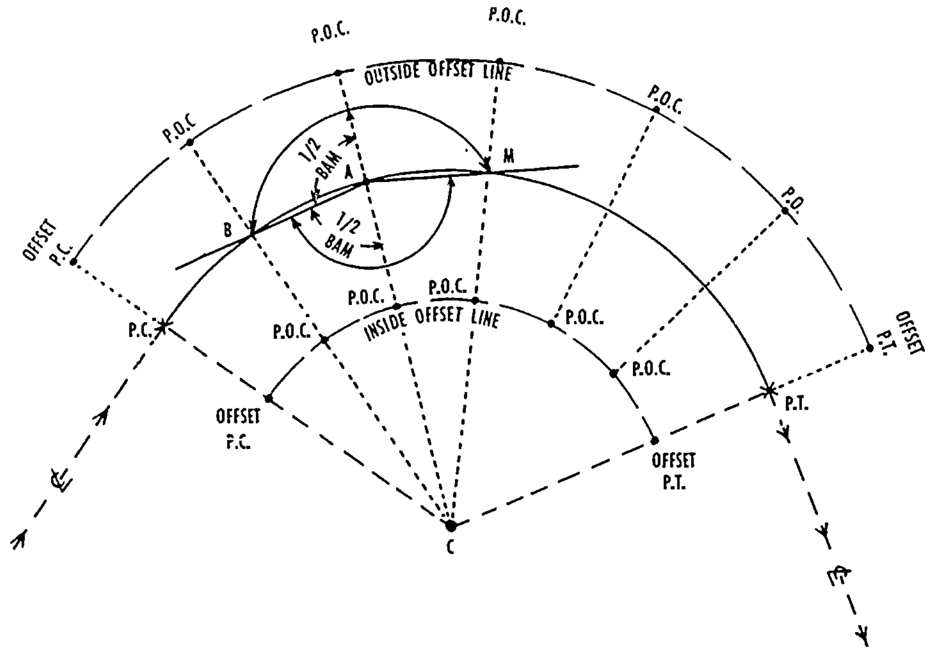
In the second column on the data page, under "Point," list the character of each station—that is, whether it is the P.C., the P.T., a P.O.L. (point on line, such as stations 78 + 00 and 84 + 00), or a P.O.C. (point on curve, such as the stations from 79 + 00 to 83 + 00 inclusive).

Next to each station on the curve (including the P.C. and the P.T.), in the column headed "Comp. Defl. A.," you list the computed deflection angle (that is, the angle between the tangent through the P.C. and the chord from the P.C. to the station) for that particular station. The computed deflection angle for the P.C. is 0°. The computed deflection angle for the P.T. is one-half of the central angle. You have computed the angles for the other stations.

Offset Curves

OFFSET CURVES are run outside a construction when it is not possible to run the centerline, or when an accurate alignment control is needed for the actual limits of the borders of a construction. In the case of a pavement, for example, offset curves are usually run on either side of the centerline and at the same distance from it.

Figure 8-33 shows a possible offset layout. Usually offset stations are set and marked to agree with the stationing along the centerline. Note that the radius to any point on a circular curve is perpendicular to the tangent which it supports along the centerline. Therefore, all the



45.361

Figure 8-33.–Offset layout.

P.O.C.'s on the offset curves will be set at right angles to the supporting tangents.

If the centerline is already in, and equal chords have been used, P.O.C.'s on the offset curves can be located by bisecting the complete angle between two adjacent P.O.C.'s. If, for example, you are set up at station A in figure 8-33, bisect angle BAM using either the outside or the inside angle. Now, with the line of sight determined, the offset station can be measured out from the centerline station to the specified offset distance.

When an offset curve is laid out without the centerline curve, compute the curve elements using the same Δ and an R increased or reduced by the distance from the centerline to the offset.

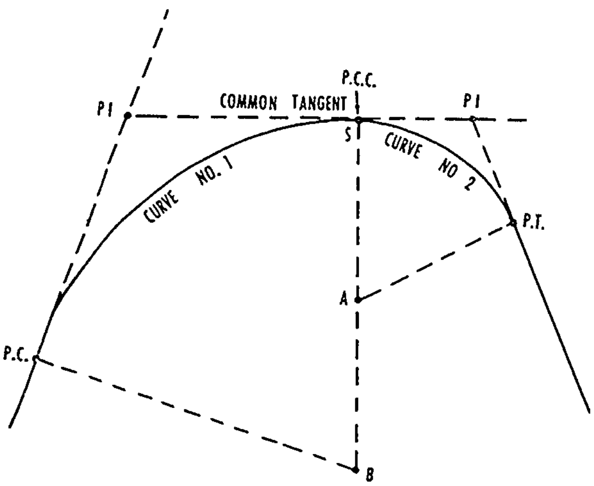
COMPOUND AND REVERSED CURVES

A COMPOUND CURVE consists of two or more simple curves of different degrees of curve following one another in the same general direction and having a common tangent at the point where they join. The point where the two curves run together is called a POINT OF COMPOUND CURVE (P.C.C.).

The following is a practical application of a compound curve layout. When running a preliminary road survey through mountainous terrain, you will most likely select a course that offers least resistance to construction. Instead of tunneling through a steep hill, follow the side of the hill, increasing or decreasing the elevation to correspond with the connecting elevation on the opposite side. In following around a hill, it will be necessary to lay out shorter tangent lines than usual with a different P.I. at each change in direction. To change over from the tangent lines to the actual proposed centerline of the road, it may be feasible to have a curved section similar to that shown in figure 8-34.

SB is the radius of curve No. 1 and SA is the radius of curve No. 2. In laying out a compound curve to intercept the course running into curve No. 1 and out from curve No. 2, it is necessary, for true alignment, that the sum of the tangents to curve No. 1 and curve No. 2 be equal to the length of the common tangent.

Begin as you would in laying out a simple circular curve from P.C. to the point of compound curvature P.C.C. Set up the transit at the P.C.C. Set the circle at half the central angle of



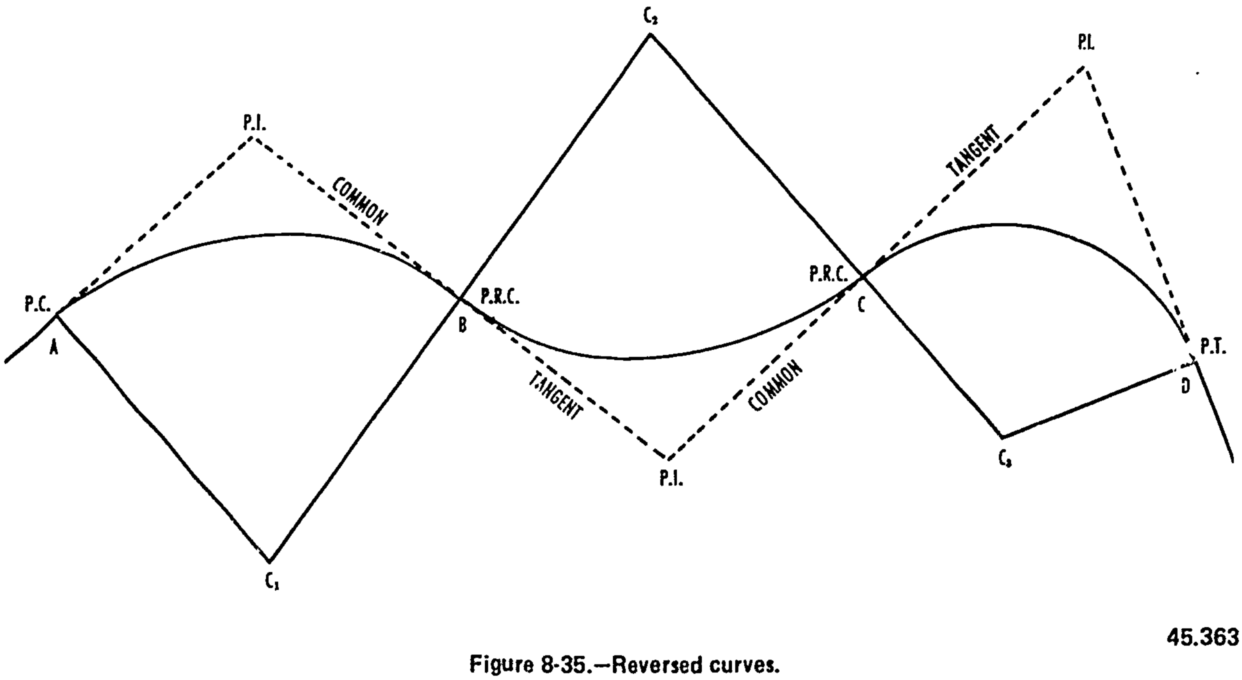
45.362

Figure 8-34.—Compound curve.

curve No. 1 and backsight on the P.C. If you now turn the circle to 0°, you should be sighting along the common tangent at the P.C.C. Lay out curve No. 2 just like any other simple curve, using the deflection angle method.

A reversed curve consists of two simple curves which turn in opposite directions as shown in figure 8-35. The two simple curves have a common tangent, where they join, but their centers lie on opposite sides of the common tangent. The point where the two curves join is called A POINT OF REVERSED CURVE (P.R.C.). The two curves may be of the same or different degrees of curve. Figure 8-35 shows a double reversed curve of two different degrees of curve. Curve ABC is a single reversed curve with the same degree of curve. Curve BCD shows two different degrees of curve. Reversed curves are used to advantage in the location of railroad cross-overs and spur tracks leading to manufacturing or industrial plants. Lay out the first section of a reversed curve just like any other simple circular curve. Set up the transit at the point of reversed curve (P.R.C.). Adjust the circle so that it sights 0° along the common tangent. Lay out the second simple curve on the opposite side of the common tangent. The P.R.C. at B may be considered as the P.T. of curve No. 1 and also as the P.C. of curve No. 2. Set the instrument up at the second P.R.C. at C and repeat the layout procedure.

The principles of computation used for simple curves apply to all horizontal curves. Compound and reversed curves merely continue on from the



45.363

Figure 8-35.—Reversed curves.

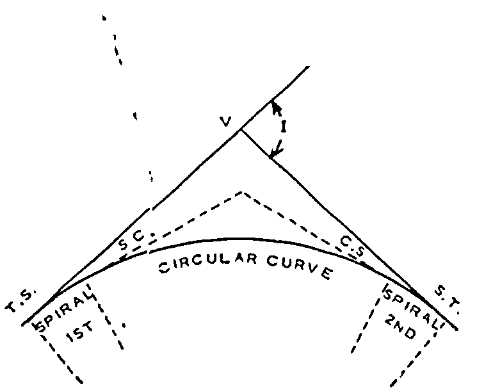
end of the preceding curve. Like any simple curve, a compound or reversed curve finally ends in a P.T.

SPIRAL TRANSITION CURVES

SPIRAL CURVES are transition curves used in railroad and highway work to provide a gradual change between a straight and a curved part of the road. Transition curves provide safer and more comfortable riding by reducing the tendency of the vehicle to lurch and to skid while going around an abrupt curve in the roadway. A more gradual transition from a straight to a curved section of roadway also gives the motorist more time and a greater distance within which to adjust his steering wheel to the anticipated curve. Spirals, therefore, should be as long as possible. They may be true spirals or a consecutive series of compound curves. The degree of curve of a spiral changes uniformly with the distance from some point of reference. For example, note in figure 8-36 that the spiral is relatively flat at the T.S. (the point of change from tangent to spiral). This point represents the beginning of the spiral where the curve starts diverging from the main tangent. As the spiral continues from the T.S. to the S.C. (the point of change from the spiral to circle), the spiral gradually becomes sharper until its radius becomes equal to that of the circular curve to which it is connected.

The spiral merges into the circular curve between the S.C. (point of change from spiral to circle) and the C.S. (point of change from circle to spiral). Approaching the end of the curve, the spiral once again flattens out between the C.S. and the S.T. (point of change from spiral to tangent). Figure 8-36 shows three distinct sections of the total curve, the central portion being the circular curve, merging gradually at each end into a spiral transition curve.

A spiral curve is laid out by setting up the instrument at the T.S. and laying out the first spiral to the S.C. using chords and deflection angles measured from the main tangent. Tables are available from which you can obtain deflection angles (θ) of a spiral curve from the T.S. to any point on the spiral. For most highway work it is conventional to use the 10-point spiral. It may increase your understanding to compare the layout of a spiral with that of a circular curve. The T.S. of a spiral may be compared to the P.C. of a circular curve, the S.C. may be compared to the P.T. of a circular curve. After laying out the first spiral, move the transit to the S.C. and lay out the circular to its end at the C.S., using chords and deflection angles measured from an auxiliary tangent at the S.C. Move the transit to the S.T. and lay out the second spiral, working back toward the C.S. The end of the second spiral should coincide with the C.S. and thereby provide a check on the accuracy of your work.



45.364

Figure 8-36.—Spiral transitions.

SUPERELEVATION AND WIDENING

"Superelevation" is the term used by the engineer to describe the banking of a curved roadway. Superelevations are closely associated with spiral transition curves in that they both attempt to compensate for the centrifugal force which tends to cause skidding outward from the center of a curve. Straight sections of highways are usually built with a slight convexity or crown to take care of drainage. If the same crown were continued around curves, it would produce a hazard for fast moving traffic. To minimize the danger of skidding, engineers superelevate or bank the outer portion of the curved section of the road. At the same time, they usually widen the pavement as an additional safety measure. No attempt will be made to discuss the computations involved in transition spirals, in superelevations, or in road widening, because they are beyond the scope of this book. Such information is available in standard textbooks on highway engineering.

VERTICAL CURVES

In addition to horizontal curves which go to the right or left, roads also have curves that go up or down. These curves in a vertical plane are called VERTICAL CURVES. 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 which go up or down at a constant slope. These lines of constant slope are called GRADE TANGENTS (see fig. 8-37.) 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 which ascend in the direction of the stationing are designated "plus", those which descend in the direction of the stationing are designated "minus." Grades are

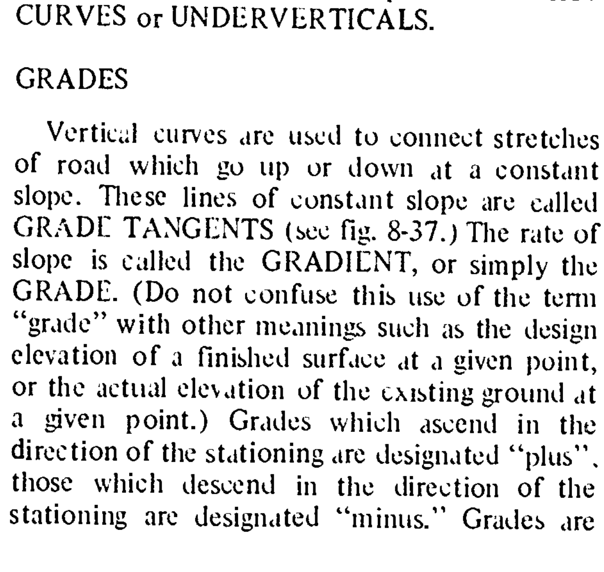


Figure 8-37.—A vertical curve.

measured in terms of percent, that is, the number of feet of rise or fall in a 100-foot horizontal stretch of the road.

After the location of a road has been determined and the necessary fieldwork has been obtained, the engineer designs, or "fixes", or "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 4 percent desired maximum, and 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 major street, the maximum grades might be 5 percent desired and 8 percent absolute maximum, and for a tertiary road or a secondary street, 8 percent desired and 10 percent (or perhaps 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, or 6 inches, 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 0 percent grade. Zero percent grades are not unusual, particularly through plains or tidewater areas. Another factor that is considered in designing the finished profile of a road is the EARTHWORK BALANCE. That is, the grades should be set so that all the earth cut off the hills may be economically hauled to fill in the low areas. In the design of urban streets, the best utilization of the building sites adjacent to the street will generally take precedence over seeking an earthwork balance.

COMPUTING VERTICAL CURVES

As you have previously learned, the horizontal curves used in highway work are generally the arcs of circles. But vertical curves are usually PARABOLIC CURVES. The parabola was chosen primarily because its shape provides a transition, and because it lends itself to computational procedures which are described in the next section of this chapter. Designing a vertical curve consists principally of deciding on the appropriate LENGTH of the curve. As indicated in figure 8-37, 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 will be the transition 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 (see figure 8-38). 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 reaction time, braking time, stopping distance, height of eye, height of object, and so on. Typical heights of eye used are 4.5 feet or, more recently, 3.75 feet; typical heights of object are 4 inches to 1.5 feet. For a sag curve, the sight distance will usually not be significant during daylight; but consideration must be given to nighttime when the reach of headlights may be limited by the abruptness of the curve. (See fig. 8-38.)

Elements of Vertical Curves

Figure 8-39 shows the elements of a vertical curve. The meaning of the symbols and the units of measurement usually assigned to them follow:

P.V.C. — point of vertical curvature; the place where the curve begins.

P.V.I. — point of vertical intersection; where the grade tangents intersect.

P.V.T. — point of vertical tangency; where the curve ends.

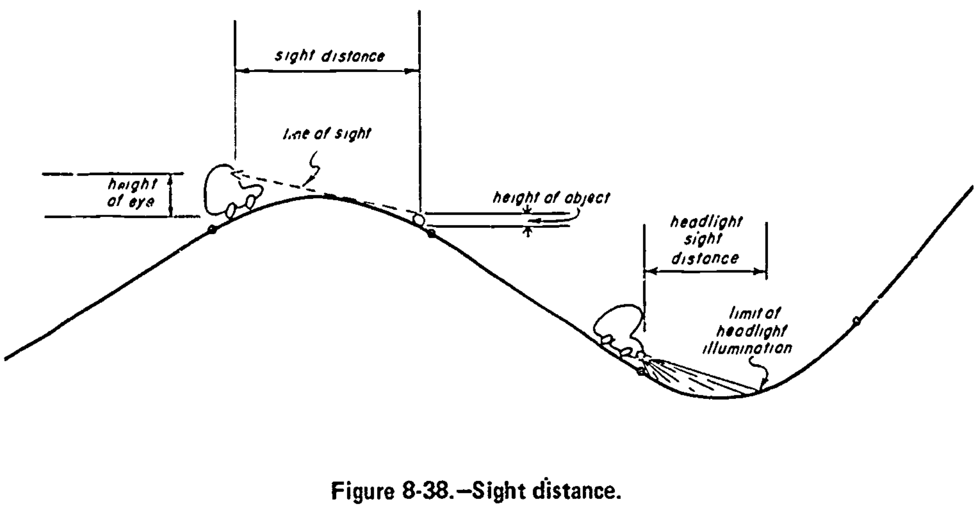
P.O.V.T. — point on vertical tangent, applies to an infinite number of points on either tangent.

P.O.V.C. — point on vertical curve; applies to any point on the parabola.

g_1 — grade of the tangent on which the P.V.C. is located; measured in percent of slope.

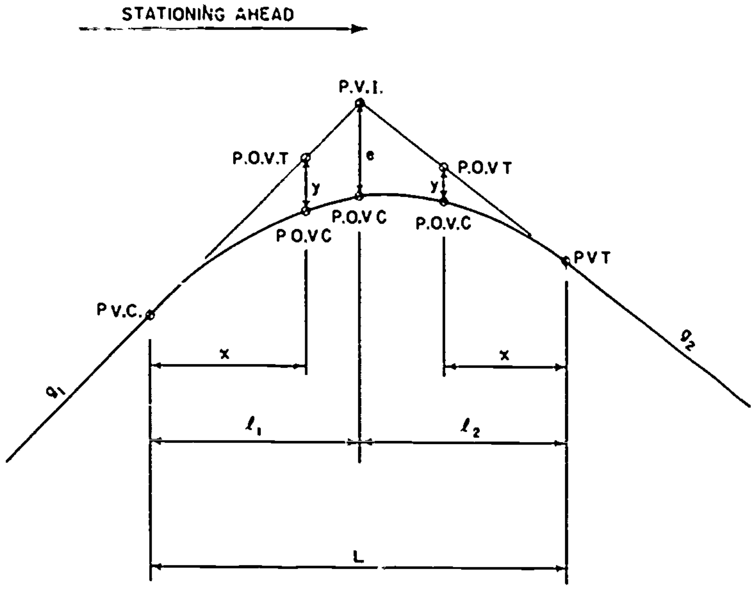
g_2 — grade of the tangent on which the P.V.T. is located; measured in percent of slope.

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; example



45.366

Figure 8-38.—Sight distance.



45.367

Figure 8-39.—Elements of a vertical curve.

of various algebraic differences are shown later in this section.

L length of the curve; the HORIZONTAL length in 100-foot stations from the P.V.C. to the P.V.T.

l_1 horizontal length of the portion of the P.V.C. to the P.V.I.; measured in feet.

l_2 horizontal length of the portion of the curve from the P.V.I. to the P.V.T.; measured in feet.

e vertical (external) distance from the P.V.I. to the curve, measured in feet; $e = \frac{LG}{8}$, where L is the total length in stations and G is the algebraic difference of the grades in percent.

x horizontal distance from the P.V.C. to any P.O.V.C. or P.O.V.T. back of the P.V.I., or the distance from the P.V.T. to any P.O.V.C. or P.O.V.T. ahead of the P.V.I., measured in feet.

y vertical distance (offset) from any P.O.V.T. to the corresponding P.O.V.C., 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 P.V.I. The general procedure is to compute the elevations of certain P.O.V.T.'s; then, using the foregoing formulas, to compute G, thence e, and thence the y's, that correspond to the selected P.O.V.T.'s. Adding or subtracting the y from the elevation of the P.O.V.T. gives the elevation of the P.O.V.C.; that is, the finished elevation on the road, which is the end result being sought. In figure 8-39, the y is subtracted from the elevation of the P.O.V.T. to get the elevation on the curve; but in the case of a sag curve the y is added to the P.O.V.T. elevation to obtain the P.O.V.C. 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 which 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 8-40. Note that the algebraic sign of G indicates whether to add or subtract y from a P.O.V.T.

The selection of the points at which to compute the y and the elevations of the P.O.V.T. and P.O.V.C. is generally based on the stationing. The horizontal alignment of a road is usually staked out on 50-foot or 100-foot stations, it is customary to compute the elevations at these same points so that both horizontal and vertical information for construction will be provided at the same point. The P.V.C., P.V.I., and P.V.T. 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 P.V.I. to the P.V.C. is equal to the horizontal distance from the P.V.I. to the P.V.T. 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 = + 9%
g_2 = − 7%
L = 400.00′, or 4 stations
The station of the P.V.I. = 30+00
The elevation of the P.V.I. = 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 8-41 shows the vertical curve to be solved.

STEP 1: Prepare a table as shown in figure 8-42.

Column 1 shows the stations, column 2, the elevation on tangents, 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 differences, and column 8, the second differences.

STEP 2. Compute the elevations and set the stations on the P.V.C. and the P.V.T.

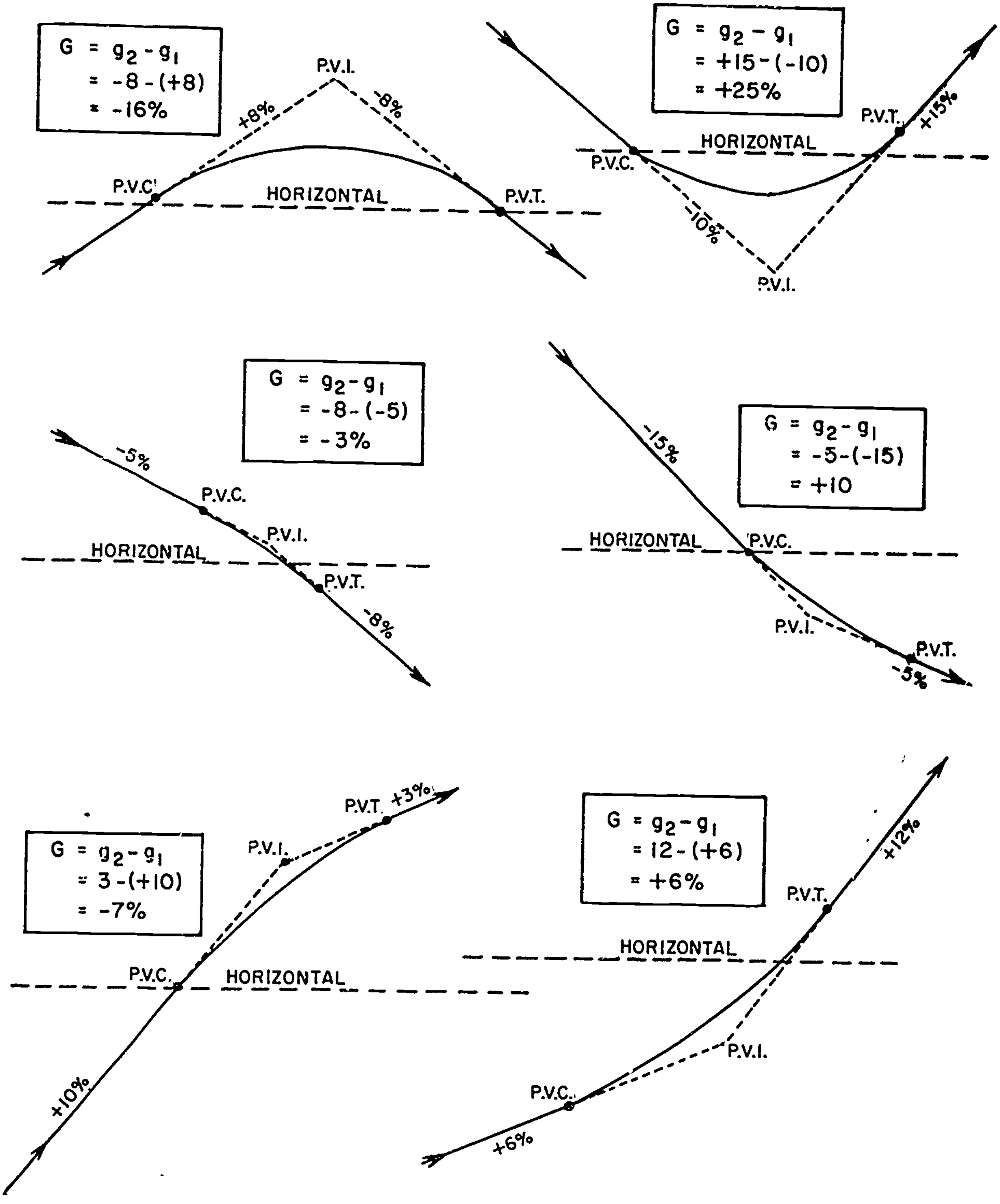
Knowing the gradients at the P.V.C. and P.V.T., the elevation and station at the P.V.I., you can compute the elevations and set the stations on the P.V.C. and the P.V.T. The gradient (g_1) of the tangent at the P.V.C. is given as + 9%. This means a rise in elevation of 9 feet for every 100 feet of horizontal distance. Since L is 400.00 feet and since this is a symmetrical vertical curve, 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 P.V.I. and the elevation at the P.V.C. The elevation at the P.V.I. in this problem is given as 239.12 feet. The elevation at the P.V.C., therefore, is 239.12 minus 18 or 221.12 feet.

Calculate the elevation at the P.V.T. in a similar manner. The gradient (g_2) of the tangent at the P.V.T. is given as -7%. 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 P.V.I. and the elevation at the P.V.T. The elevation at the P.V.I. therefore is 239.12 feet minus 14 feet or 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 P.V.I. to the P.V.C. In this problem, l_1 equals 200 feet. This is equivalent to two 100-foot stations and may be expressed as 2 + 00. Thus, if the station at the P.V.C. is 30 + 00 MINUS 2 + 00 or 28 + 00. The station at the P.V.T. is 30 + 00 PLUS 2 + 00 or 32 + 00. List the stations under column 1.

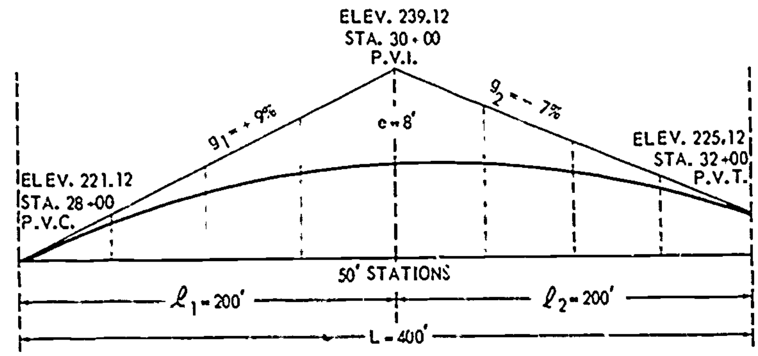
STEP 3: Calculate the elevations at each 50-foot station on the tangent.

From step 2 you know that there is a 9-foot rise in elevation for every 100 feet of horizontal distance from the P.V.C. to the P.V.I. Thus for every 50 feet of horizontal distance there will be



45.368

Figure 8-40.—Algebraic differences of grades.



45.369

Figure 8-41.—Symmetrical vertical curve.

a rise of 4.50 feet in elevation. The elevation on the tangent at station 28 + 50 is 221.12 plus 4.50 or 225.62 feet. The elevation on the tangent at station 29 + 00 is 225.62 plus 4.50 or 230.12 feet. The elevation on the tangent at station 29 + 50 is 230.12 plus 4.50 or 234.62 feet. The elevation on the tangent at station 30 + 00 is 234.62 plus 4.50 or 239.12 feet. In this problem, to find the elevation on the tangent at any 50-foot station starting at the P.V.C., add 4.50 to the elevation at the preceding station until you reach the P.V.I. At this point use a slightly different procedure in calculating elevations because the curve slopes downward toward the P.V.T. Think of the elevations as being divided into two groups—one group running from the P.V.C. to the P.V.I.; the other group running from the P.V.T. to the P.V.I.

Proceeding downhill on a gradient of -7% from the P.V.I. to the P.V.T., there will be a drop of 3.50 feet for every 50 feet of horizontal distance. To find the elevations at stations

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	1/4	1/16	− 0. 50	225. 12		+1. 00
						+3. 00	
29+00	230. 12	1/2	1/4	− 2. 00	228. 12		+1. 00
						+2. 00	
+50	234. 62	3/4	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	3/4	9/16	− 4. 50	231. 12		+1. 00
						−1. 00	
31+00	232. 12	1/2	1/4	− 2. 00	230. 12		+1. 00
						−2. 00	
+50	228. 62	1/4	1/16	− . 50	228. 12		+1. 00
						−3. 00	
32+00 (*PVT*)	225. 12	0	0	0	225. 12		

45.370

Figure 8-42.—Table of computations of elevations on a symm rical vertical curve.

between the P.V.I. and the P.V.T. 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 MINUS 3.50 or 235.62 feet. The elevation on the tangent at station 31+50 is 235.62 MINUS 3.50 or 232.12 feet. The elevation on the tangent at station 31+50 is 232.12 MINUS 3.50 or 228.62 feet. The elevation on the tangent at station 32+00 (P.V.T.) is 228.62 MINUS 3.50 or 225.12 feet. The last subtraction provides a check on your work thus far. List the computed elevations under column 2.

STEP 4: Calculate (e), the middle vertical offset at the P.V.I.

First find (G), the algebraic difference of the gradients using the formula

$$G = g_2 - g$$
$$G = -7 - (+9)$$
$$G = -16\%$$

The middle vertical offset (e) is calculated by use of the formula $e = \frac{LG}{8}$, where L is the length of the curve measured in horizontal stations and G is the algebraic difference in gradients.

$$e = \frac{(4)(-16)}{8} = -8.00 \text{ ft}$$

The negative sign indicates e is to be subtracted from the P.V.I.

STEP 5: Compute the vertical offsets at each 50-foot station, using the formula $y = \left(\frac{x}{l}\right)^2 e$.

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+00, the ratio of x/l = 50/200 = 1/4.

$$\left(\frac{x}{l}\right)^2 = \frac{1}{16}$$

The vertical offset at station 28 + 50 equals (1/16) (−8) or −0.50. 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 225.62 minus 0.50 or 225.12 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 P.V.I. 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 measured from the P.V.C. if the tangent with the lesser slope begins there, or from the P.V.T. 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 P.V.C. or P.V.T.
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:

$$x_t = \frac{gL}{G} = \frac{7(4)}{16} = 1.75$$

Therefore, the turning point is 1.75 stations, or 175 feet, from the P.V.T. (station 30+25).

The vertical offset for the turning point would be found by the formula.

$$y_t = \left(\frac{x_t}{l}\right)^2 e$$

For this curve the computations would be:

$$y_t = \left(\frac{x_t}{l}\right)^2 e = \left(\frac{1.75}{2}\right)^2 8 = 6.12$$

The elevation of the P.O.V.T. 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 take the plus or minus signs into consideration. When you round off your grade elevation figures according to the degree of precision required, you introduce an error which will cause the second differences to vary slightly from one another. However, the slight variation does not detract from the value of the second differences as a check on your computations. You are cautioned that the second differences will not always come out EXACTLY even and equal. It is merely a coincidence that the second differences have 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 P.V.I. to the P.V.C. is different from the horizontal distance between the P.V.I. and the P.V.T. 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 8-43 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 P.V.I. The gradient of the tangent at the P.V.C. is -4%, the gradient of the tangent at the P.V.T. is +6%. Note that the curve is in a dip.

Given: Elevation at the P.V.I. is 332.68 feet
Station at the P.V.I. is 42+00
l_1 is 400 feet
l_2 is 200 feet
g_1 is -4%
g_2 is +6%

To Find: Calculate the grade elevations on the curve to the nearest hundredth.

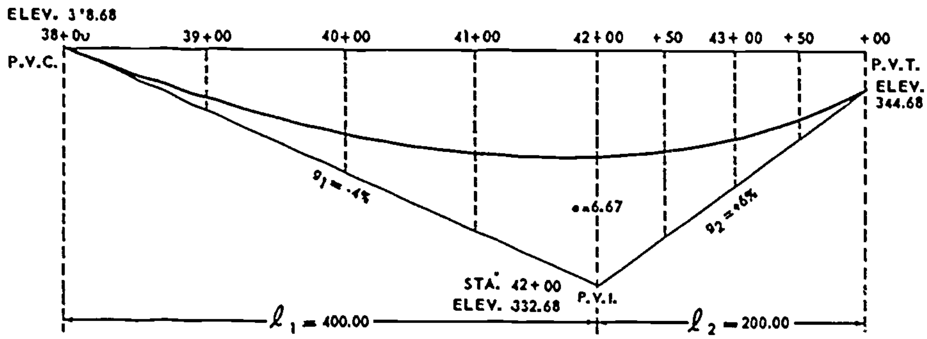
Figure 8-44 shows the computations. Set four 100-foot stations on the left side of the P.V.I. (between the P.V.I. and the P.V.C.). Set four 50-foot stations on the right side of the P.V.I. (between the P.V.I. and the P.V.T.). The procedure for solving an unsymmetrical curve problem is essentially the same as that used in solving a symmetrical curve. There are, however, important differences you should be cautioned about. First, use a different formula for the calculation of the middle vertical offset at the P.V.I. In an unsymmetrical curve, substituting in the formula:

$$e = \frac{l_1 l_2}{2(l_1 + l_2)} (g_1 - g_2)$$

$$e = \frac{(4)(2)}{2(4+2)} (-4 - (+6))$$

$$e = \frac{8}{12}(10) = 6.67 \text{ feet}$$

Second, you are cautioned that the check on your computations by use of second differences does NOT work out the same way for an unsymmetrical curve as for a symmetrical curve. The second difference will not check for the differences that span the P.V.I.; this is because an unsymmetrical curve is really two parabolas, one on each side of the P.V.I., having a common P.O.V.C. opposite the P.V.I. The second difference will check out, however, back and ahead of the first station on each side of the P.V.I.



45.371

Figure 8-43.—Unsymmetrical vertical curve.

Third, the turning point is not necessarily above or below the tangent with the lesser slope. The horizontal location is found by one of two formulas:

from the P.V.C.

$$x_t = \frac{(l_1)^2 g_1}{2e}$$

from the P.V.T.

$$x_t = \frac{(l_2)^2 g_2}{2e}$$

The procedure is to estimate which side of the P.V.I. the turning point is on, then use the proper formula to find its location. If the

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 (*P. V. C.*)	348. 68	0	0	0	348. 68	
39+00	344. 68	¼	1/16	+ . 42	345. 10	100 foot stations.
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 (*P. V. I.*)	332. 68	1	1	+ 6. 67	339. 35	
42+50	335. 68	¾	9/16	+ 3. 75	339. 43	
43+00 ($g_2 = +6\%$)	338. 68	½	¼	+ 1. 67	340. 35	50 foot stations.
43+50	341. 68	¼	1/16	+ . 42	342. 10	
44+00 (*P. V. T.*)	344. 68	0	0	0	344. 68	

45.372

Figure 8-44.—Table of computations of elevations on an unsymmetrical vertical curve.

formula indicates that the turning point is on the opposite side of the P.V.I., you must use the other formula to determine the correct location. For example, you estimate that the turning point is between the P.V.C. and P.V.I. for the curve in figure 8-43. Solving the formula.

$$x_t = \frac{(l_1)^2 g_1}{2e} = \frac{(4)^2\ 4}{(2)\ 6.67} = 4.80 \text{ or}$$

station 42+80.

Station 42+80 is between the P.V.I. and P.V.T., so use the formula:

$$x_t = \frac{(l_2)^2}{2e} g_2 = \frac{(2)^2\ 6}{(2)\ 6.67} = 1.80 \text{ or}$$

station 42+20.

Station 42+20 is the correct location of the turning point. The elevation of the P.O.V.T., the amount of the offset, and the elevation on the curve is determined as previously explained.

Checking the Computation by Plotting

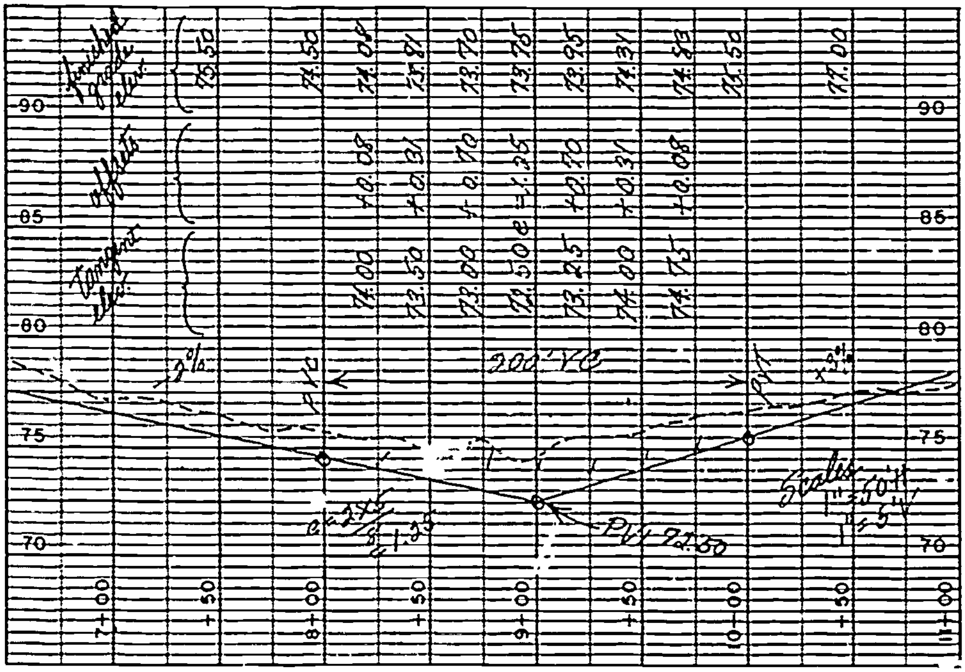
Always check your work by plotting the grade tangents and the curve in profile on an exaggerated vertical scale; that is, with the vertical scale perhaps 10 times the horizontal scale. The details of profile plotting are covered in *Engineering Aid 3 & 2*. After the P.O.V.C.'s have been plotted, you should be able to draw a smooth parabolic curve through the points with the help of a ship's curve or other appropriate 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 work print of the profile. The engineer will set the grades and indicate the length of the vertical curves. You may then scale the P.V.I. elevations and compute the grades if the engineer hasn't done so. Then, using the calculating machine, compute the P.O.V.T. elevations at the selected stations. You will find that you can set up the computations in the calculating machine so that you can carry the grades, the stations, and the elevations in the machine from one end of the profile to the other, checking in at each previously set P.V.I. elevation. Write the tangent elevation at each station on the worksheet. Next, compute e; in the many cases where three significant figures are sufficient, it is most convenient to use your slide rule. Then compute each vertical offset. mentally note the x/l ratio, then square it and multiply by e on your slide rule. 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 machine) to give you the curve elevations which you then record on the work sheet. Plot the P.O.V.C. 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 P.V.C., P.V.I., P.V.T., and the e. Figure 8-45 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. Detailed procedures for setting grade stakes are covered in *Engineering Aid 3 & 2*. The procedure for setting a grade stake is the same whether it's 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 this 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 P.O.V.C. elevation in the field using the data given on the plans and the computational procedures in this chapter.



45.373

Figure 8-45.—Profile work sheet.

CHAPTER 9

ADJUSTMENT AND REPAIR OF SURVEYING EQUIPMENT

As used in surveying, the term ADJUSTMENT has two meanings, depending on its usage and intent. When applied to the instrument, adjustment means bringing the various fixed parts into proper relation with one another, so accurate results are obtained when the instrument is used. It is distinguished from the ordinary operations of leveling the instrument, aligning the telescope, and so forth. When the term is used in connection with the results of a survey, adjustment may mean one of the following. (1) The proper distribution of errors of closure in a closed traverse, (2) the angular adjustment of a station and/or figure in a triangulation network, or (3) the adjustment of elevations in a level circuit. The adjustment of survey results was discussed fully in previous chapters of this training manual.

As used in this chapter, adjustment is considered in terms of the first definition and information is presented on minor adjustments and repairs of surveying instruments and the replacement of equipment.

As a survey crew leader or party chief, the EA1 is responsible for the accuracy in which survey results are obtained. In order to obtain accurate survey results, instruments must be maintained properly. It is important that the instruments are in adjustment at all times. Proper adjustment will eliminate instrument error, reducing the errors found in survey results.

MINOR ADJUSTMENTS

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

EA1 should be familiar with the minor adjustments covered in this chapter. These adjustments are not laborious, nor are the basis of the adjustment principles difficult to understand. In order to make proper adjustments, it is important that the EA1 take the following into consideration:

1. He must be familiar with the principles upon which the adjustments are based.
2. He must know the methods or tests used to determine if an instrument is out of adjustment.
3. He must know the procedure for making actual adjustments, and the correct sequence by which they can be made expeditiously.
4. He must be able to tell what effect the adjustment of one part will have on other parts of the instrument.
5. He must understand the effect of each adjustment upon the instrument when it is actually used for measurement.

Generally, the adjustments of surveying instruments involve the level bubbles, 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. Similarly, an optical instrument equipped with vertical and horizontal crosshairs is out of adjustment if the point of intersection between the crosshairs does not coincide with the "optical axis". Similarly again. 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 involves chiefly the steps which are necessary to bring a bubble to center when it should be at center, or to bring a crosshair 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 Keuffel & Esser *Solar Ephemeris*, an annual publication consisting chiefly of astronomical tables, is such a pamphlet. Besides the tables, the *Solar Ephemeris* contains detailed adjustment procedures for K & E transits, levels, and alidades.

The following sections, taken from the K & E *Solar Ephemeris*, are intended to give you an idea of general instrument adjustment procedures. For adjusting particular instruments, you should follow the appropriate manufacturer's instructions.

GENERAL ADJUSTMENT PROCEDURE

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, much need for adjustment is caused by previously made improper adjustments which were not really required, but resulted from errors in checking.

Before it is assumed, then, that adjustment is necessary, it must be positively ascertained that an apparent maladjustment is actually such, and not a result of error in the check, or of circumstances other than maladjustment. The following procedures should be followed in checking.

1. Check 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 up on firm ground, in shade but in a good light, where a sight of at least 200 ft can be taken in opposite directions.
4. Spread the tripod feet well apart and place them so as to bring the plate approximately level. Press the shoes in firmly, or set them in cracks or chipped depressions if on a hardened surface. (Avoid setup 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" which, 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 tightening too tight. 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 and until the same check, repeated at least 3 times, indicates the same amount of error every time.
8. Remember that most tests show an error which is DOUBLE the actual displacement error in the instrument.

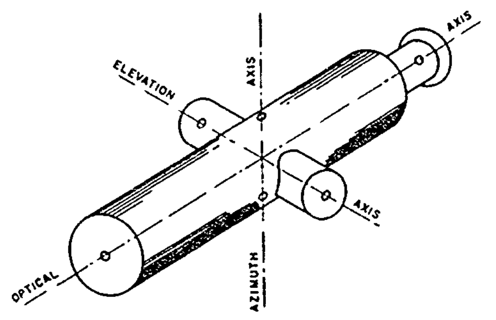
Be especially watchful for "creep"—that is, a change in position caused by settlement or by temperature change in the instrument. To detect any possible creep, allow every set bubble or set line of sight to stand for a few seconds, and ensure that no movement occurs during the interval.

Before making an adjustment, consider whether or not the error discovered will have a material effect on field results. Make adjustments in prescribed order, to avoid disturbing an adjustment by a subsequent adjustment. After an adjustment is made, set up the parts firmly but not too tight. Then repeat the original check at once. After all the contemplated adjustments have been made, 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.

TRANSIT ADJUSTMENTS

Figure 9-1 illustrates the meanings of the terms "vertical axis", "optical axis", and "horizontal axis" as they apply to a transit, engineer's level, or alidade.

The transit must be kept in good adjustment to obtain accurate results. There are six tests and adjustments of the transit that you must be capable of performing. All tests and adjustments of the transit are made with the instrument mounted on its tripod and set up in the shade. These tests should be made periodically, in the sequence in which they are discussed in the following paragraphs. When one of the tests indicates that an adjustment is necessary, this adjustment must be made and all previous tests must be repeated before proceeding with the next test.



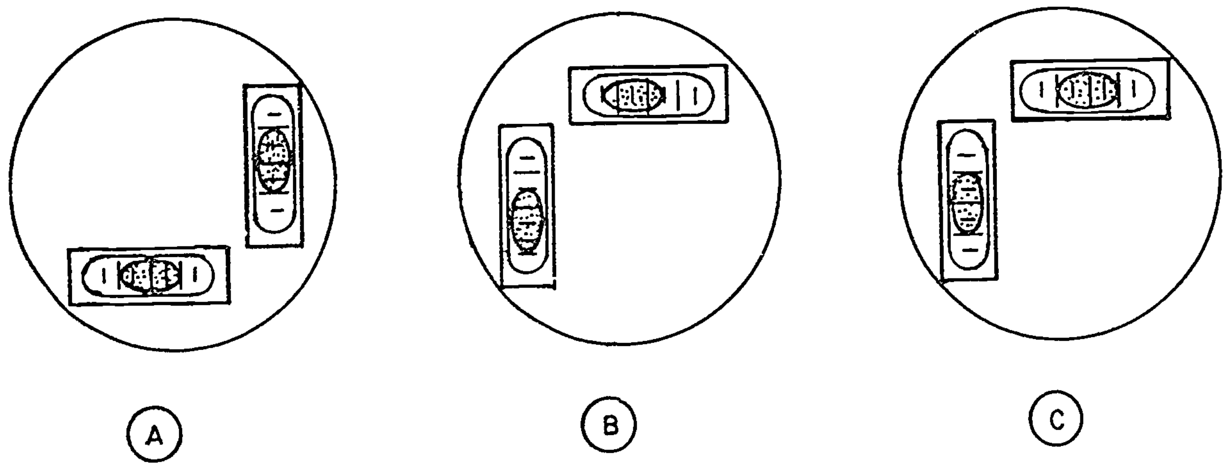
45.434

Figure 9-1.–Principal axis of surveying instruments, such as the transit, engineer's level, or the alidade.

Plate Bubbles Adjustment

The test of the plate bubbles should be made every time the instrument is set up for use. When an error in the adjustment of either plate level is indicated, it is not always necessary to make the adjustment, because the operation of bringing the bubble halfway back to center by turning the leveling screws makes the vertical axis of the transit vertical. The adjustment must be made, however, before other tests and adjustment of the instrument. To make the axis of the bubbles perpendicular to the vertical axis (fig. 9-2), perform the following steps:

1. Set up the transit and bring both bubbles to the center of their tubes by turning the leveling screws (view A, fig. 9-2).
2. Rotate the instrument about its vertical axis through 180° and note the amount the bubbles move away from their center (view B, fig. 9-2).
3. Bring the bubble of each tube half the distance back to the center of its tube by turning the capstan screws at the end of each tube.
4. Relevel with the leveling screws and rotate the instrument again. Make similar correction if the bubbles do not remain in the center of the tubes.



45.751(82B)

Figure 9-2.–Adjustment of plate bubbles.

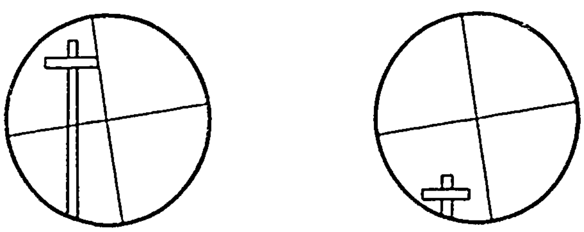
5. Check the final adjustment by noting that the bubbles remain in the center of the tubes during the entire revolution about the vertical axis (view C, fig. 9-2).

Crosshair Reticle Adjustment

The point of intersection between the horizontal and the vertical crosshairs should lie on the optical axis. The optical axis is at the center of the circular field of view through the telescope.

To make the vertical crosshair lie in a plane perpendicular to the horizontal axis (fig. 9-3), follow the procedure below:

1. See that parallax is eliminated. Sight the vertical crosshair 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 crosshair will appear to stay on the point through its entire length.
2. If it does not, loosen the two capstan screws holding the crosshairs and slightly rotate the ring by tapping the screws lightly.
3. Sight again on the point. If the vertical crosshair does not stay on the point through its entire length as the telescope is moved up and down, rotate the ring again.
4. Repeat this process until the condition is satisfied.

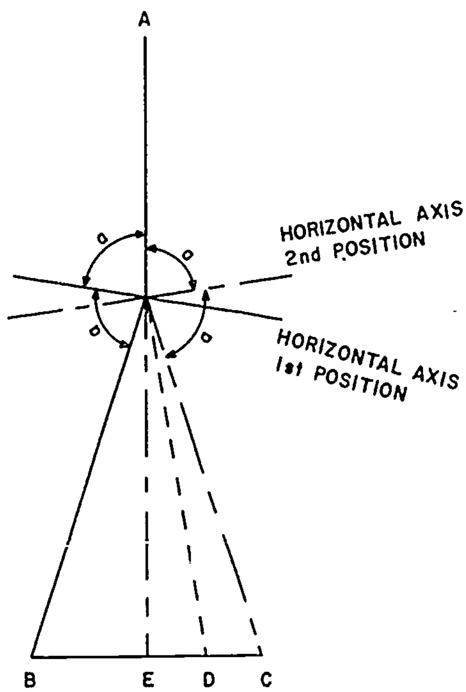


45.752

Figure 9-3.--Adjustment of the vertical crosshair.

To make the line of sight perpendicular to the horizontal axis (fig. 9-4), 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, and sight on the first point (telescope inverted) and clamp.
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 crosshairs (point C) will fall to one side of the second point, B.
5. Measure the distance BC and place a point, D, one-fourth of this distance back toward the original point B.
6. Move the crosshair reticle horizontally by loosening the screws on one side of the telescope tube and and tightening the opposite screw until the vertical crosshair appears to have moved from C to the corrected position D.
7. Repeat this operation from No. 1 above, until no error is observed.



115.75(45B)A

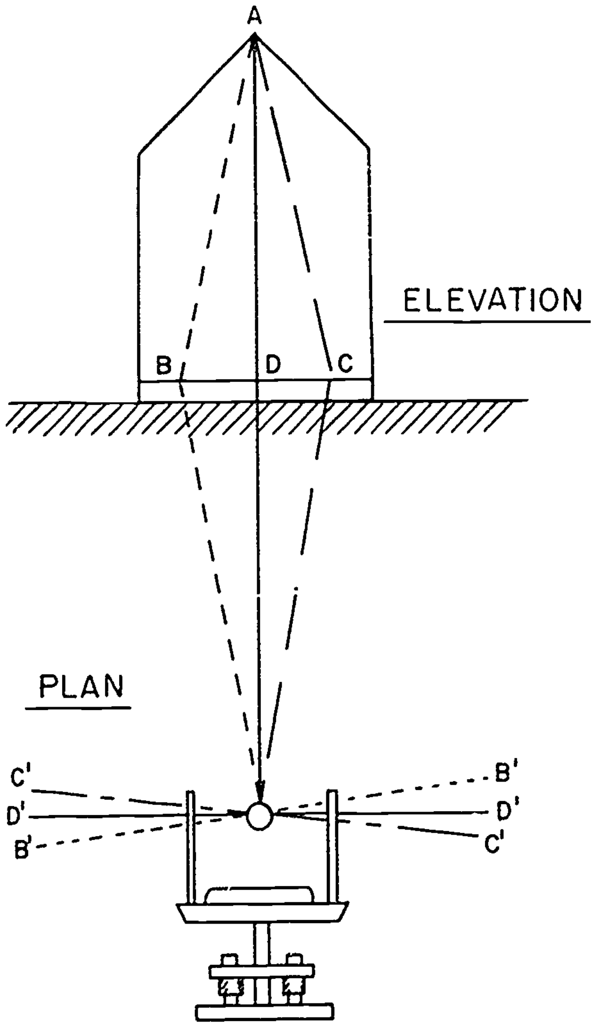
Figure 9-4.—Adjustment of the crosshair reticle.

8. Repeat the test described for adjusting the vertical crosshair, since the vertical crosshair may have rotated during this adjustment.

Horizontal Axis Adjustment

To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument (fig. 9-5), perform the following steps:

1. Sight with the vertical crosshair on some high point, A, at least 30° above the horizontal and at a distance of 200 ft, such as the corner of the eaves of a stable building or other well-defined objects, and clamp the plates.



45.754
Figure 9-5.—Adjustment of the elevation axis.

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 vertical axis and depress the telescope. If the vertical crosshair 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 by turning the small capstan screw in the adjustable bearing at one end of the horizontal axis to correct the error.

9. Repeat this test until the vertical crosshair passes through the high and low points in the direct and inverted position of the telescope.

10. Check all previous adjustments.

Telescope Level Adjustment

To make the axis of the telescope level of the transit parallel to the line of sight, use the TWO-PEG method which is used in the adjustment of the engineer's level. The method is the same except that the correction is made by raising or lowering the telescope level tube. (The TWO-PEG method for adjustment of the Engineer's level is explained fully later in this chapter.) The steps for performing the adjustment of the transit telescope level are as follows.

1. The instrument is set up midway between two stakes driven 200 to 300 feet apart.

2. A reading is taken through the telescope on a rod held on each of the stakes. The telescope must be carefully leveled before each reading. The difference between readings is the difference in elevation between the stakes.

3. The instrument is moved, set up, and leveled close to one of the stakes. The eyepiece should swing within about one-half inch of the rod.

4. The near rod is read through the objective, and the far rod in a normal manner, leveling the telescope carefully before each reading. The difference between rod readings should equal the difference from No. 2 above, if the instrument is in adjustment. If not, a correction must be made.

5. To adjust, compute the reading that should be made on the far rod. This equals the near rod reading plus the difference from No. 2 above.

6. Set the horizontal crosshair on the computed reading using the slow motion screw, and move one end of the spirit level vertically by means of the adjusting nuts until the bubble is in the center of the tube (fig. 9-6).

Vertical Circle Vernier Adjustment

To index the vertical circle vernier to read zero when the instrument is leveled (fig. 9-7), perform the following.

1. Bring the telescope bubble to the center of the tube.

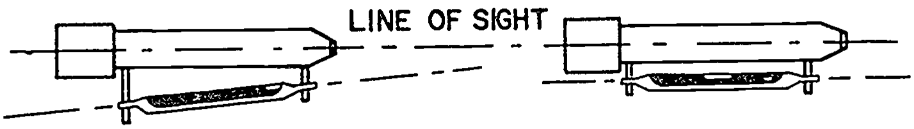
2. Read the vernier of the vertical circle.

3. If it does not read zero, loosen the capstan screws holding the vernier and move the index until it reads zero on the vertical circle.

4. Tighten the screws and read the vernier with all the bubbles in the center of their tubes to make sure that the vernier has not moved during the operation.

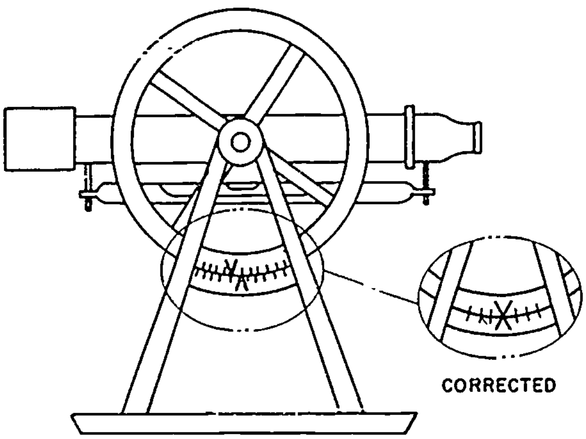
ALIDADE ADJUSTMENTS

The adjustments of an alidade are similar to those of a transit. The telescopic alidade also requires six adjustments. They should be made in the listed sequence. The seventh adjustment given here is the only one required for the self-indexing alidade. Prior to the alidade adjustment, the planetable is set up and carefully leveled.



45.755

Figure 9-6.—Adjustment of the telescope bubble.



45.756

Figure 9-7.—Adjustment of the vertical circle vernier.

Crosshair Reticle Adjustments

The following procedure is used to make the line of sight through the crosshair intersection coincide with the axis of the telescope (collimation adjustment):

1. Point the alidade at a distant well-defined point.

2. Rotate the telescope in its sleeve. The intersection of the crosshairs should remain on the distant point. If the distant point appears to move away from either or both the crosshairs, they should be adjusted.

3. Adjust each crosshair separately until the intersection of the crosshairs continually bisects the distant point as the telescope is rotated through 180°.

Vertical Crosshair Adjustment

To make the vertical crosshair perpendicular to the horizontal axis of the telescope, perform the following steps:

1. See that parallax is eliminated and that the alidade is leveled. Sight the vertical hair on a well-defined point, and move the telescope slightly up and down on its horizontal axis with the slow motion screw. If the instrument is in adjustment, the vertical crosshair will appear to follow the point through its entire length.
2. If it does not, loosen the screws holding the crosshairs and slightly rotate the ring by tapping the screws lightly.
3. Sight again on the point and if the vertical crosshair does not follow the point through its entire length as the telescope is moved up and down, rotate the ring again.
4. Repeat this process until the condition is satisfied.
5. Repeat the collimation adjustment check above to make sure that the crosshair intersection still coincides with the axis of the telescope.

Striding Level Adjustment

The following procedure is used to make the axis of the striding level parallel to the line of sight:

1. Clip the striding level into place on the telescope.
2. Center the level bubble using the tangent screw.
3. Unclip, reverse, and reclip the striding level.
4. If the bubble is off center, bring it halfway back using the tangent screw.
5. Complete the centering, using the pair of capstan screws at one end of the bubble tube.
6. Repeat the test and adjustment until a reversal of the striding level does not move the bubble off center.

Vertical Arc Control Level Adjustment

To make the vertical arc read true vertical angles, perform the following.

1. Place the alidade on a stable, flat, approximately level surface.
2. Place the striding level on the telescope.
3. Center the bubble of the striding level in its vial.
4. Move the zero graduation of the vernier into coincidence with the 30° graduation of the vertical arc. If the bubble of the vertical arc control level comes to rest off center, use the adjusting screws near one end of the vertical arc control level to move the bubble until it is centered in the vial.

Circular Level Adjustment

Circular level adjustment is made by the following procedure:

1. Set up and approximately level the plane-table.
2. Place the alidade near the center of the drawing board.
3. Draw a line along the length of the alidade blade.
4. Turn the alidade 180° and replace the edge of the blade on the line previously drawn on the board. The bubble of the circular level should now come to rest at the center of the circle.
5. If the bubble comes to rest off center, the blade must be checked for flatness. When the test indicates the blade is warped, the blade must be flattened. If a test of the level still indicates an error, the bubble should be adjusted by placing small shims under the edge of the bubble holder.

Stadia Arc Adjustment

The following procedure is used to make the stadia arc read the true stadia factors for horizontal and vertical corrections:

1. Test and adjust the vertical arc control level, as described above.
2. Inspect the stadia arc index mark or marks. The index for horizontal corrections should be in exact coincidence with the arc graduation numbered 100. The index for the vertical corrections should be in exact coincidence with the arc graduation numbered 50.

3. When the bubbles of the striding level and the vertical arc control level are both centered in their vials and the stadia arc is not properly positioned, loosen the index plate holding screws with a screwdriver, move the plate to its proper position, and clamp in place by retightening the screws.

Self-Indexing Alidade Adjustment

To set the scales of the self-indexing alidade at their correct values when the line of sight is horizontal, perform the following steps.

1. Set up and level the planetable over one of two selected points at about the same elevation and about 250 feet apart.
2. Place the rod against the planetable, slide the left side of the alidade up to the rod, and read the exact height of the friction adjusting screw on the end of the telescope axle. A pencil mark at this point on the rod will be helpful.
3. Move the rod to the other selected point, sight upon the marked point, and read the vertical angle scale.
4. Move and set up the planetable at the second position.
5. Check the height of the adjusting screw at this point and move the rod to the first point.
6. Sight on the second marked point (if not the same as the first point) and read the vertical angle scale.
7. If the instrument is in adjustment, the sum of the two readings (3 and 6 above) will equal 180°. If the sum is not 180°, the instrument needs adjustment.
8. To adjust, loosen the capstan locknut to the right of the tangent screw and move the reading an amount equal to one-half the difference between the sum and 180°.

For example:

Reading at position #1	= 89°48′
Reading at position #2	= 90°20′
Sum	= 180°08′

$$\text{Amount of correction} = \frac{08'}{2} = 04'$$

(The sum is greater than 180°, so the correction is minus.)

9. With the instrument still set up at the second position, the value is changed, 90°20′ - 04′ = 90°16′.

ENGINEER'S LEVEL ADJUSTMENTS

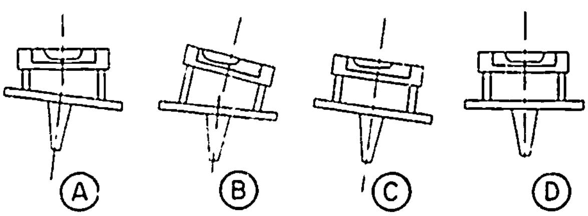
A check of the instrument's adjustment should be made upon receipt from the supplier and before it is taken to the field. It is necessary to check the adjustments every day before starting work and at any time the instrument is bumped or jolted. The instrument should be set up and approximately leveled over both pairs of screws. Since the check will also include the optical assembly, the crosshairs and objective should be focused sharply, using a well-defined object at least 250 feet away, and then the parallax removed. When parallax is present, the image is not exactly in the plane of the crosshairs and the objective focusing must be refined. Since this condition can occur each time the objective lens is focused, a parallax check must be made whenever a new object is observed.

The check and adjustment of an engineer's level is made in three steps and in the order listed.

Telescope Level Adjustments

Adjustment of the bubble tube (fig. 9-8), makes the axis of the bubble perpendicular to the vertical axis. The adjustment procedure follows:

1. Set the telescope over diametrically opposite leveling screws, and center the bubble carefully as shown in view A, figure 9-8.
2. Rotate the telescope 180° and note the movement of the bubble away from the center (view B, fig. 9-8).



45.757

Figure 9-8.—Adjustment of the bubble tube.

3. Bring the bubble half the distance back to the center of the tube by turning the capstan screws at the end of the tube (view C, fig. 9-8).

4. Relevel with the leveling screws (view D, fig. 9-8) and rotate the instrument again. Repeat (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.

Crosshair Reticle Adjustments

The crosshairs are adjusted to make the horizontal crosshair lie in a plane perpendicular to the vertical axis (See fig. 9-9.) The adjustment is made by performing the following steps:

1. Level the instrument carefully.

2. Sight one end of the horizontal crosshair on a well-defined point at least 250 feet away. Turn the telescope slowly on its vertical axis, using the slow motion screw. If the crosshairs are in adjustment, the horizontal crosshair will stay on the point through its entire length.

3. If it does not, loosen two adjacent reticle capstan screws and rotate the reticle by lightly tapping two opposite screws.

4. Sight on the point again and if the horizontal wire does not follow the point through its entire length, rotate the ring again.

5. Repeat this process until the condition is satisfied.

Line of Sight Adjustment

To adjust the line of sight parallel to the axis of the bubble tube, use the "two-peg" test method (fig. 9-10). This method requires the following steps:

1. Set up the instrument (first set-up, fig. 9-10); drive stake A about 150 feet away; drive stake B at the same distance in the opposite direction. Set up the instrument so that a pair of opposite screws is parallel with line AB.

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 set-up, fig. 9-10) so that the eyepiece swings within a half inch from the rod.

4. Take a rod reading "c" on stake A through the objective lens, and a rod reading "d" on stake B in the normal manner. If the instrument is in adjustment (d-c) will equal (b-a).

5. 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 rod reading e with a target for accurate reading. Move the horizontal crosshair to the correct reading (on target) by loosening the correct vertical capstan screw and tightening the opposite screw.

6. Check the horizontal crosshair adjustment again. The ring may have rotated during this adjustment.

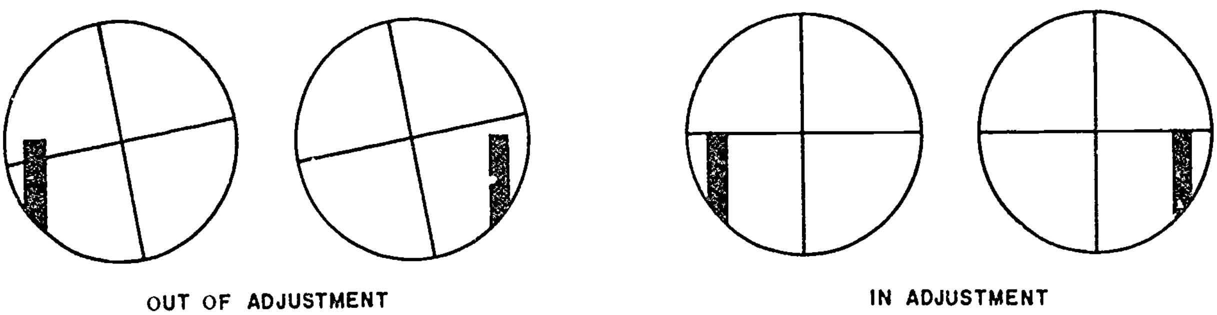
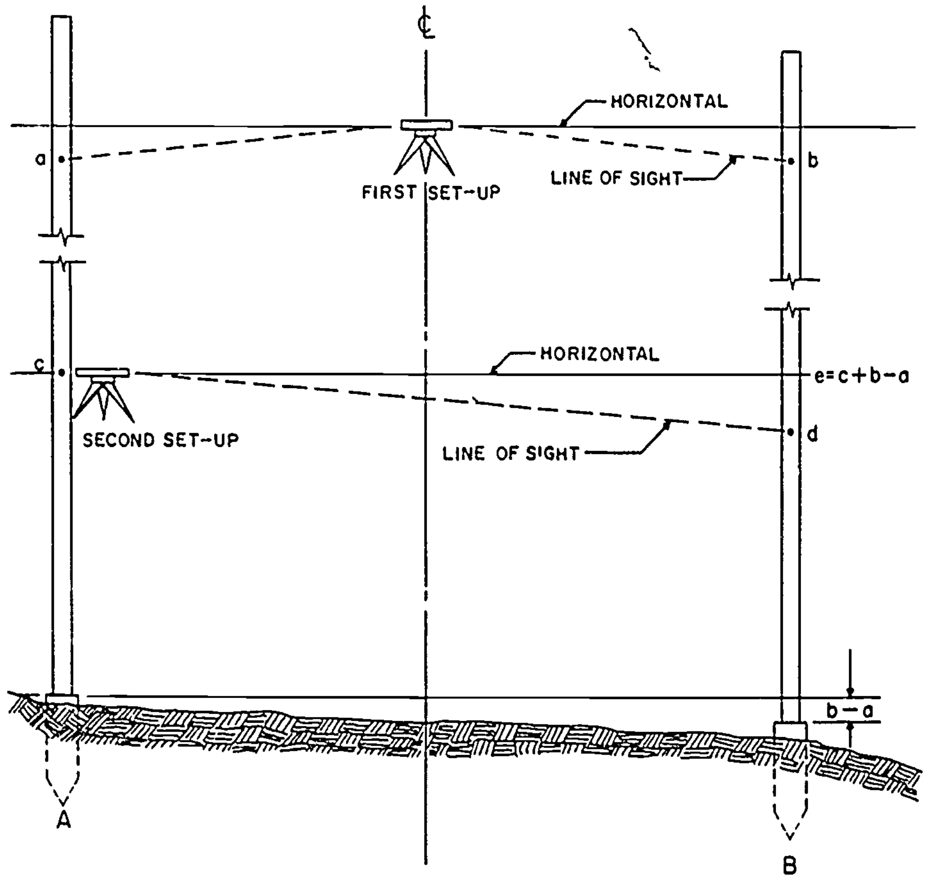


Figure 9-9.—Adjustment of the horizontal crosshairs.



45.435(45B)

Figure 9-10.—Two-peg test method.

7. Rerun the peg test to check the adjustment.

The adjustments described for the engineer's level are also applicable to adjustment of the dumpy and wye levels.

MILITARY LEVEL ADJUSTMENTS

The military level, as described in *Engineering Aid 3 & 2*, has a fixed reticle which does not permit checking or adjusting the line of sight. However, the circular level bubble and the main level bubble must be checked and adjusted. Whereas in the engineer's level, the line of sight was made parallel to the bubble axis; in the military level, the bubble is adjusted to the line of sight.

Circular Bubble Adjustment

The adjustment of the circular bubble level is similar to the adjustment of the long vial bubbles which were discussed earlier in this chapter, such as the plate level bubbles of the transit. Two axes at right angles on the bubble face are assumed and each axis is treated as if it is the longitudinal axis of a plate level bubble. The capstan screws on the base of the circular bubble housing are adjusted so that the bubble will remain in the center when the instrument is turned in any direction.

Main Telescope Level Bubble Adjustment

Adjustment makes the bubble tube axis and the line of sight parallel. The two-peg method of adjustment is also used. The bubble is brought into coincidence at each pointing with the tilting screw and the rod is read. The correction is computed and the line of sight brought to the corrected reading using the tilting screw. The bubble is then adjusted roughly using the capstan-head screw at the eyepiece end of the bubble. Fine adjusting is completed by the micrometer drum under the eyepiece of the telescope. The two-peg test should be made to check the final adjustment, and must be repeated after any disturbance of the objective.

Repair and adjustment of precision instruments such as the theodolite, self-leveling level, precise level, and lightwave and microwave measuring devices should not be attempted by the EA unless he has been to a school on these various instruments. Emergency repairs to this equipment by the EA is very rare. Precision instruments are normally sent to a Quality Evaluation Laboratory for adjustment and repair.

HAND LEVEL ADJUSTMENTS

Generally, a hand level is designed to stand up to rough usage without need for constant adjusting. The level vial is protected, sealed in position and kept firmly in adjustment. The tubing is seamless, the threads are accurate, the lens, the mirror prism, the level tube and the end-pieces are solidly mounted. Every part of the hand level is rigidly held in proper position, however, the level is very easy to adjust, if ever it becomes out of adjustment.

The simplest method of adjusting the hand level is by placing it alongside the engineer's level, the engineer's level is first leveled and sighted on a well-defined point. Then when this is done, the hand level is held alongside the telescope of the engineer's level as it is sighted on the point. The line of sight of the hand level should hit the same point when its bubble is centered.

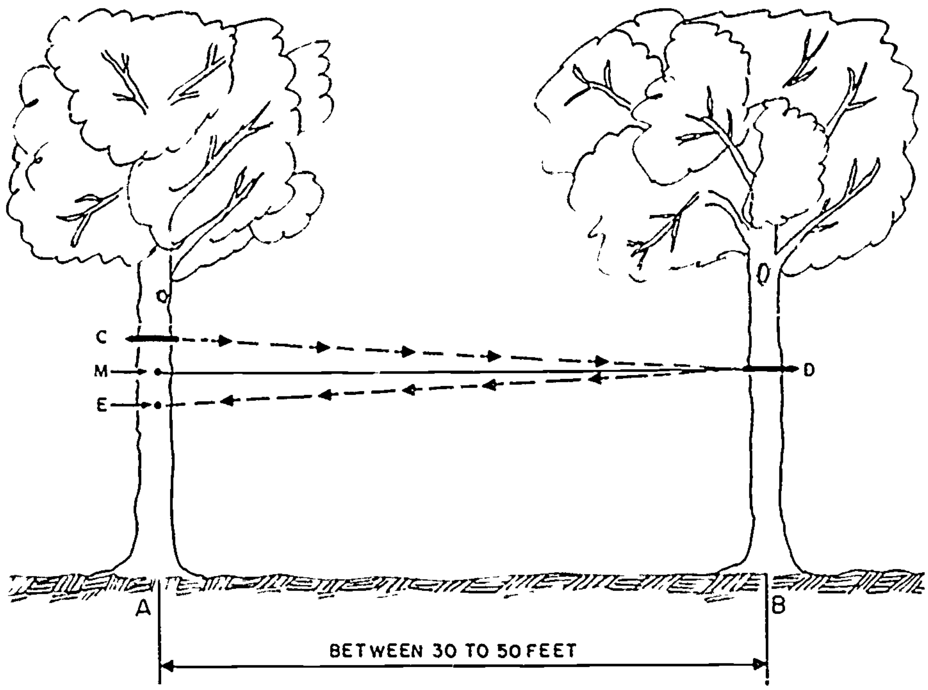
If you are adjusting a Locke level, you must manipulate the screw at the end of the level tube which controls the crosshairs defining the line of sight. If it is an Abney level, you must raise or lower one end of the level tube vial until the bubble is centered, make sure that before doing this, you have first set the index to zero on the graduated arc.

A hand level that is out of adjustment may be used to establish a horizontal line by employing the principle of the two-peg test method (explained earlier in this chapter), with a little variation. Let positions A and B, be two posts, trees, corners of a building, or other convenient objects on a fairly level ground and about 30 to 50 feet apart Let's suppose that we selected two trees for this purpose, as shown in figure 9-11. Using a sharp knife, make a small horizontal notch, C, at a convenient height on the trunk of tree A; hold the level against this notch, and with the bubble centered, establish point D–making a small notch also at this point. The level is then held at notch D and point E is established in the same manner when the level was held at notch C. The distance CE would be double the error, and point M, the midpoint between C and E will therefore represent the horizontal line through notch D. The Locke level or the Abney level is adjusted according.

MINOR REPAIRS

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. These repairs are done by the SEABEES. Major repairs are done by instrument specialists who, are generally employed by the instruments manufacturers, and the repairs are done in the factory.

Whether or not you yourself, 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 *Engineering Aid 3 & 2*). 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 battalion or Public Works Department shops. Minor damage to instruments may be repaired occasionally in battalion machine shops, but major repairs to



45.436(45B)

Figure 9-11.—Two-peg method of adjusting a hand level.

instruments, when they are economically worth while at all, should be done by manufacturers or their authorized agents, or by competent Navy instrument repairmen.

REPLACEMENT PROCEDURE

When, in the judgment of the senior EA or the Engineering Officer, an instrument is beyond economical repair, it must be surveyed using standard survey procedures which are explained in *Military Requirements for Petty Officer 1 & C*. It must be replaced with a new one, which may be obtained through the Navy supply system. Expendable items are procured in the same manner.

Each individual item of equipment or supply which is available through the Navy supply system is identified by a stock number, and listed and described in a stock catalog. The items which may be drawn from supply by a battalion, and the maximum number of such items a battalion may have, are set forth in *Mobile Construction Battalion Table of Allowance* (TOA), published by NAVFAC. 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, sounding poles, chaining pins, bull points, turning point pins, targets, stake bags, equipment boxes, and the like, may be replaced by manufacture in battalion or Public Works Department shops. Most items, however, are replaced from supply that is, they are ordered from the nearest available Naval Supply Depot.

An item is ordered by stock number in accordance with a prescribed procedure with which you must be familiar. Your source to study for most of which you should know about the Navy supply system is *Military Requirements for Petty Officer 1 & C*. The use of supply catalogs is discussed later in this training manual.

CHAPTER 10

DRAFTING LAYOUT, CHECKING, AND EDITING

The fundamental techniques of technical drawing (such as different methods of projection, symbols used to indicate various features, conventions followed with regard to line weights and other graphic considerations, structural drawing details and drafting layouts) are described in *Engineering Aid 3 & 2*. This chapter deals with checking the organization and technical accuracy of DRAFTING LAYOUT, which might be considered as comprising the following considerations:

1. What part of the data relating to a particular construction project can and should be shown graphically?
2. What is the minimum number of plans, elevations, and details required to show all the data clearly and accurately?
3. What is the most feasible arrangement of each drawing?
4. Were all applicable standards and specifications followed correctly?

Generally, Engineering Aids attached to construction battalions will be most frequently concerned with the following broad categories of drafting work:

1. Maps for advanced bases and airfields (topographic maps).
2. Construction drawings for structures, roads and utilities.

As an EA1 or EAC assigned as a drafting room supervisor,, working directly under the engineering officer, it is your primary job to see that the format and arrangement of drawings prepared by your men are in accordance with naval standards and specifications applicable to each of the above categories. The Naval Facilities Engineering Command (NAVFAC) has set up layout guidelines for specified drawing categories. Certain deviations from those guidelines may be permissible as authorized by the Operations Officer, and some deviations may be based on your personal experience in previous similar undertakings which worked superbly Instructions for construction layouts are given in *Drawings and Specifications*, NAVFAC DM-6. In addition, a great variety of completed construction drawings of all types are available for study in *Facilities Planning Guide*, Vol. 1, NAVFAC P-437 (replaces *Advanced Base Drawings*, NAVFAC P-140).

BASE MAPS

The types and quantity of shore facility planning maps prepared for an activity will vary according to the size of the activity, its complexity, and the planning problems and proposals involved. These maps fall into three categories: (1) GENERAL DEVELOPMENT maps, including INDEX OF STRUCTURES, (2) RELATED maps, and (3) SPECIAL maps.

GENERAL DEVELOPMENT MAPS

The general development map depicts the total facilities, both planned and existing, required to effectively support the mission of the activity. It must show both existing physical plant and planned facilities.

Scale

Due to the great variety in size and configuration of activities, it is impossible to specify one single scale to be used for all drawings. Two principles to be followed are. the number of drawings will be held to a minimum, and built-up or congested areas will be shown at a scale of 1 in. = 200 feet. To accomplish this, large undeveloped areas will be drawn at a small scale, and built-up areas will be shown at a scale of 1 in. = 200 feet by means of inserts or additional drawings. Graphic scales will be shown on each drawing and for each insert to facilitate measurement after reproduction and reduction.

In order to provide a comprehensive view of an activity for orientation, comparisons, presentations, and other purposes, it is required that the first drawing of a general development map show the complete outline and general layout of the entire activity. How this is accomplished will depend on the size of the activity. The entire general development map of a very small activity will fit on a single drawing drawn at 1 in. = 200 ft (or perhaps even larger). A larger but relatively simple activity may fit a single drawing when drawn at 1 in. = 500 ft, with inserts of built-up areas at 1 in. = 200 ft.

In the case of a large or complex activity which requires more than one drawing for complete presentation, a KEY MAP must be prepared, on a scale small enough to show the entire activity in a single drawing. As many additional drawings will be prepared, showing built-up areas at 1 in. = 200 ft, as are necessary to show all facilities. Each of these drawings will contain a small outline of the key map to orient the individual drawings to the larger area.

Detail Delineation

The following is considered the MINIMUM data that must be delineated and identified on a general development map:

1. Show all existing facilities. Identify each building or structure by its approved permanent identification number, placed in a conspicuous location. When possible also identify more important existing facilities by name, placed so that it is obvious to which each refers.

2. Show all planned facilities, and identify each by its ITEM IDENTIFICATION NUMBER, placed, if possible, within the facility outline. When possible, also identify more important planned facilities by name.

3. Show all planned and existing streets and parking areas. Identify existing streets by name and planned streets by letter. Define parking areas by stating car capacity.

4. Show planned and existing boundaries.

5. Show and identify any properties to be acquired or any portion to be processed for disposal, also any inactive areas.

6. Identify type of ownership or use of properties adjacent to the activity, such as residential areas, shopping centers, industrial plants, and the like.

7. Show and identify any important structures on adjacent non-Navy owned properties which might affect planning.

8. Indicate access to the activity by showing main and secondary entrances, gates, and fences, both existing and planned. Identify the roads or streets immediately adjoining the activity, and add a note at the main entrance stating the direction and distance to the nearest city.

9. Indicate double or single track for railroads, spur lines, classification yards, and the like.

10. Show U.S. bulkhead and pierhead lines, depth and flow of dredged areas, channels, streams, rivers, ponds, lakes, and the like. Show planned dredging and land to be reclaimed. Show soundings along the shoreline at frequent intervals.

11. Show topography at 5 foot intervals for the area of the activity, including any areas of planned expansion.

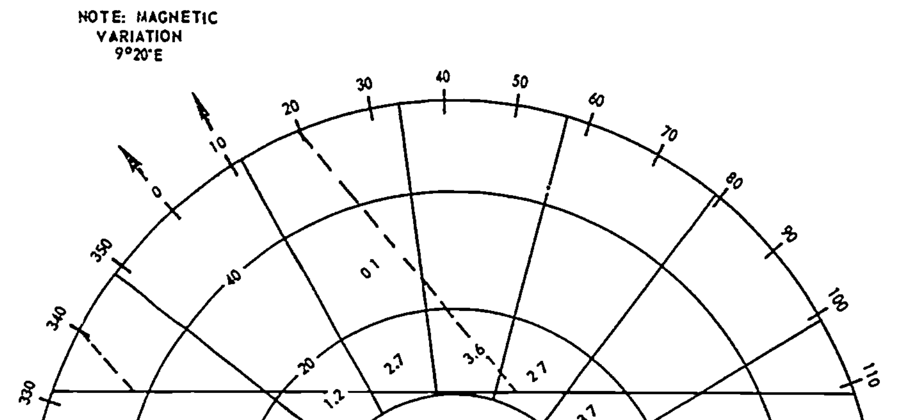
12. Show existing wooded areas, marshes and other surface soil features, including any planned mass plantings.

13. For airfields, additional data is required as follows:

a. Show a wind rose. A wind rose shows the directions and durations of the prevailing winds in the area, it may show the approximate force of these as well. A wind rose in which all three factors appear is shown in figure 10-1. The central (0-10 knots) circle indicates that for 53 percent of the time, the winds in the area are of less than 10-knot (or relatively negligible) velocity. Outside of the 10-knot circle, the complete 360-degree azimuth is divided into 16 sectors. The small figures in these sectors indicate the percentage of the time during which the wind blows, in the direction indicated by the sector, at the indicated velocity. For example, in the sector lying between azimuth about 12° and azimuth about 33°, there is a small 2.7 in the 10-20 knot space, and a small 0.1 in the 20-40 knot space. These figures mean that for 2.7 percent of the time a wind of between 10-20 knot force blows from mean azimuth 22.5°, while for 0.1 percent of the time a wind of between 20-40 knots blows from the same direction.

The parallel solid lines indicate the directional orientation of the principal landing strip of the airfield. Note that this has been oriented as nearly as possible in line with the direction of the strongest prevailing winds. The parallel dashed lines indicate the directional orientation of the auxiliary or alternate landing strip. Note that this has been oriented as nearly as possible in line with the strongest of the prevailing winds blowing oblique to the principal landing strip. This makes it possible for traffic to be shifted to the auxiliary air strip when strong winds unfavorably oriented to the principal air strip are blowing.

b. Show the airfield reference point. This is a point selected and marked as the approximate center of the usable landing area which is formed by joining runway ends.



82.59

Figure 10-1.—Wind rose.

c. Indicate the length, width, true bearing, and directional numerals of each runway. The directional numerals consist of two figures, one of which is painted at one end of the runway and the other at the other end. The figures are one-tenth, to the nearest whole number, of the degrees value of the magnetic azimuth of that particular end of the runway. Suppose, for example, that the azimuth of a runway is 72° 15′. Then the back azimuth is 72° 15′ + 180°, or 252° 15′, and the directional numerals of the runway are 7-25.

d. Label the actual glide angle, as determined by existing obstructions, in each approach zone.

e. Designate the instrument runway.

14. Add a note stating the latitude and longitude of the activity. For an air activity, this is the latitude and longitude of the AIRFIELD REFERENCE POINT, which is usually the point of intersection between the centerlines of the two principal intersecting landing strips. For other activities, the latitude and longitude given is often that of the flagpole.

15. Add brief notes summarizing important data concerning land: state acreage and type of ownership (Navy owned, leased, etc.) of the activity and of any components, tenants, outlying facilities, annexes, outleased or inactive areas, etc.

16. Show a small, simple location map to orient the activity to the surrounding area.

17. Show a standard title block, as described in *Engineering Aid 3 & 2*.

18. Show an index of structures; such an index provides a means for locating facilities shown on the drawings and lists basic data in convenient form. For convenience it is divided into two tabulations, one for existing and one for planned facilities. In the case of a small activity or an activity with few facilities, the index will fit onto the same drawing that shows the facilities. For a larger activity, the index may be placed on a separate 28″ × 40″ sheet, or on as many of these as required.

The index of structures is given in the form of a table containing six columns with the information as follows:

Column 1 contains a list of the buildings and structures in consecutive building number series, with the index of existing structures above and the index of planned structures below. A number for a planned structure is usually prefixed by the letter P. If a structure has more than one use, repeat the number in column 1 as many times as the structure has uses.

Column 2 indicates the location of the structure by map grid coordinates.

Column 3 describes the current use of the structure.

Columns 4 and 5 list the total quantity of such structures, column 4 giving the number and column 5 the unit of measure.

Column 6 contains any possible future change in use.

Delineation Rules And Conventions

The following rules and conventions apply to the delineation of general development map details:

1. Each map, drawing, or index shall be prepared on a 28″ × 40″ (size F) sheet with title block and be assigned an appropriate NavFac drawing number.

The drawing number is usually a six-digit number and should appear in the title block in this form. NAVFAC DWG NO. 482436. Each sheet shall have a 1/2-in. margin at the top, bottom, and right side, and a 1 1/4-in. margin on the left-hand side.

2. Symbols, legends, and conventions must conform to current military standards. The principal relevant standards are described in *Engineering Aid 3 & 2.*

3. Letters 3/32-in. high are the minimum size for the smallest letters and numbers.

4. Each drawing will be prepared with a title block, which will not be changed during the life of the drawing. Information in the title block is a permanent record. When a revision to a general development map is required, a new drawing will be prepared and the title block filled in with a new NavFac drawing number. When amendments or corrections to a drawing occur, this

data will be inserted directly above the title block.

The official name and location of the activity will be given the greatest prominence and largest size lettering in the title block. Identification of the particular individual sheet (such as Key Map, Outlying Facilities, Administration Area, etc.) will be the next largest size lettering.

A general development map of an auxiliary landing field is shown in figure 10-2.

RELATED MAPS

Related maps are those principal maps required to support or assist in the formulation of the general development map. Certain related maps called REQUIRED related maps are basic to all types of activities. These are:

1. A REGIONAL and/or VICINITY map. A regional map orients the activity to the larger surrounding region; a vicinity map illustrates the relationship of the activity to the immediate neighboring community.
2. A REAL ESTATE SUMMARY map, illustrating the activity's legal boundaries and summarizing its landholdings.

Other typical related maps are the EXISTING CONDITIONS map, which shows existing facilities and landscape features; and the LAND USE map, showing the size, shape, and operational use relationships between major land use areas of an activity.

Related maps are prepared in the same general format as prescribed for a general development map. Maximum use should be made of existing Navy maps and of maps available from outside sources. These existing maps will be adapted for the purpose intended and need not be redrawn merely for reasons of format, however, when new drawings are required, the format described above must be followed.

Regional and/or Vicinity Map

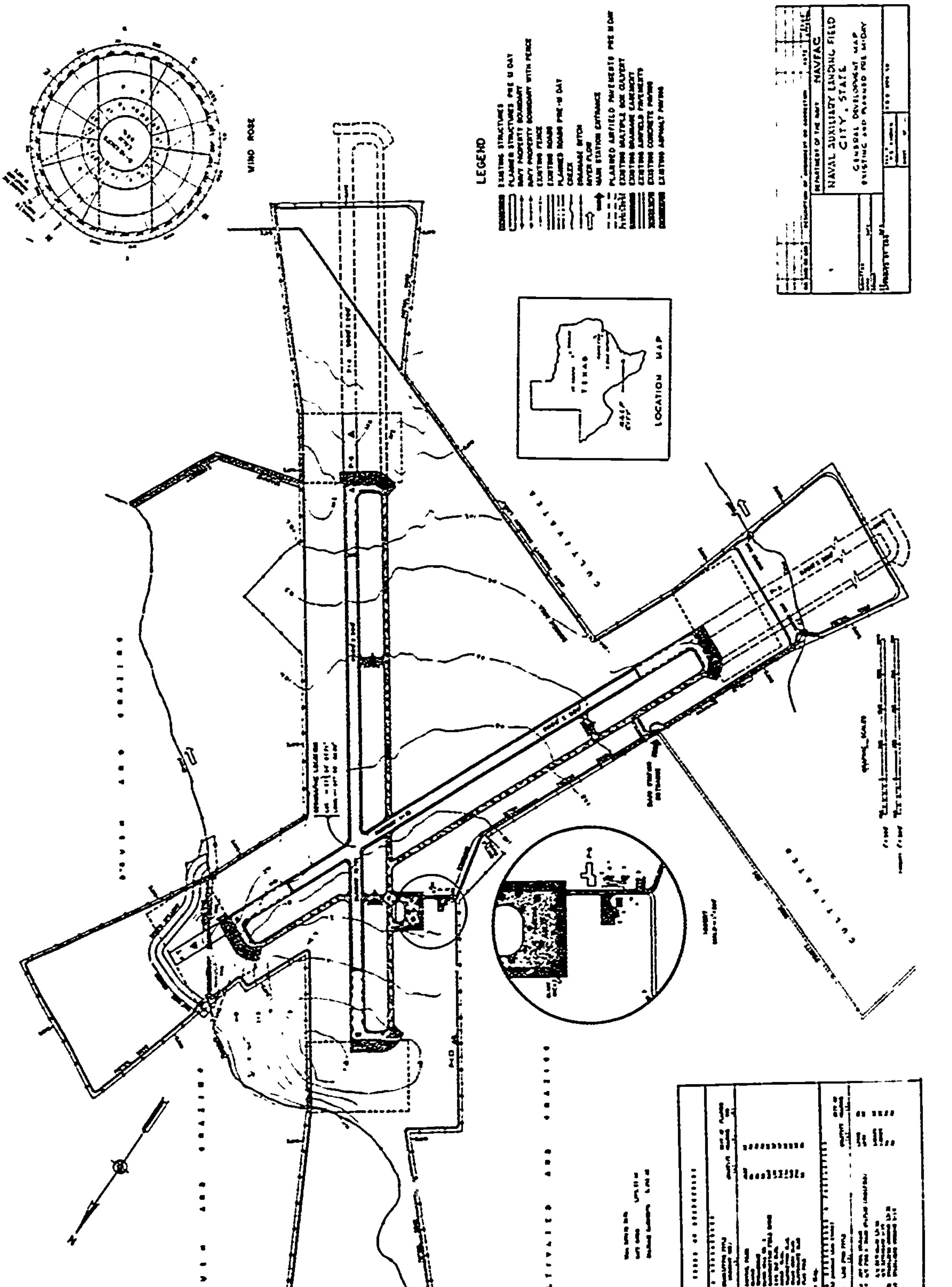
As pointed out earlier, the vicinity map illustrates the relationship of an activity to the immediate neighboring community, and the regional map orients the activity to the larger surrounding area. These maps are subject to considerable variation in the area covered and the detail shown, depending upon the size of the activity and its planning problems and the type of community in which it is located. For example, if an air station has outlying fields in several locations, separate regional and vicinity maps would be required, a vicinity map to show details of the community surrounding the air station, and a regional map to show the relationship of the outlying fields to the air station and to the area. In the case of a more compact activity, however, both the regional map and the vicinity map might be placed on a single drawing. In the event that several activities are located in one geographic area, each might require a separate vicinity map, but one regional map would suffice for all.

To save time and effort in preparing new drawings, local sources of existing maps must be checked. The principal sources for existing maps are the U.S. Army Topographic Command, the U.S. Navy Oceanographic Office, the U.S. Geological Survey, the U.S. Coast and Geodetic Survey, the Bureau of Public Roads, and the Aeronautical Chart and Information Service (Department of Commerce). In many cases, maps from these sources are available which can be adapted by adding the data peculiar to the activity.

Regional Map Information

The following information should be shown and identified on a regional map when feasible:

1. Features capable of influencing the degree or direction of future development or affecting capabilities of the activity.
2. All military installations. List all naval activities on the map in or near the title block.
3. State, county, city, and town boundaries.
4. National and State parks, forests, and recreational areas.
5. Airfields, missile and bombing ranges, etc.
6. Major highways and railroads. Identify interstate and county roads by symbols, and indicate destinations at edge of drawing.



82.60

Figure 10-2.—General development map.

7. Harbors, major rivers, streams, and bodies of water (natural or artificial). Indicate direction of flow.

8. Topography, if available, at 500′ contour or less interval.

9. Important ground forms such as mountains, swamps, etc.

10. A small location map of the area in which the region is situated.

11. Legend and graphic scale. A scale of 1 in. = 4 miles (1:250,000) is suggested.

Vicinity Map Information

The following information should be shown and identified on a vicinity map when feasible:

1. Data prescribed for the regional map, if applicable.

2. Adjacent built-up areas. Identify industrial plants, hospitals, recreational areas, cemeteries, schools, etc.

3. Main and secondary entrances to the activity.

4. Railroad data as ascertained by reference to the railroad companies servicing the activity, to the *Manual of the American Railroad Engineering Association*, and to the railroad sections in *Civil Engineering*, DM-5.

5. Highway data as ascertained by coordination with the Bureau of Public Roads, Department of Commerce. Identify principal thoroughfares and streets.

6. Runway, range, and obstacle data as ascertained by coordination with regional office of Federal Aviation Agency, or with a nearby Navy or Air Force air station or base.

7. Topography, if available, at 20′ contour intervals.

8. Waterfront and harbor facilities as ascertained by reference to waterfront operational facilities under appropriate NavFac design manual.

9. A small location map of the area in which the vicinity map is located.

10. Legend and graphic scale. A scale of 1 in. = 1 mile (1:62,500) is suggested.

A combined regional and vicinity map is shown in figure 10-3.

SPECIAL MAPS

Special maps are not a part of the general development or related group. Examples are traffic flow maps and utilities maps.

A special purpose map is made with one or a number of special purposes in mind and the map specifications are written accordingly. If the drawing is successfully executed, it will be completely satisfactory for the purpose (or purposes) for which it was intended; it may be inadequate, however, for other uses for which it was not intended.

The planning for a large activity or for a complex of activities may require special maps of a more detailed nature than the planning for a small or simple activity. Many of these special maps can be produced by adding data to existing maps. When new drawings must be prepared, they will be in the same general format prescribed for the general development map.

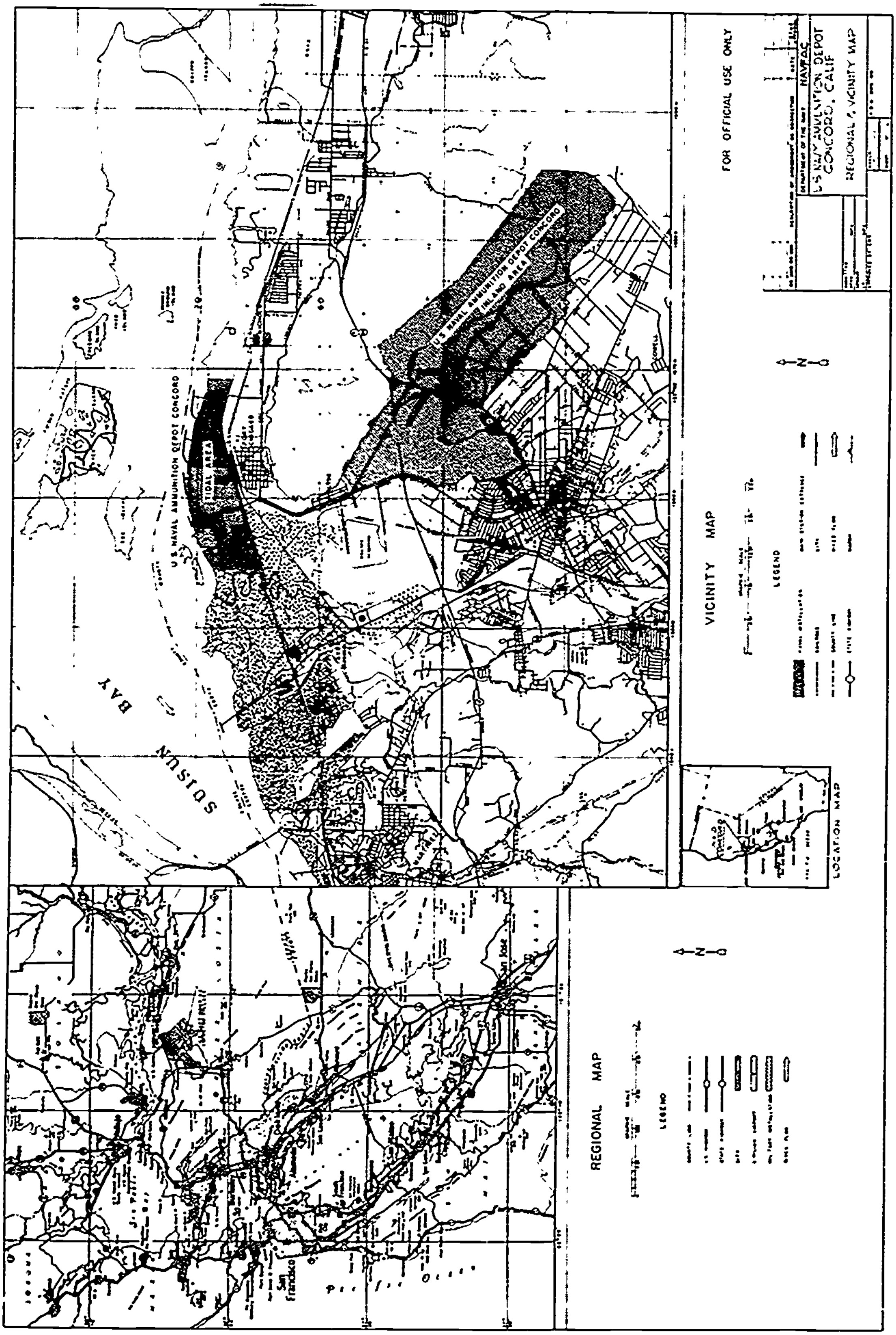
Some typical special maps are discussed in following subsections.

Airfield Pavement Map

Existing, planned, and to-be-abandoned airfield pavements will be shown on copies of the general development maps to indicate strength and type of pavements. An airfield pavement map will show the airfield runways, taxiways, aprons, shoulders, hardstands, end zones, and crash strips. Controlling elevation points on the plan drawings may be substituted for profiles in the case of mass pavement areas such as apron end zones. Runway centerline profile must be extended through the end zones and crash strips. Direction numerals, true bearings, runway dimensions and gradient changes of the runway centerline profile must be indicated, along with a tabulation of pavement load bearing capacities.

Flight Obstruction Map

A flight obstruction map consists principally of a plan and profile of each existing and planned runway, extended 10 miles beyond the end zone. The map, showing topographical contours obtained from map sources, can be drawn at an approximate scale of 1 in. = 1/2 mile. For the profile, the horizontal scale may



82.61

Figure 10-3.—Regional and vicinity map.

be 1 in. = 1/2 mile and the vertical scale 1 in. = 100 ft. The prescribed glide angles (usually 1:50) should be shown on the profiles, beginning at the end of the end zone at runway elevation. All obstructions, either natural or man-made, which extend above the glide angle must be shown on both the plan and the profile.

Utilities Maps

The utilities maps show primary existing utilities, including sanitary sewerage, storm drainage, water supply, heating, gas, electric, telephone, telegraph, fire alarm, communications, Navaids, airfield lighting, and liquid fuel systems. Copies of the general development map are used as a base.

Since it is desired to keep the number of sheets to a minimum, as many individual utility systems will be shown on a single base map as will permit legible differentiation of the systems. Each system will be delineated by a distinctive symbol.

Each utility map should show information about the following utilities systems.

SANITARY SEWERAGE: Show existing system, including location of sewerage lines, sewage treatment plant, pumping stations, manholes, and outfall sewers. Indicate pipe sizes, types of material, direction of flow, and critical invert elevations.

STORM DRAINAGE: Show existing system, including location of pipelines, major drainage ditches and channels catch basins, inlets, culverts, intakes, and outfalls. Indicate pipe sizes, type of material, direction of flow, critical invert elevations, and final drainage destination. Show also industrial waste disposal system. Note special conditions, such as flood control facilities, rainfall, frost, etc.

WATER SUPPLY. Show existing distribution lines, pumping stations, fire hydrants, water treatment plants, and storage tanks. Indicate all sources or supply, distances from source, capacities, types of purification treatment, average water pressures (residual and static), fire and domestic demands, water analysis, and pipe sizes and materials.

CENTRAL HEATING. Show existing heating plants and distribution and return lines, either overhead or underground. Include generators. Indicate type of fuel, fuel storage location, and capacity.

GAS. Show existing distribution lines and storage points. Identify supplies and indicate plant capacity.

ELECTRIC POWER. Show existing distribution lines, both primary and secondary; power plant or on-base substation and emergency generating units. Indicate source of supply (commercial or station generated), generating voltage or voltage of supply feeders, KW capacities, wire or cable sizes and voltage, fuel storage capacity and type of power plant.

TELEPHONE AND FIRE ALARM. Show existing systems, including conduits and all facilities. Indicate sizes and capacities.

AIRFIELD LIGHTING, COMMUNICATIONS AND NAVAIDS. Show existing airfield and approach lighting systems, Navaids and communication facilities, including transmitter and receiver antenna sites, on and off-base; transformer vaults, control panels, and location and capacity of emergency power units. Indicate types of permanent lighting for each runway.

FUELING: Show all facilities for the storage and distribution of Avgas, Mogas, jet fuel, diesel oil, and luboil, including transfer lines, bulk storage above and below ground, truck fill stands, pumphouses and meter pits. Indicate truck fill stands, fuel line sizes, and pump types and capacities; also tank car and trunk unloading facilities.

CONSTRUCTION DRAWING LAYOUTS

Construction drawings are any drawings which, together with the project specifications, convey to fabricators the information they must have in order to carry out the work of construction. The drawing layout must follow a sequence which permits orderly development of information to make it easy to comprehend.

METHOD OF PREPARATION

Construction drawings should be prepared in such a manner that they can be site adapted with minimum effort; that is, revised for a similar facility at another location. To accomplish this, all details pertaining to the individual site, such as location map, site plan, extension of utilities, soil boring logs, foundation plan, and foundation details, are placed on the first drawings of the set or grouped on separate drawings. The site adaptation will then consist of (a) preparing the new drawings required for a new site, and (b) making necessary revisions and adding new title to the existing working drawings to be adapted.

GENERAL INFORMATION REQUIRED

The information shown must be neither more nor less than what is required for satisfactory completion of the product. The drawings should include any additional information which might be needed for checking. Examples of such information are:

1. The square and cubic footage of structures.
2. Survey control points showing grid coordinates.
3. Bench mark locations, with elevations specifying above certain datum (MSL, MLLW, MLW, etc.).

DRAWING REQUIREMENTS

The military standards mentioned in *Engineering Aid 3 & 2* are the basis for all NavFac drawing practices. The use of these standards is mandatory.

Style Requisites

The first essential in a working drawing is CLARITY All such drawings must be accurate, explicit, clear, and legible.

REPRODUCTIONS must be as clear as originals. For normal applications, drawings for relatively simple designs, not requiring extensive duplication, must be made on tracing paper, plastic sheets, or linen by clear, sharp pencil lines of sufficient density to assure clear reproductions. For complicated designs, drawings requiring considerable duplication, or those requiring extensive changes during preparation, ink drawings on linen or plastic sheets may be used, or pencil drawings on linen may be reproduced by one of the photographic methods. Always use high quality tracing paper for drawings that require extensive reproduction.

CONCISENESS means, in general, the avoidance of superfluous drawing. Unnecessary work, such as the duplication of views, notes, and lettering, or the showing of views which need not be shown, must be rigorously avoided.

Order of Drawings

Drawings for buildings or structures are arranged in the following order:

1. Title sheet and index of drawings, when required.
2. Plot and/or vicinity plans, including civil and utility plans. The term CIVIL is applied to those plans which deal with outside-the-structure earthmoving, paving, and the like. Similarly, a utility plan in this category refers to outside-the-structure utilities.
3. Architectural drawings.
4. Structural drawings. The distinction between structural and architectural construction drawings is not always clearly defined. A floor-plan is obviously architectural, a floor or roof framing plan obviously structural. However, a foundation plan is a structural plan, though it is not essentially different in principle from a floor plan. Most details and sections are considered structural drawings.
5. Mechanical drawings.
6. Plumbing drawings. Some authorities consider these to be part of the mechanical drawings.
7. Electrical drawings.

Drawing Formats and Sizes

Requirements as to formats and sizes are contained in the latest revision of *Engineering Drawing Practice*, MIL-STD-100A. Of the drawing sizes described in that standard, the following should be used for NAVFAC drawings.

Type	Size	Purpose
Flat A–	8½ x 11	When small sheets are required
Flat B–	11 x 17	When small sheets are required
Flat C–	17 x 22	Construction drawings; when small sheets are required
Flat F	28 x 40	Construction and other drawings
Roll H–	28 x 48	Large construction drawings; minimum length = 48, maximum length – 144

The roll size sheet should be used only when necessary, since this size sheet must be rolled or folded for filing. The roll size is also very difficult to reproduce.

Title Blocks

Every drawing must have a title block. Acceptable title block formats are shown in *Drawings and Specifications*, NavDocks DM-6. Title block dimensions are given in *Engineering Drawing Practice*, MIL-STD-100A. A title block indicates the name and location of the activity, the general project, the specific features shown on the plan, the identifying numbers of the sheet, the specifications and contract numbers (if any), the surnames of the personnel concerned in the preparation of the drawing, and any other pertinent data. A standard title block used on NavFac drawings is discussed in *Engineering Aid 3 & 2.*

Scales

Scales must be uniform on all drawings for a particular project and for a particular type of work. If necessary to maintain proper scale, divide plans of large buildings or structures into two or more sheets, with appropriate key plan and "match lines."

All Navy drawings are to be provided with graphic scales in accordance with requirements given in *Engineering Drawing Practice*, MIL-STD-100A. Appropriate scales for construction drawings are as follows:

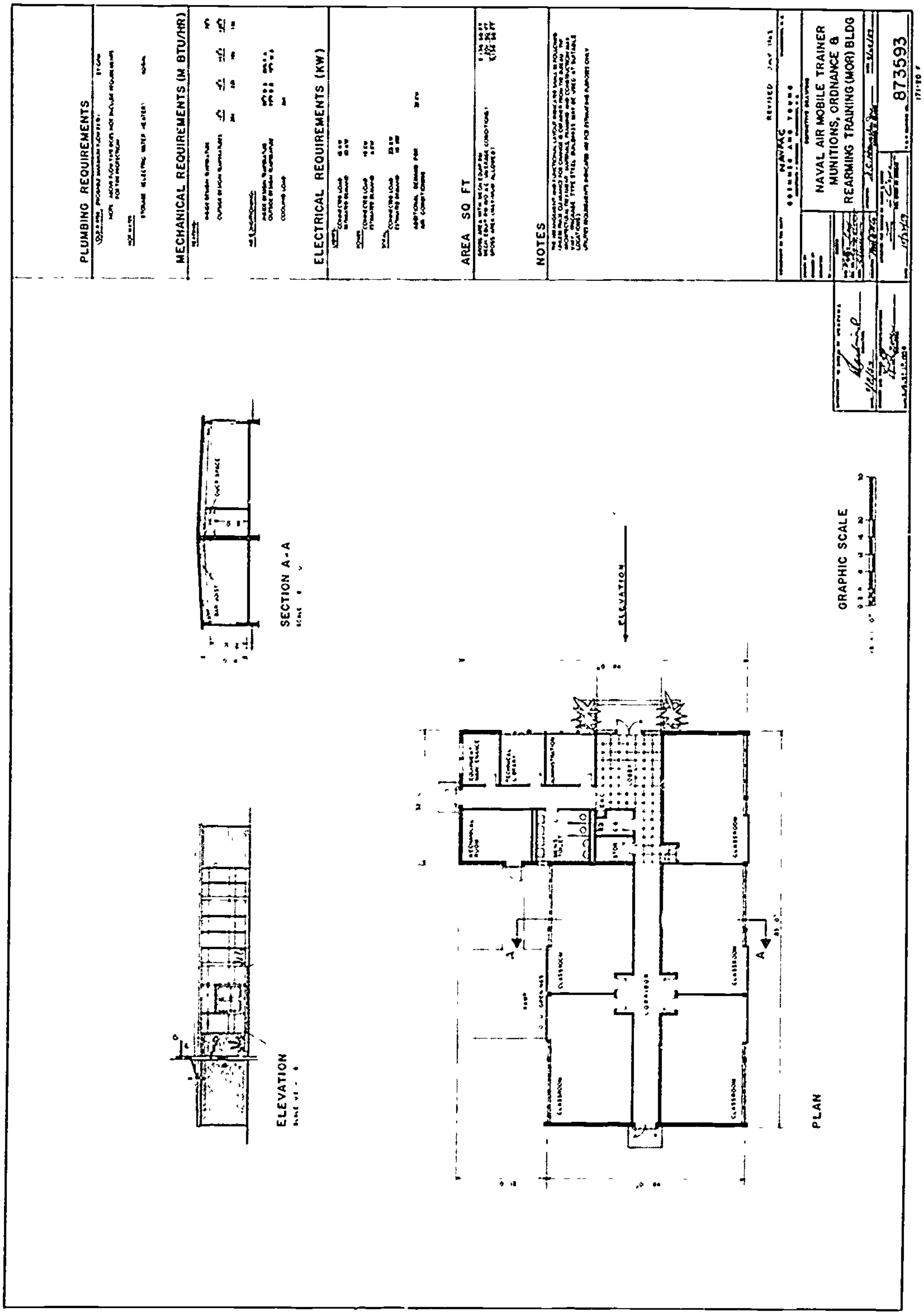
1. For floor plans and elevations: 1/4, 3/16, 1/8, or 1/16" = 1' – 0".
2. For architectural details: 3/4, 1 1/2, or 3" = 1' – 0".
3. For molding sections and similar details: full scale or half scale.
4. For mechanical and electrical details: 3/8, 1/2, 3/4, or 1" = 1' – 0".
5. For structural details: 3/8, 1/2, 3/4, or 1" = 1' – 0" (larger if necessary).
6. For structural erection drawings (such as floor and roof framing plans): 1/8 or 1/16" = 1' – 0".
7. For plot plans: 1 in. = 10, 20, 30, 40, 50, 60, 100, or 200 ft.
8. For utility plans: 1 in. = 20, 30, 40, or 50 ft.

DEFINITIVE DRAWINGS

Definitive design drawings are issued by the Naval Facilities Engineering Command for buildings and structures for which there will be a repetitive need in future military construction programs. These drawings are contained in *Definitive Designs for Naval Shore Facilities*, NavFac P-272. The preface to this publication describes the drawings it contains as follows.

> ". . . NavFac utilizes definitive designs to provide a uniform basis for planning and design . . .
>
> "While not indicated in the definitive designs, it is expected that new materials and techniques will be incorporated in preliminary engineering or working drawings whenever their use will result in economies or increased utility without sacrificing livability or quality.
>
> "It is not the intent of this Command to require mandatory use of the definitives without exception, nor is it intended that addressees shall have complete freedom to modify or discard these definitives. NavFac realizes that modifications may be necessary to meet specific requirements or local conditions. However, major modifications must be fully supported and cleared with NavFac prior to proceeding with further planning."

NavFac P-272 contains design drawings for a great many varieties of Navy structures, both habitational and functional. One of these drawings is shown in figure 10-4. You can see at once



82.62

Figure 10-4.—Definitive design drawing.

that it is a design rather than a working drawing. It is the basis, however, from which working drawings for this structure would be made. The procedure might be as follows.

Suppose that the erection of one of these buildings has been authorized and ordered at an overseas base. If the site location is definitely known, a topo map of the site is obtained and sent to the design agency. This agency might be the Engineering Division of NavFac, a NavFac Field Engineering Office, or an architectural-engineering private firm, working under contract with NavFac or with a Field Office.

On the definitive design drawing (fig. 10-4) there is a note which says. "the arrangement and functional layout indicated shall be followed unless prior clearance for change is obtained from NavFac. The architectural treatment, materials. framing. and construction may vary Utilities requirements indicated are for estimating purposes only." It follows from this that the type, dimensions, and character of the foundation members, framing members, roof members, wall covering, roof covering, and the like are to be determined by the design agency. The only binding stipulations are as shown in figure 10-4–that is, the dimensions of the building, arrangement of rooms and of doors and windows, and plumbing, mechanical, and electrical equipment must be capable of meeting the requirements shown in the definitive design.

In the selection of materials the design agency will consider the matter of availability at or near the site, and any other economic considerations. The plumbing, mechanical, and electrical equipment selected will be that which will most economically satisfy the requirements set forth in the definitive design. Even the type and character of structural arrangements (such as wall, floor, and roof framing) may be selected with an eye to the known skills and capacities of native labor in the site area, if the use of such labor is contemplated.

When all of these considera'' ns have been decided, the design agency pre: :s the actual working drawings; these, in turr › used as the basis for the material takeoffs a other planning and estimating in connection with the project.

STANDARD STRUCTURES

A structure like the one shown in figure 10-4 may be designated by NavFac as a STANDARD STRUCTURE. In that case, the construction drawings and specifications for the structure will be kept available, to be issued to construction battalions in which the erection of the structure exists as a project. A MANDATORY standard structure is one in which the use of the standard construction drawings is mandatory without deviation. For a structure designated as nonmandatory, the standard drawings are furnished as recommended guides.

A listing of both definitive drawings and drawings for standard structures (mandatory and nonmandatory) is included in NAVFAC Instruction 11012.8 series.

FACILITIES PLANNING GUIDE

The objective of the *Facilities Planning Guide*, NAVFAC P-437, is to make preengineered facility designs and corresponding material lists available to planners at all levels. While these designs relate primarily to expected needs at advance bases and to the ABFC (Advanced Base Functional Component) system, their use to satisfy peacetime requirements is appropriate.

The *Facilities Planning Guide* replaces and supersedes both *Advanced Base Drawings*, NAVFAC P-140 and the *Detailed Catalog of Equipment and Construction Material Requirements for Advanced Base Functional Components*, NAVFAC P-103.

The *Facilities Planning Guide* is published in two volumes. The first volume contains reproducible engineering drawings. These drawings have been prepared in a schematic manner to provide field personnel with information to lay out base structures and equipment. Many installations will deviate from the plans, as drawn, to meet specific field conditions; however, the principles of conservation of manpower and materials should be kept in mind when making necessary deviations.

A study of the drawings is an excellent way for you to develop the ability to determine what the drafting layout for a particular structure or facility should show, and how the graphic portrayal should be done.

Volume 2 of the *Facilities Planning Guide* contains the detailed lists of facilities, assemblies, or line items which may be referenced in the drawings contained in Vol. 1. Use of the *Facilities Planning Guide* is described in the introduction of Vol. 1 and discussed in chapter 12 of this training manual.

DESIGN MANUALS

Finally, NAVFAC instruction and guidance for design and construction draftsmen in particular engineering and structural categories is contained in the numerous design manuals (DMs) published by NAVFAC. These manuals are available in the Operation Department's technical library of the battalion. Design manuals are divided into two categories:

1. BASIC MANUALS, which cover such subjects as architecture, civil, structural, mechanical, and electrical engineering, etc.
2. SPECIFIC MANUALS, which cover specific subjects, such as airfield pavements, communications, waterfront operational facilities, etc.

The preface to *Civil Engineering*, DM-5, describes that publication, and refers in general to the other design manuals, as follows:

"This manual contains basic criteria for civil engineering design and specific design criteria for the civil requirements common to structures in various facility classes. Civil engineering criteria relating only to structures in a single facility class are given in the specific manual covering that facility class. These criteria, together with the NavFac's definitive designs and guideline specifications, constitute NavFac's design guidance and are based on functional requirements, engineering judgment, knowledge of materials and equipment, and the experience gained by the Command and other bureaus of the Navy in the design, construction, operation, and maintenance of naval shore facilities.

"This series of design manuals present the criteria which shall be used in the design of facilities under the cognizance of the NavFac. These criteria consist of direction and standards for procedures, methods, dimensions, materials, loads and stresses. These manuals are not textbooks, but are for the use of experienced architects, engineers . . .

"Bibliographies of publications containing background information and additional reading on the various subjects are included in the manuals; this material, however, is not a part of the criteria, nor is a reading of these sources necessary for the use of the criteria presented in the manuals.

"To avoid duplication and to facilitate future revisions, criteria are presented once only, as far as possible. Criteria having general application appear in the basic manuals numbered DM-1 through DM-10. Manuals numbered DM-21 and above contain criteria which generally are applicable only to the specific facility class covered by the manuals. . . ."

The following is a complete list of design manuals published by NAVFAC. Before using these manuals, consult the *NAVFAC Documentation Index*, NAVFAC P-349, to make certain all current changes have been incc.porated into them.

BASIC MANUALS:

DM-1	Architecture
DM-2	Structural Engineering
DM-3	Mechanical Engineering
DM-4	Electrical Engineering
DM-5	Civil Engineering
DM-6	Drawings and Specifications
DM-7	Soil Mechanics
DM-8	Fire Protection
DM-10	Military Construction Cost Engineering Data

SPECIFIC MANUALS:

DM-21	Airfield Pavements
DM-22	Liquid Fueling and Dispensing Facilities
DM-23	Communications, Navigational Aids, and Airfield Lighting
DM-24	Land Operational Facilities
DM-25	Waterfront Operational Facilities
DM-26	Harbor and Coastal Facilities
DM-27	Training Facilities
DM-28	Maintenance Facilities
DM-29	Drydocking Facilities
DM-30	Production Facilities

DM-31 Research, Development, and Test Facilities
DM-32 Supply Facilities
DM-33 Hospital and Medical Facilities
DM-34 Administrative Facilities
DM-35 Family Housing
DM-36 Troop Housing
DM-37 Community Facilities
DM-38 Weight-Handling Equipment and Service Craft
DM-39 Hyperbaric Facilities
DM-50 Cumulative Index

SURVEY BASED PLANS

You can see that, with regard to a great many Navy-built structures, the data for construction drawings is obtained with reference to NavFac guidance sources. However, with regard to site plans and other construction drawings which relate specifically to particular site, much of the data for graphic presentation must be obtained by field parties which survey the actual terrain. *Drawings & Specifications*, DM-6, contains the following instructions with regard to survey based plans.

Layout and Grading Plans

Exterior layout and grading construction drawings for shore activities should be generally based on survey data prepared and furnished in usable form. From these data, other designers, such as structural, architectural, mechanical, and electrical, must obtain dimensional and other control data pertinent to the preparation of their own drawings, all of which may be necessary components of the overall project design.

SCALE.–Construction drawings generally should be made at a scale of 1 in. = 20 ft, 1 in. = 40 ft, or 1 in. = 50 ft. For areas in which the longitudinal dimensions are excessively long and the transverse dimension comparatively short, a scale of 1 in. = 100 ft. may be preferable.

CONTROL.–Drawings should contain required data for both horizontal and vertical control, so that component parts of the construction project may be staked out and integration of the whole completed. In addition, they should supplement the specifications with outlines, dimensions, and other construction data necessary for bidding and construction purposes, and should contain adequate data for estimating quantities and cost.

Horizontal control for a large proportion of NavFac drawings preferably should be based on the plane-coordinate system. Exceptions may be made when the necessary data are unavailable, when the time or cost of using it is considered unnecessary, or when laying out roads and railroads whose great longitudinal and small lateral dimensions make its use impractical. In the latter case, the centerline of the road or railroad, measured from its initial point by stations (100 ft) furnishes a definite, integrated baseline from which any detail of construction throughout the length of the project may be readily identified.

Vertical control should be based on an established local activity datum. At inland activities, the datum should be based on the established relative mean low water or mean lower low water and tied to established BMs of other Federal agencies when available.

If the local activity datum has not been established, every effort should be made to establish one. If this is impracticable, a datum may be assumed by use of a permanent reference point, and a complete description of it should be made for future use. This point should later be tied to some Federal or State datum when one has been established.

BASIC DATA. The data, depicting existing conditions, to be shown on construction drawings are: contours, streams, fences, roads, railroads, structures, and outlines of wooded areas.

DESIGN GRADING.–The design grading of building areas, open areas, and swales should be described by finished-grade contours and spot-grade elevations. The grading of slopes and ditches may be shown either by contours or cut and fill slope symbols together with spotgrade elevations. The requisite design data in delineating road and railroad centerlines are: stationing, curve data (horizontal and vertical), gradients and elevations of vertical PIs.

SUPPLEMENTAL DATA. In order that accurate estimates of quantities may be compiled and that field layout may be accomplished, the following are minimum essential supplements to the above basic data that must be shown. typical sections, including grading and paving or railroad subgrade with ballast and trackage ("ballast" is the term applied to the crushed stone or similar material in which the ties are embedded). and location of retaining walls. pipe and box culverts, drainage inlets and headwalls. and all other structures.

CROSS SECTIONS.-Detailed cross sections at 50- or 100-ft intervals, or at ground breaks as necessary, may be substituted for contours on plans for road and railroad projects.

TOPOGRAPHIC MAPS

Maps, whatever their purpose. must be constructed from facts about an area which are gathered in the field and brought back to the office. As you already know, a topographic map is one of the products of this fieldwork. It should show contour lines, as well as planimetric details, like the map shown in figure 10-5. The purpose of the map illustrated is for road construction; however, it could be adapted to whatever project is intended. Alone or in combination with other types of aerial survey information, topographic maps have a great variety of uses. They are indispensable in virtually all applications of civil engineering, and have important application in geological studies, urban planning, hydraulics and military operations.

At present, due to the advance of aerial surveying and photogrammetry, topographic maps are usually developed from controlled mosaics of a given area.

Topographic plans of naval activities should include hydrography adjacent to waterfront facilities, so that both topography and hydrography may be presented as a unit with a common origin and datum plane. These plans should show facilities such as railroads, roads, walks, buildings, piers, wharves, bulkheads, shorelines, soundings, and channel outlines. Additional detailed features required include.

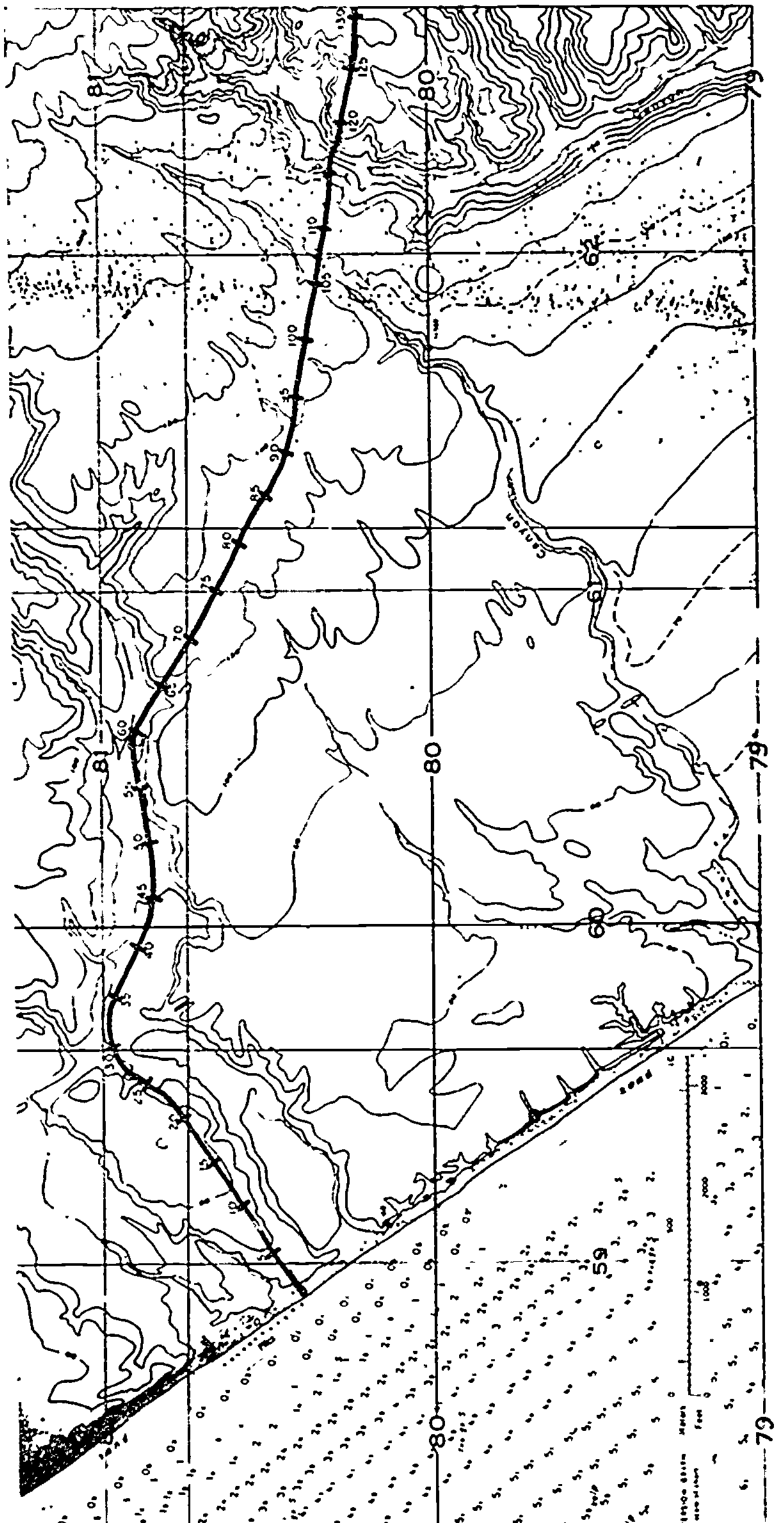
1. Local activity datum. If tidal datum, give mean low water or mean lower low water to which are referenced all other tidal stages, including extreme high and low water, if inland, show datum plane and reference to Federal or State system.
2. All property boundary or right-of-way lines with identification.
3. Airport runway, taxiway and apron pavement, including centerline location and profile or elevations, width, type of pavement, shoulder details, and cross sections.
4. Location, length, width, elevations, and miscellaneous details of jetties, wharves, drydocks, and similar objects.
5. Harbor and channel outlines, with depths and soundings from latest survey, and established pierhead and bulkhead lines.
6. Area of each watershed contributing to the project area.
7. Roads and parking areas, including centerline location and profile or elevations, curbs and gutters. width and type of pavement, and cross sections.
8. Wind rose current data and directions.
9. Walks, including widths and elevations.
10. Railroads, including centerline location, top of rail profile or elevations, location and details of all turnouts and crossovers, and weight of rails.
11. Location, dimensions, and floor or reference elevations of all structures.

UTILITY PLANS

A utilities MAP is a special map in the general development map group, as previously mentioned It is used, like other maps in that group, for general planning purposes A utilities PLAN, on the other hand, is a construction drawing, to be used as a guide by field constructors. A map and a plan contain the same general information; however, the information in a plan is more detailed. Information, which utilities plans in various categories should show, is listed below. In each case the utility line itself is indicated by a single line on the drawing.

Water Mains for Fresh or Salt Water:

1. Location and length of mains, but not piping in service galleries or drydocks.
2. Locations of fire hydrants, valves, meter pits, outlets on all piers, elevated ground or



143.1

Figure 10-5.—Topographic map showing area on which road is to be constructed.

underground water storage tanks, water wells, pumphouses and reservoirs.

3. Size and capacity of all storage reservoirs and height to elevated tank bottom.

4. Capacity and head of all water pumps in pumphouses, including minimum average and maximum residual pressures at point of connection to municipal systems.

5. Exterior sprinkler or fire mains, including indicator and main shutoff valves.

Sanitary Sewers:

1. Location and length of sanitary sewer trunklines and branches from all buildings, piers, and drydocks to sewage treatment plants or other point of final disposal.

2. Size and material of all pipes.

3. Locations and top and invert elevations of all manholes.

4. Notation where any part of the system, such as a forced main or branch, is under pressure.

5. Number, capacity and head of all pumps in sewage pumping stations.

6. All outside grease interceptors.

7. Show the slope of the sewer pipes and the direction of flow.

Storm Sewers:

1. Location, length, size, and material of all storm sewers.

2. Locations and top and invert elevations of all manholes, catch basins, curb inlets, culverts (given at both ends so slope and carrying capacity may be computed) and headwalls.

3. Collection pits and lift stations, including the number, capacity and head of all pumps.

4. Subsurface drainage lines (indicated by long dashlines), with sizes and materials noted.

5. Show the slope of the storm-sewer pipes and the direction of flow.

Gas Lines:

1. Location, length, and size of all gas pipes from point of connection of outside source, including meter pits, and to all buildings and structures.

2. Location and size of all valves, including earthquake valves and pits.

3. Gas pressure at the point of connection to the municipal system.

4. One-line diagrams of all meter pits, earthquake valve pits, and any special piping outside buildings.

5. Note gas type (natural or artificial).

Compressed Air Lines:

1. Location and length (overhead or underground) of all compressed air piping serving the various activities.

2. Sizes, elevations, and slopes of piping.

3. Location of all outlets, valves, manholes, drip points, supports, anchors, and expansion joints or loops.

4. Amount and pressure of the air delivered by each main or branch line and the locations of compressor plants.

Pneumatic Tubes:

1. Location of all pneumatic tube piping (noting whether it is two-tube or single-tube).

2. Piping sizes and elevations.

3. Locations and capacities of sending and receiving stations.

Steam and Hot Water Lines:

1. Location and length of steam and condensate return piping and/or hot water supply and return piping.

2. Sizes, elevations and slopes of all piping and whether the piping is overhead on poles, on high or low piers, in concrete trenches at or below grade, or otherwise installed.

3. Locations of all valves, manholes, expansion joints or loops, condensate-pump pits, pressure-reducing stations, supports, and anchors.

4. Locations of heating plants, with steam pressures and temperature of hottest water.

Fuel Lines:

1. Location and length of fuel lines, with indication of the types of fuel, include grades if applicable.

2. Sizes, elevations, and slopes of pipelines.

3. Locations of valves, surge absorbers, scraper traps, vents, drains, blinds, manholes, expansion joints, anchors, pumps, filters, clarifiers, water separators, and storage tanks, including connections to tanks when applicable.

Oxygen and Acetylene Lines:

1. Location and length of piping.

2. Sizes, elevations and slopes for all piping, and whether above or below ground.

3. Consuming stations with hourly gas consumption of each.

4. Location of cutout valves, pressure-reducing stations, rupture disks, hydraulic back-pressure valves, drip points, manholes, expansion joints or loops, supports, anchors, and the locations and capacities of generating stations and/or manifolded high-pressure cylinder banks.

5. Note if gases are delivered to the activity in high-pressure cylinders.

Electric Light and Powerlines:

1. Show system from source (power plant or public utility line) to point of utilization (substation, building, drydock, or other point).

2. Number, type and size of conduit and size, number, voltage, and type of cable.

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

4. Manholes and handholes, numbering manholes consecutively for identification, with type, dimensions, and top and invert elevations.

5. All transformer vaults, either below or above ground, with dimensions, top and invert elevations, numbers, type, and electrical data.

6. Substations, with electrical data.

7. Street lighting systems, with light standards, type and rating of lights.

8. Number, size, voltage and type of street lighting runs.

9. Note any buildings containing street lighting, transformers and control equipment together with type and rating of the transformers.

10. Indicate aboveground systems by proper symbols, including number and size of conductors and type and voltage of all circuits, material, class and pole heights and the rating and number of all transformers mounted on them.

Fire Alarm Systems:

1. Locate circuits to all equipment and buildings, and all manholes and pedestal stations.

2. Type, dimensions, top and invert elevations of manholes, and type and size of conduits and cables.

3. Show buildings containing sirens, horns, control panels, punch registers and transmitters.

4. Indicate alarm system manufacturer and type of system.

5. Systems above ground or below ground.

6. Locations of poles and fire alarm stations, with material, classes, and heights of poles.

Communications Lines:

1. All communications circuits to main equipment and buildings. Other requirements similar to those for fire alarm systems.

LAYOUTS FOR PLUMBING SYSTEMS

This section contains recommended standards and specifications that the EA1 or EAC will find useful in checking the technical accuracy of layouts for plumbing systems.

The following guidelines must be considered in the design of plumbing systems.

1. If municipal utilities are available, service for naval facilities must be extended to connect with these facilities.

2. All plumbing designs must conform with the requirements of NavFac specifications; for items not covered in NavFac specifications, the design must conform to the National Plumbing Code. For items or special conditions not covered by either Nav Fac specifications or the

National Plumbing Code, the design must conform to good engineering practice.

3. Plumbing systems must be designed for greatest economy under the given conditions, and the piping in limited life structures must be exposed unless it is a hazard, unsanitary, in conflict with local policy, or subject to freezing temperatures.

4. All piping must be routed straight and direct wherever possible. Generally the lines should be parallel with or at right angles to walls or other work.

5. All piping must run in such a manner that it does not block lighting fixtures, doors, windows or other openings.

6. All piping must be run so that it does not pass through beams and girders. Where piping passes through other structural members, ensure that the proper structural strength is maintained.

7. Piping should not be located over electrical apparatus or equipment where leakage could cause unusual hazards.

8. Avoid overhead piping at any location where leakage may contaminate food or water.

9. NavFac Specification 31Y (latest revision) must be used as a guide in selecting plumbing materials. However, all materials selected must have the greatest possible resistance to corrosion consistent with initial cost, maintenance, replacement and the life of the structure. For structures having a limited life, the materials specified in NavFac specifications may be too restrictive. In such cases, the National Plumbing Code should be followed in the selection of plumbing materials.

10. Ascertain that the sizes of pipes are within the minimum required by the National Plumbing Code.

11. Provide gate valves for services requiring full-flow- or no-flow. Provide globe type valves where frequent operation and throttling are required.

12. All shutoff valves and cleanouts must be installed in accessible locations.

ELECTRICAL LAYOUTS

The basic principles of electrical layouts, including wiring diagrams and methods of drawing electrical power systems are discussed in *Engineering Aid 3 & 2*. This section is concerned with sources of electrical standards which might be used in conjunction with Navy standards as guidelines in checking the technical accuracy of electrical drawings.

As mentioned earlier in this chapter, practically every Navy construction project is covered by design standards and specifications published by the Navy. In some instances, however, you will have to consult the *National Electric Code* or the city code (depending on the location of the project), in the early stage of the electrical design and drawing to avoid discrepancies in the minimum standards for quality of materials and workmanship. Generally, each city or locality has an inspection bureau that inspects electrical wirings and devices as installed, and issues a certificate stating compliance with the code standards. To prevent redrawing, reworking, and thus to minimize as-built alterations in the drawing, it is good practice to check local codes if your finished drawings are within the minimum requirements. In checking construction drawings, do not fail to consult the local electrical code standards, it is better to discover discrepancies while in the drawing stage than later when the wiring and devices are already in-place.

ACCURACY

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 for checking and editing described in chapter 2 of this training manual, 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, or utilitiesman concerning any problems which may arise. These men will have to construct from your drawings, and 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 very beneficial. They 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.

CHAPTER 11

PLANNING AND ESTIMATING

Before going into detail explaining the principles and methods of planning and estimating, it is best to give you, in general terms, the meaning of these two terms as applied to SEABEE construction.

PLANNING is the process of determining requirements and devising methods and schemes of action for the accomplishment of a certain project. ESTIMATING is the act of determining the size, the duration, and the kind of work to be performed and determining the quantities of work elements, materials, labor, and equipment needed to perform this work. In a broader sense, planning and estimating could encompass the overall mission of the battalion or could be scaled down to supervisory level of the project's basic subphase, such as the work element, materials, equipment and manpower needed in the excavation of a building foundation. However, in this chapter, we will cover planning and estimating (P & E) on the battalion level which applies to the integr P & E functions under the Operations Department.

As mentioned in chapter 2 of this training manual, P & E is one of the major functions under the supervision of the Battalion Operations Officer, various responsibilities of the P & E officer were enumerated also. In this chapter, the principles of construction planning and estimating will be discussed. The types of estimates and their uses, procedures used in estimating, and qualifications of a SEABEE estimator will also be explained.

CONSTRUCTION PLANNING AND ESTIMATING

Before members of a construction battalion are confronted with the problem of doing the planning and estimating required for the actual work of construction, a considerable amount of preplanning has been done elsewhere. Assuming that the work of construction will involve the erection of an advanced base, this preplanning may be briefly summarized as follows:

At the Navy departmental level, it is decided that Navy operations, plans, and programs require the establishment of an advanced base at a given location. The nature of the structures which will be erected at this advanced base is then determined. The ultimate result of this is a "recommendation of construction items". It is at this point that the actual construction planning and estimating for the actual work of construction begins.

Construction planning is a combination of several important considerations. In addition to day-to-day planning on the job, primary matters that must be considered in construction planning are work element estimates, material estimates, equipment estimates, manpower estimates, plant layout, material delivery and storage, work schedules, and progress control. These considerations are more or less dependent upon each other and all are taken into account in any properly planned project.

It is a basic policy of the Department of Defense not to put civil service or military construction forces in competition with private construction enterprise. Therefore, the employment of the Navy's own construction force (the SEABEES) is, in peacetime, restricted principally to projects whose "isolated character" makes the employment of American private enterprise unfeasible. However, even for an overseas project, private enterprises may participate in some construction effort. It is common knowledge, for example, that an American firm, the "RMK-BRJ Construction Company," has completed millions of dollars worth of construction contracts in the Far East, other companies are employed in Kwajalein, in Spain, and other parts of the world. These companies have worked hand-in-hand with the SEABEES. Generally, the preparation of plans and specifications for overseas advanced bases and structures are contract-awarded to civilian architectural-engineering firms in the United States. A contract of this type is called an A & E (Architectural and Engineering) contract.

The plans and specifications prepared by these firms are the principal basis for subsequent project planning and estimating. Assume that the project in question is the construction of an advanced base. A NMCB does not usually participate in the planning until the CONSTRUCTION PLAN has been prepared. A construction plan is prepared for each advanced base specified by the base development plan. In wartime a construction plan is prepared by the Commander, Advanced Base Construction Force, who will be responsible for the actual construction. The plan is submitted for the approval of the Advanced Base Commander, who issues it as a Construction Order. In peacetime, construction plans are issued by the appropriate Commander, Fleet Construction Force (COMCBLANT or COMCBPAC).

The construction plan establishes the administrative, planning, estimating, logistic, staging, communications, defense, and construction requirements for the deployment. It also establishes construction priorities and command relationships. It may be supplemented by a series of INSTALLATION ORDERS, each of which assigns a task or tasks to a subordinate unit (such as a NMCB). An installation order may include special instructions on logistic and administrative matters that apply only to the unit or units to which the installation order is directed.

The construction plan, installation order, instructions, and related drawings and specifications are the basis from which project planning and estimating proceed. Refer back now to figure 2-9 of this manual, and study the outline shown there of planning and estimating steps beginning with the basis and leading ultimately to the completion of the project.

PRINCIPLES OF ESTIMATING

Generally, construction estimates may be prepared under two categories, PRELIMINARY and DETAILED estimates. Preliminary estimates are approximations made from limited information, such as short general descriptions of projects, or preliminary plans and specifications with little or no detailed information. Preliminary estimates are usually prepared to establish costs for budget purposes and to program manpower ahead of time, or for succeeding operations. In civilian concerns, preliminary estimates may be used for submission of bid proposals.

Detailed estimates are statements of the detailed quantities of work elements, materials, equipment and manpower required to accomplish a given project. Any of these that are underestimated can cause serious delay in construction or possibly result in unfinished projects on a NMCB deployment. A detailed estimate is the most reliable that can be made and such an estimate is likely to produce the results necessary for a successful deployment this is the goal that is expected from a good SEABEE estimator. The main purpose of the estimates is to come up with the following requirements, which should be accurate insofar as possible

1. WORK ELEMENT ESTIMATE: This is a listing of quantities of each work element (such as cubic yards of earth to be moved, cubic yards of concrete to be placed, lineal feet of pipe or conduit to be laid, square feet of exterior or interior surfaces to be painted, etc.) required to accomplish a given project. Work element estimates are prepared by computing the quantities of the various items of work shown or referenced by notes on the drawings and described in the specifications. Work element estimates are sometimes referred to as Quantity Takeoffs. Work element quantities provide the basis for preparing estimates of material, equipment and manpower. They are also used in scheduling progress, which provides the basis for scheduling material deliveries, equipment and manpower. Errors in work element estimates can multiply many times through their use in the preparation of other estimates and schedules.

2. MATERIAL ESTIMATE: A listing and description of the various materials and quantities required to construct a given project are provided in the material estimate. Information for preparing material estimates is obtained from

work element estimates, drawings, and specifications. A material estimate is generally referred to in the SEABEES as a Bill of Material or a Material Takeoff. A material takeoff is also the basis for the cost of material figures.

3. EQUIPMENT ESTIMATE. This is a listing of the type of equipment, the number of pieces, and the amount of time required to construct a given project. Information from work element estimates, drawings and specifications, and information obtained from inspection of the jobsite provide the basis for preparing the equipment estimate. In building construction a topographic map may be used for estimating the required number and type of earthmoving equipment.

4. MANPOWER ESTIMATE: This estimate gives a listing of the number of man-days required to complete the various work elements of a specific project. Manpower estimates may show only the man-days for each work element and the total man-days, or they may be in sufficient detail to show the number of man-days of each rating (EA, BU, CE, EO, SW, and UT) for each element. Manpower estimates are used in determining the number of men and ratings required on a deployment, and provide the basis for scheduling manpower in relation to construction progress.

5. SCHEDULING. As used here, scheduling is the process of determining when a work element should be performed, and when materials, equipment and manpower will be required. A progress schedule is a plan for coordinating all projects of a SEABEE deployment, or all work elements of a single project. It shows the sequence, the time starting, the time required for performance, and the time for completion. Material schedules show when materials are needed on the job and may show the order in which they should be delivered. An equipment schedule is a plan for coordinating all equi ent to be used on a project and shows when and the amount of time each type of equipment is required to perform the work. A manpower schedule is a plan for coordinating the manpower requirements for a project and shows the number of men required for each work element for each period of time. In that case, it may also show the number of each rating required for each work element for each period of time. The selected unit of time to be shown in a schedule should be some convenient interval such as a day, a week, or a month.

6. PROGRESS CONTROL: This is more or less a check to determine the actual progress compared with scheduled progress and taking necessary steps to correct deficiencies and to balance activities in order to meet overall objectives.

As an EA1 or EAC you will be involved in overseeing that the above objectives of P & E are followed, especially if your designated specialty code is EA-5515 (Construction Planner and Estimator Specialist).

USE OF DRAWINGS AND SPECIFICATIONS

The construction drawings are the main basis for measuring work element and material quantities. 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. The overall dimension 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 section near the title block should be verified to check whether the indicated changes were in fact made in the drawing itself. The construction plan, the specification, and the drawing must be verified to see if in fact they are talking about the same project. When there are inconsistences 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.

Specifications must first be studied, then used with the drawings when preparing quantity estimates, and the estimator should become thoroughly familiar with all the requirements stated in the specifications. Some estimators will have to read the specifications more than once in order to fix these requirements in their minds. Notes made while reading the specifications will prove helpful when examining the drawings. These notes should list items of work or materials which are unusual, items not familiar to the estimator, and reminders for use during examination of the drawings. A list of work elements and materials which are described or mentioned in the specifications will be helpful in checking quantity estimates.

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 progress, which provides the basis for 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, if the estimator misreads a dimension for one side of a concrete slab as 300 ft instead of 800 feet, the computed area of the slab will be, if the length of the other side is 100 ft, 30,000 sq ft, when it should actually be 80,000 sq ft. 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, including equipment time, manpower, and man-hours.

CHECKING ESTIMATES

Because of the need for accuracy in quantity estimates, they should be checked in a manner which will eliminate as many errors as possible. One of the best ways to check a quantity estimate is to have another person make an independent estimate and then 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 the quantity estimate and check all measurements, recordings, computations, extensions, and copy work, keeping in mind the most common sources of error listed in the next section.

SOURCES OF ERROR

Failure to read all notes on a drawing or failure to examine reference drawings results in many omissions. For example, an estimator may overlook a note "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. Common scaling errors are: using the wrong scale, reading the wrong side of a 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, but instead the estimator must obtain dimensions from other sources.

Sometimes wrong interpretation of a section of the specifications can cause errors in the estimate. If there is any doubt in the estimator's mind 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. Check lists should be used to assure that all work elements 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 inadvertent figure transpositions, copying errors, and computational and arithmetic errors.

QUALIFICATIONS OF AN ESTIMATOR

A good estimator is one who can picture mentally the separate operations of the job as the work will progress through the various stages of construction. He must be able to read drawings and obtain accurate measurements from them. He must possess a knowledge of arithmetic and general math. and must have previous construction experience or formal P & E training. He should have a working knowledge of all branches of construction and must possess ability to use good judgment in determining what effect numerous factors and conditions will have on construction of the project and what allowances should be made for each of them. He should be able to do careful and accurate work free of errors. A SEABEE estimator should have available to him information about materials, equipment, and labor that is required to perform various types of work under conditions encountered in SEABEE deployments. Collection of such information on construction performance is part of the job of estimating. Reference information of this kind may change from time to time, and therefore should be revised frequently.

The estimator on building jobs will be called upon to calculate the areas and contents of various shaped plane and solid figures. With plane figures, the square foot or square yard areas are determined, with solid figures, the cubic foot or cubic yard contents are figured. Since most of the estimator's calculations are based on plane and solid geometry, it is important to review the basic principles of general mathematics and methods of calculation given in *Engineering Aid 3 & 2*.

Generally a good estimator must possess the following qualifications.

1. Professional knowledge and experience
2. Knowledge of construction techniques
3. Knowledge of materials
4. Knowledge of equipment
5. Good judgment

Professional Knowledge and Experience

Senior rated EAs may be sent through P & E schools (Class "C"), where they are trained in the planning and estimating of work elements, materials, manpower and equipment for utilization on various construction jobs. They are also trained in scheduling, which stresses the importance of the Network Analysis System. The best experience is attained by on-the-job training under close supervision of qualified P & E specialists. Those who are continuously assigned to this billet gain lots of know-how and they are abreast of changes in construction trends and methods. The best way to maintain your capability as a P & E specialist is to compile your own references of construction norms, estimator's manuals and even personal notes on different construction matters. Be aware of changes that will improve construction methods, and incorporate those changes as they occur—then they will not have a chance to slip your memory.

If time permits, make trips to the construction sites and observe the performance of some work elements that are not clear in your mind. For example, you could observe a Builder installing windows or doors, preferably from rough to finish. Observe the details and try to correlate the actual appearance of the construction to what you see in the drawing. Ask questions on anything you are in doubt about, personnel in the other ratings will explain to you what they are doing—especially, if you show interest in their work and let them know your motives. In the office, do not hesitate to solicit the help of the other rating groups when doubts on certain technical matters arise. It is a proven fact, that, he who asks more constructive questions understands what is going on, and thereby learns more; be humble and ask questions to clarify hazy matters.

Knowledge of Construction Techniques

Construction techniques are specialized tasks performed by appropriate construction group ratings (such as BUs for carpentry, UTs for plumbing, etc.); however, as a P & E specialist, your knowledge of various construction techniques is imperative for accurate estimate results. You must possess a broad knowledge of various phases of construction works and methods. This knowledge is attained only through tedious work, study, and on-the-job experience. P & E schools cannot cover everything you need to learn in planning and estimating for all types of construction jobs in 8 weeks, so you have to learn a lot on your own. It is not an easy task, but the knowledge you gain will enhance your advancement opportunities in the Navy. This knowledge may also be useful in civilian life as men qualified in planning and estimating are in great demand in private industry.

The procedure of planning and estimating is the same in military and civilian occupations, but the required work elements, materials, manpower, and equipment vary, depending upon the type of construction and the methods to be employed. Each particular construction job needs particular construction techniques–learn them! As suggested earlier, field trips to the jobsites, working with other ratings in P & E, and compiling your own references will greatly increase your knowledge and capability.

Knowledge of Materials

As an estimator, you must possess a thorough knowledge of materials. In addition to a knowledge of their types, sizes, and quantities, you should also know the source, suppliers and whether the types of material selected will meet requirements in the specification as to appearance, strength and durability. You must be familiar with their modular, nominal or standard sizes; you must also consider their ease in handling. If possible, to avoid additional work in shaping and cutting to fit, use standard-size materials.

Some construction materials were discussed in *Engineering Aid 3 & 2*; however, for the most part, you will have to depend on the Naval Supply System catalog, the General Services Administration (GSA) catalog, or on a private supplier's catalog. Examine the description of those materials you desire to use from these catalogs and compare their desirability as to the inherent properties referred to above. Generally, it is easier to use materials carried in the Naval Supply System; however, there are instances where we have to substitute and procure certain materials locally or from other sources. When substitution of a material is unavoidable, be sure it is the right kind you want, and above all, ensure that its chemical and physical properties are equal to, or better than, those specified for the project.

Knowledge of Equipment

As stated earlier in this chapter, information from work elements, drawings, and specifications, and also information obtained from site inspection, provide the basis for the preparation of equipment estimates. Your knowledge of various types of equipment and their capabilities will be instrumental in preparing an accurate equipment estimate for a particular job, or in determinging the total construction equipment requirements of a SEABEE deployment. It is realized that, as an EA, your knowledge of equipment may be limited to that used in surveying and the drafting room. As an estimator, however, your knowledge of equipment must cover those types used in all phases of construction. Learn the techniques of determining equipment requirements by working hand-in-hand with experienced estimators or with the other rating groups. And, pay close attention to those techniques that are not generally covered in construction norms (meaning those knowledges acquired through experience).

Generally, senior rated EOs or CMs are involved in preparing equipment estimates for excavation, hauling, and weight-handling equipment, as well as tools and equipment used in their equipment maintenance shops. Other rating groups determine their respective tools and equipment requirements; for instance, the tools and equipment requirements for a carpentry shop are the BU's responsibility; plumbing equipment requirements are the UT's responsibility, and so on. While working with the other rating groups, make it a point to make a carbon copy of your estimates and notes, for this will serve as your reference when a similar project comes up (perhaps you may even add your own notes in the margin of the carbon copy to clarify matters for you).

Good Judgment

Good judgment is usually an inherent or inborn trait of normal individuals; however, it can be acquired and developed through experience and practice. Good judgment is a by-product of learning. It is not an isolated characteristic. It is rather scrupulous regard of responsibility that allows no compromise between fact and fiction, sees objectively the true measure of action taken and action required, and projects satisfactory results that are within the construction engineering standards. In other words, your action or decision must be the best possible from all considerations. Always have a mental picture of the various work elements and evaluate the "cause and effect" as a result of your projected actions, and see how they will tie-in with the overall accomplishment of the job.

In planning and estimating, you should base your decision on facts and tested methods, the construction plan, the engineering drawings and the specifications of a particular project are your bible and must be adhered to closely in determining your estimates for that project. The following factors may help in using good judgment when given consideration in determining the choice of materials and equipment. ECONOMY (original cost, installation cost, operation and maintenance costs). MOVABILITY (ease in handling); DURABILITY; APPEARANCE; SAFETY; and other desirable engineering factors. Although the final decision rests with the Operations Officer in deciding what type of materials and equipment to use, it is your responsibility to present him with the facts.

PREPARATION OF ESTIMATES

This section contains information about the application and preparation of various estimates required for construction projects normally undertaken by the SEABEES. The procedure in preparing detailed estimates of work elements, material quantities, equipment requirements, and manpower requirements will be presented in this section. Procedures in the use of various P & E forms, construction norms and tables are also presented.

WORK ELEMENT ESTIMATES

A WORK ELEMENT estimate provides a basis for preparing estimates of material, equipment, and manpower requirements. For example, a work element estimate might show 1,000 sq ft of 12-in. concrete block wall to be constructed. In the materials estimate derived therefrom, this much concrete wall would be converted into required quantities of 12-in. block, mortar sand, cement, and lime. In the equipment estimate it would be converted into mixer time required to mix the mortar. In the manpower estimate it would be converted into the number of man-days required to perform the work.

The quantity of block, together with the length and height of the wall, would be used to estimate the number of scaffold frames and boards required, together with requirements for special tools or equipment such as mortar boxes and hods.

Information shown in work element estimates is also used in scheduling progress, which in turn provides the basis for scheduling material deliveries, equipment, and manpower.

The estimator should have a good general knowledge of the project before performing any actual work element estimates. Such a knowledge can be obtained by a general study of the drawings and specifications, plus an examination of all available information about the project site and local conditions.

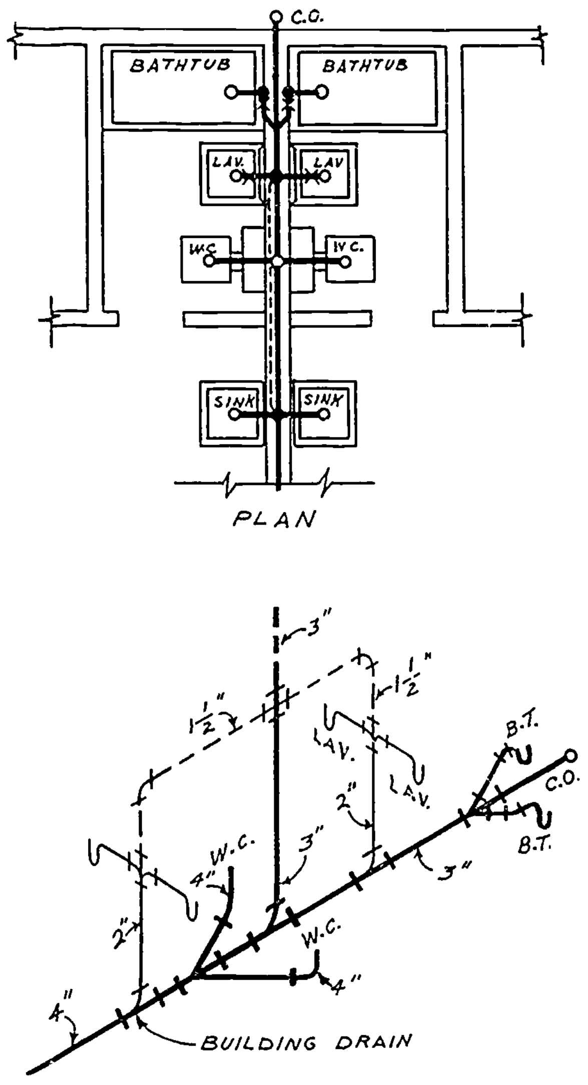
Measuring Work Element Quantities

Normal practice is to begin by measuring work elements on the foundation and footing plan and to proceed through the basement and each succeeding floor plan of the architectural and structural drawings. All reference and detail drawings that refer to a particular plan are examined and worked in conjunction with that plan. After examination of the plans is completed, the elevations and then the details are examined one by one, and all work not previously taken off is measured and recorded.

Sometimes concrete, reinforcing, and structural features are shown on drawings separate from those showing architectural features. When this is the case, it is best to work the concrete and reinforcing drawings first, and then the structural and architectural drawings.

After the architectural and structural drawings, the mechanical and then the electrical drawings are worked. These are followed by specialty or shop drawings, if any. In each division the order should be (1) plans, (2) elevations, (3) details.

Mechanical drawings usually include the elevations of the plumbing system, which is often called the "RISER DIAGRAM". Generally, they have one for the water system (hot and cold), and another for the sewer system. If you are working on a mechanical drawing, such as plumbing, and the plan does not show enough information, it is to your advantage to draw the riser diagram yourself, in order to have a vivid picture of the system (see figure 11-1). By doing this, you can see every fixture fitting, and riser, these cannot all be represented in the plan alone. Your riser diagram does not have to be very elaborate simple lines and symbols will serve the purpose. Often these diagrams which you prepare for your own use in estimating may be given to the construction company with a copy of the material estimate to ensure that they understand where you intended the materials to be used. Or, if time permits, your diagrams may be given to the drafting section to be incorporated into the construction drawings.



NOTE, USE STANDARD HEIGHTS FOR PLUMBING FIXTURES AS RECOMMENDED IN THE NATIONAL PLUMBING CODE OR AS REQUIRED BY SPECIFICATION.

82.179

Figure 11-1.—Riser diagram.

In electrical wiring measurements, allowances must be provided for splicing and connection to receptacles and outlets. The specification must be checked for height of outlets, switches and drops of hanging fixtures, if not otherwise shown in the drawing or notes.

Examining a Drawing

When measuring work element quantities on a drawing, it is a good idea to begin at one side and work across to the opposite side, marking with a colored pencil each particular work element as it is measured and recorded. Work such as concrete, reinforcing, and similar items can be marked with a simple checkmark; but items such as conduit and piping should be marked by tracing over with a colored pencil. The colored marks not only show the estimator what has been taken off (thus preventing duplication), but also provide a means of checking for omissions.

Recording and Computing Work Elements

As each work element is measured, the information is recorded and computations are shown on a WORK SHEET. Typical work sheets are shown in figures 11-2, 11-3, and 11-4. These are three sheets from a set of six giving work element quantities relating to the footings and foundations for a staging-out warehouse. You can see how, on sheet 1, the total excavation yardage, not only for the footings and foundations themselves, but also for the necessary form working space, is computed. On sheets 2 and 3 the total cubic yardage of concrete for the footings and foundations is similarly computed. The heading on each sheet shows the sheet number, estimator's name, date of takeoff, checker's name, date checked, battalion number, deployment location, year, project number, and project description. The first sheet shows drawing numbers, drawing revision, and date of latest drawing issue.

SHEET NO. 1 OF 6

ESTIMATED BY Smith DATE 7-7-7-

CHECKED BY Jones DATE 8-9-7-

WORK ELEMENT ESTIMATE
WORK SHEET

NMCB 15 LOCATION Saipan YEAR 197-

PROJECT 08 DESCRIPTION Staging-Out Warehouse

WORK ELEMENT	LOCATION	MEASUREMENT AND COMPUTATION	QUANTITY
Footings and Foundations Dwg		A-40152 Rev 2 dated 11-3-73	
		A-40161 Rev 3 dated 3-15-73	
Excavations	Exterior	46 ftgs 8'-3" sq x 6'-3" deep	
	col. ftgs	46 x 8.25 x 8.25 x 6.25 =	19,568 CF
	Interior	38 ftgs 7'-3" sq x 6'-3" deep	
	col. ftgs	38 x 7.25 x 7.25 x 6.25 =	12,484 CF
	Grade	20 spaces ea side bet col etc	
(Excavate 6'-6" wide	beam	(20'-0 minus 8'-3" = 11'-9")	
to provide space	sides	6'-6" wide and 4'-6" deep	
for setting forms)		2 x 20 x 11.75 x 6.5 x 4.5 =	13,748 CF
	Grade	8 spaces ea end bet col etc	
	Beam ends	(33'-5" minus 8'-3" = 25'-2")	
		6'-6" wide and 4'-6" deep	
		2 x 3 x 25.17 x 6.5 x 4.5 =	4,417 CF
			50,217 CF
Total	excav	ftgs & fndtns	1860 CY

87.1(82A)1

Figure 11-2.—Work element estimate work sheet, sheet 1 of 6.

SHEET NO. 2 OF 6
ESTIMATED BY Smith DATE 7-7-7-
CHECKED BY Jones DATE 8-9-7-

WORK ELEMENT ESTIMATE
WORK SHEET

NMCB 15 LOCATION Saipan YEAR 197-
PROJECT 08 DESCRIPTION Staging-Out Warehouse

WORK ELEMENT	LOCATION	MEASUREMENT AND COMPUTATION	QUANTITY
Footings and foundations (cont'd)			
Concrete	Ext col	46 ftgs 8'-3" sq x 1'-9" deep	
	ftgs	46 x 8.25 x 8.25 x 1.75 =	5479 cF
	Int col	38 ftgs 7'-3" sq x 1'-9" deep	
	ftgs	38 x 7.25 x 7.25 x 1.75 =	3495 cF
	Int col	38 piers 2'-4" sq x 4'-6" high	
	piers	38 x 2.33 x 2.33 x 4.5 =	928 cF
	Grade bm	2 sides 402'-4" lg	
	sides	14" wide, 4'-6" hi	
		2 x 402.33 x 1.17 x 4.5	4237 cF
	Grade	2 ends 100'-3" lg, 14" wi, 4'-6" hi	
	bm ends	2 x 100.25 x 1.17 x 4.5 =	1056 cF
		Subtotal	15,195 cF

87.1(82A)2

Figure 11-3.—Work element estimate work sheet, sheet 2 of 6.

SHEET NO. 3 OF 6
ESTIMATED BY Smith DATE 7-7-7-
CHECKED BY Jones DATE 8-9-7-

WORK ELEMENT ESTIMATE
WORK SHEET

NMCB 15 LOCATION Saipan YEAR 197-
PROJECT 08 DESCRIPTION Staging-Out Warehouse

WORK ELEMENT	LOCATION	MEASUREMENT AND COMPUTATION	QUANTITY
Footings and foundations (cont'd)			
Concrete (cont'd)	Balance brought forward		15,195 CF
	Extra for	42 piers proj 2'-4" lg	
	wall piers	1'-2" wide, 4'-6" hi	
		42 x 2.33 x 1.17 x 4.5 =	516 CF
	Extra for	4 piers proj 1'-2" sq	
	corner	x 4'-6" hi	
	piers	4 x 1.17 x 1.17 x 4.5 =	25 CF
			15,736 CF
Total concrete - ftgs & fndtns →			582.8 CY
Forms	Interior	38 piers 2'-4" sq	
(Concrete placed	piers	x 4'-6" hi	
against earth wall		38 x 4 x 2.33 x 4.5 =	1596 SFCS
in col ftgs	Grade bm	2 sides 402'-4" lg 4'-6" hi	
Grade beams		2 x 2 x 402.33 x 4.5 =	7242 SFCS
formed sides only)	Grade bm	2 ends 100'-3" lg 4'-6" hi	
	ends	2 x 2 x 100.25 x 4.5 =	1805 SFCS
		Subtotal forms	10,643 SFCS

87.1(82A)3

Figure 11-4.—Work element estimate work sheet, sheet 3 of 6.

Work elements are entered on the work sheet in the order in which they are measured on the drawings. Usually all measurements from the drawing are entered on the work sheets before computations are made. Computations are made in the units of measure given on the drawings concrete, for example, is computed and totaled in cubic feet, then converted to cubic yards.

The lower portion of sheet 3 and the remaining three sheets of the set contain computations relating to the remaining work elements connected with the footings and foundations. You can see on sheet 3 that for the forms it is the area of form SQUARE FEET CONTACT SURFACE (SFCS) that is computed—that is, the area of form sheathing that will be in actual contact with the concrete. Following the form contact surface will come the reinforcing steel, with quantities computed in pounds as follows.

Suppose each of the footings, for exterior columns is to contain 11 #6 bars 7 ft 9 in. long, each way, top and bottom. This means that there will be 4 sets of 11 bars in each exterior column footing. There are 46 exterior column footings, and #6 bar weighs 1.50 lbs per ft. The bar quantity for these footings, then, would be 46 X 4 X 11 X 7.75 X 1.50, or 23,529 lbs.

After the reinforcing steel will come the volume of the BACKFILL—that is, the volume of earth required to backfill the form working spaces. This volume amounts to the total excavation volume, which is 1860 cu yd (see sheet 1, fig. 11-2), minus the total volume of underground concrete, which is 582.9 cu yd (see sheet 3, fig. 11-4), or about 1277 cu yd.

After the backfill will come the volume of EXCESS EARTH—that is, the volume of excavated earth remaining after backfilling is completed. This amounts to the total excavation volume minus the backfill volume, or 1860 cu yd minus 1277 cu yd, or 583 cu yd. Finally, the amount of earth requiring hand compaction is listed, this amount is, simply, the amount of the backfill, or 1277 cu yd.

Work Element Estimate Summary Sheet

Work element quantities are transferred from work element estimate sheets to work element estimate SUMMARY sheets like the one shown in figure 11-5. The order in which quantities should be set down is prescribed in COMCBLANT and COMCBPAC instructions. The prescribed order is the one which will ensure that work elements will be in correct sequence for reporting or recording on work schedules that is, it follows as closely as possible the actual order in which work elements will be accomplished on the project.

MATERIAL ESTIMATES

Material estimates are used as a basis for construction material procurement, and also as a check to determine if sufficient materials are available to construct or complete a project. For example, the Operations Officer might have some doubts about availability of materials to complete a certain project, so an estimate is prepared listing quantities of materials that will be required to complete the project. This estimate is compared with the stock of materials on hand.

The following is a suggested procedure for preparation of a material estimate. First, obtain the work element quantity, which is usually done by referring to the work element estimate summary sheet. Convert this into quantities of materials required to perform the work. In this connection, tables containing construction norms conversion units, supplied in Naval Schools Construction courses, or taken from standard estimator's manual, may be used.

Material Estimate Work Sheets

Conversions are done on material estimate work sheets like the one shown in figure 11-6. The material estimate work sheet (commonly called material take-off work sheet) is presented here only as a typical work sheet. The estimator may use any form similar to this which will serve the intended purpose. Generally, this work sheet is a series of horizontal lines with several vertical columns in which the estimator may fill in the desired headings.

On the work sheet in figure 11-6 the material requirements for 4000 square feet of concrete slabs on grade are computed. First comes the form lumber. The material estimate worksheet indicates that there are 440 linear feet of 2 X 6 edge forms. Since it takes 1 linear foot to make

SHEET 1 OF 6
ESTIMATED BY Smith DATE 7-7-7-
CHECKED BY Jones DATE 8-9-7-

WORK ELEMENT ESTIMATE
SUMMARY SHEET

NMCB 15 LOCATION Saipan YEAR 197-
PROJECT 08 DESCRIPTION Staging-Out Warehouse

WORK ELEMENT	QUANTITY
Footings and foundations	
Machine excavation	1860 CY
Machine backfill	1277 CY
Hand compaction	1277 CY
Spread excess-earth machine	583 CY
Form and strip	11,083 SFCS
Place reinforcing steel	34.6 tons
Place, finish, & cure concrete	582.8 CY

145.4(82A)1

Figure 11-5.—Work element estimate summary sheet.

SHEET 1 OF 4

ESTIMATED BY Smith DATE 8-16-7-

CHECKED BY Jones DATE 8-23-7-

MATERIAL ESTIMATE
WORK SHEET

NMCB 21 LOCATION Bermuda YEAR 197-

PROJECT 01 DESCRIPTION Naval Stores Warehouse

DESCRIPTION	WORK ELEMENT QUANTITY	CONVERSION UNIT	QUANTITY REQUIRED	REMARKS
Concrete slabs on Grade				4000 SF
Forms & screeds				
2"x6" edge forms	440 LF	1	440 LF	S4S #2 YP or equal
2"x4"	4000 SF	0.1 LF	400 LF	do
1"x4"	do	0.1 LF	400 LF	do
Form oil	220 SFCS	1 gal/200 SFCS	2 gals	
nails	16,700	6 lbs/1000	100 lbs.	
Reinforcing				
Reinf. mesh	4000 SF	1.12	4480 SF	6x6-8x8 mesh
Reinf. bars	1069 lbs		40-#4x40'	
Tie wire (for reinforced steel)	.5 ton	12 lbs/ton	6 lbs.	
Concrete	75 CY			6 sacks/CY
Portland cement	do	6	450 sks	
Fine aggregate	do	0.6	45 CY	
Coarse aggregate	do	1	75 CY	
Curing compound	4000 SF	1 gal/200 SF	20 gals	
Floor hardener	do	3 lbs/100 SF	120 lbs	Magnesium fluosilicate

87.2(82A)

Figure 11-6.—Material estimate work sheet.

1 linear foot, the conversion unit here is obviously 1, and the quantity required therefore is 440 X 1, or 440 linear feet. The lumber is to be S4S (surfaced 4 sides), and of quality equal to that of yellow pine.

After the edge forms come the 2 X 4's, for braces, stakes and screed guides. Some construction norm tables show that 0.1 linear feet of a 2 X 4 is required for every square foot of slab; therefore, the conversion unit is 0.1, and the quantity required is 4000 X 0.1 linear foot or 400 linear feet. Next comes a supply of 1 X 4's, probably for bracing and miscellaneous. A table indicates that 0.1 linear foot of a 1 X 4 is required for every square foot of slab; therefore, the conversion unit is 0.1; and the quantity required is 4000 X 0.1 linear foot or 400 linear feet.

Form oil will be applied only to the contact surface of the forms; the material estimate worksheet indicates that the area of the contact surface is 220 square feet. A table indicates that 1 gallon of form oil will cover 200 square feet of contact surface. There are more than 200 square feet here, and the estimator has rounded off the quantity required at 2 gallons, probably because the oil is not available in less than 1 gallon increments.

Nail requirements for the form work are computed from a conversion table, based on the total board feet of lumber and square feet of plywood to be used. Reinforcement for the slabs will consist of 6X6 - 8X8 WWF or mesh and #4 rebars. The mesh will be laid flat over the whole slab area, which amounts to 4000 square feet. A table shows that it takes 1.12 square foot of this mesh to cover 1 square foot of slab – the extra 0.12 square foot is probably an allowance for overlap. The quantity of mesh required is therefore 4000 X 1.12, or 4480 square feet.

The material estimate work sheet (fig. 11-6) shows that 1069 lbs of the #4 rebars are required. The estimator knows, probably from studying the drawings, that 40-ft lengths are the most feasible lengths for ordering the rebars. From tables and computations, he determines that there are forty 40-ft bars in 1069 lbs of #4. Tie wire for the reinforcing steel is 12-lb per ton.

Last on the sheet come the concrete ingredients. The material estimate work sheet indicates that 75 cubic yard of concrete is required. The specifications say that there shall be 6 sacks of cement to each cubic yard of concrete. Either from the specifications or from quality control tests, it has been determined that there shall be 0.6 cubic yard of fine aggregate and 1 cubic yard of coarse aggregate for every cubic yard of concrete. The conversion units and quantities required are therefore as indicated.

A curing compound is to be applied to the slab surface. A table shows that 1 gallon of the compound is required for every 200 square feet of surface. The quantity required is therefore 4000/200, or 20 gallons. A hardening compound (magnesium fluosilicate) is also to be applied to the slab surface. A table shows that 3 pounds of this is required for every 100 square feet of surface; the quantity required is therefore 4000 X 3/100, or 120 pounds.

Waste and Loss Factors

During construction there is a certain amount of material which must be wasted because of cutting, fitting, and handling requirements. It goes without saying that the only tolerable waste is UNAVOIDABLE waste, and lumber (for example) must be ordered in those lengths which will ensure that cutting waste is reduced to a minimum. Besides cutting, fitting, and handling, there are other causes of unavoidable waste. Mortar sand, for example, is normally piled on the ground, and sand at the bottom of the pile becomes mingled with earth to the extent that it is unusable for concrete. There is also a possibility of loss due to pilferage, vandalism, and weather damage.

When materials are ordered, allowances must be made for all foreseeable material losses. This is done by increasing the computed material quantity by the application of a WASTE AND LOSS factor. Factors as supplied by Naval Schools, Construction are based on a large number of jobs performed under varied conditions and at many different locations. The estimator has specific information about the job and is in a position to determine if conditions require that a tabulated waste and loss factor be increased, or permit that it be decreased.

Material Estimate Recap Sheets

Waste and loss computations are done on material estimate RECAP sheets like the one shown in figure 11-7. Notice that like materials are grouped together and totaled. The sheet shown in figure 11-7 deals with form lumber. The material estimate work sheets show that, for the slabs on grade, 200 linear feet of 1 X 4 #2 yellow pine or equal are required. A table shows that the waste and loss factor in this category is 5 percent; therefore, a waste and loss of 200 X 0.05, or 10 linear feet, should be anticipated. Therefore, the quantity procured should be 200 + 10, or 210 linear feet. Under remarks, the board footage is computed for future cost calculations. The board footage amounts to 1 X 4 X 210/12, or 70 board feet.

The other computations on the sheet are similar. Note, however, that no waste and loss allowance is made for the 4 X 4's and the 4 X 6's. The reason is the fact that this large-section lumber is expensive to the extent that ordering more than the basic computed required quantity would be uneconomical.

Material Summary Sheet

For the actual procurement of materials, the material quantities shown on the material estimate recap sheets are transferred to a MATERIAL SUMMARY sheet. Besides quantities, the summary sheet shows the date material is required, description of material, use, and purchase specifications. Material control numbers and requisition numbers should be shown as soon as they are assigned, also whether material is to be purchased by CBCEN or locally, or drawn from local stock. When information becomes available, the unit price and total cost should also be shown. A material summary work sheet, used for preparation of the material summary sheet, is shown in figure 11-8. The peculiar arrangement of the sheet shown is due to the fact that it is a data card, from which all the material data shown thereon will be entered in the storage bank of an electric accounting machine. For procurement specifications the estimator should confer with the Supply Department personnel for correct procedures.

EQUIPMENT ESTIMATES

Equipment estimates are used together with work schedules as a basis for determining the construction equipment requirements of a project and the total construction equipment requirements of a SEABEE deployment. They may also be used as a basis for estimating the amount of spare parts, the number of mechanics, the size of shop, and the tools and shop equipment needed to maintain construction equipment in operating condition during a SEABEE deployment.

Suggested Procedure

The work element estimate should be examined and all work elements requiring equipment for their performance should be listed—those which don't require equipment should, of course, be omitted. Each work element listed should be treated in the following manner:

1. The type of equipment required, and the method of using it, are determined.
2. The production rate per day is estimated for each piece of equipment, taking into account the factors discussed later in this section.
3. The work element quantity is divided by the production rate per day, to compute how many days of equipment operation will be required to perform the work. In a case where several items of equipment will be used as a group rather than individually, the days of group operation are shown. For example: if one endloader and five trucks are to be used for 10 days loading and hauling earth fill, this is shown as 10 days for 1 endloader and 5 trucks, not as 10 days of endloader time and 5 X 10 days of truck time.

After determination of the number of days of equipment operation required, the work schedule is consulted to find the time allotted for completion of the work element. It may be necessary to work several pieces or groups of equipment at the same time in order to complete the work within the scheduled time. Also, it may be advantageous to use several pieces or groups of equipment at the same time to attain more efficient operation.

SHEET 1 OF 5

ESTIMATED BY Smith DATE 8-16-7-

CHECKED BY Jones DATE 8-24-7-

MATERIAL ESTIMATE
RECAP SHEET

NMCB 21 LOCATION Bermuda YEAR 197-

PROJECT 01 DESCRIPTION Naval Stores Warehouse

DESCRIPTION	QUANTITY	WASTE & LOSS FACTOR	WASTE & LOSS	QUANTITY TO PROCURE	REMARKS
Form lumber					
1"x 4" S4S #2 YP or equal-					
Slabs on grade	200 LF	5%	10	210 LF	70 BF
1"x6" S4S YP or equal					
Roof slab	1000 LF	5%	50	1050 LF	525 BF
2"x4" S4S #2YP or equal					
Slabs on grade	400 LF				
Walls	6250LF				
Roof slab	2000LF				
	8650LF	20%	1730	10,380 LF	6920 BF
2"x6"S4S #2YP or equal					
Slab on grade	440LF	20%	88	528 LF	528 BF
2"x10"S4S #2 YP or equal					
Roof slab	500LF	10%	50	550 LF	917 BF
4"x 4"S4S #2 YP or equal					
Roof slab	1500 LF			1500 LF	2000 BF
4"x6"S4S #2 YP or equal					
Roof slab	500LF			500 LF	1000 BF

87.3(82A)

Figure 11-7.—Material estimate recap sheet.

MATERIAL SUMMARY WORK SHEET

MAT'L CONT. NO.	EAM SER. NO.	DESCRIPTION	UNIT	QTY.	UNIT COST	TOTAL COST
000-0000	1	LUMBER 1X4 IN	BF	70	0.10	7.00
	2	YELLOW PINE S4S STANDARD				
	3	GRADING AND DRESSING GRADE #2				
	4	FEDERAL SPECIFICATION MM-L-000				
	5	INCLUDING AMENDMENTS 1 AND 2				
	6	ASTM DESIGNATION O-00				
	7	REF NAVFAC INSTRUCTION 0000.0				
	8	SLABS ON GRADE-FORMS				
	9					
	0					
	1	LUMBER 1X6 IN	BF	525	0.12	6300
	2	YELLOW PINE S4S STANDARD				
	3	GRADING AND DRESSING GRADE #2				
	4	FEDERAL SPECIFICATION MM-L-000				
	5	INCLUDING AMENDMENTS 1 AND 2				
	6	ASTM DESIGNATION O-00				
	7	REF DIRLANTDOCKS INSTR 0000.0				
	8	ROOF SLABS-FORMS				
	9					
	0					

EAM SEQUENCE CODES
1. TITLE LINE
2. FIRST DETAIL DESCRIP. LINE
3. TRAILER DETAIL LINES
4. STANDARD SPECIFICATIONS
5. INCLUSIVE SPECIFICATIONS
6. ATTACHED SPECIFICATIONS
7. NOTES TO PROCUREMENT
8. REMARKS – LOCATION, USE, Y & D DRAWING

PREPARED BY Smith | CHECKED BY Jones | DATE PREPARED 8-16-7–

82.83

Figure 11-8.—Material summary work sheet.

An equipment schedule should be prepared for the total deployment, using the work schedule to determine when the work will be performed. The number of pieces of each equipment type required at any one time can be determined from this schedule. The schedule will indicate the peak work loads for each equipment type. A study of the peak loads may show that it is desirable to revise the work schedule to more evenly distribute the equipment work load and thereby reduce the amount of equipment required for a deployment.

For example, suppose an equipment schedule shows 80 dump trucks required during May and 20 dump trucks required during June and July. It may be possible to revise the work schedule to distribute the work load for these dump trucks evenly over the 3 months so that 40 dump trucks are required during May, June and July. This would reduce the number of dump trucks needed for the total deployment by 40 trucks.

Following a review of the equipment and work schedules, and making all possible adjustments to them, a list of the equipment requirements for the deployment can be prepared. In preparing this list, downtime should be anticipated, and sufficient equipment added so that when equipment is out of service for repairs or maintenance, reserve pieces will be available. The number of pieces of equipment required for a deployment is obtained by adding the required reserve equipment of each type of the peak figure indicated on the equipment schedule.

Equipment Estimate Computations

It is not practical to use a columned form for equipment estimate computations. Figures 11-9 and 11-10 show equipment estimate sheets. Note that these are sheets 4 and 6 of 6, the

SHEET 4 OF 6

ESTIMATED BY Brown DATE 5-10-7-

CHECKED BY Jones DATE 5-16-7-

EQUIPMENT ESTIMATE

NMCB 14 LOCATION Bermuda YEAR 197-

PROJECT 02 DESCRIPTION Mountain Road

Equipment Production Rate

Rate using 12 cu yd scraper with pusher dozer for loading assistance

Loading time

$1.5\ \text{min}/60\ \frac{\text{min}}{\text{hr}} = 0.025\ \text{hr}$

Loaded haul

$3000\ \text{lf}/5\ \frac{\text{miles}}{\text{hr}} \times 5280\ \frac{\text{lf}}{\text{mile}} = 0.114\ \text{hr}$

Unloading time

$0.5\ \text{min}/60\ \frac{\text{min}}{\text{hr}} = 0.008\ \text{hr}$

Turning time

$0.5\ \text{min}/60\ \frac{\text{min}}{\text{hr}} = 0.008\ \text{hr}$

Return haul

$3000\ \text{lf}/20\ \frac{\text{miles}}{\text{hr}} \times 5280\ \frac{\text{lf}}{\text{mile}} = 0.028\ \text{hr}$

Total round trip 0.183 hr

Total @ 80% efficiency $0.183/0.80 = 0.229$ hr

$12\ \text{CY}/0.229\ \text{hr} = 52\ \text{CY per hr}$

145.5(82A)4

Figure 11-9.—Equipment estimate, sheet 4 of 6.

SHEET 6 OF 6

ESTIMATED BY Brown DATE 5-10-7-

CHECKED BY Jones DATE 5-16-7-

EQUIPMENT ESTIMATE

NMCB 14 LOCATION Bermuda YEAR 197-

PROJECT 02 DESCRIPTION Mountain Road

Equipment Required for Job

Number of 12 cu yd scrapers with wheel tractor and pusher dozer for loading assistance

Assume operation must be completed in 30-12 hr days (360 hrs)

One scraper would require 95370 CY/52 $\frac{CY}{hr}$ = 1834 hrs

Therefore, required no. scrapers is 1834 $\frac{hrs}{scraper}$/360 hrs = 5 scrapers

One pusher dozer can handle 0.229 $\frac{hr}{rd\ trip}$/0.025 $\frac{hr}{load\ time}$ = 9 scrapers

Therefore, one pusher dozer enough, but include another in case of breakdown

Summary

5 scrapers with wheel tractor

2 pusher dozers for loading assistance

145.5(82A)6

Figure 11-10.—Equipment estimate, sheet 6 of 6.

other 4 sheets contain cut and fill volume computations for the project, a mountain road. These computations reveal that 95,370 cubic yard must be hauled from cut to fill, a mean or average distance of 3000 linear feet. It has been decided that the earthmoving equipment shall consist of 12-yard scrapers, with pusher dozers for loading assistance.

From equipment manuals and a study of site conditions, the estimator has determined the following with regard to the capacity of a 12-yard scraper:

Loading time (with pusher dozer). 1.5 min.
Loaded haul: 5.0 mph
Unloading time: 0.5 min.
Turning time: 0.5 min.
Return haul: 20.0 mph
Operation efficiency: 80%

In figure 11-9, the time quantities, converted into hours and applied to the mean haul distance of 3000 linear feet, are totalled to determine the total time required for a round trip (0.183 hr) by one scraper The scraper has an operating efficiency of 80%, which is applied to convert the estimated round trip time to 0.229 hour by dividing 0.183 hour by .80. The scraper carries 12 cubic yard; therefore, the number of cubic yard carried per hour by one scraper will be 12/0.229, or 52 cubic yard per hour.

In figure 11-10 the time it would take a single scraper, carrying 52 cubic yard per hour, to do the whole job is computed. This is applied, as shown, to the assumed time allowed, to determine how many scrapers are required to do the job in the actual time allowed. Similar computations indicate the number of pusher dozers required for loading assistance.

Factors Affecting Production

PERMISSIBLE SPEEDS are established either by a governing authority, such as a highway or street speed limit, or by a command limitation, such as maximum operating speed prescribed for the equipment. In either case the speed limit must be considered when estimating the average hauling speed which, in turn, controls the maximum amount of material the equipment can move in a given time. However, the estimator must not make the mistake of using the maximum speed limit as the average speed at which the equipment will be operated. Operating average speed is usually between 40 and 60 percent of set maximum speed, depending upon condition of the road, number of intersections to be crossed, traffic conditions, and length of haul. Everything else being equal, long hauls usually attain higher average speed than short hauls.

The TYPE OF MATERIAL to be handled has a definite effect on the amount of time required. For example: wet, sticky clay is slow to dig, load, and dump, because it sticks to the bucket, pan, or truck bed, and requires jarring and shaking to loosen and dump the load. On the other hand, damp, sandy loam does not stick to buckets, beds or pans, and requires little or no jarring or shaking; therefore, the time required for these extra maneuvers is saved. Sand handles easier and quicker with a clamshell bucket than does gravel or crushed rock. When lifting with a crane, bulky, hard-to-rig material and equipment require more time to load and unload. For example. a large timber or steel beam is easy to handle by simply putting a choker sling around the midpoint and lifting, while a large bulky piece of equipment requires bridle slings placed so as to balance the equipment as it is lifted. Several trial lifts usually are required, moving the slings after each lift, before the equipment is balanced for safe lifting.

Safety factors sometimes limit the amount of work which can be produced with a machine, and therefore they must be considered as a production factor. For example, although the manufacturers's crane rating may show it to be capable of lifting 40 tons with a 70-foot boom at a 45° angle, for reasons of safety the maximum lifting capacity of that particular crane may have been limited to 85 percent of the manufacturer's rating. The crane can then only be used to lift 34 tons with a 70-foot boom at a 45° angle. Certain pieces of equipment may have their speed limited because of safety reasons, which would reduce the rate of production (as discussed earlier).

The EXPERIENCE OF THE OPERATOR must be considered when estimating production of equipment. An experienced man operating equipment knows the short cuts and performs work with minimum effort and movement, thus getting maximum production from a machine. For example: an experienced operator will spread a load of dirt with fewer passes than an inexperienced man, and do a better job of uniform spreading. Also, inexperienced operators are likely to forget some of the required maintenance operations, and as a result tend to have more downtime with their equipment.

The CONDITION AND THE AGE OF THE EQUIPMENT must be considered in estimating the number of days required to perform work. Old equipment and poorly maintained equipment is more likely to require downtime than new equipment or equipment in good operating condition. Also, old and worn equipment responds more slowly to control, has less power, and is generally less efficient. Furthermore, downtime for one piece of equipment may affect the production of several pieces of dependent equipment. For example, if the equipment used to load five trucks breaks down, those five trucks are put out of action.

TIME ALLOTTED FOR COMPLETION affects production if crews must work extra-long hours daily, or if work must be done under crowed conditions to meet the allotted deadline. Men working long hours daily without sufficient rest and relaxation tend to slow down, and production per machine and per man is then reduced. Also, when work is performed under crowded conditions, efficiency drops and unit production is lowered. More efficient operation and better production are usually obtained by working two or more shifts per day.

Weather conditions, of course, have a considerable effect on the production of outside equipment. Rain always slows down the work, and may even bring it to a halt. In climates with considerable rainfall, the average hourly production rate of equipment is less than it is in dry climates. Extremely cold weather, too, slows down the operator and lowers the efficiency of equipment. Climate also has an effect on spare parts requirements. Very dry climates with considerable dust cause more rapid wear on friction parts, while wet climates with mud cause more rapid wear on parts such as track assemblies.

Estimating Equipment Production

There are various sources of information concerning average equipment production rates available in most SEABEE headquarters. As it is seldom practical to draw up a production table which is adjusted to all possible local circumstances, production rates found in tables must be adjusted to fit the circumstances to be expected on the project. In order to make this adjustment intelligently, the estimator should know the circumstantial basis on which the table rates were established. This information is usually given in a foreword, in notes, and/or in instructions for using the tables.

An equipment manufacturer usually provides TABLES and DIAGRAMS showing production rates and operating speeds of his equipment. Since these tables are usually part of the sales literature, they usually give an optimistic picture of the equipment's capacity, in any event representing production rates under highly favorable conditions and with experienced operators.

Several GOVERNMENT MANUALS are available which give information about production to be expected from equipment of various types and sizes. Similar manuals have been prepared by many NAVFAC field engineering offices.

MANPOWER ESTIMATES

Construction manpower estimates are concerned with what is called DIRECT labor—that is, the manpower used in constructing the project. The labor cost of a project is not, however, confined exclusively to the cost of the direct labor, because there is other labor (the labor of, for example, cooks, hospitalmen, personnelmen, yeomen, and others) required to maintain a battalion in the field. In cost accounting, labor of this latter type is called INDIRECT labor.

PRELIMINARY manpower estimates are estimates prepared from limited information, such as general descriptions of projects, or preliminary plans and specifications with little or no detailed information. They are usually prepared on the basis of area, length, or other suitable general dimensions, the purpose being to establish rough cost estimates for budget purposes, and/or to program manpower broadly for succeeding years.

DETAILED manpower estimates are, on the other hand, more accurate estimates used to determine manpower requirements for specific projects.

Manpower Estimating Tables

For both preliminary and detailed manpower estimates, estimators use manpower production rates obtained from tables.

Table 11-1 shows a preliminary estimating table.

In preparing preliminary estimates on the basis of area or linear measurement, it is first necessary to compute the area or other measurement of the project for information at hand. Next the conditions under which it will be constructed must be considered, and a suitable man-day per unit figure selected. The quantity of measurement is then multiplied by the man-day figure to obtain the estimated man-days required for the project.

Table 11-1.—Page from manpower production table for preliminary estimating

ROAD, WALK, PARKING AREA AND FENCE INSTALLATION

WORK ELEMENT DESCRIPTION	UNIT	MAN-DAYS PER UNIT		
		ADVERSE CONDITION	AVERAGE CONDITION	FAVORABLE CONDITION
For preliminary estimates only:				
Roads (including grading and base)				
Asphalt	1000 SY	130	65	27
Concrete	1000 SY	240	140	67
Gravel	1000 SY	75	45	20
Concrete curbs	1000 LF	260	160	75
Parking areas (includes grading, base, and curbs)				
Asphalt	1000 SY	140	70	30
Concrete	1000 SY	240	150	72
Gravel	1000 SY	85	50	22
Walks				
Asphalt	1000 SF	34	23	12
Concrete	1000 SF	44	30	15
Pipe culverts (includes concrete headwalls) (No excavation or backfill)				
24" and smaller	LF	0.56	0.34	0.18
26" to 45"	LF	0.95	0.58	0.30
48" to 72"	LF	1.50	0.93	0.48
Chain link fence				
5' high	1000 LF	111	74	37
8' high	1000 LF	153	102	51

82.86

Suppose, for example, that the project is the construction of 5,000 linear feet of concrete highway 30 feet wide. The area here is 5000 X 30, or 150,000 square feet, which is 150,000/9, or 16,700 square yards. Suppose it is assumed that construction will proceed under average conditions. Under such conditions, the table shown in table 11-1 indicates that 140 man-days are required for every 1000 square yards of concrete highway. Man-day requirements for 16,700 square yard, then, amount to the value of 16,700/1000 X 140 = 2338 man-days.

Obviously, the overall work element "construct 16,700 square yard of concrete highway" contains a number of subelements, such as (for a new highway through rough country) clearing and grubbing, excavating and earthmoving, preparing base and subbase, setting forms, batching, mixing concrete, placing concrete, finishing concrete, curing concrete, stripping forms, and so on. A detailed manpower estimate determines the man-day requirements for each of these work elements.

Again the estimator refers to manpower production tables, a sample page from a table for detailed estimating is shown in table 11-2. The basis for computations is the work element summary sheet previously described. Figure 11-11 shows the work element summary sheet previously shown in figure 11-5 but with manpower requirements computed and inscribed thereon.

For the man-days per unit production factors the estimator referred to the data shown in tables 11-3 and 11-4. For machine excavation, footings and foundations, table 11-3 shows for 1000 cubic yards. under favorable conditions, 12 man-days, under average conditions, 25 man-days, and under adverse conditions, 50 man-days. In figure 11-11 the estimator selected 40, a figure only a little better than the adverse. He may have known that the ground was exceptionally hard, or that the available equipment was old and worn, or that some other adverse conditions existed with regard to the excavating.

For the machine backfill, table 11-3 shows 6 man-days per 1000 cubic yards under average conditions; you can see that the estimator selected this figure. For hand compaction he selected 0.30 man-days per cubic yards (see fig. 11-11), a figure just a little better than that given for average conditions in table 11-3. For machine spreading of excess earth he selected. 1.6 man-days per 1000 cubic yards, a figure not quite as good as that given for favorable conditions in table 11-3.

For forming and stripping he selected 44 man-days per 1000 SFCS, the figure given for average conditions in table 11-4. For placing reinforcing steel he again used the average-conditions figure. 10 man-days per ton. For placing, finishing, and curing the concrete he selected 0.75 man-days per cubic yard, approximately the figure shown for adverse conditions in table 11-4. He may have known that the mixing and finishing equipment was obsolete or in poor condition, or that the skill of the masons was below average.

Factors Affecting Manpower Production

The principal factors affecting manpower production are weather conditions during the construction period, the skill and experience of the men who will perform the work, the time allotted for completion of the job, the size of the crew to be used, the accessibility of the jobsite, the availability of materials, and the types of material and equipment to be used.

WEATHER can have an important effect on the number of man-days required to do a job. Cold, damp climates, as well as hot, humid climates, reduce a man's daily production and similarly affect the output of construction equipment. Although time lost due to rain is not normally charged against a project, rain in the midst of a construction operation slows production and sometimes causes additional work which will increase the number of man-days required. Continuous rain will hamper the compaction of roadways, airfields and construction sites, if not stop the work altogether, because the soil will be too wet. Extra man-days may be required to repair damages caused by rain and to remove water from flooded areas before work may be resumed. In very cold climates it is usually necessary to provide heat and protection for some parts of a project. Allowances must be made in the estimate for weather conditions, either by selecting a man-days per unit range which will provide some extra labor for these

Table 11-2.—Page from manpower production table for detailed estimating

SITE PREPARATION – CLEARING AND GRUBBING

WORK ELEMENT DESCRIPTION	UNIT	MAN-DAYS PER UNIT		
		ADVERSE CONDITION	AVERAGE CONDITION	FAVORABLE CONDITION
Clearing and grubbing by hand:				
Cutting trees and brush	1000 SY	7.0	4.8	2.0
Piling and burning	1000 SY	1.7	1.2	0.5
Digging and blasting stumps	each	0.3	0.2	0.1
Cutting large trees	each	0.6	0.4	0.2
Clearing and grubbing with equipment:				
Clearing trees and brush	1000 SY	0.7	0.4	0.2
Rooting out stumps	each	0.2	0.1	0.05
Loading and hauling	1000 SY	2.8	1.6	0.8
Burning trees and brush	1000 SY	0.7	0.4	0.2
For quick estimates; [1]				
Clearing and grubbing:				
By hand	1000 SY	9.6	6.6	2.8
With equipment	1000 SY	2.2	1.3	0.65

Typical crew: Hand work – 1 crew leader, 4 to 8 men with brushhooks and axes, 1 to 2 men with portable chain saws.

Typical crew: With equipment – 1 crew leader, 1 bulldozer operator, 2 to 5 men with chain saw and axes cutting and trimming large trees.

Typical crew: Burning – 2 to 5 men.

Note: Most stumps can be rooted out with a bulldozer unless the ground is very hard. Brush should not be burned until it has dried for several weeks. Old tires burned with the brush pile help to keep the fire going.

[1] Based on burning brush and trees at site, and 1 large tree per 1000 SY.

82.87

possibilities, or by directly adding man-days to provide for them.

The SKILL AND EXPERIENCE of the men who will be assigned to the work must be considered when selecting a man-day range. The production rate of experienced men is, of course, better than that of inexperienced men. If a crew consists of a few experienced men and many inexperienced men, some of the time of the experienced men must be spent in instructing and training the inexperienced. If a deployment consists of essentially the same type of construction on all its projects, inexperienced men will increase their skill before the deployment is completed. Jobs performed towards the end of the deployment may therefore be estimated at a higher production rate.

The TIME ALLOTTED FOR COMPLETION of the project will have a definite bearing on the number of man-days required to do the work.

SHEET 1 OF 6

ESTIMATED BY Cato DATE 9-6-7-

CHECKED BY Stiles DATE 9-11-7-

WORK ELEMENT ESTIMATE
SUMMARY SHEET

NMCB 15 LOCATION Saipan YEAR 197-

PROJECT 08 DESCRIPTION Staging - Out Warehouse

WORK ELEMENT	QUANTITY	MAN-DAYS PER UNIT	MAN-DAYS REQUIRED
Footings and foundations			
Machine excavation	1860 cy	40/1000 cy	74.4
Machine backfill	1277 cy	6/1000 cy	7.7
Hand compaction	1277 cy	.30/cy	383.1
Spread excess earth-machine	583 cy	16/1000 cy	0.9
Form and strip	11,083 SFCS	44/1000 SFCS	487.7
Place reinf. steel	34.6 Ton	10/Ton	346.0
Place finish + cure concrete	582.8 cy	.75/cy	437.1
	Total man-days		1,736.9

82.88

Figure 11-11.—Detailed manpower estimate on work element summary sheet.

Table 11-3.—Detailed manpower estimate on excavation for footings and foundations

WORK ELEMENT DESCRIPTION	UNIT	MAN-DAYS PER UNIT		
		ADVERSE CONDITION	AVERAGE CONDITION	FAVORABLE CONDITION
Machine evcavation for footings and foundations:				
Excavation [1]	1000 CY	50	25	12
Load excess earth	1000 CY	9.0	4.5	2.0
Haul excess earth	1000 yd miles	5.2	3.1	1.4
Spread spoil pile	1000 CY	2.1	1.4	0.7
Spread excess earth	1000 CY	4.5	3.0	1.5
Backfill	1000 CY	9	6	3
Compaction	1000 CY	12	8	4
Hand excavation for footings and foundations:				
Excavation	CY	1.2	0.7	0.3
Load excess earth	CY	0.8	0.4	0.2
Spread excess earth	CY	0.18	0.12	0.06
Backfill	CY	0.35	0.20	0.10
Compaction	CY	0.55	0.35	0.15
For quick estimates for excavating footings and foundations: [2]				
Machine excavation, complete	1000 CY	72	38	18
Hand excavation, complete	CY	2.1	1.0	0.5

Typical crew: Machine work – 1 crew leader, 2 men on excavating equipment, 2 to 6 trucks with operators, 1 man on equipment spreading and backfilling, 1 man on compacting equipment.

Typical crew: Hand work – 1 crew leader, 2 to 10 men excavating, loading and/or spreading excess dirt, backfilling and tamping.

[1] Includes trimming and fine grading.

[2] Includes removal and disposal of excess dirt, backfilling, and compaction.

82.89

Rush jobs may require a crew to work long hours and seven days per week. A man's production per hour decreases sharply under these conditions. Sometimes it is better to increase the number of men in a crew or to work several crafts at the same time in one location in order to complete a job quickly. When work areas are crowded, men are likely to get in each other's way, talk and visit instead of working, or slow production in other ways. This results is more man-days being used to accomplish the same amount of work.

The SIZE OF CREW used can affect production in another way. A crew is usually made up of men with the various skills required to do a certain job. When a crew has a job requiring less than a full day, there is a human tendency to slow down and make the job last the full day.

ACCESSIBILITY OF THE SITE can affect labor requirements. For a relatively inaccessible

Table 11-4.—Detailed manpower estimate for concrete footings and foundations

WORK ELEMENT DESCRIPTION	UNIT	MAN-DAYS PER UNIT		
		ADVERSE CONDITION	AVERAGE CONDITION	FAVORABLE CONDITION
Erect and strip forms	1000 SFCS*	70	44	22
Place reinforcing	Ton	16	10	5
Place, finish, and cure concrete	CY	0.7	0.4	0.2
For quick estimate: Concrete footing and foundation, complete	CY	3.4	2.0	0.8

Typical crew: 1 crew leader, 3 men erecting and stripping forms, 3 men placing reinforcing steel, and 4 men placing, spading, vibrating and finishing concrete.

* Square feet of contact surface.

82.90

site, irregular delivery of materials may cause time-consuming delays. Difficulty of personnel in getting to and back from the site, or meals which are delayed or served cold, tend to lower morale and reduce production.

Perhaps the AVAILABILITY OF CONSTRUCTION MATERIALS should not have been mentioned because, theoretically, once a project is started, the materials needed to build it with are on hand; however, that's not always the case. There might be some delays in procurement action or transportation; there might be some overlooked items in the estimates; or the materials might be available but of wrong sizes or types—if these predicaments occur, then production is greatly hindered.

The TYPE OF MATERIAL HANDLED may affect the number of man-days required for a project. For instance. some types of soil are easier to dig and spread than others, some types of rock are easier to quarry and crush than others; some form materials require less labor than others; and some types of sheet piling are easier to drive and pull than others. These factors must be considered when estimating manpower requirements for a project.

The TYPE OF EQUIPMENT AVAILABLE often has a considerable affect on the amount of labor required to perform a certain task. It is therefore necessary for the estimator to know what equipment will be used on a project before he can make an accurate estimate of manpower requirements. For instance: if earth is to be hauled in 5-yard trucks, a certain number of drivers will be required, if it is to be hauled in 10-yard trucks, half as many will be required. Similarly, more men will be required for concrete placement by wheelbarrow than will be required for placement by bucket-and-crane.

GENERAL CONSIDERATIONS AFFECTING MANPOWER ESTIMATE PHASES

In the following sections, general considerations affecting manpower estimates for the various common phases of construction of various types are given. For each phase there are production tables, which may be found in the *Seabee, Planner's and Estimator's Handbook*, NAVFAC P-405. Examples of the production tables are shown in tables 11-2, 11-3, and 11-4.

Earthmoving

Earthmoving is generally divided into the following: site preparation, excavation and backfill, dredging, preparing subbase, and erosion control.

The type of equipment has a considerable effect on earthmoving manpower production. For example: earth can be moved by rubber-tired tractor-scraper units with about 2/3 the manpower required for movement by trucks. Before manpower estimates can be prepared, a decision must be reached on the type of equipment and method of operation; here, of course, your choice is controlled by the availability of equipment. For example: if one project of a deployment is a paving job requiring a large number of dump trucks, and roadway fill must be placed before paving can begin, it might be better to haul the fill with the dump trucks (which might otherwise be idle) than to ship out scrapers, especially if the scrapers would be used only for this operation.

SITE PREPARATION includes the work of removing trees and brush by machine clearing or hand cutting, piling and burning removed trees and brush, removing stumps by digging and blasting and/or machine uprooting, and loading and hauling cut trees when necessary. It also includes, when necessary, the removal of existing structures, grading, disposal of excess earth, excavating and hauling fill, and spreading and compacting fill.

EXACAVATION AND BACKFILL includes the work of trenching and ditching by machine or hand, excavating for footings and foundations by machine or hand, general excavating by machine or hand, and disposing of excess earth. It involves trimming and grading trenches, ditches, and excavations for footings and foundations; removing water from trenches, ditches, and excavations; and shoring and bracing trenches, ditches, and excavations. It also includes backfilling and compacting trenches and ditches, backfilling and compacting around footings and foundations, excavating and hauling fill, spreading and compacting fill, and general grading.

DREDGING includes the work of preparing the spoil area for dredged material (including construction of dikes when required), setting and connecting discharge lines from dredge, operating dredge (including cutterheads and pumps), operating and unloading material barges when used, and disconnecting and removing discharge lines. Dredging also includes any underwater excavation with dragline or clam-shell from shore or barge, hauling of excavated material by truck or barge, and disposal.

PREPARING BASE AND/OR SUBBASE includes the work of grading and smoothing in preparation for placing selected material in base and/or subbase. It also includes excavating, loading, hauling, spreading, rolling, sprinkling, and fine-grading selected material to form the base and/or subbase. A factor for compaction should be added to the computed compacted quantity to obtain the quantity of loose material which must be handled. For example, most granular material will shrink 15 percent to 25 percent from a loose state to a compacted state. If the selected material shrinks 20 percent on compaction, it will be necessary to spread it loose at an average thickness of 7.5 in. to get a compacted thickness of 6.0 in. This means that for every 1000 cubic yards of compacted thickness, 1250 cubic yards of loose material must be loaded, hauled, and spread.

EROSION CONTROL includes the work of sloping and trimming shoulders, banks, and ditches to the ANGLE OF REPOSE—that is, to a slope less than any which allows gravitational downslope movement of material. It involves hauling, dumping, and placing riprap (rubble stone) on slopes and other areas for protection against erosion. In addition, it includes plowing, fertilizing, planting, seeding, disking, rolling, and watering to obtain a grass cover.

Plant Operation

Plant operation includes the operation of asphalt, concrete batching, concrete block, and rock crushing plants. It also includes the operation of quarries, precast concrete yards, and metal and wood fabrication shops.

Here, also, the type of equipment used in any plant will affect the manpower requirements, therefore, the equipment must be decided upon before a manpower estimate can be prepared. In general, large-capacity equipment requires less manpower per unit than small-capacity equipment.

The operation of a plant for MANUFACTURING ASPHALTIC CONCRETE involves setting up and dismantling of plant equipment, plus operation of the plant, including ingredient handling, dust removal, drying aggregate, gradation control, and hauling to jobsite.

The operation of a plant for BATCHING CONCRETE MATERIALS includes the setting up and dismantling of batching hoppers, scales, cement storage, materials handling and water supply facilities. It also includes operation of the plant and hauling to the jobsite. In addition, it includes the installation and operation of equipment for heating aggregate and water.

The operation of a CONCRETE BLOCK PLANT includes setting up and dismantling the plant, handling of ingredients, mixing ingredients, operating the block machine, curing blocks, loading, and hauling to jobsite.

The operation of a ROCK CRUSHING PLANT includes setting up and dismantling the crusher, material handling equipment, gradation control equipment, and washing and drying equipment. It also includes hauling from quarry to crusher, operation of the plant, stockpiling crushed material, loading, and hauling to jobsite.

QUARRY OPERATION includes removal and disposal of OVERBURDEN (surface soil strata above the rock), drilling, blasting, handling and loading of quarried material, stockpiling rubble, loading, and hauling to a rock crushing plant or jobsite.

Operation of a PRECAST CONCRETE YARD includes constructing of casting beds; fabricating of forms; erecting forms; stripping forms, cutting, bending, and placing reinforcing, placing, finishing and curing concrete, storing, loading, and hauling to jobsite.

The operation of a METAL FABRICATION SHOP includes cutting, burning, drilling, reaming, milling, fitting, assembling, welding, riveting, bolting, storing, loading, and hauling to jobsite.

The operation of a WOOD FABRICATION SHOP (commonly called a carpentry shop or woodworking shop) includes handling and storing materials, cutting, planing, jointing, shaping, mortising, joining, priming for protection, loading, and hauling to jobsite.

Paving

Paving involves the construction of asphalt and concrete pavements, curbs and sidewalks. In paving operations the selection of equipment to be used will affect the manpower required to perform the work. The use of transit-mix trucks rather than paving mixers will usually increase the manpower required. Placing, spreading, and finishing equipment should be sized, whenever possible, to the plant equipment. If the paving equipment cannot handle the plant output, the plant will be idle a portion of the time waiting for the paving crew to catch up. If the plant output, on the other hand, is less than the paving equipment can handle, the paving crew will be idle part of the time, waiting for the plant to catch up. With some equipment spreads it is possible to cut the crew size and thereby slow the paving operation to plant capacity. However, this is not always possible, and, since it works equipment at less than capacity, is not efficient. In any case, the estimator must know what equipment will be used, so that he may take all factors into consideration.

ASPHALT PAVING CONSTRUCTION requires manpower for heating asphalt, marking pavement edges, brooming, priming, spreading and finishing asphaltic concrete, rolling asphaltic concrete, applying tack coat, applying seal coat, loading and hauling chips or gravel, spreading and rolling chips or gravel, and brooming chips or gravel.

CONCRETE PAVING CONSTRUCTION includes placing forms, placing reinforcement, placing dowels, mixing concrete, placing concrete, curing concrete, removing and cleaning forms, cutting or forming joints, pouring joint sealer, and installing expansion joints.

CURBS AND SIDEWALKS may be constructed of either concrete or asphaltic concrete material. Construction includes placing forms, installing expansion joints, and installing reinforcement. It also includes placing, finishing, and curing concrete, and placing, finishing, priming for, and rolling asphaltic concrete.

Waterfront Construction

Waterfront construction includes pile driving, pile bracing, pile capping, bridge and pier framing, installation of deck and deck hardware, pile extraction, and driving sheet piles. For waterfront construction, the selection of driving and extracting equipment does not much affect the number of men required, but has a considerable effect on the time the job will take. For example: a drop hammer works much more slowly than a steam or diesel hammer.

PILE DRIVING includes the work of assembling leads and hammer, preparing equipment for driving, sharpening pile tips, installing steel tips on wood piles, squaring and trimming pile butts, cutting holes in steel piles to facilitate handling, moving and placing the driver, placing piles in leads, driving piles, splicing, and cutting piles to grade.

PILE BRACING includes cutting, drilling, handling into place, and fastening braces.

PILE CAPPING (wood or steel) includes cutting, drilling, handling into place, and fastening caps. Concrete pile capping includes forming for caps, placing of reinforcement, placing cap concrete, curing concrete, and stripping cap forms.

BRIDGE AND PIER FRAMING includes the cutting, drilling, handling into place, and fastening of stringers, decking, wearing surface, bull rails, and bumpers.

Installation of DECK HARDWARE includes drilling for, handling into place, and fastening of bollards, chocks, cleats, and pad eyes.

PILE EXTRACTION includes the work of rigging equipment for extraction, extracting piles, and handling to stock pile. It also includes cutting off piles below water surface level and the handling of cut-off segments to stock pile.

DRIVING SHEET PILES includes preparation of leads and equipment for driving, preparation of piles for driving, placing piles in leads, driving piles, cutting off permanent piles to grade, bracing, and installing deadmen and tiebacks.

Carpentry

Carpentry includes rough carpentry, flooring, and finish carpentry.

ROUGH CARPENTRY includes the work of measuring, cutting, and installing wood framing, including joists and sills, bridging, studs and plates, roof rafters, rough door and window frames or BUCKS, and wall and roof sheathing and siding. Bucks are wood or metal member which are set in concrete or masonry walls, so that door or window frames may be attached.

FLOORING includes the work of measuring cutting, and installing subflooring, finish flooring and resilient tile (asphalt, cork, rubber, and vinyl). It also includes the installation of building paper under finish floors and of adhesive under plywood or tempered hardboard under resilient tile laid over single subfloors.

FINISH CARPENTRY includes the work of installing baseboard, molding, door and window smooth frames and trim, kitchen cabinets, wooden stairs, closets, and finish walls. This work also includes the installation of fastening devices such as plugs, expansion shields, and toggle bolts; also blocking for leveling and plumbing, as well as scribing fillers and trim to walls and adjacent pieces.

Concrete Construction

All concrete construction usually requires forming, reinforcing, mixing concrete, placing concrete, finishing concrete, and curing concrete. In addition some concrete construction requires fine grading, vapor barriers, expansion joints, and cold weather protection.

FORMING is usually computed in SQUARE FEET OF CONTACT SURFACE (SFCS), which means the area of concrete surface is direct contact with form sheathing. An exception to this is when form construction for concrete slabs on grade is computed in square feet of slab area. This method is sufficiently accurate for most ordinary slab work. When slabs are odd shaped, thinner than usual, thicker than usual, or contain an abnormal number of screed guides, more satisfactory estimates are obtained by computing forms in SFCS. A screed guide is a board set on edge within the perimeter of the slab; it serves as one of the end supports of a finishing board called a SCREED, which is worked back and forth along the prescribed grade line to strike the poured concrete down to finished grade elevation. Sometimes screed guides are iron pipes embedded on small concrete mounds which were poured in place a day or so earlier, this does away with driving and pulling stakes and nailing. The top of the pipes are set to the desired finished grade elevation by simply pressing the pipe down on the soft concrete mounds until the desired grade rod reading is reached. The concrete mounds become part of the slab.

Labor required for forming includes. fabrication, installing in place, erection, and oiling, installing form ties, tie wires, struts, chamfer strips, screed guides, bracing, and shoring, erecting runways and scaffolds, checking forms to ensure against displacement before and during pouring, stripping, cleaning, and reconditioning forms, removing form ties, and patching holes or chipped places left after removal of forms and ties.

Concrete is usually REINFORCED with steel bars, but sometimes welded steel wire mesh is used for slabs. In some cases both mesh and bars are used. Reinforcing steel is computed in tons of bars, mesh in square feet of area. Labor for reinforcing steel includes handling into place, tying, supporting, and any cutting which becomes necessary at the site, such as cutting around embedded materials or cutting stock lengths to fit slab dimensions. Labor for wire mesh reinforcing includes handling into place, cutting to fit, tying at overlaps, and pulling up into position curing placement of concrete.

Sometimes concrete must be MIXED at the jobsite rather than be delivered in transit-mix trucks. Labor for mixing concrete at the jobsite includes loading, measuring, wheeling, and dumping aggregate and cement into mixer, bringing water to the mixer by truck, hose, pipe, or pump; and operating the mixer.

Labor for PLACING CONCRETE includes the handling of concrete from the mixer or transit-mix truck to final position, spreading, vibrating, and screeding to grade.

Labor for FINISHING includes floating (smoothing with a rectangular wooden smoother called a FLOAT), troweling, and tooling (scouring) slabs, filling any voids or honeycombs, and (when required) rubbing, scrubbing, and washing.

CURING includes covering surfaces with a curing compound, or covering with sand, paper, tarpaulin, burlap, or straw, and keeping wet as required.

FINE GRADING includes site clean up, removing excess earth, spreading, leveling, and (when necessary) sprinkling.

An EXPANSION JOINT is filled with a premolded elastic material, or with a melted compound which hardens to form an elastic material. Labor for a premolded joint includes handling into place, cutting to fit, placing in position, and fastening to hold in position until concrete is placed. Labor for a poured joint includes cleaning joint of foreign matter, handling material to melting pot, melting, handling to joint, pouring, and dusting.

Labor for COLD WEATHER PROTECTION includes covering with extra thickness of sand, straw, or paper; installation and operation of pipe and equipment for heating aggregates and water, building enclosures, installation and operation of equipment to heat enclosures, removal of cold weather protection, and cleanup.

Masonry

Masonry includes the installation of brick, concrete block, mortar-bound rubble, ceramic tile, quarry tile, structural tile, lathing, and plastering.

Labor required for the installation of BRICK and CONCRETE BLOCK includes mixing mortar, carrying materials to mason, laying brick and block, tooling joints, erecting and dismantling scaffold, sawing block, culling (cutting into partial sizes) brick and block, hoisting materials, and cleaning brick and block in place.

MORTAR-BOUND RUBBLE is stone of random sizes and irregular shape, set in mortar. Labor includes mixing mortar, rough-cutting stone, carrying mortar and rubble to mason, hoisting materials, laying rubble, tooling and pointing (filling surface gaps in joints), erecting and dismantling scaffold, and cleaning rubble in place.

Labor required for the installation of CERAMIC TILE (glazed tile, used mostly for interior finish) and QUARRY TILE (unglazed tile. used mostly externally for roofs, walls, heads, etc.) includes mixing mortar for bed coat and joints, carrying mortar and tile to tile setter, spreading bed coat, cutting tile, setting tile, slushing (filling to surface level) and finishing joints, cleaning tile in place, and erecting and dismantling scaffold.

Labor required for the installation of STRUCTURAL TILE includes mixing mortar, carrying mortar and tile to mason, laying tile, tooling joints, erecting and dismantling scaffold, cutting tile, hoisting materials, and cleaning tile in place.

Labor required for LATHING and PLASTERING includes handling material into place; cutting and installing hanging wires and straps; cutting and fastening lathing channels, angles, beads, and moldings, installing furring strips, metal lath, and gypsum lath, mixing plaster, installing and finishing plaster, erecting and dismantling scaffold, curing and drying plaster, and hoisting materials.

Painting

Painting includes the application of cementitious paint, enamel, lacquer, paint, and varnish to masonry, metal, and wood surfaces, exterior and interior. It also includes preparation of surfaces.

Selection of the METHOD OF APPLICATION must be made before the estimator can make a detailed estimate of the manpower required to do the painting. Brush application usually requires more manpower than spray or roller painting.

The labor required to paint EXTERIOR SURFACES includes surface preparation, mixing paint materials, and application of paint materials. SURFACE PREPARATION for exterior painting includes removing rust and mill scale from metal surfaces with wire brushes or by sandblasting, removing dust with brush or cloth, removing oil and grease, masking and taping adjacent surfaces which must be kept free of paint, and removing masking and taping. Sometimes it is necessary to lightly sand a first coat before putting on a second, sometimes SIZING (filling of surface pores) is required before painting.

Labor requirements for INTERIOR PAINTING are based on the same work elements mentioned for exterior painting. Interior painting will require more labor, because of many corners, partitions, trim and other obstacles.

Metal Work

Metal work includes erection of structural and miscellaneous steel; fabrication and erection of sheet metal; and installation of metal fencing, windows, doors, and miscellaneous items.

Erection of STRUCTURAL STEEL includes unloading, erecting, temporary bolting, plumbing, leveling, and high strength bolting and/or welding. Erection of MISCELLANEOUS STEEL includes unloading setting in place, plumbing, leveling, and fastening (usually by bolting or welding).

SHEET METAL WORK includes the fabrication and erection of gutters, downspouts, ridges, valleys, flashings, and ducts. Fabrication is usually performed in the sheet metal shop, and includes making patterns, cutting, forming, seaming, soldering, attaching stiffeners, and hauling to site. Erection includes unloading, storing on site, handling into place, hanging, fastening, and soldering.

INSTALLATION OF MISCELLANEOUS METAL PRODUCTS includes unloading, storing at site, handling into place, installing fastening devices including drilling, fastening metal products in place, and installing hardware and trim.

FENCE installation includes digging holes; unloading and distributing materials; setting, plumbing, aligning, and concreting posts; installing braces; setting, stretching, and fastening fence fabric; installing caps and/or brackets on posts; stringing barbed wire; and installing gates, including hardware.

Installation of METAL DOORS AND WINDOWS includes drilling for and installing fasteners: installing door frames, including blocking, plumbing, and fastening; installing windows; hanging doors; and installing hardware.

Roofing

Roofing includes the installation of built-up roofing, asphaltic roofing, shingle roofing, and corrugated roofing, together with insulation.

The installation of BUILT-UP ROOFING includes unloading and storing materials on the jobsite, hoisting to the roof, melting pitch or asphalt, laying dry sheet, mopping tar or asphalt, laying insulation sheets, laying felt sheets, installing flashings, and installing chip or gravel cover.

Installation of ASPHALTIC ROOFING includes unloading and storing materials, hoisting, cleaning and sweeping roof, applying asphaltic prime coat, and applying asphaltic aluminum finish coat.

Installation of SHINGLE ROOFING includes unloading and storing materials at the jobsite, hoisting, placing, and nailing.

Installation of CORRUGATED ROOFING includes unloading and storing at the site, hoisting, placing, applying caulking strip, drilling, and fastening.

Electrical Construction

Electrical construction includes the erection of electrical distribution, outdoor lighting, and underground powerlines, also of interior electrical services, transformers, and substation equipment.

ELECTRICAL LINE WORK includes the work of unloading materials, excavation, installing crossarms and insulators, setting poles, backfilling, and stringing and sagging wire. It also includes installing and connecting transformers, switches, breakers, capacitor, and regulators. A capacitor is a device which stores electricity for quick high-voltage release. A regulator controls voltage of amperage automatically.

OUTDOOR LIGHTING includes street and security lighting, airfield lighting, and athletic field lighting. The work of installation includes excavation, pouring foundations, setting poles, backfilling, installing standards, installing light fixtures, stringing wire, laying cable, installing duct, encasing duct in concrete, pulling cable, installing control devices, installing lamps, installing control vaults, and installing transformers.

The construction of an UNDERGROUND POWER SYSTEM includes excavating, installing ducts, encasing ducts with concrete, backfilling, compacting, pulling cable, constructing transformer vaults, installing transformers, constructing manholes and handholes.

Electrical ROUGH-IN includes installing service mains, switches, panels, conduits, fittings, outlet boxes, cable, transformers, and motor control centers. It also includes the pulling and splicing of cable in conduit.

Electrical FINISH AND TRIM includes installing and connecting receptacles, switches, light fixtures, light duty devices, heavy duty utility devices, controls, and appliances. It also includes circuit testing.

Installation of TRANSFORMERS and SUBSTATION EQUIPMENT includes unloading, moving into position, leveling, plumbing, fastening, trimming, and connecting.

Plumbing

Plumbing includes the work of installing cast iron and steel pipe, valves and fittings, fire hydrants, thrust blocks, concrete pipe, vitrified clay pipe, asbestos-cement pipe, galvanized pipe culverts, fire protection systems, and compressed air systems, in addition to roughing-in plumbing and installing fixtures. It also involves the work of installing pipe insulation and lagging.

The installation of CAST-IRON and STEEL PIPE includes unloading, placing, caulking and leading joints, welding joints, bolting flanged joints, cutting, threading, joining threaded joints, and testing.

The installation of VALVES and FITTINGS includes unloading, placing, caulking and leading, welding, and bolting flanges. It also includes installing gaskets, packing, handwheels, and trim.

The installation of FIRE HYDRANTS and POST INDICATOR VALVES includes unloading, placing, caulking, bolting, clamping, adjusting to grade, and plumbing stems.

The installation of THRUST BLOCKS includes bracing, forming, reinforcing, placing concrete, and stripping forms. A thrust block is a concrete block, cast around a bend-point, to prevent displacement of the pipe under water pressure.

The installation of CONCRETE and VITRIFIED CLAY PIPE includes unloading, placing, caulking, grouting, installing gaskets, and testing.

The installation of ASBESTOS-CEMENT PIPE includes unloading, placing, installing gaskets, soaping, pulling sleeve over joint, and testing. Soaping means the lubrication of joint members to make joining easier.

The installation of PIPE INSULATION and LAGGING includes unloading, storing at the jobsite, placing on pipe, fastening, mudding (covering with insulating material in plaster form) fittings and valves, installing metal lagging, and waterproofing fittings and valves. Lagging is a protective and confining covering or jacket, placed over the actual insulating material.

The installation of GALVANIZED PIPE CULVERTS includes unloading, fine grading, placing, caulking, installing joint clamps, and installing head and wing walls.

The ROUGHING-IN of plumbing includes unloading and placing cast-iron drain lines, wrought-iron vents and drains, roof flashing at vents, copper and iron water pipe, and testing. The installation of cast-iron drains includes caulking and leading joints, plumbing and grading pipe, installing pipe hangers and straps, cutting pipe, and installing fittings. The installation of wrought-iron vents and drains includes cutting and threading pipe, making joints including applying joint compound, plumbing and grading pipe, installing pipe hangers and straps, and installing fittings. The installation of copper and iron water pipe includes cutting, threading, and joining pipe, cleaning and soldering copper pipe joints, plumbing and grading pipe, and installing pipe hangers and straps.

The installation of FINISH PLUMBING includes setting and connecting all plumbing FIXTURES, such as bathtubs, lavatories, water closets, urinals, showers, and sinks.

The installation of FIRE PROTECTION SYSTEMS includes construction of piping systems, installing sprinkler heads, grading laterals and supply lines, installing hose cabinets and hose, installing hose racks and hose, and insulation when required.

The installation of COMPRESSED AIR SYSTEMS includes cutting, threading, making joints, welding joints, pickling pipe, installing valves and quick connectors, and installing hose reels. Pickling means the removal of scale or impurities by means of an acid bath.

Equipment Installation

The installation of equipment includes the unloading, moving into location, uncrating, cleaning, assembling, positioning, aligning, supporting, and anchoring the various kinds of equipment installed by SEABEES.

The work of UNLOADING and MOVING IN includes lifting or skidding from truck and transporting with equipment or by rolling or skidding into approximate position.

The work of CLEANING and ASSEMBLING includes uncrating, removing protective paper and coating, removing grease and oil, removing rust, assembling and attaching any parts shipped loose, removing shipping oils, flushing oil reservoirs, and filling with proper operating lubricant.

The work of POSITIONING and ALIGNING includes moving into position, bringing to grade, leveling, aligning, and connecting drives.

The work of SUPPORTING and ANCHORING includes installing shims and plates, grouting, drilling for expansion shields, installing expansion shields, drilling and tapping base plates, and installing bolts, washers, and nuts.

The work of CONNECTING includes making the initial wiring, piping, or duct connections.

Communications

Communications include the installation of overhead telephone lines, telephone exchanges, interior telephone services, underground telephone lines, and intercom systems.

The installation of OVERHEAD TELEPHONE LINES includes excavating, setting poles, installing crossarms and insulators, installing grounding, backfilling, stringing and sagging wire, splicing, and making terminal connections.

The installation of TELEPHONE EXCHANGES includes unloading, moving in, setting, fastening switchboard and power pack, and making connections to switchboard and power pack. The power pack means the source of power for the system, such as a generator or a battery.

The installation of INTERIOR TELEPHONE SERVICES includes installing conduit, pulling cable, installing exposed cable, splicing, connecting, and installing telephone sets.

The installation of UNDERGROUND TELEPHONE LINES includes installing duct and fittings, installing risers, encasing duct and risers in concrete, installing terminal boxes, installing handholes and manholes, pulling cable, splicing, and making connections.

The installation of INTERCOM SYSTEMS includes installing master stations, substations, amplifiers, microphones, speakers, and conduit. It also includes pulling wire, running exposed cable, splicing, and connecting.

CHAPTER 12

ESTIMATOR'S CATALOGS AND SPECIFICATIONS

In the previous chapter, estimating of material quantities was described. This chapter deals with the various supply catalogs which the estimator will use in identifying and procuring the materials which he has estimated. In addition, you will be introduced to the use and application of the *ABFC Facilities Planning Guide,* NAVFAC P-437. This reference catalog has a wide variety of uses, from procurement of complete advanced base components to merely using the catalog as a material checklist.

The last section of this chapter explains various types of reference specifications which the estimator uses in preparing material estimates. Also explained are the techniques involved in preparing construction PROJECT SPECIFICATIONS. The EA will learn the general format and phraseology used by the specification writer.

MATERIAL IDENTIFICATION

The estimator's task is not completed with the estimating of material quantities. These materials must be procured through the Navy supply system. Procedures for submitting material requests may vary with each NMCB or activity. The estimator must adhere to the guidelines set forth by the Supply Department which receives the requests.

Storekeepers are not normally familiar with construction materials, therefore, you must be able to identify these materials for procurement. In order to correctly identify the requested materials, you need a knowledge of the Federal Supply Catalog System.

The Federal Supply Catalog System requires that only one identification number be assigned for each item of material used by the Department of Defense and civil agencies of the Federal Government. The Federal Catalog System includes naming, describing, classifying, and numbering all items carried under centralized inventory control by the Department of Defense and the civil agencies as well as the publication of catalogs and stock and identification lists. The system is managed by the Defense Supply Agency (DSA) under the authority of the Secretary of Defense.

MATERIAL CLASSIFICATION

The Defense Supply System contains over 4 million different items, and the Navy stocks and uses over 1.3 million items. All of these items must be cataloged, procured, and accounted for. To do this job by relying only on names and descriptions would be impossible.

The Federal Supply Classification (FSC) System is a tool which has been designed to permit the classification of all items of supply used by the Federal Government. It provides a common language so that it is now possible for one service or agency to use available materials held by another. The system also serves as an economy measure. Instead of the Army, Navy, Air Force, and civil agencies each purchasing and maintaining large stocks of material, all agencies can make use of centralized stocks.

The FSC is a commodity classification designed to classify all items used by the Government. To accomplish this purpose, groups and classes have been established for the numerous commodities with emphasis on the items in the supply systems of the military departments.

As presently established, the FSC consists of 90 groups (some currently unassigned), which are subdivided into approximately 550 classes. Each class covers a particular area of commodities, in accordance with their physical or performance characteristics, or based on the fact that the items in the class are usually requisitioned or issued together.

So that each stock group may have 2 digits, the first group starts with 10. (01-09 are for forms and publications.) A list of groups with titles which are commonly used by SEABEE estimators is as follows:

Group	Title
41	Refrigeration and Air-Conditioning Equipment
43	Pumps and Compressors
45	Plumbing, Heating, and Sanitation Equipment
46	Water Purification and Sewage Treatment Equipment
47	Pipe, Tubing, Hose, and Fittings
48	Valves
51	Handtools
53	Hardware and Abrasives
54	Prefabricated Structures and Scaffolding
55	Lumber, Millwork, Plywood, and Veneer
56	Construction and Building Materials
59	Electrical and Electronic Equipment Components
61	Electric Wire, and Power and Distribution Equipment
62	Lighting Fixtures and Lamps
80	Brushes, Paints, Sealers, and Adhesives
91	Fuels, Lubricants, Oils, and Waxes
95	Metal Bars, Sheets, and Shapes

These stock groups cover rather broad categories of material. Therefore, they are further divided into classes. The number of classes within each group vary. You will learn the frequently used classes within the groups by using them. Below is an example of how the classes are used to divide types of material within a stock group.

GROUP 53 Hardware and abrasives	
	5305 - Screws
	5306 - Bolts
	5307 - Studs
	5310 - Nuts and washers
	5320 - Rivets

Together, the stock group and class are known as the Federal Supply Classification (FSC).

The Defense Supply Agency Cataloging Handbooks, H2-1, H2-2, and H2-3 contain a complete listing of assigned Federal Supply Classification classes.

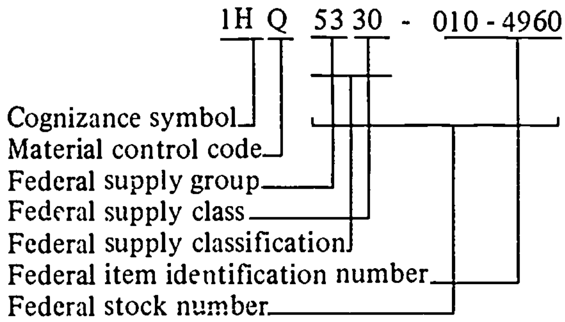
FEDERAL ITEM IDENTIFICATION NUMBER

The Federal Item Identification Number (FIIN) is a seven digit number which identifies each item-of-supply used by the Department of Defense (DOD). Although the FIIN is part of the Federal Stock Number (FSN), it is referenced in locating an item in the Navy Material Data Listing (NMDL). Except for identification lists, most federal supply catalogs are arranged in FIIN order.

FEDERAL STOCK NUMBER

The Federal Stock Number (FSN) for an item of supply consists of the four digit classification code number from the Federal Supply Classification System (FSC–Group and Class) and the seven digit Federal Item Identification Number (FIIN). The cognizance symbol and material number are not discussed here since they will be used only by the Supply Department.

The following illustrates the elements of a Federal Stock Number and their proper sequential order:



SUPPLY CATALOG

Various supply catalogs are available to you for identifying construction materials to FSN's. The most commonly used catalogs are the *Navy Management Data List*, the *Illustrated Shipboard Shopping Guide*, the *Master Cross-Reference List*, the *Federal Supply Catalog*, the *GSA Catalog*, and the *SERVMART Catalog*. This chapter is intended only to acquaint you with these catalogs, which are located in the Supply Department of the NMCB. With the assistance of the Storekeeper and a little practice, you will quickly become proficient in their use.

Navy Management Data List

The Navy Management Data List (NMDL) is produced on microfilm by the Navy Fleet Material Support Office (FMSO). It includes the basic management data necessary for preparing requisitions. It contains such data as stock numbers, units of issue, unit price, shelf life codes, and other information.

Figure 12-1 shows the different columns of information and what they contain. The introduction to the NMDL lists all of the codes used and their meaning, but with a few minutes of study, you can see from figure 12-1 the wide range of information provided and how it is shown. The NMDL is listed numerically by the FIIN. You will find the NMDL a handy tool for use in determining units of issue and cost per unit for items with a known stock number.

Illustrated Shipboard Shopping Guide

The Illustrated Shipboard Shopping Guide (ISSG) has been developed to provide an illustrated reference for common use Navy items and general purpose type material. Because of the illustrations and descriptive data, you can also use it to determine possible substitutions.

The ISSG consists of two parts: (1) introduction and master index and (2) individual sections for a specified Federal Supply Class or Group.

The introduction contains the purpose and content of the ISSG. The master index is an alphabetical listing of material by noun name and shows the appropriate FSC or group in which the item will be found.

The individual sections may cover an entire stock group or be divided by class depending upon how many items are involved.

The introduction contains an alphabetic index by noun name and shows the item number(s) which pertain to the material. If appropriate, a list of abbreviations used in the descriptive section will also be shown along with their meanings. Other information may be shown that will help you use that particular section.

The descriptive section contains all of the descriptive information and illustrations necessary to identify the items therein. They are listed in "Item Number" sequence referred to in the above paragraph.

The cross-reference section contains a listing of FINNs (in FIIN sequence) for all of the material in that section and shows the appropriate item number. It may also contain a listing of specification numbers and commercial designations cross-referenced to the appropriate item number. A page from the ISSG is shown in figure 12-2.

Master Cross-Reference List

The *Master Cross-Reference List (MCRL)* is designed to provide a cross-reference from a Reference Number (a manufacturer's part number, a drawing number, a design control number, etc.) to its assigned Federal Stock Number (FSN). It is kept current by the publication of quarterly cumulative bulletins.

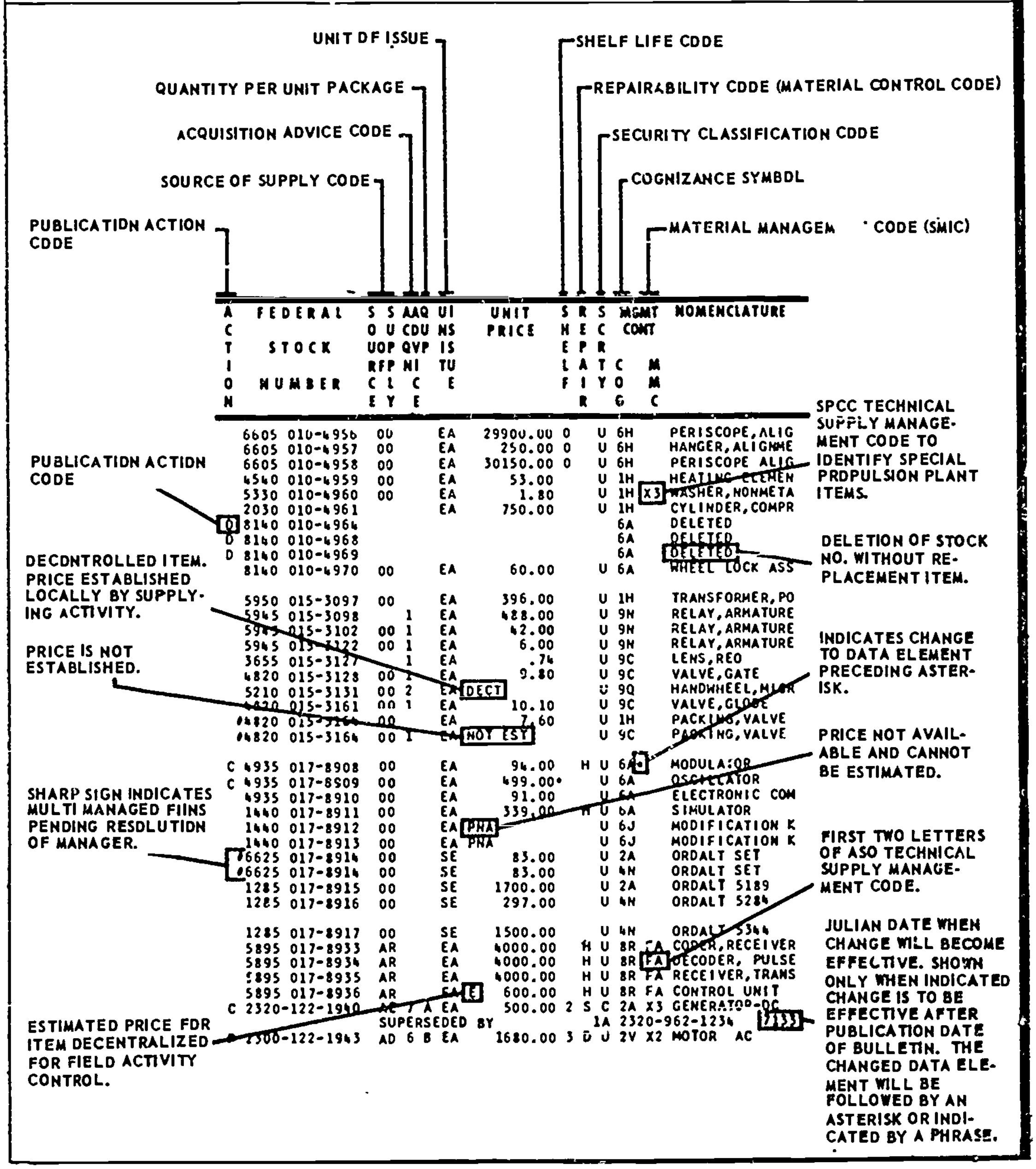
The reference numbers are arranged in a basic alpha-numeric sequence which recognizes the existence and placement of spaces and special characters. Reference number location is determined by considering each individual character of the number beginning at the extreme left position (first character) and continuing from left to right. Precedence of the characters in sequence is as follows:

Space (blank)
Special Characters (symbols)
Letters "A" through "N" and "P" through "Z"
Numerals "0" through "9"

Alphabetical "O" is considered as numerical "O". The following example illustrates the relative precedence used in sequencing:

AN2030-1	11562-1
AN850	14-AB45
A3460	143211
MS12552	15-12-07
RV 4225	187662
RV12406	2517-5
YP6825	333P-620
OBD-5600	777B-255-5740
11-432-1	9-RV-450

CURRENT PLANS PROVIDE FOR REPLACING THE BOOK-TYPE NMDL WITH A MICROFICHE SYSTEM BY JULY 1972. THE FORMAT IS EXPECTED TO REMAIN THE SAME, BUT IT WILL ELIMINATE THE NEED FOR CHANGE BULLETINS SINCE THE ENTIRE NMDL CAN BE ECONOMICALLY AND QUICKLY REISSUED AT MORE FREQUENT INTERVALS.



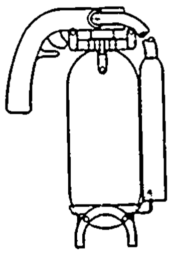
63.51

Figure 12-1.—Page from the Navy Management Data List.

318

EXTINGUISHER, FIRE, CARBON DIOXIDE

FOR FIRES INVOLVING OILS, GREASES, FLAMMABLE LIQUIDS OR ENERGIZED ELECTRICAL EQUIPMENT



Items 1200,1300,1400,1800,1900

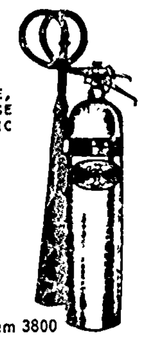
HAND TYPE, PERMANENT SHUTOFF TYPE VALVE, TRIGGER CONTROL, RIGID DISCHARGE TUBE, CHARGED NONSHATTERABLE CYLINDER

ITEM	FIIN	CAPACITY
	WITH MOUNTING BRACKET	LB
1200	528-2410	1.73
1300	060-4647	2.65
1400	528-2409	3.70
	WITHOUT MOUNTING BRACKET	LB
1800	223-9901	5
1900	223-9308	7.25

HAND TYPE, PERMANENT SHUTOFF TYPE VALVE, BUTTON. SQUEEZE-GRIP OR TRIGGER CONTROL, RIGID DISCHARGE TUBE, CHARGED NONSHATTERABLE CYLINDER

ITEM	FIIN	CAPACITY
	WITH MARINE MOUNTING BRACKET	LB
2900	262-7067	5

HAND TYPE, PERMANENT SHUTOFF TYPE VALVE, SQUEEZE-GRIP CONTROL, FLEXIBLE DISCHARGE HOSE, CHARGED NONSHATTERABLE NONMAGNETIC CYLINDER



Item 3800

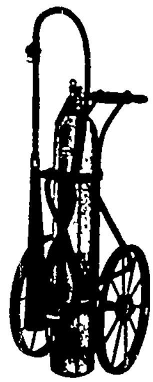
ITEM	FIIN	CAPACITY
	WITHOUT MOUNTING BRACKET	LB
3800	529-5127	15

FOR 15 LB CARBON DIOXIDE RECHARGE SEE FSN 6830-682-6839

EXTINGUISHER, FIRE, CARBON DIOXIDE continued

ITEM	FIIN	CAPACITY
		LB
4700	203-0341	50

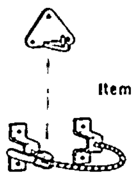
FOR 50 LB CARBON DIOXIDE RECHARGE SEE FSN 6830-682-6841



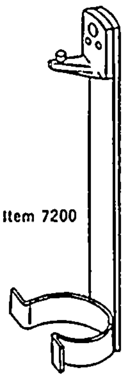
WHEELED TYPE, PERMANENT SHUTOFF TYPE VALVE, HANDWHEEL, SQUEEZE-GRIP OR TRIGGER CONTROL, CHARGED NONSHATTERABLE CYLINDER, 15 FT OF FLEXIBLE DISCHARGE HOSE

Item 4700

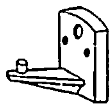
BRACKET, FIRE EXTINGUISHER



Item 6400



Item 7200



Item 6800

DESIGNED FOR VERTICAL MOUNTING OF CARBON DIOXIDE FIRE EXTINGUISHER

ITEM	FIIN	ACCOMMODATES FIRE EXTINGUISHER CAPACITY
	NAVSHIPS DRAWING 810-1385843 OR EQUAL	POUNDS
6400	268-9730	15
	WALTER KIDDE AND CO., PART NO. 61194 OR EQUAL	POUNDS
6800	262-7070	15
	WALTER KIDDE AND CO., PART NO. 62273 OR EQUAL	POUNDS
7200	262-7071	15

123.138

Figure 12-2.—Page from the Illustrated Shipboard Shopping Guide (ISSG).

If a number cannot be found in the form shown in the technical manual, illustrated parts breakdown, or other reference, try various arrangements of the part number before deciding that it is no longer listed. For example:

137 BCA 123 B
137-BCA–123-B
137BCA-123B
137BCA123B

The Reference Number Verification Code (RNVC) is a single digit code used to indicate whether the reference number is item identifying or requires additional data to correctly identify the item. The two codes you will encounter most often are shown below:

Code 1–Non-identifying–The reference number or part number will not identify an item without the use of additional information.

Code 2– Identifying–The reference number or part number is item identifying.

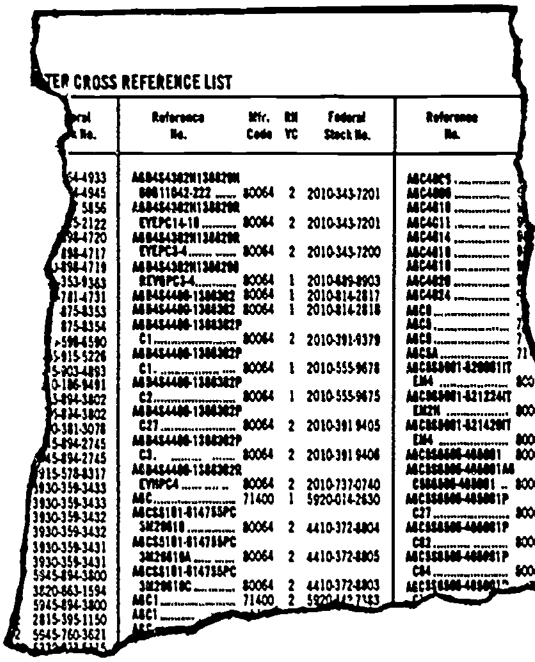
Figure 12-3 shows a portion of a MCRL page and illustrates the above information.

Federal Supply Catalog

The *Federal Supply Catalog Identification List* contains all Navy-interest items and follows the same format as the ISSG except that all illustrations are placed in the front of the identification list. It is more difficult to use than the ISSG because of the large amount of material it describes. The NMCB Supply Department maintains a complete current set of the *Federal Supply Catalog.* Individual sections may be requested for the estimator's use.

GSA Catalog

The General Services Administration (GSA) exercises inventory control over, and is responsible for, cataloging non-military items in general use by both military and civil agencies of the United States. Their *Stores Stock Catalog* is a handy reference in identifying consumable type materials. The GSA catalog format is similar to the ISSG. This handy catalog should be a must for every estimator's office. Ensure that the GSA catalog being used is the latest edition. It is revised annually.



63.52
Figure 12-3.—Columns of the Master Cross-Reference List.

Local Catalogs and Lists

Besides the aforementioned catalogs and lists, you will have access to various other catalogs and lists which are compiled by local supply departments. Available from NAVFAC is the *Navy Stock List of the Naval Facilities Engineering Command,* which includes materials and equipment used by the Naval Construction Force. SERVMART catalogs may be obtained from the SERVMARTS and list common consumable items which may be picked up quickly. A Supply Department SERVMART is like a shopping center for ready issue material.

You will find it very convenient to compile personal lists or a card index of common materials which you use frequently. The information contained on these lists or card index must be updated periodically.

USE OF ADVANCED BASE FUNCTIONAL COMPONENTS

The *Advanced Base Functional Component Facilities Planning Guide,* NAVFAC P-437, is an additional estimating guide which the SEABEE estimator has at his disposal. This NAVFAC publication will be a part of every NMCB technical library.

The Advanced Base Functional Component (ABFC) System catalogs used by logistic construction and tactical planners consist of two general purpose documents. OPNAV-41P3, *Table of ABFC* and NAVFAC P-437, *ABFC Facilities Planning Guide.*

Early in World War II, logistic and tactical planners found that providing support to a constantly changing tactical and strategic situation required identification of basic functions and determination of what was specifically required to perform each task. A modular or building block concept was developed. Components made up of men, materials, equipment and facilities were designed to serve specific functions no matter where they were placed. The Navy's ABFC System was based on experience gained in early advanced base planning and shipment in World War II. It has been improved based on lessons learned in Korea and Vietnam.

THE ABFC SYSTEM

The Navy ABFC System is a tool of Naval Logistics. It is the quantitative expression and measurement of planning, procurement, assembly and shipping of material and personnel needed to satisfy emergency facility support requirements overseas. An ABFC is a grouping of personnel and material designed to perform one of the specific functions or to accomplish a particular mission of an advanced base.

The grouping of material and personnel that make up an ABFC represents preplanning in the material and personnel necessary to perform a prescribed function. Determination of material and personnel requirements, procurement of material, determination of personnel complements, and procedures to obtain, assemble and ship ABFC's are described in part below.

ABFC's are normally complete entities. However, housing, messing and medical facilities, defensive ordnance, communications equipment, power plants and water supply equipment may not be supplied with each component and are themselves service components to be integrated into the overall base plan.

A detailed Advanced Base Initial Outfitting List (ABIOL) is an itemized line-item printout of the material in each ABFC. Each SYSCOM/Bureau is responsible for maintaining a detailed listing of that portion of the ABIOL of an ABFC for which it has been assigned contributory responsibility.

ABFC's are assigned descriptive names to indicate their function and unclassified alphanumeric designators to facilitate reference. ABFC's listed but under development or under revision are indicated as such by the use of U/D (Under Development) or U/R (Under Revision).

The *Table of ABFC,* OPNAV 41P3, with Abridged Initial Outfitting Lists, is a consolidation of each SYSCOM/Bureau contribution to the ABFC System. As such, it is the only document where a complete listing of items, at the abridged level, contained within a functional component can be found.

NAVFAC P-103, *ABFC Catalog,* has been superseded by NAVFAC P-437, *ABFC Facilities Planning Guide.* This new publication contains only that part of NAVFAC's ABIOL which deals with structures and associated utilities necessary to make these facilities operational.

NAVFAC P-437 consists of two volumes. Volume I contains advanced base drawings organized as follows. Part One, Component Site Plans, Part Two, Facility Drawings, Part Three, Assembly Drawings. Volume II is the data display for each component and associated facilities and assemblies used to construct the component. Volume II is also arranged in three parts. Part I quantifies and describes by DOD category code the facilities requirement for each component (see figs. 12-4 and 12-5). Part II quantifies and describes by assembly number the assembly requirements for each facility (see fig. 12-6). Part III quantifies line item requirements by FSN for each assembly (see figs. 12-7 and 12-8). Other useful information for planners is contained within the guide, such as the crew size, skill man-hours, land area and fuel necessary to make a component, facility or assembly operational.

FROM TABLE OF ABFC COMPONENTS

COMPONENT P25 — APR 24 73

NAVAL MOBILE CONSTRUCTION BATTALION

DOD CATEGORY CODE

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

NAVFAC DRAWING NUMBER

SITE PLAN 6002580 — MAJOR REV 07 01 68

FACILITY	DESCRIPTION	FACILITY CAPACITY	QTY	COMPONENT CAPACITY	WEIGHT SHORT TON	CUBE MEAS TON	DOLLAR VALUE	CONST EFFORT MANHOURS
111 20B	HELICOPIER LANDING PAD SMALL	10019 SY	1	10019 SY	6.1	36.1	27,965	48
123 10A	MOGAS STOR-DSPNSG FACIL 20000 GAL	20000 GL	1	20000 GL	4.8	14.6	20,583	111
123 10B	DIESEL STOR-DSPNSG FACIL 200000 GAL	200000 GL	1	200000 GL	39.6	72.8	108,559	231
131 15A	COMMUNICATION CENTER	240 SF	1	240 SF	6.9	12.8	2,531	558
141 75C	ARMORY	210 SF	2	420 SF	.0	.0	0	0
213 410	CENTRAL TOOL ROOM-SUPPLY ROOM	4000 SF	1	4000 SF	2.7	10.3	14,635	72
214 20N	A CO AUTO VEHICLE SHOP	4000 SF	1	4000 SF	7.8	9.9	18,219	124
218 20A	A COMPANY CONSTRUCTION EQUIP SHOP	4000 SF	1	4000 SF	2.3	6.8	13,219	82
219 100	B, C AND C COMPANY SHOP	7744 SF	1	7744 SF	4.8	16.1	24,996	266
421 35A	READY MAGAZINE	180 SF	1	180 SF	.5	10.7	805	0
441 10G	GENERAL WAREHOUSE REPAIR PARTS	4000 SF	2	8000 SF	5.4	20.6	29,270	144
441 10H	GENERAL WAREHOUSE MLO	4000 SF	2	8000 SF	5.4	20.6	29,270	144
441 10J	GENERAL WAREHOUSE GALLEY	936 SF	2	1872 SF	1.6	8.2	7,277	82
441 10K	GENERAL WAREHOUSE SUPPLY	4000 SF	2	8000 SF	5.4	20.6	29,270	144
510 77A	MEDICAL STORAGE		1		.5	10.7	805	0
540 10J	CENTAL CLINIC	250 SF	1	250 SF	.0	.0	0	0
550 10C	DISPENSARY	936 SF	2	1872 SF	1.8	8.4	8,026	94
610 10N	ADMINISTRATIVE OFFICE	936 SF	10	9360 SF	6.0	21.0	24,831	440
610 73A	COMPANY HEADQUARTERS (C AND O CO)	936 SF	1	936 SF	.6	2.0	2,109	38
610 73B	A COMPANY OFFICE/DISPATCHER	936 SF	1	936 SF	.6	2.0	2,109	38
723 10R	GALLEY MESS	8936 SF	1	8936 SF	55.8	265.4	115,399	613
723 20J	LATRINE	48 SF	1	48 SF	2.0	3.1	431	112
723 20K	HEAD/WASHROOM 6 FT X 8 FT	144 SF	3	432 SF	2.7	6.6	2,273	339
723 30G	LAUNDRY	133 SF	1	133 SF	.6	2.0	2,109	38
725 10S	TROOP HSG EMERG OFF/CPO W/SH-WR	5616 SF	2	11232 SF	23.0	77.0	41,519	1,816
725 10T	TROOP HS" EMERG W/SHOWER-WASHROOM	10296 SF	6	61776 SF	90.0	240.0	168,743	7,116
730 30B	BAKERY PLANT FIELD PORTABLE		1		4.0	27.5	20,182	55
740 02A	EXCHANGE-BARBER SHOP	512 SF	1	512 SF	.7	2.3	2,297	38
740 33E	SPECIAL SERVICES/POST OFFICE	936 SF	1	936 SF	.6	2.0	2,109	38
740 54B	RECREATION FACILITY	936 SF	3	2808 SF	1.8	6.0	6,326	114
740 63A	CLUB ENLISTED MENS	4000 SF	1	4000 SF	3.9	19.2	16,969	122
750 20A	PLAYING FIELD	1 EA	1	1 EA	.0	.0	0	0
750 50A	OUTDOOR THEATER		1		.0	.0	C	0
811 10AU	ELECTRIC PWR PLANT 2-200KW GEN SETS	500 KV	1	500 KV	1.1	4.1	9,028	84
811 60AU	STAND-BY PWR PLANT 2-200KW GEN SETS	500 KV	1	500 KV	1.1	4.1	9,028	84
812 30CX	ELECTRICAL DISTR LINES-UGND 17000LF	17000 LF	1	17000 LF	57.0	93.8	325,346	1,008
812 40A	PERIMETER LIGHTING 1100 LF	1100 LF	8	8800 LF	4.8	12.8	6,885	1,344
831 30A	LEACH FIELD		3		2.4	8.1	456	216
833 40A	GARBAGE HOUSE	936 SF	1	936 SF	.7	3.3	1,935	14

PAGE 227 — P25

82.235

Figure 12-4.—Page 227 from Part I, Facilities, NAVFAC P-437.

COMPONENT P25 APR 24 73

FACILITY	DESCRIPTION	FACILITY CAPACITY	QTY	COMPONENT CAPACITY	WEIGHT SHORT TON	CUBE MEAS TON	DOLLAR VALUE	CONST EFFORT MANHOURS
841 10M	WATER TREATMENT FACILITY 1500 GPH	30 TG	3	90 TG	15.6	22.5	28,026	54
841 40E	WATER STORAGE POTABLE 30000 GAL	30000 GA	3	90000 GA	14.4	31.8	46,525	168
842 10J	WATER DISTRIBUTION LINE POTABLE	7640 LF	1	7640 LF	14.7	26.2	20,334	260
851 10A	ROAD DRAINAGE		1		13.2	25.9	4,907	4,698
852 10A	PARKING		1		.0	.0	0	2,992
872 10B	SECURITY FENCING 1100FT	9900 LF	5	49500 LF	766.0	2,203.5	671,468	16,200
872 20B	GUARD/WATCH TOWER	4 EA	4	16 EA	72.0	31.2	13,559	1,440
872 20C	BUNKER FIGHTING 7F		40		128.0	168.0	20,544	4,560
872 20D	BUNKER COMMAND POST		1		8.9	12.8	2,531	558
890 27A	ICEMAKING PLANT	1 TN	1	1 TN	1.5	4.7	6,871	4
			TOTAL NORTH		1,391.3	3,608.1	1,910,279	46,901
			TOTAL TROPICAL		1,345.2	3,529.3	1,724,812	44,281

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 MOGAS	FUEL GAL/30DAYS PWR GEN DSL
	0	18.5	448	313	305,134	0	66,656	83,778	0

SKILLS MANHOURS	EA	BU	UT	CE	SW	EO	UNSKILLED CN
	0	6,257	7,665	3,507	1,919	7,917	19,636

PAGE - 228 P25

82.236

Figure 12-5.—Page 228 from Part I, Facilities, NAVFAC P-437.

FACILITY 123 108 JCS PLANNING FACTOR APR 20 73

DIESEL STORAGE AND DISPENSING FACILITY
200000 GALLON

THIS FACILITY PROVIDES 200000 GALLON OF DIESEL OIL
STORAGE AND RECEIVING-DISPENSING CAPABILITY.

NAVFAC DRAWING NUMBER 6002621

ASSEMBLY	DESCRIPTION	ZONE	QTY.	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
20002	TANK FUEL PILLOW 50000 GAL		4	7,610.[illegible]	644.4	20,805.76	112
20124	HOSE MANF F/200000 GAL TANK ARR		1	470.2	58.9	1,191.16	2
20204	FUEL TRANSFER ASSEMBLY 350 GPM		1	2,566.1	153.1	4,276.25	44
20305	FUEL DISPENSING ASSY PORTABLE		1	1,269.9	48.9	2,249.39	8
20506	FUEL FILTER AND METER ASSY 350 GPM		1	3,329.4	276.1	9,129.69	22
20508	HEATER FUEL HOT OIL 350 GPM	N	1	62,739.[illegible]	1,619.1	71,260.04	24
20703	TANK FUEL 275 GAL W/ACCESSORIES		2	759.2	91.9	321.24	16
29702	EXTINGUISHER FIRE W/BRKT PYP 20 LB		3	540.[illegible]	18.9	325.14	3

	SHORT TON	MEAS TON	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE	CONST EFFORT MANHOURS
TOTAL NORTH	39.6	72.8	79,285.0	2,911.3	108,558.67	231
TOTAL TROPICAL	8.3	32.3	16,546.6	1,292.2	37,298.63	207

FACILITY 123 108 PRIMARY 200,000 GL SECONDARY 0

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	0	1.28	17	8	208	3	0	0	0	

FUEL (GAL/30DAYS) HEATING DSL	HEATING MOGAS	PWR GEN DSL	SKILLS MANHOURS EA	BU	UT	CE	SW	EO	UNSKILLED CN
5,600	490	0	0	0	119	0	0	88	24

PAGE-12 123 108

82.237

Figure 12-6.—Page 12 from Part II, Assemblies, NAVFAC P-437.

A D V A N C E D   B A S E   F U N C T I O N A L   C O M P O N E N T   S Y S T E M

FACSO RPT SYM/NO. 04040/B2420R01 PART III APR 20 73

ASSEMBLY 20001 ZONE 20001

THIS ASSEMBLY PROVIDES MATERIALS FOR AN OIL STORAGE TANK BERM DRAIN TO ALLOW RAIN WATER AND FUEL SPILLAGE TO BE DRAINED OFF FROM INSIDE OF BERM.

NAVFAC DRAWING NUMBER

COG	STOCK NUMBER	DESCRIPTION	UI	CTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9Q	5630-267-1553	BEND 1-8 BFP 4N	EA	2	4.00	.5800	4.44
9Q	5630-962-7382	PIPE BFP 4NX8FT W/CPLG	EA	5	120.00	12.0000	11.05
		ASSEMBLY 20001		TOTAL	124.00	12.5800	15.49

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

ASSEMBLY 20002 ZONE 20002

TANK FUEL PILLOW 50000 GAL

THIS ASSEMBLY PROVIDES 50000 GALLON OF FUEL STORAGE.

NAVFAC DRAWING NUMBER 6002614

COG	STOCK NUMBER	DESCRIPTION	UI	CTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9C	4710-639-9445	PIPE STL BLK 2	FT	20	75.00	.7800	9.80
9C	4710-950-2482	PIPE CULVT NEST 12N ALUM	EA	4	26.40	2.1600	21.52
9C	4720-978-8887	HOSE ASSY RBR 4X10 SUCT	EA	3	171.00	7.5000	246.00
9C	4730-088-9286	COUPLING HLF QCPLR 4FX4F	EA	2	16.00	.4000	34.80
9C	4730-196-2079	NIPPLE PP SHRT 4X4	EA	1	3.15	.0600	1.20
9C	4820-289-0674	VALVE GATE QUICK 2NPT	EA	1	11.00	.2000	27.70
9Z	5330-899-4509	WASHER RBR 4 HSE CPLG	EA	3	.15	.0030	.42
2C	5430-999-3739	TANK FAB COL 50000GL	EA	1	1,600.00	150.0000	4,860.00
		ASSEMBLY 20002		TOTAL	1,902.70	161.1030	5,201.44

PAGE-155

82.238

Figure 12-7.—Page 155 from Part III, Line Items, NAVFAC P-437.

ADVANCED BASE FUNCTIONAL COMPONENT SYSTEM

FACSO RPT SYM/NO. C4040/8242GRG1 PART III APR 20 73

ASSEMBLY 200C2 ZONE 200C2

FUEL (GAL/30DAYS) HEATING DSL	MOGAS	PWR GEN DSL	SKILLS MANHOURS EA	BU	UT	CE	SW	EO	UNSKILLED CN	CONST EFFORT MANHOURS
0	0	0	0	0	2	0	0	22	4	28

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

ASSEMBLY 20003 ZONE 20003

MANIFOLD AND HOSE FOR 200000 GALLON MODULE

PROVIDES NECESSARY MANIFOLDS AND HOSE FOR CROSS-CONNECTING FOUR 50000 GALLON PILLOW TANKS.

NAVFAC DRAWING NUMBER

COG	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
2C	3835-974-1951	MANIFOLD FLANGED 5WAY	EA	1	192.00	46.0000	760.00
9C	4720-978-8887	HOSE ASSY RBR 4X10 SUCT	EA	12	684.00	30.0000	984.00
9C	4820-999-3580	VALVE 4N F/FAB TANK	EA	4	140.00	6.0000	1,824.00
	ASSEMBLY 20003			TOTAL	1,016.00	82.0000	3,568.00

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

ASSEMBLY 20004 ZONE 20004

TANK FUEL PILLOW 10000 GAL

THIS ASSEMBLY PROVIDES 10000 GALLON OF FUEL STORAGE.

NAVFAC DRAWING NUMBER 6002630

COG	STOCK NUMBER	DESCRIPTION	UI	QTY	WEIGHT POUNDS	CUBIC FEET	DOLLAR VALUE
9C	4710-639-9445	PIPE STL BLK 2	FT	20	75.00	.7800	9.80
9C	4710-950-2482	PIPE CULVT NEST 12N ALUM	EA	4	26.40	2.1600	21.52
9C	4720-978-8887	HOSE ASSY RBR 4X10 SUCT	EA	3	171.00	7.5000	246.00
9C	4730-088-9286	COUPLING HLF CCPLR 4FX4F	EA	2	16.00	.4000	34.80
9C	4730-196-2079	NIPPLE PP SHRT 4X4	EA	1	3.15	.0600	1.20

PAGE-156

82.239

Figure 12-8.—Page 156 from Part III, Line Items, NAVFAC P-437.

P-437 lists additional facilities and assemblies not directly related to components shown in OPNAV 41P3 that provide the planner better alternative choices for the satisfaction of contingency requirements.

For the purpose of compatibility with other DOD planning systems, NAVFAC P-437 has been oriented to the standard DOD category codes for classifying real property of the Navy as listed in NAVFAC P-72. The cardinal category codes are as follows:

100 Operational and Training
200 Maintenance and Production
300 Research Development and Evaluation
400 Supply
500 Hospital and Medical
600 Administrative
700 Housing and Community Support
800 Utilities and Ground Improvement
900 Real Estate

Thus, if a facility is required for enlisted men's quarters, it could probably be found in the 700 series, "Housing and Community Support." The assemblies contained within each facility will consist of a grouping of line items at the Federal Stock Number level, which when assembled will perform a specific function in support of the facility. These assemblies are functionally grouped so that the function they perform in support of the facility is related to the Group VIII SEABEE skill ratings. These groupings are numbered as follows.

DESCRIPTION	NUMBER SEQUENCE	
	START	STOP
Builder Oriented (BU)	10,000	19,999
Utility Oriented (UT)	20,000	29,999
Construction Electrician Oriented (CE)	30,000	39,999
Steelworker Oriented (SW)	40,000	49,999
Equipment Operator Oriented (EO)	50,000	54,999
Waterfront Equipment	55,000	57,999
Underwater Construction and Diving Equipment	58,000	59,999
Operational Supplies	60,000	62,499
Operating Consumables	62,500	64,999
NBC Warfare	65,000	67,499
Personnel Related Supplies	67,000	69,999
Unassigned	70,000 Series	
Shop Equipment Including Maintenance Tools	80,000	80,999
Unique ABFC Tool Kits	81,000	81,999
NCF TOA Construction Tools & Kits (Power Tools)	82,000	82,099
NCF TOA Construction Tools & Kits (Electrical)	82,500	82,599
NCF TOA Construction Tools & Kits (Miscellaneous)	83,000	83,199
NCF TOA Construction Tools & Kits (Rigging)	84,000	84,099
Shop Equipment (ABFC Unique)	85,000	87,499
Unassigned	87,500	87,999
Unassigned	90,000	99,999

USE AND APPLICATION OF THE FACILITIES PLANNING GUIDE

Although listings in the guide may be of assistance in ordering individual items, they are not intended as a replacement for Stock Lists of Commands/Bureaus, Offices, Single Managers, or Inventory Control Points. Verification of stock numbers and descriptions should be made through use of appropriate Stock Lists. Note that consumable items are intended to cover requirements for the first 90 days only unless otherwise specified.

Full size drawings are shipped with components, facilities and assemblies. Reduced scale drawings are contained in NAVFAC Publication P-437, Volume I, *Facilities Planning Guide.*

Figures 12-4 and 12-5 show a sample component, P-25, which lists all of the facilities required for the mobilization of one Naval Mobile Construction Battalion. A close examination of this component reveals a great deal of information predetermined for the planner such as facility capacity, measurements required for transportation, dollar value, and manhours necessary to construct each facility. Following the listing of facilities, in figure 12-5, are the total utility requirements and the total manhours, by skills, to construct the component.

A further breakdown of the Facilities Planning Guide is presented in figure 12-6. This illustration shows a breakdown, by assemblies, of facility 123-10B, listed in the component of figure 12-4. The same type of information is provided for the assemblies as was shown in figures 12-4 and 12-5 for the facilities.

The third part of the guide lists the line items which are required for each assembly. Figures 12-7 and 12-8 show a line item listing of Assembly 20002, which was one of the assemblies listed in the facility in figure 12-6. Unlike the information provided for components and facilities, the assembly line items are identified by Federal Supply Stock Number. The other information provided is basically the same.

Tailoring may be employed to obtain the specific material required and to prevent waste of unneeded items. Tailoring can be accomplished by the following means:

1. Deleting or adding facilities, assemblies, or line items
2. Specifying requirements for Tropical (T) or Northern (N) Zone

(Note that items required only in Tropical installation are coded with the letter "T" in the Zone column to the right of the quantity. Conversely, items required only in Northern installation are coded with the letter "N". Uncoded items are common to both locales.)

By carefully studying the guide, NAVFAC P-437, the planner and estimator will realize that the publication provides an unlimited reference source.

SPECIFICATIONS

In his work, the estimator may use various types of specifications, such as Federal specifications, NAVFAC specifications, and project specifications. Besides using specifications for preparing estimates, the EA may also be assigned to assist with the preparation of project specifications for a particular project. To be able to use and prepare project specifications, the EA must have an understanding of the general format used in the above-mentioned specifications.

FEDERAL AND MILITARY SPECIFICATIONS

FEDERAL SPECIFICATIONS cover the characteristics of materials and supplies used jointly by the NAVY and other Government departments. Federal specifications do not cover installation or workmanship. These specifications are extremely important to the estimator during the procurement of materials, ensuring that suitable materials are being used in accordance with project specifications.

Pages from Federal Specification FF-N-105B (nails, wire, etc.) are shown in figures 12-9, 12-10, and 12-11. Suppose the project specification states that ". . . for all carpentry, nails shall conform to Federal Specification FF-N-105B, Type II." To further identify the nails required, it will be necessary to refer to Federal Specification FF-N-105B to define the different styles under Type II before proper selection of the nails may be made. In the Federal Stock Catalog, nails are listed by styles under each type.

When the estimator is using a set of project specifications, he should obtain a copy of each reference specification listed, ensuring that he has the latest revisions. 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 "JAN" or "MIL" preceding the first letter and serial number, such as MIL-L-10547 (Liners, Case, Waterproof). They were formerly called Joint Army and Navy specifications, or "JAN". As they are revised, the JAN is being replaced by MIL, but the serial number remains the same.

NAVFAC SPECIFICATIONS

NAVFAC specifications are prepared by the Naval Facilities Engineering Command, setting

FF-N-105B
March 17, 1971
SUPERSEDING
Fed. Spec. FF-N-105A
July 26, 1963
(See Sec. 6)

FEDERAL SPECIFICATION

NAILS, BRADS, STAPLES AND SPIKES:
WIRE, CUT AND WROUGHT

This specification was approved by the Commissioner, Federal Supply Service, General Services Administration, for the use of all Federal agencies.

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification covers wire and cut nails and spikes, wire brads and staples, and wrought spikes.

1.2 Classification.

1.2.1 Types and styles. Nails, brads, staples and spikes shall be of the following types and styles, as specified (see 6.2).

Type I - Brads

Type II - Nails
Style 1 - Asbestos Shingle
2 - Barrel
3 - Boat
4 - Box
5 - Broom
6 - Casing
7 - Coolers
8 - Sinkers
9 - Corkers
10 - Common
11 - Concrete
12 - Double-Headed
13 - Fine
14 - Finishing
15 - Flooring

FSC 5315

82.240

Figure 12-9.—Page 1 from Federal Specification FF-N-105B.

FF-N-105B

Style 16 - Lath
17 - Masonry
18 - Pallet
19 - Gypsum Wallboard
20 - Roofing
21 - Shingle
22 - Siding
23 - Slating
24 - Rubber Heel
25 - Underlayment
26 - Square Barbed
27 - Masonry Drive
28 - Escutcheon

Type III - Staples
Style 1 - Fence
2 - Poultry Netting
3 - Flat Top Crown
3a - Round or "V" Crown
4 - Preformed

Type IV - Cut Nails
Style 1 - Common
2 - Basket
3 - Clout
4 - Trunk
5 - Cobblers
6 - Extra-Iron Clinching
7 - Hob

Type V - Spikes
Style 1 - Common (Cut)
2 - Gutter
3 - Round
4 - Barge and Boat

1.2.2 Sizes. Nails, brads, staples and spikes shall be of the sizes listed herein or as otherwise specified (see 6.2).

2. APPLICABLE DOCUMENTS

2.1 The following documents of the issue in effect on date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein.

Federal Specifications:

NN-P-71 - Pallets; Materials-Handling, Wood (General Construction Requirements).
QQ-Z-325 - Zinc Coating, Electrodeposited, Requirements For.
MMM-A-250 - Adhesive, Water-Resistant (For Closure of Fiberboard Boxes).
PPP-B-566 - Boxes, Folding Paperboard.
PPP-B-601 - Boxes, Wood, Cleated-Plywood.
PPP-B-621 - Boxes, Wood, Nailed and Lock-Corner.
PPP-B-636 - Box, Fiberboard.

82.241

Figure 12-10.—Page 2 from Federal Specification FF-N-105B.

FF-N-105B

Uniform Classification Committee, Agent:

Uniform Freight Classification.

(Application for copies should be addressed to the Uniform Classification Committee, Tariff Publishing Officer, Room 202 Union Station, 516 W. Jackson Blvd., Chicago, IL 60606.)

National Motor Freight Traffic Association, Inc., Agent:

National Motor Freight Classification.

(Application for copies should be addressed to the National Motor Freight Traffic Association, Inc., Agent, 1616 P Street, N.W., Washington, DC 20036.)

(Technical society and technical association specifications and standards are generally available for reference from libraries. They are also distributed among technical groups and using Federal agencies.)

3. REQUIREMENTS

3.1 Material. Nails, brads, staples and spikes shall be of the following materials, as specified (see 6.2).

3.1.1 Steel wire. Steel wire shall be of good commercial quality, entirely suitable for the purpose and sufficiently ductile to insure that the finished product shall withstand, without fracture, cold bending through 180 degrees over a diameter not greater than the diameter of the wire. Except as specified in 3.1.2, the cold bend test will not be applied to barbed nails, or nails having mechanically formed or deformed shanks.

3.1.2 Hardened steel. Hardened steel nails shall be heat treated to a minimum hardness of Rockwell C37. The finished product shall withstand, without fracture, cold bending through 20 degrees over a diameter not greater than the diameter of the wire.

3.1.3 Medium-carbon steel sheet. Cut nails (Type IV) and cut spikes (Type V, style 1) shall be sheared from medium-carbon steel sheet of good commercial quality, entirely suitable for the purpose. The finished product shall withstand, without fracture, cold bending through 90 degrees over a diameter not greater than the thickness of the sheet.

3.1.4 Copper. Copper nails shall contain a minimum of 98 percent pure copper. Copper nails shall withstand, without fracture, cold bending through 180 degrees over a diameter not greater than the diameter or thickness of the nail.

3.1.5 Copper-clad steel wire. Copper-clad steel wire shall be not less than 20 percent copper by weight. The average thickness of the copper shall be not less than 10 percent of the radius of the finished wire; the minimum thickness shall be not less than 8 percent of the radius of the finished wire. The finished product shall withstand cold bending through 180 degrees over a diameter not greater than the diameter of the wire without fracture and without separation of the copper from the steel.

82.242

Figure 12-11.–Page 4 from Federal Specification FF-N-105B.

forth standards of construction for the Naval Construction Force and all work performed under the jurisdiction of NAVFAC. When NAVFAC specifications are used in project specifications, they must be consistent with the conditions of usage mentioned in them. Major deviations in these specifications should not be made without prior NAVFAC HQ approval.

Current NAVFAC specifications are listed in *Specifications Used In Contracts For Public Works*, NAVFAC P-34. Included in NAVFAC specifications are Y-Series specifications, Standard (S-Series) specifications, and Type and Guide (TS, GSH, TSM) specifications. Also listed in NAVFAC P-34 are Federal, Military, and Special specifications and standards which are cited in the NAVFAC specifications.

Y-SERIES SPECIFICATIONS define, describe, and establish criteria for the design and construction of various specialities. They are the NAVFAC specifications that are most commonly used by SEABEES. NAVFAC Y-Series specifications are referenced in project specifications. They may be modified by taking exceptions, or amplified by additional requirements.

EXAMPLE: "Concrete construction shall conform to Specification 13Y, except as otherwise specified."

EXAMPLE: "Protection and curing of piles shall be in accordance with Specification 13Y, however, the side forms can be removed approximately 48 hours after the concrete is placed."

STANDARD (S-SERIES) SPECIFICATIONS are written for a small group of specialized structures, which 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-M8, except that all concrete shall be Class F-1."

TYPE AND GUIDE (TS, GSH, TSM) SPECIFICATIONS define, describe, and establish minimum criteria for construction, materials, workmanship, and maintenance. They are divided into the following categories:

1. TS–type specifications for use in regular military construction projects.
2. GSH - guide specifications for use in family housing projects.
3. TSM–type specifications for use in contract maintenance projects.

Type specifications must not be referenced in project specifications. They may be used as manuscripts for project specifications. Portions of type specifications that are not applicable to a project must not be incorporated into the project specifications. When portions of a project are not covered by a type specification, amplify where necessary, using language and form similar to that of the type specification.

COMMERCIAL SPECIFICATIONS AND STANDARDS

Where the quantity of material is small and does not require testing, a suitable standard commercial product may be used. Manufacturers' standards, however, cannot be referred to or copied verbatim in project specifications.

TECHNICAL SOCIETY AND ASSOCIATION SPECIFICATIONS: These specifications —for example, those published by the United States of America Standards Institute (USASI), 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.

MANUFACTURERS' STANDARDS: These should not be referenced in project specifications. They may be used to aid in preparing the requirements for project specifications, but must not be copied verbatim. Do not base requirements on standards of several manufacturers.

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; and the project specifications indicate what the drawings do not portray, or they clarify further details that are not covered amply by the drawings and notes on the drawings. Whenever there is conflicting information on the drawings and project specifications, the project specifications take precedence over the drawings.

General Format

The Naval Facilities Engineering Command has developed a format for use in the preparation of project specifications. This format is described in NAVFAC Type Specification TS-M129 (latest revision), *Format and General Paragraphs for the Preparation of Manuscripts of Specifications for Public Works*. The format is patterned generally after the Construction Specifications Institute's format for Construction Specifications.

Division 1 of the project specifications contains the GENERAL REQUIREMENTS for the project, stating types of structure foundations, character of load-bearing members (wood-frame, steel-frame, concrete), type or types of doors and windows, types of mechanical and electrical installations, and the principal function of the completed project.

A project specification is divided into 16 divisions as follows:

Division 1 – General Requirements
Division 2 – Site Work
Division 3 – Concrete
Division 4 – Masonry
Division 5 – Metals
Division 6 – Carpentry
Division 7 – Moisture Control
Division 8 Doors, Windows, and Glass
Division 9 – Finishes
Division 10 – Specialties
Division 11 – Equipment
Division 12 – Furnishings
Division 13 – Special Construction
Division 14 – Conveying Systems
Division 15 – Mechanical
Division 16 – Electrical

Divisions 2 through 16 set forth SPECIFIC CONDITIONS which must be carried out by the constructors. These specific conditions, or general categories, are grouped into divisions under headings applying to each major phase of construction. Categories or items not included in the above listed 16 divisions should be specified in the most closely related division. Categories or units of work related to divisions are listed in NAVFAC Type Specification TS-M129 (latest revision).

All 16 divisions should be included in the project specifications. Where no work is required in a particular division, a statement to that effect should be included under that division. Where only a small amount of work is necessary under one division, it may be included in another related division with proper cross reference. For example, if there are only a small number of doors, windows, and glass required for a project, they could be included in division 6, with reference in division 8 to read division 6 for requirements for doors, windows, and glass.

Each division is further broken down into SECTIONS. Division numbers and titles are fixed, but the numbers and titles of sections and the arrangement of sections within a division are flexible. The project specification table of contents, as shown in figure 12-12, for a typical project lists the divisions by number and title. Under each division, the sections are also listed by number and title. Sections are designated by division number with the appropriate alphabetical suffix.

DIVISION 1. GENERAL REQUIREMENTS
Section
1A General paragraphs.

DIVISION 2. SITE WORK
Section
2A Clearing of site
2B Earthwork
2C Site drainage
2D Site utilities

DIVISION 3. CONCRETE
Section
3A Concrete formwork
3B Concrete reinforcement
3C Cast-in-place concrete

DIVISION 4. MASONRY
Section
4A Mortar
4B Unit masonry

DIVISION 5. METALS
Section
5A Structural steelwork
5B Miscellaneous metals

DIVISION 6. CARPENTRY
Section
6A Carpentry and woodwork

DIVISION 7. MOISTURE CONTROL
Section
7A Waterproofing
7B Roofing and sheet metal work
7C Caulking

DIVISION 8. DOORS, WINDOWS, AND GLASS
Section
8A Metal doors and frames
8B Metal windows
8C Glazing

DIVISION 9. FINISHES
Sections
9A Tilework
9B Painting

DIVISION 10. SPECIALTIES
(None in this project)

DIVISION 11. EQUIPMENT
(None in this project)

DIVISION 12. FURNISHINGS
(None in this project)

DIVISION 13. SPECIAL CONSTRUCTION
(None in this project)

DIVISION 14. CONVEYING SYSTEMS
Section
14A Hoists

DIVISION 15. MECHANICAL
Section
15A Plumbing
15B Air conditioning

DIVISION 16. ELECTRICAL
Section
16A Electrical work

82.243

Figure 12-12.—Table of contents for a typical project specification.

Under sections are subsections or SUBPARAGRAPHS. Subparagraphs are given appropriate captions and numbered with a standard decimal system, following the section number and alphabetical suffix.

EXAMPLE:

15A.12 Fixtures and Fixture Trim.–
15A.12.1 Fixtures and Trim.–
15A.12.2 Fixture Connections.–
15A.12.3 Finish of Fittings and Trimmings.–
15A.12.4 Fixtures.–
15A.12.4.1 Item P-1, Water Closet.–

REFERENCE SPECIFICATIONS.–Federal and Military specifications, NAVFAC specifications, Technical Society and Association specifications, and Manufacturers' specifications and standards are used as reference for the preparation of project specifications. Certain specifications, as described previously for each type of specification, form basic references for project specifications, while others are used merely in the preparation of manuscripts.

When specifications are referenced in project specifications, the following rules apply:

LISTINGS. Specifications referred to are listed in the paragraph entitled Applicable Documents at the beginning of each section of the project specification, or at the beginning of a division which is small or contains only a few sections. Reference specifications are listed by specification number and complete title.

EXAMPLE:

6A.1 Applicable Documents.–Except where modified by this specification, the following specifications and standard of the issue in effect shall govern.

FEDERAL

O-C-105 Calcium chloride, dihydrate and calcium chloride, anhydrous; technical.

SS-C-192 Cement, portland.

TT-C-800 Curing compound, concrete, for new and existing surfaces.

NAVFAC

13Yh Concrete construction.

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 318 Building code requirements for reinforced concrete.

ACI 613 Recommended practice for selecting proportions for concrete.

AMERICAN WELDING SOCIETY (AWS)

D12.1 Welding reinforcing steel, metal inserts and connections in reinforced concrete construction.

REFERENCE. When a specification is referred to elsewhere in the project specifications, the applicable or nonapplicable portions should be identified, whichever is more appropriate. All specifications so referenced must be listed at the beginning of each section as described above. Reference specifications must be spelled out, for example, "Reinforcement shall conform to Specification QQ-S-632, Type II, Grades C,D,E,F, or G."

PHRASEOLOGY.–The following instructions and examples stress common errors in phraseology which are sometimes used in preparing project specifications:

1. General Requirements.

EXAMPLE:

Wrong: "The work consists of"
Right: "The work includes"

2. Coordination with Drawings. If drawings indicate clearly the exact limitations of several classes of work within a section, do not provide parallel definitions of scope in the project specifications. Such treatment can be contradictory by failure to mention something shown clearly on the drawings. Also, avoid the repeated use of the expression, "as indicated on the drawings."

3. Minimize the use of cross references, and do not use paragraph numbers for this purpose. Refer to a particular paragraph by its title and the section title under which it belongs. Do not use superfluous cross references, such as "Painting of the woodwork is covered under 'painting'."

4. Specify the work included in each section. Do not include a paragraph in each section titled "Work Not Included."

5. Do not repeat in each section requirements already covered in Division 1.

6. Avoid terms that are too indefinite for inspection purposes, such as, "etc." or "as may be required."

7. Avoid ungrammatical omission of articles of speech.

EXAMPLE:

Wrong: "Contractor shall paint ceiling of office."
Right: "The ceiling of the office shall be painted."

8. Customary Navy terms and designations should be avoided in project specifications. For example: bulkhead for wall, deck for floor, ladder for stairs, head for toilet, and galley for kitchen.

9. Use of Abbreviations and Symbols. The specification writer should always have, for reference, a copy of Military Standard MIL-STD-12 (latest revision), *Abbreviations for Use on Drawings and In Technical-Type Publications.* The following rules for the use of abbreviations and symbols is applicable in the preparation of project specifications:

a. Limit the use of abbreviations to those generally understood and accepted; for example, psi, cfm, kw.

b. Avoid the use of symbols; particularly, do not use ('), ("), (°), and (#) for feet, inches, degrees, and pounds, respectively. Spell out the word or abbreviate.

c. Spell out figures, except when they are dimensions; for example, nine buildings, 100 ft long. Exception: "one" and "zero" shall always be spelled out when used singly.

d. Never use both written numbers and numerical figures, for example, ten (10).

10. Improper use of words can lead to misinterpretation of requirements and subsequent confusion. Pay particular attention to the following words:

a. "Any" versus "all."

Incorrect: "Any defects shall be corrected".
Correct: "All defects shall be corrected."

b. "Either" versus "both."

Incorrect: "painted on either side."
Correct: "painted on both sides."

c. "And" versus "or." Do not confuse these words since they have different meanings.

d. "Shall" versus "should" or "may." "Shall" is imperative and allows no latitude for choice. "Should" indicates preference but is not imperative. "May" is permissive and allows free choice.

e. Use of "replaced". Do not use this word as a substitute for "reinstalled" or "renewed." A phrase such as "The equipment shall be removed and replaced as indicated" can be misleading if the intent is to have the original equipment removed and reinstalled. The phrase, as written, suggests replacement of old equipment by new equipment.

PROJECT SPECIFICATION EXAMPLE

The following excerpts, taken from a NAVFAC specification, are for one specific NAVFAC project and are not necessarily applicable to other projects. However, the section that deals with the testing of the plumbing system may be used in the preparation of other project specifications. When studying the following example, keep in mind that the general format and phraseology used are typical for all project specifications.

15A.12 Fixtures and Fixture Trim.–

15A.12.1 Fixtures and Trim.–Fixtures and trim shall be provided complete with fittings and shall conform to Federal Specification WW-P-541. Item numbers correspond with the P-numbers indicated. Faucet handles shall be of the same design in all bathrooms. Exposed traps and supply pipes for all fixtures and equipment shall be connected to the rough piping systems at the wall. Floor plates, wall plates, and escutcheons shall be as covered by the outfit numbers. Steel or cast-iron bathtub hangers shall be provided to be fastened to the wood studs, furring strips, or walls to permanently fix the tub elevation. Four hangers shall be provided for recessed bathtubs, two to be installed at the backwall and one at each end of the tub. Stops shall be provided at each fixture.

15A.12.2 Fixture Connections.–Plumbing fixture compound shall be used for fixture connection between earthenware fixtures and flanges on soil pipe. Water-closet floor flanges shall conform to Federal Specification WW-P-541, Type 127. Closet bolts shall be not less than 1/4-inch in diameter and shall be equipped with chromium-plated nuts and washers. Type 114 traps shall be provided for lavatories and kitchen sinks.

15A.12.3 Finish of Fittings and Trimmings.–The exposed piping, fittings, and trimmings shall be chromium-plated or nickel-plated brass with polished bright surface conforming to Federal Specification WW-P-541.

15A.12.4 Fixtures.–Plumbing fixtures are designated on the drawings by the following P-numbers:

15A.12.4.1 Item P-1, Water Closet, siphon jet, elongated bowl, close-coupled. Outfit No. VW9, seat Type SVET, closed front.

15A.12.4.2 Item P-2, Lavatory, vitreous china, 20 inches by 18 inches. Outfit No. VL.20G or VL.20H.

15A.12.4.3 Item P-3, Bathtub, porcelain-enameled steel, recessed, with shower-bath combination. Outfit No. F60R or F60L. Drain location at right or at left end as indicated. Shower-bath combination shall be Type 26, except that shower flow shall be controlled by diverter valve instead of diverter spout. A parts shall be removable and renewable from the face of wall. A flow-control device shall be provided either integral with the shower head or a separate unit between the shower head and arm to limit the flow to a maximum of 4.5 gallons per minute. Waste fitting shall be Type 122 pop-up, concealed, with all parts removable and renewable through the overflow and outlet openings inside the tub. Shower curtain rods, Fig. 15.05, of corrosion-resisting metal or brass with chromium finish shall be provided. Offsets in shower curtain rods shall be provided where windows interfere with normal installation. Tub bottoms shall be insulated with a sound deadening mineral-wool blanket.

15A.12.4.4 Item P-4, Kitchen Sink, stainless-steel, flat rim, single-compartment, 24 inches by 21 inches by 7-3/8 inches deep. Seamless drawn, 20 gauge nickel bearing Type 302 alloy stainless-steel, satin finished, sound deadened, integral mounting rim, with spray fitting, cup strainer and plug.Type 80, and tube type P-trap. Provide single lever faucet constructed of materials conforming to WW-P-541.

15A.13 Shower shall be outfit SPC, Figure No. 15.02.

15A.14 Installation.–

15A.14.1 General.–No plumbing fixtures, devices, or piping shall be installed that will provide a cross connection or interconnection between a distributing supply for drinking or domestic purposes, and a polluted supply such as a drainage system or a soil or waste pipe that will make possible the backflow of sewage, polluted water, or waste into the water-supply system.

15A.14.1.1 Protection of Fixtures, Materials and Equipment.–Pipe openings shall be closed with caps or plugs during installation. Fixtures and equipment shall be tightly covered and protected against water, dirt, and chemical or mechanical injury. At the completion of the work, the fixtures, ma rials, and equipment shall be thoroughly cleaned, adjusted, and placed in operation.

15A.14.1.2 Cutting and Repairing.–Work shall be laid out in advance. Any excess cutting of construction will not be permitted. Cutting shall be carefully done, and damage to buildings, piping, wiring, or equipment as a result of cutting for installation, shall be repaired by skilled mechanics of the trade involved, at no additional expense to the Government. No cutting of structural members shall be done without express written approval of the OICC. Contractor shall be responsible for proper fitting of materials and equipment in each building as indicated, without substantial alteration.

15A.14.2 Trenching and Backfilling.–Do necessary excavating and trenching to accommodate underground plumbing piping.

15A.14.2.1 Excavating and Trenching.–Trenches for underground pipelines shall be excavated to the required depths. Bottoms of trenches shall be tamped hard and graded to secure required fall. Recesses shall be excavated to accommodate bells and joints so that pipe will rest on firm ground of uniform density for the entire length of the pipe. Rock, where encountered, shall be excavated to a depth of 6 inches below the bottom of the pipe, and before the pipe is laid, the space between the bottom of the pipe and the rock surface shall be filled with gravel. Soft, spongy, or otherwise unstable material that will not provide a firm foundation for the pipe shall be removed and replaced with satisfactory fill material as defined in Section 2A, EXCAVATING, FILLING, AND BACKFILLING FOR BUILDINGS. Sewer and water pipes shall be laid in separate trenches at least 6 feet apart.

15A.14.2.2 Backfilling.–After pipelines have been tested, inspected, and approved by the OICC, and prior to backfilling, trenches shall be cleaned of trash and debris. Material for backfilling shall consist of satisfactory excavated material, or borrow of sand or gravel, free of trash, lumber, or other debris. Backfill shall be placed in layers not exceeding 9 inches in thickness, and shall be properly moistened to approximate optimum requirements. Each layer shall be compacted by hand or machine tampers or by other approved equipment to a density as specified in Section 2A, EXCAVATING, FILLING, AND BACKFILLING FOR BUILDINGS, laboratory and field tests of compaction shall be made as specified therein.

15A.14.2.3 Soil, Waste, Drain, and Vent Piping.–Horizontal soil and waste piping shall be sloped 1/4 inch per foot, except that pipes larger than 2 inches may be installed with a slope not less than 1/8 inch per foot where required. All main vertical soil and waste stacks shall be extended to and above the roof line as vents, except where otherwise indicated. Where practicable, two or more vent pipes shall be connected together and extended as one pipe through the roof. Vent piping in roof spaces shall be run as close as possible to the underside of the roof with horizontal piping pitched down to stacks without forming traps in piping, using fittings as required. Vertical vent pipes may be connected into one main vent riser above vented fixtures. Where circuit vent or wet vent from any fixture or line of fixtures is connected to a vent line serving other fixtures, the connection shall be at least 3 feet above the floor on which the fixtures are located, to prevent the use of any vent line as a waste line. Horizontal waste lines receiving the discharge from two or more fixtures shall be provided with end vents, unless separate venting of fixture is indicated. Plastic piping straight runs of 25 feet or over shall be provided with anchor at center span and expansion loops and turns or expansion joints. Copper and plastic piping shall be installed by methods recommended by the manufacturer.

(1) Fittings: Changes in size on soil, waste, and drain lines shall be made with reducing fittings or recessed reducers. Changes in direction shall be made by the appropriate use of 45-degree wyes, half-wyes, long-sweep 1/4 bends, 1/6, 1/8, or 1/16 bends, except that sanitary tees may be used on vertical stacks, and short 1/4 bends or elbows may be used in soil and waste lines when the change in direction of flow is from the horizontal to the vertical, and on the discharge from water closets.

(2) Union Connections: Slip joints will be permitted only in trap seals or on the inlet side of the traps. Hubless, Tucker or hub drainage fittings shall be used for making union connections wherever practicable in connection with dry vents. The use of long screws and bushings is prohibited.

(3) Joints:

a. Hub-and-Spigot Pipe: Joints in hub-and-spigot cast-iron soil, waste, and vent pipes, or between cast-iron soil, waste, and vent pipes and threaded pipes, or calking ferrules shall be firmly packed with oakum or hemp and calked with lead at least 1 inch deep. Threaded pipe shall have a ring or half-coupling screwed on to form a spigot end.

b. Hubless Pipe: Hubless cast-iron pipe joints shall conform to CISPI* 301. Each bolt of the shield and clamp assembly shall be torqued to 60 inch pounds with a torque wrench, and shall be re-torqued not sooner than 4 hours later. The use of screwdrivers or other types of wrenches will not be permitted in making these joints.

*Cast Iron Soil Pipe Institute.

c. Threaded Pipe: Threaded joints shall have American National taper pipe threads conforming to NBS* H28 with graphite or inert filler and oil, with an approved graphite compound, or with polytetrafluoroethylene tape applied to the male threads only.

*U.S. Dept. of Commerce, National Bureau of Standards.

d. Tubing: Tubing shall be cut square, and burrs shall be removed. Both inside of fittings and outside of tubing shall be well cleaned with abrasive material before sweating. The installation shall be made in accordance with the manufacturer's recommendations. Joints shall be made with fittings. Mitering or notching for the purpose of making joints will not be permitted. Joints shall be made with a noncorrosive paste flux and solid string or wire solder composed of not less than 50 percent tin and 50 percent lead.

e. Plastic Pipe: Jointing of plastic pipe and fittings shall be with a solvent cement conforming to CS272* or CS270* as applicable. The solvent cement joining method and connection to nonplastic materials shall be in accordance with Appendix 1 of CS272 or CS270 as applicable.

*U.S. Dept. of Commerce, Commercial Standards

15A.14.3 Water Piping and Connections.–

15A.14.3.1 Service Valve.–A gate valve with drain on the service line shall be installed in an accessible location inside each building. The piping shall be extended to all fixtures, outlets, and equipment from the valve. The cold water system shall be installed with a fall toward the shutoff valve.

15A.14.3.2 Wall Hydrants.–Wall hydrants shall be installed where indicated, approximately 18 inches above grade.

15A.14.3.3 Dielectric Unions.–Dielectric unions shall be provided between ferrous and nonferrous piping to prevent galvanic action.

15A.14.3.4 Piping.–Piping for mains, branches, and runouts shall be cut accurately to measurements established at the building by the Contractor, and shall be worked into place without springing or forcing. Care shall be taken not to weaken the structural portions of the building. Piping aboveground shall be run parallel with the lines of the building unless otherwise indicated. Underground piping shall be installed with a minimum number of joints. Unions shall not be installed in walls and ceilings, partitions or under floors. Branches from service lines may be taken off top of main, bottom of main, or side of main, using such crossover fittings as may be required by structural or installation conditions. Changes in size of pipe shall be made with reducing fittings. Flexibility shall be provided on all branches to allow for expansion and contraction of piping. Expansion loops, offsets or swing joints shall be provided for each straight main run of over 50 feet in length. No valve shall be installed with the stem below the horizontal.

15A.14.3.5 Drains: Drains shall be 1/2-inch brass plugs and shall be installed at all low points in hot- and cold-water piping. When waterlines are installed below floor slabs on grade, or other locations where it is impossible to drain by gravity, provide valved tees for purging.

15A.14.3.6 Relief Valves. The temperature-sensing element shall be in contact with the hottest water in the tank. No valve shall be installed on the discharge line of the relief valve

15A.14.4 Pipe Covering.—After the piping has been cleaned and satisfactory tests have been completed, mineral-fiber pipe covering shall be installed in hot-water and cold-water lines installed in exterior walls and attics. Valves and fittings shall be covered with premolded, prefabricated, or field-fabricated insulation of the same material and thickness as the pipe covering. Insulation for cold-water lines shall have a vapor barrier jacket, factory-applied. Pipe covering shall be installed in conformance with the approved recommendations of the manufacturer.

15A.14.5 Pipe Sleeves, Pipe Hangers, and Fixture Supports. Pipe sleeves, pipe hangers, and fixture supports shall be furnished and set, and the Contractor shall be responsible for the proper and permanent locations.

15A.14.5.1 Pipe Sleeves: Install and properly secure pipe sleeves in place at all points where pipes pass through masonry or concrete except slabs on or below grade. Pipe sleeves in footings shall be cast-iron or steel. Pipe sleeves in masonry walls and partitions shall be cast-iron, wrought-iron, or steel and of sufficient size to accommodate insulation on insulated pipes. Pipe sleeves in floors shall be zinc-coated 26-gauge sheet steel, fiber with wall thickness not less than 1/4-inch, or other suitable approved material.

15A.14.5.2 Pipe Hangers:

a. Copper Tubing: Horizontal runs of copper tubing shall be supported by bronze-coated steel or copper hangers spaced not more than 8 feet on centers.

b. Drainage and Vent Piping: Horizontal runs of drainage and vent piping shall be supported by zinc-coated steel strap hangers.

c. Threaded Piping: Hangers on horizontal threaded piping shall be spaced not more than 10 feet on centers.

d. Bell-and Spigot, and Hubless Piping: Hangers on bell-and-spigot and hubless piping shall be spaced 5 feet on centers, anchored to joists with lag screws of a diameter equal to the diameter of the supporting rod.

Plastic Piping. Hangers for plastic-piping shall be spaced 4 feet on centers, and shall have a minimum of 7/8-inch wide surface in contact with the pipe, material as recommended by the manufacturer.

Vertical Piping: Vertical runs of piping shall be supported by heavy wrought-steel clamps, spaced not over 15 feet apart.

15A.14.6 Supports and Fastenings for Fixtures and Equipment. Provide necessary supports for fixtures and equipment as follows:

(1) Wood Studs: Wood crosspieces shall be installed and fixtures shall be fastened with not less than No. 10 wood screws or 3/8-inch steel hanger or table bolts with nut. The wood crosspieces shall extend the full width of the fixture and shall be securely supported.

15A.14.7 Floor, Wall, and Ceiling Plates.—Uncovered exposed pipes, where passing through floors, finished walls, or finished ceilings, shall be fitted with chromium-plated cast-brass plates on chromium-plated pipe, and with cast-iron on steel plates on ferrous pipe. Plates shall be large enough to completely close holes around pipes and shall be square, octagonal, or round, with the least dimension not less than 1-1/2 inches larger than diameter of pipe. Plates shall be securely fastened in place with a set screw or similar device.

15A.14.8 Fixture Connections.—Fixture connections between earthenware fixtures and flanges on soil pipe shall be made gastight and watertight.

15A.15 Inspection and Tests.—

15A.15.1 Tests for Plumbing Systems. Soil, waste, vent, drainage, and water piping shall be tested by the Contractor and approved by the OICC before acceptance. Soil or waste piping located underground shall be tested before backfilling. Equipment required for tests shall be furnished by the Contractor without additional cost to the Government.

(1) Drainage, Soil, Waste, and Venting System: Piping shall be tested with water or air before fixtures are installed. After the plumbing fixtures have been set and the traps filled with water, the entire drainage and venting system shall be submitted to a final test with smoke or peppermint.

(a) Water Test: Water test shall be applied to the drainage, soil, waste, and venting system either in the entire system or in sections. If the test is applied to the entire system, all openings in the piping shall be tightly closed except the highest opening, and the system shall be filled with water to the point of overflow. If the system is tested in sections, each opening except the highest opening of the section under test shall be tightly plugged, and each section shall be filled with water and tested with at least a 10-foot head of water. In testing successive sections, at least the upper 10 feet of the next preceding section shall be tested so that each joint or pipe in the building except the uppermost 10 feet of the system has been submitted to a test of at least a 10-foot head of water. Water shall be kept in system, or portion under test, for at least 15 minutes before inspection starts, the system shall then be tight at all joints.

(b) Air Test: If tests are made with air, a pressure of not less than 5 pounds per square inch shall be applied with a force pump and maintained at least 15 minutes without leakage. A mercury-column gauge shall be used in making the air test.

(c) Final Tests: Smoke or peppermint type tests shall be used for final testing. Smoke, produced by a smoke machine, shall be used to make the test, and pressure equal to a 1-inch water column shall be maintained for 15 minutes before inspection is started. At Contractor's option, peppermint may be introduced into each line or stack, in the amount of 2 ounces.

(2) Water System: Upon completion of roughing-in operations and prior to concealing in the structure and the setting of plumbing fixtures, the entire hot- and cold-water piping systems shall be tested at a hydrostatic pressure of not less than 100 pounds per square inch gauge, and proved tight at this pressure. Where a portion of the water-piping system is to be concealed before completion, such portion shall be tested separately in the same manner as specified for the entire system.

(3) Defective Work: If an inspection or tests show defects, such defective work or material shall be replaced, and inspection and tests shall be repeated. Re-tests shall be made by the Contractor, when directed by the OICC, with no additional cost to the Government. Repairs to piping shall be made with new material. Calking of screwed joints or holes will not be acceptable.

For additional information on writing project specifications see *Format and General Paragraphs for the Preparation of Manuscripts of Specifications for Construction Contracts for Public Works*, NAVFAC Specification TS-M129 (latest revision); *Drawings and Specifications*, NAVFAC DM-6, chapter 3; and *Uniform System for Construction Specifications, Data Filing, and Cost Accounting*, Document No. K103, published by the American Institute of Architects, 1785 Massachusetts Avenue, N.W., Washington, D.C. 20036.

CHAPTER 13

SCHEDULING

When a CONSTRUCTION ORDER is received by the Commanding Officer of a Naval Mobile Construction Battalion, a detailed and careful study should be made on construction planning, estimating, and scheduling of the proposed project. Through this construction order, which is in fact the CONSTRUCTION PLAN itself, the Commander, Advanced Base Construction Force, assigns the construction projects to his subordinate units. He designates their objectives and defines the limits of their responsibilities and authorities. Regardless of the makeup of construction units in a joint operation, subordinate units are responsible for carrying out the task assignments and logistic provisions of the plan. The construction order shows the relative priorities for the components of each project. It indicates a target date for initial occupancy and the final completion date required by operational plans. The scope of the construction plan is, therefore, the basis in the preparation of schedules. The urgency in completing the project will certainly affect the progress, manpower, equipment, and material schedules.

As an EA1 or EAC, you will be involved in the preparation of various schedules for those projects assigned to the battalion for accomplishment. You will also be concerned with planning and estimating; detailed information on planning and estimating is given in the preceding chapter. In this chapter we will discuss some of the primary factors relating to scheduling, such as elements of scheduling, types of schedules, and techniques of scheduling. We will also discuss procedures used to control progress on construction jobs. Of course there are various methods of scheduling. In this training manual, however, special attention is given to Network Analysis Systems, particularly the use of the arrow diagram used to determine the Critical Path Method (CPM). Various fundamentals of CPM are covered, and the method of constructing a CPM diagram is explained. From experience you may already have learned that Network Analysis Systems are a valuable management tool when it comes to planning, scheduling, and controlling construction operations. Therefore, a thorough knowledge of Network Analysis Systems, particularly arrow diagrams, may be to your advantage—both now and later.

Perhaps from your experience you also have heard of, or have been involved in, the Program Evaluation and Review Technique (PERT) of planning and evaluation of schedules. It could be said that PERT is a parallel of CPM, and that PERT is both adaptable to manual and computerized data processing. The computer is used as a clerical aid to process data when the volume exceeds the amount that can be handled efficiently by hand. PERT has been used intensively to aid managers in planning and controlling the three variables of large weapon system development programs—time, cost, and technical performance. There are programmed instructions on development of the PERT network as applied to planning and evaluation of schedules. The PERT scheduling method, however, is beyond the scope of this training manual.

SCHEDULING PRINCIPLES

Scheduling is the process of determining when a work element should be performed and when materials, equipment, and manpower will be required. The purpose of scheduling is to prepare a plan of future procedure which will ensure the most efficient use of equipment and manpower in the construction of a project within the allotted time. The achievement of this objective is complicated by the fact that a battalion on deployment has a fixed number of men available (usually within narrow limits), and a fixed amount of equipment. This means that men cannot be "laid off" during slack times, or the supply of men increased by hiring new ones during peak times; similarly, extra equipment cannot be rented in peak times, nor idle equipment be disposed of in slack times.

For this reason, absolute efficiency must occasionally be sacrificed to keep men and equipment fully employed to the best advantage. For example, to keep a concrete crew busy, excavation should be made by hand instead of waiting several days for equipment to become available. The art of scheduling is a variable one, and to arrive at the best possible schedule, several trials are needed. Analyze every approach you make carefully, and then utilize the one that will give the maximum use of manpower and equipment in the least time.

APPLICATION OF SCHEDULING

Scheduling is used to plan the sequence of projects on a deployment, and also the sequence of operations on each project. Work schedules show the planned starting and completion time for each operation, thus indicating the time required for each. These schedules are the basis for determining when and how much manpower and equipment are required for each portion of the work, and are therefore the basis for scheduling manpower and equipment, and for determining delivery times for materials not initially shipped within the battalion's equipment and gear.

The planned work schedules of the deployment as a whole, and of each project of the deployment, are used in preparing monthly progress and performance reports.

ELEMENTS OF SCHEDULING

The elements used in scheduling work include the work item number, the item description, the unit of measurement (cu yd, sq yd, ton, each, etc.), the quantity of work to be performed, the relation of each item to the whole in terms of work to be performed (such as percentage of the total work required for each item), the units of time to be used in the schedule, the starting date, the time required for each item, and the completion date. The elements used in scheduling equipment and manpower are similar, but in addition include the number of pieces of equipment and number of men.

TYPES OF SCHEDULES

Work schedules are usually prepared for the deployment as a whole and for each project of the deployment. Manpower and equipment schedules are normally prepared at the same time, because the information they contain is required for preparation of the work schedules. The separate projects of a deployment are scheduled in the deployment schedule, the separate work elements of a project are scheduled in a project schedule.

A typical deployment work schedule is shown in figure 13-1. The deployment will accomplish three projects: the construction of 22 replacement housing units, the laying of 12,600 lin ft of petroleum oil lubricant (POL) system, and the construction of 28,000 sq yd of road. It is estimated that, of the total work time allotted, 58.7 percent will be required for the replacement housing, 23.9 percent for the POL system, and 17.4 percent for the roads.

Project 1 will begin in March and end in October, project 2 will begin in April and end in October, and project 3 will begin in March and end in July. The estimated percentage of completion of each project for each month is as shown. These monthly figures are used to determine the estimated percentage of completion of the total project (deployment) shown at the bottom of the page. For example, in April, 25 percent of 58.7 percent, 2 percent of 23.9 percent, and 31 percent of 17.4 percent of the work will be completed. This works out to be 21 percent of the total work.

Figure 13-2 shows the work schedule for one of the projects shown in figure 13-1.

Figure 13-3 shows the deployment manpower schedule for one month of the deployment. The total man-days per month figure at the bottom is simply the sum of the total men per day full-day figures plus half the sum of the total men per half-day figures.

Figure 13-4 shows a one-month manpower schedule for one of the projects shown in figure 13-3.

Figure 13-5 shows the equipment schedule for the deployment. The interval during which each

DEPLOYMENT WORK SCHEDULE

NMCB 12 Location -- Bermuda Year -- 19 Prepared 1-3- by J. Smith

PROJECT NO.	DESCRIPTION	UNIT	QUANTITY	WEIGHTED VALUE [1]	MONTHLY PRODUCTION - EST. AND ACT.							
					Mar	Apr	May	June	July	Aug	Sept	Oct
1	Replacement Housing	Units	22	58.7	10	25	34	43	52	66	85	100
2	POL System	LF	12,600	23.9		2	18	39	58	80	91	100
3	Roads	SY	28,000	17.4	8	31	58	75	100			
	Total Project			100.0	7	21	34	48	52	76	89	100

[1] Weighted value is the percentage of the total man-days allocated to each project.

82.91

Figure 13-1.—Deployment work schedule.

PROJECT WORK SCHEDULE

NMCB 12 Location -- Bermuda Year -- 19 Prepared 1-3- by J. Smith
Project -- POL System

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	WEIGHTED VALUE	MONTHLY PRODUCTION - EST. AND ACT.							
					Mar	Apr	May	June	July	Aug	Sept	Oct
2A11	Trenching, Ditching, & Backfilling	CY	2,200	9.1		10	27	44	61	78	95	100
2M2	Install Valves	Each	25	0.9					15	50	80	100
2M4	Construction Valve Pits	Each	10	10.9			10	40	65	90	100	
2M13	Install 12" Pipe	LF	12,600	58.2			20	39	58	77	95	100
2R9	Pump House	Each	1	15.4			15	40	65	85	100	
2Q3	Work not covered above	L S	1	5.5		5	20	40	55	70	90	100
	Total Project			100.0		2	18	39	58	80	91	100

82.92

Figure 13-2.—Project work schedule.

DEPLOYMENT MANPOWER SCHEDULE

NMCB 12 Location -- Bermuda Year -- 19 Prepared 1-3- by J. Smith
Project -- POL System

PR. NO	DESCRIPTION		July 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	Replacement Housing	E	47	47	49	X	49	X	49	41	48	48	48	59	X	46	54	54	50	54	54	X	54	47	47	43	50	47	X	47	47	42	42
		A																															
2	POL System	E	50	50	48	X	49	X	48	56	49	49	49	43	X	51	43	43	47	43	43	X	43	50	50	54	47	50	X	50	50	55	55
		A																															
3	Roads	E	40	40	40	X	40	X	40	40	40	40	40	40	X	40	40	40	40	40	40	X	40	40	40	40	40	40	X	40	40	40	40
		A																															
		E																															
		A																															
		E																															
		A																															
		E																															
		A																															
		E																															
		A																															
Total Men per Day		E	137	137	137	X	137	X	137	137	137	137	137	137	X	137	137	137	137	137	137	X	137	137	137	137	137	137	X	137	137	137	137
		A																															
Total Man-Days per Month		E	3288																														
		A																															

☒ Denotes Sundays and holidays when no work is scheduled.

◸ Denotes Saturdays when half day's work is scheduled.

82.93

Figure 13-3.–Deployment manpower schedule.

PROJECT MANPOWER SCHEDULE

NMCB 12 Location -- Bermuda Year – 19 Prepared 1-3- by J. Smith
Project -- POL System

IT. NO	DESCRIPTION		July 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2A11	Trenching, Ditching, Backfill	E	2	2	2	X	2	X	2	2	2	2	2	2	X	2	2	2	2	2	7	X	7	7	7	1	7	7	X	7	7	7	7
		A																															
2M2	Install Valves	E			2	X	2	X	2	2					X							X	2	2	2				X				
		A																															
2M4	Construct Valve Pits	E	6	6	6	X	6	X	6	10	5	5	5	6	X	10	6	6	10	6	6	X	6	6	10	5	5	5	X	5	5	10	10
		A																															
2M13	Install 12" Pipe	E	26	26	26	X	26	X	26	26	26	26	26	26	X	26	26	26	26	26	26	X	19	26	22	33	23	26	X	26	26	26	26
		A																															
2R9	Pump House	E	12	12	12	X	12	X	12	12	12	12	12	9	X	9	9	9	9	9	9	X	7	7	7	7	10	10	X	10	10	10	10
		A																															
2Q3	Work not covered above	E	4	4		X		X		4	4	4	4	4	X	4						X	2	2	2	2	2	2	X	2	2	2	2
		A																															
		E																															
		A																															
Total men per day		E	50	50	48	X	48	X	48	56	49	49	49	47	X	51	43	43	47	43	43	X	43	50	50	54	47	50	X	50	50	55	55
		A																															
Total man-days per month		E	1268																														
		A																															

82.94

Figure 13-4.–Project manpower schedule.

DEPLOYMENT EQUIPMENT SCHEDULE

NMCB 12 Location--Bermuda Year--19 Prepared 1-3- by J. Smith

PROJECT NO. & DESCRIP.	EQUIPMENT	NO. REQ.	Mar	Apr	May	June	July	Aug	Sept	Oct
1 Replacem't Housing	Air Compressor, 210 CFM	1								
	Bulldozer, 113/130 DBHP	1								
	Crawler Crane, 45 Ton	1								
	Mortar Mixer, 6 CF	2								
	Motor Grader, 12' Blade	1								
	Trucks, 2 Ton, Stake	3								
2 POL System	Bulldozer, 113/130 DBHP	1								
	Mortar Mixer, 6 CF	1								
	Motor Crane, 20 Ton	2								
	Trenching Machine	1								
3 Roads	Asphalt Distributor, 24' Width	1								
	Asphalt Finisher, 10'-14' Width	1								
	Asphalt Plant, Complete, 100 Ton	1								
	Bulldozer, 110/113 DBHP	2								
	Motor Grader, 12' Blade	1								
	Scrapers, Self-Propelled, 12 CY	3								
	Tandem Roller, Self-Propelled	1								
	Tractor, Pusher, 113/130 DBHP	1								
	Trucks, 10 Ton, Dump	3								
	Vibrating Compactor	1								
All Projects	Concrete Batch Plant, Complete	1								
	Transit-Mix Trucks, 5½ CY	3								

82.95

Figure 13-5.—Deployment equipment schedule.

item of equipment will be required is indicated by a BAR at the right, for this reason, this type of schedule is called a Bar Chart. In figure 13-6 a similar bar chart shows a typical equipment schedule for one of the projects. Figure 13-7 shows a simple tabular type of project work schedule.

PREPARATIONS FOR SCHEDULING

Certain preparations should be made before scheduling is begun. The work element estimate, the equipment estimate, the manpower estimate, and the material estimate should be available for ready reference as sources of information. If possible, a visit should be made to the proposed construction site to determine availability of local materials, obstructions on the site, types of soil to be worked, special equipment required, and any other conditions which might affect construction. If it has not already been done, the plant and equipment to be used should be planned, including storage of construction materials. Crew sizes should be determined. Estimated time of arrival of the battalion and the advance party at the deployment site must be known. Priorities for projects must have been established, and any critical completion dates must be known. When all this information has been assembled, scheduling of the various construction operations can begin.

TECHNIQUES OF SCHEDULING

It is usually best to begin scheduling with a preliminary work schedule of the whole deployment, listing each project and showing the estimated starting and completion dates for each. The estimated time of arrival (ETA) of the battalion or advance party is usually the starting

PROJECT EQUIPMENT SCHEDULE

NMCB 12 Location -- Bermuda Year -- 19 Prepared 1-3- by J. Smith
Project -- POL System

ITEM NO. & DESCRIPTION	EQUIPMENT	NO. REQ.	Mar	Apr	May	June	July	Aug	Sept	Oct
2A11 Trench & BF	Trenching Machine	1		—	—	—	—	—		
	Bulldozer, 130 DBHP	1			—	—	—	—	—	—
2M2 Inst Valves	Motor Crane, 20 Ton	1								
			Work in conjunction with 12" pipe							
2M13 Inst 12" Pipe	Motor Crane, 20 Ton	2			—	—	—	—	—	—
	Bulldozer, 130 DBHP	1		—	—					
2R9 Pump House	Motor Crane, 20 Ton	1				—				
	Mortar Mixer, 6 CF	1			—	—				

82.96

Figure 13-6.—Project equipment schedule.

PROJECT WORK SCHEDULE

NMCB 12 Location -- Bermudo Year -- 19 Prepared 1-3- by J. Smith
Project -- POL System

ITEM NO.	DESCRIPTION	UNIT	QUANTITY	WEIGHTED VALUE	ESTIMATED		ACTUAL	
					START	FINISH	START	FINISH
2A11	Trenching, Ditching, & Backfilling	CY	2200	9.1	4-16-66	10-18-66		
2M2	Install Valves	Each	25	0.9	7-16-66	10-16-66		
2M4	Construct Valve Pits	Each	10	10.9	5-14-66	9-20-66		
2M13	Install 12" Pipe	LF	12,600	58.2	4-30-66	10-16-66		
2R9	Pump House	Each	1	15.4	5-14-66	9-29-66		
2Q3	Work not covered above	L/S	1	5.5	4-16-66	10-18-66		
	Total Project			100.0	4-16-66	10-18-66		

82.97

Figure 13-7.—Simple tabular project work schedule.

date of the highest priority projects. The time required for completion of each project may be obtained by dividing the man-days estimated to construct the project by the average number of men expected to be assigned to it. Using this time allotment and the starting day, and allowing for days not worked, the estimated completion date can be determined.

In determining the average number of men, some projects should be considered in phases. For instance, a larger number of men will be used during construction of the foundation and shell of a building than during the finishing of the interior.

Each project of the deployment is scheduled, listing the work elements of the project. The construction sequence is determined (obviously, excavating comes before foundation placement, wall construction before the installation of finish door and window frames, subbase and base before pavement, and so on). The starting date on the preliminary work schedule is used as the starting date of the work element which is first in construction sequence.

The time required for each work element can be determined by dividing the estimated man-days by the number of men expected to be assigned for construction of the element. Each work element is scheduled in its proper construction sequence, showing starting and completion dates. Often, however, it is not necessary that one element be completed before another is started. For example. concrete foundations and walls can be started at one end of a building while excavating is still going on at the other, or paving can begin at one end of a road while grading is still going on at the other.

After all the projects are scheduled, they are checked against the preliminary work schedule for the deployment to see if the starting and completion dates agree. If they do not, the preliminary work schedule is revised to conform to the project schedules. A manpower schedule is prepared for each project, listing the work elements and the number of men assigned each day (or a longer period, if more convenient). If this schedule shows, as is likely, periods of high and low manpower requirements, adjustments must be made in the project schedules to level out the manpower demand.

For example. if only 150 men are available for construction, obviously the schedule must not show days when 200 men are required, however, it should not show days when only 100 are required, either. Similar considerations apply to equipment schedules. Adjustments must be made, not only to ensure that manpower and equipment assignments remain within the limits of availability, but also to ensure that all available manpower and equipment are utilized.

At this point, changes in any one schedule will probably require corresponding adjustments in all of the others. Several adjustments will probably be required before a practical, workable schedule is attained, permitting all of the work to be completed within the time allotted for the deployment.

PROGRESS CONTROL

Progress control is exercised by:

1. Measuring actual production against planned production.
2. Determining causes of discrepancies, if there are any discrepancies.
3. Taking remedial action to correct deficiencies in production, and to balance activities in order to attain overall objectives.

REPORTING PROGRESS

Work accomplished should be reported on daily labor reports. However, in some types of work, it is more convenient to report work quantities when a portion has been completed, rather than attempt to report partial completion of the portion. For example: if 2000 sq ft of forms are required for a section of concrete wall, it is difficult to estimate partial progress, and no report is usually made until the form work is completed, ready for concrete casting.

Items suitable for daily reporting are those which may reasonably be expected to show a fairly steady production rate per man, such as laying concrete block, placing concrete or asphalt paving, or the excavating and/or hauling of large quantities of cut and fill. For such items, daily reports provide a continuous, running check on progress.

A daily report should show the hours worked on each work element. Preparation of weekly or monthly reports is accomplished by recording daily reports in ledger form and totaling for a week or month. Ledgers should show both the man-days and quantities of each work element of each project.

Monthly progress reports are usually made in narrative form, with a progress chart (explained later) included in the report. Major problems affecting progress are described, and any unusual construction methods are reported in detail, with sketches included if necessary. If progress is behind schedule, the report should describe what measures are being taken to bring it back on schedule, or explain why the completion date cannot be met and what extension of time is needed for completion. The procedure of preparing monthly progress reports by the battalions is explained in the latest COMCBPAC or COMCBLANT INSTRUCTION on the subject.

CHARTING PROGRESS

A common way of charting progress is to insert percentages of actual work complete in spaces left adjacent to the figures for estimated completion percentages on work schedules. With the critical path method (CPM) of scheduling (which is described in this chapter) a time grid chart is used to show progress, as will be explained.

FOLLOW-UP ACTION

As soon as it becomes apparent that the job is falling behind schedule, an investigation should be made to determine where the fault lies, and action should be taken to bring the project back on schedule, if possible. Because work on a project usually has to be performed in a sequence of operations, delays in completing an activity may cause delays in other activities and cause the project to fall behind schedule. When this happens, the usual remedy is to increase the crew on the work that is behind, or work the existing crew overtime.

Often it is possible to start work before preceding work is completed, thereby gaining some time. It is usually necessary during construction to increase some crews and reduce others because work is being performed slower or faster than was estimated. Changes of this type must be made as soon as the need for them becomes obvious.

Sometimes work can be speeded with additional equipment, either by using additional units of a type of equipment already in use, or by using equipment not originally scheduled to be used.

Sometimes rescheduling for a longer allotted time is unavoidable. This is usually the case only when conditions are different from those originally presumed such as the unexpected discovery of much rock in an excavation area previously assumed to be rock-free.

After changes have been made to correct a lagging schedule, frequent checks must be made to see if the changes are accomplishing the desired results. If not, additional changes must be considered.

THE CRITICAL PATH METHOD

In recent years a new system of project planning, scheduling, and control, called the CRITICAL PATH METHOD (CPM), has come into existence and into widespread use in the construction industry. The inception of this system was developed and tested with great success in the construction of polaris submarines. CPM came into being because it was believed that traditional methods were inadequate for controlling large-scale engineering projects. The object of CPM is to combine all the information relevant to the planning and scheduling of project functions into a single master plan—a plan that coordinates all of the many different efforts required to accomplish a single objective, that shows the interrelationships of all of these efforts, that shows which efforts are critical to completion, and hence enables the most efficient use of equipment and manpower.

ARROW DIAGRAMMING

Instead of using several sets of bar chart schedules, difficult to coordinate with each other, CPM represents each work element by an arrow on one chart. The tail of the arrow represents the start of the element, the head represents the finish. When the arrows are related to time required for each element, the time length of the longest path through the diagram equals the total time required for completion. Shorter paths are followed by arrows indicating elements which can be performed simultaneously with others. Every element on the longest path is CRITICAL, in that any delay in one of these delays the whole project. An element on a shorter path is noncritical, in that a delay here (within limits, of course) will not delay the whole project. It follows that, if a project falls behind, only elements on the critical path require speeding up.

PLANNING

Two of the basic ground rules of CPM are that planning and scheduling are considered to be two distinctly separate operations, with planning always preceding scheduling.

A project plan is made without taking time or the availability of resources (such as men and equipment) into consideration. Planning consists of analyzing the project, breaking it into work elements, and arranging these work elements into the arrow diagram which becomes the working model of the project. As each work element is defined, three questions are asked about it, as follows:

1. What immediately precedes this work element?
2. What immediately follows this work element?
3. What other elements (if any) can be done simultaneously with this one?

Development of Arrow Diagram

An arrow is drawn for each work element. The head of the arrow represents the completion of the job; the tail represents the beginning. The tail is connected to all of the work elements that must be completed immediately before the job under consideration can begin. The head is connected to all of the jobs that cannot begin until the job being considered has been completed. See, for example, figure 13-8. In this diagram, job A must be completed before jobs B and D can start. When job B has been completed, job F and C can start. Jobs E, C, and F must be finished before job G can begin. Finally, job H can begin when job G is finished.

Figure 13-9 shows an arrow diagram for a project consisting of the construction of an arch-type high explosives magazine. The project contains the following work elements:

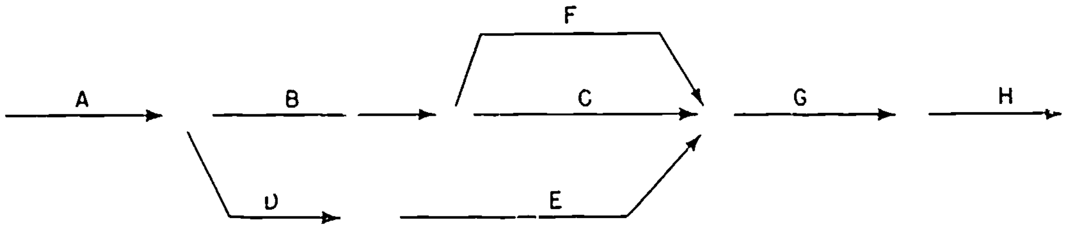
Excavate the foundations
Reinforce, pour, and cure footings
Pour and cure floor slab
Form, reinforce, pour, and cure the arch
Form, reinforce, pour, and cure front and rear walls
Waterproof topside of arch
Install ventilator
Place and compact magazine earth cover
Perform final grading and cleanup.

Obviously, the foundations must be excavated before anything else can be done, so you draw an arrow at the left and label it "Excavate Foundations." When the foundations are excavated, the footings can be poured; therefore, the tail of an arrow marked "Reinforce, Pour, and Cure Footings" is connected to the head of the previous arrow. When the footings have set and cured, the floor slab can be poured; therefore, the tail of an arrow marked "Pour & Cure Floor Slab" is connected to the head of the footings arrow. Once the floor slab is set and cured, the arch can be formed, poured and cured; therefore, the tail of an arrow marked "Form, Pour, & Cure Arch" is connected to the head of the floor slab arrow.

With the arch cured, the front and rear walls can be built. Simultaneously with this operation, two others can be carried on: installing the ventilator and waterproofing the arch. Since all three of the simultaneous jobs must be completed before anything else can be done, however, the heads of the three arrows all converge at the same point. When all three jobs are done, the earth cover can be placed and compacted, and then the final grading and cleanup done.

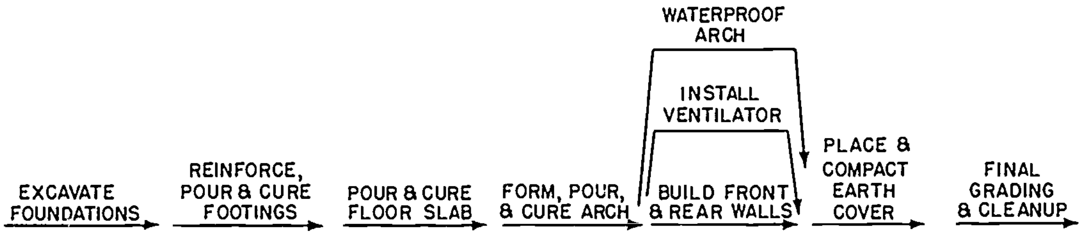
PARALLEL WORK ELEMENTS.—Suppose a project consists of laying a pipeline from A to B. Work elements might be: (1) trenching, (2) pipelaying, (3) welding, and (4) backfilling. Obviously, however, it would not be necessary or economical to complete one of these before starting the next; as soon as an appreciable amount of trenching is done, pipe laying can begin, and so on, until all four elements are being performed simultaneously. However, no one element can be COMPLETED until the previous element has been completed; welding, for example, cannot be completed until all the pipe has been laid.

In a case of this kind, you break each work element arrow into two parts, one showing the start and the other the finish, as shown in figure 13-10.



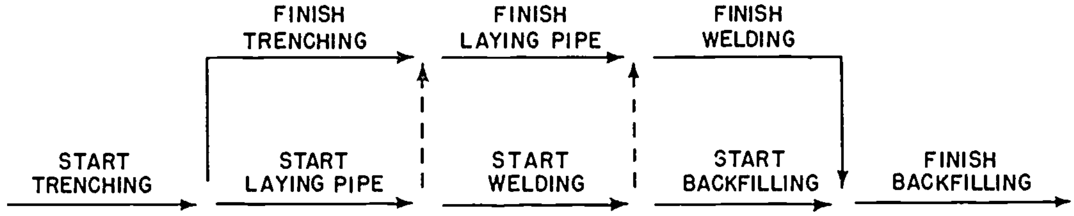
82.98

Figure 13-8.–Arrow diagram for critical path method.



82.99

Figure 13-9.–Work element arrow diagram–arch-type high explosives magazine.



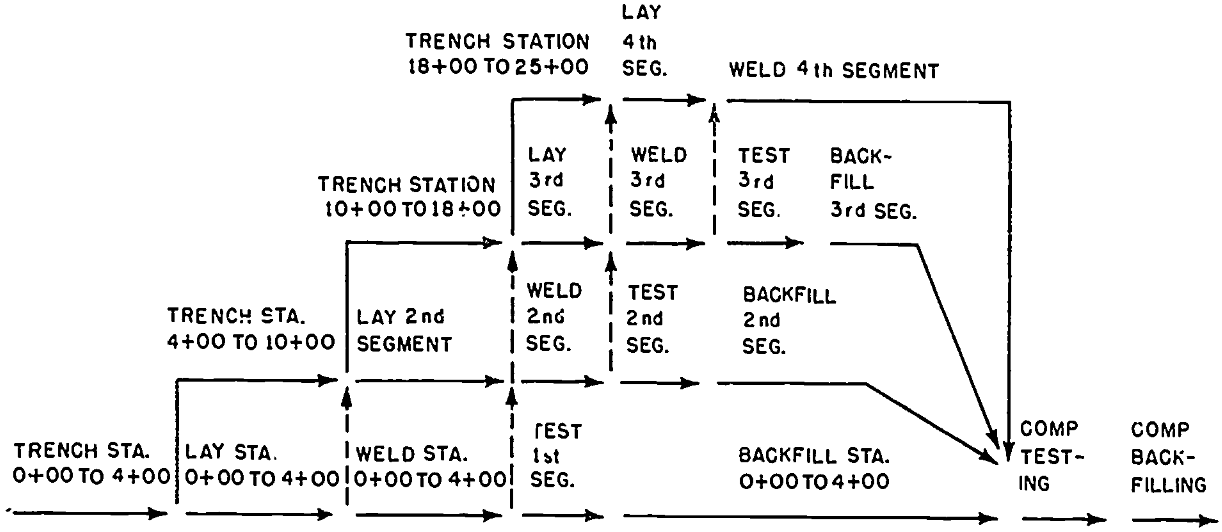
82.100

Figure 13-10.–Arrow diagram showing parallel work elements.

On a specific project such as the installation of a 2,500-ft POL welded pipeline, you can even break down the work elements further into segments, as shown in figure 13-11.

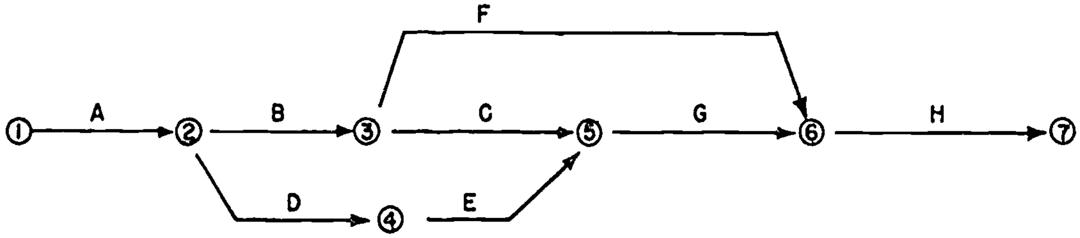
EVENTS AND EVENT NUMBERING.–The points where arrows connect are called EVENTS; these points are points in time, marking the completion of some work and the beginning of other work. Events are numbered from left to right through the diagram. The event number at the head of an arrow must always be greater than that at the tail.

Figure 13-12 shows an arrow diagram with events numbered correctly. You can see that the arrows start from a circle and end on a circle enclosing the event numbers. These circular junctions are called NODES. It would be incorrect to label the event at the end of job C with the number 4 and that at the end of job D with 5; if you did this, the event at the beginning of job E would be 5 and that at the end 4–meaning that the number at the tail of that arrow would be greater than the number at the head.



82.100(82A)

Figure 13-11.—Arrow diagram showing parallel and overlapping work elements for a 2,500-ft welded pipeline.



82.101

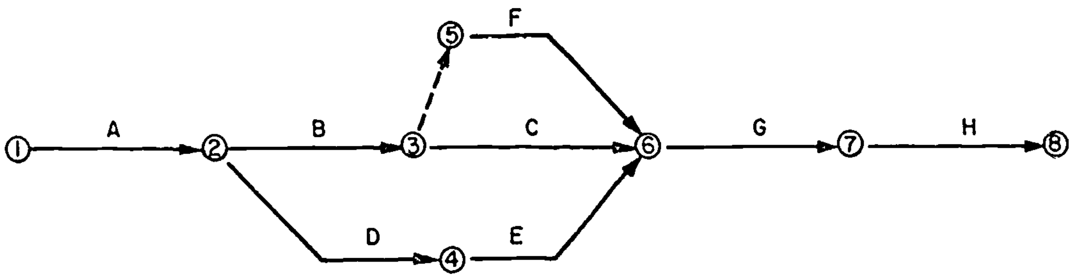
Figure 13-12.—Events and event numbering.

Each work element is identified by the event numbers of its arrow. Job B in figure 13-12, for example, would be identified as job (2,3).

NOTE: In actual practice, the events would not be numbered until after the diagram is completed.

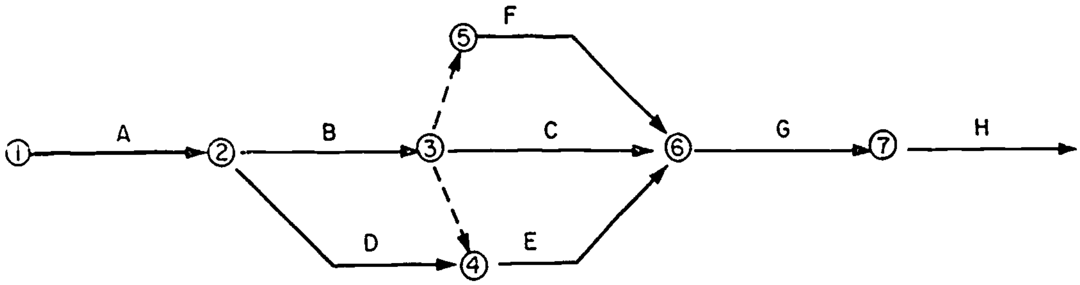
USE OF DUMMY EVENTS.—Now, there may be two or more jobs going on simultaneously, in which case, in the absence of a device of some kind, the events for these jobs would have the same event numbers. To avoid this, DUMMY EVENTS are used with ARTIFICIAL event numbers, as shown in figure 13-13. The artificial event number 5 and the dummy event (dotted from 3 to 5) have been introduced so that job F will not have the same event numbers as job C.

DEPENDENCY.—If the job B cannot start until job A is completed, job B is said to be DEPENDENT on job A. In that case, a dummy event is used to indicate this relationship. The dummy event (3,4) in figure 13-14, indicates that job E, which is job (4,6), cannot begin until job B, which is job (2,3), is completed. The fact that the tail of the arrow for job E lies at the head of the arrow for job D already indicates



82.102

Figure 13-13.–Dummy event (3,5).



82.103

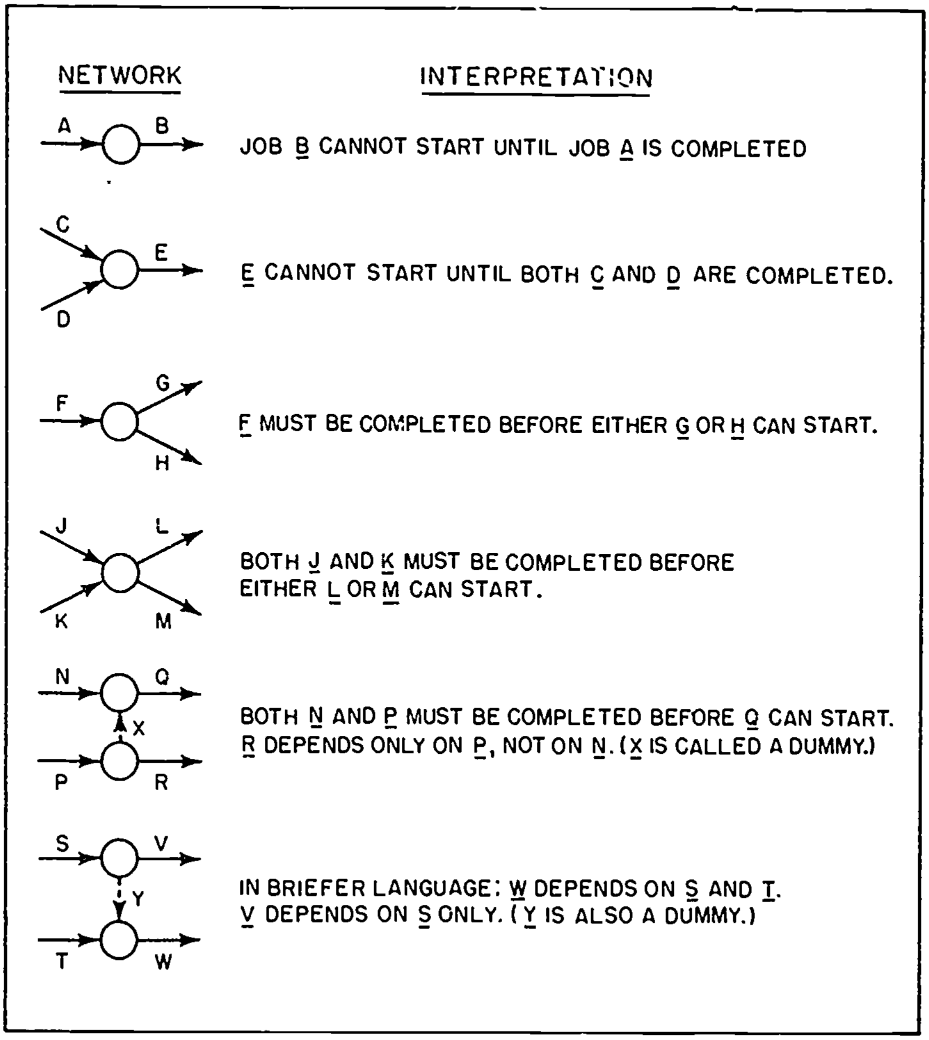
Figure 13-14.–Dummy event (3,4) indicates dependency.

that E cannot start until D is completed. With the dummy event added, the diagram indicates that E cannot start until both D and B are completed.

RESTRAINT.–A condition which is not a work element in a project, but on the fulfillment of which project work depends, is called a RESTRAINT. Suppose, for example, that a bulldozer is required before a certain element can be started. Requisitioning the bulldozer is project work which must be scheduled, delivery of the bulldozer, however, is not project work, but a restraint, or condition on which the work element involving the bulldozer depends.

FINAL CHECK OF DIAGRAM.–The completion of the arrow diagram ends the planning stage of CPM planning and scheduling A word of caution. if you don't KNOW the sequence of work, find out what it is before you complete the arrow diagram. Before you assign event numbers to your diagram, go over it carefully and make sure that the work sequence is correct, and that all necessary dummies for artificial events and restraints are shown. Examine it, too, for superfluous dummies; these only confuse the diagram. If you were not thoroughly familiar with the sequence of operations before you started the diagram, you will find that the necessity for analyzing the project step-by-step has very much improved your understanding of it. The elements of network diagramming shown in figure 13-15 are included to clarify your interpretation of job sequences in the preparation of the arrow diagram.

It is important to realize that the arrow diagram is hardly ever prepared by a single person. Because the accomplishment of the schedule produced from the arrow diagram affects a large number of people, all persons who have anything to do with the project must be consulted when preparing the arrow diagram. Company commanders, company chiefs, and



82.180

Figure 13-15.—Elements of network diagramming.

crew leaders should be asked to review the proposed arrow diagram carefully to make certain that the work elements are accurately and realistically placed on the diagram. This procedure also applies to the duration estimates for the work elements.

SCHEDULING

When a project has been planned on an arrow diagram, the next step is to SCHEDULE it—that is, to put it on a working timetable. When this has been done, it will be possible to determine when each of the various jobs must be performed, when deliveries must take place, how much (if any) spare time there is for each job, and when completion of the whole operation may be expected. It will also be possible to determine which jobs are critical, and to what extent a delay in one job will affect jobs that follow.

Work Element Duration

To schedule an operation, you must first know how long each job will take under expected circumstances. The expected duration of each job is marked on the diagram beside the corresponding job arrow, as shown in figure 13-16. On the diagram, dummy (3, 5) is simply a device introduced to give job F distinctive event numbers, and dummy (3, 4) is introduced to show that job E cannot start until job B is completed, therefore, on this diagram the dummies have no duration times. A dummy indicating a restraint, however, would be marked with the duration time required for the performance of the restraint.

Determining Critical Path

When the job durations have been placed on the arrow diagram, the CRITICAL PATH can be determined. The critical path is the LONGEST path through the diagram, in terms of time. In figure 13-16 there are three possible paths through the diagram. the path for 1 through 2, 4, 6, 7, and 8, which totals 24 days, the path from 1 through 2, 3, 6, 7, and 8, which totals 42 days, and the path from 1 through 2, 3, 5, 6, 7, and 8, which totals 30 days. The middle path is the longest, therefore, this is the critical path. It is indicated by marking the arrows with small double slants, as shown in figure 13 16.

This path represents the normal duration of the project. Every work element on the path is critical to the completion of the project in 42 days. If any one of these elements is delayed, the project as a whole will be delayed.

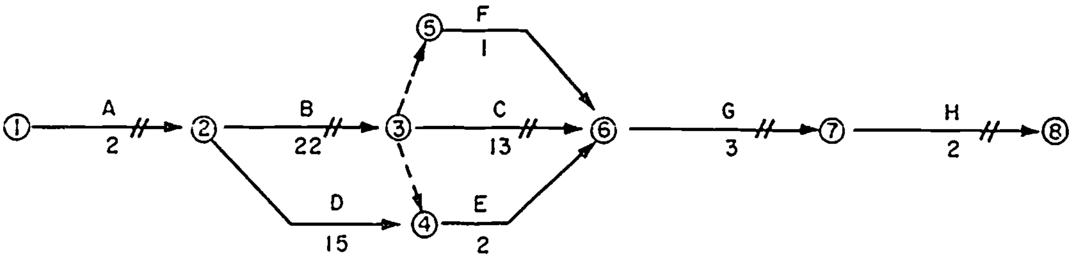
Earliest and Latest Job Start and Finish Times

The EARLIEST TIME at which an event can occur is the sum of the durations of the work elements on the LONGEST PATH leading up to the event. This time is entered in a box next to the event on the arrow diagram, as shown in figure 13-17.

The times shown are, of course, project times, or successive WORKING days measured from 0 at the beginning of the first work element arrow. The duration of the first job in figure 13-17 is 2 days; therefore, event 2 occurs at project time 2. The time for event 3 is the sum of the duration times of (1,2) and (2,3), or 24. However, event 4 has two paths leading to it, one from 1 through 2 and 4 for a total of 17, the other from 1 through 2 and 3 for a total of 24. Following the rule of selecting the longest path, the event time for event 4 is 24. Similarly, three paths lead to event 6, and the longest (from 1 through 2 and 3) is selected from an event time for 6 of 37.

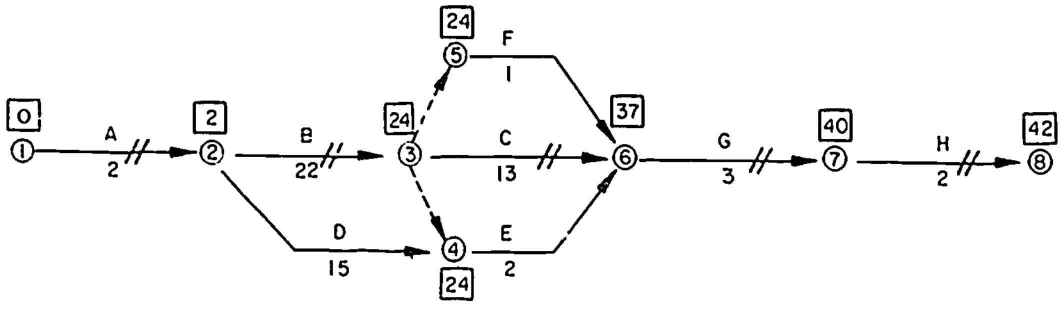
Note that where more than one path leads to an event, all of the possible earliest event times must be calculated in order to determine the true earliest event time, this one being the LARGEST of the results obtained.

It is also necessary to know the LATEST TIME at which an event can occur. To determine latest event times, you begin at the end of the project and work backward. To calculate the latest time at which an event can occur, subtract the duration of the immediately following job from the immediately following latest event time. The latest event time is entered in a small



82.105

Figure 13-16.—Job durations on arrow diagram.



82.106

Figure 13-17.—Earliest event times on arrow diagram.

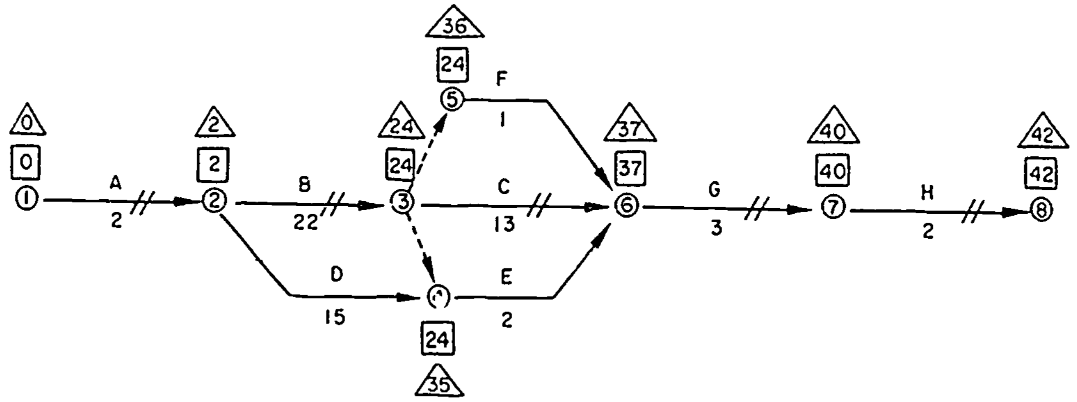
triangle (Δ) adjacent to the square containing the earliest event time, as shown in figure 13-18.

In that figure the latest event times for events 6, 7, and 8 are the same as the earliest event times. This follows from application of the rule given: the latest event time for event 7 equals the latest event time for event 8 is 42 minus the duration of (7,8) 2, or 40; the latest event time for event 6 equals the latest event time for 7 is 40 minus the duration of (6,7), 3, or 37.

However, the latest event time for event 4 equals the latest event time for 6 is 37 minus the duration of (4,6) 2, or 35. The latest event time for event 5 equals the latest event time for 6 is 37 minus the duration of (5,6) 1, or 36. When an event like event 3 has more than one arrow leaving it, you must calculate all of the possible latest events in order to determine the latest time at which the event can occur. The latest event time is the SMALLEST of the results obtained. It is obvious that the latest event time for event 3 equals the latest event time for 6 is 37 minus the duration of (3,6) 13, or 24—the other two being 35 and 36 through events 4 and 5, respectively, which are greater.

Note that it is only events not on the critical path for which the latest event time differs from the earliest event time. For events on the critical path, these times are identical. This fact may be used to identify which job arrows lie on the critical path. For a job to be critical, both of the following conditions must exist:

1. At each end of the arrow for the job, the number in the box (earliest event time) and the



82.107

Figure 13-18.—Latest event times on arrow diagram.

number in the triangle (latest event time) must be the same.

2. The job duration must equal the difference between either number at the head of the arrow and either number at the tail of the arrow.

In other words, critical jobs start on a certain day and end on a certain day. If they do not, the project will be delayed. Therefore, their earliest and latest start times are identical, as are their earliest and latest finish times. Note that the critical path must be continuous and must be given a distinguishing mark or the arrows are made heavier than the rest of the arrows in the diagram.

Figure 13-19 shows a fully developed arrow diagram for the project of building an arch-type magazine, with all work elements included, and with earliest and latest event times inscribed. Having established earliest and latest event times, earliest and latest starts and finishes for work elements can be determined. In figure 13-19, for example, what are the latest and the earliest days on which waterproofing of the topside of the arch can be started? What are the earliest and latest days on which the installation of the ventilator can be started?

Before either of these jobs can begin, the stripping of the arch forms, work element (9,10), must be completed. This job is on the critical path, and will be completed at event time 24. The waterproofing and the installation of the ventilator must be completed by event time 37, if the project is not to be delayed. The waterproofing is a 2-day job. It can begin as early as day 25 (event time 24 plus 1 day) or as late as day 36 (event time 37 minus 2 days plus 1). It can be completed as early as day 26 or as late as day 37. Similarly, the installation of the ventilator can begin as early as day 25 or as late as day 37, and can end as early as day 25 or as late as day 37. The rules for calculating start and finish days for a work element, then, are as follows:

Earliest start day = earliest event time at the tail of the arrow plus 1.

Earliest finish day = earliest event time at the tail of the arrow plus job duration.

Latest start day = latest event time at the head of the arrow minus job duration plus 1.

Latest finish day = latest event time at the head of the arrow.

To calculate earliest finish days, you work from left to right on the diagram, adding job durations to earliest event times. To calculate latest start times, you work from right to left, subtracting job duration from preceding latest event time.

Results are entered in a schedule as shown in figure 13-20. This schedule assumes that all jobs start as early as possible.

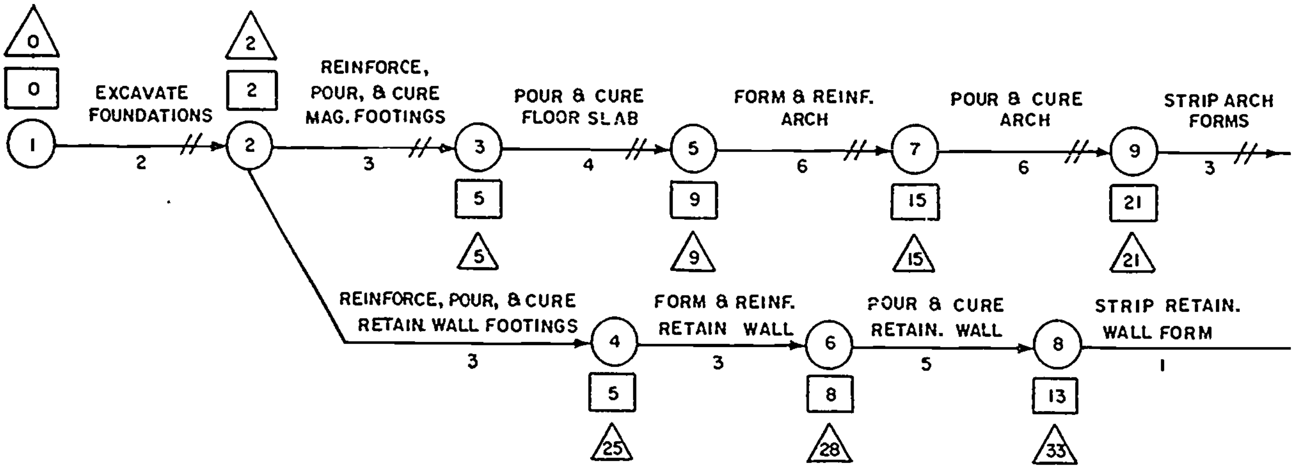
Concept of Float

The spare time available to perform a task like the installation of the ventilator in figure 13-19 is called FLOAT. Properly controlled, the manipulation of float is valuable in determining the most efficient use of manpower, equipment, and materials. The existence of float allows latitude in the timing of the jobs with which it is associated. A job having no float is inflexible, it must start and end precisely on time, or the completion of the project will be affected.

In figure 13-19, the installation of the ventilator has 12 days of float, because it is a 1-day job and there are 13 days available in which it may be performed. Similarly, the waterproofing job in the same figure has 11 days of float. To calculate float, subtract both the duration and the earliest event time at the tail of the arrow from the latest event time at the head of the arrow. For job (6, 8), for example, the float time is 33 - 8 - 5, or 20.

Each of the non-critical jobs along the path from event 2 to event 11 has 20 days of float when considered independently, however, there are only 20 days of float available for the whole chain, calculated as follows. 34 - 2 - (3+3+5+1) = 34 - 2 - 12 = 20. The reason for this is the fact that for each separate job the float is calculated on the assumption that all preceding jobs were started at the earliest possible time. However, if any of the float is used (that is, if any job is started later than the earliest possible time), all of the following jobs in the chain of floaters will be affected.

Suppose, for example, that job (4,6) was delayed for 3 days. The preceding jobs would not be affected, because their durations, earliest



starts, and earliest finishes would remain the same The following job (6, 8), however, would have 3 days added to its earliest event time and subtracted from its float. Float for job (6, 8) would now be 33 - 11 - 5, or 17.

Use of Float in Allocation of Manpower and Equipment

In the construction of the high-explosives magazine diagrammed in figure 13-19, there are three jobs of form stripping to be done. The stripping of the arch is critical, and must be performed between event times 21 and 24. Similarly, the stripping of the front and rear wall forms must be done between days 32 and 34. The stripping of the retaining wall forms is a 1-day job which may be done at any time between event time 13 and event time 34. Obviously, this crew should not be scheduled to strip the retaining wall when they are busy with the arch or front and rear wall forms. Similarly, the pouring and curing should be scheduled so as to take advantage of the float in job (6,8). By starting job (6,8) one day after its earliest start time, it can be performed concurrently with job (5,7). By using up a day of float, more efficient use is made of crew and equipment.

Preparing a Timetable

After the arrow diagram has been completed and the float has been calculated, a timetable like the one shown in figure 13-21 can be prepared. This is a timetable derived from the arrow diagram shown in figure 13-19. Obviously, project day 1 falls on 1 March, a Thursday. No work is done on Saturdays or Sundays, therefore, project days 1 and 2 fall on Thrusday and Friday, March 1 and 2, but project day 3 falls on Monday, March 5. As you can see, however, Saturdays and Sundays are included in the calendar when they can be utilized as curing time for concrete jobs. When this is done, such as Saturday or Sunday becomes a project day, and if the day relates to a job on the critical

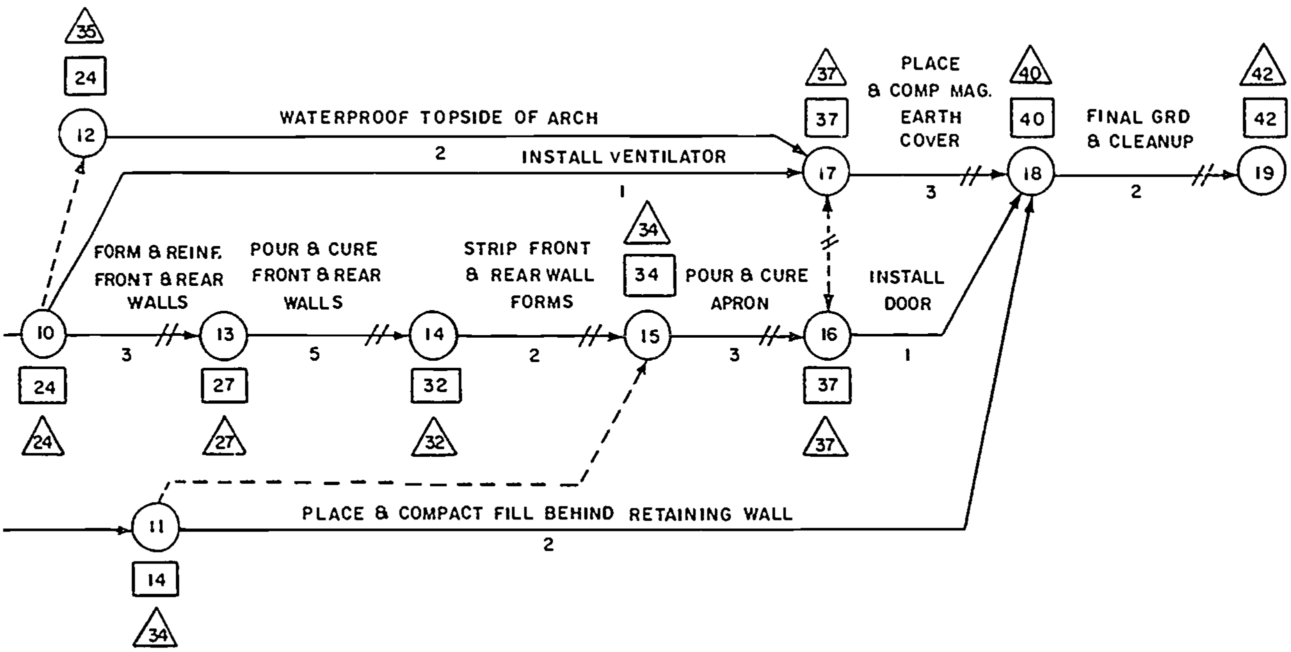


Figure 13-19.–Arrow diagram–arch-type high explosives magazine.

path, the effect is to gain time by cutting a day from the schedule. In figure 13-21, 5 days were cut from the critical path by scheduling concrete work so that curing could fall on weekends.

For example: job (3, 5) consisted of pouring and curing the magazine footings. It was started on Thursday, so that curing could be scheduled for Saturday and Sunday. Since this job was on the critical path, the use of Saturday and Sunday for curing cut two days from the schedule.

Earliest and latest event times shown in the arrow diagram (fig. 13-19) were changed to reflect the days dropped out as a result of weekend curing, a check was then made to ensure that the critical path was still the same, since shortening the original critical path might cause a different one to take its place. Next the float was recalculated, and the new float values entered in the timetable. Notice that on the timetable, job (11, 18) and job (17, 18), both of which consist of placing and compacting fill (see fig. 13-19), are scheduled a month apart. Since job (11, 18) shows 24 days of float, however, and since the same equipment will be used for both jobs, the float for job (11, 18) will be used to schedule one of these jobs to end the day before the other begins.

MONITORING AND CONTROL

The arrow diagram produced at the beginning of a project should never be considered as fixed for the duration of the project. If the full benefit of the critical-path method is to be realized, the basic information–job durations, job delays expected job completions–must be updated regularly in accordance with circumstances, generally weekly or every other week, but even oftener than weekly for high-priority complex projects.

A feedback system must be established to provide the Operations Officer with changed information and keep him aware of current job progress. As a project proceeds, it may be discovered that the original estimates of the

JOB	PROJECT DAY				REMARKS
	START		FINISH		
	EARLIEST	LATEST	EARLIEST	LATEST	
(1, 2)	1	1	2	2	critical
(2, 3)	3	3	5	5	critical
(2, 4)	3	23	5	25	
(3, 5)	6	6	9	9	critical
(4, 6)	6	26	8	28	
(5, 7)	10	10	15	15	critical
(6, 8)	9	29	13	33	
(7, 9)	16	16	21	21	critical
(8, 11)	14	34	14	34	
(9, 10)	22	22	24	24	critical
(10, 13)	25	25	27	27	critical
(10, 17)	25	37	25	37	
(11, 18)	15	39	16	40	
(12, 17)	25	36	26	37	
(13, 14)	28	28	32	32	critical
(14, 15)	33	33	34	34	critical
(15, 16)	35	35	37	37	critical
(16, 18)	38	40	38	40	
(17, 18)	38	38	40	40	critical
(18, 19)	41	41	42	42	critical

82.109

Figure 13-20.—Project schedule from CPM arrow diagram shown in figure 13-19.

times required to complete jobs were not accurate, or that deliveries cannot be made on time, or that anticipated manpower will not be available. Correction of the arrow diagram to reflect the true picture will induce changes in vital information, such as:

Changes of completion date
Changes in the critical path
Changes in intermediate target dates
Changes in floats for non-critical jobs
Changes in critical manpower or equipment schedules.

Occasionally, there may be design changes which may lead to the addition of new jobs, the cancellation of previously planned jobs, or the necessity for making a more detailed breakdown of work elements on the arrow diagram. Such changes may result in a shift of the critical path, or in new target dates; or they may make it necessary for certain parts of the project to be expedited in order to keep on schedule.

Crew leaders should report regularly on current work in progress. A WORK PROGRESS REPORT should include:

The completion date of each job
The beginning date of each job
Significant delays in current jobs
Estimated number of man-days required to complete current jobs.

JOB	PROJECT DAYS		CALENDAR DAYS		FLOAT
	START	DURATION	START	FINISH	
(1, 2)	1	2	March 1, Thurs.	March 2, Fri.	0
(2, 3)	3	3	March 5, Mon.	March 7, Wed.	0
(2, 4)	3	3	March 5, Mon.	March 7, Wed.	16 [2]
(3, 5) [1]	6	4	March 8, Thurs.	March 11, Sun.	0
(4, 6)	6	3	March 8, Thurs.	March 12, Mon.	16 [2]
(5, 7)	10	6	March 12, Mon.	March 19, Mon.	0
(6, 8)	9	5	March 13, Tues.	March 17, Sat.	16 [2]
(7, 9)	16	6	March 20, Tues.	March 25, Sun.	0
(8, 11)	14	1	March 19, Mon.	March 19, Mon.	16 [2]
(9, 10)	22	3	March 26, Mon.	March 28, Wed.	0
(10, 12)	–	0	–	–	0
(10, 13)	25	3	March 29, Thurs.	April 2, Mon.	0
(10, 17)	25	1	March 29, Thurs.	March 29, Thurs.	11 [2]
(11, 15)	–	0	–	–	0
(11, 18)	15	2	March 20, Tues.	March 21, Wed.	20 [2]
(12, 17)	25	2	March 29, Thurs.	March 30, Fri.	10 [2]
(13, 14) [1]	28	5	April 3, Tues.	April 7, Sat.	0
(14, 15)	33	2	April 9, Mon.	April 10, Tues.	0
(15, 16)	35	3	April 11, Wed.	April 13, Fri.	0
(16, 18)	38	1	April 16, Mon.	April 16, Mon.	2
(17, 18)	38	3	April 16, Mon.	April 18, Wed.	0
(18, 19)	41	2	April 19, Thurs.	April 20, Fri.	0

[1] Curing scheduled for weekend.
[2] Adjusted to reflect weekend curing.

82.110

Figure 13-21.—Timetable from arrow diagram shown in figure 13-19.

This information enables the Operations Officer to spot trouble areas immediately and to take corrective action. A suggested work progress report form is shown in figure 13-22.

RESOURCES ALLOCATION

Until now, it has been assumed that whatever men, materials, and equipment were required would be available to perform a job in the allotted time. In practice, this is often not the case, and it is often necessary to plan for the best allocation of a resource which is in short supply. The allocation of any resource may be thus planned, for illustration purposes, we'll select manpower.

One man is often not qualified to do another's job—or, at least, a man not fully qualified to do another's job will do it less efficiently than the fully qualified man. Therefore, the disposition of manpower in accordance with qualifications which means, in practical effect, principally in accordance with ratings—must be considered. As an example, take the erection of a temporary steel and timer warehouse. The arrow diagram for this job is shown

PROJECT STATUS REPORT

JOB NO.	BRIEF DESCRIPTION	DURATION	SCH. STAR.	ACT. STAR.	SCH. COMP.	TIME TO DATE	TIME REQ. TO COMP.	REMARKS

REPORT DATE ____________

SHEET _____ OF _____

82.111

Figure 13-22.—Suggested work progress report form.

in figure 13-23. For the sake of simplicity, it is assumed that only Builders, Equipment Operators, and Steelworkers will be used on the job.

There must be some sort of schedule as a point of departure. Referring to the arrow diagram, you list all of the jobs in the order in which they can begin, as shown in figure 13-24. When several jobs can begin on the same day, list them secondarily in order of the amount of float they contain. If two or more jobs have the same amount of float and start on the same day, it doesn't matter which is placed first. The easiest way to arrange the jobs in order for copying on the schedule is to list each job on a 3 x 5 card and sort the cards into proper order.

Next you transfer the values shown in this preliminary schedule to a bar chart like the one shown in figure 13-25. The broken lines indicate float. Note that a dummy can have float. If the dummy represents a delivery restraint and the delivery is delayed, use may be made of the float to compensate for the delay. The bar graph is a schedule for the project, but based on the assumption that available manpower is unlimited.

At this point, or previously, you enter on the arrow diagram the manpower requirements shown already entered in figure 13-23. These are, of course, based on estimates of how many men of each rating it will take to do each of the jobs shown in the diagram. By referring to these figures and to the bar chart (fig. 13-25), you can now make a manpower schedule as shown in figure 13-26.

Examination of the manpower totals in figure 13-26 shows undesirable peaks in the Builder requirements—14 called for on day 5, 19 on day 6, 8 on day 7, and so on. To correct this situation, you would decide what the maximum practically available number of Builders would be for a day, and rework the chart on the basis of this limitation. The general procedure is as follows:

1. List all jobs in the same order as before (fig. 13-24).

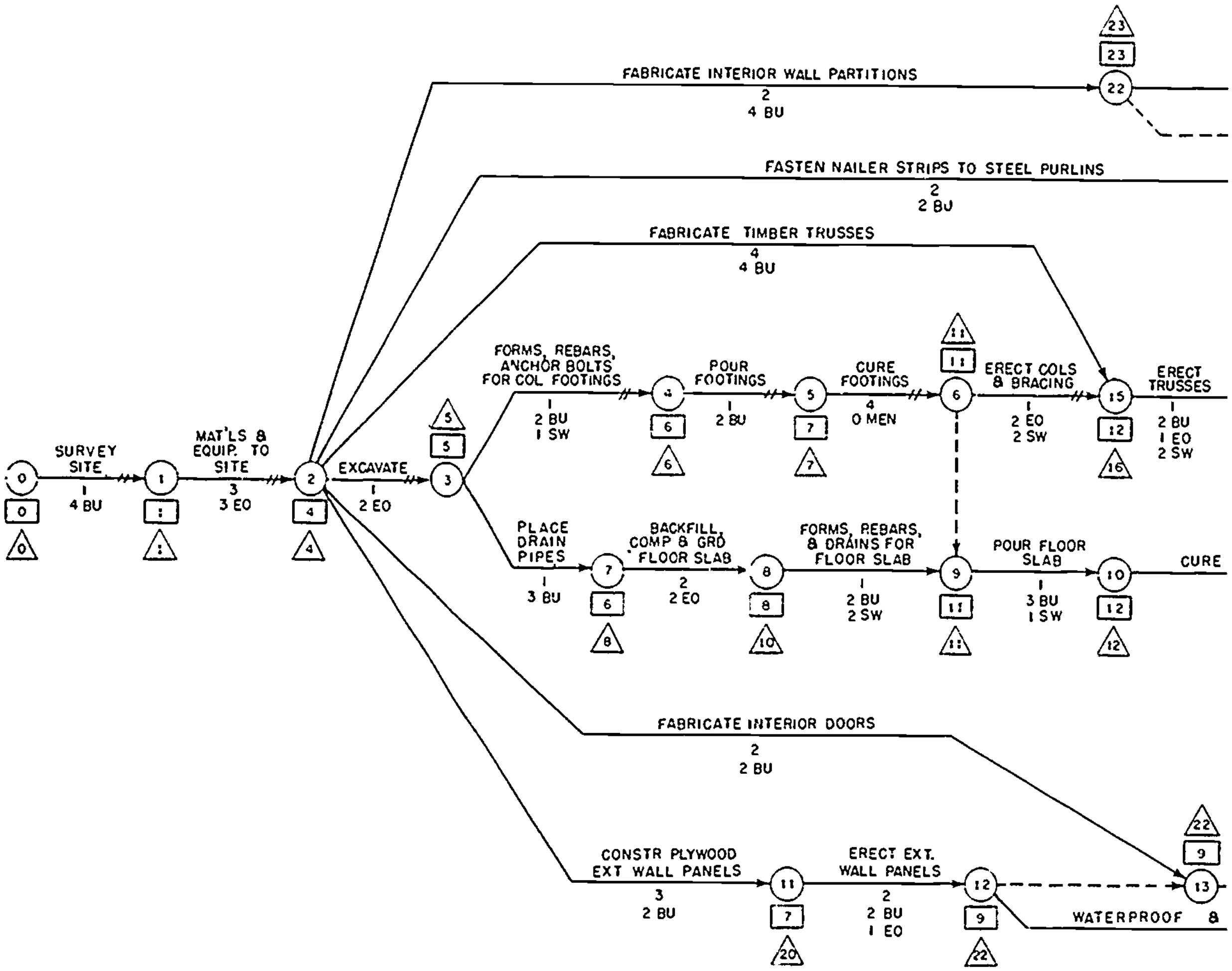
2. Enter the critical jobs in the same places as before; these cannot be displaced.

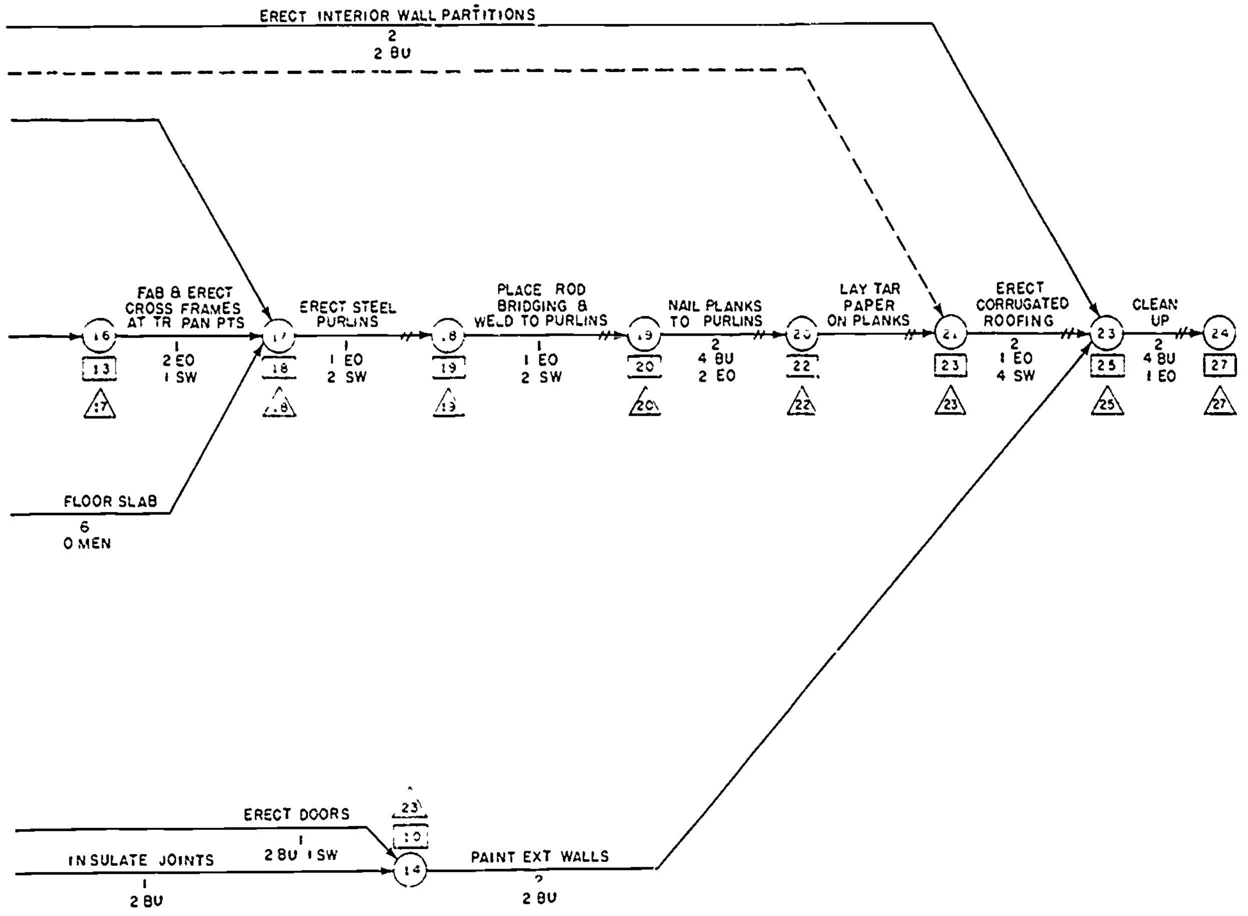
3. Use float time on non-critical jobs to shift jobs using Builders to days on which, on the previous chart, Builders were not shown employed. For example: job (2, 15) in figure 13-26 could be shifted to days 13 through 16, since the chart shows only 2 Builders working on day 13 and none on days 14, 15, and 16.

4. After every adjustment of this kind, refer back to the arrow diagram and the schedule, to see whether in rescheduling jobs you have moved back the times at which following jobs can start.

In practice, it is often possible to split jobs—to do part of the work on the fabrication of doors (for example) on one day, then drop this and pick it up at a later day when Builders are available.

Remember that, when you make this or any other type of adjustment, you must immediately check the arrow diagram for the effect on following jobs. On even a small project, the possibility for improving efficiency through adjustments in scheduling or through job splitting nearly always exists—or, at any rate, exists until the most efficient schedule is found. Because of the interrelationship between work elements and the effect they have on each other, much experimentation and readjustment may be required to attain the most efficient and economical schedule.


FABRICATE INTERIOR WALL PARTITIONS
2
4 BU
FASTEN NAILER STRIPS TO STEEL PURLINS
2
2 BU
FABRICATE TIMBER TRUSSES
4
4 BU
FORMS, REBARS, ANCHOR BOLTS FOR COL FOOTINGS
1
2 BU
1 SW
POUR FOOTINGS
1
2 BU
CURE FOOTINGS
4
0 MEN
ERECT COLS & BRACING
1
2 EO
2 SW
ERECT TRUSSES
1
2 BU
1 EO
2 SW
SURVEY SITE
1
4 BU
MAT'LS & EQUIP. TO SITE
3
3 EO
EXCAVATE
1
2 EO
PLACE DRAIN PIPES
1
3 BU
BACKFILL, COMP & GRD FLOOR SLAB
2
2 EO
FORMS, REBARS, & DRAINS FOR FLOOR SLAB
1
2 BU
2 SW
POUR FLOOR SLAB
1
3 BU
1 SW
CURE
FABRICATE INTERIOR DOORS
2
2 BU
CONSTR PLYWOOD EXT WALL PANELS
3
2 BU
ERECT EXT. WALL PANELS
2
2 BU
1 EO
WATERPROOF
8



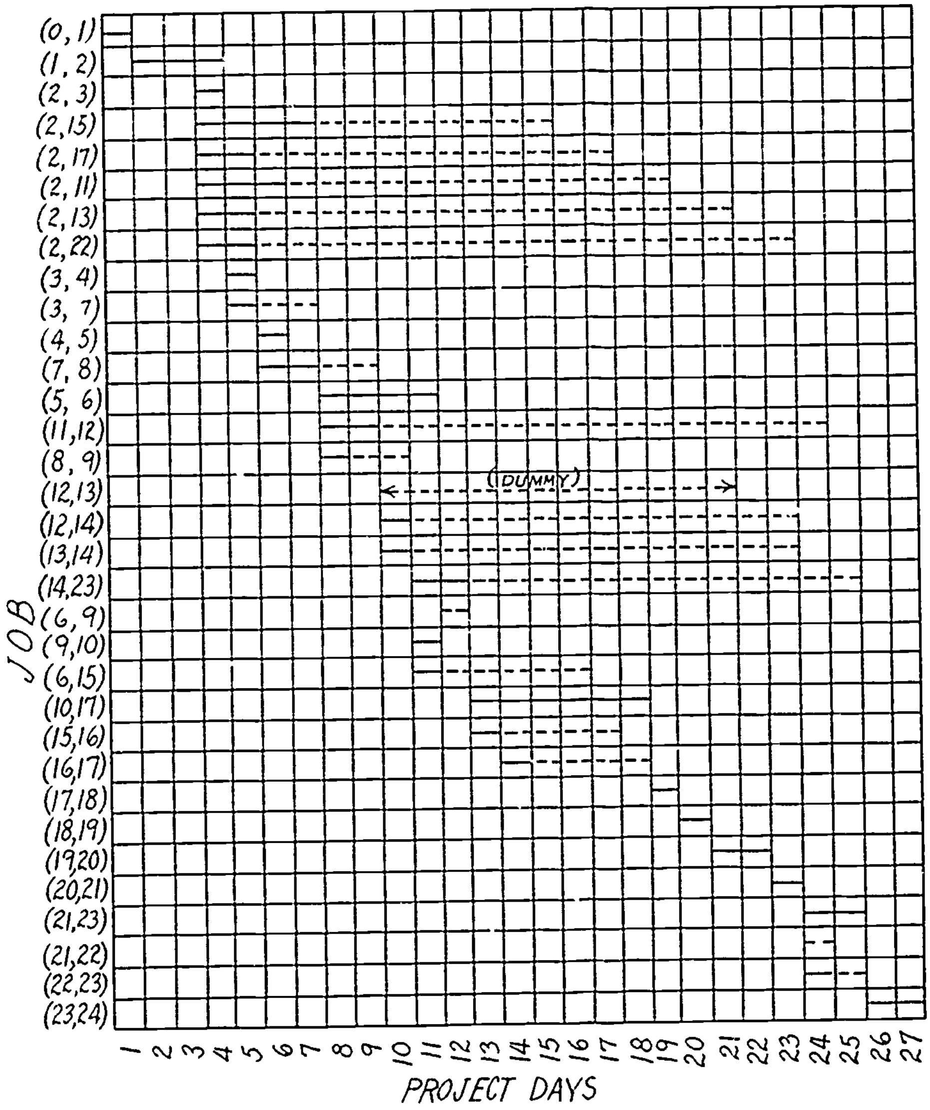
82.112

Figure 13-23.—Arrow diagram—temporary steel and timber warehouse.

EARLIEST EVENT AT TAIL OF ARROW	JOB	DURATION	LATEST EVENT AT HEAD OF ARROW	FLOAT
0	(0, 1)	1	1	0
1	(1, 2)	3	4	0
4	(2, 3)	1	5	0
4	(2, 15)	4	16	8
4	(2, 17)	2	18	12
4	(2, 11)	3	20	13
4	(2, 13)	2	22	16
4	(2, 22)	2	24	18
5	(3, 4)	1	6	0
5	(3, 7)	1	8	2
6	(4, 5)	1	7	0
6	(7, 8)	2	10	2
7	(5, 6)	4	11	0
7	(11, 12)	2	22	13
8	(8, 9)	1	11	2
9	(12, 13)	0	22	13
9	(12, 14)	1	23	13
9	(13, 14)	1	23	13
10	(14, 23)	2	25	13
11	(6, 9)	0	11	0
11	(9, 10)	1	12	0
11	(6, 15)	1	16	4
12	(10, 17)	6	18	0
12	(15, 16)	1	17	4
13	(16, 17)	1	18	4
18	(17, 18)	1	19	0
19	(18, 19)	1	20	0
20	(19, 20)	2	22	0
22	(20, 21)	1	23	0
23	(21, 23)	2	25	0
23	(21, 22)	0	24	1
23	(22, 23)	1	25	1
25	(23, 24)	2	27	0

82.113

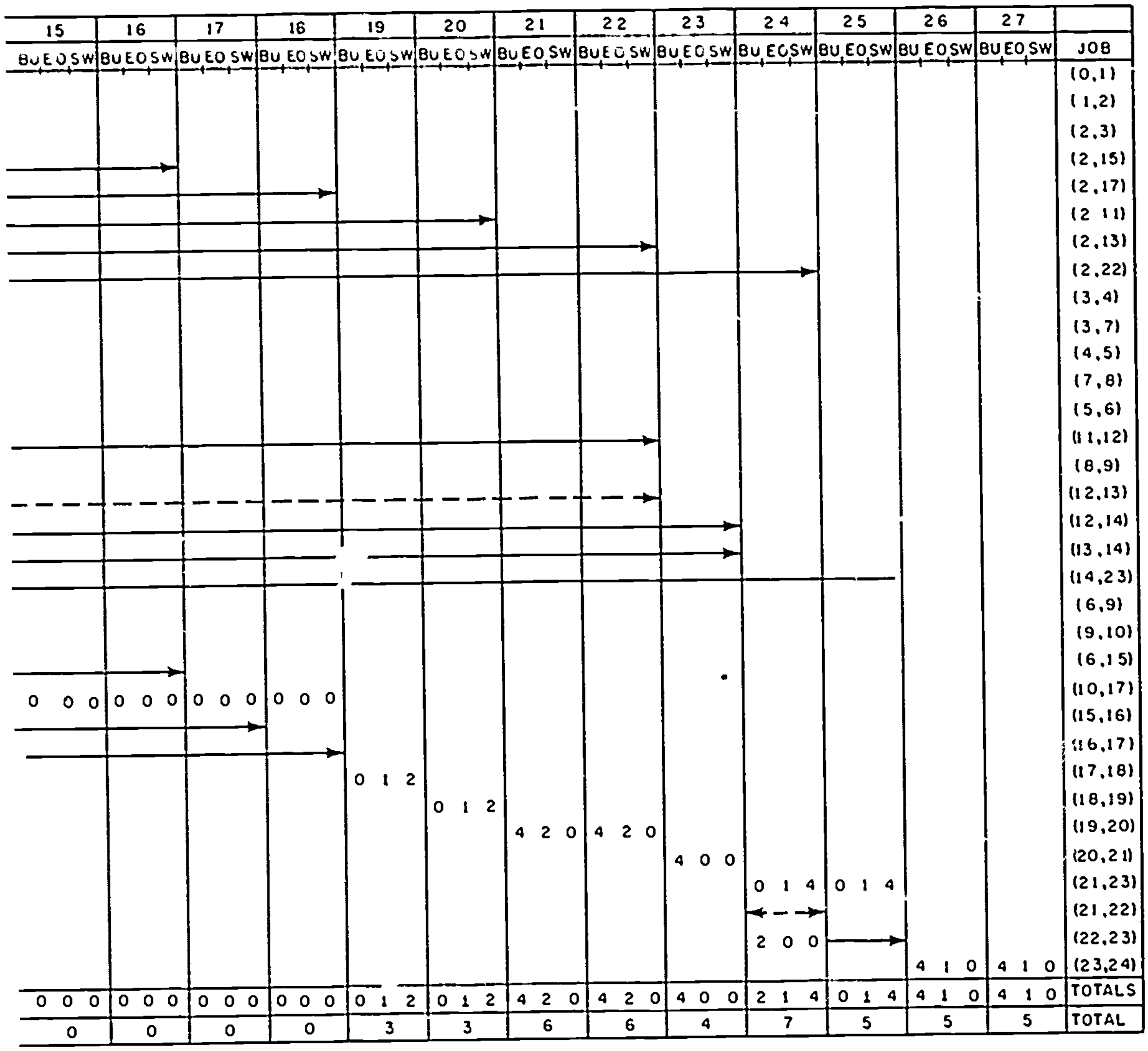
Figure 13-24.—List of jobs in figure 13-23, in order of earliest events (tail of arrows).



82.114

Figure 13-25.—Bar chart—preliminary schedule of jobs listed in figure 13-24.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
JOB	EA EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW	BU EO SW
(0,1)	4 0 0													
(1,2)		0 3 0	0 3 0	0 3 0										
(2,3)					0 2 0									
(2,15)					4 0 0	4 0 0	4 0 0	4 0 0						
(2,17)					2 0 0	2 0 0								
(2,11)					2 0 0	2 0 0	2 0 0							
(2,13)					2 0 0	2 0 0								
(2,22)					4 0 0	4 0 0								
(3,4)						2 0 1								
(3,7)						3 0 0								
(4,5)							2 0 0							
(7,8)							0 2 0	0 2 0						
(5,6)								0 0 0	0 0 0	0 0 0	0 0 0			
(11,12)								2 1 0	2 1 0					
(8,9)									2 0 1					
(12,13)														
(12,14)										2 0 0				
(13,14)										2 0 1				
(14,23)											2 0 0	2 0 0		
(6,9)														
(9,10)												3 0 1		
(6,15)												0 2 2		
(10,17)													0 0 0	0 0 0
(15,16)													2 1 2	
(16 17)														0 2 1
(17,18)														
(18,19)														
(19,20)														
(20,21)														
(21,23)														
(21,22)														
(22,23)														
(23,24)														
TOTALS	4 0 0	0 3 0	0 3 0	0 3 0	14 2 0	19 0 1	8 2 0	6 3 0	4 1 1	4 0 1	2 0 0	5 2 3	2 1 2	0 2 1
TOTAL	4	3	3	3	16	20	10	9	6	5	2	10	5	3



82.115.2

Figure 13-26.–Manpower schedule–temporary timber and steel warehouse (considering four ratings).

CHAPTER 14

SOIL MECHANICS

The branch of engineering science which includes (1) determining the bearing capacity of the soil on which a structure will rest, and (2) increasing this, when required, to the minimum necessary to support the structure, is called SOIL MECHANICS.

Soil, by definition, is a heterogeneous accumulation of uncemented or loosely cemented mineral grains enclosing voids of varying sizes. The voids may contain air, water, organic matter, or different combinations of these materials in varying amounts. The Engineering Officer assisted by the EA must therefore concern himself not only with the sizes of the particles, but also with the voids between them and particularly what these voids enclose (water, air, or organic materials).

There are a tremendous number of different soils, and when a structure is to be erected, various tests must be made to identify the soils concerned and to determine their engineering characteristics. These tests are necessary to determine whether the soils are adequate to support the proposed structure. The testing of soils is a major responsibility of the EA rating. In that case, a knowledge of soil behavior, testing procedures, and other factors involving soil mechanics is needed by the EA engaged in soils testing.

In this chapter, we will discuss some of the physical characteristics of soils. We will cover soil classification, giving special attention to the Unified Soil Classification System. Procedures applicable to field and laboratory testing of soils also are explained. In addition, information is presented on seismic surveying.

PHYSICAL CHARACTERISTICS OF SOILS

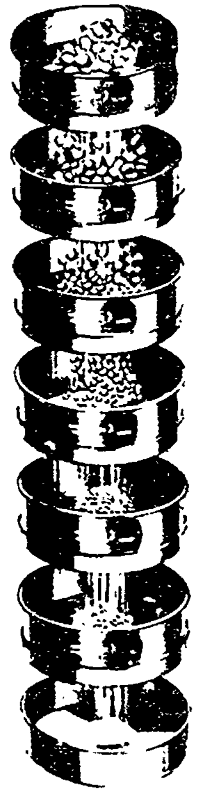
The physical characteristics of soils aid in determining their engineering characteristics and their proper classification. Some of the characteristics of concern to the EA are discussed below.

PARTICLE SIZE

Soils are divided into groups on the basis of the size of particles (or grains) included in the soil mass. Various methods may be used to determine grain size. One common method is through the use of sieves. Particle sizes are defined by passing a soil mass through several sieves with different sizes of openings, as illustrated in figure 14-1. Particles which pass through a given sieve are said to be PASSING that sieve size, particles which fail to pass through a given sieve are said to be RETAINED ON that sieve. The sieve permits particles smaller than the openings to fall through and retains the larger particles on the sieve. By using sieves with screen openings of different sizes (the largest on the top and the smallest at the bottom), the soil can be separated into particle groups based on size. The amount remaining on each sieve is measured and described as a percentage by weight of the entire sample. This method of determining grain size, known as sieve analysis, is described in more detail later in this chapter.

Soils may be divided into several different groups on the basis of the size of particles included in each group. Many different grain-size scales have been proposed and used. The scale used in the Unified Soil Classification System is indicated in the tabulation below:

	Sieved Size	
	Passing	Retained on
Cobbles		3 inch
Gravels	3 inch	No. 4
Sands	No. 4	No. 200
Fines	No. 200	-------
Organic Material	(No size boundary)	



82.181

Figure 14-1.–Sieve analysis.

Coarse gravel particles are comparable in size to a lemon, an egg, or a walnut, while fine gravel is about pea size. Sand particles range in size from that of rock salt, through table salt or granulated sugar, to powered sugar. Below a No. 200 sieve, the particles (fines) are designated as SILT or CLAY, depending on their plasticity characteristics.

PARTICLE SHAPE

The shape of the particles influences the strength and stability of a soil. Two general shapes are normally recognized–BULKY and FLAKY.

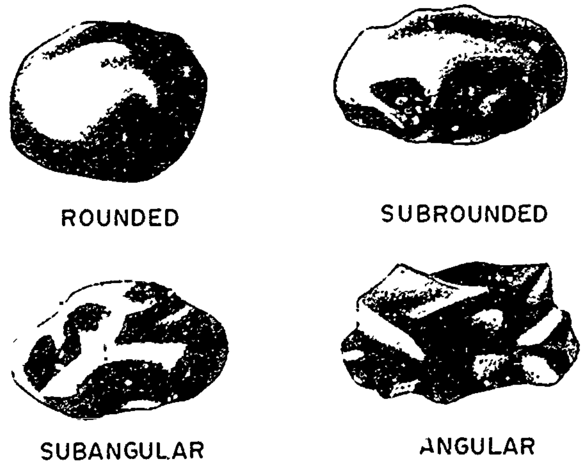
Gravel, sand, and silt particles, although they cover a large range of sizes, are all of bulky shape. The term is confined to particles which are relatively large in all three dimensions, as contrasted to flaky particles, in which one dimension is small as compared to the other two. There are four subdivisions of the bulky shape, in descending order of desirability for construction, as follows:

ANGULAR particles are those which have been recently broken up and are characterized by jagged projections, sharp ridges, and flat surfaces (see fig. 14-2). Angular gravels and sands are generally the best materials for construction, because of their interlocking characteristics. Such particles are seldom found in nature, however, because the weathering process does not naturally produce them. Angular material must usually be produced artifically, by crushing.

SUBANGULAR particles (fig. 14-2) are those which have been weathered to the extent that the sharper points and ridges have been worn off.

SUBROUNDED particles are those in which weathering has progressed to a still further degree (see fig. 14-2). They are still somewhat irregular in shape, but have no sharp corners and few flat areas. Materials with this shape are frequently found in stream beds. If composed of hard, durable particles, subrounded material is adequate for most construction needs.

ROUNDED particles (fig. 14-2) are those on which all projections have been removed, with few irregularities in shape remaining. The particles approach spheres of varying size.



82.182

Figure 14-2.–Bulky grains.

Rounded particles are usually found in or near stream beds or beaches.

FLAKY particles are those which have flat, plate-like grains. It follows that a flaky particle has a larger ratio of surface area to weight than a bulky particle. This increased surface area provides a greater contact area for moisture. Clay is a common example of platy-particle material. These flake-like particles are undesirable for construction purposes and should be avoided.

PARTICLE GRADATION

The size and shape of the soil particles discussed above deal with characteristics of the individual grains in a soil mass. Gradation describes the distribution of the different size groups within a soil sample. The soil may be well graded or poorly graded.

A WELL-GRADED soil is one having a good representation of all particle sizes from largest to smallest. It follows that a POORLY-GRADED soil is one which does not possess this characteristic. There are two types of poorly-graded soil: (1) UNIFORMLY GRADED, in which the particles are all of approximately the same size, and (2) GAP-GRADED, in which there is an adequate range of sizes from large to small, but with one or more intermediate sizes not well represented.

EFFECT OF PARTICLE CHARACTERISTICS ON BEARING CAPACITY

Specifications controlling the percentages of particle sizes in various size groups making up well-graded soil samples (that is, the gradations which constitute well-graded soil samples) have been established on the basis of engineering experience. A well-graded gradation provides for the maximum density and stability of particles in a given soil. An ideally well-graded gravel, for example, is one graded in such a manner that the large voids between the coarsest gravel particles will be filled with smaller particles, this mixture in turn produces smaller voids, which will in turn be filled by the coarsest sand particles. In this mixture, remaining voids will be filled by finer particles, until the smallest voids are finally filled by the smallest fine particles. The end sought, ideally, is the entire elimination of voids.

Such a soil mass would have three advantages not possessed by a poorly graded soil. First, the mass would be denser, this density, with the related interlocking of particles, would make for greater load-bearing capacity. Second, since the particles would be "form-fitted," the best load distribution downward would be obtained. Third, with each particle surrounded and "locked" by other particles, the tendency for displacement of individual grains by loads or moisture is minimized.

SOIL MOISTURE CONDITIONS

The moisture content of a soil mass is often the most important factor in effecting the engineering characteristics of the soil. The water may enter from the surface or may move through the subsurface layers either by gravitational pull, by capillary action, or by hygroscopic action. This moisture, present in most cases, influences various soils differently, and may have the greatest implication upon the soil's behavior when subjected to loading.

Sources of Water in Soils

Water enters through soil SURFACES unless some means is taken to seal the surface and prevent such entry. Even sealed surfaces may often have cracks, joints, or fissures through which water may be admitted. In concrete pavements, for instance, the contraction and expansion joints are points of entry for water. After the pavement has been subjected to many cycles of expansion and contraction, the joint filler may become imperfect, thereby allowing water to seep into the base course or subgrade.

Surface water may also enter from the sides of a road or airfield, even though the surface itself remains waterproof. To reduce this tendency to a minimum, shoulders and ditches are usually provided with a slope sufficient to carry water away at an acceptable rate. Immediately following construction, these slopes are usually satisfactory. Often, however, because of inadequate maintenance, the growth of undesirable vegetation or the accumulation of sediment may cause water to begin standing in the drainage ditches. This water may then be absorbed into the base and subgrade.

SUBSURFACE water may exist because of any or all of the following circumstances.

FREE or GRAVITATIONAL water which percolates down from the surface through the influence of gravity. Such water eventually reaches a depth beyond which no further percolation is possible because of the existence of an obstruction. The obstructing medium is often bedrock; however, it may be a layer of soil which is not wholly solid, like bedrock, but which contains very small void spaces which eventually absorb and retain all the gravitational water arriving from the surface. The result is a zone of saturation. The upper limit of this zone is called the GROUND WATER TABLE; its subsurface depth varies with climatic conditions. During a wet winter. the ground water table will rise, during a dry summer. it may descend.

Gravitational water which is entrapped under pressure is called ARTESIAN water. Artesian water is enclosed between two layers of impermeable soil such as clay. An artificial disturbance of the top layer may release the pressure, in which case the water will rise with a quick or boiling action.

CAPILLARY subsurface water results from what might be termed the capillary potential of soil. Dry soil grains attract moisture in a manner similar to the capillary attraction observable in a small-bore glass tube. If such a tube is positioned vertically in water placed in a pan, capillary attraction will cause the water in the tube to rise above the surface level of that in the pan.

A similar capillary action in soil causes a "capillary fringe" immediately above the ground water table. The height of this capillary rise depends upon numerous factors, one of which is the character of the soil. Since the pore openings in a soil vary with the grain size, a fine-grained soil will develop a higher capillary fringe area than a coarse-grained soil. In clays, capillary water rises sometimes as high as 30 ft.

When the capillary fringe extends to a natural ground surface, wind and high temperature help to dissipate the moisture, thus reducing its effect on the soil. When a pavement or other sealing surface has been applied, however, capillary moisture may accumulate below the artificial surface.

Another force acting on soil water is absorption by the atmosphere. As the moisture evaporates from the soil's surface, it draws more moisture from the soil below. This process will continue until the soil moisture reaches an equilibrium with the water vapor in the air. The amount of water held by the soil is called the HYGROSCOPIC MOISTURE.

Effects of Moisture on Soils

Coarse-grained soils are much less affected by moisture than fine-grained soils. First of all, coarser soils have larger void openings, and therefore as a rule drain more rapidly. Capillarity is practically nonexistent in gravels, and in sands containing little fines. These soils, if they are above the ground water table, will not usually retain large amounts of water. Secondly, since the particles in gravelly and sandy soils are relatively large (in comparison with clay and silt particles), they are, by weight, heavy in comparison to the films of moisture which might surround them.

On the other hand, the small (sometimes microscopic) particles of a fine-grained soil weigh so little that water in the voids has considerable effect. It is not unusual, for example, for clays to undergo large volume changes with variations in moisture content, as witness the shrinkage cracks in a dry lake bed. Consequently, unpaved clay roads, though hard enough when sun-baked, often lose stability and turn into mud in rainy weather.

Not only do clays swell and lose stability when they become wet; they also, because of their flat, plate-like grain shapes and small size, retard the drainage of water. Since drainage is of the greatest importance in (for example) the construction of airfield pavement, design engineers must know whether or not subsurface clay exists. Plasticity is, as you know, the characteristic by which clay is primarily identified.

Plasticity

Plasticity is that property of a fine-grained soil which permits it, under certain moisture conditions, to be remolded without crumbling or rupturing. Many very fine-grained minerals do not possess plasticity, regardless of how small the particles are. All clay minerals, on the other hand, are plastic. Since practically all fine-grained soils contain some clay, most of them are plastic.

SOIL CLASSIFICATION

Soils are classified in accordance with what is called the UNIFIED SOIL CLASSIFICATION SYSTEM. In this system, soils are broadly divided into COARSE GRAINED soils and FINE GRAINED soils. A soil is a coarse grained soil if more than half of it will not pass the No. 200 sieve. It is a fine grained soil if more than half of it will pass the No. 200 sieve.

The coarse grained soils are further divided into GRAVELS and SANDS. A soil is a gravel if more than half OF ITS COARSE FRACTION will not pass the No. 4 sieve, it is a sand if more than half OF ITS COARSE FRACTION will pass the No. 4 sieve.

Fine grained soils are SILTS and CLAYS.

ORGANIC soils are soils containing vegetable matter. An organic soil may be an organic silt or clay, or it may be a HIGHLY ORGANIC soil like peat or meadow mat. Organic soils are usually black in color, and often have a characteristic musty odor.

The broad categories of gravels, sands, and silts/clays are broken down into a total of 15 subcategories, each of which has a group symbol, as shown in figure 14-3. In figure 14-4, you will see the conventional graphic soil symbols used for plotting various soil layers in boring logs.

COEFFICIENT OF UNIFORMITY

In figure 14-3, 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. It is determined as follows.

Suppose that the sample is identified as FT-P1-1. The numbering system of samples will be explained later. However, in this particular sample, the designation FT-P1-1 means that the sample was taken from project FT (Footing Trench), Pit No. 1 (P1), and that only one bag was taken for testing. The sieve analysis 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

You plot these values on a form like the one shown in figure 14-5. The graph on this form is a logarithm-type 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 C_u is:

$$C_u = \frac{D_{60}}{D_{10}}$$

D_{60} means the grain size, in millimeters, indicated by the gradation curve at the 60 percent passing level. In figure 14-5, 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 1.25 mm.

D_{10} means, similarly, the grain size indicated by the gradation curve at the 10 percent passing level. In figure 14-5, this is about 0.11 mm. 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:

$$C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$$

Primary divisions			Group symbol	Secondary divisions	Laboratory classification criteria		Supplementary criteria for visual identification
Coarse grained soils. (More than half of material is larger than No. 200 sieve size.)	Gravels. (More than half of the coarse fraction is larger than No. 4 sieve size.)	Clean gravels. (Less than 5% of material smaller than No. 200 sieve size.)	GW	Well graded gravels, gravel-sand mixtures, little or no fines.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3		Wide range in grain size and substantial amounts of all intermediate particle sizes.
			GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.	Not meeting all gradation requirements for GW.		Predominantly one size or a range of sizes with some intermediate sizes missing.
	... do	Gravels with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	GM	Silty gravels, and gravel-sand-silt mixtures, which may be poorly graded.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" line with PI between 4 and 7 is borderline case GM-GC	Non-plastic fines or fines of low plasticity.
			GC	Clayey gravels, and gravel-sand-clay mixtures, which may be poorly graded	Atterberg limits above "A" line, with PI greater than 7		Plastic fines.
Do	Sands. (More than half of the coarse fraction is smaller than No. 4 sieve size.)	Clean sands. (Less than 5% of material smaller than No. 200 sieve size.)	SW	Well graded sands, gravelly sands, little or no fines.	$C_u = \frac{D_{60}}{D_{10}}$ greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ between 1 and 3		Wide range in grain sizes and substantial amounts of all intermediate particle sizes.
			SP	Poorly graded sands, gravelly sands, little or no fines.	Not meeting all gradation requirements for SW		Predominately one size or a range of sizes with some intermediate sizes missing.
	... do	Sands with fines. (More than 12% of material smaller than No. 200 sieve size.)[1]	SM	Silty sands, and sand-silt mixtures, which may be poorly graded.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" line with PI between 4 and 7 is borderline case SM-SC	Non-plastic fines or fines of low plasticity.
			SC	Clayey sands, and sand-clay mixtures, which may be poorly graded.	Atterberg limits above "A" line, with PI greater than 7		Plastic fines.

82.116.1

Figure 14-3.—Unified Soil Classification System.

Primary divisions		Group symbol	Secondary divisions	Laboratory classification criteria		Supplementary criteria for visual identification		
						Dry strength	Reaction to shaking	Toughness near plastic limit
Fine grained soils. (More than half of material is smaller than No. 200 sieve size.)	Silts and clays. (Liquid limit less than 50.)	ML	Inorganic silts, clayey silts, rock flour, silty very fine sands.	Atterberg limits below "A" line, or PI less than 4	Atterberg limits above "A" line with PI between 4 and 7 is borderline case ML-CL	None to slight	Quick to slow	None
	...do	CL	Inorganic clays of low to medium plasticity; silty, sandy or gravelly clays.	Atterberg limits above "A" line, with PI greater than 7		Medium to high	None to very slow	Medium
	.. do	OL	Organic silts and organic silt-clays of low plasticity.	Atterberg limits below "A" line		Slight to medium	Slow	Slight
Do	Silts and clays. (Liquid limit greater than 50.)	MH	Inorganic silts, clayey silts, elastic silts, micaceous or diatomaceous silty or fine sandy soils.	Atterberg limits below "A" line		Slight to medium	Slow to none	Slight to medium
	...do	CH	Inorganic clays of high plasticity, fat clays.	Atterberg limits above "A" line		High to very high	None	High
	...do	OH	Organic clays and silty clays of medium to high plasticity.	Atterberg limits below "A" line		Medium to high	None to very slow	Slight to medium
	Highly organic soils	Pt	Peat, meadow mat, highly organic soils.	High ignition loss, LL and PI decrease after drying		Organic color and odor, spongy feel, frequently fibrous texture.		

[1]Materials with 5 to 12 percent smaller than No. 200 sieve are borderline cases, designated: GW-GM, SW-SM.

82.116.2

Figure 14-3.—Unified Soil Classification System—Continued.

MAJOR DIVISIONS 1	2	LETTER 3	SYMBOL HATCHING 4	SYMBOL COLOR 5	NAME 6
COARSE-GRAINED SOILS	GRAVELS AND GRAVELLY SOILS	GW		RED	GRAVEL OR SANDY GRAVEL WELL GRADED
		GP			GRAVEL OR SANDY GRAVEL POORLY GRADED
		GM		YELLOW	SILTY GRAVEL OR SILTY SANDY GRAVEL
		GC			CLAYEY GRAVEL OR CLAYEY SANDY GRAVEL
	SANDS AND SANDY SOILS	SW		RED	SAND OR GRAVELLY SAND WELL GRADED
		SP			SAND OR GRAVELLY SAND POORLY GRADED
		SM		YELLOW	SILTY SAND OR SILTY GRAVELLY SAND
		SC			CLAYEY SAND OR CLAYEY GRAVELLY SAND
FINE-GRAINED SOILS	SILT AND CLAY SOILS (LOW LIQUID LIMIT)	ML		GREEN	SILTS, SANDY SILTS, GRAVELLY SILTS, OR DIATOMACEOUS SOILS
		CL			LEAN CLAYS, SANDY CLAYS, OR GRAVELLY CLAYS
		OL			ORGANIC SILTS OR LEAN ORGANIC CLAYS
	SILT AND CLAY SOILS (HIGH LIQUID LIMIT)	MH		BLUE	MICACEOUS SILTS, DIATOMACEOUS SOILS, OR ELASTIC SILTS
		CH			FAT CLAYS
		OH			FAT ORGANIC CLAYS
FIBROUS ORGANIC SOILS		Pt		ORANGE	PEAT, HUMUS, AND OTHER ORGANIC SWAMP SOILS

82.183

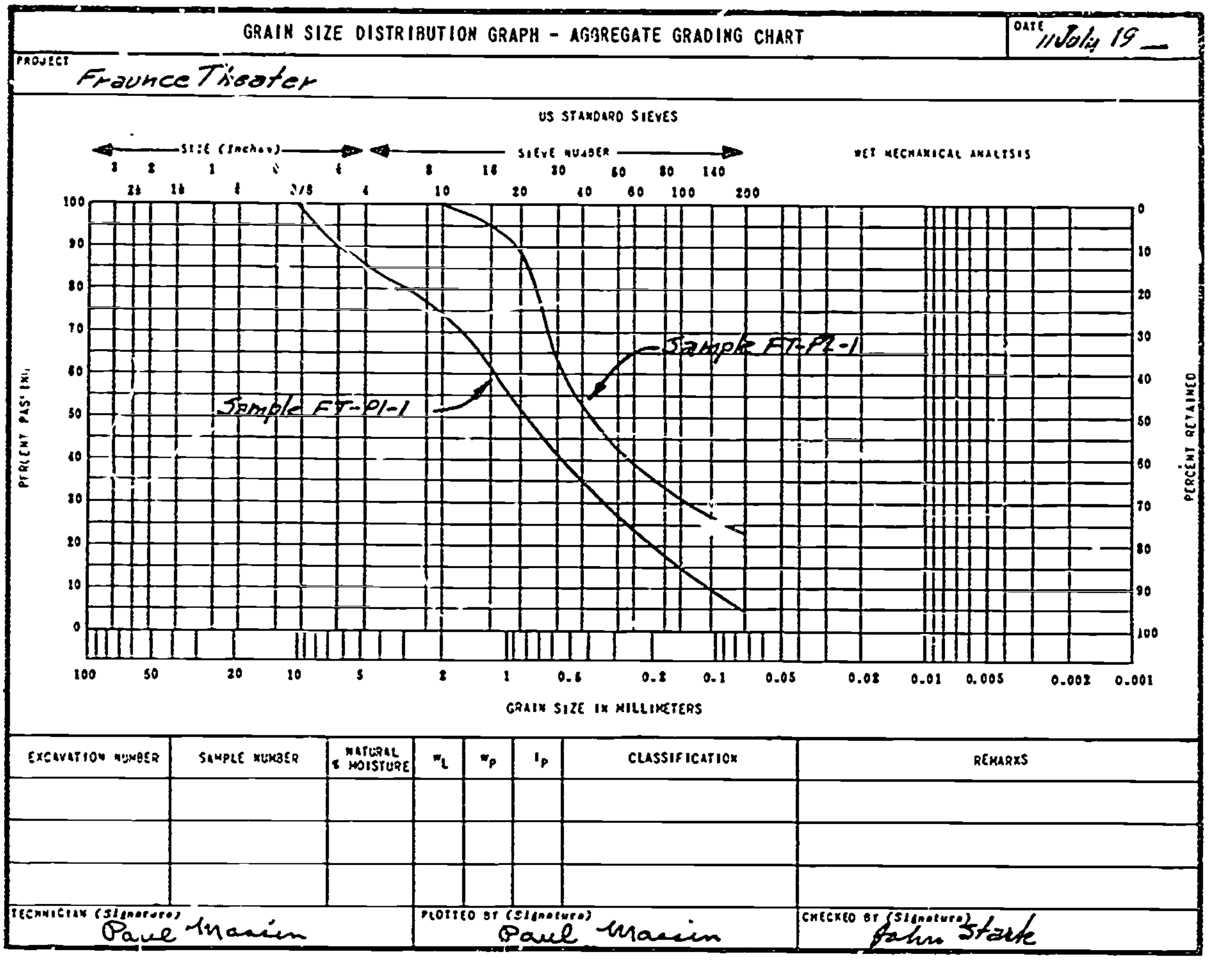
Figure 14-4.—Conventional graphic soil symbols.

D_{30} is the grain size, in millimeter, indicated by the gradation curve at the 30 percent passing level. In figure 14-5 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 0.88.

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 fig. 14-3) 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 fig. 14-3), its C_c is less than 1, the minimum prescribed for SW in fig. 14-3. Therefore, it is in the SP (poorly graded sands, gravelly sands, little or no fines) category

ATTERBERG LIMITS

Note that for a silt or clay, a silty gravel or gravel-sand-silt mixture (GM), a clayey gravel or gravel-sand-clay mixture (GC), a silty sand (SM), or a clayey sand (SC), the Atterberg limits are laboratory classification criteria. A clay or related fine-grained soil, when dry or nearly dry, has a semisolid consistency. As moisture content



82.118

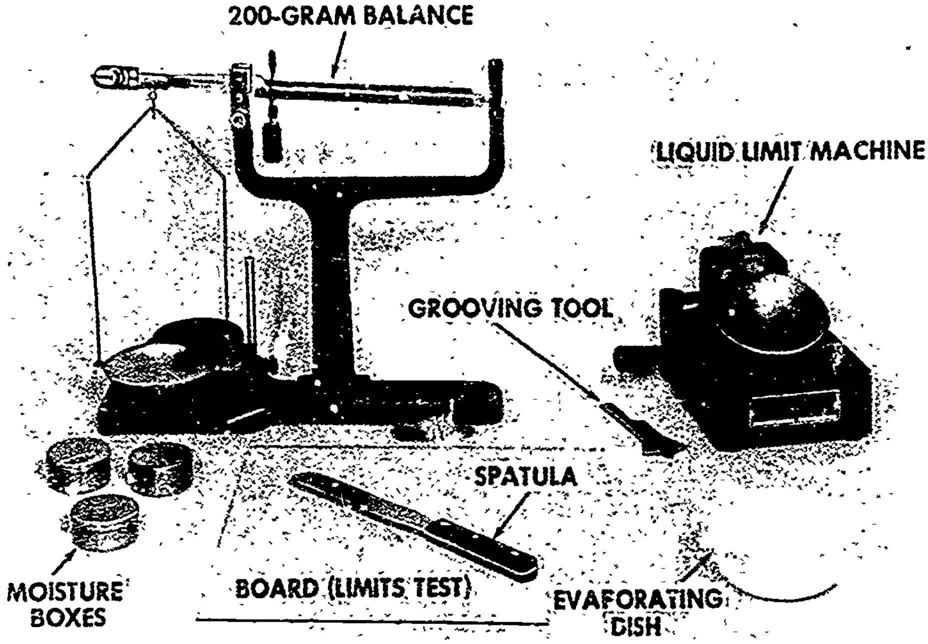
Figure 14-5.—Grain size distribution chart.

increases, a point is reached where the material has a PLASTIC (putty-like) consistency. This point is called the PLASTIC LIMIT (PL). As moisture content continues to increase, the material remains plastic over a certain RANGE. Finally, however, at a point called the LIQUID LIMIT (LL) the consistency of the material changes to SEMILIQUID.

The upper and lower limits of the plastic range (that is, the liquid and plastic limits) are called "ATTERBERG LIMITS", after a Swedish scientist who developed the concept of these limits. The liquid limit (LL) is simply the moisture content (W_L) at the upper limit of the plastic range, expressed as a percentage. The plastic limit (P_L) is the moisture content at the lower limit of the plastic range.

Atterberg Limits Test Equipment

Figure 14-6 shows equipment for determining the Atterberg limits of a soil sample. The LIQUID LIMIT TESTING DEVICE consists of a brass bowl, mounted on a box-type apparatus which, when crank-turned, elevates the bowl (containing sample), and then drops it downward a specific distance onto the hard-rubber anvil of the testing device. Each of these drops is called a BLOW; the purpose of the procedure will be explained as the test procedure is described.



82.119

Figure 14-6.—Apparatus for determining Atterberg limits.

Atterberg Limits Test Procedure

The liquid and plastic limit tests normally are conducted only on the portion of the soil which p ,ses the No. 40 sieve. A few particles which are large enough to be retained on the No. 40 sieve will not cause serious difficulty, but generally it is more expedient to remove these larger particles by hand by kneading the soil between the figures. If the percentage of particles retained on the No. 40 sieve is higher, they must be removed by passing the soil through the No. 40 sieve. The sample should not be oven-dried or subjected to any artificial drying before processing or testing.

The sample is soaked in water for 24 hours prior to washing. It is then washed through the No. 40 sieve and collected in a large evaporating dish or collecting can. Material retained on the sieve is oven-dried, then dry sieved through the No. 40 sieve. The portion dry sieved through the No. 40 is combined with the material washed through the sieve; the combined material is used for the tests. Soil particles lumped together or adhering to aggregate particles can be broken up and separated by rubbing with the hands.

Next the sample is dried to approximately the liquid limit, by decanting or blotting the water off, by evaporating it off (taking care to stir the soil frequently during evaporation), or by a combination of both procedures.

The water content at the liquid limit is arbitrarily defined as the water content at which the soil mass, placed in the liquid limit testing device cup and divided into the sections by a central groove made with the grooving tool (fig. 14-6), will make contact for a distance of 0.5 in. when the cup is dropped 25 times (i.e., for 25 blows) for a distance of 1 cm (0.3937 in.) at a rate of two drops per second. First adjust the machine for this drop distance as follows:

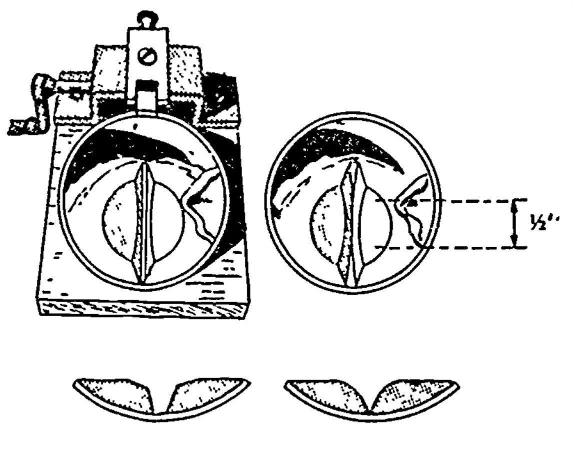
On the handle of the grooving tool there is a metric gage, and on the machine there is an ADJUSTMENT PLATE and a pair of ADJUSTMENT SCREWS. By manipulating the screws, adjust the height to which the cup is lifted so that the point on the cup that comes in contact with the anvil of the machine is exactly 1 cm above the anvil (the anvil is simply the upper surface of the hard-rubber base of the machine). Check adjustment by turning the crank at a rate of two drops per second. A slight click will be heard when adjustment is correct.

Steps in the test procedure are as follows:

1. Take a sample weighing about 100 gm from the prepared test material, and place a portion of this in the cup above the spot where the cup rests on the base. Squeeze it down and spread it with as few strokes of the spatula as possible, taking care to prevent the entrapment of air bubbles within the mass. With the spatula, level the soil and, at the same time, trim it to a depth of 1 cm at the point of maximum depth. Then divide the soil in the cup by making a groove, with the grooving tool, along the centerline of the cam follower or hook that holds the cup. When making the groove, hold the cup in the left hand with the hook upward, and draw the grooving tool, beveled edge forward, through the material downward away from the hook. With some soils, especially sandy soils and soils containing organic matter, it is not possible to draw the grooving tool through the specimen without tearing the sides of the groove. In such cases, the groove is made with a spatula, using the tool only for final shaping. The groove, when made, will be wedge-shaped in section and open at the bottom for a distance equal to the width of the tip of the grooving tool.

2. Attach the cup to the carriage and turn the crank at a rate of 2 revolutions per second, counting the blows, until the two halves of the soil cake come into contact at the bottom of the groove along a distance of about 0.5 in (see fig. 14-7). Record the number of blows required to close the groove in this manner.

After recording, remove the cup from the testing device, remix and regroove the sample, place the cup again in the testing device, and repeat the test. If the second test number of blows differs from the first by not more than 1, record both numbers on the data sheet and consider the test finished. If the second test number of blows differs by more than 1, repeat the test until three successive determinations give a reasonably consistent sequence. The average of the three is taken as the number required for the closure.



82.184

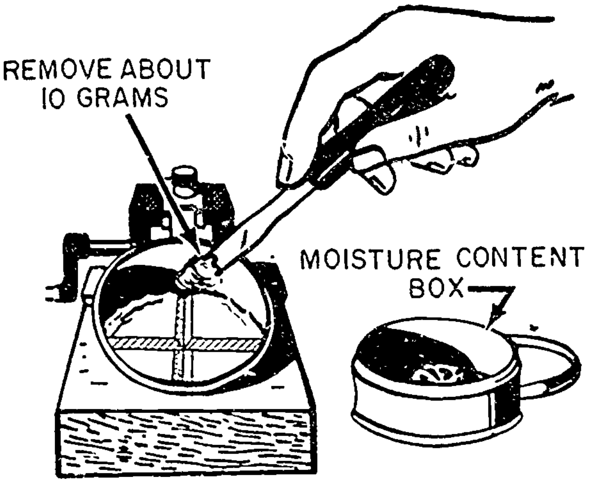
Figure 14-7.—Liquid limit test.

3. Remove a slice of soil approximately the width of the spatula, say about 10 gm, extending from the edge of the soil cake at right angles to the groove (see fig. 14-8); place this in a moisture content box, weigh, and record the weight. Record the difference in weights, which is, of course, the weight of the water content.

4. Transfer the soil remaining in the cup to the evaporation dish. Wash and dry the cup and grooving tool and reattach the cup in preparation for the next run.

5. It is recommended that at least 5 tests be run on each soil, with 2 closures above, two closures below, and one closure at or near the 25-blow line. An ideal spread would be closures at 16, 23.5, 29, and 33 blows. If each test is perfect, the plotted line through all points will be a straight line. If some tests are imperfect, the operator can usually obtain good results by using the three plotted points lying most nearly in a straight line.

You determine the liquid limit by plotting a FLOW CURVE on a graph like the one shown in figure 14-9. This is a semi-logarithmic graph, in which the vertical coordinates are water contents and the horizontal coordinates numbers of blows. The flow curve is a straight



82.185
Figure 14-8.–Removing moisture content portion.

line plotted as nearly as possible through three or more of the plotted points.

In figure 14-9, for example, the first-run sample was tested three times, for an average number of hammer blows of 16. The water content was 47.3 percent. On the graph, 16 and 47.3 are the coordinates of one of the three X's shown plotted. For the second-run sample, the hammer blows were 24 and the water content 46.6 percent; these are the coordinates of another of the X's plotted to the right. Coordinates for the third X are the hammer blows and water content for the third-run sample. For the rest of the plotted points, their coordinates are as indicated by the hammer blows and water contents for the succeeding runs. The plotted points in the graph might not form a straight line; however, the Liquid Limit line (or flow curve) will be a straight line, drawn approximately passing through the mean of the plotted points, as shown in figure 14-9. To have a more representative result, five or six trials are usually recommended.

The liquid limit (LL) is the water content for 25 blows; it is therefore indicated by the point of intersection between the flow curve and the vertical line representing 25 blows. The water content indicated is approximately 46.4 percent; this, therefore, is the liquid limit, which rounded off is 46.

The plastic limit of a soil is defined as the lowest water content at which the soil will just begin to crumble when rolled into threads 1/8 in. in diameter, at slowly decreasing water contents. First prepare the sample as follows:

If only the plastic limit is required, take a quantity of soil weighing about 15 gm from the prepared material in the evaporating dish. Place this air-dried soil in an evaporating dish and thoroughly mix with distilled water, adding water until the soil mass becomes plastic enough to be easily shaped into a ball. Take a portion of the ball weighing about 8 gm for the sample.

Steps in the test procedure are as follows:

1. Squeeze and form the 8 gm test sample into an ellipsoidal-shaped mass. Roll this mass between the fingers and the test board (fig. 14-10), with just enough pressure to roll the mass into a thread of uniform diameter throughout its length. The rate of rolling should be between 80 and 90 strokes a minute, considering a stroke to be one complete motion of the hand forward from and back to starting position.

2. When the diameter of the thread has been reduced to 1/8 in., break the thread into six or eight pieces (fig. 14-11). Squeeze the pieces together between the thumbs and fingers of both hands into a uniform mass roughly ellipsoidal in shape, and again roll out into a thread. Continue this alternate rolling to a thread 1/8 in. in diameter, breaking, combining together, and rerolling, until the thread crumbles under the pressure required for rolling and the soil can no longer be rolled into a thread. The crumbling may occur when the diameter of the thread is still greater than 1/8 in. This is considered a satisfactory end point, provided the soil has previously been rolled into a 1/8-in. thread at least once.

3. Gather the portions of the crumbled soil together, place it in the moisture content and determine the water content from the difference in weight before and weight after oven drying.

4. Repeat the process on at least two additional specimens. All three tests should agree within 1 percent.

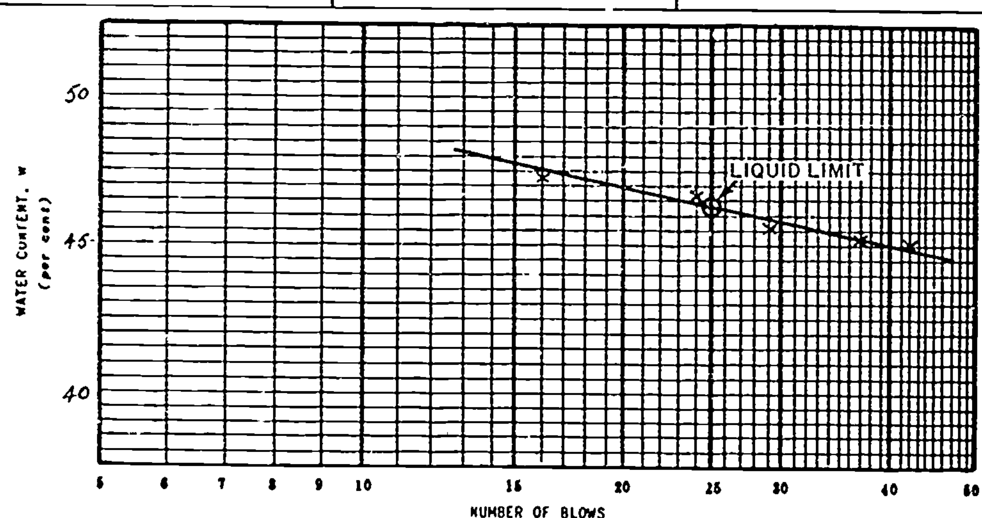
The plastic limit is, simply, the d[illegible]mined water content.

ATTERBERG LIMITS DETERMINATION		DATE: 1 June 19–
PROJECT: Britt Airfield	EXCAVATION NUMBER	SAMPLE NUMBER: B-P3-1

LIQUID LIMIT, w_l

RUN NUMBER	1	2	3	4	5	6
TARE NUMBER	41	42	43	44	45	46
A. WEIGHT OF WET SOIL + TARE	44.41	44.89	41.07	41.27	41.17	40.91
B. WEIGHT OF DRY SOIL + TARE	41.08	41.52	38.16	38.39	38.32	38.08
C. WEIGHT OF WATER, W_w (A.-B.)	3.33	3.37	2.91	2.88	2.85	2.83
D. WEIGHT OF TARE	34.04	34.29	31.88	32.06	32.01	31.80
E. WEIGHT OF DRY SOIL, W_s (B.-D.)	7.04	7.23	6.28	6.33	6.31	6.28
WATER CONTENT, $w=(\frac{W_w}{W_s} \times 100)$ %	47.3	46.6	46.3	45.5	45.2	45.0
NUMBER OF BLOWS	15-17-16	23-24	29-28-30	33-33	37-38	41-42

LL	PL	PI=LL-PL
46	18	28



PLASTIC LIMIT, w_p

RUN NUMBER	1	2	3		NATURAL WATER CONTENT
TARE NUMBER	45	46	47		48
F. WEIGHT OF WET SOIL + TARE	56.21	55.15	60.60		58.72
G. WEIGHT OF DRY SOIL + TARE	55.90	54.89	60.10		57.82
H. WEIGHT OF WATER, W_w (F.-G.)	0.31	0.26	0.50		0.90
I. WEIGHT OF TARE	54.10	53.40	57.43		55.02
J. WEIGHT OF DRY SOIL, W_s (G.-I.)	1.80	1.49	2.67		2.80
WATER CONTENT, $w=(\frac{W_w}{W_s} \times 100)$	17.2	17.4	18.7		32.1
PLASTIC LIMIT, w_p (Average w)			18		

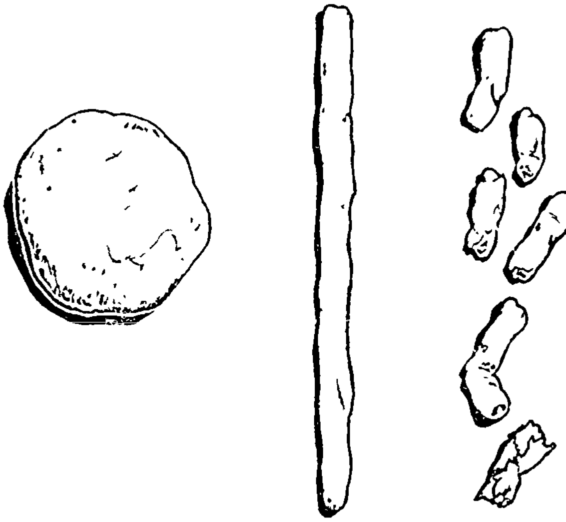
REMARKS

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
William Deni	William Deni	Joseph Stephen

82.186

Figure 14-9.—Data sheet, Atterberg limits determination.

82.187
Figure 14-10.—Roll or thread test.



82.188
Figure 14-11.—Roll or thread test, before and after crumbling.

Plasticity Index

The PLASTICITY INDEX (PI) of a soil is the numerical difference between its liquid limit and its plastic limit; that is: PI = LL - PL. The PI which appears in figure 14-9 means plasticity index.

Plasticity Chart

The PLASTICITY CHART is shown in figure 14-12. This chart is a graph in which the horizontal coordinates represent liquid limits and the vertical coordinates plasticity indexes. The "A" line is an empirical boundary between silts and clays. A soil whose plotted LL and PI lies below the "A" line is a silt (M). Take the soil tested in figure 14-9, for example. For this soil the LL is 46 and the PI is 28. The plotted point for these coordinates is the point marked by X in figure 14-12. This point is above the "A" line; therefore, the material is a clay.

There is another heavy line on the chart: the one running vertically from LL 50. This line (called the "B" line) is the empirical boundary between soils of low plasticity (L) and soils of high plasticity (H). Since compressibility increases with plasticity, it may be said that the "B" line is an empirical boundary between soils of low and high compressibility. The soil tested in figure 14-9 lies on the L side of the "B" line; therefore, its complete symbol would be CL.

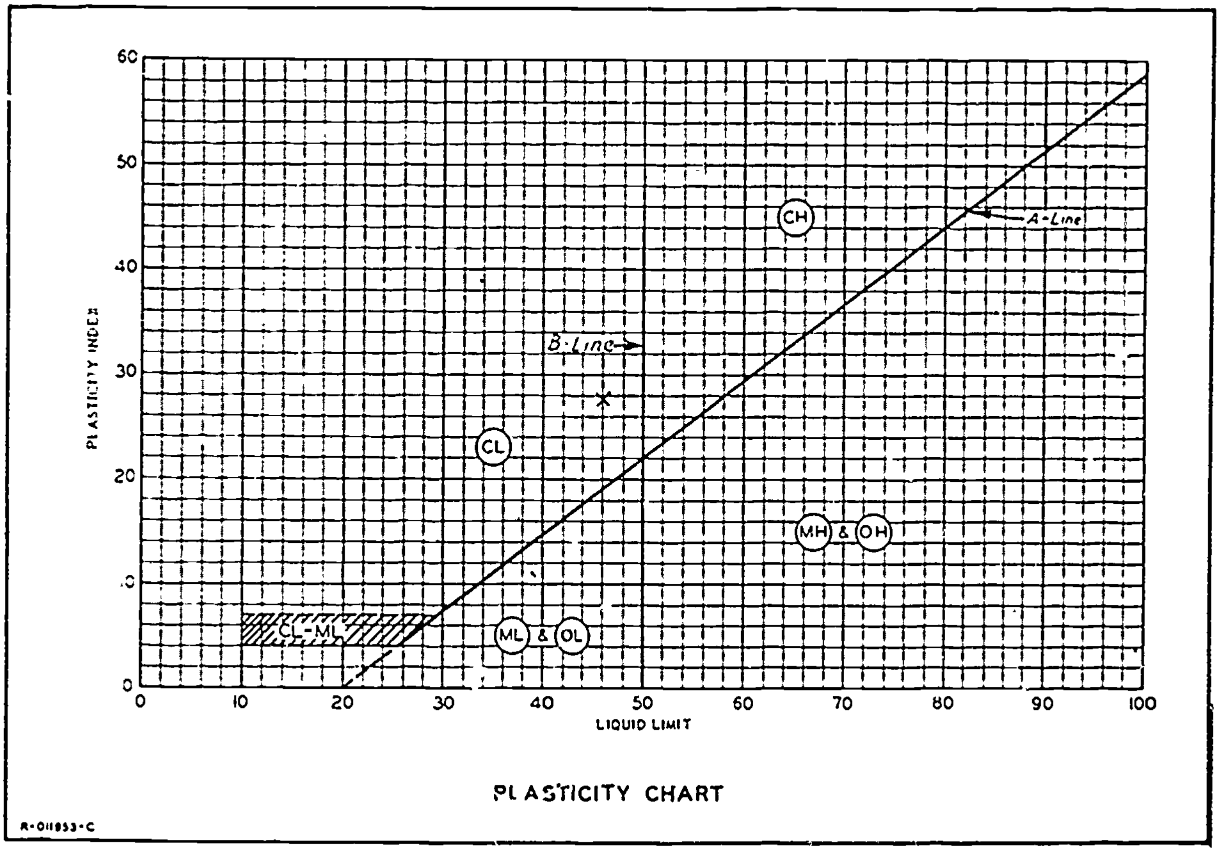
Borderline Soils

In figure 14-3 you can see the GW and GP are gravels in which less than 5 percent of the material is smaller than the No. 200 sieve, while GM and GC are gravels in which more than 12 percent of the material is smaller than the No. 200 sieve. This leaves the gravels having between 5 and 12 percent of the material smaller than the No. 200 sieve unaccounted for. Gravels in this category are classed as BORDERLINE, and carry a duel symbol, such as GW-GM (well-graded silty gravel).

The shaded area shown in figure 14-12 applies to similar borderline fine-grained soils. If you look closely, you will see that the "A" line turns horizontal below LL about 29, and becomes, instead of a line, a zone (the shaded zone) ranging between PI values of 4 and 7. A soil whose LL and PI plot within this zone is designated as CL-ML (low-compressible silty clay), since no distribution between clay and silt can be made in the zone.

Nonplastic Soils

When the liquid limit or plastic limit cannot be determined, the soil is designated as NP (nonplastic). If, during a LL test, the groove will not close after a certain maximum number of



82.121

Figure 14-12.—Plasticity chart.

blows (designated by some authorities as 33, by others as 50), the LL cannot be determined, and the soil is nonplastic. If, on the other hand, the groove closes after less than a certain number of blows (considered by most authorities to be 15), the PL cannot be determined, and the soil is nonplastic.

Also, if the plastic limit is equal to, or greater than, the liquid limit, the soil is nonplastic.

SAMPLE CLASSIFICATION PROBLEMS

The following soil classification problems are presented to show you how the soil classification chart (fig. 14-3) 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). Working directly from the uniform soil classification chart (fig. 14-3), the first question is whether the soil is coarse-grained or fine-grained. In order to be coarse-grained, a soil must have less than 50 percent fines. This soil contains no fines, therefore, it is a coarse-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.

Next 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 60 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. If 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. 14-12), 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 will 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 therefore CL, meaning: "clay with low compressibility."

SUMMARY OF SOIL CLASSIFICATION

An infinite number of separate soils exist on the earth, and it would be impossible to study each individually. Fortunately, it is possible to divide and subdivide soils into GROUPS having similar physical properties. One of the most convenient systems of doing this is the Unified Soil Classification System.

In this system soils are identified by 2-letter group symbols or by combinations of these called DUAL symbols. The letters used are the first letters of corresponding names or descriptive terms, except that for silt the letter M is used.

The first division is that between coarse-grained soils (less than 50 percent fines) and fine-grained soils (50 percent or more fines). Coarse-grained soils are either sands or gravels, having the letter designations S or G. For a coarse-grained soil, having less than 5 percent fines, the second letter in the group designation symbol describes gradation (W for well-graded, P for poorly graded). For a coarse-grained soil having more than 12 percent fines, the second letter describes the type of fine, as: GM (silty gravel), GC (clayey gravel), SM (silty sand), and SC (clayey sand). For a coarse-grained soil containing between 5 and 12 percent fines, both gradation and type of fine is indicated by a dual symbol. Similarly, a dual symbol is used to describe a soil with less than 5 percent fines which are plastic, as: GW-GM (well graded silty gravel).

The plasticity chart is the instrument used to determine type of fines. A LL-PI point plotting above the "A" line indicates clay; one plotting below the "A" line indicates silt (assuming the soil to be nonorganic).

Besides the C or M designation, a fine-grained soil is given a second letter designation in accordance with its plasticity or compressibility. A LL of less than 50 indicates a soil of low plasticity/compressibility (L); one of more than 50 indicates a soil of high plasticity/compressibility (H).

SOIL EXPLORATION

A SOIL EXPLORATION is a survey conducted principally to determine what kind of soils exist in a construction area, and how the different types of soil are distributed, both horizontally and vertically. The survey is also intended to secure other important engineering information, such as drainage conditions, location of bedrock, elevation of the water table, and soil moisture conditions.

Basically, the earth's crust consists of rock. When exposed for sufficient length of time, all rock undergoes disintegration and decomposition, and is ultimately converted into a loose, incoherent mixture of sand, gravel, and finer material. This process is called WEATHERING.

The weathering process produces soils of various designations as indicated below.

RESIDUAL SOILS

Any soil which results from weathering in place, and which is not moved during the weathering process, is called a RESIDUAL soil. A mantel of residual soil will reflect the characteristics of the underlying parent rock from which it was derived.

TRANSPORTED SOILS

When the forces of nature cause the mantel of soil to be moved to a place other than that of its origin, the soil becomes a TRANSPORTED soil. One of these soils will often bear properties induced by its mode of transportation. The chief agents of transportation are water, wind, ice, and the force of gravity.

Waterborne soils are the most common of the transported soils. They are further divided into ALLUVIAL, MARINE, and LACUSTRINE soils, depending upon the type of water body by which the soil was transported and deposited.

Alluvial Soil

This type of soil is formed as a soil-carrying stream gradually loses its carrying capacity with decreasing velocity. In slowing down, a river will not have sufficient power to keep the larger particles of soil suspended, and they will settle to the river bed. Further decrease in velocity causes smaller particles to settle. As the river becomes slow and sluggish (as in the lowlands, where its gradient becomes small), it holds only the extremely fine particles in suspension. These particles are deposited, finally, at the mouth of the river, where they form DELTAS of fine-grained soil.

Marine Soil

Marine soil is formed from materials carried into the seas by streams, and by material eroded from the beaches by wave tidal action. Part of the material is carried out and deposited in deep water; part is heaped up on the beaches along the coast.

Lacustrine Soil

Fresh water lake deposits are called LACUSTRINE soils. Generally speaking, they are fine-grained soils resulting from material brought into fresh-water lakes by streams or rivers.

Aeolian Soil

Wind transported grains make up aeolian soils. Sand deposits from wind are called "dunes," and the finer particles (which are generally carried further) are deposited to form a material called LOESS. Dune deposits seldom contain material larger than sand size.

Glacial Soil

Glacial soil is often called DRIFT. It consists of material carried along with or upon an advancing ice sheet, or of material pushed ahead of it. As glaciers melt, deposits of various forms occur, such as MORAINES, KAME TERRACES, ESKERS, and OUTWASH PLANES. Moraines consist of mixtures of unstratified boulders, gravels, sands, and clays. The other forms mentioned consist of somewhat stratified and partly sorted stream gravels, sand, and fines transported outward from the glacier by streams during the melting period.

Culluvial Soils

Mixed deposits or rock fragments and soil material accumulated at the bases of steep slopes, through the influence of gravity, are called culluvial soils.

OBJECTIVES OF A SOIL EXPLORATION

The overall objective of a soil exploration 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. Ground water 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 only be accomplished when the types and depths of soil to be encountered are known. By classification of the soils encountered, a prediction as to the extent of problems concerning drainage, frost action, settlement, stability, and similar factors can be made. While an estimate of the soil characteristics may be obtained by field observations, samples of the major soil types as well as less extensive deposits, which may conversely influence design, should be obtained for laboratory testing.

Condition of Soils in Place

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 in place to meet the required specifications, no compaction of subgrade will be required. On the other hand, extremely dense soil lying in cut sections may be difficult to excavate with ordinary tractor scraper units, thus requiring scarification or rooting before excavation.

Drainage Characteristics

The drainage characteristics, both surface and subsurface, of a soil greatly affect the soil's strength. This characteristic is controlled by a combination of factors, including void ratio, soil structure and stratification, temperature of soil, depth to water table, and the extent of local disturbance by roots and worms. The coarse-grained soils have better internal drainage than the fine-grained soils.

Ground Water and Bedrock

All structures must be constructed at an elevation which will ensure that they will not be adversely affected by the ground water table. If a proposed grade line lies below the elevation of the ground 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 tremendously increases the time and equipment requirements for the excavation. If the amount of the rock is very 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 see to it that field notes and logs are kept properly. He is responsible for surveying, numbering, and recording each boring, test pit, or other exploration investigation. A log is kept of each test hole, showing the depth below the surface (or the top and bottom elevations) of each soil layer revealed, the field identification of each soil encountered, and the number and the type of each sample taken. Other information which may be included in the log is that relating to density of each soil, changes in moisture content, depth to ground water, and depth to rock. A detailed field log is kept of each auger boring or test pit made during the soil survey. When the survey has been completed, the information contained in the separate logs are consolidated. In addition to the classification and depth of soil layers encountered in each log, it is desired to show the natural water contents of fine-grained soils along the side of each log, when possible. Also, the elevation of the ground water table should be noted. This elevation is simply that of any free water standing in the test hole. To get an accurate determination, an interval of 24 hours should be allowed to elapse, before the elevation is measured, to permit the water to reach maximum elevation.

The soil profile 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. Those soil symbols illustrated in figure 14-4 should be used to indicate the various soil layers—the standard procedure is to add the proper color symbol representing the various soil types discovered.

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, which 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 if borrow soils will be required instead. It may show the existence of undesirable soils, such as peat or other highly organic soils, or the existence of bedrock too close to the surface. It aids in the planning of drainage facilities, since these 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. Some of these, such as published information and previous soil analyses, may be secured without field exploration. These sources are used mostly to locate small areas in a large general area which are suitable for further investigation. 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 which 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 have been published in the Folios of the U.S. Geological Survey. Generally, the smallest rock unit mapped is a formation, and geologic maps indicate the areal extent of formations by means of letter symbols, color, or symbolic patterns. Letter symbols on the map indicate the locations of sand and gravel pits, and on the back of the map sheet a brief discussion entitled "Mineral Resources," describing the location of construction materials, is sometimes available.

Ordinary TOPOGRAPHIC MAPS may be of some use in estimating soil conditions, particularly when 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 SOIL 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 ft. 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 AIR PHOTOGRAPHS in delineating and identifying soils is based upon the recognition of typical patterns formed under similar conditions of soil profile and weathering. Principal elements which can be identified on a photograph, and which provide a trained observer with clues to the identification of soils, are land form, slopes, drainage patterns, erosional characteristics, soil color or "tone" vegetation, and land use.

The form or configuration 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 sands 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 is frequently indicative of pervious soil. A highly integrated drainage pattern is frequently indicative of impervious soils, which in turn are plastic and lose strength when wet. Drainage patterns also frequently reflect underlying rock structure.

The erosional pattern often provides clues as to the character of the soil. The cross section or shape of a gully, for instance, is controlled primarily by the cohesiveness of the soil. Each abrupt change in grade, direction, or cross section is indicative of a change in the soil profile or rock layers. Short, V-shaped gullies with steep gradients are typical of cohesionless 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 air photographs by shades of gray, ranging 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 very flat appearance, and no conformation indicating natural surface drainage. Clays and organic soils frequently appear as dark gray to black areas. In general, a sharp change in color tone 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. With local experience, both cultivated and natural vegetation cover are good indicators of soil type.

The use of 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.

SOIL SAMPLING

The selection of representative sample of soil for testing is called "soil sampling."

Sampling Tools

There are three basic types of tools used for extracting samples. One of these tools is a sounding rod, which is driven into the ground, principally to locate the upper level of any firm stratum such as rock or a dense layer of sand, gravel, or shale.

The other two basic types of tools, an auger and a sampler, are used to bring up subsurface soil. An auger is a boring tool, similar to a wood-boring auger bit. It brings up a DISTURBED sample. A sampler has a cylindrical end-cup which, when driven into the ground, brings up an UNDISTURBED sample.

Hand-operated augers can be bored to a depth of about 20 ft. A hand-driven sampler can attain only a relatively shallow depth (about 4 ft), but there are power-driven samplers which can be driven (by hydraulic mechanism or winch-operated drop-hammers) to 20 ft or more.

Locating, Recording, and Numbering Samples

For a given area in which the soil is to be tested (such as the area on which a structure is to be erected), the officer in charge of soil exploration decides how numerous the points must be, and where they must be located, to produce a representative test of the soil in the area. This information is recorded in a sketch like the one shown in figure 14-13.

This figure shows the locations of exploratory points along a highway, the point locations being referenced by centerline station and distance from the centerline. To the left of the centerline, between stations 2 + 80 and 4 + 60, there will be a "borrow pit," from which soil for fill will be taken. The soil here will be tested by samples taken from a 60-ft trench (T 1), located

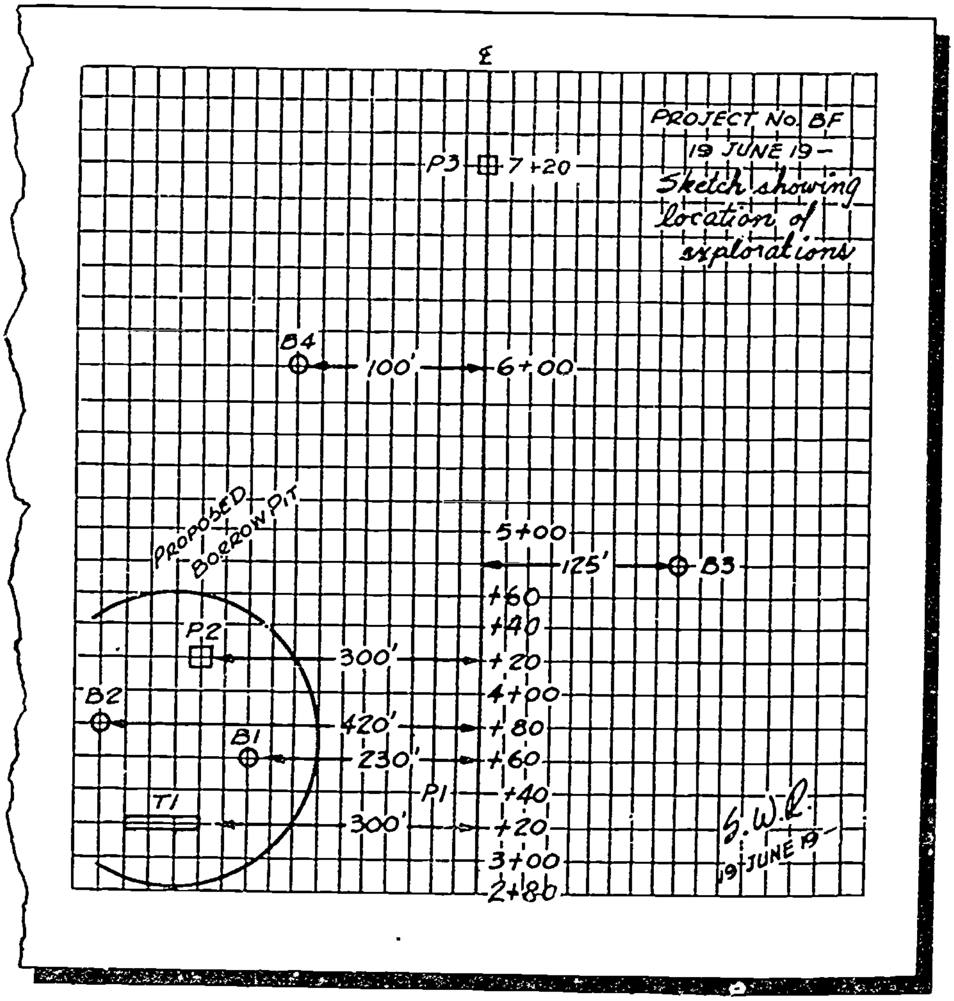


Figure 14-13.—Sketch showing locations of soil exploration points.

45.547

at station 3 + 20, 300 ft from the highway centerline; from two borings (B 1 and B 2) at stations 3 + 60 and 3 + 80, 230 ft and 420 ft from the centerline, respectively; and from a 20-ft square pit at station 4 + 20, 300 ft from the centerline.

Besides the borrow pit exploration, there will be a boring (B 3) at station 4 + 80, 125 ft to the right of the centerline; another boring (B 4) at station 6 + 00, 100 ft to the left of the centerline; and a 20-ft square pit (P 3) on the centerline at station 7 + 20.

Each sample taken is tagged according to the location from which it was taken. Locations are given consecutive numbers; for those shown in figure 14-13, the numbers might run from the bottom up, with T 1 being No. 1, B 1 No. 2, and so on. A sample is also tagged with the project symbol (the symbol for the project shown in fig. 14-13 is BF) and the location symbol (such as T 1 or B 1); also with still an additional number if more than one sample is taken from the same location.

For example: a sample taken from B 2 in figure 14-13 might be tagged "BF—B 2—4, bag 1 of 6," meaning: "project BF, boring No. 2, location No. 4, the first of 6 bags taken from that location."

Disturbed and Undisturbed Samples

"Disturbed" samples are samples taken by hand scoops, shovels, auger borings, or wash borings. No attempt is made to obtain the material in its natural state of structure or density.

"Undisturbed" samples are taken by samplers when it is desired to know the natural or in-place density of the soil stratum, the shear strength, and the compressive strength.

Quartering a Sample

A disturbed sample is reduced to a smaller, more manageable size for testing by the procedure called "quartering." The procedure is followed to ensure that the smaller portion will be representative of the whole sample.

The sample is first thoroughly mixed, then poured out on a canvas and spread into a circular layer of uniform thickness. The layer is divided into quarters by cutting two diameters through it at right-angles to each other, just as you would cut a pie into four equal wedges. Two diagonally opposite quarters are discarded. The remaining two are combined, taking care to include all dust and fines. The process is then repeated, until the sample residue has been reduced to the size desired.

For sandy soil a "sample splitter" or "riffler" may be used to reduce the size of the sample. The splitter divides the sample into halves, by repeating the operation, you get quarters, eighths, sixteenths, and so on.

Field Observations

Through the use of the various types of published information and air photographs, the exploration of a general area may be narrowed down to several smaller areas suitable for further investigation. The extent and method of collecting more detailed information by field observations will depend on the time available.

Rapid ground observation, along the proposed highway or airfield location, may yield valuable information when circumstances do not permit a complete or deliberate soil survey. The soil profile may be observed along the natural banks of streams, eroded areas, bomb craters, road cuts, or other places where the stratification is exposed. Such observations may indicate types of soil and depths of layers. Loose surface soil should be scraped off before the examination and field identification are made. Samples may be taken from exposed soils for testing in a field laboratory; however, sampling and testing are normally 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 sub-soil 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 third method of investigation, which reveals information about the sub-soil structure, is the SEISMIC SURVEY, described later in this chapter.

A test pit is an open excavation which 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, but power excavation by dragline, clamshell, bulldozer, backhoe, or a large 24-in. diameter power-driven earth auger can expedite the digging—if the equipment is available. Excavations below the ground water 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 but 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, the earth auger may be used to a depth of about 30 ft 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-in. 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 are collected 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 wash water; they are so disturbed, however, that their value is limited. They should not be used unless no 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. Special samplers are used for this purpose. To minimize the amount of disturbance, they must be jacked gradually into the ground, with twisting or jarring carefully avoided. These samples can best be obtained from relatively cohesive soils.

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 enter the drill's CORE BARREL and is retained by a holding device when the drill is removed from the hole. This is the best method for determining the characteristics and condition of subsurface rock.

The SEISMIC SURVEY is made from the ground surface, using the MODEL R-117B SEISMIC TIMER. This method gives information about the depth of soil, and about the thickness and dip of subsurface layers of rock or other dense materials. Seismic survey data is often useful in planning the best location for test pits and test holes. It is also useful in extending test hole information over a large site area. The method is described later.

PLANNING FIELD EXPLORATIONS

The location of test holes or test pits will depend upon the particular situation. In any case, since soil tests should be made on samples which are representative of the major soil types in the area, 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 land forms and soil conditions in ditches and cuts. Seismic surveys should be made to detect the presence of subsurface HORIZONS or layered materials or bedrock, and the depths to such materials. 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 the making of 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, especially the seismic survey and the technique of locating soil boundaries from aerial photographs, will permit strategic spacing of the preliminary borings to obtain maximum information with a minimum number of borings.

Soil samples should be obtained for classification purposes in these preliminary borings. After these samples are classified, soil profiles should be developed. Additional seismic surveys can be made, as required, to assist in extending soil profile lines where no preliminary borings exist. 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 will depend on the characteristics of the subgrade soils. Sub-soil 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, borings carried 2 to 4 ft below the anticipated depth of borrow should be made in these areas. Samples should be classified and tested for water content, density, and strength.

Areas within a reasonable haul from the site should be explored for possible sources of select material suitable for use as subbase. Exploration procedures are similar to those described for subgrades. Test pits or large auger borings drilled with power augers are needed in gravelly materials.

SOIL TESTING

In soil testing the Navy follows procedures laid down by the American Society for Testing Materials (ASTM). Soil tests are described in NAVFAC DM-7, *Soil Mechanics*.

The ultimate support for the combined live and dead load of a structure is the natural earth or "soil" on which the structure is erected. The bearing capacity of a given soil increases with its density, and density is measured in terms of the "unit weight," or "weight per cu ft," of the soil.

The density (and hence the bearing capacity) of a soil can be increased by compaction. For a given compactive effort, there is an "optimum moisture content" of the soil–meaning the moisture content which will result in the highest density for a given compactive effort. To express this another way. if the moisture content is above or below the optimum, a given compactive effort will not attain the maximum possible density.

STEPS IN SOIL TESTING

Generally speaking, then, a complete soil test proceeds in steps as follows.

1. Determining the moisture content of representative samples. (This is preceded, of course, by the extraction of representative samples.)
2. "Mechanical analysis," or the determination of sizes of soil particles (or grains) and the "distribution" of sizes—meaning the percentage of each size which the whole mass contains.
3. Determination of the "specific gravity" of representative samples. The specific gravity of a substance is expressed in terms of the weight of a given volume of the substance to the weight of an equal volume of water. A cu ft of water weighs 62.43 lbs.

For soil it is the "absolute" specific gravity which is determined meaning the ratio of the weight of a "dense" volume (volume exclusive of air spaces) to the weight of an equal volume of water. A cu ft of dry sand, for example, weighs about 100 lbs. With air exhausted, however, a cu ft of sand weighs about 165.44 lbs. Therefore, the specific gravity of sand equals 165.44 divided by 62.43, or about 2.65.

4. If the soil is clay or a similar fine-grained soil, determining the Atterberg limits. Over a certain range of moisture content, a fine-grained soil remains plastic. Reduction below the bottom of the range causes the soil to become semi-solid, increase above causes it to become fluid. The upper moisture content is called the "liquid limit," the lower is called the "plastic limit."
5. Compaction testing, to determine the "moisture-density" relationships, and thus to determine what moisture content will result in maximum compaction for a given compactive effort.
6. "Field control" testing, to determine (a) the field moisture content (with an eye to reducing or increasing it to the optimum, if

feasible), and (b) the point when the specified density has been obtained by compaction.

DETERMINING MOISTURE CONTENT

The moisture content of a sample is determined by weighing the sample, first in its natural state, then after oven-drying. The difference in weight is the weight of the moisture content. However, moisture content (w) is expressed as a percentage, obtained from the following formula:

$$w = \frac{100\,Ww}{Ws}$$

Ww stands for the weight of the moisture content, Ws for the oven-dry weight of the sample.

Apparatus

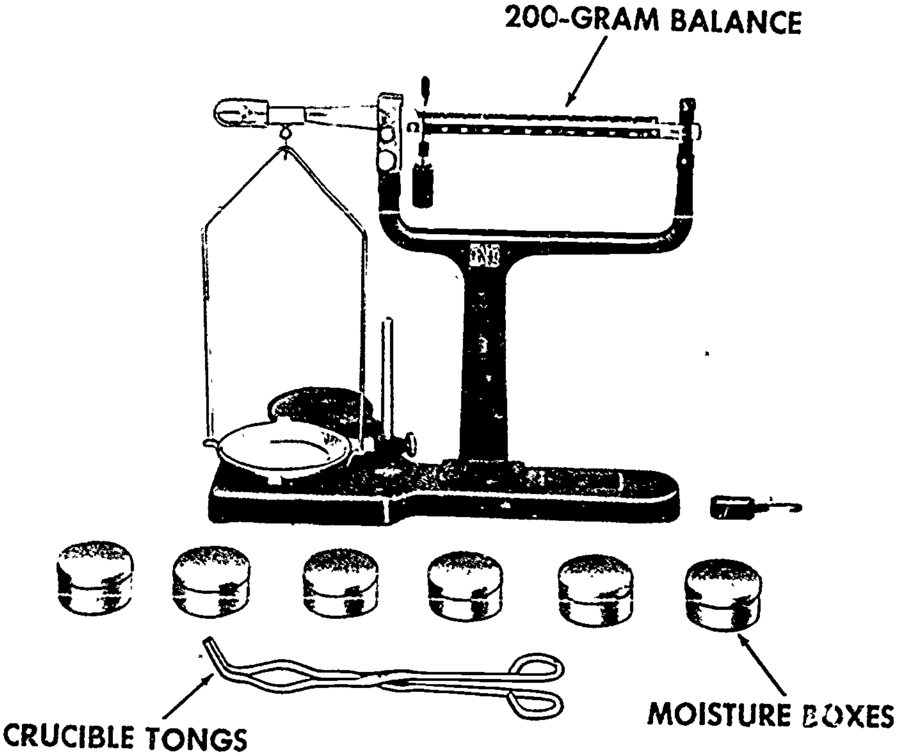
Laboratory apparatus for moisture content determination includes the following items:

A balance (fig. 14-14) for weighing material in grams. There are 453.6 grams in a pound.

Several small circular "moisture boxes" (fig. 14-14) in which samples are placed for weighing and drying.

An electric oven or a portable gasoline oven in which samples are dried.

In the absence of an electric oven or gasoline oven, material may be dried in a frying pan held over an ordinary stove or hot plate. The disadvantage here is that temperature is hard to control, and organic material in the sample may



45.548

Figure 14-14.—Apparatus for determining moisture content.

be burned, causing a slight to moderate inaccuracy in the result. An electric oven can be set for temperature.

Procedure

Prior to beginning the tests, the weight of each of the moisture boxes (familiarly called "cans") is obtained and recorded by can number. This weight is recorded as "tare" weight, the expression "tare" meaning simply "a deduction of weight, made in allowance for the weight of a container or vehicle." Each can is then filled with sample, and the can (with lid on) and contents are weighed.

The lid is then removed, and can, contents, and lid are placed in the oven or pan for drying. If the electric oven is used, temperature is maintained between 212° F and 230° F, and the sample is dried for at least 8 hours for clay or silt, even longer. The dry can, contents, and lid are then weighed.

Results are recorded on a form like the one shown in figure 14-15. Here three tests (called "runs") were made, with can Nos. 5, 10, and 1. Beside "weight of tare" the weight of each can is recorded, note that although the cans are identical in appearance, they vary slightly in weight. Beside "weight of tare and wet soil," the weight of each with wet contents is recorded. Beside "weight of tare and dry soil," the weight of each after drying is recorded.

Line C shows the weight of the moisture content (Ww), obtained by subtracting "weight of tare and dry soil" (B) from "weight of tare and wet soil" (A). Line E shows "weight of dry soil" (Ws), obtained by subtracting "weight of tare" (D) from "weight of tare and dry soil" (B).

Beside "water content" are the results obtained by substituting the known values in the formula $w = \frac{100\,Ww.}{Ws}$ The average of these three values, or 12.7 percent, would be taken as w (percentage moisture content) for the sample.

MECHANICAL ANALYSIS

Mechanical analysis (meaning, the determination of grain sizes and the percentage distribution of each size) is done by a screening process called "sieve analysis."

Apparatus

Typical sieve analysis apparatus includes, besides a gram weighing balance, a number of sieves with apertures of varying sizes which are used to determine grain sizes (see fig. 14-1). Sieves may be of the ordinary circular "sifter" type (usually about 8 in. diameter), or they may be of the "rocker" type, consisting of a rocker frame in which screens with apertures of various sizes can be placed.

The sieve used for analysis is the so-called "standard" sieve. A standard sieve has a square aperture. Screen sizes are designated as follows. A sieve with less than 4 apertures to the linear inch is designated by the size of an aperture. A 1/4-in., 1/2-in., 3/4-in., or 1-in. sieve, for example, means a sieve with an aperture 1/4 in., 1/2 in., 3/4 in., or 1 in. square.

A sieve with 4 or more apertures to the linear inch is designated by a number which represents the number of apertures to the linear inch. A No. 4 sieve, for example, has 4 apertures to the linear inch, a No. 6 has 6 apertures, and so on. The finest sieve used is a No. 200, with 200 apertures to the linear and an aperture size slightly smaller than one two-hundredth of an inch square.

Sieve Analysis, Dry

Samples containing cohesive soil which forms hard lumps must be prewashed as described later. Other samples are analyzed "dry" by the following procedure:

1. Oven-dry the sample.
2. Break up lumps. For coarse material, a rolling pin on a clean, hard, smooth surface will do. For fine material, use a mortar-and-pestle (usually a part of the laboratory apparatus), taking care not to crush individual grains. The object is to separate aggregations of clustering grains.
3. Weigh the sample.
4. Select the sieves to be used in the test. This selection varies according to the type of soil being tested. The following is a selection commonly used:

SOIL MOISTURE CONTENT

DATE: 16 June 19—

PROJECT: Faulkner Airbase

EXCAVATION NUMBER: 3 | SAMPLE NUMBER: FA-P2-1 | FORMULA: Water Content, $w = \frac{W_w}{W_s} \times 100$

TEST: Natural Soil Moisture Content						UNIT
RUN NUMBER	1	2	3			
TARE NUMBER	5	10	1			
A. WEIGHT OF TARE + WET SOIL	189.3	175.0	223.0			gm.
B. WEIGHT OF TARE + DRY SOIL	170.0	162.1	204.0			gm.
C. WEIGHT OF WATER, W_w (A.-B.)	19.3	12.9	19.0			gm.
D. WEIGHT OF TARE	44.0	42.9	45.2			gm.
E. WEIGHT OF DRY SOIL, W_s (B.-D.)	126.0	119.2	158.8			gm.
WATER CONTENT, w	15.3 %	10.8 %	12.0 %	%	%	

TEST						UNIT
RUN NUMBER						
TARE NUMBER						
A. WEIGHT OF TARE + WET SOIL						
B. WEIGHT OF TARE + DRY SOIL						
C. WEIGHT OF WATER, W_w (A.-B.)						
D. WEIGHT OF TARE						
E. WEIGHT OF DRY SOIL, W_s (B.-D.)						
WATER CONTENT, w	%	%	%	%	%	

TEST						UNIT
RUN NUMBER						
TARE NUMBER						
A. WEIGHT OF TARE + WET SOIL						
B. WEIGHT OF TARE + DRY SOIL						
C. WEIGHT OF WATER, W_w (A.-B.)						
D. WEIGHT OF TARE						
E. WEIGHT OF DRY SOIL, W_s (B.-D.)						
WATER CONTENT, w	%	%	%	%	%	

REMARKS

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
James Perry	James Perry	Thomas Connors

45.550

Figure 14-15.—Data sheet for moisture content tests.

3 in.
1 1/2 in.
1/2 in.
3/8 in.
No. 4
No. 10
No. 20
No. 40
No. 100
No. 200

Place each one over the other in descending order of size–that is, with the coarsest on top. The coarsest sieve actually recorded will be the next above the first one which retains any material. The weight recorded as retained on this sieve will be 0 grams, the weight recorded as passing in will be the total weight of the sample.

5. Place the sieve pan under the stack of sieves; place the total sample in the top sieve, and shake. The shaking interval will depend on the amount of fine material, but 5 minutes is usually enough for most coarse-grained soil and 15 minutes for most fine-grained soil.

6. Remove the sieves from the shaker and, starting with the first to retain any material, carefully weigh the material retained on each. Finally, weigh any material which reached the pan–that is, which passed the No. 200 or finest sieve.

Results are entered on a data sheet like the one shown in figure 14-16. In this analysis, all the material (359.1 grams) passed the 3/8 in. sieve–meaning that none was "retained" on this one. On the No. 4, 51.0 grams was retained, which means that (359.1 - 51.0), or 308.1 grams "passed" this one. You can see how the weight passing was determined from the weight retained in each subsequent case. In column d the "percent passing" is computed for each sieve, by multiplying the weight passing by 100 and dividing the result by the total weight of the sample.

The "total weight of fractions" plus the weight of what reached the pan, comes to 359.0 grams. The weight of the sample originally was 359.1 grams, so there is an "error" here of 0.1 grams. At the lower right, you can see how the "percentage of error" is computed. A maximum permissible percentage of error will have been previously prescribed. If the percentage exceeds the maximum, the test must be re-run. For an error smaller than the maximum permissible, correction is made by adding the value of the error to the largest amount listed as "retained." The value of the error in this case is 0.1 gram. The largest amount retained is 83.3 grams for the No. 20 sieve. This amount would be changed to 83.4 grams.

Sieve Analysis with Prewashing

When inspection indicates that a sample contains an excessively high portion of superfine (material which will pass the No. 200 sieve), analysis with prewashing is done as follows.

1. Oven-dry the sample.
2. After cooling, weigh and record the total weight.
3. Place the sample in a clean pan and add clean water until completely covered. Allow to soak until completely disintegrated–which may require from 2 to 12 hours. Stirring to break up lumps will hasten the action.
4. Wash the material thoroughly on a No. 200 sieve under running water, and discard the material which passes.
5. Oven-dry and re-weigh. The difference between this weight and the original weight is recorded as "washing loss."
6. Continue as for sieve analysis, dry.

Figure 14-17 shows a data sheet for sieve analysis with prewashing. The oven-dry weight of the original sample was 75.0 grams; the oven-dry weight after prewashing was 55.0 grams, therefore, the washing loss was (75.0 - 55.0), or 20.0 grams. The sum of the weights retained, plus the 2.0 grams which, despite prewashing, was still left in the sample to pass the No. 200 sieve, equalled the total weight of the original sample. There was therefore no error.

DETERMINING SPECIFIC GRAVITY

The general definition of specific gravity is: the ratio between the weight of a volume of a substance and the weight of an equal volume of

SIEVE ANALYSIS DATA			DATE 11 July 19—
PROJECT Fraunce Theater		EXCAVATION NUMBER 2	SAMPLE NUMBER FT-P1-1
DESCRIPTION OF SAMPLE 25 lb. bag sample			PREWASHED ☐ YES ☒ NO
WEIGHT ORIGINAL SAMPLE (gm.) 359.1	WEIGHT AFTER PREWASHING[1] (gm.)	WASHING LOSS[1] (gm.)	

SIEVE OR SCREEN	WEIGHT RETAINED ON SIEVE (gm.) b	PASSING SIEVE WEIGHT (gm.) c	PASSING SIEVE PERCENT d
*	0		100
3/4			
1/2			
3/8		359.1	100.0
No. 4	51.0	308.1	85.8
10	40.9	267.2	74.4
20	83.3	183.9	51.2
40	75.4	108.5	30.2
100	49.9	58.6	16.3
NUMBER 200	47.4	11.2	3.1

A. WEIGHT SIEVED THROUGH NO. 200 (gm.) 11.1	ERROR (Original weight - total weight of fractions)(gm.) 359.1 - 359.0 = 0.1
B. WASHING LOSS[1] (gm.)	
TOTAL PASSING NO. 200 (gm.) (A. + B.) C. 11.1	PERCENT ERROR ($\frac{\text{Error (gm.)}}{\text{Original weight (gm.)}}$ x 100) = .028%
TOTAL WEIGHT OF FRACTIONS (Total of all entries in Col. b + c) 359.0	
REMARKS	

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Paul Massin	Paul Massin	John Stark

[1]For prewashed samples only. *Maximum particle size.

45.551.1

Figure 14-16.—Data sheet for sieve analysis, dry.

SIEVE ANALYSIS DATA

DATE: 11 July 19–

PROJECT: Fraunce Theater | EXCAVATION NUMBER: 2 | SAMPLE NUMBER: FT-P2-1

DESCRIPTION OF SAMPLE: 25 lb bag sample

PREWASHED: [X] YES [ ] NO

WEIGHT ORIGINAL SAMPLE (gm.): 75.0 | WEIGHT AFTER PREWASHING[1] (gm.): 55.0 | WASHING LOSS[1] (gm.): 20.0

SIEVE OR SCREEN a	WEIGHT RETAINED ON SIEVE (gm.) b	PASSING SIEVE WEIGHT (gm.) c	PASSING SIEVE PERCENT d
	0		100
No. 10		75.0	100.0
20	8.7	66.3	88.4
40	29.0	37.3	49.8
100	13.3	24.0	31.1
NUMBER 200	2.0	22.0	29.4

A. WEIGHT SIEVED THROUGH NO. 200 (gm.): 2.0

B. WASHING LOSS[1] (gm.): 20.0

TOTAL PASSING NO. 200 (gm.) (A. + B.) c: 22.0

TOTAL WEIGHT OF FRACTIONS (Total of all entries in Col. b + c): 75.0

ERROR (Original weight - total weight of fractions)(gm.): none

PERCENT ERROR $\left(\frac{\text{Error (gm.)}}{\text{Original weight (gm.)}} \times 100\right)$ none

REMARKS

TECHNICIAN (Signature): Paul Masin | COMPUTED BY (Signature): Paul Masin | CHECKED BY (Signature): John Stark

[1]For prewashed samples only. *Maximum particle size.

45.551.2

Figure 14-17.—Data sheet for sieve analysis with prewashing.

water. For "absolute" specific gravity, the weight of the substance must be the solid weight, exclusive of voids or pores.

Apparatus

Some of the apparatus used to perform specific gravity tests include:

Balance, 2000-gram capacity
Balance, 200-gram capacity
Boxes, moisture
Dishes, evaporating
Flask, volumetric, 500 ml
Funnel
Hotplate, electric
Mortar and pestle
Pump, vacuum (optional)
Stirrer, soil dispersion (optional)
Thermometer, general laboratory

Procedure

In determining the solid weight of a soil, the air must be exhausted from the sample. This may be done by means of a vacuum pump, attached to the neck of a volumetric flask. The sample, immersed in water, is placed in the flask, and the air is exhausted with the pump. In the absence of a pump, the air is exhausted from the sample by boiling the contents for at least 10 minutes, while occasionally rotating the flask to assist the process.

Procedure for determining soil specific gravity is as follows:

1. Air- or oven-dry the sample, and break up all lumps with mortar and pestle. About 50 grams of clay type and about 100 grams of coarser type sample are the usual quantities.
2. Fill a moisture can with dry sample, oven-dry, and determine the weight to the nearest 0.01 gram. This weight (less the tare weight) is vital to the accuracy of the test; therefore, you must take great care not to lose any of the material during subsequent phases.
3. Place the material in the vacuum flask, using a funnel.
4. Fill the flask two-thirds full of clean water. For a clean, sandy soil a soaking period is unnecessary; for other soil, allow a soaking period of from 4 to 6 hours.
5. Exhaust the air by pump or boiling. The exhaustion of air will be indicated by rising bubbles. For most ordinary soil, 30 minutes of pumping is enough. A heavy clay may require as much as 2 hours.
6. Disconnect the pump or cease boiling, and add water until the flask is filled to the ring marked on the neck.
7. Carefully wipe off any water adhering to the outside; then weigh flask and contents to the nearest 0.01 gram.
8. Take the temperature of the water-soil mixture with a thermometer.

Test results are entered on a data sheet like the one shown in figure 14-18. As shown on the sheet, the formula for determining the specific gravity is:

$$G = \frac{Ws}{Ws + Wbw - Wbws},$$

Ws is the oven-dry weight of the sample. Wbw is the amount the flask would weigh if it were filled to the mark with water only, at test temperature. This value is obtained from a calibration curve or table, previously prepared for that particular flask, giving the weight of the flask, filled with water, over a range of temperatures.

Wbws is the weight of the flask, water, and sample at test temperature. If you study the formula, you will see that it works out to give you the ratio between the weight of the oven-dry sample and the weight of an equal volume of water. Substituting the data in the formula, you have:

$$G = \frac{75.13}{75.13 + 638.47 - 685.25} = 2.65$$

COMPACTION TESTING

Compaction testing is done to determine the optimum moisture content—that is, the content which will result in maximum density for a given compactive effort.

SPECIFIC GRAVITY TEST DATA FLASK METHOD		DATE 18 June 19–
PROJECT Building K-7	JOB #721	EXCAVATION NUMBER 2

FORMULAS

W_{bws} = Weight of flask + water + sample at T°C

W_{bw} = Weight of flask + water at T°C (from calibration curve)

$$\text{Specific Gravity, } G = \frac{W_s}{W_s + W_{bw} - W_{bws}}$$

SAMPLE NUMBER	K-P1-2					
FLASK NUMBER	1					
TARE NUMBER	3					
TEMPERATURE, T OF WATER IN FLASK WHEN WEIGHED (°C)	25.0					
DRY WEIGHT OF SAMPLE + TARE (gm.)	280.28					
WEIGHT OF TARE (gm.)	205.15					
DRY WEIGHT OF SAMPLE, W_s (gm.)	75.13					
W_{bw} (gm.) (from calibration curve)	638.47					
$W_s + W_{bw}$ (gm.)	713.60					
W_{bws} (gm.)	685.25					
$W_s + W_{bw} - W_{bws}$ (gm.)	28.35					
SPECIFIC GRAVITY, G	2.65					

REMARKS

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Bernard Higgins	Bernard Higgins	John Johnston

45.554

Figure 14-18.—Data sheet for soil specific gravity test.

Apparatus

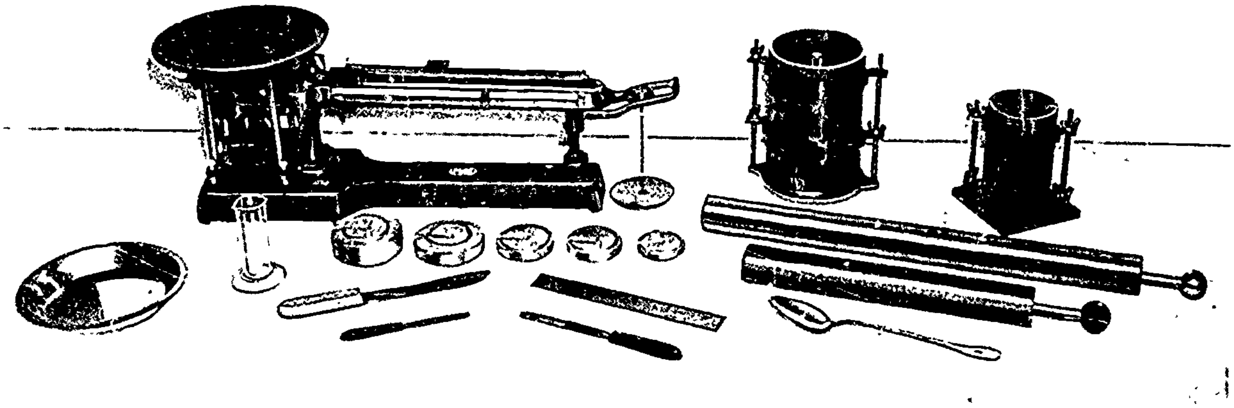
Typical apparatus includes the following.

1. A balance or scale for weighing material in grams.
2. Two cylindrical metal "soil compaction cylinders" or "molds". The smaller or PROCTER mold, has a volume of 1/30 cu ft and is used for fine-grained material, the larger, or CBR mold, when a 2 1/2-in. high "spacer" is placed inside, has a volume of about 0.0735 cu ft and is used with gravelly material.
3. Two "soil tampers," each consisting of a drop-tamper in a cylindrical "guide." The guide is placed on the top of the test sample (which is itself in one of the molds), and the tamper is drawn to the top of the guide and allowed to drop on the material. A certain number of blows (that is, of drops) is required to attain the tamper's designated compactive effort. The number varies with the size of the mold used and the number of layers of material which are tamped The larger tamper weighs 10 lbs, the smaller 5 1/2 lbs.
4. Two sieves, one a 3/4 in., the other a No. 4. Figure 14-19 shows the weighing balance, two compaction molds, two tampers, and some small utensils which are useful in testing. Note that each compaction mold consists of the cylinder proper, plus a removable collar at the top, and a "base plate" at the bottom.

Preparation of Samples

About five specimens, containing successively increasing moisture contents, are needed to determine the optimum moisture content which will give maximum density for a given compactive effort. For the 1/30-cu ft mold, about 6 lbs for each specimen, or a total of about 30 lbs, will be needed. For the larger mold, about 12 to 14 lbs per specimen, or a total of from 60 to 70 lbs, will be needed.

Before compacting, a sample is air-dried, and the water content as air-dried is determined. Air drying may be done by spreading out in the sun or in front of an electric fan. The air-dry water content is determined as a basis for estimating the amount of water which should be added to each trial specimen. The driest should contain just enough water to produce a damp mixture which crumbles readily. For each succeeding specimen the water content should be increased by about 2 percent, until the "wettest" specimen is quite wet and plastic.



45.555

Figure 14-19.—Apparatus for soil compaction testing.

Compaction Procedures

There are two compaction procedures commonly used in testing. (a) the "modified" AASHO (American Association of State Highway Officials), and (b) the "standard" AASHO.

Steps in the modified AASHO are as follows.

1. Attach the base plate and collar to the mold, and set the mold on a steel "compaction pedestal," or on some other level, solid object, such as a steel or hardwood block.
2. Fill the mold to the top of the collar with material, by placing approximately 5 equal layers and compacting each layer. For the modified AASHO procedure the 10-lb tamper, falling a distance of 18 inches, is used. For the 1/30 cubic foot mold, each layer receives 25 blows (drops of the tamper); for the CBR mold, 55 blows. Be sure to distribute blows evenly over the surface of the layer.
3. Remove the collar, and use a steel straightedge to strike off the material flush with the top of the mold.
4. Weigh the mold and compacted sample (minus the collar) to the nearest gram.
5. Remove the base plate, take moisture content samples from top and bottom of the sample, and determine moisture content of these as previously explained. If the two differ, use the average between them as the moisture content of the whole sample.

The standard AASHO procedure is the same, except that the 5 1/2-lb tamper is used and the material is place in 3 layers rather than 5.

Data and Calculations

Test results are entered and calculations made on a data sheet like the one shown in figure 14-20. This was a standard AASHO test, using the 5 1/2-lb tamper with 25 blows per layer. The smaller mold was used, with a volume of 1/30, or 0.033 cu ft.

Five runs were made. After compaction, the weight of the compacted soil (struck off even with the top of the mold) and the mold (without collar) were recorded for each run. From this the weight of the mold was subtracted, to get the "weight of wet soil" for each run. From this 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 are two tests, one of soil from the top of the mold, the other of soil from the bottom. The averages are set down beside "Average water content." Finally, the "dry unit weight in lbs per cu ft" (that is, the density) for each run is calculated by the formula shown.

As you can see, the density, for the same compactive effort, varied with the average moisture content. The ultimate object of the test was to determine the optimum moisture content–that is, the moisture content which would attain maximum density for a given compactive effort. This is determined by applying the test results to plot a curve like the one shown in figure 14-21.

In this curve, the horizontal coordinates are the average moisture contents, and the vertical coordinates are the dry unit weights (densities). The curve indicates that the maximum attainable density for the given compactive effort was 127.2 lbs per cu ft, for which the optimum moisture content was 10.9%.

The dotted line marked "98% maximum density" indicates that in this case the specifications required that 98% of the maximum attainable density be attained through compaction. The maximum attainable was 127.2 lbs per cu ft; 98% of this is 124.7 lbs per cu ft. The dotted line is drawn at the 124.7 lbs per cu ft 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%.

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. We will take as typical for description purposes the so-called "California bearing ratio" (CBR) test.

DATA SHEET — COMPACTION TEST for OPTIMUM MOISTURE CONTENT

Project Camp Covington, Guam, M I Date 2 Apr 19__

Report Submitted By CE A3 Naylor Sample Number 1

Number of Layers 3 Number of Blows per Layer 25 Weight of Tamper 55 Height of Drop 12"

Test No.	Units	1		2		3		4		5	
Wt. wet sample + mold	lb	12.8		13.1		13.3		13.4		13.2	
Wt. mold	lb	8.7		8.7		8.7		8.7		8.7	
Wt. wet sample	lb	4.1		4.4		4.6		4.7		4.5	
Wet Unit Wt., $\gamma = \frac{\text{Wt. wet soil}}{\text{vol Soil sample}}$	lb per cu.ft.	123.0		132.0		138.0		141.0		135.0	
Can No.	gm.	12	13	14	15	16	17	18	19	20	21
A. Wt. wet sample + can	gm.	47.7	44.7	44.1	42.8	44.1	45.6	45.1	46.7	45.2	45.6
B. Wt. dry sample + can	gm.	46.5	43.6	42.5	41.2	42.2	43.7	42.5	44.0	42.3	42.4
C. Wt. water $W_w (A - B)$	gm	1.2	1.1	1.6	1.6	1.9	1.9	2.6	2.7	2.9	3.2
D. Wt. can	gm.	22.6	22.2	21.5	20.8	22.2	23.2	21.4	22.5	22.2	21.9
E. Wt. dry sample $W_s (B - D)$	gm	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 moisture content	percent	5.1		7.7		9.4		12.5		15.0	
Dry unit wt.,	lb.per cu.ft.	117.0		122.6		126.1		125.3		117.4	
$\gamma_d = (\frac{\gamma}{1 + W/100})$											

45.556(82B)

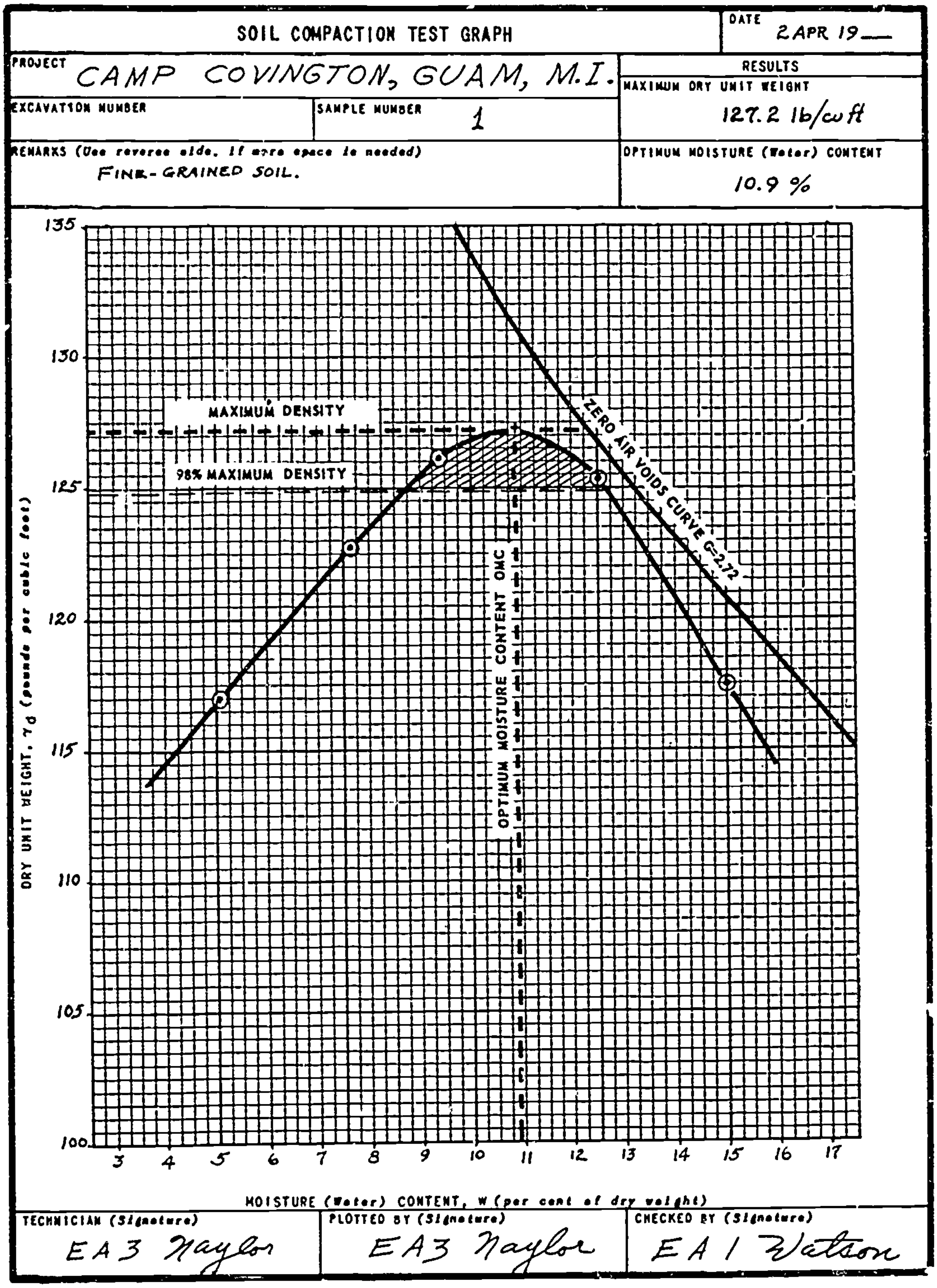
Figure 14-20.—Data sheet for soil compaction test.

In the CBR 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, placed in a CBR compaction mold, is placed in a "jack" like the one shown in figure 14-22. The piston shown is placed on top of the material, and a "proving ring" is placed between the top of the piston and the anvil of the jack. There are three rings available, with capacities of 2,000, 5,000, and 7,000 lbs respectively.

As the jack is cranked up, the dial in the center of the proving ring records the pressure being applied to the piston. The lower, right-hand dial measures the extent to which the piston penetrates the material.

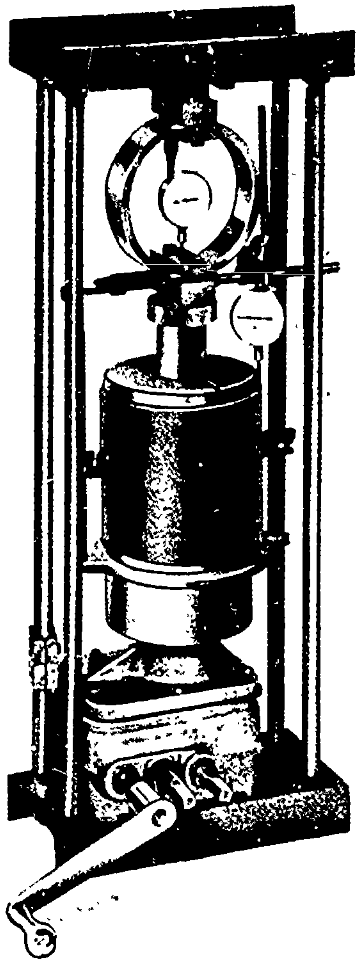
There are variations in the preparation of samples which will be discussed later. Steps in the penetration test are the same, regardless of these variations. To understand the explanation of the procedure, study the data sheet shown in figure 14-23.

Figure 14-23 indicates that the sample used was compacted in 5 layers with the 10-lb tamper, 55 blows per layer. A "surcharge weight" of 25 lbs is listed; this means that a circular section of the surface and base courses of the airfield pavement 6 in. in diameter will weigh 25 lbs. This weight was simulated on the surface of the sampie by placing splitring weights totaling 25 lbs on top of the material.



45.557(82B)

Figure 14-21.—Determination of optimum moisture content.



45.558
Figure 14-22.—Apparatus for bearing ratio test.

The 5000-lb proving ring was used, for which the "proving ring constant" was 12 lbs for every 0.00001 read on the ring dial. This means that (for example) when the proving ring dial reads 0.0111, the force being exerted by the piston is (12 X 111), or 1332 lbs.

Under "penetration data" the first column at the left is headed "penetration." Under this heading there is a list of penetrations, beginning with 0.025 in., and increasing in increments of 0.025 in. The test was carried out by cranking the jack until the penetration dial read the given penetration, then reading the load for that penetration on the proving ring dial. Note that there is first a dial reading and then a "corrected" dial reading. The corrected reading is in each case 0.003 in. less than the uncorrected reading. This indicates that the proving ring dial contained a previously determined "index error" of 0.003 in.—that is, that under no pressure the dial read 0.003 in. An error of this kind develops as a result of repeated compressions of the proving ring during testing.

Under "total load" are the results obtained by multiplying the corrected ring dial reading by the proving ring constant. Under "unit load" are the results obtained by dividing total load by 3. Finally, the bearing ratios for penetrations of 0.100 and 0.200 in. are obtained, by dividing corrected unit load by standard unit load, and multiplying the result by 100. The bearing ratio for 0.100 in. was 56%; for 0.200 in. it was 62.7%.

Preparation of Bearing Ratio Test Samples

When a bearing ratio test is made of a compacted sample, a mold 7 in. deep is used, with a perforated spacer 2-1/2 in. deep placed in the bottom. The use of the spacer reduces the depth of the sample to 4-1/2 in.

When moisture conditions are such that the subgrade of the finished road or airfield will not accumulate moisture approaching the saturation point, samples are given a moisture content approximately equal to that expected during the use of the road or airfield. In other cases, samples are tested in "saturated" condition.

This condition is attained by soaking the sample. The sample is placed in the mold, compacted, and trimmed. The base plate and spacer block are then removed. A piece of filter paper is placed over the trimmed or struck-off top of the sample, and the base plate is placed over this top. The mold is then turned over and set in a bucket on the base plate. The bottom of the sample, which was next to the spacer block during compaction, is now uppermost. The split-ring surcharge weights which were previously described are set in as shown in figure 14-24, and a "tripod dial," used to measure any contraction or swelling of the sample, is set in place as well.

The mold and sample are immersed in water in the bucket and left to soak for about 4 days.

CALIFORNIA BEARING RATIO TEST DATA	DATE 27 April –

PROJECT: Franklin Airfield

[ ] FIELD-IN-PLACE	TEST SITE: Runway R-2		
[X] LABORATORY	EXCAVATION NUMBER: 2	SAMPLE NUMBER: SF-P1-4	TYPE: [ ] UNSOAKED [ ] SOAKED [X] DRAINED [ ] UNDRAINED

CONDITION	NUMBER OF LAYERS	NUMBER OF BLOWS PER LAYER	WEIGHT OF HAMMER (lb.)	DROP (inches)
[ ] UNDISTURBED [X] 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.)
9	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 Dial 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.)	15.67	
WEIGHT OF MOLD (lb.)	5.38	
WEIGHT OF WET SOIL (lb.)	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 ($\frac{\text{Actual}}{\text{Maximum}} \times 100$): $\frac{99.7}{127.2} \times 100 = 78\%$

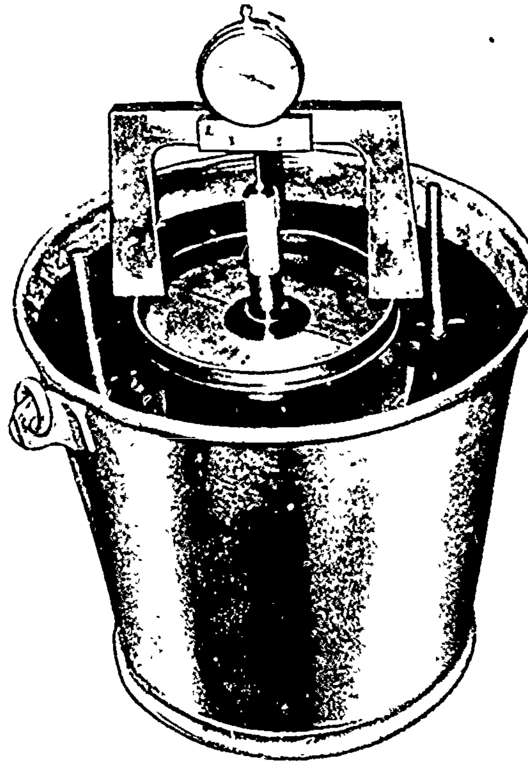
REMARKS

USE REVERSE SIDE FOR SWELL DATA AND GRAPH

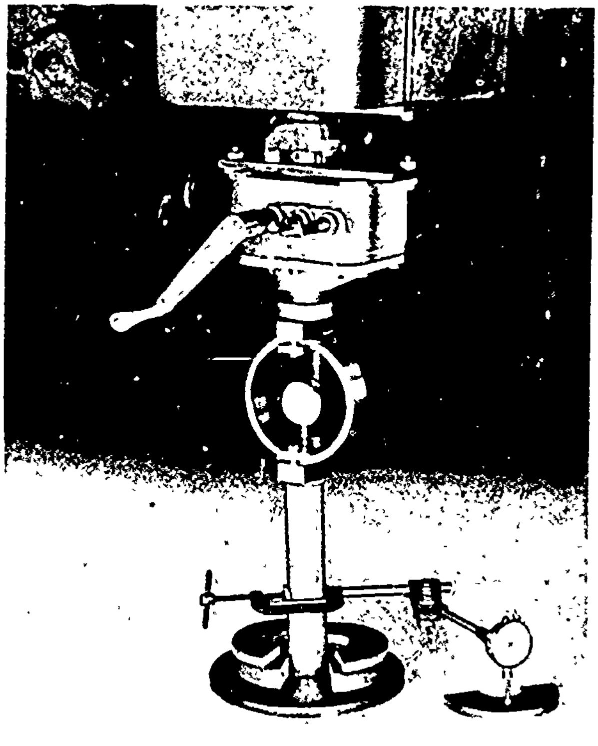
45.559

Figure 14-23.—Data sheet for soil bearing ratio test.

407



45.560
Figure 14-24.—Apparatus for soaking bearing ratio sample.



45.561
Figure 14-25.—Apparatus for field-in-place bearing ratio test.

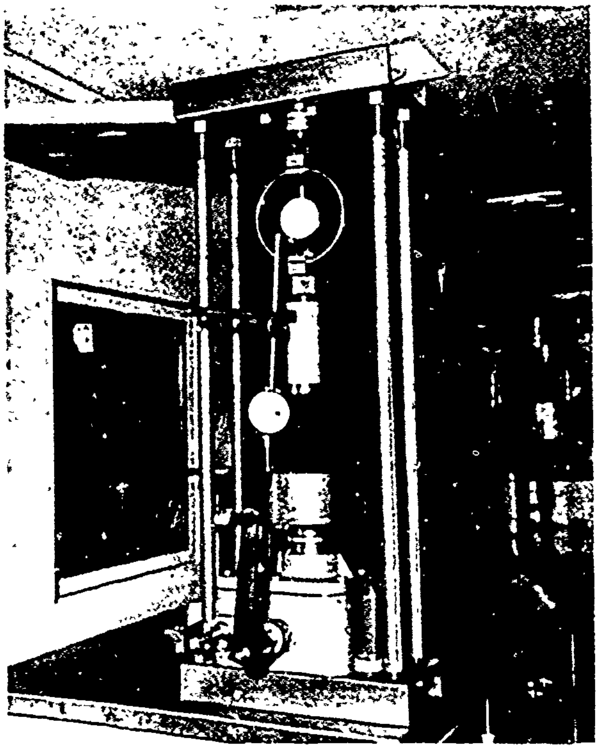
Field-in-Place Bearing Ratio Test

For a bearing ratio test on soil in place in the field, apparatus like that shown in figure 14-25 is used As you can see, the apparatus is basically the same as that used in the laboratory test, except that the jack is reversed and fastened to the bumper of a truck. The truck is parked at the place where the soil is to be tested, and loaded heavy enough to resist being lifted by the action of the jack. The body is jacked up high enough to permit attachment of the bearing-ratio jack, the piston and split-ring are set in place, and the truck body is lowered until the piston just bears on the soil surface. The penetration dial is then attached to the piston by a clamp, as shown.

UNCONFINED COMPRESSION TEST

The shear strength of a cohesive, clay-type soil is determined by an "unconfined compression test." An unconfined sample (that is, a cylinder or chunk of the material, not placed in a container or mold) is subjected to pressure to determine the pressure at which the sample "fails" (begins to collapse under pressure). The pressure at which the sample fails is the "unconfined compressive strength" of the soil. The shear strength is presumed to be one-half the unconfined compressive strength.

A bearing-ratio test jack is used to make the test, as shown in figure 14-26. A sensitive proving ring and dial are used; a common combination is a dial which reads to 0.0001 in., with a constant of 0.15 lb. The sample, consisting of a cylinder of soil extruded from a soil sampler, is placed on the jack plunger, and the plunger is raised until the top of the sample just contacts the piston attached to the proving ring.



45.562

Figure 14-26.—Apparatus for unconfined compression test.

A dial with a sensitivity of 0.0001 in. is then placed with plunger in contact with the jack plunger, and clamped to the piston as shown. This dial (called the "vertical" dial) measures the upward motion of the jack plunger, and concurrently therefore the progressive decrease in height of the sample.

To understand the test procedure, study the data sheet shown in figure 14-27. Here the proving ring constant was 0.15 lb for every 0.0001 in. read on the dial. The diameter and height of the extruded sample were very carefully measured, with micrometer or micrometer caliper. Three diameters were taken, from which three cross-section areas were computed; and these were averaged for a cross-section area of 2.75 sq in., or 0.0191 sq ft. The height of the sample was 3.45 in.

The proving ring dial was to be read for every 0.01-in. rise in the jack plunger, as indicated by the column headed "vertical dial difference." The actual dial reading corresponding to each 0.01-in. increment was computed and set down in the column headed "vertical dial reading." The dial reading decreased 0.01 in. for every 0.01-in. rise of the plunger, however, the dial had an index error of 0.9 in. to start with.

The test was made by raising the jack plunger to each of the computed vertical dial readings, and recording the proving ring dial reading for that particular vertical dial reading. For each proving ring dial reading the load for that reading (listed in the column headed "load") was computed, by multiplying the proving ring dial reading by the proving ring constant (0.15 lb).

As indicated by the formula given at the top of the sheet, the "unit strain" for each vertical dial reading was computed by dividing delta L (the reduction in height of the sample for the particular vertical dial reading) by the original height of the sample. For example: delta L for the vertical dial reading of 0.87 was 0.03 in., as indicated in the vertical dial difference column. Therefore, unit strain for this vertical dial reading was 0.03 divided by 3.83, or 0.0078. For "percentage" of unit strain, this is multiplied by 100 to get a percentage of 0.78.

As indicated by the formula at the top of the sheet, the "corrected area" for each vertical dial reading was computed by dividing the original average area (0.0191 sq ft) by 1 minus in unit strain for that particular dial reading. For example. the corrected area for the vertical dial reading of 0.85 is 0.0191 divided by 1 minus 0.0131 (the unit strain), or 0.0191 divided by 0.987, or 0.0194 sq ft.

As again indicated by a formula at the top of the sheet, "unit stress" for a particular vertical dial reading is computed by dividing the load for that reading by the corrected area for that reading. For example. the load for the vertical dial reading of 0.92 is 31 lbs, the corrected area for that reading is 0.0195 sq ft, therefore, the unit stress for that reading is 31 divided by 0.0195, or 1590 psf.

Unit stress measures, in fact, the resistance offered by the sample to the pressure exerted on it. You can see that it rises to a maximum 1590 lbs, and then declines. This means that the sample sustained a pressure of 1590 lbs, but "failed" when pressure greater than that was

UNCONFINED COMPRESSION TEST

DATE: 27 Aug 19 —		
PROJECT: Building K-3	EXCAVATION NUMBER: 1	SAMPLE NUMBER: K-B1-1
PROVING RING DIAL NUMBER: 3	PROVING RING NUMBER: 3	CALIBRATION CURVE NUMBER: 6
PROVING RING CONSTANT, K_r: 0.15 lb/0.0001"	VERTICAL DIAL NUMBER: 2	RATE OF LOAD APPLICATION: 0.05"/min

FORMULAS

$$\text{Area} = \frac{\pi D^2}{4} = \frac{C\,D}{4} \qquad \text{Corrected Area, } A = \frac{A_0\ (\text{sq. ft.})}{1-\epsilon} \qquad \text{Unit Strain, } \epsilon = \frac{\Delta L}{L_0} \qquad \text{Unit Stress} = \frac{P\ (\text{lb.})}{A\ (\text{sq. ft.})}$$

	INITIAL MEASUREMENTS ON SAMPLE			AVERAGE AREA, A_0	
	DIAMETER, D (in.)	CIRCUMFERENCE, C (in.)	AREA (sq. in.)	SQ. IN.	SQ. FT.
TOP	1.869	5.872	2.743	2.746	0.0191
CENTER	1.870	5.875	2.746	HEIGHT, L_0 (in.)	
BOTTOM	1.871	5.878	2.749	3.45	

ELAPSED TIME (min.)	PROVING RING DIAL READING (0.0001 in.)	LOAD, P (lb.) (Ring Dial × K_r, or from calibration curve)	VERTICAL DIAL READING (in.)	VERTICAL DIAL DIFFERENCE, L (in.)	% UNIT STRAIN,	CORRECTED AREA, A (sq. ft.)	UNIT STRESS (lb./sq. ft.)
0	0.0	0.00	0.900	0.00	0.00	0.0191	0
	25.3	3.80	0.890	0.01	0.26	0.0192	199
	59.9	8.98	0.880	0.02	0.52	0.0192	463
	74.9	11.24	0.870	0.03	0.78	0.0193	582
	149.3	22.39	0.860	0.04	1.04	0.0193	1160
	189.6	27.25	0.850	0.05	1.31	0.0194	1410
	200.6	30.11	0.840	0.06	1.57	0.0194	1552
	206.1	30.91	0.830	0.07	1.83	0.0195	1585
	206.7	31.00	0.820	0.08	2.09	0.0195	1590
	206.4	30.97	0.810	0.09	2.35	0.0196	1580
	201.2	30.18	0.800	0.10	2.61	0.0196	1540
	197.7	29.65	0.790	0.11	2.87	0.0197	1505
	193.9	29.08	0.780	0.12	3.13	0.0197	1476
	191.4	28.71	0.770	0.13	3.39	0.0198	1450
	188.1	28.21	0.760	0.14	3.67	0.0198	1425
3.0	184.4	27.66	0.750	0.15	3.92	0.0199	1390

WATER CONTENT (%): 39.2%	UNCONFINED COMPRESSIVE STRENGTH, q_u (lb./sq. ft.): 1590

REMARKS AND CALCULATIONS (Use reverse side, if more space is needed)

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Paul Masin	Paul Masin	Arthur Mason

45.563

Figure 14-27.—Data sheet for unconfined compression test.

applied. Therefore, the sample's unconfined compressive strength is 1590 psf. Its shear strength is one-half of this, or 795 psf.

FIELD IDENTIFICATION

Sometimes the lack of time and facilities makes laboratory soil testing impossible in military construction. Even though laboratory tests are to follow, field identification tests must be made during the soil exploration to distinguish different soil types encountered so that duplication of samples for laboratory testing will be 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 as approximations. The number of tests employed will depend on the type of soil and the experience of the individual employing them. Experience is the greatest asset in field identification, and learning the technique from an experienced technician is the best method of acquiring the skill. Lacking such assistance, experience is gained by getting the "feel" of the soil during the 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, since this will change the grain size and the character of the soil. A rubber-faced or wooden pestle and a mixing bowl are recommended, but for an approximate identification, mashing underfoot on a smooth surface will suffice for that purpose.

Field tests may be performed with little or no equipment other than a small amount of water. However, accuracy and uniformity of results will be 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, or 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. A pick and shovel or a set of entrenching tools is used for collecting samples. A hand earth auger is useful if samples are desired from depths more than a few feet below the surface.

STIRRER: The spoon issued as part of mess equipment serves in mixing materials with water to desired consistency. It will also aid in collecting samples.

KNIFE: A combat knife, or engineer pocket knife, is useful for collecting samples and trimming them to the desired size.

MIXING BOWL: A small bowl with a rubber-faced pestle is used in pulverizing the fine-grained portion of the soil. Both may be improvised, such as by using a canteen cup and wood pestle.

PAPER: Several sheets of heavy paper are needed for rolling samples.

PAN AND HEATING ELEMENT: A pan and heating element are used for drying samples.

SCALES: Balances or scales are used in weighing samples.

The Unified Soil Classification System, as shown in figure 14-3, considers three soil properties. percentage of gravel, sand, or fines, shape of the grain size distribution curve; and plasticity. These are the primary ones to be considered, but other observed properties should also be included in the soil description, whether made in the field or in the laboratory.

The following characteristics may be used in describing soil:

1. Dark brown to white or any suitable color shade description.
2. 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).
3. Poorly graded (gap-graded, insufficient fine gravel).
4. Gravel particles subrounded to rounded, or predominantly gravel.
5. Nonplastic.
6. With considerable sand and a small amount of nonplastic fines (silt).
7. Slightly calcareous, no dry strength, dense in the undisturbed state.

VISUAL EXAMINATION

Visual examination should establish the color, the grain sizes, the 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, may be 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.

1. Generally, colors become darker as the moisture content increases and lighter as the soil dries.
2. Some fine-grained soils (OL, OH) with dark, drab shades of brown or gray, including almost black, contain organic colloidal matter.
3. In contrast, clean, bright looking shades of gray, olive green, brown, red, yellow, and white are associated with inorganic soils.
4. Gray-blue or gray and yellow mottled colors frequently result from poor drainage.
5. Red, yellow, and yellowish-brown result from the presence of iron oxides.
6. 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 are just distinguishable by the naked eye. The eye can normally see individual grains about 0.05 mm. in size, or about the size of the No. 200 screen. Thus, silt and clay particles (which are smaller than this dimension) are indistinguishable as individual particles.

While examining the sample for grain sizes, the shapes of the visible particles can be determined. Sharp edges and flat surfaces indicate angular shape while smooth, curved surfaces are associated with the rounded shape. Particles may not be completely angular nor completely rounded. These particles are called subangular or subrounded depending on which shape predominates.

Laboratory analysis must be performed when accurate distribution is to be determined. However, an approximation can be made during the visual examination.

1. Separate the larger grains (gravel and some sand particles) from the remainder of the soil by picking them out individually.
2. Examine the remainder of the soil and estimate the proportion of visible individual particles (larger than 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 0); if the coarse material exceeds 50 percent, the soil is coarse-grained (G or S).
4. Examine 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 less than 5 percent (nonplastic fines) of the total, the soil may be classified either as a GW, GP, SW, or SP type, depending on the other information noted above.
6. If the fine-grained portion (5 above) exceeds 12 percent, the soil will be either silty (M) or clayey (C) and requires further testing to identify.
7. Fine-grained portions (5 above) between 5 and 12 percent (nonplastic fines or fines not interfering with drainage, or 0 - 12 percent plastic fines) total are borderline and require a double symbol (GW-GM or SW-SM).
8. Fine-grained soils (M, C, or 0) from 3 above, require other tests to distinguish further. Grain-size distribution of fine portions is not normally performed in field identification. However, should it become necessary, an approximation can be made by shaking the fine portions in a jar of water and allowing the material to settle. The materials will 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.

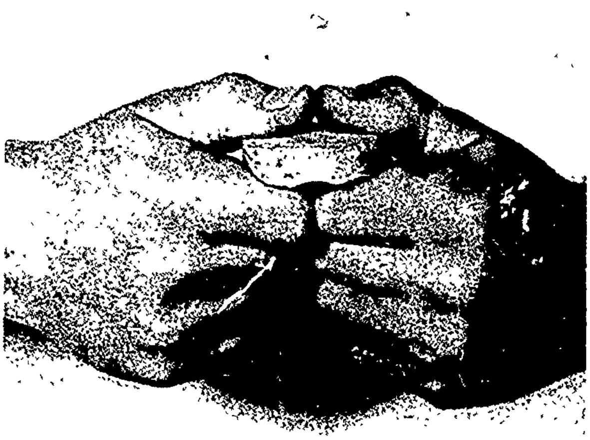
Using characteristics determined up to this point, it is possible to evaluate the soil as it appeared in place (undisturbed). Gravels or sands can be described qualitatively as "loose," "medium," or "dense." Clays may be "hard," "stiff," or "soft." The ease or difficulty with which the sample was removed from the ground is a good indicator. Soils which have been cultivated or framed 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 performed 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 a half 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, but too much reliance must not be given to such tests because of the variations that exist in the drying conditions under field circumstances. Such a test may be used as an approximation, however, and verified later by a carefully prepared sample.

After the prepared sample is thoroughly dry, attempt to break it using the thumb and forefinger of both hands, as shown in figure 14-28. If it can be broken, try to powder it by rubbing it with the thumb and fingers of one hand.

The typical reactions that are obtained in this test for various types of soils are described below.



82.189

Figure 14-28.—Breaking or dry strength test.

1. Very highly plastic soils (CH). Very high dry strength. Samples cannot be broken or powdered by use of finger pressure.
2. Highly plastic soils (CH). High dry strength. Samples can be broken with great effort, but cannot be powdered.
3. Medium plastic soils (CL). Medium dry strength. Samples can be broken and powdered with some effort.
4. Slightly plastic soils (ML, MH, or CL). Low dry strength. Samples can be broken quite easily and powdered readily.
5. Nonplastic soils (ML or MH). These cannot be rolled into a thread at any moisture content.

The cohesiveness of the material near the plastic limit may also be described as weak, firm, or tough. The higher the position of the soil on the plasticity chart, the stiffer are the threads as they dry out and the tougher are the lumps if the soil is removed 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 the material in the palm of the hand and, starting at one end, flatten the roll, forming a ribbon 1/8 to 1/4 inch thick, by squeezing it between the thumb and forefinger (fig. 14-29). The sample should be handled 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 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.

82.190
Figure 14-29.—Ribbon test.

WET SHAKING TEST

The wet shaking test is performed only on the material passing the No. 40 sieve. In preparing a portion of the sample for use in this test, enough material to form a ball of material about 3/4 inch in diameter is moistened with water. This sample should be just wet enough that the soil will not stick to the 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 when, on shaking, water comes to the surface of the sample producing a smooth, shiny appearance. This appearance is frequently described as "livery" (fig. 14-30).

Then, upon squeezing the sample between the thumb and fore finger of the other hand, the surface water will quickly disappear and the surface will become dull. The sample will become firm, resisting deformation, and cracks will occur as pressure is continued, with the sample finally crumbling like a brittle material.

The vibration caused by the shaking of 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 dis-

82.191
Figure 14-30.—Livery appearance produced by wet shaking test.

arrange the soil grains and increase the voids space; and the water is drawn into the soil. If the water content is still adequate, shaking the broken pieces will cause them to liquefy again and flow together, and the complete cycle may be repeated. This process can occur only when the soil grains are bulky in shape and non-cohesive 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 will tend to greatly retard this reaction. 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 which 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 will impart some plasticity and slow up materially 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 which, with experience, can be used as an aid in the identification of such materials. This odor is especially apparent from fresh samples. It is gradually reduced by exposure to air, but can again be made more pronounced by heating a wet sample. Organic soils are undesirable as foundation or base course material and usually are removed from the construction site and wasted.

BITE OR GRIT TEST

The bite or grit test is a quick and useful method of identifying sand, silt, or clay. In this test, a small pinch of the soil material is ground lightly between the teeth and the soils are identified as follows:

SANDY SOILS. The sharp hard particles of sand will grate very harshly between the teeth and will be 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 the teeth, and 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 will stick when lightly touched with the tongue.

SLAKING TEST

The slaking test is used to assist in determining the quality of certain soft shales and other soft "rocklike" materials. The test is performed by placing the soil in the sun or in an oven to dry, and then allowing it to soak in water for at least 24 hours. The strength of the soil is then examined. Certain types of shale will completely disintegrate, losing all strength.

ACID TEST

The acid test is used to determine the presence of calcium carbonate and 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, and the degree of reaction gives an indication of the concentration. Calcium carbonate normally is desirable in a soil because of the cementing action it provides to add to the stability. (In some very dry noncalcareous soils, the absorption of the acid creates the illusion of effervescence. This effect can be eliminated in all dry soils by moistening the soil prior to applying the acid.) Since this cementation normally is developed only after a considerable curing period, it cannot be counted upon for strength in most military construction. The primary use for this test is, therefore, to permit better values on fine-grained soils which are tested in-place, where this property may exert considerable influence.

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 will give a definite shine when rubbed with a finger nail, a pocket knife blade, or any smooth metal surface On the other hand, a piece of lean clay will not display any shine, but will remain dull.

FEEL TEST

The feel test is a general purpose test, and one that requires considerable experience and practice before reliable results can be obtained. The extent of its use will grow with increasing familiarity with soils, Consistency and texture are two characteristics which can be determined.

The natural moisture content of a soil is of value as an indicator of the drainage characteristics, nearness to water table, or other factors which 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." The soil is then remolded by working it in the hands, and changes, if any, are observed. By this test, the natural water content is estimated relative to the liquid or plastic limit of the soil. Clays which 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. It 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 more tender skin area such as the wrist. Fine sand will feel 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.

SEISMIC SURVEYING

Seismic surveying is a geophysical technique, used for many years in the study of deep geological structure, such as in the search for oil-bearing strata. It is based on the measurement of shock waves in the earth. More recently, the method has been greatly simplified for use in shallow (0 to 100-feet deep) investigations of soils and related geology. These depths are of interest to engineers who must obtain soil and rock profiles for road construction, airport design, pipeline routes, damsites, large building foundations, site grading, waterfront structures and similar projects. They are also important in the study of groundwater sources, underground drainage, and the location of rock sources for quarrying concrete aggregates.

SHALLOW SEISMIC SURVEYING has become a reliable, fast and economical method for obtaining sub-surface soil and rock profiles, due to the development of portable, self-powered SEISMIC TIMERS, such as the MODEL R-117B, and its accessory equipment. The instrument can be carried over any terrain, and operated by a two-man party. Instead of the large explosive charges and elaborate recording equipment used in deep seismic work, most of the shallow seismic surveying is accomplished by using an eight-pound sledge hammer and a small steel strike plate to produce shock waves in the earth. The travel-times of these shock waves, from the impact point to a GEOPHONE, are measured with the SEISMIC TIMER. A complete discussion of the theory and field methods of shallow seismic surveying is given in the instruction manual for the R-117B Seismic Timer. Personnel assigned to conduct seismic surveys must be those who have received special training in the method. However, personnel holding EA1 and EAC ratings should be generally familiar with the applications and objectives of shallow seismic surveying. For that reason, the essential features of the method are presented here.

PRINCIPLES OF SEISMIC SURVEYING

An explosion in the ground, or the impact of a heavy weight on the ground, produces disturbances in the earth, similar to the "sound waves" produced in the air. These disturbances are called ELASTIC WAVES. These waves travel out in all directions from the impact point. Their energy is of course gradually absorbed by the earth, so that their effect for practical purposes eventually dies out. But over the first part of their path, they can be detected and used to determine earth structure. In uniform soils, the waves travel along straight paths, from the source. The WAVE FRONT is thus an ever-expanding spherical surface.

Travel-Time and Wave Velocity

In seismic surveying, an instrument called a GEOPHONE (item 5, fig. 14-31) is used to detect the arrival of the wave front at a desired point on the ground surface. The waves are created in the earth by the impact of an eight pound sledge hammer (item 2, fig. 14-31) on a STRIKE PLATE (item 3). The strike plate is placed on firm topsoil at the IMPACT POINT. When the hammer strikes the plate, a SHOCK SWITCH (item 4) on the hammer sends a START signal to the seismic timer (item 1). The geophone is located at a point on the ground some distance away from the impact point, as explained later. When the leading edge of the wave front reaches the geophone, the geophone sends a STOP signal to the timer. The time for the wave to travel from the impact point to the geophone is indicated on the instrument panel. The seismic timer is the equivalent of a precision high-speed stop watch. It measures TRAVEL TIMES.

If hammer impacts are made at a series of impact points along the SEISMIC SURVEY LINE, the travel-times from each impact point to a geophone at the beginning of the line can be measured. At each impact station, the travel-time is plotted, to make a TRAVEL-TIME GRAPH (fig. 14-32). The time unit used for measurement is the millisecond. One millisecond is .001 second. The distance unit used for measurement along the survey line is the foot. Impact stations are usually 10 feet apart. The scale of the travel-time graph used for work in soils is 1 millisecond (vertical) equals 1 foot (horizontal). The graph paper is divided into 1-inch X 1-inch major squares, with 10 divisions per inch. Thus, one inch equals 10 feet or 10 milliseconds.

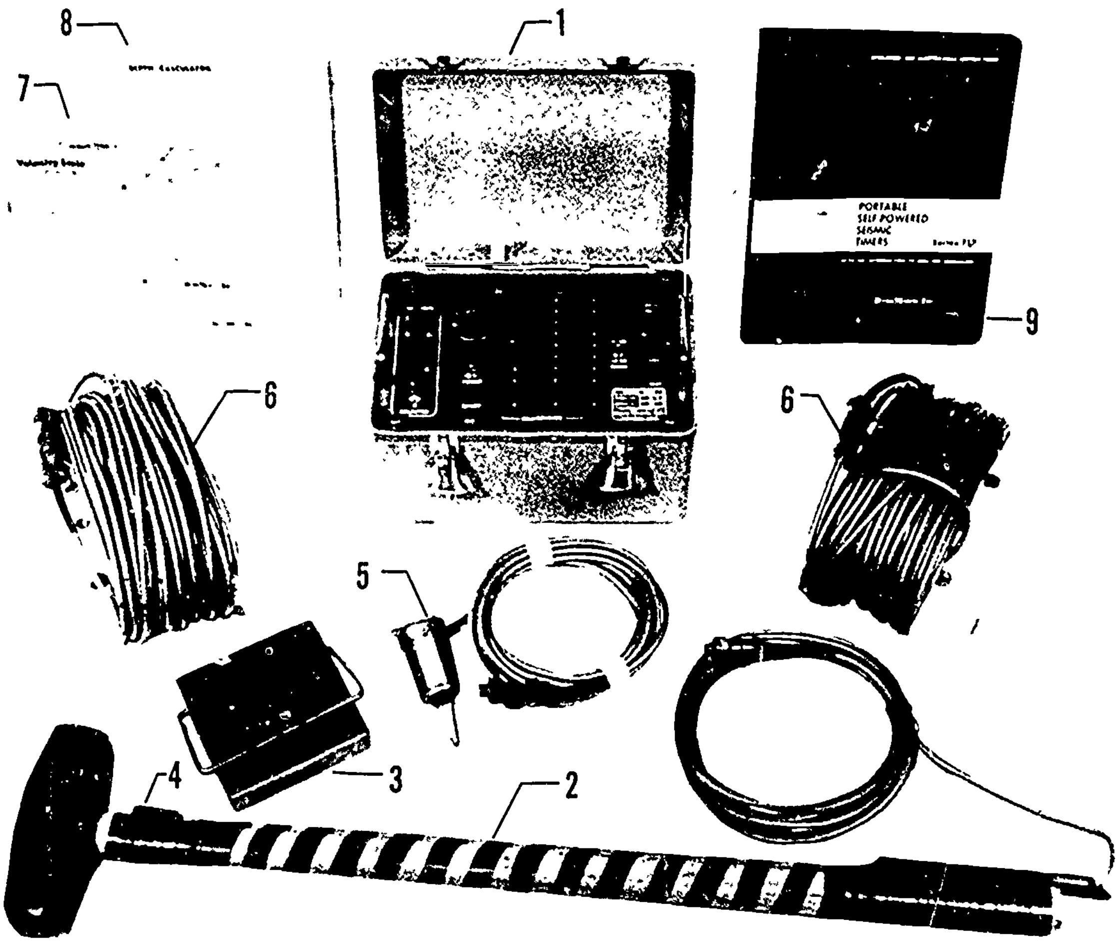
If the soil is uniform for a considerable depth, the plotted travel times will make a straight line travel-time graph (fig. 14-32). The distance along any portion of this line, divided by the increase in travel-time for that portion of the line, gives the wave velocity, in feet per second. In the example shown, the distance between impact stations 10-ft and 40-ft, is 30 feet. The time difference between travel from station 10-ft and travel from station 40-ft, is 25 milliseconds (.025 sec.). Therefore, the velocity at which the elastic wave is traveling through the soil is 30 feet divided by .025 sec, or 1,200 feet-per second. This is a typical velocity for topsoil.

Remember then, that the VELOCITY is indicated by the slope of the travel-time graph over a straight portion. A VELOCITY SCALE, provided with the instrument, allows velocities to be read directly from the plotted graph. The flatter the slope, the higher the velocity. On 10 X 10 graph paper, a slope of 45° (one to one) indicates a velocity of 1,000 feet-per second. Velocities in the subsurface materials are one of the two pieces of information needed to discover subsurface layers and find their depth below ground surface.

Subsurface Horizons and Seismic Refraction

So far, we have considered only the case of uniform soil. Now let us see what happens to the wave path when the expanding wave front encounters a subsurface layer of material different from the top soil. This situation is shown in figure 14-33.

When the elastic waves encounter a subsurface HORIZON (top of a new layer of different material) the direction of the wave paths is changed. This change in direction is called REFRACTION. It is the same thing that happens when light rays enter a lens or a prism,



1. Model R-117B seismic timer
2. Seismic sledge hammer
3. Strike plate
4. Shock switch for start signal
5. Geophone
6. Cable, 150-ft, shielded
7. Velocity scale
8. Depth calculator
9. Operation and maintenance instruction

82.192X

Figure 14-31.—Model R-117B Seismic Timer and accessories.

or the smooth surface of water, at an angle with the surface. Remember how a pencil appears to bend when inserted in a glass of water. A similar thing happens when ocean waves encounter a headland at an angle, they are bent toward the shoreline.

Refraction is caused by a change in wave velocity, in passing from one material into another Wave paths that enter straight (perpendicular to the interface) are not bent at all. Wave paths that enter at an angle (called the ANGLE OR INCIDENCE) are bent, more and more as the angle becomes sharper. When the angle becomes sharp enough, the wave path will not enter the second material, but will be REFLECTED from the surface, rather than refracted.

For any particular angle of incidence, the amount of bending, or refraction, depends on the velocities in the two materials. If the

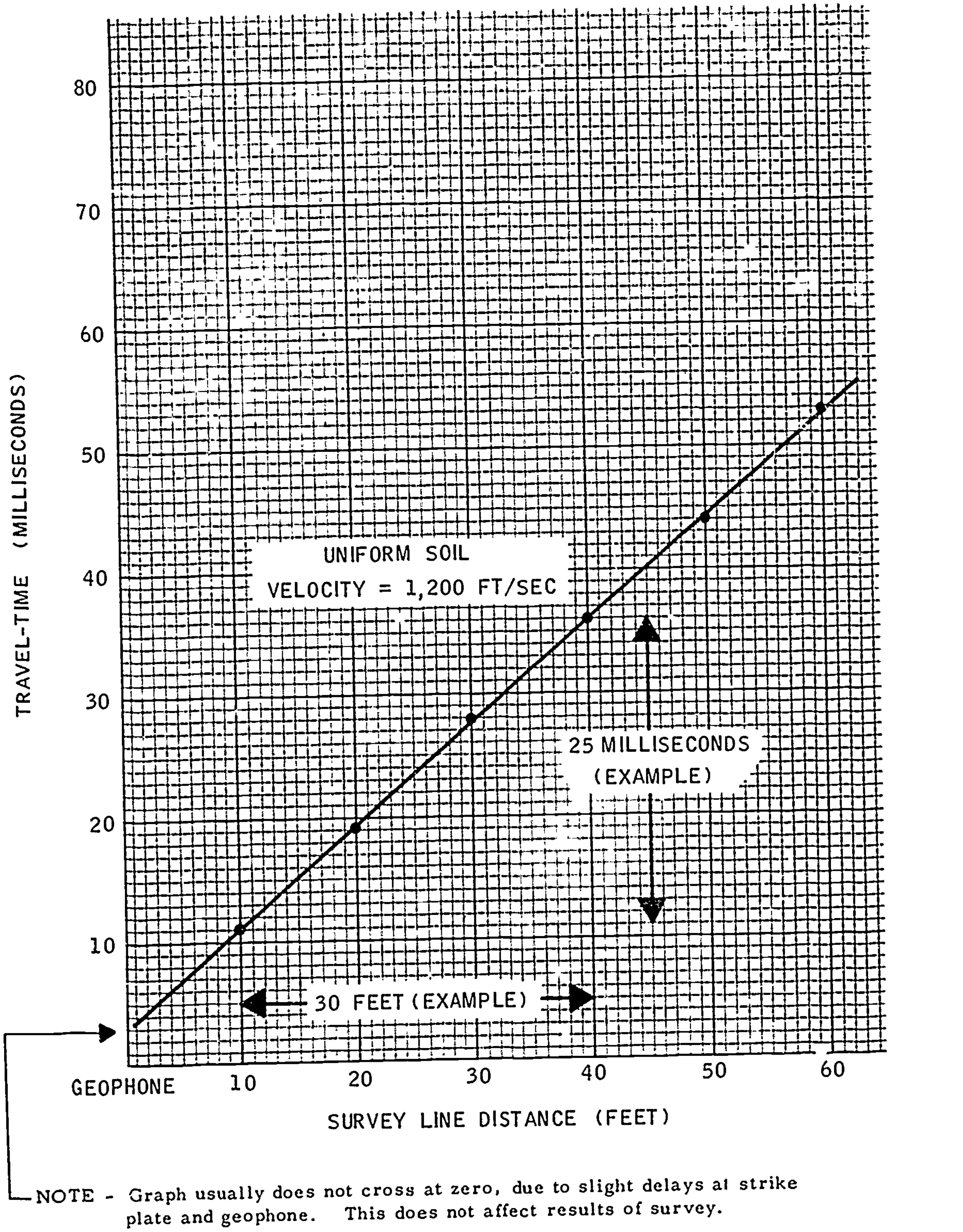


Figure 14-32.—Travel-time graph, uniform soil.

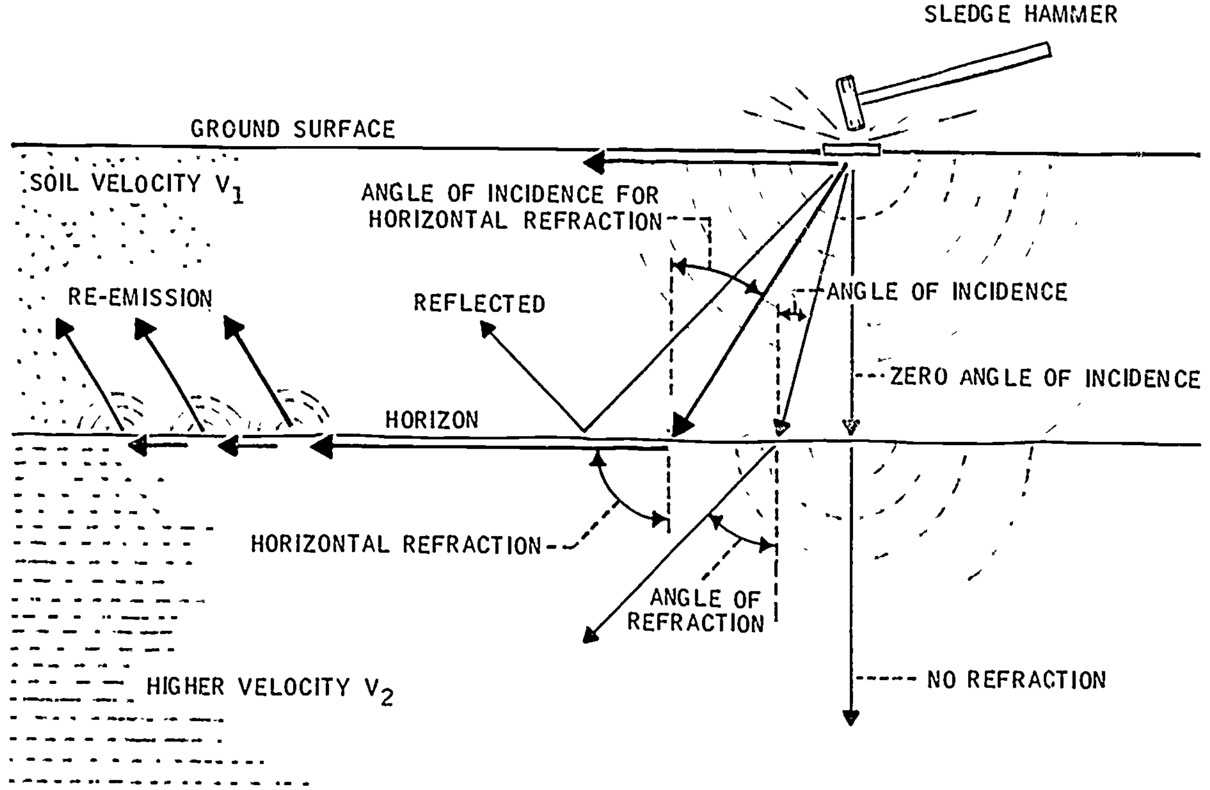


Figure 14-33.—Elastic wave paths at a subsurface horizon.

82.194X

velocities are almost the same, very little bending will occur. If the velocities are greatly different, a great deal of bending will take place.

In the case of light entering a glass lens or prism, the velocity in the second material (glass) is lower than the velocity of light in air. So the light waves are bent TOWARD the perpendicular (into the glass). This case is not applicable to seismic refraction, since the elastic waves would be bent downward, into the earth, and not return to the surface. For this reason, seismic refraction cannot discover layers of soil having lower velocities than the overlying materials. Fortunately, in almost every case, the lower materials, being more compacted, have higher velocities.

When the elastic waves enter a subsurface horizon of a higher velocity material, they are bent AWAY from the vertical. At one particular angle of incidence, the wave path will be bent enough to travel right along the surface of the horizon, parallel to the interface. It is this wave path that makes seismic refraction surveying possible.

As the refracted, horizontal wave travels along in the higher velocity material, it constantly gives off energy in all directions. Some of this energy returns to the ground surface, along a path at the same angle that the wave entered the refracting horizon. This energy eventually reaches the geophone.

We now have two different paths which the elastic waves can take to reach the geophone from any impact point. The DIRECT PATH is through the top soil to the geophone. It travels at the velocity of the top soil, V_1. The REFRACTED PATH is down through the top soil at some angle, traveling at velocity V_1, then along the subsurface horizon at velocity V_2, then back up to the geophone at velocity V_1. The two paths are shown in figure 14-34.

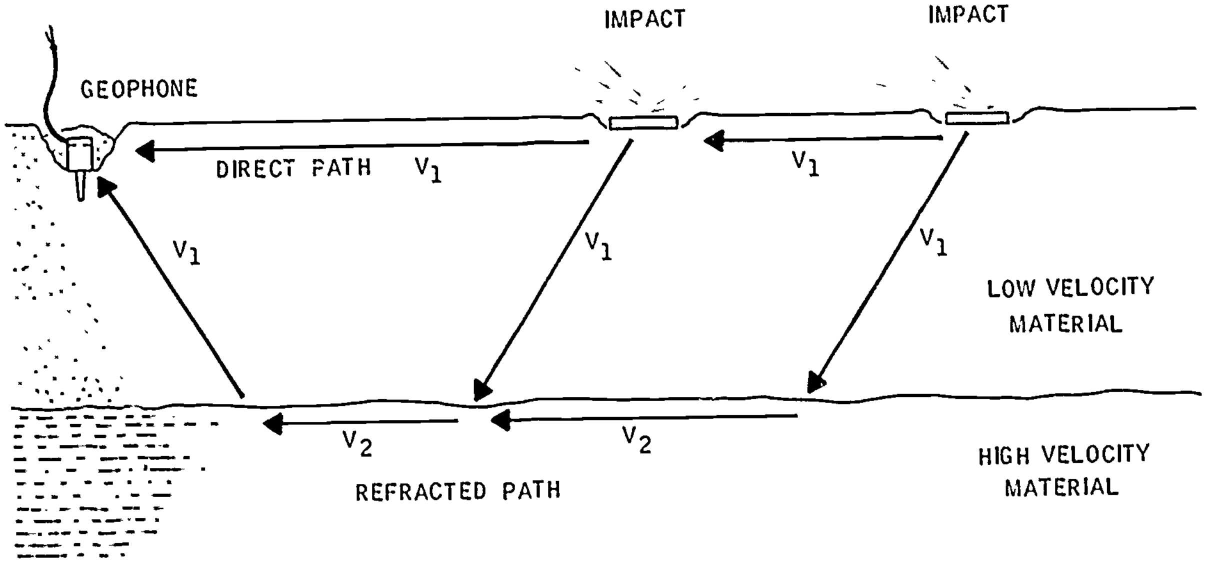


Figure 14-34.—Direct and refracted elastic wave paths.

First-Arrival Refraction Surveying

The geophone is placed at the beginning (zero) end of the survey line. The hammer man moves out along the line, making impacts at each 10-ft station. The instrumentman measures the travel-time of the FIRST ARRIVAL of elastic wave energy at the geophone, since it is the first-arrival which stops the timer. The resulting travel-time graph is shown in figure 14-35. When the impacts are close to the geophone, the shortest travel time is directly through the top soil, as in the example for uniform soil (fig. 14-32). However, at some point along the survey line, because of the faster velocity in the second layer, the first-arrivals of the direct path and for the refracted path will be the same. And at all points beyond that point, the refracted path will give the shorter travel-time. This point where the two travel-time graphs intersect is called the CRITICAL POINT. The distance from the geophone to the critical point is called the CRITICAL DISTANCE (Symbol, L).

The critical distance is important because at this distance, THE TRAVEL TIMES over both the DIRECT and the REFRACTED path are the SAME. The depth determination formula is based on this fact. Derivation of the formula can be found in any standard geophysics text.

The velocity V_1, in the first layer, is taken from the first portion of the travel-time graph. The velocity in the second layer, V_2, is taken from the second portion of the travel-time graph. The critical distance, L_1, (in this case, L_1 = L in fig. 14-35) is shown on the graph because it is the distance to the point where the first travel-time curve "breaks" to the second travel-time curve.

Seismic refraction surveying is not limited to the case of two layers. For each successive, higher-velocity layer, a new portion of the travel-time curve will be observed, each at a flatter slope (higher velocity) and at a new critical distance, L_2, L_3, and so on. All critical distances are measured from the beginning of the survey line.

Determination of Depth to Successive Horizons

The critical distances are the second piece of information needed to determine depth of subsurface horizons. Calling the depth to the first subsurface horizon (top of second layer) "d_1", the formula is:

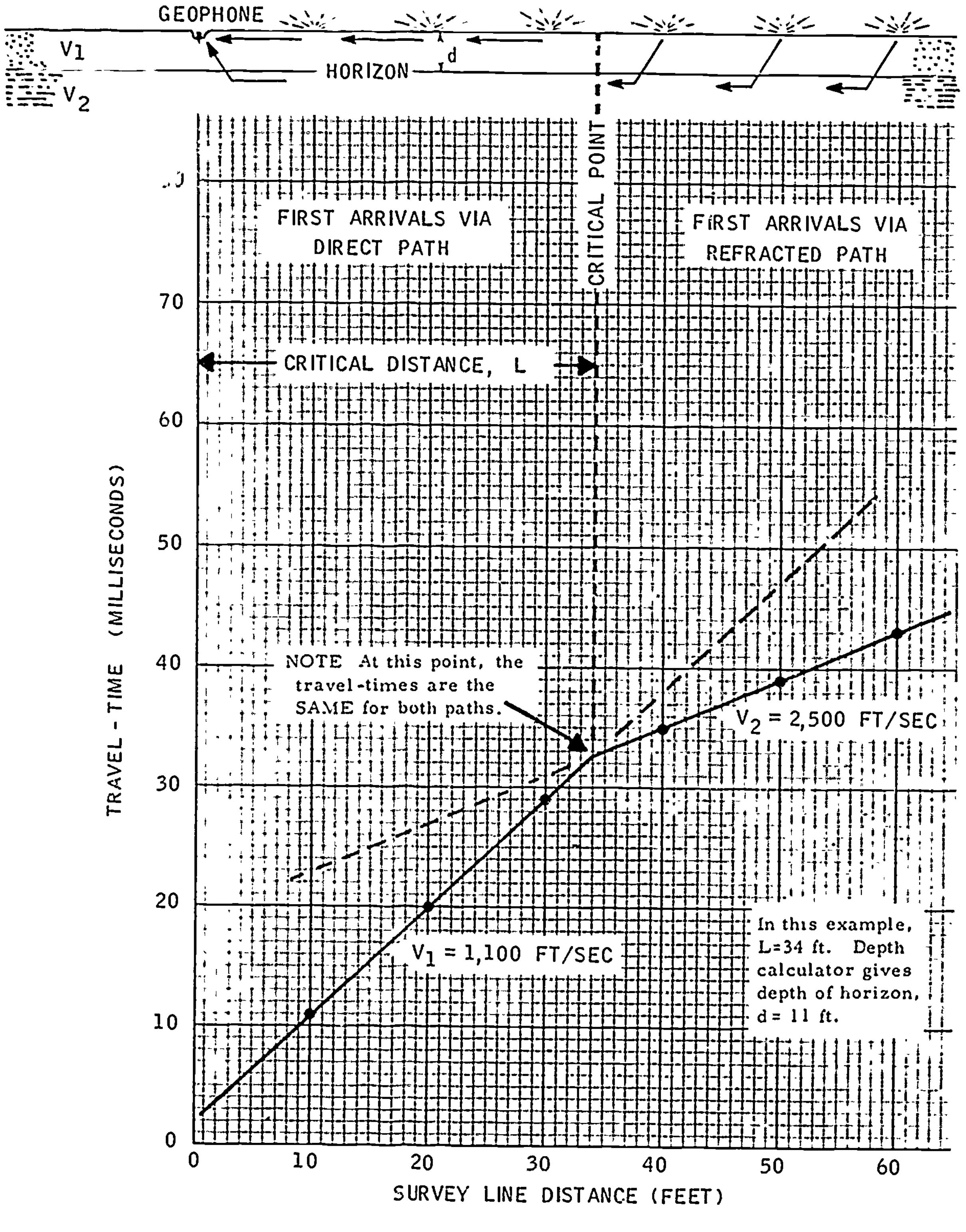


Figure 14-35.—Travel-time graph showing discovery of a subsurface horizon.

$$d_1 = \frac{L_1}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

It is not necessary to work out the mathematics to find the depth. A depth calculator nomograph, provided with the instrument, solves the problem. The critical distance L_1 is taken from the travel-time graph. The velocities V_1 and V_2 are read from the graph by using the VELOCITY SCALE, which is a transparent overlay.

In the same manner, by observing critical distances and velocities on the travel-time graph, and by using the depth calculator, the depths to successively deeper layers of material can be determined. If the layers do not lie parallel to the ground surface, they are said to have an APPARENT DIP with respect to the ground surface. This is detected when a geophone is placed at each end of the survey line (DOUBLE-HEADED LINE) and two travel-time graphs are plotted, one from each end of the line. For this reason, double-headed lines are used whenever possible. The seismic timer has provision for two geophone inputs, with a geophone selector switch. The hammer man moves down the survey line only once, but by switching from GEOPHONE 1 to GEOPHONE 2, the instrumentman can obtain travel-times to both geophones from each impact station. The survey line is normally 150 feet long. A double-headed travel-time graph is shown in figure 14-36.

A complete discussion of shallow seismic surveying is beyond the scope of this text. Personnel qualified as seismic surveyors are trained, using the R-117B, the instruction manual, and additional reference material. The present discussion is intended to give general familiarity with the method, for supervisory personnel and those interested in further study.

SEISMIC SURVEY FIELD PROCEDURES

In general, the field procedure for making a seismic survey consists of the following:

(a) Locate the desired seismic survey lines on a map or plan of the area. If possible, this should be a topographic map showing the ground surface contours.

(b) Lay out the seismic survey lines in the field and conduct the seismic survey. Wherever possible, the survey lines should be double-headed, using a geophone at each end of the line. Plot the travel-time data directly on field seismic survey data sheets, so that the graphs are available as the work progresses.

(c) In the office, using the field data, replot the travel-time graphs on profile paper. Calculate the various depths to subsurface materials and their apparent dips relative to ground surface, if any. Plot the subsurface soils profile directly above the corresponding travel-time graphs, noting all discontinuities, dips and other features encountered. Correlate the profile with other data, such as observed surface outcrops and information from any test pits or borings adjacent to the survey site.

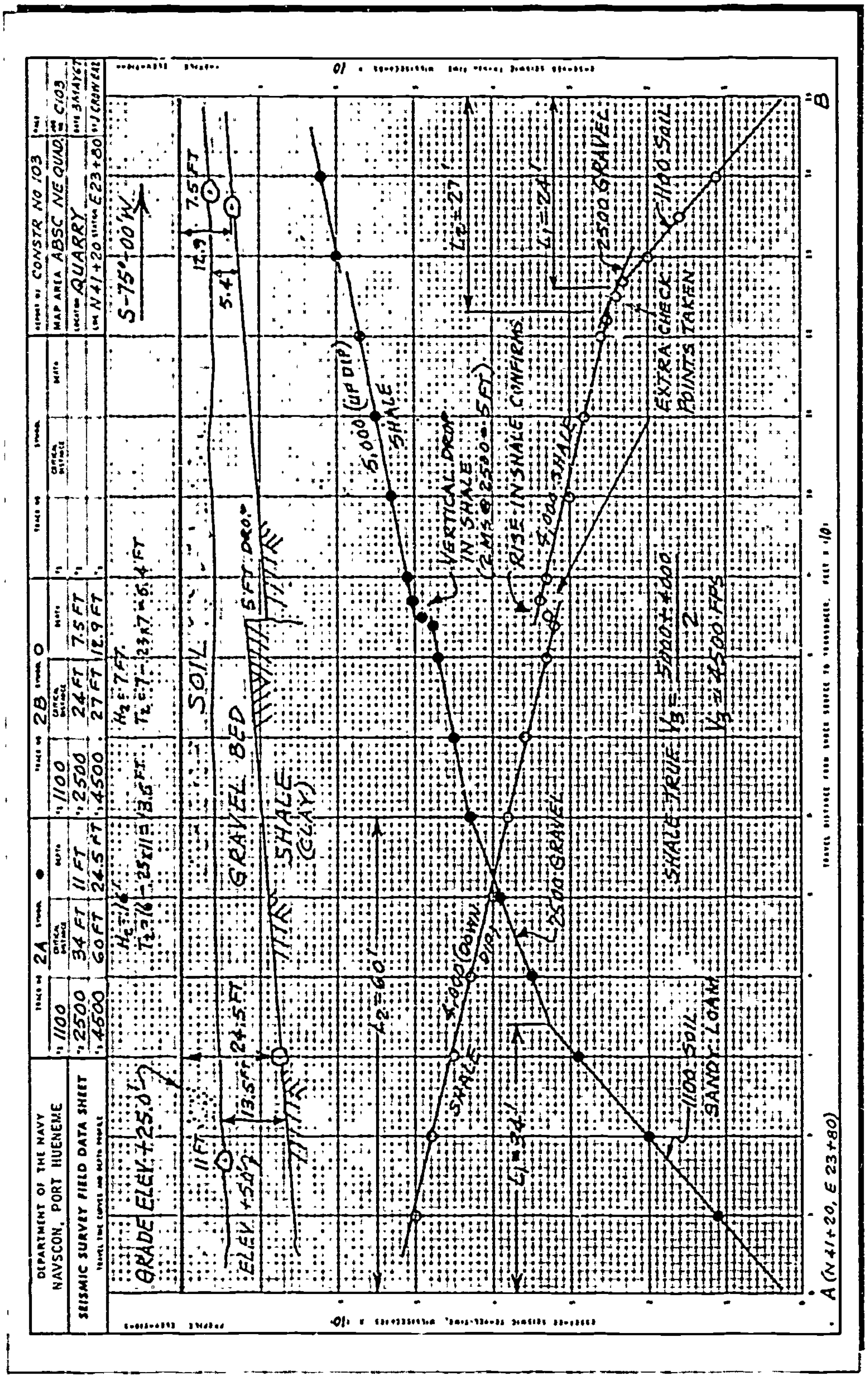
(d) Show the location of the constructed soil profile line on the area topographic map.

These procedures are discussed in more detail in the following paragraphs.

Planning the Seismic Survey

The exact location of the seismic survey lines will depend on the purpose of the survey (site or airport grading, road cut, heavy foundation construction, quarry location, and so on). The locations should be decided after discussion with the engineer in charge of the work. Indicate the location of each seismic line on the area topographic map or plan as shown in figure 14-37. A heavy black line indicates the survey line, with a solid black dot at each geophone location. Number the tracks, and number the geophone locations with a track number followed by the letter A or B. In figure 14-37, survey lines have been located for a single airstrip profile, a beach-head profile, and a search for rock materials at the foot of the rolling hills to the north of the base. The location of seismic track 2, at the quarry site and its geophones, A and B, are shown on figure 14-37. The seismic data is shown in figure 14-36. Note, also, the seismic checks made on shale and gravel outcrops at the quarry site.

As the seismic surveys progress, additional survey lines may be added where necessary to



82.197X

Figure 14-36.—Double-headed travel-time graph, seismic track No. 2 at quarry site of figure 14-37.

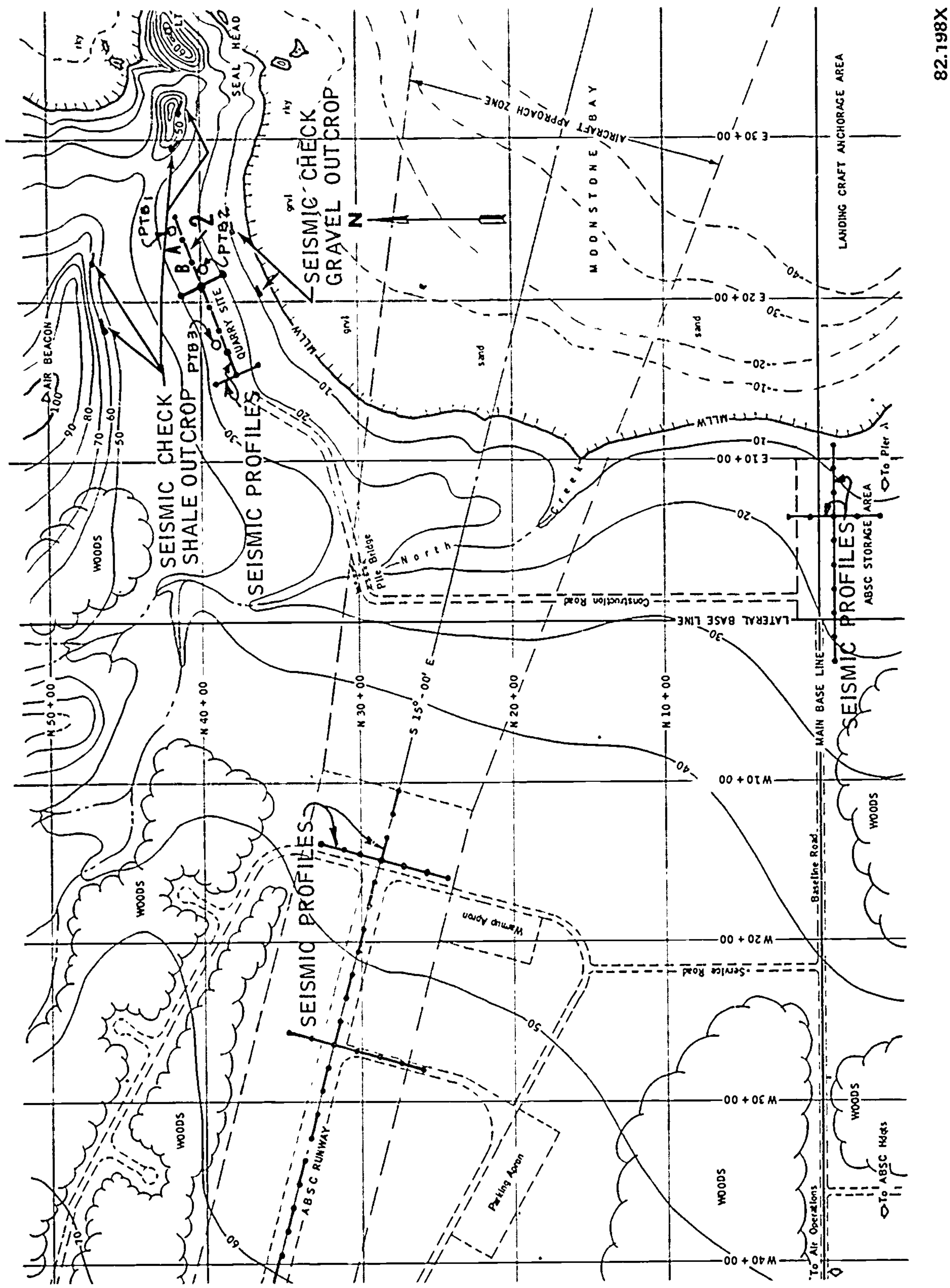


Figure 14-37.—Area topographic map, showing seismic survey lines.

clarify a subsurface situation or continue an exploration line.

Making the Seismic Survey

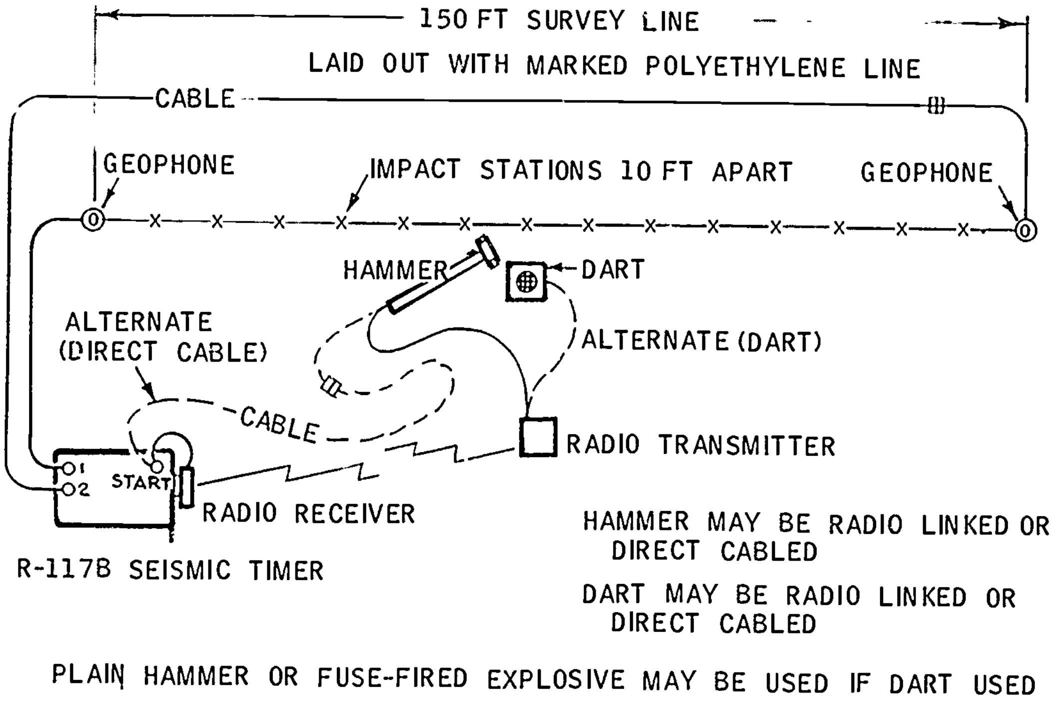
The detailed, step-by-step procedure for the seismic survey is given in the instruction manual for the R-117B Seismic Timer. In general, the procedure is as follows:

1 Hammerman and instrumentman lay out 150-foot survey line, using 1/4-inch yellow polyethylene survey line marked at 10-foot stations with black tape.

2. Plant geophone at each end of the line. Clear away any loose top material or grass. Dig a 6-inch to 8-inch hole. Press geophone spike firmly into ground. Cover geophone with loose soil and stand firmly on top to make good coupling between geophone and ground. If soil is very dry, add a little moisture to get firm compaction.

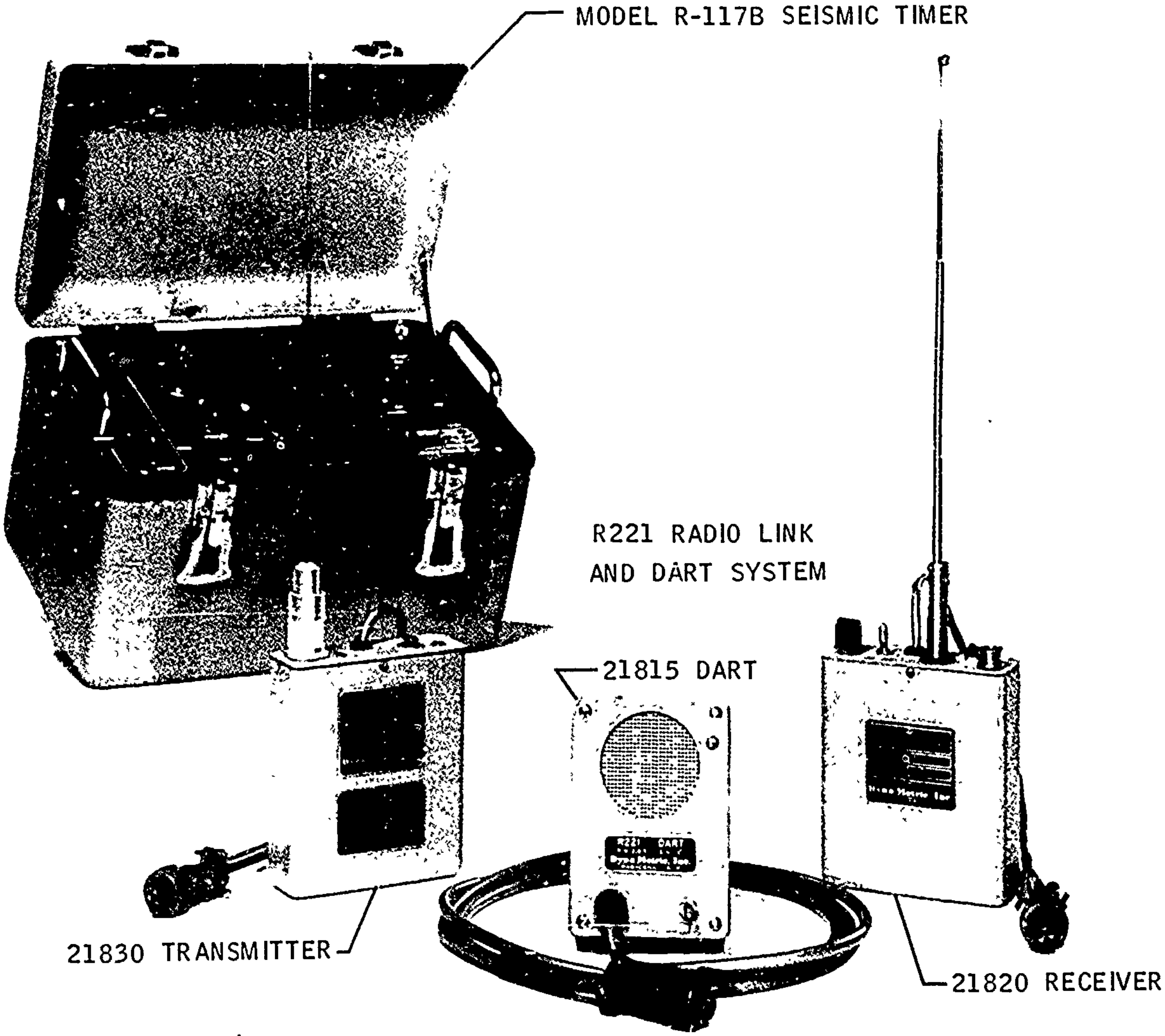
3. Connect both geophones to the input connectors on the seismic timer, using one of the 150-foot cables for the geophone at the far end of the line. The field set-up is shown in figure 14-38.

4. Connect the sledge hammer to the seismic timer. It can be directly connected by cable, or it can be connected using the R221 RADIO LINK (fig. 14-39) as explained in the instruction manual. The work will proceed faster if the radio link is available, since the hammer man is free to move without dragging the long hammer cable. For the impact start signal, either the shock switch on the sledge hammer can be used, or a plain hammer can be used with the DART pickup of the radio link system. The DART is worn clipped to the impact man's belt.. It "hears" the hammer below and sends the start signal to the timer, either through direct cable or over the radio link system. The hammerman should position himself for each blow so that the DART is always the same distance from the strike plate, within a few inches. This makes the start time uniform from blow to blow, within one millisecond.



82.200X

Figure 14-38.—Field set-up for 150-foot, double-headed seismic survey line.

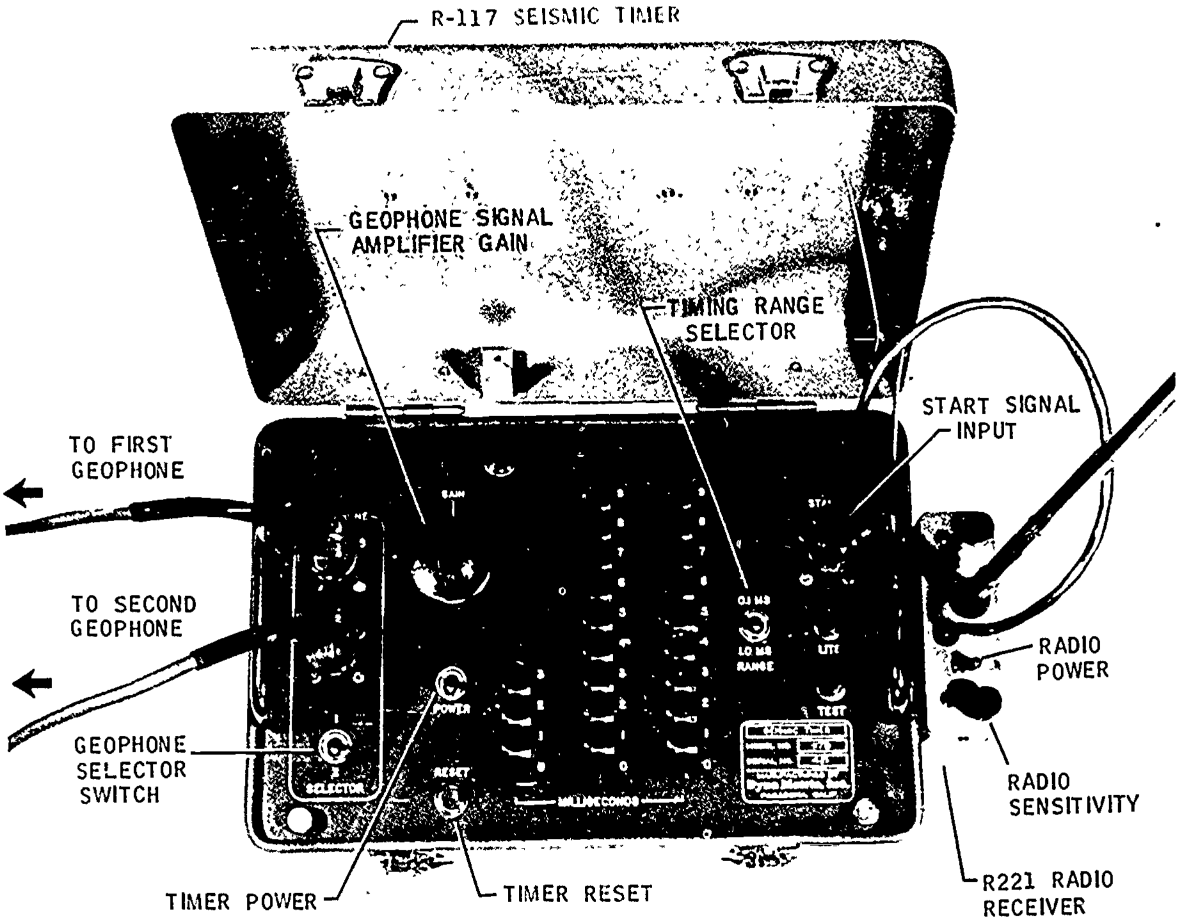


82.199X

Figure 14-39.–R221 radio link and dart system with R-117B seismic timer.

5. The control panel of the R-117B Seismic Timer is shown in figure 14-40 with the R221 Radio Link Receiver attached and connected to the START input of the timer. When the Radio Link is not used, the long hammer cable is connected to the START input. To begin the survey, turn the instrument POWER switch ON. Press the RESET button and note that the time lights indicate 0-0-0 milliseconds. The RANGE switch should be on 1.0 MILLISECONDS for normal surveying. Turn the GAIN control to a low value. Press the TEST button and note that the timer starts counting (lights flickering). Now turn up the GAIN until the timer is stopped by the seismic BACKGROUND noise. This is the normal disturbance in the ground being received by the geophone. No one should walk or move near a geophone during the testing or surveying. After finding the GAIN setting at which the timer will count for several cycles without being stopped by background noise, reset the timer and proceed with the survey.

6. The hammer man places the strike plate on a cleared ground surface at the first station mark



82.201X

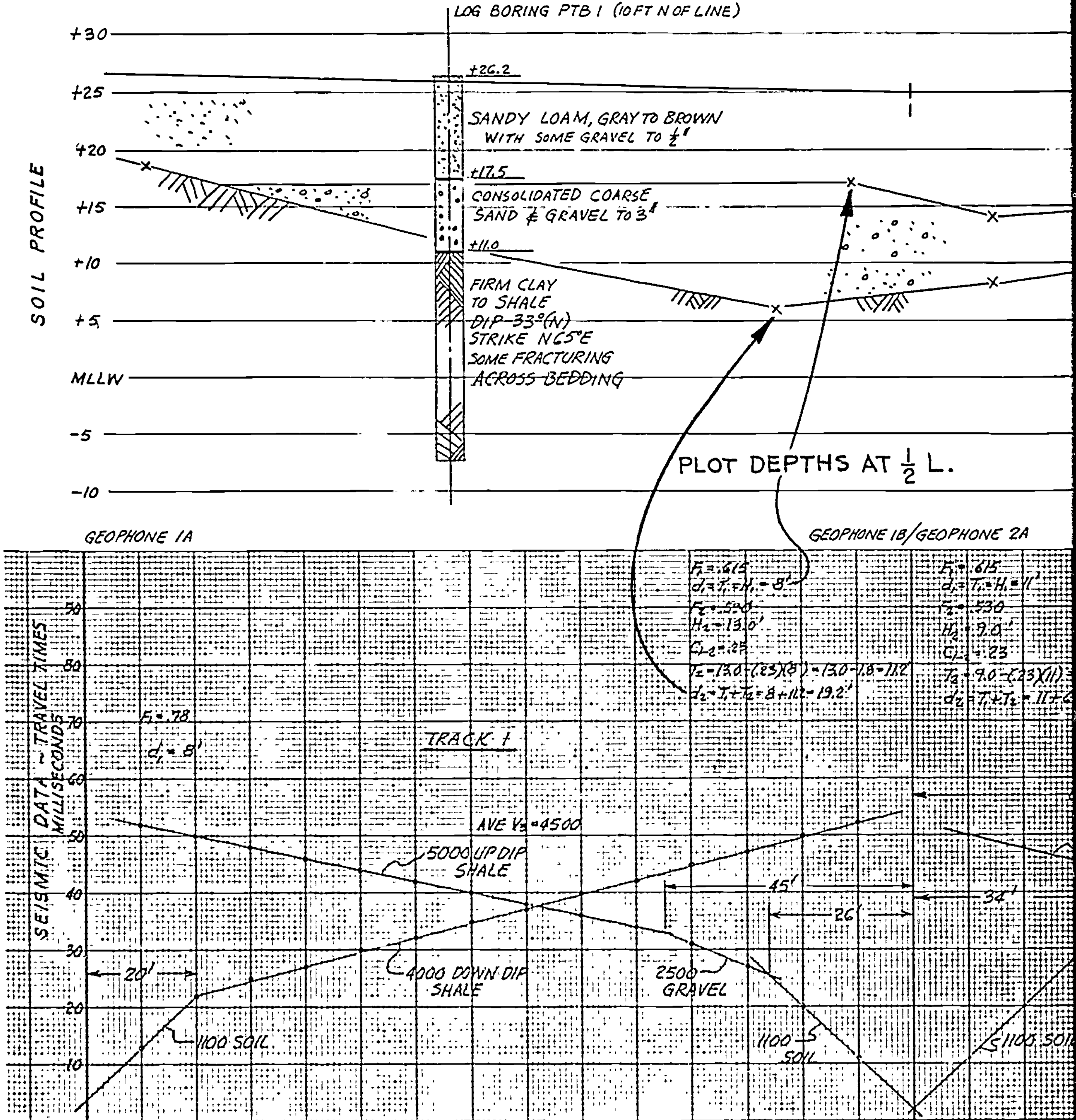
Figure 14-40.—Control panel of R-117B seismic timer, with radio receiver and geophone cables attached.

on the yellow survey line. He taps it firmly with the sledge hammer to set the plate. With the timer geophone selector switch on GEOPHONE 1, the instrumentman then takes several travel-time readings from impacts at the first station, and plots the most REPEATABLE readings on his data sheet. He then places the geophone selector switch on GEOPHONE 2, and takes several time readings to the far geophone, plotting the most repeatable time also at station 10-ft on his data sheet (since this is the 140-ft station for the reverse line).

7. The hammerman then proceeds to each impact station in turn along the line, and the procedure is repeated, until the complete forward and reverse travel-time graphs are plotted, as shown in figure 14-36.

Constructing the Soil Profile

In the office, the seismic survey data, topographic data, and other information from surface sampling and preliminary test borings are combined on the SOIL PROFILE SHEET. The lower part of this continuous roll paper has the same 10 X 10 graph markings as the seismic field data sheet. The upper half of the paper is plain, for drawing the profile. The seismic travel-time



LOG BORING PTB 1 (10 FT N OF LINE)
SOIL PROFILE
+30
+25
+20
+15
+10
+5
MLLW
-5
-10
+26.2
SANDY LOAM, GRAY TO BROWN WITH SOME GRAVEL TO ½"
+17.5
CONSOLIDATED COARSE SAND & GRAVEL TO 3"
+11.0
FIRM CLAY TO SHALE DIP 33°(N) STRIKE N65°E SOME FRACTURING ACROSS BEDDING
PLOT DEPTHS AT ½ L.
GEOPHONE 1A
GEOPHONE 1B/GEOPHONE 2A
SEISMIC DATA ~ TRAVEL TIMES MILLISECONDS
TRACK 1
AVE V3 = 4500
5000 UP DIP SHALE
4000 DOWN DIP SHALE
2500 GRAVEL
1100 SOIL
1100 SOIL
1100 SOIL
20'
45'
26'
34'

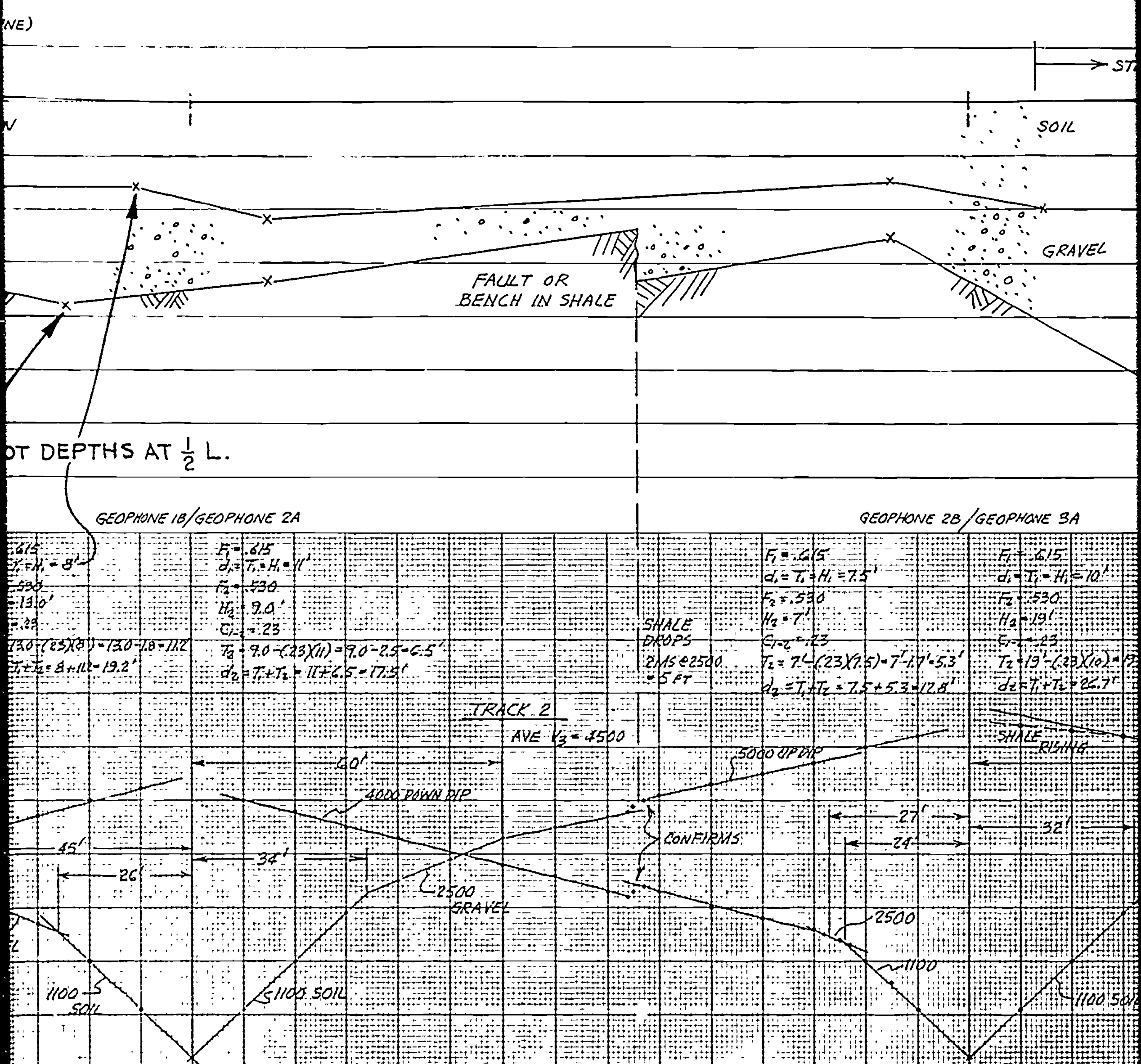
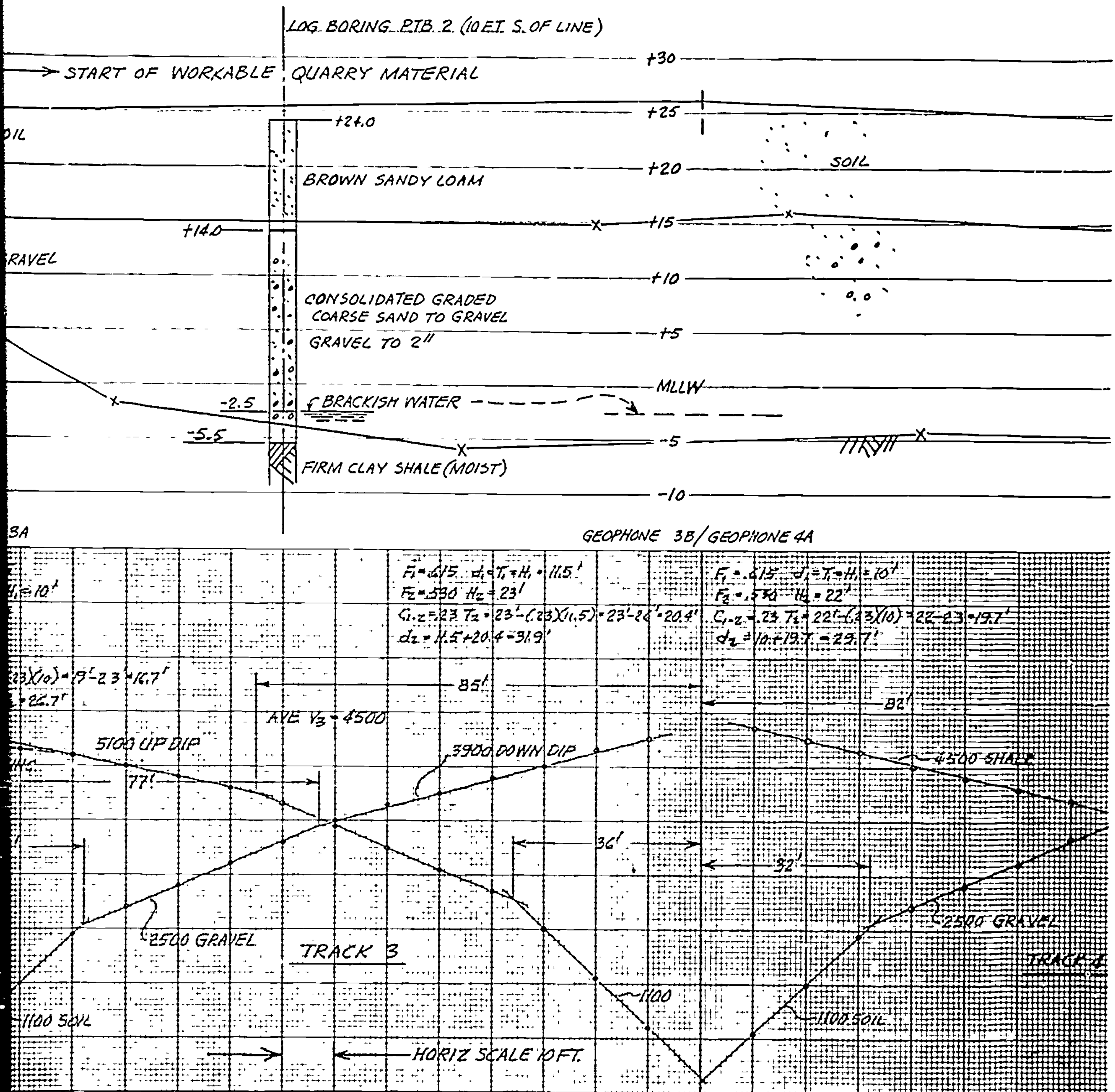


Figure 14-41.—Portion of soil profile sheet at quarry site, showing seismic data and logs of preliminary test boring.


LOG BORING PTB 2 (10 FT. S. OF LINE)
START OF WORKABLE QUARRY MATERIAL
+30
+25
+24.0
SOIL
+20
BROWN SANDY LOAM
+15
+14.0
GRAVEL
+10
CONSOLIDATED GRADED COARSE SAND TO GRAVEL
+5
GRAVEL TO 2"
MLLW
-2.5
BRACKISH WATER
-5.5
-5
FIRM CLAY SHALE (MOIST)
-10
3A
GEOPHONE 3B/GEOPHONE 4A
85'
82'
AVE V3 = 4500
5100 UP DIP
3900 DOWN DIP
4500 SHALE
77'
36'
32'
2500 GRAVEL
TRACK 3
TRACK 4
1100
1100 SOIL
HORIZ SCALE 10 FT.

82.202X

graphs are replotted, and the necessary interpretations and depth determinations are made directly on the sheet. The soil profile is drawn above, with notations of all correlating information. A portion of a soil profile sheet is shown in figure 14-41.

In determining depths to subsurface layers for plotting on the solid profile, use is made of the MULTIPLE STRATA DEPTH CALCULATOR, PN 11786, furnished with the seismic timer. The two sides of this depth calculator are shown in figures 14-42 and 14-43. Instructions for its use appear on the calculator. A sample depth determination is shown on the soil profile (fig. 14-41).

ADDITIONAL SEISMIC SURVEY TECHNIQUES

The seismic timer instruction manual gives methods for handling a large variety of possible field situations, including the determination of apparent dip, true dip and strike of subsurface strata, and so on. Two additional techniques should be mentioned here for information of supervisory personnel.

High-Speed Surveys on Outcrops

Quite often, when examining the area to be surveyed, a number of outcrops of rock or bedded materials will be observed, particularly when adjacent to hills or canyon walls. Usually, similar materials will be encountered beneath the soil cover during the regular seismic surveys. In such cases, the outcrops should be examined by conducting a very short seismic survey directly on the outcrop material. For this purpose, the seismic timer (fig. 14-40) has a high-speed range (RANGE switch at 0.1 MILLISECOND). In this range the timer counts in tenths of milliseconds, up to 39.9 milliseconds. The impact stations along the survey line should be 1 foot apart. On the travel-time graph, a ten-times expanded scale (1 inch = 1 foot, or 1 millisecond) is used. The resulting seismic survey will give the velocity in the outcrop material. If the material is weathered for a depth of a few feet, this depth of weathering will appear on the graph, and the velocity in the deeper, unweathered material will appear as a velocity in a second layer.

NOTE

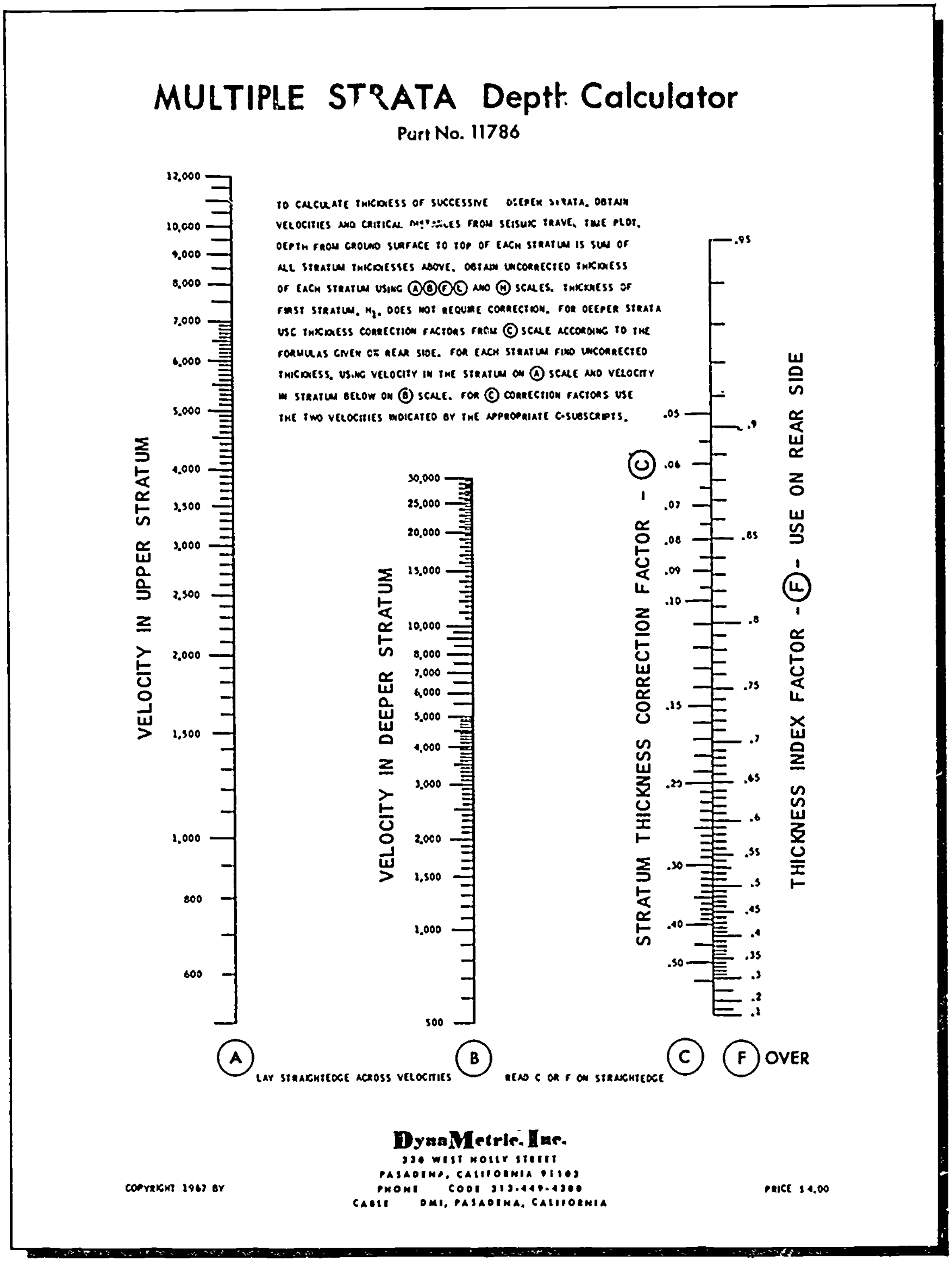
> The geophone can be coupled to a rock outcrop by using a large wad of modeling clay. Press the clay firmly against the rock and press the geophone spike firmly into the clay wad. Be sure to keep the geophone body vertical.

The information from outcrop surveys is of great value when interpreting the results of regular seismic surveys in the deeper soil areas, since the characteristic velocity of the bedded material will permit its identification on the regular survey lines. See the outcrop checks at the quarry site, figure 14-37.

Seismic Surveys Beyond Sledge Hammer Range

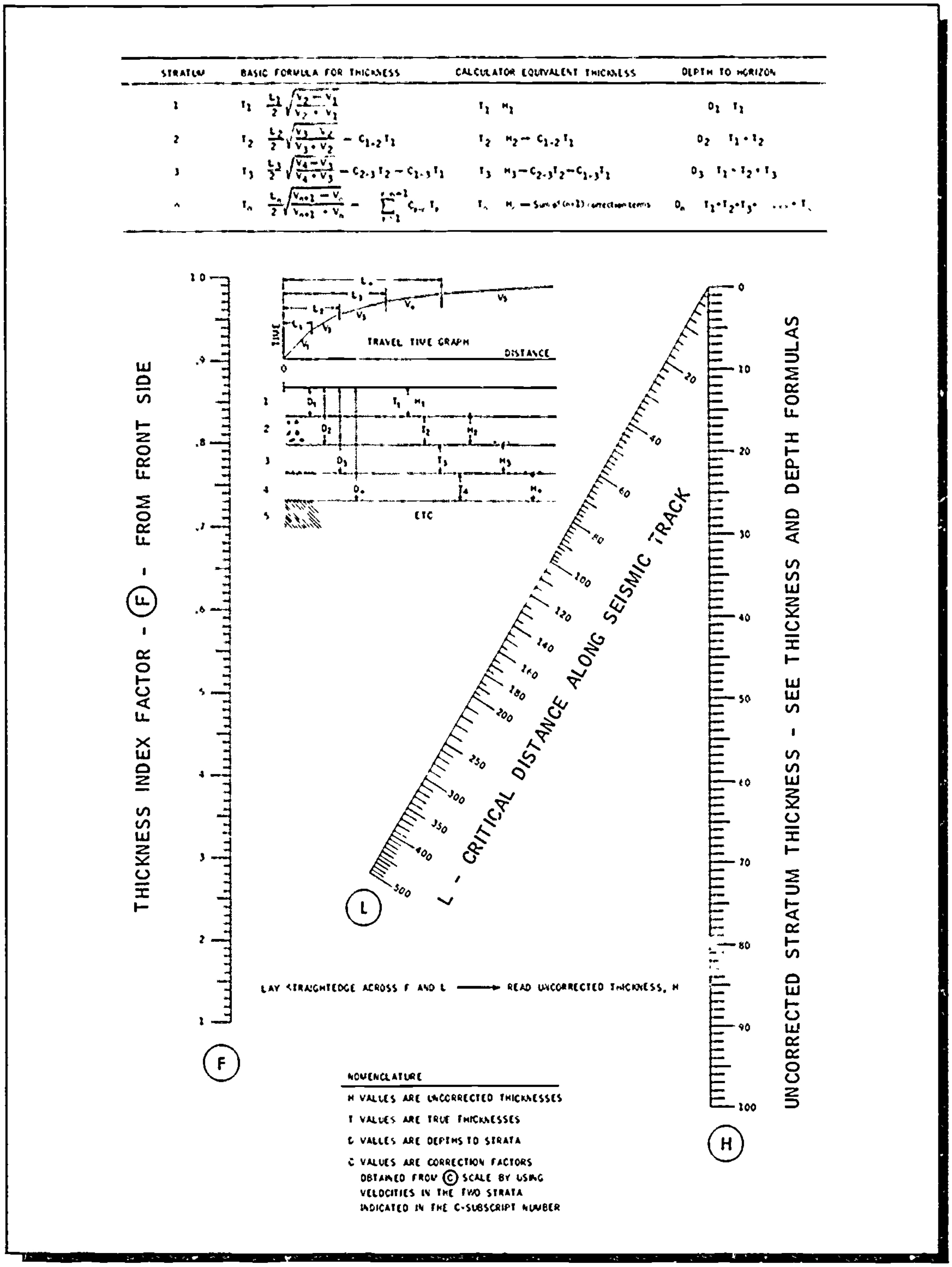
In some cases, the work may require information about depths so great that useful data cannot be obtained with the available energy of the sledge hammer impacts. With the R221 Radio Link and Dart, the hammer survey line can be extended, using small fuse-fired explosive charges. When the last station where the hammer blow still gives first-arrival travel times is reached, a charge is set off. Its travel time is correlated with the hammer blow travel time (it will usually be shorter than the hammer time since much more energy is available and produces a higher-amplitude wave form, although the velocity is the same). The survey line is then continued, using the small fuse-fired charges at 50-foot intervals. When a time reading is questionable, the shot should be repeated for confirmation.

The proper procedure for setting off the charges is as follows. At the impact point, drive a 3/4-inch diameter steel pipe or rod into the ground about 1 foot. Work the pipe back and forth slightly and withdraw it from the ground, leaving a hole for the charge. The charge will not be effective if fired on ground surface. Drop the charge in the hole, leaving its fuse extending above ground. Place the DART on the ground, microphone up, exactly 4 feet from the shot



82.203X

Figure 14-42.—Multiple strata depth calculator, PN 11786 (front).



82.204X

Figure 14-43.–Multiple strata depth calculator, PN 11786 (back).

hole in any direction. Light the fuse with a burning punk. Step away at least 15 feet and wait for the shot to fire.

WARNING

If for any reason, the charge does not fire, wait for at least 30 seconds. Then cautiously approach the shot hole, keeping the face averted, and place a shovel full of loose dirt over the shot hole. Later, at a safe time, the charge can be dug up and examined.

Note, however, that this is a small explosive charge and will do no particular damage, other than that of a firecracker. While some degree of caution is needed, precautions observed in the handling of large explosive charges do not apply. (A large explosive charge would be harmful to equipment, as well as require special handling.)

NOTE

When lighting the charge, be careful not to make a loud noise or step near the DART, producing a premature start signal for the timer. The instrumentman should be watching, and make sure the timer is properly reset at 0-0-0 immediately before the shot fires.

TESTING EQUIPMENT AND INFORMATION SOURCES

All of the soil tests discussed in this chapter may be performed with the equipment and apparatus contained in kit no. 0026, material testing kit, which is listed in the *Mobile Construction Battalion Table of Allowance.* Equipment used for performing seismic surveys is not included in the material testing kit, but is available upon request.

As an EA1 or EAC in charge of material testing, you must ensure that the material testing kit is complete. You must also ensure that the consumable items are ordered far in advance to replace depleted items. It is difficult to substitute items and still maintain accurate test results. An ample supply of data sheets and computation forms must be kept on hand. The data sheets which are shown in this chapter are used only as examples. You may choose to design your own forms or use standard forms and data sheets.

A "Speedy" moisture content kit is included with the aforementioned materials testing kit. This "Speedy" moisture content kit is very handy in the field for determining approximate moisture content, especially for field compaction tests. Instructions for its use are included with the kit.

In setting up a material testing lab, you should acquire an enclosed space separate from any other function. A material testing lab must be large enough to perform several tests simultaneously and to provide adequate storage space for all of the equipment in the material testing kit. Many large work benches and tables are advisable. A MUST for all material test labs is a sink with running water for washing soil samples and cleaning equipment.

The tests discussed in this chapter are only a few of the tests which an EA may be required to perform. For other tests and modified tests, consult such sources as: *Soil Mechanics, Foundations and Earth Structures,* NAVFAC DM-7; *Material Testing,* TM 5-530; ASTM publications; and various civilian material testing publications. At many overseas locations, where civilian construction companies are contracted by the Navy, there will be an Officer-In-Charge of Construction (OICC), who may operate a material testing lab. By establishing contact with the OICC soils engineer, he may assist you with any problems which may arise, and he might permit you to use the lab to perform tests which cannot be performed in the battalion test lab, or perform the tests for you. He will also have information on soil conditions peculiar to your particular construction area.

Never hesitate to consult knowledgeable persons or information sources. An incorrectly performed test could result in faulty construction.

CHAPTER 15
QUALITY CONTROL

Quality control consists, in general, of (1) the testing of construction materials to determine that their inherent characteristics meet minimum quality requirements, and (2) inspection to ensure that the construction methods used are those which will ensure the attainment of prescribed quality standards. Quality standards for both materials and methods are usually set forth in the specifications.

In this discussion, we are mainly interested in the first phase of quality control mentioned above—the testing of construction materials. The EA must be able to make certain tests on three important construction materials. One of these is the soil—that is, the natural earth—which will support the foundations of a structure. The other two are bituminous pavement material and concrete, both being synthetic materials made by combining certain ingredients. It is with these latter two materials that we are concerned here, since information on soils and soil testing was presented in the preceding chapter.

A point to note is that the Operations or Engineering Officer has the ultimate responsibility for construction quality control. When the EA functions as materials tester, he is acting strictly as the representative of that officer. He carries out tests as directed, and reports his findings back for action which can be taken only by superior authority—not by himself. Bear in mind, however, that materials testing is a primary responsibility of the EA rating. The results obtained from tests of bituminous pavement materials and portland cement concrete can be very useful toward achieving proper design and quality in Navy construction, especially construction involving roads and airfields.

BITUMINOUS PAVEMENT MATERIALS

A bituminous pavement is one which is made up of a mixture of coarse and fine aggregate, bound together by a liquid or semisolid bituminous binder. Bituminous pavements are used as the top portion of the flexible pavement structure to provide a resilient, waterproof, load distributing medium which protects the base course from detrimental effects of water and abrasive action of traffic.

AGGREGATES

The aggregate used in bituminous pavements may consist of crushed stone, gravel, sand, mineral filler, or similar material. The aggregate transmits the load from the surface to the base course, takes the abrasive wear of the traffic, and provides a nonskid surface. Aggregates normally constitute 90 percent or more by weight of bituminous mixtures, and their properties have a very important effect upon the finished product.

For bituminous construction, aggregates are classified according to particle size; such as coarse aggregate, fine aggregate, and mineral filler. The maximum size of the aggregate will vary, depending upon construction requirements. Particle size is determined by sorting the materials on standard sieves.

COARSE AGGREGATE, usually consisting of pieces of crushed rock, broken gravel, slag, or other mineral material, is retained on a No. 8 standard sieve. If the pavement is laid with an asphalt finishing machine, the maximum size of coarse aggregate is one-half the surface course thickness and two-thirds the thickness of the base or binder course lift. When the mix is spread by a method other than the asphalt finisher, the maximum size aggregate may be two-thirds the lift thickness.

FINE AGGREGATE consists of particles of fine sand or small pieces of crushed rock that are small enough to pass through a No. 10 sieve, but too large to pass a No. 200 sieve.

MINERAL FILLER consists of inert nonplastic particles which are small enough to pass through a No. 200 sieve. Rock dust, hydrated lime, inert fine soil, and portland cement may be used as mineral filler. Most clays are too plastic for this purpose.

The desired characteristics of aggregate include angular shape, rough texture, hydrophobic, strength and durability, cleanliness, and proper moisture content.

The interlocking action of the aggregate in a bituminous surface is more pronounced when angular shaped, rough-textured particles are used. Angular particles may require more asphalt for the coating than round ones, but it is desirable to incorporate as much asphalt as possible for durability without impairing stability.

For strength and durability, the aggregate must be sufficiently strong and durable to resist weathering and to hold up under applied loads over a period of time without cracking or breaking. The hardness of a material is its ability to resist abrasion or scratching.

Individual particles of the aggregate must be clean and dry to permit the binder to penetrate into the pores to hold the particles together. If the aggregate is coated with clay or dust, or if the pores are wet, the binder will not penetrate. Moisture content should be less than 2 percent for cutback asphalt and tars for windrows or cold plant mixes, and less than 5 percent for an emulsion.

The three types of aggregates discussed earlier--coarse aggregate, fine aggregate, and mineral filler--may be blended in different proportions to produce various aggregate gradations. Gradation of the particles largely determines the mechanical stability of the bituminous mix. Some types of bituminous wearing surfaces require an aggregate blend with a wide range of particles sizes, other types require a uniform gradation of particles of approximately the same size Trial-and-error procedure is generally used in the field for blending aggregates to conform to recommended gradations. The four major aggregate gradations used in bituminous construction are: uniform gradation, macadam gradation, open gradation, and dense gradation.

Uniform gradation consists of aggregate particles that are all approximately the same size, usually less than 1 inch.

Macadam-graded aggregate consists of uniformly graded particles, usually 1 inch or larger. Although there may be some variation, the particles are approximately the same size. For example, a macadam gradation designated as a 1 1/2-inch aggregate may include 1-inch and 2-inch pieces, but most of the particles will be about 1 1/2 inches.

Open gradation is a blend of aggregate ranging in size from coarse to fine. Open spaces, or voids, remain in the mix because there is insufficient fine aggregate or mineral filler to fill the voids left by the larger particles.

Dense-graded aggregate blends are a well-graded mix of coarse aggregate, fine aggregate, and mineral filler. In contrast to the open gradation, dense-graded aggregate has only a few voids because the fine particles and the mineral filler fill up the small openings.

BITUMINOUS BINDERS

The binder for a bituminous pavement may be either an ASPHALT or a TAR. Asphalt exists in a natural state in deposits such as the large asphalt lakes in Trinidad and Venezuela; however, most pavement asphalt is a byproduct obtained in the process of refining petroleum. Tars are extracted from coal. Coal tar produced as a byproduct of coke production, and water-gas tar distilled from tar vapors produced, condensed, and collected during the production of natural gas, are both used as paving tars.

Asphalt Bitumens

An asphalt bitumen is identified by a letter symbol which, in most cases, refers to the rapidity with which that type of bitumen hardens, after application, to the point where the pavement may be used. The symbol AC, however, means ASPHALT CEMENT, which is simply refined asphalt, or a combination of refined asphalt and flux, of suitable consistency for paving purposes.

The symbol RC (rapid curing) and the symbol MC (medium curing) mean a CUTBACK asphalt that is, asphalt cement which has been mingled with (or "cut back" by) a volatile liquid DISTILLATE which speeds up the curing process. For RC, the distillate is NAPHTHA or GASOLINE: for MC, it is KEROSENE.

The symbol SC (slow curing) means an ASPHALT ROAD OIL--that is, a low-volatile oil left or blended with asphalt residues near the end of the refining process. To toughen SC, it is often mixed with PA (powdered asphalt), which is exceptionally hard and solid asphalt cement, ground to powder.

The symbols RS (rapid setting), MS (medium setting), and SS (slow setting) stand for the three types of ASPHALT EMULSION that have been established according to the setting rate, that is, the rate of separation or breaking of the asphalt from the water. This rate, in general, depends upon the amount and kind of emulsifying agent used.

Asphalt emulsion is composed of a nonflammable liquid substance, produced by combining asphalt and water with an emulsifying agent, such as soap or certain special colloidal clays or dust. The emulsifying agent promotes emulsification and controls certain physical properties of the emulsion. When the emulsion is deposited on a surface, the water and asphalt break (separate), leaving a thin film of asphalt cement.

As shown in table 15-1, two basic KINDS of emulsion have been established according to their electric charge. Each of the three TYPES of asphalt emulsion is graded on the basis of viscosity and grouped according to its usage. The use of ANIONIC (negatively charged) emulsions has been somewhat restricted in the past, since this type did not easily adhere to negatively charged siliceous aggregates. Certain CATIONIC (positively charged) emulsion will improve adherence to these negatively charged aggregates. In addition, cationic emulsions will coat damp aggregates better than anionic emulsions.

There are some advantages and disadvantages, however, in the use of asphalt emulsions. Besides being nonflammable and liquid at ordinary temperatures, emulsions also have another advantage over asphalt cutbacks, which is: they can be used with damper aggregate than cutbacks. The use of water in an emulsion is also a disadvantage in freezing weather since it will freeze and break the emulsion. Also, emulsions are difficult to store or stockpile as they tend to break while still in the unopened drums. Because of these disadvantages in storage and freezing, emulsions are not extensively used in the theater of operations.

In addition to the letter symbol, an asphalt bitumen has a number symbol representing its VISCOSITY. The property of a liquid that resists internal flow by releasing counteracting forces is called viscosity. This property is actually indicated by the relative CONSISTENCY (that is, the range from fluid to semisolid to solid) of the bitumen. Viscosity is found in asphalt by laboratory tests. 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. At present, a

Table 15-1.—Asphalt Emulsions According to Their Electric Charge

KIND	TYPE	VISCOSITY GRADE	MIXING ABILITY
Anionic	RS	RS-1, RS-2	Spraying
	MS	MS-2	Mixing and spraying
	SS	SS-1, SS-1h	Mixing and spraying
Cationic	RS-C	RS-2C, RS-3C	Spraying
	MS-C	SM-C	Mixing (sand) and spraying
	MS-C	CM-C	Mixing (coarse aggregate) and spraying
	SS-C	SS-C, SS-Ch	Mixing and spraying

Note: C denotes cationic emulsion.
h denotes a lower penetration grade of asphalt cement.

82.244

set of specifications for cutbacks based on kinematic viscosity is being used. The number of each grade corresponds to the lower limit of kinematic viscosity as determined by a standard test. The upper limit of each grade is equal to twice the lower limit or grade number. The units used in the test are stokes or centistokes, (stokes). Thus, viscosity range of 70 to 140 (100)
centistokes. The other grades and their limits are 250 (250-500), 800 (800-1600), and 3,000 (3,000-6,000); in addition, the MC has a 30 grade. For cutbacks then, just remember the grades range from 30, 70, 250, 800, and 3,000, the grade 30 being very fluid and grade 3,000 less fluid.

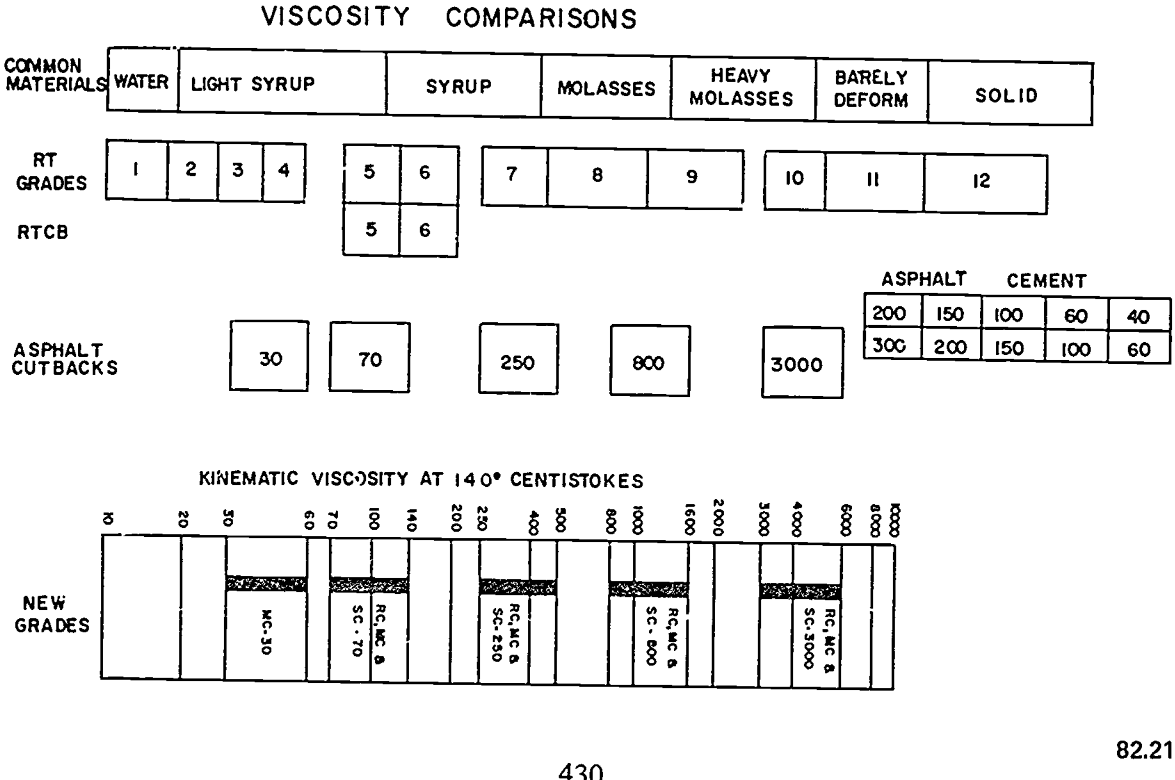
Asphaltic cement (AC) in its natural state is much more solid than it is after being cutback, and more solid than SC. It is, in fact, solid enough to be tested by a "penetration test," in which relative solidity is determined by the distance a needle penetrates the material under test conditions. Asphalt cement is, therefore, often called "penetration asphalt," and its relative solidity, instead of being indicated by a grade number, is indicated by a number which corresponds to the result of penetration testing. Numbers range from 40-50 (semi-solid) to 200-300 (semi-liquid). Viscosity comparisons are shown in table 15-2.

Road Tars

A road tar is designated by the symbol RT, plus a viscosity grade number. Viscosity grades range from 1 through 12. RT-1, RT-2, and RT-3 are called PRIMING OILS. RT-4 through RT-7 are called COLD TARS, because they are fluid enough to be mixed and applied at relatively low temperatures. RT-8 through RT-12 are called HOT TARS, because they are solid enough to require high temperatures for mixing and applying.

The symbol RTCB refers to ROAD TAR CUTBACKS, which are manufactured only in viscosity grades 5 and 6. Highly volatile coal distillate, such as benzene or a solution of naphtalene in benzol, may be used to cut back

Table 15-2.—Viscosity Grades at Room Temperature



82.212

the heavier grades of road tar to produce these two grades of road tar cutbacks. Like asphalt cutbacks, road tar cutbacks cure rapidly. The viscosity grades of road tars and road tar cutbacks are comparable to the viscosity grades of asphalt cutbacks and asphalt cement as shown in table 15-2.

USE OF BITUMINOUS MATERIALS

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 usually used in warm weather, and lighter grades in cold weather.

Asphalt Cement

Asphalt cement is the most satisfactory type of bitumen for pavements. It is a semisolid at room temperature of 77°F. To make it fluid enough for mixing with aggregate or for spraying, asphalt cement must be heated to a temperature ranging from 250°F to 350°F, depending upon the grade of the asphalt cement used. A disadvantage of asphalt cement is that adequate heating equipment may not always be available. The various penetration grades are suitable for different uses, including plant mixes, penetration macadam, and surface treatment.

Asphalt Cutbacks

Different types and grades of asphalt cutbacks may be used with various climatic conditions for different types of pavement. The cutterstock evaporates, leaving asphalt cement as the active binding and waterproofing agent. Prevailing atmospheric temperature during construction is a factor that must be considered in selecting the grade of asphalt cutback. Lighter grades are usually used in cool weather. If the preferred grade of a given type of asphalt cutback is not available, a comparable grade of another type may be substituted. For example, RC-800 may be used instead of MC-800, or RC-70 instead of MC-70, without seriously affecting the finished pavement. Light grades of asphalt cutback may be produced in the field by adding solvents to asphalt cutback. The composition of asphalt cutbacks, expressed in percent of total volume, is shown in table 15-3.

Asphalt Emulsions

The mixing grades of asphalt emulsions can be mixed with damp aggregate with little or no heating. Recommended usage is dependent on the setting rate and mixing ability. Emulsions are used for surface treatment, for roads and plant mixes, and for crack and joint filling.

Paving Tars

Tars do not strip easily from the aggregate in the presence of water, they are preferred for prime coats. Because they will not dissolve in petroleum distillates, tars are also suitable for use on areas where asphalt is unsuitable, such as

Table 15-3.—Asphalt Cutback Composition (Expressed in Percent of Total Volume)

Type	Components		Grades				
		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

82.213

on a refueling apron of an airfield where petroleum distillates are likely to be spilled. In addition, tars penetrate more deeply into the base course than asphalt of the same viscosity and curing rate. Cold tar mixes are used for road mix and patching; hot tar mixes for plant mix, surface treatment, penetration macadam, crack-fillers, and similar uses. Road tar cutbacks are used for patching mixes. Because they are flammable, an open flame must not be used near storage tanks and drums. Extreme consistency variation as a result of average temperature changes limits the use of tars in comparison to the wider use of asphalts. Tars become soft at high temperatures, and brittle at low temperatures.

FIELD IDENTIFICATION OF BITUMENS

Bituminous materials are often found stockpiled in unmarked or incorrectly marked containers. Fairly accurate identification is necessary to decide on the type of construction, the method of construction, the type and quantity of equipment, and applicable safety regulations. Field tests must be performed to identify the bituminous material as asphalt cement, asphalt cutback, asphalt emulsion, road tar, or road tar cutback, and to identify the grade. Field identify the grade. Field identification of bitumens is summarized in figure 15-1. Field tests are discussed in the following sections.

Solubility Tests

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 simple solubility test. To perform the test, 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 is usually available to the EA in the field. Since asphalt is derived from petroleum, it will dissolve in the petroleum distillate. If 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 consist of a dark, uniform liquid. If it is a road tar, the sample will be a dark, stringy, undissolved mass in the distillate. A check can be made by spotting a piece of paper or cloth with the mix. The solubility test provides a positive method of identification. See figure 15-1 for clarification.

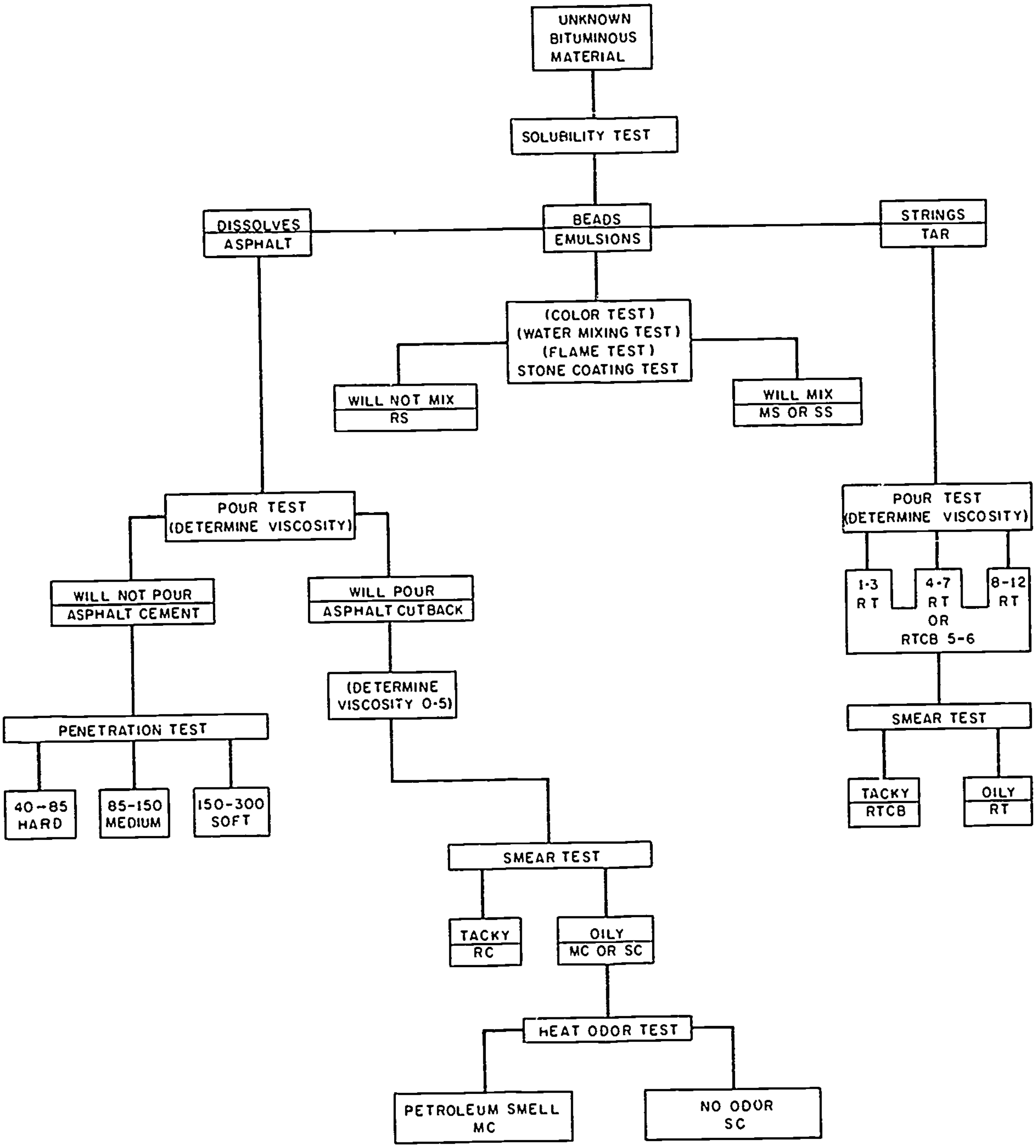
Tests for Asphalt Cement

After the bituminous material has been identified as an asphalt, a POUR TEST is used to distinguish asphalt cement from asphalt cutback. To perform this test, a small sample of asphalt is placed in a container at room temperature of 77°F. Asphalt cement is a solid at room temperature, and will not pour. Even the highest penetration grade (200 to 300) will not pour or immediately deform. At 77°F, even the thickest asphalt cutback will commence to pour in 13 seconds.

The various grades of asphalt cement are distinguished principally by their hardness, as measured by a FIELD PENETRATION TEST. For purposes of field identification, the consistency of asphalt cement may be 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. An approximation of the hardness may be made 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 grade or soft.

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 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 "cutback" with a petroleum distillate to make it more fluid. If the material doesn't pour, it is an asphalt cement. If



82.205

Figure 15-1.–Field identification of unknown bituminous materials.

it pours, it is a cutback or emulsion. If it is soluble or dilutable in water, it is an emulsion. It has been found that the cutbacks will pour like the following:

Viscosity in the	30's –	water
"	70's -	light syrup
"	250's –	syrup
"	800's –	molasses
"	3000's	barely deform

A SMEAR test is used to separate an RC from an MC or SC. The smear test is primarily based on the fact that RCs are cutback with a very volatile material (naphtha or gasoline). It is possible to tell whether a sample is an RC or not by smearing some of it in a thin layer on a non-absorbent surface, such as a piece of glazed paper. This will give the volatiles a chance to evaporate. In fact, volatiles will leave an RC within a few minutes. The surface will become extremely tacky–sufficiently so that the specimen, paper and all, will stick to the fingers and be lifted into the air if touched. This is not so for MCs or SCs, which remain fluid and oily for some time, for hours or days in some cases, depending upon the type and grade of the material. If a 4 or 5 grade MC is present, though, it too may become sticky in a few minutes since there is already such a small amount of cutter-stock in it. If such a viscous grade is present, it is well to confirm the identification of the sample by a prolonged smear test.

A PROLONGED SMEAR TEST is used to distinguish the more viscous grades 4 and 5 of the rapid-curing asphalt from the medium-curing and slow-curing grades. To perform this test, a thin smear of asphalt cutback is placed on a non-absorbent surface and allowed to cure completely RC-4 will cure in approximately 6 hours; RC-5 in about 3 hours. Medium- and slow-curing grades 4 and 5 will remain uncured, or sticky, even after a 24-hour period.

HEAT-ODOR TEST is used to distinguish between medium-curing and slow-curing asphalt cutback by identifying the cutterstock as kerosene, fuel oil, or diesel oil. A sample of the material is heated in a closed container to retain the vapors. (Care should be taken to avoid the use of too much heat.) Medium-curing asphalt cutback will have a strong odor of kerosene. Slow-curing asphalt cutback will lack the kerosene odor, but a faint odor of motor oil may be present.

Tests for Asphalt Emulsions

Asphalt emulsions may be identified by their dark brown color, in contrast to the black color of bituminous materials. Types of asphalt emulsions, grades of viscosity, and mixing quantities were discussed earlier.

Another test used is the WATER-MIXING TEST. Because emulsions are made with water, more water may be added to emulsions without disturbing the uniformity of the liquid. None of the other bituminous materials will dissolve in water.

A FLAME TEST also is used in testing asphalt emulsions. A cloth saturated with asphalt emulsion will smolder, but will not burn or burst into flame. Other bituminous materials are combustible.

A test known as the STONE-COATING TEST is used to distinguish the non-mixing type (rapid-setting) emulsion from the mixing type (the medium- and slow-setting emulsions). This test will give positive results in the field where large quantities may be used. The stone-coating test consists of adding damp sand to a sample of the emulsion to test the mixing quality of the emulsion. A rapid-setting emulsion breaks, or separates, too quickly to mix with the sand. A medium- or slow-setting emulsion mixes easily with the sand and completely coats all of the particles. Identification of an emulsion merely as a mixing or nonmixing type is sufficient for field conditions. Difference in viscosity is unimportant because there are so few grades. No distinction is necessary between medium- and slow-setting emulsions because both are mixing types used largely for the same purpose.

Tests for Tars

A POUR TEST is used to identify the 12 viscosity grades of tar. Viscosity grades of road tars are comparable to the viscosity grades of asphalt cutbacks and asphalt cement as shown in table 15-2. RT-1, the most fluid, is similar in viscosity to the 30 grades of the rapid-curing, medium-curing, and slow-curing types of asphalt cutbacks. RT-8 is similar to grade 800 asphalt cutback. RT-12 has the approximate consistency of asphalt cement of 200-300 penetration.

A SMEAR TEST also is used for road tar. Road tar, grades 4, 5, 6, and 7, which are identical in appearance to road tar cutback grades 5 and 6, may be distinguished by use of the smear test. Like rapid-curing asphalt cutbacks, road tar cutbacks are thinned with highly volatile materials, which will 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.

LABORATORY TESTS OF BITUMENS

In addition to field tests, various tests are conducted on bituminous materials in the laboratory. These tests usually are made for the purpose of checking compliance with established specifications. However, laboratory tests may also be made to identify the material beyond field identification, to furnish information for mix design, or to establish safe handling procedures.

In regard to specifications, note that bituminous materials are manufactured to meet specifications established by the Federal Government, American Association of State Highway Officials (AASHO), and American Society for Testing 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 which the EA should be able to perform in the laboratory are discussed below.

Identification Tests

There is a "laboratory identification kit" for bitumens, consisting of a number of jars containing samples of bitumens in all the recognized categories. To use this kit, bring an unidentified sample to approximately the same temperature as the kit samples, and then make identification on the basis of similarity of color, feel, consistency, and odor, following instructions that come with the kit.

A bituminous material suitable for use in pavement has a considerably higher "ductility" (which may be roughly defined as "stretchability") than one which 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 sample lies somewhere in the pavement-material category.

Distillation Test

If the unknown bitumen proves to be an asphalt, and it has an odor which 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, while the basis for SC is not asphaltic cement, but an asphalt residual oil too fluid to be penetration-tested for grade.

However, RC, MC, and SC all contain a distillate—that is, a volatile (subject to evaporation) liquid which evaporates during the curing process. For RC and MC the distillate is highly volatile (quick-evaporating); for SC it is considerably less volatile.

Now, 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, running about as follows:

Grade	30	70	250	800	3000
Percentage Bitumen	54	64	74	82	86

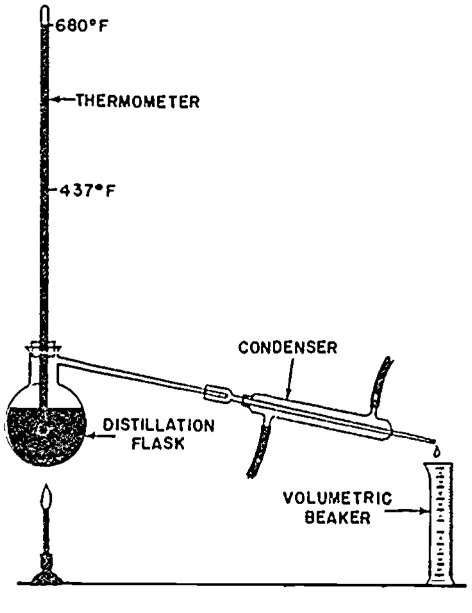
These figures mean that for MC-30 (for example), the percentage of bitumen is 54—the percentage of distillate being determinable, of course, by subtracting the percentage of bitumen from 100.

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 hence whether the material is SC or whether it is either 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 15-2 shows the apparatus used in distillation testing. A measured (by volume) quantity of the bitumen is placed in a "distillation flask," the flask having 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 (which is 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° to 680°F, for RC asphalt cutbacks; from 437° to 680°F, for MC; and only at 680°F, for SC. Road tars are distilled at temperatures which range from 338° to 572°F, and tar-rubber blends from 170° to 355°F. The amount distilled is expressed as a percentage of the total. The residue is then the difference



45.564
Figure 15-2.—Apparatus for distillation testing.

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 50 percent when RC and MC cutbacks and tars are heated to the higher temperatures.

The volume of bitumen remaining in the flask is recorded. This residue is subjected to the penetration test described later—provided it is solid enough to be thus tested. If it is solid enough for this, 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 either RC or MC. If it is not solid enough for penetration testing, the original material was SC.

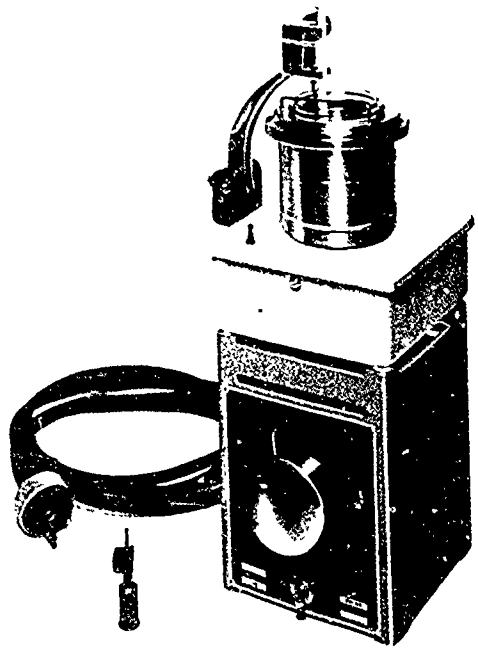
Finally, the grade can be determined by calculating the percentage of bitumen and comparing with the ranges previously given.

Flash Point Tests

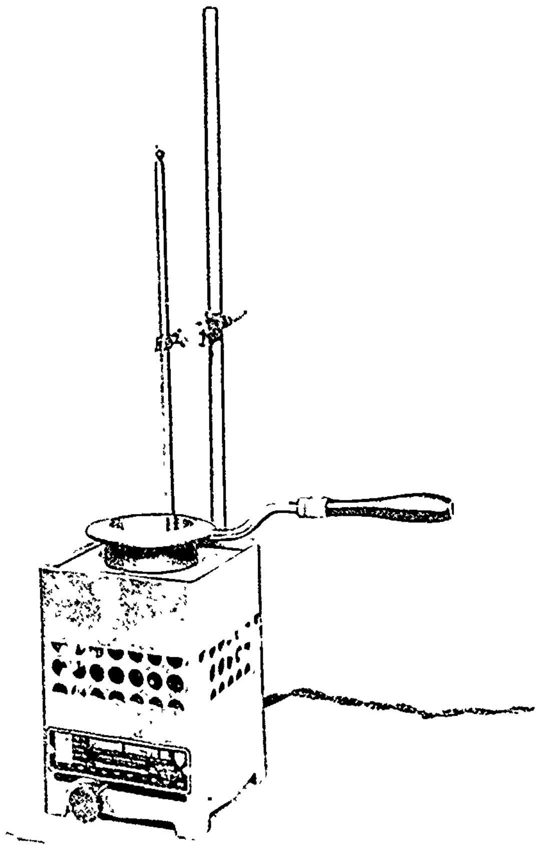
The "flash point" of a bitumen which contains a volatile distillate is the temperature at which it begins to give off ignitable vapor. The principle purpose of flash point tests is to determine maximum safe mixing and applying temperatures. However, these tests are an aid to identification as well. RC 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 15-3. About half a pint of the material is placed in a glass "sample cup," which is in turn placed in a copper "water bath." The test procedure is as follows:

1. Fill the water bath, set the glass cup in place, and clamp the thermometer with bowl 1/4 in. from the bottom of the cup.
2. Fill the cup with material to a line 5/16 in. from the top.
3. Increase the temperature at about 2°F per minute.
4. As the temperature nears 150°F, pass a "test flame" over the surface of the sample. A small alcohol torch is used for this purpose, adjusted to a flame about 5/32 in. in diameter. The flame is passed at every 5°F rise in temperature. The flash point is reached when



45.566
Figure 15-3.–Tag open-cup flash point tester.



45.565
Figure 15-4.–Cleveland open-cup apparatus for flash point test.

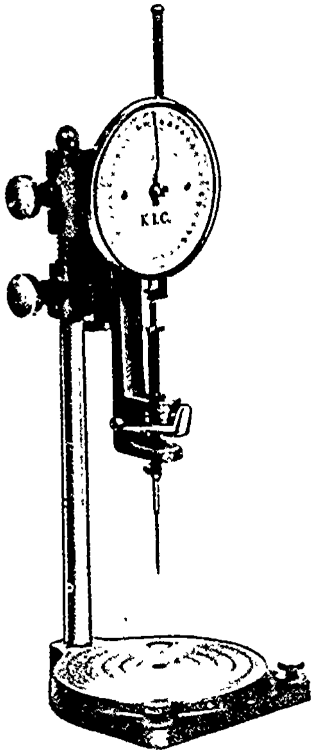
the test flame raises a distinct flash on the surface of the material.

Testing for a flash point above 175°F is done with the "Cleveland open-cup" apparatus shown in figure 15-4. The test procedure is as follows:

1. Heat about half a pint of the sample, in a frying pan or similar container, to a temperature between 300°F and 350°F.
2. Remove the frying pan from the hot plate, set the "open cup" (frying-pan-like container) shown in figure 15-4 in its place, and clamp the thermometer with bulb 1/4 in. from the bottom of the cup.
3. Fill the open cup exactly to the line with the heated sample from the frying pan.
4. Raise the temperature at a rate of not more than 30°F per minute until a temperature about 100°F below the estimated flash point is reached. From then on, slow down the rate of temperature increase, so that the last 50°F rise before the flash point is made at a rate of between 9°F and 11°F per minute.
5. As the temperature nears the estimated flash point, pass the test flame as previously described.

Penetration Test

Figure 15-5 shows an asphalt "penetrometer," used to determine the grade of an asphalt cement. The needle can be brought to contact with the surface of the sample, then released so



45.567

Figure 15-5.—Asphalt penetrometer.

as to exert a pressure of 100 grams. Five seconds after the needle is released the distance it penetrated is read, to the nearest 0.01 centimeter, on the penetrometer dial.

Standard conditions for the test are 100 grams pressure on the needle, a 5-second interval, and a temperature of 77°F for the sample. Besides the penetrometer, test equipment includes a water bath, in which the box containing the sample is placed to bring the sample temperature as close as possible to 77°F, a hot plate for melting the sample, a circular can about 2 in. diameter x 1 7/8 in. high for containing the sample, and a stop watch for timing the 5-second interval.

Steps in the penetration test are as follows.

1. Melt the sample in a frying pan or similar container, at the lowest temperature at which melting can be achieved.

2. Fill the cylindrical can with sample to a depth of not less than 3/8 inch for the harder grades, and 5/8 inch for the softer grades. The sample is protected from dust and allowed to cool for at least 1 hour in a room temperature of not less than 65°F.

3. With the water bath temperature maintained at 77°F, immerse the sample can in the water bath for at least 1 hour.

4. Place the can on the penetrometer stand, and bring the needle point into exact contact with the surface of the sample. This can be done by carefully joining the needle point with its reflection on the surface.

5. Bring the dial reading to zero if the dial can be so adjusted; otherwise, take the dial reading.

6. Test at least three points on the surface not less than 3/8 inch from the side of the container and not less than 3/8 inch apart.

The reported penetration is the average of at least three tests whose values do not differ more than four points between maximum and minimum.

TESTS ON AGGREGATE

The quality and grain distribution of the aggregate in a paving mix have a large effect on the quality of the resulting pavement. What might be called the mechanics of pavement structure may be explained as follows. The larger coarse aggregate particles are the main structural members of the pavement. If there were nothing but large particles, however, there would be many unfilled "voids" between adjacent particles. The fewer voids there are, the more dense, and therefore the more durable, the pavement will be. Ideal density would be obtained by filling the voids between the largest particles with smaller particles, the voids between these with still smaller particles, and so on, right down through the whole range of sizes from coarsest to finest. At the same time it would be necessary to ensure that just enough of each particle size was included in the mix to fill voids between larger-size particles, because a superfluity or shortage of any size would have an adverse effect on density.

Besides being ideal from the standpoint of density, this ideal gradation would have the advantage of presenting the maximum number of particle surfaces for coating by the binder. The function of the binder is simply to bind aggregate particles to adjacent aggregate particles. The more numerous these "binds" are, the more solidly the whole mass is bound together.

The EA must be able to perform a number of tests on aggregates to determine their acceptability for bituminous construction. One test is the grain size distribution test, which is made by sieve analysis using the same procedure as described for soil in chapter 14 of this text. A test for mineral filler and a specific gravity test also are needed; instructions to follow in conducting both these tests are given below.

Test for Mineral Filler (Superfine)

If the aggregate contains more than a specified maximum percentage of mineral filler, it must be cleared of this by washing. For the mineral filler test on aggregate with a maximum particle size of 1 1/2 in., a sample weighing about 5,000 grams is required. For a maximum particle size of 3/4 in., about 2500 grams is required. For a maximum particle size of 1/4 in., about 500 grams is required.

Equipment for the mineral filler test includes two testing sieves, No. 40 and No. 200, two pie plates or similar containers, an oven for drying; and a 2,000-gram weighing balance.

Steps in the mineral filler test are as follows:

1. Oven-dry the sample and record the ovendry weight.
2. Place the sample in a pie plate and cover it with water.
3. Agitate the sample in the water until all the mineral filler is washed clear of the larger particles.
4. Place the No. 40 sieve atop the No. 200, place the sieve pan below, and pour the wash water and sample onto the No. 40 sieve.
5. Pour out what is caught in the sieve pan, fill the pan with clean water, and pour this over the material still in the sieves. Repeat this process until nothing but clean water is caught in the sieve pan. All the material left on the sieves is now larger than mineral filler, and all the mineral filler, has been discarded.
6. Brush all the retained aggregate carefully onto a clean, smooth, hard surface, and thence into the original moisture can in which the original sample was oven-dried.
7. Ovendry the retained aggregate and record the ovendry weight. Compute the percentage of mineral filler in the original sample by dividing 100 times the difference between the original and the washed ovendry weight by the original ovendry weight. In formula form, it appears thusly:

$$\text{Percent finer than No. 200} = \frac{100\,(W_o - W_w)}{W_o}$$

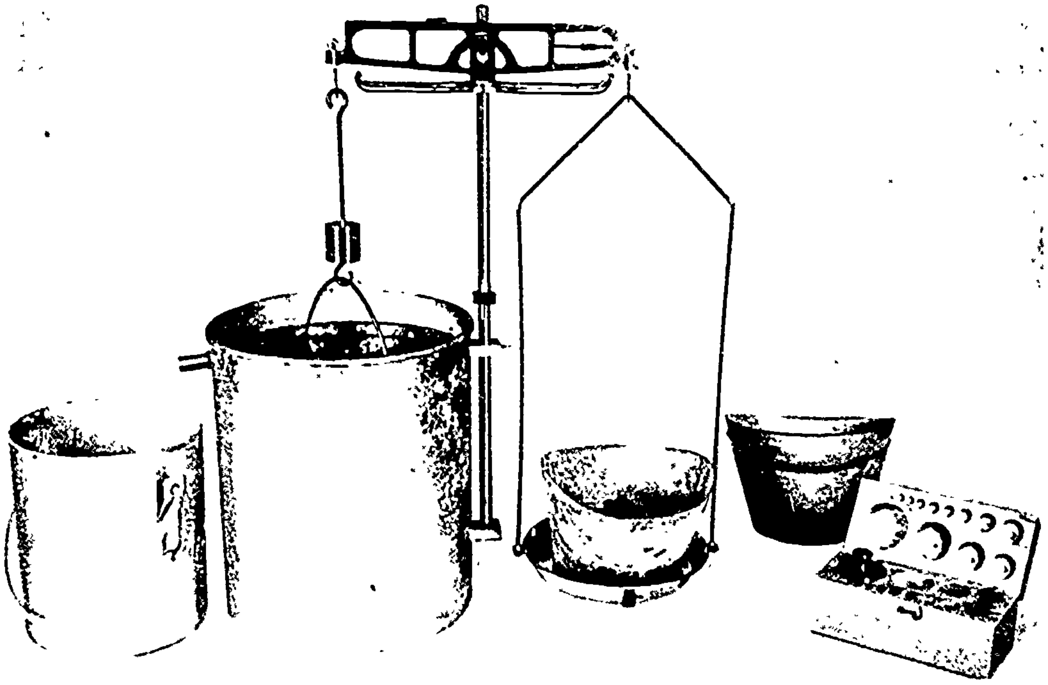
Where: W_o = Original dry weight
W_w = Washed dry weight

Specific Gravity Test

The specific gravities of aggregates used in bituminous paving mixtures are required in the computation of the percent of air voids and percent 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 which are permeable to water. Bulk-impregnated specific gravity is used for aggregate blends with 2 1/2 percent or greater water absorption.

The apparent specific gravity of aggregate, fine enough to pass the 3/8-in. sieve, is determined by the flash method previously described for soil (chapter 14). For larger aggregate, the "apparent" specific gravity is obtained by the procedure about to be described. If the sample contains particles both coarser and finer than the 3/8-in. sieve size, the material which will pass the 3/8-in. sieve is sifted out and tested separately by the flask method, while the coarser material is tested by the "Dunagan" method.

Figure 15-6 shows the Dunagan apparatus. It includes a balance scale having a weight scoop on one arm and a perforated, colander-like container for the sample on the other. The perforated container can be placed inside a larger bucket, as shown. The step-by-step test procedure is as follows:



45.568

Figure 15-6.—Dunagan apparatus for specific gravity test.

1. Approximately 5,000 grams of aggregate is selected from the sample, not including particles smaller than 3/8-in. sieve.

2. The aggregate is washed to remove any dust or other coating and dried to constant weight in the oven. The total weight of ovendry aggregate is recorded on the data sheet, as illustrated in figure 15-7.

3. The aggregate is immersed in water at 15° to 25°C, for a period of 24 hours.

4. After soaking, the sample is placed in the bucket which is filled with water, and bucket and aggregate are then turned sharply back and forth to assist in removing any air.

5. The bucket is suspended from the brass hanger and the water level brought up to the overflow pipe.

6. The submerged weight is determined using weights placed in the scoop on the right-hand pan. Weights are recorded in the appropriate spaces on the form. The calculations required for the determination of the apparent specific gravity of coarse aggregate are shown on the form and are self-explanatory.

MIX DESIGN TESTS

Bituminous pavement mix design tests are tests carried out on samples mixed and compacted in the laboratory to determine the optimum bitumen content and the optimum aggregate content and gradation required to produce a pavement which will meet given quality specifications. Mixes with various bitumen contents and various 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 only give a general description of more or less typical procedures.

Section 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 5 contents: 2

SPECIFIC GRAVITY OF BITUMINOUS MIX COMPONENTS		DATE 19 JUNE 73		
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 = (Line 1)/(Line 3)	378.3/137.3 = 2.755			
FINE AGGREGATE	UNITS (Grams)			
MATERIAL PASSING NUMBER 3/8" SIEVE				
SAMPLE NUMBER	FRB5			
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) A. McMurray	COMPUTED BY (Signature)	CHECKED BY (Signature) Arthur Price		

82.206

Figure 15-7.—Data sheet, specific gravity of bituminous mix components.

above, 2 below, and 1 at a content estimated to be about right Bitumen content is expressed in terms of the percentage of bitumen by weight to the total weight of the mix. Percentages commonly run from about 3 to about 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, trial percentages for "test blends" can be determined by design engineers, and test blends are made with these trial percentages. Again a sieve analysis is made, this time to determine the "combined gradation for blend," as shown in figure 15-8.

The explanation of this figure is as follows. The aggregate here was first sifted into four categories. "coarse," "fine," "fine river bar sand (FRB)," and "limestone dust (LSD)," the last being a commonly used mineral filler. All of the coarse consisted of material which would not pass the No. 8 sieve, 89.5 percent of the fine consisted of material which would not pass the No. 80 sieve, and 90 percent of the FRB consisted of material which 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 thus 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 which would exist in pavements made with the aggregate used in various combinations. Percentages which would minimize void percentage were estimated.

For trial blend No. 1 these percentages are listed under "percent used." The percentages are 27 coarse, 63 fine, 8 FRB, 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 which met the specifications for the pavement, this gradation would be specified for the aggregate used in the highway.

Specimen Mixing and Compacting for Testing

Enough aggregate blend for two specimens (about 3000 grams) is thoroughly mixed and heated to desired mixing temperature. The aggregate blend is troughed, and the test amount of bitumen is heated to mixing temperature and poured into the trough. The aggregate and bitumen are then thoroughly mixed together, using a mechanical mixer if one is available. After mixing, the mix is placed in a compaction mold and compacted with a tamper, the number of blows being the number required to produce the density which will be attained under the traffic for which the pavement is being designed. NAVFAC DM-5, *Civil Engineering*, specifies 50 blows for secondary roads, 75 blows for primary roads. Seventy-five blows produce the equivalent of a tire pressure of 200 psi, 50 blows the equivalent of a tire pressure of 100 psi. After compaction, the mold is placed in a bearing-ratio jack and the compacted sample is extracted with extraction equipment.

Density and Voids Determination

The density–that is, the unit weight in lbs per cu ft–of the specimen is determined by multiplying the specific gravity of the specimen by 62.4 lbs (weight of 1 cu ft of water). The first test on a compacted specimen, then, is a specific gravity test by the Dunagan apparatus. The void percentage is computed on the basis of the specific gravity of the blend and the specific gravity of each aggregate fraction used in multiplying the specific gravity of the specimen by 62.4 lbs (weight of 1 cu ft of water). The first test on a compacted specimen, then, is a specific gravity test by the Dunagan apparatus. The void percentage is computed on the basis of the

BITUMINOUS MIX DESIGN
AGGREGATE BLENDING

DATE 29 Aug 19–

PROJECT Highway #203 | JOB # 47326

GRADATION OF MATERIAL

SIEVE SIZE	PER CENT USED	1	3/4	1/2	3/8	4	8	20	40	80	200
Coarse	100		100	70.0	34.5	3.0					
Fine	100			100.0	99.8	90.0	66.0	43.0	27.0	10.5	3.0
FRB	100							100.0	99.0	80.0	10.0
LSD	100								100.0	99.0	90.0

COMBINED GRADATION FOR BLEND – TRIAL NUMBER 1

SIEVE SIZE	PER CENT USED	1	3/4	1/2	3/8	4	8	20	40	80	200
Coarse	27.0		27.0	18.9	9.3	0.8					
Fine	63.0		63.0	63.0	62.9	56.7	41.6	27.1	17.0	6.6	1.9
FRB	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	PER CENT USED	SIEVE SIZE* – PER CENT PASSING									
BLEND											
DESIRED											

REMARKS (Continue on reverse side)

SEE REVERSE SIDE

45.569

Figure 15-8.—Data sheet for aggregate gradation of trial blends.

specific gravity of the blend and the specific gravity of each aggregate fraction used in the blend. The computational procedure is shown in figure 15-9.

Stability and Flow Determination

Apparatus used for testing "stability" and "flow" of the specimen is shown in figure 15-10.

TEST RESULTS OF BITUMINOUS MIX BY MARSHALL STABILITY METHOD — DATE: 1 Sept 19 –

DESCRIPTION OF MIX AND/OR JOB: Job No. 47326
27% Sample #7328, 63.0% Sample #6720
8% Sample #7334, 20% Sample #6814
AC Sample #6875

DESCRIPTION OF BINDER: TYPE AC; W_b = 5.0 %; G_b = 1.04

SPECIMEN TEST VALUES				
SPEC. NUMBER	WEIGHT IN AIR (a)	WEIGHT IN WATER (b)	PROVING RING DIAL READING	LOAD (lb)
1	1477.6	878.3	.0235	2505
2	1492.5	881.6	.0224	24.5
AVE.	1485.1	879.9	.0230	2455

COMPUTATIONS FOR 3000 GM. BATCH

AGGREGATE FRACTION	% OF AGGREGATE	% OF MIX	SPECIFIC GRAVITY	% OF MIX / SPECIFIC GRAVITY	FRACTION WEIGHT (gm.)
3/4 TO #4	27.0	25.65 $= W_1$	2.738 $= G_1$	9.34	769
1/2 TO –	63.0	59.85 $= W_2$	2.695 $= G_2$	22.20	1796
20 TO –	8.0	7.60 $= W_3$	2.768 $= G_3$	2.74	228
40 TO –	2.0	1.90 $= W_4$	2.861 $= G_4$	0.65	57
TO		$= W_5$	$= G_5$		
BINDER		5.0 $= W_b$	1.04 $= G_b$	4.81	150
		(100% TOTAL)		TOTAL 39.74	3000 GM. TOTAL

DEFINITION OF SYMBOLS

G_1 - Specific gravity of aggregate #1
G_2 - Specific gravity of aggregate #2
G_b - Specific gravity of binder
G_m - Specific gravity of compacted mix
G_t - Theoretical max. sp. gr. of mix (assuming zero voids)
S_b - Percent binder by volume
U_t - Unit weight of mix in pounds per cubic foot
V_f - Percent voids filled with binder
W_1 - Percent of mix composed of aggregate #1, by weight
W_2 - Percent of mix composed of aggregate #2, by weight
W_b - Percent of Mix composed of Binder, by weight
S_t - Percent Solids in total Mix
V_a - Percent voids in aggregate
V_t - Percent voids in total mix
% of Mix = % of aggregate (100 - W_b)

STABILITY (Load (lbs) x correlation ratio)

2455 x .96 = 2360 lb

FLOW (Final value - initial value) (.01 in.)

.46 - .29 = .17   17

UNIT WEIGHT TOTAL MIX, $U_t = 62.4 \times G_m$ (lbs/cu. ft.)

(1) $G_m = \frac{a}{a-b} = \frac{1485.1}{1485.1 - 879.9} = 2.46$

(2) $U_t = 62.4 \times G_m = 2.46 \times 62.4 = 153.5\ lb/ft^3$

% VOIDS TOTAL MIX, $V_t = 100 - S_t$

(1) $S_t = 100 \times G_m / G_t = \frac{100 \times 2.46}{2.52} = 97.6\%$

$G_t = \frac{100}{\frac{W_1}{G_1} + \frac{W_2}{G_2} \cdots \frac{W_b}{G_b}} = \frac{100.0}{39.74} = 2.51$

(2) $V_t = 100 - S_t = 100 - 97.6 = 2.4\%$

% VOIDS FILLED WITH BINDER, $V_f = 100\ S_b/V_a$

(1) $S_b = \frac{G_m \times W_b}{G_b} = \frac{2.46 \times 5.0}{1.04} = 11.8\%$

(2) $V_a = S_b + V_t = 11.8 + 2.4 = 14.2\%$

(3) $V_f = 100\ S_b/V_a = \frac{100 \times 11.8}{14.2} = 83.1\%$

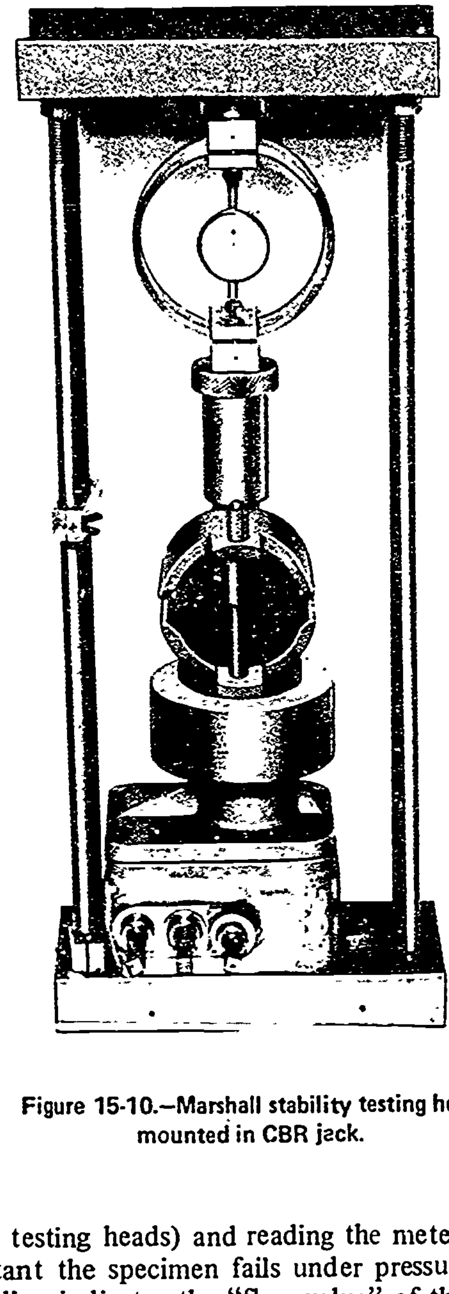
TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
Alexander M. Murray	Alexander M. Murray	Arthur Price

45.571

Figure 15-9.—Data sheet for stability and flow tests.

This figure shows a "Marshall stability testing head" containing the specimen, mounted on the plunger of a bearing-ratio jack. The test head consists of upper and lower "breaking" heads. A 5000-lb proving ring with dial is installed in the jack Test for stability is made by applying pressure gradually, about 2 in. per minute, and reading the maximum pressure the specimen sustains before failing.

Test for "flow" is carried out simultaneously, by holding a "flow meter" over the testing head "guide rod" (vertical rod shown running through



45.570

Figure 15-10.—Marshall stability testing head mounted in CBR jack.

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 in.

Sample Mix Design Test Problems

A study of figure 15-9 will show you how test results are applied to produce mix design criteria. Tests were here made on a mix using the aggregate proportions indicated in figure 15-8—that is, 27.0 percent coarse, 63.0 percent fine, 8.0 percent FBR, and 2.0% filler. Asphalt cement, in the proportion of 5.0 percent by weight, was used as the binder.

A 3000-gram batch of aggregate was mixed; first, however, the specific gravity of each separate fraction was determined and listed in the column headed "specific gravity" under "computations for 3000-gm batch." The percentage by weight of each fraction to the total weight was likewise computed. The binder comprised 5.0 percent of the total weight; therefore, the aggregate comprised 95.0 percent. The coarse comprised 27.0 percent by weight of the aggregate; therefore, the coarse comprised 95.0 X 0.27, or 25.65 percent of the total weight. The specific gravity of the binder was determined, as shown.

The total batch was mixed and then divided into two specimens. After compaction, each of these was weighed in the air and weighed submerged. The average air weight was 1485.1 grams; the average submerged weight was 879.9 grams. The specific gravity of the compacted specimen was therefore 1485.1 divided by (1485.1 - 879.9), or 2.46. The density of the mix (that is, the unit weight in lbs per cu ft) was the product of the specific gravity times 62.4, or 2.46 X 62.4, or 153.5 lbs per cu ft.

The average maximum load sustained in the Marshall stability test was 2455 lbs. Note that this is multiplied by a "correlation factor" of 0.96. The standard thickness for a test sample is exactly 2.5 in. If the actual thickness varies from this, a correlation factor must be applied to the load. Tables are available which give factors for various thicknesses. A factor of 0.96 indicates that the actual thickness of the specimen in this case was 2 9/16 in.

The flow value was 17. In the lower righthand part of the sheet you can see how the test data was used to compute the void percentage of the total mix, and the percentage of this void percentage that was filled by the binder.

Job Mix Proportions

Assume that these test results were satisfactory—that is, that 5.0 percent binder, 27 0 percent coarse, 63.0 percent fine, 8.0 percent

FRB, and 2.0 percent filler produced a mix which had satisfactory density and stability and less than the maximum permissibl' void percentage.

In that case, the specifications for aggregate gradation for the job would be as shown beside "blend" under "combined gradation for blend" in figure 15-8. This means that the specifications would state that all of the aggregate must pass the 3/4-in. sieve, 91.9 percent of it must pass the 1/2-in. sieve, and so on. In actual practice, specifications usually state a range, such as from 89 to 92 percent passing the 1/2-in. sieve, and so on.

Now, aggregate is obtained from an "aggregate batching plant," in which aggregate of various particle sizes is stored in bins equipped with apparatus for weighing out required amounts. The aggregate in a particular bin will range between two sizes, such as 3/4–3/8, or 3/8–No. 10. One bin will contain fine–that is, material all of which will pass the No. 8 sieve.

The laboratory aggregate mix formula for the blend must be transposed into a job mix formula which will apply to the available bin sizes. Suppose that this plant has bins with aggregate sizes 3/4–3/8, 3/8–10, and 10–200, with a fourth bin containing limestone dust finer than No. 200.

The specifications indicate that the percentage of aggregate in the 3/4–3/8 range must be (100-82.2), or 17.8 percent. The percentage lying in the 3/8–10 range must be (82.2-51.6), or 30.6 percent. The percentage passing the No. 10 but not the No. 200 must be (51.6-4.5), or 47.1 percent. Only 4.5 percent may consist of material which will pass the No. 200 sieve.

Now, 5.0 percent of the total by weight is to consist of binder. Therefore, the aggregate percentages are percentages of 95 percent, not of 100 percent, of the total. Therefore, the percentage by weight of each batch coming from the 3/4-3/8 bin will be (95.0 X 0.178), or 16.9 percent, the percentage from the 3/8–10 bin will be (95.0 X 0.306), or 29.0 percent, and so on.

PORTLAND CEMENT CONCRETE

Like asphalt concrete, portland cement concrete consists of coarse aggregate, fine aggregate, and a binder. In this case, however, the binder consists of portland cement combined with water. The introduction of water causes a chemical reaction called "hydration" in the cement, and it is the chemical reaction which causes the concrete to harden.

It is essential to remember that the hardening of concrete is a chemical process and not one of "drying out." That drying out is not a factor in the process is indicated by the fact that concrete must be prevented from drying out during hardening, and by the additional fact that it hardens as well under water as it does in the air.

Concrete aggregate is about the same as bituminous aggregate, except for the following differences. For bituminous aggregate, any material which will pass the No. 8 sieve but not the No. 200 sieve is considered fine aggregate, and anything which won't pass the No. 8 is considered coarse. For portland cement concrete, the dividing line between coarse and fine is the No. 4 sieve. For bituminous aggregate, the maximum size of coarse seldom exceeds 3/4 in. For concrete aggregate the maximum size of coarse may be 2 in., 3 in., or (for massive structures like concrete dams) even larger stones.

TYPES OF PORTLAND CEMENT

Portland cement is a manufactured material obtained through the Navy supply system, and that system is responsible for testing it for quality. There are a few things you should know, however, about the most commonly used types of portland cement, as follows:

Type I, or "normal" portland cement, is an all-purpose type, used to make ordinary concrete pavements, buildings, bridges, masonry units, and the like.

Type II, or "modified" portland cement, is a type which generates less heat than Type I during the hardening process. The heat generated in a large mass of concrete during hardening can become great enough to have an adverse effect on the concrete. Type II is also more sulphur-resistant than Type I. Sulphur exists in water or soil having a high alkali content, and sulphur has an adverse effect on concrete.

Type III, or "high early strength" portland cement, is–as the name suggests–cement which hardens more rapidly than the other types. It is used when advancing the time when a structure may be used is desirable.

Type IV, or "low-heat" portland cement, has the heat-resisting quality of type II, but to a higher degree.

Type V, or "sulphate-resistant" portland cement, has the sulphur-resisting quality of type II, but to a higher degree.

You may also encounter white cement, waterproofed cement, and oil well cement. White cement is made from selected materials to prevent coloring, staining or darkening of the finished concrete. Waterproofed cement has water-repellent material added. The finished and set concrete has water-repellent action. Oil well cement is specially made to harden properly when used under high temperature in deep oil wells.

The addition of the letter A to a portland cement type designation indicates that, in addition to the other qualities peculiar to that type, the cement is "air-entraining." This means that it includes an "air-entraining agent" which causes billions of tiny bubbles to form in the mix as hydration proceeds. The presence of these bubbles makes the hardened concrete more resistant to the damage caused by alternate freezing and thawing of the surface, and also more resistant to sulphur. Air-entraining also increases the fluidity of a mix, thus making it more "workable."

The most important factor controlling the strength of concrete is the "water-cement ratio," meaning. the ratio of water to cement in the mix.

The ideal ratio would be the amount of water (and no more) required fully to hydrate the cement. More than this amount would attain less than the maximum possible strength.

However, the ideal amount of water required to attain maximum hydration would for most mixes be less than the amount required to attain minimum workability. Therefore, a mix usually contains more water than would be required simply to hydrate the cement fully. Experimentation has determined tabular values for water-cement ratios for given compressive strengths of concrete (in lbs per sq in.) as shown in Table 15-4.

WATER-CEMENT RATIO

The strength of concrete is usually specified in terms of the compressive strength in lbs per sq in. attained after the mix has hardened for 28 days. Note that 28-day compressive strength decreases as the W-C ratio increases; also that air entrainment causes some reduction in strength. In considering the ratios shown, you must not get the impression that, in order to ensure desirable qualities in a concrete mix, all you need to do is add the given amount of water per sack of cement. In the first place, any free water which is already in the aggregate must be considered. Coarse aggregate may contain little or no free water, but sand is nearly always damp to wet. The amount of free water (if any) in sand must be determined, and an equivalent amount deducted from the quantity of water added to the mix.

Next, a mix must be workable enough to satisfy the job requirements–it must be, for example, fluid enough to fill all forms spaces. Therefore, the amount of water actually put into a mix must be the minimum amount required to attain the required workability–then the amount of cement added must be that which will cause the W-C ratio to be the ratio required to attain specific compressive strength.

Table 15-4.—Values for Water-Cement ratios for Given Compressive Strengths of Concrete (in lbs per sq in.)

Water-cement ratio gals per sack	Nonair-entrained p.s.i.	Air-entrained p.s.i.
4	6000	4800
5	5000	4000
6	4000	3200
7	3200	2600
8	2500	2000
9	2000	1600

82.245

Finally, the climatic conditions to which concrete will be exposed in service have an influence on the optimum W-C ratio. Tables are available which give optimum ratios for various conditions. For example: for concrete pavement laid where climatic conditions are severe (where there is a wide range of temperature, much rain, frequent freezing and thawing, and the like), 5 gals per sack is recommended for thin pavement, 5.5 gals per sack for medium pavement, and 6 gals per sack for thick pavement. For the same pavements under milder climatic conditions, 5.5 gals per sack is recommended for thin, 6 gals per sack for medium, and 7.5 gals per sack for thick.

Generally speaking, the higher the water-cement ratio is, the cheaper the concrete is to make. The basic reason for this is the fact that the cement is the most costly item in a mix. For a batch of aggregate of a given type, there is a minimum amount of water which must be used to make the batch workable. Let's say this is x gallons. If the water-cement ratio is high, x gallons of water won't require much cement. If it is low, x gallons of water will require considerably more cement.

Concrete mixing water must be free of harmful impurities, such as super abundant alkali and salt, decayed vegetable matter, oil, or sewage. Generally speaking, any "potable" (suitable for drinking) water will do.

CONCRETE AGGREGATE TESTS

Concrete aggregate is first tested by sieve analysis to determine the existing gradation (distribution of particle sizes). This is then compared with "desirable" gradation.

Desirable gradations for coarse and fine aggregate for ordinary paving and structural concrete have been worked out as shown in tables 15-5 and 15-6.

Aggregate Gradation Test

Aggregate is gradation-tested to determine (1) the existing particle distribution of the aggregate, and (2) the proportions of existing supply required to approximate desirable gradation. Table 15-7 illustrates the procedure which is followed in aggregate blending.

Here the maximum size of coarse aggregate was 1 1/2 in. Coarse was available in two bins, one containing No. 4 to 3/4-in., the other 3/4-in. to 1 1/2-in. The columns headed "separate sizes individual % retained" show the sieve analyses of these two bin contents—using percentage retained, however, rather than percentage passing.

As a first attempt to attain an approximation of desirable coarse gradation, it was decided to try a blend consisting of 50 percent from the 3/4-in. to 1 1/2-in. bin. The probable aggregate gradation for this blend is worked out in the remainder of the table. Under "50%" for each bin size a figure is placed which is one-half the value of the corresponding figure listed under "separate sizes individual % retained." Under "combined gradation" in the column headed "individual percent retained" a figure is placed which is, except for the 1/2-in. size, the same as the figure listed in the "50%" column. For the

Table 15-5.—Desirable Coarse Aggregate Gradation

Sieve size	Percent passing indicated sieve						
	3	2 1/2	2	1 1/2	1	3/4	1/2
3	100.0						
2 1/2	88.4	100					
2	75.5	85.5	100				
1 1/2	60.9	69.9	80.7	100			
1	43.6	49.4	57.8	71.6	100		
3/4	33.3	37.7	44.1	54.7	76.4	100	
1/2	21.1	23.9	27.9	34.6	48.3	63.3	100
3/8	13.8	15.6	18.3	22.6	31.6	41.4	65.4
No. 4	0	0	0	0	0	0	

82.246

Table 15-6.–Desirable Fine Aggregate Gradation

Sieve No.	Percent Passing
4	100
10	75 - 90
20	40 - 70
40	20 - 50
60	10 - 25
100	3 - 10

82.247

Table 15-7.–Example of Calculations, Aggregate Blending

Sieve size	Separate sizes individual % retained		50%	50%	Combined grading 50–50			Desired grading	
	No. 4 to ¾ in.	¾ to 1½ in.	No. 4 to ¾ in.	¾ to 1½ in.	Individual % ret.	Cumulative % Ret.	Cumulative % Pass.	Individual % ret.	Cumulative % Pass.
1½ in.	----------	----------	----------	----------	----------	----------	100.0	0.0	100.0
1 in.	----------	60.0	----------	30.0	30.0	30.0	70.0	28.4	71.6
¾ in.	----------	36.0	----------	18.0	18.0	48.0	52.0	16.9	54.7
½ in.	34.0	4.0	17.0	2.0	19.0	67.0	33.0	20.1	34.6
⅜ in.	24.0	----------	12.0	----------	12.0	79.0	21.0	13.2	21.4
No. 4	40.0	----------	20.0	----------	20.0	99.0	1.0	21.4	0.0
Pan	2.0	----------	1.0	----------	1.0	100.0	----------	----------	----------
Total-----	100.0	100.0	50.0	50.0	100.0	----------	----------	100.0	----------

82.214

1/2-in. size, it is the sum of the two different figures listed in the "50%" columns.

From the "individual percent retained" column the "cumulative percent retained" for each size is computed. For the 1-in. size, it is 30.0 percent; for the 3/4-in. size, it is the sum of 30.0 + 18.0 or 48.0 percent; for the 1/2-in. size, it is 48.0 + 19.0, or 67.0 percent, and so on. Finally, the percent passing for each size is computed by simply subtracting the cumulative percent retained from 100.0.

The result is a gradation which comes pretty close to the desirable gradation for coarse aggregate with maximum size of 1 1/2 in.

Specific Gravity, Absorption, and Surface Moisture Tests

These tests must be performed on the aggregates before the necessary calculations can be made to design the concrete mixture. In aggregates used in portland cement concrete, measurements are made of the bulk specific gravity with the aggregates in a saturated, surface-dry condition. Specific gravity determinations are thus based upon determinations of the total volume occupied by the aggregate particles, including the permeable pore space. Absorption and surface moisture determinations are necessary to the calculation of the amount of mixing water to be used in concrete mixture.

The following equipment is necessary to perform tests for bulk specific gravity, percent absorption, and surface moisture:

Chapman flask
Concrete test apparatus, Dunagan
Cone pycnometer
Fan, electric
Gloves, lineman's

Mold, cone, water-absorption
Oven, electric
Pan, bake
Rod, tamping, steel, flat-head
Scoop, kitchen
Shovel, square-point
Spatula, 4-inch

The bulk specific gravity of coarse aggregate in a saturated, surface-dry condition is determined as follows:

1 The Dunagan concrete test apparatus is assembled.

2 A representative sample weighing approximately 5,000 grams is secured.

3 The sample is immersed in water and allowed to soak for not less than 24 hours.

4 The sample is removed from the water and rolled in a large, absorbent cloth until all visible films of water are removed, although the surfaces of the particles will still appear to be damp. The larger fragments may be wiped individually.

5. Exactly 2,000 grams of this saturated, surface-dry aggregate is weighed out. To do this, add a 2 kg slotted weight to the left hanger and pour the sample into a scoop on the right-hand pan until balanced. Remove the 2 kg weight and pour the sample into the bucket. Place the spare scoop, clean and dry, on the right-hand pan and balance with weights. This weight is the immersed weight.

6. The bulk specific gravity is calculated as follows:

Bulk specific gravity (saturated, surface-dry conditions) =

$$\frac{2{,}000}{2{,}000\text{-immersed weight}}$$

The test procedure for determining the bulk specific gravity of fine aggregate in a saturated, surface-dry condition is as follows:

1. The Dunagan concrete test apparatus is assembled.

2. A representative sample weighing approximately 3,000 grams is secured.

3. The sample is immersed in water and allowed to soak for 24 hours.

4. At the end of the 24-hour soaking period, the sample is spread on a flat surface and stirred frequently so as to obtain uniform drying. Drying is continued until the sample approaches a moisture-free surface condition.

5. The conical mold is placed large end down on a smooth surface and filled loosely with the aggregate, after which the surface of the aggregate is tamped lightly 25 times with the metal rod.

6. The conical mold is lifted vertically from the sand. If free moisture is present, the cone of fine aggregate will retain its shape.

7. Drying is continued, accompanied by constant stirring, and the cone tests (5) and (6) repeated at frequent intervals until the cone of fine aggregate slumps upon removal of the mold. This indicates that the fine aggregate has reached a surface-dry condition.

8. Exactly 1,000 grams of the saturated, surface-dry sample is weighed out. This may be conveniently done by placing a 1-kg slotted weight on the left hanger and the sample in a scoop in the right-hand side.

9. Using the Dunagan apparatus, the weight in water of this 1,000 grams of saturated, surface-dry sample is obtained immediately. This is recorded as "immersed weight."

10. The specific gravity is calculated as follows.

Bulk specific gravity (saturated, surface-dry)

$$= \frac{1{,}000}{1{,}000\text{-immersed weight}}$$

The test procedure for determining the percent absorption of either coarse or fine aggregate is as follows:

1. Representative samples of the fine and coarse aggregates are secured. The sample of fine aggregate should weigh approximately 500 grams. Coarse aggregate which contains no pieces larger than 1½ inches should be represented by at least 3,000 grams, while coarse aggregate which contains pieces larger than 1½ inches should be represented by at least 5,000 grams.

2. The samples of fine aggregate and coarse aggregate are immersed in water. The fine

aggregate is allowed to soak for 2 hours and the coarse aggregate for at least 24 hours.

3. The samples are dried to a saturated, surface-dry condition, following the methods described in the specific gravity test procedures above.

4. The weights of the samples in a saturated, surface-dry condition are obtained and recorded.

5. The samples are dried to constant weight in the electric oven, maintained at a temperature between 100° and 110°C. (212° and 230°F.).

6. The oven-dry weights of the samples are obtained and recorded.

7. The percent absorption is calculated by the use of the following formula:

$$X = \frac{(SSD-D)}{D} (100)$$

Where:

X = percent absorption by the aggregate,
SSD = weight of saturated, surface-dry sample, grams, and
D = oven-dry weight of sample, grams.

8. The percent absorption represents the moisture content (oven-dry basis) of the fine aggregate when the aggregate is in a saturated, surface-dry condition.

Surface moisture is the water which is present in the fine aggregate, over and above that which corresponds to a saturated, surface-dry condition. This water will become part of the mixing water when the fine aggregate is used in making concrete. The amount of mixing water used must be corrected to allow for its presence. The test described in this paragraph is used only if the total moisture content of the aggregate is greater than the total moisture content corresponding to a saturated, surface-dry condition is the percent absorption. If the bulk specific gravity (saturated, surface-dry) has not been determined previously, this determination is made, using the procedure given above. The test procedure for determining the amount of surface moisture present in fine aggregate is as follows:

1. Exactly 1,000 grams of the sample on which the surface moisture determination is desired is weighed out. The sample will be representative of the condition of the fine aggregate at the time the test is made.

2. Using the Dunagan apparatus, the weight of this 1,000-gram sample immersed in water is obtained. This weight is recorded as (W_2).

3. The amount of surface moisture is calculated from the following formula:

$$SM = (W_1 - W_2)\frac{Sp\ Gr}{Sp\ Gr-1}$$

Where:

SM = grams of surface moisture in sample
W_1 = weight of a 1,000-gram sample of saturated surface-dry material immersed in water (taken from data for bulk specific gravity determination, grams)
W_2 = immersed weight of the 1,000-gram test, sample, (2) above, grams, and
Sp Gr = bulk specific gravity (saturated, surface-dry).

4. The surface moisture expressed as a percent (P_1) of the saturated surface dry weight of fine aggregate is:

$$P_1 = \frac{SM}{1000 - SM} (100)$$

5. The surface moisture expressed as a percent (P_2) of the weight of wet fine aggregate is:

$$P_2 = \frac{SM}{1000}(100)$$

An alternative determination of surface moisture on fine aggregate is obtained by drying completely a sample having known weight of wet fine aggregate, and calculating total moisture as:

$$\text{Total moisture} = \frac{\text{wet weight}-\text{dry weight}}{\text{dry weight}}(100)$$

The absorption, expressed as percent of dry weight, is subtracted from this total moisture to give the surface moisture in percent of dry weight. Drying of this sample is accomplished in an oven maintained at a temperature between 100° and 110°C. (212° and 230°F.) or by placing the sample in a metal pan, pouring alcohol over it, and burning off the alcohol to evaporate the water.

Test for Organic Matter in Sand

An excess of organic matter in sand aggregate will have an adverse effect on concrete. Sand is tested for the presence of organic matter by a color test. Sand which, under test conditions, shows a color darker than standard contains an excess of organic matter.

Figure 15-11 shows color-test equipment. The "color plate" shows the standard colors which sand containing not more than an acceptable amount of organic matter should show. In the absence of a color plate, you can prepare a "reference standard color solution" as follows:

1. Make a 2-percent tannic acid solution by adding 10 milliliters of 190-proof ethyl alcohol and 2 grams of tannic acid powder to 90 milliliters of water. Place in a 12-oz bottle, shake well, and allow to stand for 24 hrs.
2. Make a 3-percent sodium hydroxide solution by dissolving 1 oz of sodium hydroxide in enough water to make 32 fluid oz.
3. Make the reference standard color solution by adding 2.5 milliliters of the tannic acid solution to 97.5 milliliters of the sodium hydroxide solution.

To make the color test, fill a 24-oz graduated bottle to the 4½-oz mark with sample, and add sodium hydroxide solution to bring the level to the 7-oz mark.

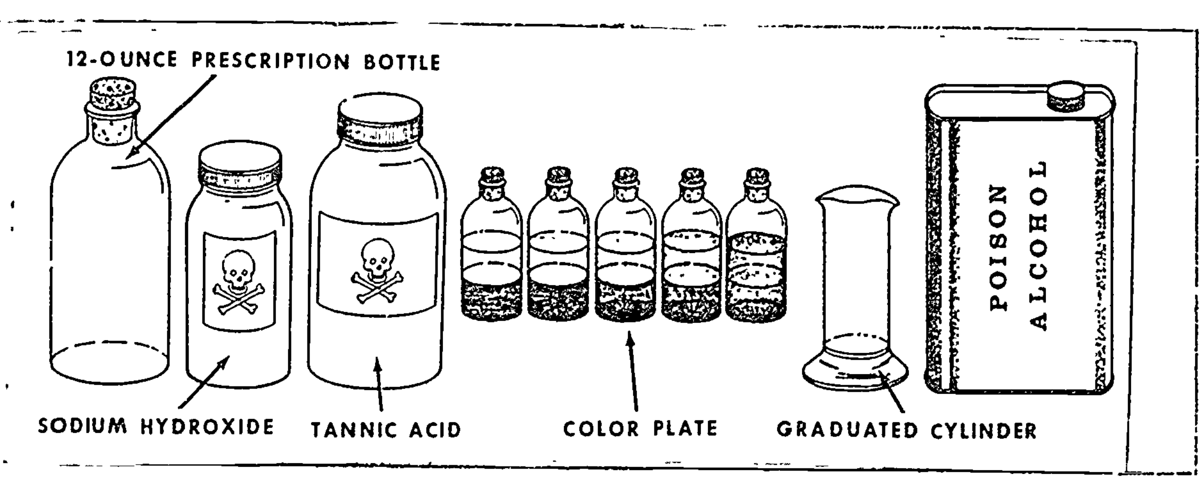
Shake the bottle well, and allow it to stand for 24 hrs. Then compare the color of the solution above the settled sand with the reference color, as indicated by the color plate or by the reference standard color solution.

If the liquid above the sample is darker than the standard color solution, the sand may contain organic impurities which will reduce the strength of the concrete in which the sand is used. A decision may then be made as to whether the sand contains an excessive amount of organic matter.

TESTS FOR SILT AND CLAY

The presence of fine particles of soil and clay can affect the 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). This results in a surface covered by hair cracks and a tendency for the fines to dust off when dry.

In testing for silt and clay, you will need two sieves, No. 16 and No. 200, and a container large enough to hold the sample covered with water.



45.572

Figure 15-11.—Apparatus, color test for organic matter.

The container should allow vigorous shaking without loss of either sample or water.

One method used in testing for silt and clay is given below.

1. Select a representative sample as follows.

Nominal Maximum Sieve Size	Approx. Minimum Weight (KG)
No. 4	0.5
3/4 inch	2.5
1½ inch or larger	5.0

2. Ovendry the sample at 110°C and weigh it.
3. Place the dry material into the container and cover it with water.
4. Agitate the material vigorously to bring the fine portion into suspension.
5. Decant the water and run it through the sieves. Any material retained on the sieves is returned to the sample container.
6. Repeat the operation until the water runs clear.
7. Ovendry the sample at 110°C to a constant weight.
8. Weigh the dry sample and record the weight.

The percent of fines can now be calculated as follows:

$$\text{Percent fines} = \frac{\text{original dry weight} - \text{dry weight after washing} \times 100}{\text{original dry weight}}$$

The maximum amount of fines permitted depends upon the aggregate and the use of the concrete. By way of example, some of the requirements are as follows:

IN SANDS, no more than three percent by weight if concrete is subject to abrasion, and no more than five percent for all other classes.

IN COARSE AGGREGATE, no more than one percent by weight.

The method described above is accurate but time consuming. For a quick and approximately correct determination, an EXPEDIENT test can be made. For this test, a 1,000 gram representative sample is obtained. About 2 inches is placed in a quart mason jar which is then filled three-fourths full with water. The mixture is shaken vigorously and then allowed to stand for 1 hour. The silt and clay layer will form on top of the sand. If the layer is more than 1/8 inch thick, the material has more than three percent fines and should be washed before using.

TESTS FOR SOUNDNESS

Soundness is the property of resisting disintegration. Some aggregates disintegrate when they absorb water and are exposed to a freezing and thawing cycle. Others containing shale can disintegrate under load pressures. One test which will indicate the presence of these materials is the freeze-thaw test.

In the FREEZE-THAW TEST, the aggregate is saturated with water and subjected to freezing and thawing cycles. The amount of breakage is measured to evaluate the soundness of the material.

The freeze-thaw operation requires considerable equipment and has generally been replaced by a simpler one, known as the salt test, which requires less equipment. The SALT TEST uses solutions of special salts in which the aggregate is immersed and saturated. The crystals of these salts are permitted to grow and create a disruption similar to freezing water. The salts used are sodium sulfate (Glauber's salt) and magnesium sulfate (Epsom's salt). The procedure for the salt test follows:

Secure a representative sample. The sample must be separated until the minimum amount is retained on individual sieves as indicated in table 15-8. If there is any indication that there is less than five percent of any sieved size in the entire sample, that size need not be tested for soundness. Instead, the average of the next two immediate sizes can be assumed to be representative of the non-tested size. Table 15-8 lists the minimum amounts of material for the aggregate soundness test.

Immerse the aggregate fractions in saturated solutions of the specified salts for a period of 16 to 18 hours. Ovendry the aggregate at a temperature of 105° to 110°C. Repeat the cycle as specified (generally five cycles are sufficient). Wash the fractions until all the salt is removed.

Table 15-8.–Minimum Amounts of Material for Aggregate Soundness Test

Sieve size	Minimum amount for testing	
Fine aggregate:		
No. 50	100 g.	
No. 30	100 g.	
No. 16	100 g.	
No. 8	100 g.	
No. 4	100 g.	
Coarse aggregate (after all sizes finer than No. 4 are removed):		
No. 4	300 g.	
⅜ in.	1000 g.	⅜ in.–½ in.–33%; ½ in.–¾ in.–67%
¾ in.	1500 g.	¾ in.–1 in.–33%; 1 in.–1½ in.–67%
1½ in	3000 g.	1½ in.–2 in.–50%; 2 in.–2½ in.–50%
Larger sizes (1-inch spread in sieves sizes)	3000 g.	

82.215

Adding 20-30 grams of barium chloride to the wash water will cause a precipitate to form if any salt is left. Dry the washed fractions to a constant weight and place each one, in turn, on its designated sieve. The amount passing the sieve is measured and is called the "loss." It represents the particles that are chipped off during the test. Convert the loss of each fraction into a percentage of the total sample. The report shall include the following information. (1) total weighted loss for the sample, and (2) for particles larger than 3/4-inches, the number of particles before and after the test.

The permissible limits are as follows:

SAND: Total weighted loss not greater than 10 percent if sodium sulfate is used, or 15 percent if magnesium sulfate is used.

COARSE AGGREGATE: Total weighted loss not greater than 12 percent if sodium sulfate is used, or 18 percent if magnesium sulfate is used.

Aggregates failing to meet these r[illegible]rements are rejected unless they pass an ac[illegible] freeze-thaw test.

For example. Fraction tested (passing No. 30–retained No. 50).

Weight at start ------------ 100.0 grams
Weight at end ------------ 95.8 grams
Loss 4.2 grams

$$\text{Percentage loss of fraction} = \frac{4.2 \times 100}{100} = 4.2 \text{ percent}$$

Sieve analysis indicated that this fraction is 26 percent of the total sample. Adjusting fraction loss to total sample is as follows:

Percentage loss (No. 30–No. 50 fraction) of total $= \frac{4.2 \times 26}{100} = 1.09$ percent. This result signifies that 1.09 percent of the sand sample is lost in the No. 30 to No. 50 range. To complete the procedure, all size fraction losses (in percent of total) are added and reported as the soundness test weighted loss.

TEST FOR UNDESIRABLE LIGHTWEIGHT MATERIAL

Soft, laminated pieces of aggregate such as chert or shale are detrimental to concrete. Visual examination of the coarse aggregate will often show these minerals. The amount of these minerals in an aggregate can be determined by immersing the aggregate in a liquid with a specific gravity that will allow the shale and other light particles to float, and the heavier particles to sink. A saturated solution of zinc chloride at room temperature (78°F) has a specific gravity of 1.95. Any liquid with this specific gravity will serve well. Place a portion of the sample, dried to constant weight, into a container partly filled with the heavy liquid. Agitate the mixture five times. Skim off the lighter particles. Separate the liquid and pebbles and repeat the operation. When all the undesirable lightweight material has been removed, wash, dry, and weigh the remaining material. The difference between the final weight and the original dried weight (expressed as a percentage of the total weight) represents the undesirable material in the aggregate.

CONCRETE MIX DESIGN TESTS

Concrete mix design tests are trial tests in which mixes containing various proportions are prepared and tried, to see how close they come to quality specifications for concrete on the job.

Preparation of Mix Design Test Samples

One-fifth of a sack of cement is used for a test batch. A sack contains 94 lbs; therefore, the weight of a test quantity of cement is one-fifth of 94 lbs, or 18.8 lbs. The amount of water used with this will depend on the W-C ratio for the test. Suppose this is 6 gals per sack. If there shall be 6 gals per 94 lbs of cement, it follows that there shall be 1.2 gals-for the 18.8 lbs of cement. Water weighs 8.345 lbs per gal; therefore, the weight of water for the test batch is 10.0 lbs. This weight presumes aggregate is in saturated surface-dry condition. If free water is present, the weight of water added must be reduced accordingly.

Trial mix aggregate proportions are started around those commonly specified in practice. For ordinary concrete, a common specification is proportions by weight of 1:2:3–that is, 1 cement to 2 sand to 3 coarse aggregate. For 18.8 lbs of cement, this would call for (18.8 X 2) or 37 6 lbs of sand, and (18.8 X 3), or 55.6 lbs of coarse aggregate.

Mix Design Data and Calculations

Mix design data and calculations are entered on a sheet like the one shown in figure 15-12. Here type II portland cement was used, together with sand aggregate, and coarse aggregate of which 50% was in the 3/4-in. to No. 4 range and 50% in the 1½-in. to 3/4-in. range. Bulk specific gravity of the cement and aggregate, and absorption percentage of the aggregate, were determined by the processes previously described and set down under "materials." The type II cement was made air-entraining by the addition of an air-entraining admixture, neutralized vinsoll resin (NVR solution), to the amount of 0.01 percent of the weight of cement.

The ingredients are listed by weight under "mixture by weight," by a system in which the weight of the cement in the trial batch is given a value of 1.00. This 1.00 represents 18.8 lbs. The weight of the water was 53 percent of 18.8 lbs, or just about 10.0 lbs–which implies a W-C ratio of 6 gals per sack. The trial-batch weights of the fine aggregate and of coarse aggregate A and coarse aggregate B can be similarly computed.

The trial batch weights, each multiplied by 5 (for a one-fifth-bag batch), are set down under "net weights 1-bag batch," as shown in figure 15-12. In the next column, under "solid volume 1-bag batch," the actual volume of concrete each ingredient will produce (including the volume of air-entrained bubbles), computed as explained later, is set down. The "total" below (4.712 cu ft) is the "yield" for a 1-bag batch.

The solid volume which each ingredient in the 1-bag batch will contribute is obtained by the "unit weight solid" of the ingredient. The unit weight solid is obtained by multiplying the specific gravity of each ingredient by 62.43 lbs (weight of 1 cu ft of water). The specific gravity of portland cement is known to be 3.15. Therefore, the unit weight solid of portland cement is (3.15 X 62.43), or 196.65 lbs per cu ft, and the solid volume of a 94-lb sack is 94 divided by 196.65, or 0.478 cu ft. You can see this value listed in the column headed "solid volume 1-bag batch."

Thus, a sack of cement, which has a loose or void volume of 1 cu ft, has a "solid volume" of only 0.478 cu ft, and contributes only this amount to the volume of mixed concrete. The solid volumes of the other ingredients are computed in the same way, using the predetermined specific gravities of the aggregate. Because the specific gravity of water is 1, the solid volume of the water can be obtained simply by dividing the net weight of the water by 62.43.

With regard to the volume contributed by air-entrained air bubbles, apparatus is available for determining the percentage of air content of an air-entrained mix. For this mix, a percentage of 4.6 percent is listed. The volume which air bubbles will contribute to a 1-bag mix can be determined by the following formula.

$$\text{Air volume} = \frac{100 \times \text{solid volume}}{100 - \text{air percentage}} - \text{solid volume.}$$

The solid volume of 1-bag ingredients is 4.497 cu ft; the air percentage is 4.600%. Substituting the values, we have:

$$\text{Air volume} = \frac{100 \times 4.497}{100 - 4.600} - 4.497 = 0.215 \text{ cu ft.}$$

CONCRETE MIXTURE DESIGN DATA DATE 30 Sept-19—

PROJECT #1375 — JOB B-32

PORTLAND CEMENT		OTHER ADMIXTURE	AIR-ENT ADMIXTURE	
TYPE II	ADDITIONS	TYPE None	TYPE	AMOUNT[1]
BRAND & MILL Universal		SOURCE	NVR Solution	0.01%

FINE AGGREGATE	COARSE AGGREGATE	
TYPE Mfg. Sand, Trap Rock	TYPE Crushed Trap Rock	SIZE
SOURCE New Haven, Conn.	SOURCE New Haven, Conn.	4-1½"

MATERIALS

MATERIALS	SERIAL NUMBER	SIZE RANGE	BULK SP. GR.	ABSORPTION %
CEMENT	C-1	—	3.15	—
FINE AGGREGATE	S-1	No.4 to -200	2.92	0.8
COARSE AGGREGATE (A)	(50%) G-1	3/4" to No.4	2.92	0.6
COARSE AGGREGATE (B)	(50%) G-1	1½" to 3/4"	2.92	0.6
COARSE AGGREGATE (C)				
COARSE AGGREGATE (D)				

MIXTURE DATA

MATERIALS	SAMPLE NUMBER: MIXTURE BY WEIGHT	NET WEIGHTS 1 BAG BATCH (lb.)	SOLID VOLUME 1 BAG BATCH (cu. ft.)	SAMPLE NUMBER: MIXTURE BY WEIGHT	NET WEIGHTS 1 BAG BATCH (lb.)	SOLID VOLUME 1 BAG BATCH (cu. ft.)
CEMENT	1.00	94.00	0.478			
FINE AGGREGATE	2.69	252.86	1.385			
COARSE AGGREGATE (A)	1.78	167.32	0.917			
COARSE AGGREGATE (B)	1.78	167.32	0.917			
COARSE AGGREGATE (C)						
COARSE AGGREGATE (D)						
WATER	0.53	50.00	0.800			
AIR			0.215			
TOTAL		731.50	4.712			

WATER/CEMENT (gal. per bag)	6.0	THEO. UNIT WEIGHT (lb./cu. ft.)	162.66
SLUMP (in.)	2	ACTUAL UNIT WEIGHT (lb./cu. ft.)	155.15
AIR CONTENT (%)[2]		THEO. CEMENT FACT. (bag/cu. yd.)	6.22
AIR CONTENT (%)[3]	4.6	ACTUAL CEMENT FACT. (bag/cu. yd.)	5.73
SAND/AGGREGATE (% volume)	43		

REMARKS (Condition of mix, workability, plasticity, bleeding, etc.)

TECHNICIAN (Signature)	COMPUTED BY (Signature)	CHECKED BY (Signature)
J. Baker	J. Baker	B. Higgins

1. Calculated on the basis of:
2. In the entire batch as mixed. ✓
3. In that portion of the concrete containing aggregate smaller than the 1½ inch sieve.

45.575

Figure 15-12.—Data sheet for concrete mix design tests.

You can see this value inscribed beside "air" in the column headed "solid volume 1-bag batch."

You can see a sand/aggregate ratio of 43% listed at the bottom of the sheet. This ratio (which is a quality factor and may be specified) is computed by dividing 100 times the solid volume of sand (which in this case is, for a 1-bag batch, 1.385 cu ft) by the sum of the solid volumes of sand and coarse aggregate (which in this case is 3.219 cu ft). This works out to 138.5 divided by 3.219, which equals 43 percent.

The "theoretical unit weight" is computed by dividing the weight of the ingredients by the solid volume. This works out in this case to 731.50 divided by 4.497, or 162.66 lbs per cu ft. The "actual" unit weight is computed by dividing the ingredient weight by the total volume plus the air volume, which in this case is 731.50 divided by (4.497 + 0.215), or 155.15 lbs per cu ft. The "cement factor," or number of sacks of cement required per cu yd of mixed concrete, is a quality factor which is usually specified. The "theoretical" cement factor is determined by dividing 27 (number of cu ft in a cu yd) by the total solid volume of ingredients in a 1-sack batch. The theoretical factor here equals 27 divided by 4.497, or 6.22 sacks per cu yd. The "actual" cement factor is determined by dividing 27 by the sum of the total solid volume plus the air volume. In this case the actual factor equals 27 divided by (4.497 + 0.215), or 5.73 sacks per cu yd.

AIR-ENTRAINED CONCRETE

Air-entrained concrete is a comparatively recent development used to reduce scaling, particularly in areas where concrete must be resistant to severe frost action and impervious to the harmful effects of chemicals used for melting snow and ice. Air-entrained concrete is more durable than normal portland cement concrete, but strength is slightly reduced. The air-entrained mix has increased workability and less segregation, but control is more critical.

Air-entrained concrete consists of cement, sand, gravel, and an admixture as mentioned earlier in Type II concrete. The addition produces millions of tiny air bubbles ranging from a few microns to 75 microns in diameter which are entrained, or diffused, in the cement paste. Calculations indicate that there are approximately 600 billion air bubbles entrained in a cubic yard of concrete. Specified percentage by volume usually requires 4½ percent entrained air, with an acceptable range of 3 to 7 percent. Although normal portland cement concrete usually contains from ½ to 1½ percent of air, this air is usually entrapped in the form of voids and it is not dispersed uniformly throughout the mix.

The recommended method of producing air-entrained concrete is to add the air-entraining agent to the mixing water at the mixer. The use of commercially prepared air-entrained cement is not recommended because the air-entraining agent may lose effectiveness when it is premixed. Air-entraining agents usually are used with Types I, II, III, IV, and V portland cement in quantities specified by the manufacturer. Air content of the mix must be accurately controlled to obtain the desired uniformity.

The amount of air-entraining agent required to produce any given air content increases with an increase in concrete temperature. Therefore, frequent tests should be made of air contents, particularly if there are changes in the concrete temperatures.

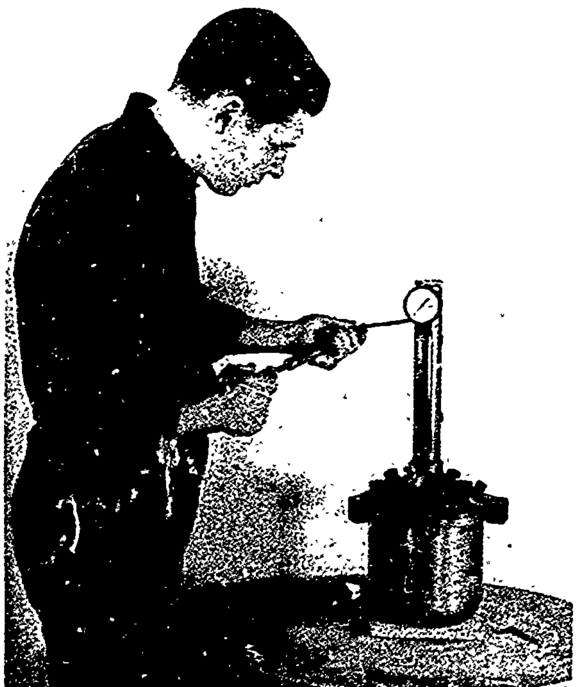
To ensure proper air content, the concrete should be mixed for about 1 or 2 minutes. Air content increases about 1 percent as the mixing time is increased from 1 to 5 minutes. From 5 to 10 minutes, air content remains unchanged. Beyond 10 minutes, air content remains unchanged. Beyond 10 minutes, it gradually decreases until after 60 minutes the air content is identic. to the 1-minute mixing period. The vibration of air-entrained concrete for 1 minute or more in the same spot reduces air content 15 to 20 percent. Internal vibration reduces air content more than external vibration.

The three methods of measuring air content of freshly mixed concrete are the pressure method, the gravimetric method, and the volumetric method. The method most widely used is the pressure method. The principle of the pressure method is based on Boyle's Law, that is, the volume of gas at a given temperature is inversely proportional to the pressure to which it is subjected. An air meter is calibrated so that the percentage of entrained air is read when a known volume of concrete is subjected to a known pressure. The air content test apparatus is shown in figure 15-13.

The strength of air-entrained concrete is inversely proportional to a percentage of entrained air. For a given water-cement ratio. strength is reduced about 5 percent for 1 percent of entrained air. Rich mixes are reduced in strength slightly more than lean ones. For pavements, the mix must be adjusted for strength as shown in the following example.

EXAMPLE. Adjust the mix for 4½ percent of air, assuming a trial mix of 1 sack of cement, 195 lbs of sand, 350 lbs of gravel. and 5½ gallons of water.

PROCEDURE: For a 1-sack batch, decrease the amount of water ¼ gallon per percent of air and decrease the amount of sand 10 pounds per percent of air. (Air bubbles will make the mix appear oversanded unless the amount of sand is reduced.)



82.207X
Figure 15-13.—Apparatus for air content test.

SOLUTION:

Trial mix	Correction	Adjusted mix
Cement 1 sack	---------	1 sack
Sand 195 pounds	10X4½=45	150 pounds
Gravel 350 pounds	---------	350 pounds
Water 5½ gallons	¼ X 4½ = 1 1/8	4 3/8 gallon
Air	---------	4½ percent

To adjust the yield to include the entrained air, the yield as determined from the absolute volumes of the adjusted mix is divided by one minus the percentage of air entrained over 100. Yield adjusted for air entrainment =

$$\frac{\text{Yield (no admixture)}}{1 - \frac{\text{percent of air}}{100}}$$

SOIL-CEMENT CONSTRUCTION

Through the years, many efforts were made to combine soil and cement to produce a satisfactory low-first-cost paving material. The idea dates back to 1917, when various state highway agencies in the United States experimented with adding cement to subgrade soils to increase stability. But soil science as applied to roadbuilding was new at that time and these trials resulted in unpredictable and varied results.

Of special significance to the development of soil-cement was the pioneer work of the South Carolina State Highway Department, initiated in 1932. During 1933 and 1934, five short sections of highway were built with soil and cement. The results of this work were most promising and provided the stimulus for extensive research on soil-cement mixtures by the Portland Cement Association, starting in 1935. At present, the use of soil-cement is very much scientifically controlled and is not only limited to road construction, but used in airfields, parking and storage areas, drainage ditches and canal linings, sidewalks, helipads and many other uses you could think of. Due to the low initial costs, soil-cementing is greatly utilized in the advanced theater of operations by the SEABEES.

TYPES OF SOIL CEMENT

Soil-cement is a simple, intimate mixture of pulverized soil and measured amounts of portland cement and water, compacted to high density. As the cement hydrates, the mixture becomes a hard, durable paving material. There are three general types of soil and cement mixtures:

1. Compacted soil-cement
2. Cement-modified soil
3. Plastic soil-cement

Compacted soil-cement contains sufficient cement to harden the soil and enough moisture both for adequate compaction and for the hydration of the cement. For purposes of this training course, all mixtures of soil and cement are classified as soil-cement or cement-modified soil without regard to the type or source of soil or aggregate.

Cement-modified soil is an unhardened or semihardened mixture of soil and cement. When relatively small quantities of portland cement and moisture are added to granular soil or silt-clay soil, the chemical and physical properties of that soil are changed. Cement reduces the soil's plasticity and its water-holding capacity 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 desired degree less cement is used than is required to produce a hard soil cement. Cement-modified soils may be used for base courses, subbases, treated subgrades, highway fills, and as trench backfill material.

Plastic soil-cement is also a hardened mixture of soil and cement that contains, at the time of placing, sufficient water to produce a consistency similar to that of plastering mortar. By comparison, compacted soil-cement is placed with only sufficient moisture to permit adequate compaction and cement hydration. Plastic soil-cement is used to pave steep, irregular or confined areas such as highway ditch linings and other erosion-control structures, where it is difficult if not impossible to use road-building equipment.

MATERIALS FOR SOIL-CEMENT

Only three basic materials are needed in soil-cement. soil, portland cement, and water. Low first cost is achieved mainly by using cheap local materials. The soil, which 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.

The quantities of portland cement and water to be added and the density to which the mixture must be compacted are determined by tests. The water serves two purposes. it helps to obtain maximum compaction (density) by lubricating the soil grains, and it is necessary for cement hydration, which hardens and binds the soil into a solid mass. Soil-cement properly built contains enough water for both purposes.

The cement could be any type of portland cement that complies with the requirements of the latest ASTM, AASHO, or federal specifications. Types 1 and 1A, normal and air-entraining portland cements, are 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 was 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 the 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.

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, limerock, and almost all granular materials work well, if they contain 55 percent or more material passing the No. 4 sieve. 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, and windblown sands, make good soil-cement though the amount of cement needed for adequate hardening usually is slightly greater than with the soil in Group 1. 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 the three fundamental control factors for soil-cement, which are:

1. Proper cement content
2. Proper moisture content
3. Proper density

An adequate cement content is the first requisite for quality soil-cement. Well in advance of construction, the soils on the project should be identified, the limits of each soil defined, and a representative sample of each soil type forwarded to the laboratory to determine the quantity of cement required to harden it. A soil survey of the construction area should be made.

A soil survey includes the examination of soils on a project, a description of these soils, and a location of the limits of extent of the various soils. Experience and a good working knowledge of soils are valuable aids in making complete soil surveys.

Proper soil surveying, identification, and sampling are important. For instance, if one soil type were sampled and tested while actual construction involved a different soil, 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-lb sample of each soil type is an adequate quantity for laboratory tests.

Soil samples are usually taken from a graded roadway by digging a trench from the centerline to the edge of the proposed pavement and to the depth of processing. Soil samples for proposed roadways not yet graded are taken from the various soil horizons of each soil type from the "dressed-down" face of exposed cuts, or from the surface with an auger. 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 do 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 bottom to top of the vertical face after the over-burden has been removed. On small projects, it is not uncommon to sample only the poorest soil on the job. The cement content for this sample is used throughout the job. Be sure that complete identification is supplied with each sample.

Only an outline is given here of the tests normally run on soil samples submitted for soil-cement construction. The objective of these tests is to determine the minimum cement content required to harden each soil adequately. The following tests are usually run:

Soil identification Tests
- Grain size
- Liquid limit
- Plastic limit

Soil-cement tests
- Moisture-density relations–AASHO Designation: T134
- Wetting and drying test–AASHO Designation: T135
- Freezing and thawing test–AASHO Designation: T136

Unconfined compressive-strength tests are commonly made also.

The moisture-density test establishes the optimum moisture and maximum density at which test specimens should be molded. It also provides approximate values for use in construction. Wet-dry and freeze-thaw test specimens containing various amounts of cement are molded at optimum moisture and maximum density and tested after 7 days' hydration to determine the lowest cement content that will harden the soil adequately.

INSPECTION AND FIELD CONTROL

The purpose of inspection and field control is to assure that the results set out in plans and specifications are obtained. As mentioned earlier, there are three major control factors in soil-cement construction. They are:

1. Adequate cement content
2. Proper moisture content
3. Proper compaction

A thorough mix of pulverized soil, cement, and water must also be obtained. To assist in attaining these objectives, the following list of check items is given:

1. Inspection of the grade and correction of all soft subgrade areas.
2. Proper identification of the soils so that the correct percentage of cement may be added to each soil.
3. Adequate pulverization.
4. Calculation of cement spread.
5. Checking cement spread.
6. Incorporation of the correct amount of moisture.
7. Uniformity of mix; depth and width of treatment.
8. Degree of compaction–density.
9. Proper finishing.
10. Adequate curing.

Proper inspection is primarily good judgment based on experience and the requirements of the plans and specifications. Many of the items are automatically controlled as the EO learns proper construction procedures.

Before construction starts, the area to be paved should be graded and shaped as required to construct the base course to the lines, grades, thickness, and typical cross section that are shown on the plans.

During grading, all debris should be removed and all soft subgrade areas corrected. The latter is important since adequate compaction cannot be obtained in the base course if the subgrade does not support the compacting and finishing equipment. Most soft areas can be easily detected by observing the stability as the motor grader shapes the area prior to soil-cement processing.

The success of soil-cement depends mainly on mixing the correct amount of cement with the soil. The soil survey report, laboratory test reports, plans, specifications, and the engineer's knowledge of the soils on the job supply the information needed. On most jobs, this is a simple step since only one or possibly two cement contents are needed. Usually cement requirements and soil types have been established long before construction starts, but they should be checked.

Most soils used in soil-cement construction need little or no preliminary pulverization. Specifications generally require that at the time of compaction 80 percent of the soil-cement mixture pass the No. 4 sieve and 100 percent pass the 1-in. sieve, exclusive of any gravel or stone retained on these sieves. If a clayey soil is being used, the degree of pulverization needs to be checked. The degree of pulverization required before cement is added depends on the soil and the mixing equipment

A pulverization test is made by screening a representative sample over a No. 4 sieve and computing the percentage that passes. The computation is as follows:

$$\text{Percent pulverization} = \frac{\text{Dry weight of soil-cement mixture passing No.4}}{\text{Dry weight of total sample exclusive of gravel retained on No. 4 Sieve.}} \times 100$$

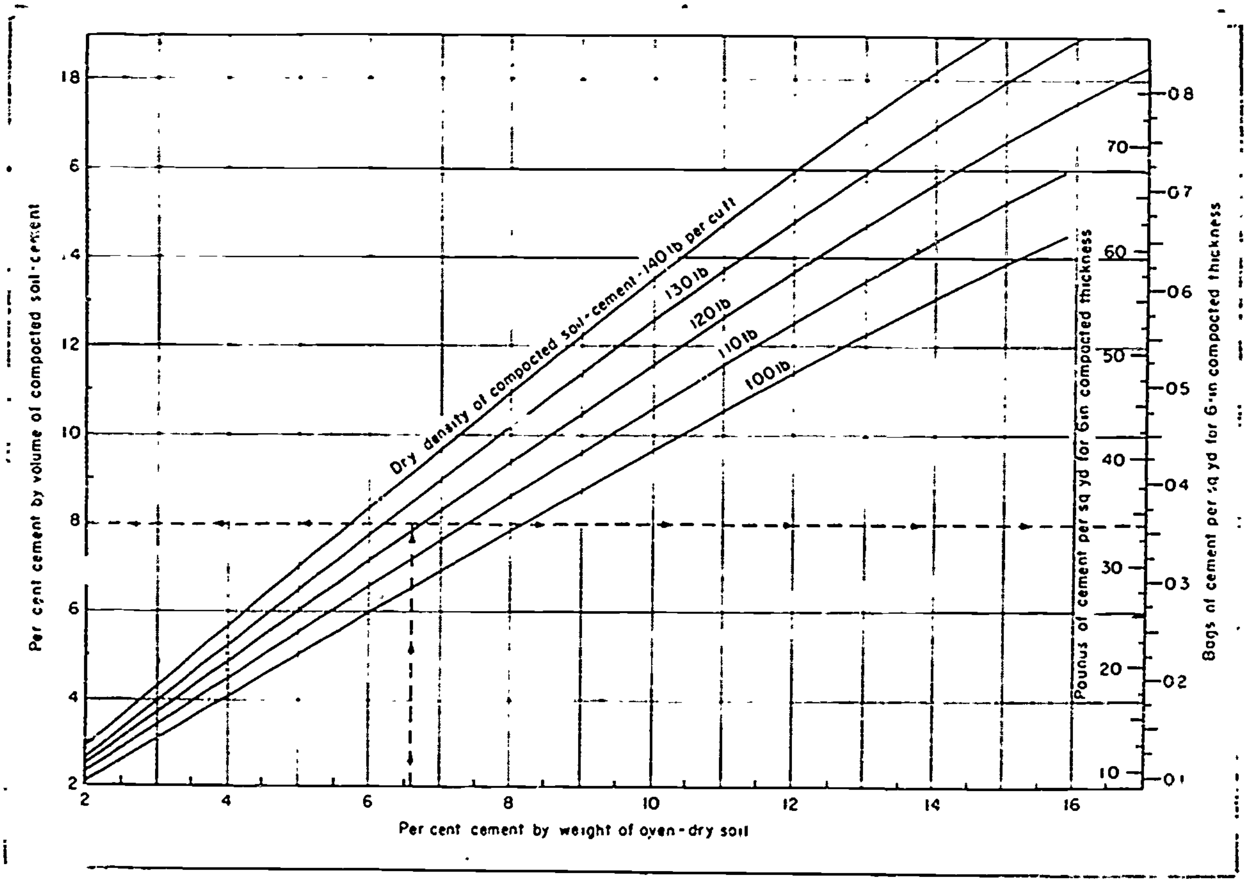
For practical purposes, this test is usually run with wet weights instead of correcting each portion for moisture. This is reasonably accurate if the moisture content of each portion is about the same. Usually no correction is made for the weight of cement present.

Calculation of Cement Spread

Bulk or bag cement may be used. The plans and special provisions specify the quantity of cement to be spread, determined from laboratory tests. Generally, the cement is specified as percent cement by volume of compacted mixture. Specified cement contents by weight of ovendry soil can be converted to cement contents by volume if the maximum density is known (see fig. 15-14). One bag of cement weighs 94 lb and its volume is considered to be 1 cu ft.

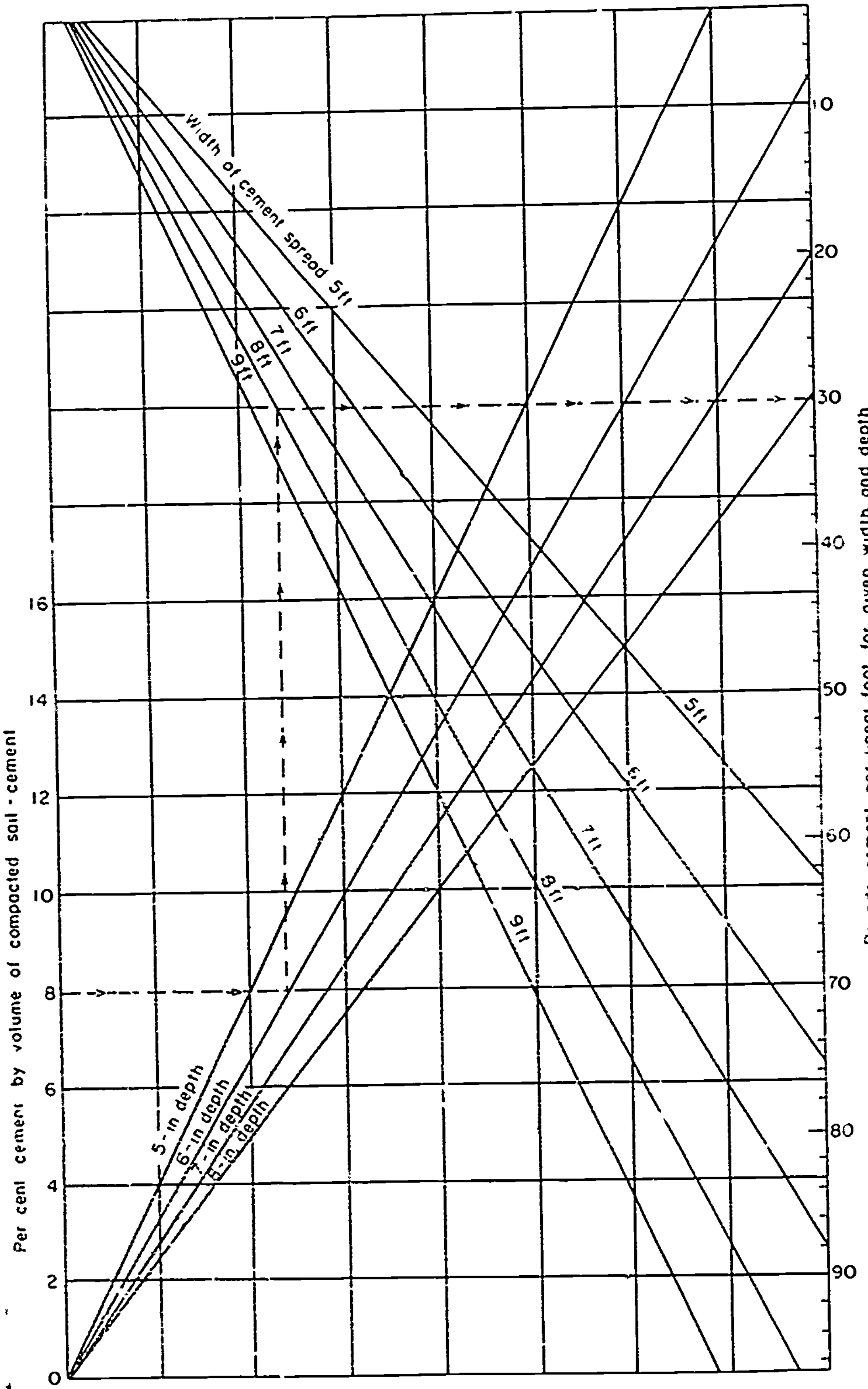
Before cement is spread, the area to be processed should be shaped to approximate grade if the soils are processed in place. If the soils are processed in windrows, the quantity of soil in each windrow must be known either the ovendry weight of soil per lineal foot of windrow or the volume of roadway per lineal foot represented by each windrow.

Figures 15-15 and 15-16 and table 15-9 can be used to convert specified cement contents to the quantity of cement per square yard or to the quantity of cement per lineal foot. Figure 15-17 shows the spacing of bags of cement for speci-



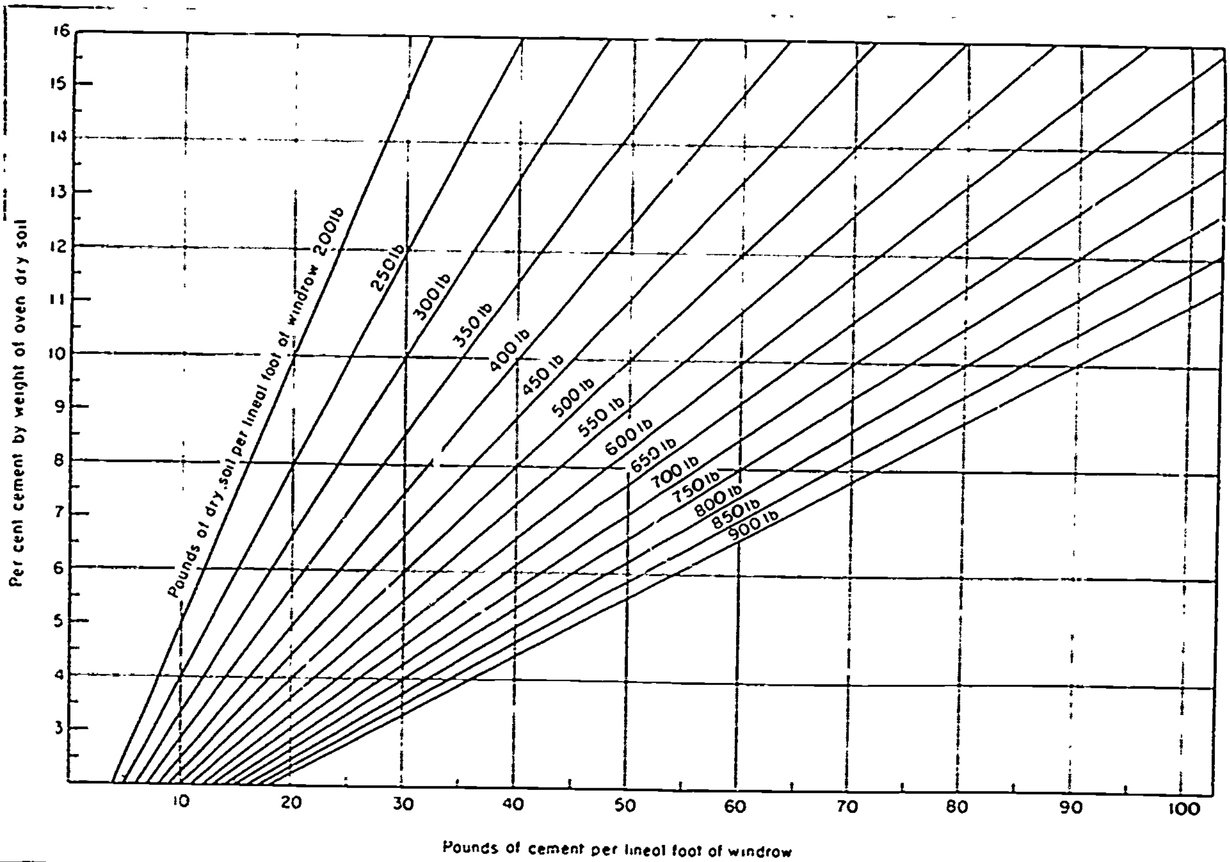
82.208X

Figure 15-14.—Cement factor conversion chart.



82.209X

Figure 15-15.—Pounds of cement required per lineal foot for various widths and depths for specified cement contents by volume.



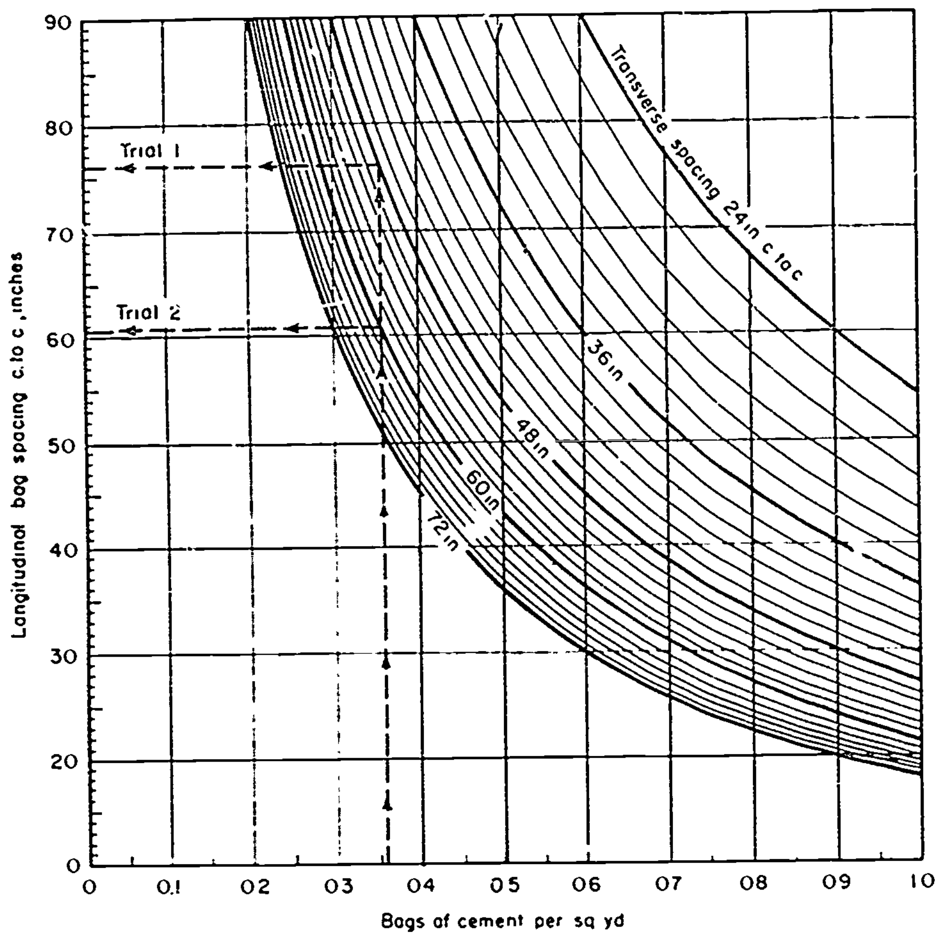
82.210X

Figure 15-16.—Pounds of cement required per lineal foot of windrow for specified cement contents by weight.

Table 15-9.—Cement Spread Requirements Per Square Yard

Per cent cement by volume	Compacted depth, in. 5		6		7		8	
	Lb	Bag	Lb.	Bag	Lb.	Bag	Lb.	Bag
4	14.1	0.15	16.9	0.18	19.75	0.211	22.55	0.24
5	17.6	0.188	21.2	0.225	24.8	0.263	28.2	0.30
6	21.1	0.225	25.4	0.27	29.7	0.315	33.9	0.36
7	24.7	0.263	29.6	0.315	34.6	0.368	39.5	0.42
8	28.2	0.30	33.8	0.36	39.5	0.421	45.1	0.48
9	31.8	0.338	38.1	0.405	44.6	0.474	50.8	0.54
10	35.2	0.375	42.3	0.45	49.5	0.527	56.4	0.60
11	38.8	0.413	46.5	0.495	54.4	0.579	62.0	0.66
12	42.3	0.45	50.8	0.54	59.4	0.632	67.7	0.72
13	46.8	0.488	55.0	0.585	64.4	0.684	73.3	0.78
14	49.4	0.525	59.2	0.63	69.3	0.737	78.9	0.84
15	53.0	0.563	63.5	0.675	74.3	0.79	84.6	0.90
16	56.4	0.60	67.7	0.72	79.2	0.842	90.2	0.96

82.216X



82.211X

Figure 15-17.—Transverse and longitudinal spacing of bags of portland cement for specified cement contents.

fied cement contents. Study the examples given below.

EXAMPLE 1. Bulk-Cement Spread

Given: Cement content by volume required . . . . 8 percent
Depth of compacted soil-cement . . . . . . 6 inches
Width of spread . . . . 8 feet
Weight of truckload of cement . . . . 7,520 lbs

Required. Lineal distance that one truckload of cement should travel to spread the required amount of cement–8 percent in this example.

Procedure:
1. Enter figure 15-15 on left side at the required cement content by volume–8 percent in this example.
2. Proceed horizontally to depth line–6 in. in this example.
3. Then proceed vertically to intersection with line representing the width of spread–8 ft in this example.
4. From this intersection, proceed horizontally to the right side of the chart and read pounds

of cement per lineal foot—30.0 lbs.

Answer: Divide the total weight of cement on truck by the pounds per lineal foot required.

$$\frac{7,520}{30.0} = 250.7 \text{ ft.}$$ The answer is the required distance of travel for this truckload to obtain the specified cement spread.

Bags of cement should be spaced at practically equal transverse and longitudinal intervals. Bag spacings can be obtained from figure 15-17.

EXAMPLE 2. Bag-Cement Spread

Given: Width of roadway . . . . . . 20 feet
Cement content by volume required . . . . 8 percent
Depth of processing . . . 6 inches

Required. Transverse and longitudinal spacing of bags.

Procedure: Trial #1

1. From table 15-9, obtain correct amount of cement required per square yard for 6-in. depth and 8 percent cement by volume: 0.36 bag per square yard.
2. Assume five longitudinal rows of cement bags across roadway. Divide width of roadway by number of rows to determine transverse spacing:

$$\frac{20}{5} = 4 \text{ ft} = 48 \text{ in.}$$

3. Enter figure 15-17 at 0.36 bag per square yard and proceed vertically to intersection with 48-in. curve, then proceed horizontally to edge of chart and read longitudinal spacing of 76 in.

Note: Longitudinal and transverse spacing should be approximately equal. This was not attained in Trial #1; therefore, proceed with Trial #2.

Trial #2

1. Assume four longitudinal rows of cement bags across roadway. Transverse spacing equals:

$$\frac{20}{4} = 5 \text{ ft} = 60 \text{ in.}$$

2. Enter figure 15-17 at 0.36 bag per square yard and proceed vertically to intersection with 60-in. curve; then proceed horizontally to edge of chart and read longitudinal spacing of 61-in.

Answer: Bags should be placed in four longitudinal rows 60 in. apart with 61-in. longitudinal spacing between bags.

Check on Cement Spread

A check on the accuracy of the cement spread is advisable to ensure that the proper quantity is actually being applied. When bulk cement is being used, this is done in two ways:

1. Place a canvas, usually 1 square yard in area, on the roadway ahead of the cement spreader. After the spreader has passed, pick up the canvas carefully and weigh the cement collected on it.

2. Check the distance or area over which a known weight of a truckload of cement is spread. For instance, in Example 1, a 7,520 lb load of cement was supposed to cover an area 250.7 ft by 8 ft, or 222.9 square yards. If the truck traveled 245 ft, the quantity of cement actually spread would be:

$$7,520 \text{ lb} \div \frac{(245 \text{ ft} \times 8 \text{ ft})}{9 \text{ sq ft}} = 34.5 \text{ lb per sq yd.}$$

This is compared to 33.8 lb per sq yd from table 15-9, as required in Example 1. Therefore, the spreader should be adjusted to spread less cement per square yard.

Bulk cement that is spread mechanically in the top of a windrow of soil may be checked by pushing two metal plates into the top of the windrow exactly 1 ft apart. All cement between the plates is carefully scraped out and weighed.

Generally, checking the cement on the square yard basis is used to adjust the spreader, while a final check is made by figuring the quantity of cement spread per unit area from the area covered by a truckload of cement. Bag cement is checked by counting the number of bags actually placed per 100-ft station. It is desirable to keep a continuous check on cement-spreading operations.

For an intensive study of soil-cementing, you will find various publications put out by the Portland Cement Association very useful.

CHAPTER 16
PUBLIC WORKS

The intent of this chapter is to acquaint the EA with the basic organization and objectives of Public Works activities. EAs assigned to Public Works activities may fill several different types of billets, depending on the particular activity's organization and the capabilities of the EA assigned. Although most Public Works activity jobs are filled by civilians, a few military billets do exist Most of the existing EA billets are in the Engineering Division, where the EA works hand-in-hand with civilians in performing drafting or surveying tasks. Senior EAs, with planning and estimating experience, may also be assigned to the Maintenance Control Branch and work as planners and estimators or maintenance inspectors. At smaller Public Works activities the senior EA may supervise the planning and estimating section or control work requests and help plan the activity workload.

A unique situation exists at most Public Works activities. The military billets filled by an EA are usually under the direct supervision of a civilian engineer. The adjustment may be difficult at first, but the alert EA will benefit from the varied experience of the professional civilian engineer A good working relationship between you and your civilian coworker is of the utmost importance. Once this relationship is established, duty at a Public Works activity becomes very interesting and rewarding.

PUBLIC WORKS DEPARTMENT

At a shore activity, the first organizational breakdown within the activity is that of the department. Departments are established to perform a clearly defined major function o functions that are closely related or homogeneous. Thus, the maintenance and operation of public works and public utilities are the principal functions for which the PUBLIC WORKS DEPARTMENTS have been established.

The basic organization for a Public Works Department (PWD) is shown in figure 16-1. An alternate organization for PWDs with a limited workload is shown in figure 16-2.

Organizational components of a PW department are. Divisions, Branches, Sections, and Units. Certain traditional names may be used, for instance, paint shop.

The organization consists of two basic parts that are broadly termed the Administrative and Technical Divisions and Operating Division. With the exception of the Maintenance Control Division, these divisions are predominately staffed with graded civil service employees. The administrative and technical divisions are listed below.

1. Administrative Division.
2. Engineering Division.
3. Maintenance Control Division.

ADMINISTRATIVE DIVISION

The Administrative Division is responsible for all matters pertaining to organization, methods, procedures, work flow, civilian personnel, office services, reproduction reports and statistics, budget and finance, and housing management. In addition, when local conditions warrant, material purchases by the Public Works Department will normally be performed by the Administrative Division. The position of Director requires an incumbent with a well-rounded background of education and experience in the field of business or public administration. The functions of this position should be heavily weighted with requirements for analysis of organization, work flow, personnel utilization, and for development of financial and budget techniques that constitute valuable management tools.

The Administrative Division will normally have four or five branches. The PERSONNEL BRANCH is concerned with timekeeping and

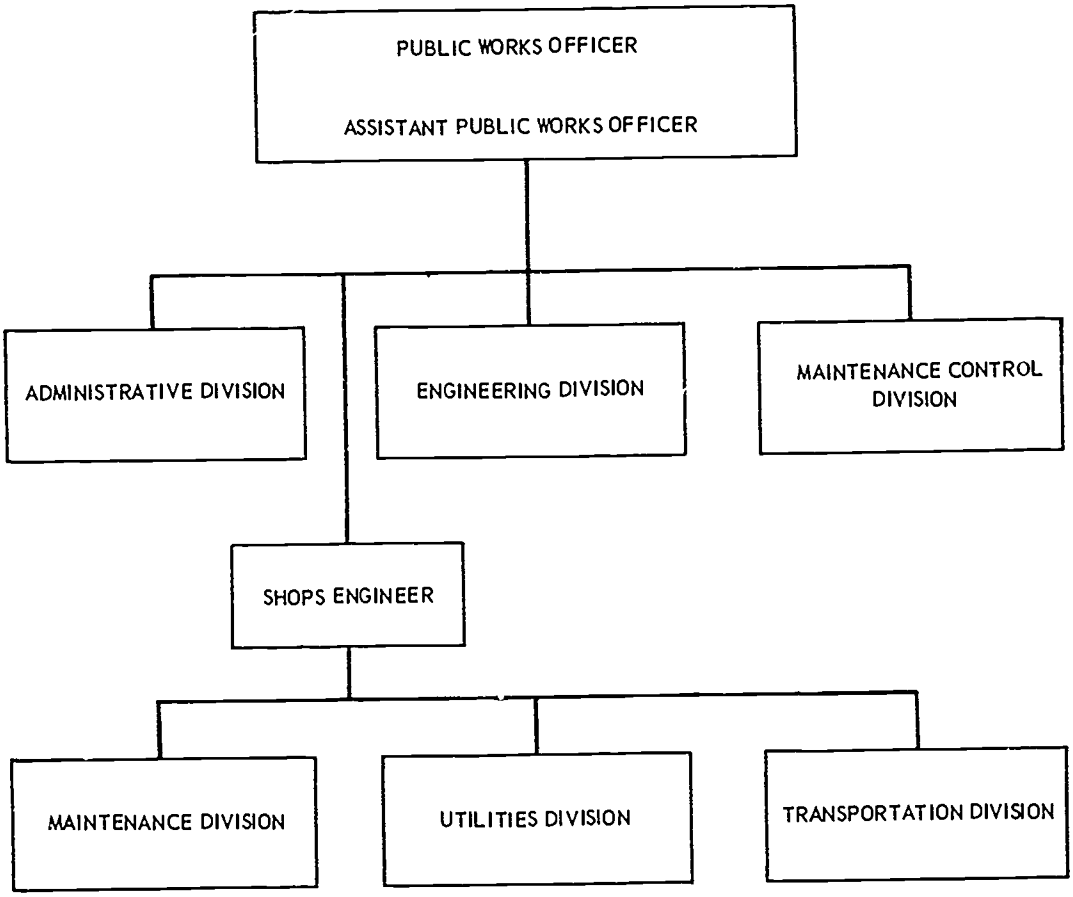


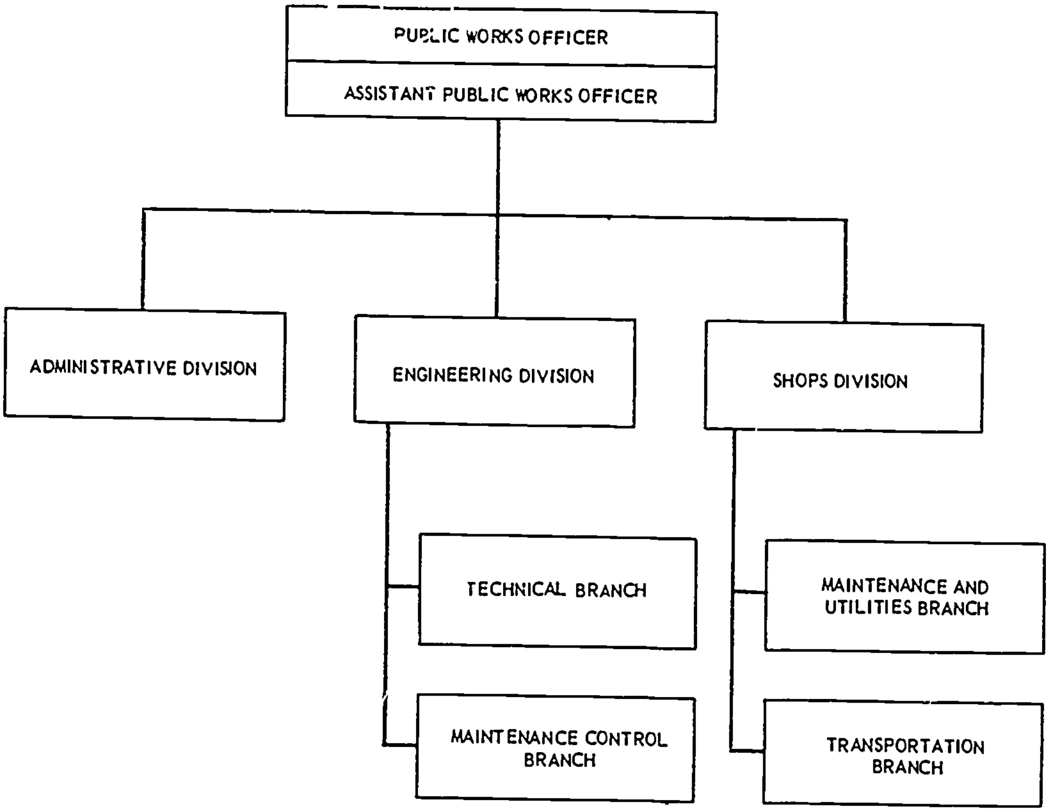
Figure 16-1.–Public Works Department organization (standard).

personnel records and for maintaining liaison with the activity Civilian Personnel Department (CPD). The services which CPD is prepared to provide should not be duplicated by the personnel branch.

The OFFICE SERVICES BRANCH procures and distributes office supplies, furniture, and office equipment. It is responsible for services relating to the stenographic and typing pool, duplicating machines, messenger assignments, central files, and other internal matters.

The FINANCIAL BRANCH is responsible for the development, coordination, and presentation of budgets, fiscal auditing and accounting matters; compiling, recording, and reporting real property data; and the inventory and records of PUBLIC WORKS materials. The Branch maintains accounting controls on allotments made to the Public Works Department. It controls, from a financial standpoint, job orders written against such allotments. It also provides accounting data for all job orders. It assures that accounting data on job orders are not only technically accurate, but also that the work described is properly chargeable to the allotment and appropriation cited and that funds are available. The minimum of accounting and fiscal records should be maintained by the activity fiscal officer. It is possible that the Public Works Department of larger activities may find it necessary to establish other sections, such as budget, finance, and plant material inventory sections.

The MANAGEMENT ANALYSIS BRANCH conducts analysis studies (except shop work



16.9

Figure 16-2.—Public Works Department organization (alternate) for Public Works Department with limited workload.

methods and techniques) pertaining to organization, staffing, workflow and civilian personnel utilization; provision of special procedures and methods studies; maintenance of records of all reports required by the Department, including certain reports required by the PW Management Programs, the due dates of such reports, and information showing compliance with reporting requirements; the accumulation of statistics and the preparation of statistical reports; and charts and graphs as required.

The establishment of a HOUSING BRANCH or division to perform functions of management of HOUSING PROJECTS is optional. Factors that should be considered are the number of housing units and the number of personnel required to handle the housing management workload. In exceptional circumstances the magnitude of housing responsibilities may warrant a separate Housing Division.

ENGINEERING DIVISION

The Engineering Division is responsible for all matters pertaining to engineering studies and reports, including preliminary designs and estimates for special repair and improvement projects; for engineering design, including development of plans and specifications, with due recognition of the support available from the Field Division Office; for field engineering, including hydrographic and subsurface surveys, and photographic services; and for the maintenance of technical plan files and records. This division is responsible for preparation of shore facilities development reports and for the submission of basic data required by the Field Division Director for preliminary engineering studies.

Whenever the workload justifies or requires such action, the Engineering Division is subdivided into the following branches, with each one responsible for the performance of functions noted above in the particular fields indicated by the branch titles:

Electrical Branch
Mechanical Branch
Architectural and Structural Branch
Civil Branch
Plans and Specifications Branch.

In some PW departments, it will be desirable to combine the Mechanical and Electrical Branches, or to merge the Civil Branch into the Architectural and Structural Branch. In all cases, survey work is performed as a part of the Civil component.

The PW Officer should establish an Engineering Division sufficient to handle only routine work and should rely upon the Engineering Field Division for the design of major public works and public utilities, for the preparation of specifications in connection with them, and for the engineering investigations in specialized fields.

When approval or review of design work of proposed plans or specifications is desired from a technical engineering standpoint, the activity should call upon the Field Division Director.

PW Departments with limited workload and staffing should combine the engineering and maintenance control components into a single Engineering Division.

As mentioned previously, the majority of the EAs assigned to Public Works activities will work in the Engineering Division. With the exception of supervision, your tasks will be similar to those performed in the Engineering Division of the NMCB, such as design, reproduction, surveying, etc. Normally you will be the only EA assigned to a particular Public Works activity; therefore, your supervisory duties, if any, will be limited.

MAINTENANCE CONTROL DIVISION (MCD)

This is the division in the Public Works Department whose entire effort is directed toward maintenance management. The Maintenance Control Division's existence is based on the premise that the functions of inspection, work reception, job planning and estimating, and work input control will be more successfully administered, and will have a more positive managing effect on maintenance, when they are assigned to a staff division rather than a group concerned primarily with the performance of maintenance work.

Functions of the Maintenance Control Division

The Maintenance Control Division is responsible for the integration of a maintenance workload program, the screening and classifying of all work requests, including emergency/service type work, prior to submission to shops for accomplishment; the continuous inspection of public works and public utilities to reveal the need for maintenance work; the preparation of manpower and material estimates for job orders; the determination of the need for engineering advice and assistance, and the initiation of requests to the Public Works Officer for approval to perform work by contract. The Maintenance Control Division is also responsible for review, recommendations, and justification to the Public Works Officer for funding of special maintenance, alteration, and repair projects when indicated by recurring or costly maintenance experiences. For the usual types of maintenance work, and within limits specified by the Public Works Officer, authority to approve job orders is delegated to the Director of the Maintenance Control Division. In addition, the Maintenance Control Division is responsible for various functions that apply to the maintenance and operation of transportation equipment.

Public Works Departments which have less than 100 total personnel in the Maintenance and Utilities Divisions usually have a combined Maintenance Control and Engineering Division called the Engineering Division, as shown on the chart in figure 16-2. When the two divisions are combined as such, the responsibilities of each division are also combined under one director.

Work Reception and Control Branch

Clerical personnel assigned to the MCD are attached to the Work Reception and Control Branch. It is their responsibility to:

1. Check the general information on incoming requests and/or estimates for maintenance work, and make corrections.
2. Classify (preliminary), numerically identify, and record incoming requests and/or estimates for maintenance work, including emergency/service calls.
3. Approve and sign Emergency Work and Service Work Authorizations within the limits established by the Public Works Officer.
4. Control the step-by-step processing of work requests, inspection reports, job orders, and emergency/service work authorizations.
5. Perform general clerical and typing functions such as typing job orders, maintaining inspection frequency files, and maintaining suspense files.
6. Post job titles of maintenance and repair work, special projects or unfunded deficiencies, on the correct work input control chart.

Inspection Branch

The Inspection Branch of the MCD is responsible for:

1. Developing inspection standards and practices to meet the conditions at the activity.
2. Establishing an effective inspection program.
3. Performing assigned inspections of public works and public utilities within established schedules.
4. Preparing inspection reports which describe below-standard physical conditions and recommending necessary maintenance and repair work.
5. Inspecting public works and public utilities when requested by the Planning and Estimating Branch of the MCD.
6. Preparing preliminary manpower and material estimates for work generated by the Inspection Branch.
7. Evaluating the effectiveness of continuous inspections through review of work input control and personal observation, and reporting apparent deficiencies to the MCD.
8. Detecting abnormally repetitive maintenance work on specific facilities or components or other abnormal conditions, such as requests that indicate the need for major corrective measures, and referring such matters to the inspector for field investigation when necessary.

The personnel who staff the Inspection Branch are experienced tradesmen who specialize in structural, electrical, or mechanical inspecting. They are normally planning and estimating specialists. At some PWDs, the Inspection Branch is supplemented with experienced BUs, CEs, UTs, SWs, and a few EAs with broad construction experience. Public Works Departments that are primarily staffed with SEABEES may have senior or master chief petty officers for Inspection Branch and Planning and Estimating Branch supervisors.

Planning and Estimating Branch

The Planning and Estimating Branch of the MCD is responsible for the preparation of manpower and material estimates (including the application of engineered performance standards) for work generated either from the continuous inspection program or other work requests; the compilation of estimating information designed to improve estimating techniques for labor and material costs, and the analysis of facility history records. This Branch is also responsible for overall job planning and for preparing estimates for work to be accomplished, and for initiating and expediting job orders for all work performed by the operating divisions in the PW Department. The substantive parts of the job orders are prepared by the Planning and Estimating Branch, accounting data being provided by the Financial Branch of the Administrative Division. Job orders are approved by the PWO, the Assistant PWO, or the Director of the Maintenance Control Division within their specific monetary limitations.

The Planning and Estimating Branch also assists in controlling work input. Planning and estimating procedures provide necessary data for evaluation by the Division Director, Assistant PWO, or PWO to aid in reaching a decision as to approval of work requested, and to assist the cognizant shop supervisor in assigning personnel without again surveying the jobsite.

Another responsibility of the Planning and Estimating Branch is to prepare all specific job orders in operational sequence with manhour estimates for each operation and to provide an overall material cost estimate for each work center involved. In addition, shop personnel are provided with a detailed material list by the Planning and Estimating Branch to indicate what material is required and are also provided with specifications for "special purchase" items. Detailed material requirements functions are a shop responsibility, performed by shop planner personnel.

Further responsibilities include preparation of a periodic backlog report containing the overall shop force distribution data and other information required by the PWO for overall control of the operating divisions.

Qualifications for personnel who staff the Planning and Estimating Branch are the same as for the personnel assigned to the Inspection Branch. Military personnel from the Planning and Estimating Branch and Inspection Branch are sometimes rotated periodically. At a small PWD these two branches may be combined, utilizing the same person for both inspection and planning and estimating.

OPERATING DIVISIONS

The Operating Divisions of the PWD are predominately staffed with nongraded civil service employees, consisting of supervisors and various craft workers. The operating divisions of a standard PWD consist of a Maintenance Division, a Utilities Division, and a Transportation Division, as shown in figure 16-1. The operating divisions are under the direction of the Shops Engineer. The Shops Engineer is always a military billet. In the absence of the Assistant Public Works Officer, the Shops Engineer becomes acting Assistant Public Works Officer.

At PWDs with a limited workload, the operating divisions are combined to form a Shops Division, which is divided into a Maintenance and Utilities Branch and a Transportation Branch, as shown in figure 16-2. Under this organization the Shops Division is normally under the direction of a civilian rather than a Shops Engineer. The civilian Shops Division Director is directly under the Assistant Public Works Officer.

At PWDs where SEABEES are assigned, BUs, SWs, UTs, and CEs will normally work in the Maintenance and Utilities Divisions, whereas the EOs and CMs will work in the Transportation Division. The SEABEES may perform special project tasks or they may work hand-in-hand with their civilian coworkers.

Shops Engineer

The Shops Engineer generally directs and coordinates all matters pertaining to the operations of the Maintenance, Utilities, and Transportation Divisions. The Shops Engineer more specifically:

1. Analyzes management reports provided by other organizational components to determine excessive direct or overhead labor cost, and directs the corrective measures when variances from plans are reflected.
2. Reviews reported cause of variance between actual and estimated costs for work in progress, and institutes appropriate action.
3. Verifies physical progress of specific jobs by personal on-the-job inspections and keeps the Assistant Public Works Officer and/or Public Works Officer advised of the status of important or urgent work.
4. Compares the available labor with apparent or anticipated workload, as shown on the Work Input Control Charts, and recommends changes in the work force to the Assistant Public Works Officer and/or to the Public Works Officer.
5. Reviews special and routine work methods to assure the adoption of the most economical procedures, including utilization of manpower and equipment.
6. Assures that work improvement suggestions and methods are fully utilized.
7. Prepares or reviews justifications and recommends the procurement of equipment and tools, as required.

The Shops Engineer will have under his immediate direction one to three division officers who are designated as Maintenance Officer, Utilities Officer, and/or Transportation Officer. These officers normally function in a line capacity, when determined to be qualified by the PWO to carry out these functions.

Maintenance Division

The Maintenance Division is responsible for the maintenance of buildings, grounds, ground structures, refrigeration units, Government-owned internal communication and fire-alarm systems, roads and railroad trackage; and public utilities including electrical, water, steam, air, gas, fuel oil, and sanitary systems. This includes, when authorized, repair, alteration, and new construction incident to maintenance, except work that may be done by private contract. The Division is responsible for accomplishing all work on utilities plants and systems, providing caretaking services, maintaining all grounds of the activity, collecting garbage and trash, and controlling insects and rodents.

The shop components of the Maintenance Division will vary among types and sizes of activities because of the availability or nonavailability of certain crafts and shop facilities within other organizational components of the activity. For example, the variety of crafts and shops required in the Public Works Department at a nonindustrial activity, such as a Naval Training Center, will be greater than at an industrial activity, such as a shipyard, because of the availability of support from production shops at the latter. The grouping of shops by branches as shown below may require realignment locally to give maximum supervisory efficiency depending on the size of the shops and the availability of support from other shops within the activity.

The following shops are established within the Maintenance Division as required:

BUILDING TRADES BRANCH

Carpentry
Paint
Wharf Building
Masonry
Rigger (Local conditions may warrant placing riggers in one of the other branches or in the Transportation Division)

METAL TRADES BRANCH

Plumbing and Pipe Fitting (includes boiler work when the workload does not warrant a Boiler Shop)
Boiler (at activities where boiler workload warrants)
Sheetmetal
Metal (welders and steelworkers)
Machine

ELECTRICAL BRANCH

Electrical
Communications and Fire Alarm
Refrigeration and Air Conditioning

GENERAL SERVICES BRANCH

Janitorial and Grounds (including Labor Pool)
Refuse Disposal and Pest Control
Grounds Structures (Railroad Trackage, Roads, Paving, etc).

EMERGENCY/SERVICE BRANCH

The Emergency/Service Branch is responsible for accomplishing work of an emergency/service nature, thus allowing other shops to devote their time to scheduled maintenance work. At overseas activities, Emergency/Service requests may be handled by SEABEES assigned to the Maintenance Division.

The staff of the Director of the Maintenance Division may include clerical personnel, a maintenance scheduler, and shop planner. The primary requirement for clerical personnel in the Maintenance Division is the provision of clerical assistance to the division director and scheduling personnel.

The maintenance scheduler provides overall job planning at the Maintenance Division level. The shop planners provide supplemental detailed planning at the work center level. A ratio of approximately one shop planner to sixty employees in the Maintenance Division or one shop planner to forty personnel in the basic trade areas (building trades, metal trades, electrical) is adequate.

Organizationally, the shop planners should be on the staff of the Director of the Maintenance Division. If less than six shop planners are employed, they are placed under the supervision of the scheduler. If six or more are employed, a Shop Planning Staff is formed, with the supervisory shop planner under the direct supervision of the Director of the Maintenance Division.

Utilities Division

The Utilities Division is responsible for the operation of utility plants and distribution systems. This Division is responsible for the operation, operator inspection, preventive maintenance inspection, and service work in accordance with maintenance control procedures for power, heating, refrigerating, compressed air, water, and sewage treatment plants, fixed pumping stations and substations, also of electric, water, steam, air, gas, and fuel oil distribution systems, except Supply Department fuel storage plants.

Another responsibility of the Utilities Division is determining the need of maintenance, scheduling shut-down time for the availability of equipment and systems for accomplishment of maintenace and overhaul, inspecting the work in progress, and final acceptance inspection of the work when completed. The Utilities Division will provide the necessary assistance as requested for control inspection in specialized areas.

The Utilities Division is staffed with the minimum number of personnel of utilities and related utilities trades to perform the above functions. Maintenance work beyond the responsibilities stated above should be recommended by the Director of the Utilities Division and processed through the Maintenance Control Division for accomplishment either by contract or by station forces. When maintenance or overhaul work is accomplished by station forces, the Utilities Division provides technical journeyman assistance as necessary and available.

The components of the Utilities Division will vary among types and sizes of activities and will also depend on the degree to which utilities are generated or purchased. The following components are established within the Utilities Division as required:

GENERATION AND DISTRIBUTION BRANCH

- Steam
- Electric
- Miscellaneous

WATER AND SEWAGE BRANCH

- Water Treatment
- Sewage Treatment

The staff of the Utilities Division may include clerical personnel for division administration and for clerical assistance to the Division Director.

Transportation Division

The Transportation Division is responsible for providing transportation and equipment services to all components of the activity. These include. operating vehicle and equipment pools, operating scheduled and unscheduled passenger and freight transport systems, maintaining automotive, construction, railroad, mobile firefighting, weight-handling and, material-handling equipment where applicable.

This Division authorizes maintenance work on assigned equipment chargeable against approved estimated standing job orders subject to limitations as follows. maintenance work required for any specific job should not exceed (a) a maximum of 16 man-hours direct labor or (b) a maximum cost of $100 labor and material without being referred to the Maintenance Control Division for approval prior to proceeding with the work. The Transportation Division is also responsible for inspection, testing, and maintaining weight-handling equipment except that located in, and considered part of the building structure, such as bridge, wall jib, pillar, and mono-rail cranes, which fall under the cognizance of the Maintenance Control Division.

The Transportation Division is responsible for determining the maintenance and repair required, the scheduling of the work, the accomplishment of the maintenance and overhaul; the inspection of the work in progress, and the final acceptance inspection of the work when completed.

In order to obtain the maximum in efficiency and economy, maintenance and repair beyond the responsibilities specified above is recommended by the Director of the Transportation Division and processed through the Maintenance Control Division for accomplishment either by contract or by station forces.

Normally, the Transportation Division consists of two branches: an Operations Branch and a Repair Branch. The Director of the Division will be responsible for such functions as: scheduling preventive maintenance inspections of all equipment, inspecting to determine necessary repairs, authorizing all work within approved man-hour and dollar limitations, and scheduling, dispatching, and expediting authorized work. These functions are to be consistent with the policy and guidance provided by the Maintenance Control Division. The major functions of these branches are as follows:

OPERATIONS BRANCH

1. Determine number and types of vehicles and equipment to effectively and efficiently meet station requirements.
2. Operate intra-station transportation systems for the movement of personnel and material.
3. Authorize transportation work requests and provide equipment and operators to other organizations for specific work assignments.
4. Assign vehicles and equipment to other station activities on a semipermanent basis ("B" assignments).
5. Examine and license motor vehicle and equipment operators.
6. Develop budget estimates for operations funding requirements and prepare vehicle and equipment allowance and requirements requests.
7. Coordinate and supervise commercial contracts, leases, and charter transportation service.

REPAIR BRANCH

1. Accomplish all repair work authorized on Shop Repair Orders (SRO) or work requests as dispatched by the Division Director.
2. Determine additional work uncovered during work accomplishment and refer to the Division Director.
3. Perform quality control inspection after work accomplishment.

At large Public Works Departments, the Repair Branch may consist of an Automotive Repair Section, an Equipment Repair Section, and a Materials-Handling Equipment Repair Section.

PUBLIC WORKS MAINTENANCE MANAGEMENT

Good management consists of three basic factors: objectives, resources, and the utilization of resources. These fundamentals apply throughout all phases and levels of maintenance management, but particularly so at the Public Works Department level. It is at this level that the maintenance and operating funds are expended, and good management is required to obtain the greatest return from the funds provided.

The objectives of the Public Works Department are:

1. To economically maintain the public works and public utility facilities of the activity in a state of readiness to permit the activity to carry out its mission.
2. To provide essential utilities and to efficiently operate these systems.
3. To satisfactorily provide transportation and other required services, and to economically maintain the related equipment.

The resources available to the PWO for achieving these objectives are money, manpower, material, equipment, and assistance from others. Generally, all these resources are available, but they occur in varying amounts and with varying restrictions at individual activities.

The PWO can frequently supplement the manpower in his organization by obtaining required assistance from other departments at the same Navy activity, other Navy activities, or other agencies of the Government. Contract capability provides another source of manpower, and exists in varying degrees in all locations.

Field Divisions provide the PWO with technical and program management assistance. In addition, many technical and management publications are available for guidance.

A knowledge of the type and amount of all resources available is essential for proper public works management. While many of these items may be beyond the control of the PWO, he is in a position to influence the amount of some of the resources made available to him by a detailed knowledge and appreciation of his objectives and what is required to meet these objectives.

The maintenance management program is being constantly reviewed, and changes are made as necessary to improve its effectiveness. These changes affect only the details, and not the fundamental elements.

In order to assist the PWO in achieving his overall objectives, the aims and purposes of the maintenance management program are designed to:

1. Perform maintenance on a scheduled, planned basis rather than on an intermittent breakdown basis.
2. Assure that the various items of public works and public utilities meet their functional requirements in relation to the mission of the activity.
3. Provide more direct control over the use of the maintenance labor force.
4. Guard against and eliminate overmaintenance and undermaintenance.
5. Take corrective action before advanced deterioration necessitates major repairs.
6. Free the maintenance supervisor from administrative details and burdens that interfere with direct supervision of the maintenance force.
7. Correlate the work force and work capacity of shop or work center with its workload.
8. Obtain equitable distribution of shop forces.
9. Determine what each maintenance job should cost for comparison with actual cost
10. Provide facts and statistics indicative of trouble areas that need corrective action by management.
11. Reduce to a minimum the number of record keeping systems.

The basic elements of maintenance management are those that have been proved by experience to be fundamental to any maintenance program. They are discussed in the following sections, in the approximate chronological order required to install an effective program.

INVENTORY

A maintenance manager must know what facilities he must maintain, how many exist, and where they are located. For this reason, the establishment of an inventory of all facilities is part of the foundation of maintenance management. The data for these inventory records are taken from activity plant account records and those used in conjunction with the Shore Facilities Planning System. Since these records do not contain all essential information about the amount and types of electrical and mechanical systems and related equipment contained in the individual facilities, they form a basis only, and it is necessary to resort to a physical survey of all facilities to complete the inventory of what and how much is to be managed. The resulting information forms the basis for developing the continuous inspection schedule, and for planning maintenance requirements.

MAINTENANCE STANDARDS

The maintenance standards for a facility or a component of a facility is the established level at which it should be maintained in order to ensure overall economy consistent with its functional requirement, and with the protection of the investment by the Government. A specific level of maintenance is established for each facility, taking into consideration its relation to the mission of the activity and the estimated remaining life of the facility.

INSPECTION

Once the inventory and the maintenance standards have been developed, it is necessary to inspect the individual facilities on a scheduled basis, to obtain information on deficiencies which must be corrected if the established maintenance levels are to be maintained. This is accomplished through a procedure known as continuous inspection, whereby an inspection will be made of each facility, at specified intervals. Three types of inspection are made: operator, preventive maintenance, and control.

Operator Inspection

Operator inspection consists of examination, lubrication, and minor adjustments of equipment and systems for which the PWO is responsible and to which a specific operator is assigned.

Preventive Maintenance Inspection

Preventive maintenance inspection consists of examination, lubrication, minor adjustment, and minor repair of equipment and systems for which the PWO is responsible but to which a specific operator is not assigned. Preventive maintenance inspection is concerned primarily with items that, if the equipment were disabled, would: (1) interfere with an essential operation of the naval activity; (2) endanger life and/or property; or (3) involve high cost or long lead time for replacement.

Control Inspection

This is a scheduled examination and/or test of public works and public utilities to determine the physical condition with respect to the established maintenance standards. These inspections are performed by full time inspectors in the Maintenance Control Division (MCD) of the Public Works Department.

All deficiencies, whether reported by operators, preventive maintenance inspectors, or control inspectors, are reviewed to determine need, urgency, and fund availability. As a result of the review, they are either (1) processed for accomplishment by station forces or contract, (2) included as an item of the Unfunded Facilities Deficiencies, formerly known as Backlog of Essential Maintenance, or (3) reported as projected maintenance requirements.

Unfunded Facilities Deficiencies

This classification includes those items of maintenance and repair of public works and public utilities such as buildings, structures, pavements, utility systems, grounds, and so forth, which should be corrected to conform to maintenance standards, but which cannot be corrected because of lack of resources. The deficiencies are of such urgency that they should be funded within approximately 12 months following the reporting date.

Maintenance and repair items which will ultimately require corrective action but not within the period noted above will be classified and reported as Projected Maintenance. If improvements are involved in repair items, only the estimated repair portion is listed in the unfunded facilities deficiencies. Neither does it include items of alteration, improvement, or new construction.

Maintenance and repair deficiencies are reported regardless of the source of funds for correction of the deficiency and regardless of the method used for correction, such as station forces (civilian or military), contract, or by other means.

Projected Maintenance

Projected maintenance provides information on funding requirements for advance budget planning purposes only. In general, it consists of items similar to those included in the unfunded facilities deficiencies but for which the urgency of correction is not so great and the item may be funded in periods later than that for items in the deficiencies list.

For an item to be classified as projected maintenance, it should be an item subject to scheduled overhaul, an item subject to cyclic maintenance, such as painting and reroofing, or there should be some evidence of deterioration or wear insufficient at the time of inspection to classify it as an item of unfunded facilities deficiency, which is expected to increase with the passage of time and subsequently require corrective action.

Projected maintenance should not include items of alteration, improvement, new construction, or deficiencies which are to be corrected only for reactivation of facilities. Nor should it include items of a housekeeping nature, for example, items costing less than $100 to correct.

WORK INPUT CONTROL

Work input control is a formalized means of managing the facilities deficiencies work. It is an essential tool for management to evaluate the major maintenance work requirements and to make sound decisions on what work is to be done, who is going to do it, and when it should be done in consideration of relation of each facility to the mission of the activity and the resources available. It also serves as centralized reference for information on the status of all major or specific work. However it is not intended as a substitute for, nor does it require modification of, master or work center scheduling.

Scope

Work input control provides basic planning and status information about the work from its inception to its termination or completion. It includes those actions of screening the individual jobs for necessity, determining the relative urgency and programming them through the planning phase, authorizing the work, maintaining a balanced and adequate workload in each work center, assuring proper completion of the jobs, and keeping informed on the status of the jobs. The system may be modified at individual activities to fit the specific needs of that activity.

Some activities may desire to list minor work authorizations, or to include individual standing job orders that may vary in scope with the seasons of the year. Guidelines provided by NAVFAC cover specific jobs accomplished by the maintenance or utilities divisions and are considered to contain fundamental information essential to proper management. Local management will generally take the form of expanding the scope and coverage of the system. It can also decide the format and internal procedures most suitable to its purposes.

Responsibility

Work input control–that is, the work fed to the shops–is the maintenance control director's responsibility, but is subject to close review and approval by the PWO or his designee. Many of the decisions required must take into consideration the total resources available to the Public Works Department and frequently involve several divisions of the PWD. Active participation in work programming and decision making by the PWO are essential to effective work input control.

At large activities this active participation and review of the action of the maintenance control director would normally be the responsibility of the Assistant PWO, whereas at small activities, the PWO would serve as the day-to-day manager of public works overall operations.

WORK CLASSIFICATION

To properly identify individual jobs and to provide a means of obtaining costs and statistical information for management use, work is classified as Emergency, Service, Minor Work, Specific Jobs, Standing Jobs, Supplements or Amendments to Existing Jobs, and Rework.

EMERGENCY WORK.–The primary characteristic of emergency work is the necessity for immediate performance of a specific job, in order to prevent loss of or damage to Government property, to restore essential services that have been disrupted, or to eliminate hazards to personnel or to equipment.

SERVICE WORK.–This work is relatively minor in nature–requiring 16 hours or less–and is not classifiable as emergency work.

MINOR WORK.–This is work that will require more than two mandays for accomplishment, but less time than that normally authorized by a specific job order. This work is charged to a standing job order, and must be funded from the activity Operation and Maintenance (O&M) funds.

SPECIFIC JOBS.–In general, these jobs are requested by another department, or another activity.

STANDING JOBS.–Standing jobs involve work that is repetitive, or for which costs are accumulated for a definite period. They may include work that normally would be classified as emergency, service, or minor work, but they may be issued on a monthly, quarterly, semiannual, or annual basis.

SUPPLEMENTS TO EXISTING JOBS.–This type of work, as its name implies, covers additional work on a job for which final costs have already been submitted, or for which the job order has been closed. At the same time, there must be a continuation of work already covered in a previous job order.

AMENDMENTS TO EXISTING JOBS.–These job orders authorize job processes not within the limits of the original job order, or rectify omissions or errors in the original job order, but not evident until the work had been put into the input control system.

REWORK. These jobs are necessary in order to correct faulty work already accomplished.

NUMERICAL IDENTIFICATION FOR REPORTING

Maintenance management relies to a great extent on the availability and accuracy of various data. The key to this data is provided by codes that identify and classify the numerous actions that are part of maintenance management. The rules governing the use of code numbers provided for these purposes and, in certain cases, the actual prescribed code numbers (for instance, labor class code numbers) are intended to be applied uniformly by activities throughout the Naval Shore Establishment. The control numbers for job orders are not so standardized, although the principles underlying their use are applicable to all naval activities.

Codes have been established to designate the following areas.

1. Job Order Numbers, to identify a particular job and to relate that job to specific fiscal data.
2. Labor Class Codes, to identify the various types of work performed in the productive and overhead areas.
3. Work Center Codes, to identify the organizational components who are performing work.

EMERGENCY OR SERVICE AUTHORIZATION

During regular working hours, emergency/service requests (TROUBLE CALLS) are received by telephone at a TROUBLE DESK, usually located at the Work Reception and Control Branch of the MCD. The functions of the trouble desk require that it be an around-the-clock operation. Alternate points, such as the public works duty office or other 24-hour service locations, are used after working hours to receive and process only emergency trouble calls.

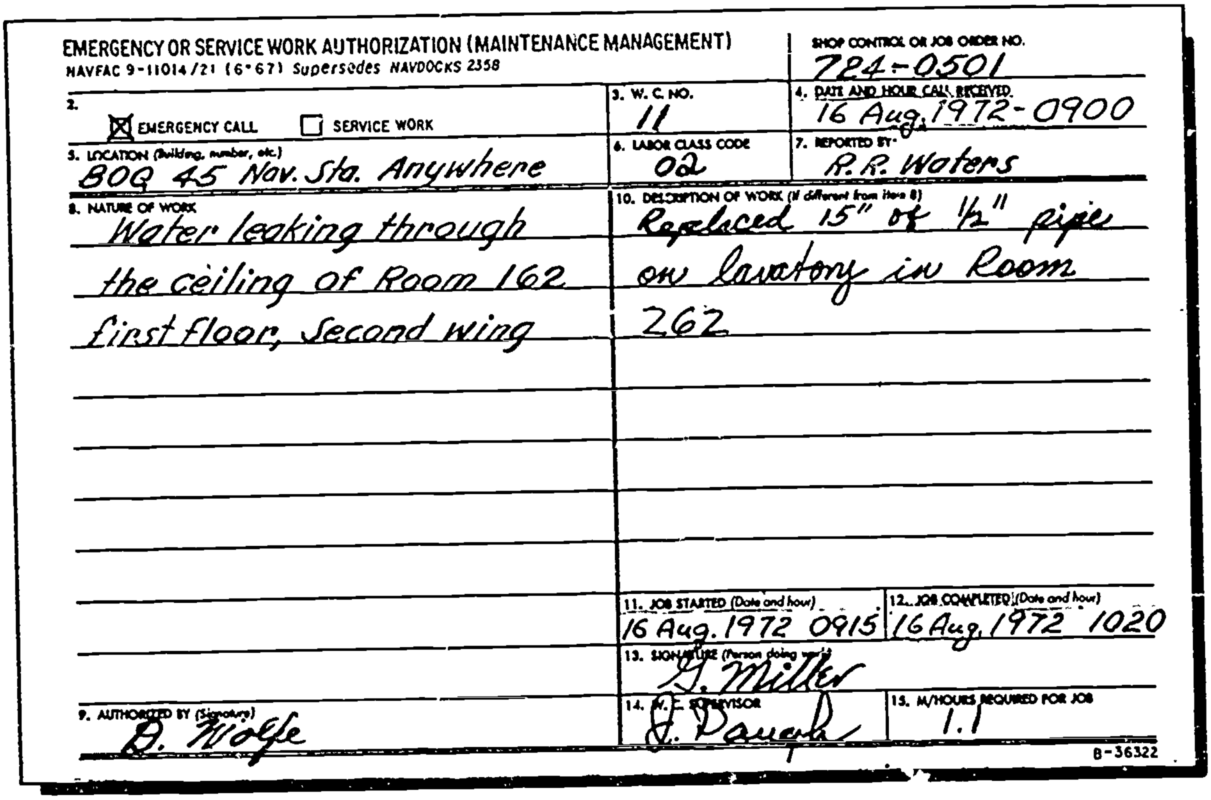
When a trouble call is received, all pertinent information is entered on an Emergency or Service Work Authorization, NAVFAC Form 9-11014/21, in blocks 1 through 9, as shown in figure 16-3. The form is then given to the work center responsible for emergency/service work. When the work has been completed; blocks 10 through 15 are filled in with appropriate information and returned to the MCD. In emergency situations, the person at the trouble desk will call the work center immediately to dispatch an emergency crew and later follow up with the emergency work authorization.

WORK REQUESTS

Work requested, other than emergency/service work, by persons other than designated inspectors is forwarded to the MCD Work Reception and Control Branch on a Work Request (NAVFAC Form 9-11014/20, as shown in figure 16-4. Blocks 1 through 10 on the work request are filled in by the requester. The work request is then usually forwarded to a maintenance liaison representative. Maintenance liaison representatives are personnel of departments, divisions, or other component units within the naval activity, or other activities, through whom requests for maintenance work are channeled for review and verification. They are responsible for checking duplication of work requests, necessity for the work, compliance with forms and procedures, assignment of work request numbers, and obtaining current status of work requests.

At large activities, with many departments or tenant activities, the PWC/PWD will have junior CEC Officers who act as Activity Liaison Officer (ALOs). The duty of each ALO is to provide liaison between the PWC/PWD and the maintenance liaison representatives concerning services performed by the Public Works activity. He will channel work requests to the MCD, expediting important requests, and provide up-to-date work request status. The ALO reduces the amount of direct communication between the customer and the MCD, except for emergency work.

Once the work request is received by the Work Reception and Control Branch of the MCD, it is logged in and given to the Inspection Branch to ensure that the work is not included on current job orders for continuous inspections. If the work is covered by a job order, the work request is returned to the customer advising him of that fact. If the work is not covered by a job order, the work request is forwarded to the Planning and Estimating Branch for an estimate of the work. If the work request indicates that a cost estimate is required prior to


EMERGENCY OR SERVICE WORK AUTHORIZATION (MAINTENANCE MANAGEMENT)
NAVFAC 9-11014/21 (6-67) Supersedes NAVDOCKS 2358

SHOP CONTROL OR JOB ORDER NO. 724-0501

2. [X] EMERGENCY CALL [ ] SERVICE WORK

3. W. C. NO. 11

4. DATE AND HOUR CALL RECEIVED 16 Aug. 1972-0900

5. LOCATION (Building, number, etc.) BOQ 45 Nav. Sta. Anywhere

6. LABOR CLASS CODE 02

7. REPORTED BY: R.R. Waters

8. NATURE OF WORK Water leaking through the ceiling of Room 162 first floor, Second wing

10. DESCRIPTION OF WORK (If different from item 8) Replaced 15" of 1/2" pipe on lavatory in Room 262

11. JOB STARTED (Date and hour) 16 Aug. 1972 0915

12. JOB COMPLETED (Date and hour) 16 Aug. 1972 1020

13. SIGNATURE (Person doing work) G. Miller

9. AUTHORIZED BY (Signature) D. Wolfe

14. W.C. SUPERVISOR J. Dauch

15. M/HOURS REQUIRED FOR JOB 1.1

B-36322

117.295

Figure 16-3.—Emergency or Service Work Authorization, NAVFAC Form 9-11014/21.

authorization of the work, a preliminary cost estimate is entered in Part II of the work request and returned to the customer as directed. If the estimate is acceptable, the customer will complete Part III of the work request and return it to the MCD. This is the authorization for the MCD to proceed with the final estimate, programming, and scheduling of the work. But if the work request indicates performance of work rather than a cost estimate, the Planning and Estimating Branch will prepare a final estimate without returning the work request to the customer for authorization to proceed.

Now the Work Request is assigned to one Planner and Estimator who is responsible for the entire job estimate. This Planner and Estimator is usually the one who estimates for the craft having the largest number of man-hours of work among the several crafts involved. He is also responsible for coordinating the estimates of the other Planners and Estimators and assembling all phases of the job in the sequence they will appear on the Job Order.

Each Planner and Estimator will use a separate Job Phase Calculation Sheet for each craft phase of his particular assignment or craft responsibility within the total work required by the Work Request. A job phase is a task, or group of tasks, that can be accomplished during an uninterrupted period of work by a particular craft. The job phases should be prepared as illustrated in figure 16-5, giving the craft phase number, job identity number, the date the P&E made the estimate, work center number and title, job phase description (this is the exact wording to be placed on the job order), and task description. Each Planner and Estimator will furnish to the Planner and Estimator responsible for the entire job the sequence of his assignment

WORK REQUEST (MAINTENANCE MANAGEMENT)
NAVFAC 9 11014/20 (REV. 2-58) S/N-0105-002-7310
Supersedes NAVDOCKS 2331

(PW Department see Instructions in NAVFAC MO-321)

Requestor see Instructions on Reverse Side

PART I—REQUEST (Filled out by Requestor)

1. FROM: Supply Officer
2. REQUEST NO.: 12-711
3. TO: Public Works Officer
4. DATE OF REQUEST: 25 June 1972
5. REQUEST FOR: ☐ COST ESTIMATE ☒ PERFORMANCE OF WORK
5a. REQUEST WORK START:
6. FOR FURTHER INFORMATION CALL: LTJG L. Moore Bldg. C. Ext. 891
7. SKETCH/PLAN ATTACHED: ☐ YES ☒ NO
8. DESCRIPTION OF WORK AND JUSTIFICATION (Including location, type, size, quantity, etc.)

Fabricate and erect extension to wood storage rack, southwest corner, Bldg. 107. Start from the south wall and extend through bays 3-4 approx: 30' long
2' deep
10' high

Storage rack to be anchored to wall and have 5 shelves spaced approx. 2' apart. Shelves should be capable of storage of material weighing up to 5 lbs. per sq. ft. No paint required.

Extra storage space needed for small shop store items.

9. FUNDS CHARGEABLE: 37602 (S&A)
10. SIGNATURE (Requesting Official): J. R. Brown
J. R. BROWN, LCDR, USN

PART II—COST ESTIMATE
(Filled out by Maintenance Control Division if estimate requested)

11. TO: Supply Officer
12. ESTIMATE NO.: 307

13. COST ESTIMATE	
a. Labor	$ 140.
b. Material	$ 90.
c. Overhead and/or Surcharge	$
d. Equipment Rental/Usage	$
e. Contingency	$ 25.
f. TOTAL	$ 255.

14. SKETCH/PLAN ATTACHED: ☐ YES ☒ NO
15. ☐ APPROVED. PROGRAMMING TO START IN ____
☒ APPROVED. BASED ON PRESENT WORKLOAD, THIS JOB CAN BE PROGRAMMED TO START IN August, IF AUTHORIZED BY 25TH OF July AND FUNDS ARE MADE AVAILABLE.
☐ DISAPPROVED. (See Reverse Side)
16. SIGNATURE: William B. King
17. DATE: 2 July 1972

PART III—ACTION (Filled out by Requestor)

18. TO: Public Works Officer
19. AUTHORIZATION TO PROCEED IS ATTACHED (Check one if other than PW funds are involved): ☒ NAVCOMPT 140 ☐ OTHER
20. WORK REQUESTED: ☐ HAS BEEN CANCELLED ☐ HAS BEEN DEFERRED ☐ WILL BE PERFORMED BY OTHERS
21. SIGNATURE: J. R. Brown
J. R. BROWN, LCDR, USN
22. DATE: 7 July 1972

(See Part IV on Reverse Side)

117.294

Figure 16-4.—Work Request, NAVFAC Form 9-11014/20.

JOB PHASE CALCULATION SHEET
NAVFAC 11014/23 (REV. 9-72)

*See NOTE below

Work Site			
Cost Phase No	Job Phase No	Job Identity No	Date
1	1	602	19 Sept 1972

Work Center No and Title: 01 Carpenters

Job Phase Description: Construct 30' long, 12' high full partition, gypsum wall board both Sides, 2" x 4" Studs 24" O.C.; 5" baseboard, Shoe molding, 3" Ceiling cove molding both sides to match; install 2'-8" x 6'-8" door. Install 4" chair rail on interior walls and 1/4" Plywood Subfloor.

Reference	Task Description	EPS Estimated Time: Unit Hours a.	Occurrence b.	Craft Time c.	Non-EPS Estimated Time 10
39L	Construct 30' long, 12' high partition 2" x 4" Studs 24" O.C., gypsum board shoe molding and 5" baseboard both sides, 1 door Opening framed and closed.	16	1	16.0	
34 E	Install 3" Ceiling cove molding each side partition (60 L.F)	1.8	.6	1.1	
12 E	Hang 2'-8" x 6'-8" door in partition	1.8	1	1.8	
51 C	Install 4" chair rail on interior wall of office (180 L.F.)	.6	2.5	1.5	
22 E	Lay 1800 S.F 1/4" Plywood Subfloor	1.8	9.4	16.9	

TOTALS (Craft & Estimated Time)	37
TOTAL (EPS from Nomograph)	57
TOTAL JOB PHASE TIME	57 *

*NOTE: This form should be used for BOTH EPS and NON-EPS estimates.

SHEET OF

87.5

Figure 16-5.—Job Phase Calculation Sheet, NAVFAC Form 9-11014/23.

for each of his craft phases, for inclusion on the Estimate and Job Order.

The Planner and Estimator responsible for the entire estimate collects all job phase estimates and assembles them in the sequence they will appear on the job order, by entering the Job Phase No. on each sheet. Then he completes the estimate (fig. 16-6). The estimate is placed on top of the job phase calculation sheets with any drawings that are pertinent and this package is given to the MCD for review and approval.

Upon approval by the proper authority the MCD will give the entire estimate to the Work Reception and Control Branch for typing, posting, dispatching and filing The Work Reception and Control Branch will type the job order from the information contained on the estimate (fig. 16-6) and the job phase calculation sheets. Only the work center number, job phase description, and total job phase time will be taken from the job phase calculation sheet and entered on the job order. The craft phase description on the job order should be identical with the job phase description on the job phase calculation sheet.

The completed job order (fig. 16-7) is submitted to the MCD for approval, and released to the shops for purchase of material, scheduling, and accomplishment of work.

PUBLIC WORKS PLANNING AND ESTIMATING

The Planner and Estimator holds a key position in the maintenance management system for public works and public utilities. His function is to technically plan jobs and correctly estimate the number of hours needed to accomplish maintenance work. His estimates are the initial basis upon which management must plan, schedule, and subsequently evaluate the maintenance labor efforts and costs. To a great extent, the judgment and technical experience of the Planner and Estimator can be measured by his job plan.

PLANNING THE JOB

The job plan prepared by Planners and Estimators should specify the work, material and equipment, how work should be phased, and what craft will do the work. In terms of Maintenance Management this means that complete specifications will be provided, the several phases that make up the job will be described, and the applicable Work Centers will be indicated. The clarity, correctness, and completeness of the job plan is most important when there is to be accurate estimating, effective material coordination, and realistic shop scheduling. Plans and estimates must coincide with the work request and/or inspection reports, to correct the cause of deficiency and reflect the scope of work required to achieve the level of maintenance desired. By this is meant not over or under maintenance, but the quality and quantity of maintenance established for the facility being maintained.

ADEQUATE SPECIFICATIONS

Adequate specifications are an important part of every job order. The test of adequacy is the degree of reliance that the Maintenance and Utilities Divisions can place on the specification to justify ordering materials, obtaining the necessary tools and special equipment or personnel, scheduling the work, and setting manpower in motion without prior visits to the jobsite by the various Work Center supervisors concerned.

Planners and Estimators in the Maintenance Control Division should not hesitate to seek technical assistance in obtaining necessary specifications. This may call for on-site inspections, consultation with Maintenance Division personnel, or, in the case of difficult technical problems, the advice and engineering assistance of the Engineering Division. Wherever necessary, sketches or drawings should be furnished describing sizes, dimensions, or other pertinent technical characteristics.

MATERIALS

Grouping material requirements can be of assistance to the Planner and Estimator in procuring materials. This technique is based on assembling detailed material estimates into related in-place items. As an example, rather than list and price separately the quantities of felt, nails, asphalt, and gravel, needed to install a three-ply built-up roof, the Planner and Estimator will use in-place descriptions. These de-

ESTIMATE (CONTROLLED MAINTENANCE)
NAVDOCKS 2353 (REV 3-60)

1. ACTIVITY: Naval Station, Anywhere		2. ACTIVITY CODE	3. JOB ORDER NO. / 4. SHOP CONTROL NO. / 5. ESTIMATE NO.: 602
6. ACTIVITY ACCOUNTING NO.: 62690	7. BUDGET FUNCTION CODE: 10	8. P W CODE: 1085	9. PROPERTY: 77
10. APPROPRIATION: 1721804	11. SUBHEAD: 2515	12. ALLOTMENT/PROJECT: 12008	13. EXPEND. ACT: 44376
14. FOR FURTHER INFORMATION CALL: Walter Mason 601			15. SKETCH/PLAN ATTACHED: ☒ YES ☐ NO Drawing No. SK-1721
16. GENERAL JOB DESCRIPTION	17. Use Labor Class Code 07 except for overhead		COMPLETION STARTING DATE: December

Convert East end of warehouse Bldg #14 for office use. Install 30' long full partition with door as shown by sketch. Install new lighting system and duplex outlets; 2 radiators and water cooler. Lay plywood sub-floor and tile. Paint interior surfaces and exterior of new partition. Install awning over the windows on the East and South sides of the building.

18. BREAKDOWN OF WORK

WORK CENTER (a)	DESCRIPTION (b)	EST. HOURS (c)
	For continuation see Sheets ____ through ____	

19. SUMMARY OF ESTIMATES

WORK CENTER (a)	LABOR HOURS (b)	LABOR (c) $	MAT'L. (d) $	TOTAL EST. (e) $
01	107*	318.86	667.47	986.33
21	67*	207.03	750.36	957.39
11	47*	145.23	622.50	767.73
02	100*	298.00	62.40	360.40
01U	5	20.00	100.00	120.00
TOTAL	326*	989.12	2202.73	3191.85
f. CONTINGENCY				
g. OVERHEAD AND/OR SURCHARGE				
h. GRAND TOTAL				3192

20. DISTRIBUTION

INSP	1	FISC	i
MCD	1	MAINT.	9
FIN.	1		
R&S	1		

21. PLANNER AND ESTIMATOR (Signature): Walter Mason
22. DATE: 27 Sept. 1972

SHEET 1 OF

117.304

Figure 16-6.–Estimate (Controlled Maintenance), NAVDOCKS Form 2353.

JOB ORDER (CONTROLLED MAINTENANCE)
NAVDOCKS 2356 (REV. 10-64)

Field	Entry
1. ACTIVITY	Naval Station, Anywhere
2. ACTIVITY CODE	
3. JOB ORDER NO.	724432
4. SHOP CONTROL NO.	
5. ESTIMATE NO.	602
6. ACTIVITY ACCOUNTING NO.	62690
7. BUDGET FUNCTION CODE	10
8. W.M. CODE	1085
9. PROPERTY NO.	77
10. APPROPRIATION	1721804
11. SUBHEAD	2515
12. ALLOTMENT/PROJECT	12008
13. EXPEND. ACT.	44376
14. FOR FURTHER INFORMATION CALL	Walter Mason
15. SKETCH/PLAN ATTACHED?	☐ NO ☒ YES — Drawing No. Sk-1721
16. GENERAL JOB DESCRIPTION	17. *Use Labor Class Code* 07 *except for overhead.*
COMMITTED STARTING DATE	December

Convert East end of warehouse Bldg. # 14 for office use. Install 30' long full partition with door as shown by sketch. Install new lighting system and duplex outlets; 2 radiators and water cooler. Lay plywood sub-floor and tile. Paint interior surfaces and exterior of new partition. Install awning over the windows on the East and South sides of the building.

USE REVERSE SIDE FOR REPORTING CONDITIONS THAT AFFECT THE JOB PERFORMANCE.

18. BREAKDOWN OF WORK

a. WORK CENTER	b. DESCRIPTION	c. EST. HOURS
01	Construct 30' long, 12" high full partition, gypsum wall board both sides; 2" x 4" studs 24" o.c., 5" baseboard, shoe molding, 3" ceiling cove molding both sides to match; install 2'-8" x 6'-8" door. Install 4" chair rail and interior walls and ¼" plywood subfloor.	57•
21	Install 3 new lighting and new outlet circuits as shown on sketch consisting of switch a· ᐟ distributio· panel, rigid conduit, wire anc c ıtlet boxes. Connect new light panel wi·h existing	46•

For continuation see sheets 2 *thru* 2

19. SUMMARY OF ESTIMATES

a. WORK CENTER	b. LABOR HOURS	c. LABOR $	d. MAT'L. $	e. TOTAL EST. $
01	107•	318.86	667.86	986.33
21	67•	207.03	750.36	957.39
11	47•	145.23	622.50	767.73
02	100•	298.00	62.40	360.40
01U	5	20.00	100.00	120.00
TOTALS	326	989.12	2202.73	3191.85
f. CONTINGENCY				
g. OVERHEAD AND/OR SURCHARGE				
h. GRAND TOTAL				3192

20. DISTRIBUTION

INSP.	1	FISC.	1
MCO	1	MAINT	9
FIN.	1		
R & S	1		

21. AUTHORIZED WORK TO BE PERFORMED (Signature) A. R. Dale

22. DATE 5 Oct. 1972

SHEET 1 OF 2

JOB ORDER CONTINUATION SHEET (CONTROLLED MAINTENANCE)
NAVDOCKS 2357 (3-56)

1. JOB ORDER NO. 724432
2. ESTIMATE NO. 602
3. SHOP CONTROL NO.

4. WORK CENTER NUMBER	5. DESCRIPTION OF WORK	6. ESTIMATED HOURS
11	Install two 2" steam supply and two ½" condensate return lines and connect in crawl space. Install two 10 section radiators. Install water supply and waste line and connect new water cooler.	44*
02	Prepare, prime, paint interior of new office and exterior of new partition 2 coats. Ceiling, sprinkler pipes, exterior of new partition—flat white. Interior—upper walls, ceiling molding light green semi-gloss enamel; lower walls, chair rail, baseboard, doors, windows and trim, dark green semi-gloss enamel.	100*
21	Install 6 Nema type duplex receptacles and 18 – 48", 4 tube louvre fixtures with lamps.	21*
01	Lay 1800 s.f. asphalt tile, light and dark green, checker pattern.	50*
11	Move and install water cooler. Connect cooler into system and check cooler after installation.	3*
01U	Install awning over the windows on the East and South sides of building #14.	5

Sheet 2 of 2

87.4

Figure 16-7.—Job Order completed and work authorized.

scriptions refers to a material cost per square of all materials in place. These descriptions and the cost figures, corrected for price changes, can be used for similar jobs.

Selection of appropriate materials may be based on information contained in maintenance and operations technical publications (NAVFAC Series 100 thru 312), activity policy, maintenance standards, fund limitations, or similar data. Under certain circumstances these reasons should be briefly noted in the specifications to indicate to the Maintenance Division why the materials are specified.

COMPLETENESS

The Planner and Estimator must not overlook his responsibility for stating clearly and accurately the nature of the work to be accomplished Assuming that the Planner and Estimator is conscientious, his failure to convey all aspects of the required work may come from over-familiarity or lack of familiarity with the type of work. If he is thoroughly conversant with the work to be done, he may assume wrongly that a general reference to the work by name will be sufficient. If he does not have enough experience with the type of work, his inadequacy may only be the result of a lack of information.

WORKLOAD ASSIGNMENT

Planners and Estimators workload consists of jobs requiring only an estimate, all jobs programmed for accomplishment during the current 3 month period, and also those jobs programmed in the 4 to 12 month period that require a long lead time for scheduling, procuring, or purchasing of material. Work input control charts, work requests, and inspection reports should be available to the Planners and Estimators for all work programmed and requiring an estimate. The Planner and Estimator representing the craft with the largest amount of work is usually responsible for coordinating the work of the other Planners and Estimators, and the assembling of the craft phases into a complete job estimate.

Jobs should be assigned to planners and Estimators far enough in advance to allow them to estimate the job in time to be released to the shops for securing material and for scheduling of work as programmed on the work input control charts. Although the work input control charts may reflect many jobs to be estimated, a Planner and Estimator's workload should be maintained in the range of 5 to 10 days.

ESTIMATING

One of the most important functions of the Maintenance Control Division is estimating. It has greater significance under Maintenance Management than the usual limited concept of a dollars-and-cents cost estimate. An estimate is the informed analysis of all the known elements of a proposed job and the resulting forecast of the manpower, materials, and related requirements that will be needed to accomplish the job. The principal purposes of estimating are to:

(1) Provide a basis for approval, disapproval, or deferment of proposed or projected jobs.

(2) Provide data for shop planning and scheduling.

(3) Provide a bench mark for evaluating the effectiveness of the Maintenance and Utilities Divisions and their Work Centers.

Estimating Guide

Maintenance management needs reliable guides upon which to base its judgment of satisfaction or dissatisfaction with all aspects of the maintenance effort. Because of the variable, nonrepetitive character of most maintenance work, the task of accumulating universal performance guides is slow and difficult. Two areas of information will help you develop these guides in terms of time and method; they are accumulated experience data and Engineered Performance Standards (EPS). Maintenance management emphasizes the need for accurate estimating.

In order to make planning and estimating more accurate in the maintenance of public works and public utilities, Engineered Performance Standards were developed. By observing maintenance craftsmen at work and measuring that work through the application of approved industrial engineering techniques, these standards were developed; they specify the time that should be required for work, rather than the time that is customarily used for unmeasured shop work.

The accuracy of estimating is increased if the work being estimated is analyzed by its constituent tasks and phases. Management, through reports provided under maintenance management, studies the deviations between estimated and actual labor hours, material costs, and total cost. These studies provide a check on work force productivity, estimate quality, and a basis for initiating corrective management action, if required.

Estimating Procedure

The Planning and Estimating Branch Manager selects jobs that have been programmed on the work input control charts, or assigned to the branch for an estimate, and then designates the Planner and Estimator who will be responsible for the final plans and estimate of the job.

SCOPE OF PROPOSED WORK. The Planner and Estimator then determines the work to be accomplished and which crafts are involved in the job. A good, clear and brief description of the entire job is then entered under the "General Job Description" of the Estimate (Controlled Maintenance), NAVDOCKS Form 2353 (fig. 16-6).

JOB PHASES DELINEATED. The job is divided into phases by craft, or within a craft, when a finer breakdown is required for planning and scheduling. Then each Planner and Estimator prepares a Job Phase Calculation Sheet for each phase under his responsibility, including sketches, plans, specifications or other data. The description of each job phase should be written just as it is to appear on the job order. The same Planner and Estimator responsible for the work content of the job collects all phases in the order they will appear on the Job Order, and prepares the Estimate. The description of the entire job and each job phase must be clear enough as to scope and nature of work to be performed so as not to create any misunderstanding regarding work accomplishment. The Estimate, which includes the Job Phase Calculation Sheets, is then presented to the Supervisor of the Planning and Estimating Branch and MCD for review.

PREPARATION OF THE JOB ORDER. When reviewed and corrected, the Estimate is transmitted to the Work Reception and Control Branch for typing of the Job Order and its distribution to the various crafts and supervisors. The information on the Job Order and the Job Order Continuation Sheet, NAVDOCKS Form 2357, will be the same as that on the Estimate, and the Job Phase Calculation Sheets, NAVFAC 9-11014/23. The job phases will be arranged on the Job Order (fig. 16-7), in the sequence they are to be scheduled or accomplished.

Types of Estimates

Three basic types of estimates prepared by the MCD are: preliminary estimates, rough estimates, and final estimates. Each conforms to a particular need.

PRELIMINARY ESTIMATE. It is probable that in some instances work for which estimates have been requested will not be authorized; therefore, to eliminate unnecessary work for the Planning and Estimating Branch, only preliminary estimates will be made in the early stages of a project.

Included are items that are uncovered by inspectors and that cannot be accomplished in the near future, such as projected maintenance or items assumed to be of a contract nature. Preliminary estimates usually will be relatively simple computations made on an overall basis using up-to-date unit cost information as a guide. As an example, a preliminary estimate for exterior painting of a frame structure may be based on the prevailing overall cents per square foot cost for labor and material.

ROUGH ESTIMATE. This is an approximation of man-hour or dollar requirements. It is given in terms of a job or work center and is used to compute the total man-hours and dollar requirements projected on work request and work input control charts for which final estimates have not been prepared.

Rough estimates include:

1. Work for which funds are available but for which no final estimate has been prepared and which is expected to be accomplished by activity forces.

2. Work for which funds are available but for which no final estimate has been prepared and no decision has been made as to accomplishment by activity forces or by contract. Rough estimates are never used in customer contracts.

FINAL ESTIMATE. This is the type of estimate in which all work operations and elements listed on the job plan are analyzed and considered in detail. It should be the most accurate forecast that can be made, within a reasonable time, of the costs and the man-hour and material requirements for a given job.

Estimating Criteria

In preparing final estimates the following factors should be considered:

1. TRAVEL TIME. This is the time required for the round trips between the shop and the jobsite for each man each day he works on the job.

2. PREPARATION. This is the time required for preparation of the jobsite, receiving instructions from superiors, and the layout of materials and equipment at the jobsite.

3. PERFORMANCE OF THE WORK. This is the time required for the actual performance of the craft work that is required to complete the job order. This calls for an analysis of each phase of the job listed in the job plan.

4. DIRECT AND INDIRECT MATERIAL REQUIREMENTS. It is the responsibility of the Planner and Estimator to specify the types of materials that are to be used for the job and to estimate the realistic cost of such materials. The Planner and Estimator should make available to the Shop Planner the quantity data used in arriving at the estimated material costs.

5. RENTAL OF EQUIPMENT. Equipment rental costs from commercial sources must be included when it is expected that necessary specialized equipment cannot be obtained without charge and must be rented.

6. CLEAN-UP AND RESTORATION OF THE JOBSITE. This factor includes the normal clean-up during the performance of the job and at the end of the working day, the restoration of the jobsite for use during nonworking periods, and the restoration of the jobsite to the condition that prevailed when the job began.

7. DELAY IN JOB AUTHORIZATION. If the job order is not authorized and issued within a reasonable time after submittal of the final estimate, the estimate should be reviewed before it is resubmitted for authorization. If necessary, it should be revised for conformance with current material and labor costs and other relevant factors.

8. CONTINGENCY. A contingency may be included as an additional factor in an estimate when the funds involved are not under the control of the Public Works Department or when a strict financial limitation has been placed on the job. A contingency factor should not exceed 10 percent. It is not generally applied to jobs involving Public Works Department Maintenance and Operating funds.

PUBLIC WORKS CENTER (PWC)

The Public Works Center (PWC) is similar to a Public Works Department but on a much larger scale, as a matter of fact the PWC was originally created by the consolidation of a number of individual PWDs for purposes of efficiency and responsiveness. The PWC is an independent organization under the command of the local area commander vice' a department of some command. Specific advantages that accrue from the PWC may be summarized as follows:

1. They permit an economical accomplishment of maintenance work by eliminating the duplication of public works facilities within the concentrated area, by reducing overhead costs, by reducing manpower requirements, and in general by achieving maximum utilization of personnel, materials, and equipment.

2. They permit flexibility in assigning personnel and equipment among activities, to correspond with shifts in workload.

3. They facilitate the employment of high-caliber technical supervisors, since they can usually offer higher grade jobs than could be justified for an activity employing a small force of personnel.

4. They concentrate the technical responsibility for public works maintenance in an organization that, because of wider experience,

can usually provide the required technical ability and specialized professional training.

5. They make feasible the purchase of more diversified and specialized equipment than would normally be available to the Public Works Departments of individual activities.

Figure 16-8 shows a standard organization chart for Public Works Centers.

Primarily, a PWC is a service agency that should operate, in general, like the city engineering department of a metropolitan area, except that its scope of activity is even wider than that of most such organizations. A PWC has basic interests in matters of civil, mechanical, electrical, and sanitary engineering, public safety, and automotive and rail transportation. More specifically, these interests extend to

1. structural safety and weathertight integrity of all structures, including weightlifting facilities
2. engineering for public safety and fire prevention
3. production, procurement, and distribution of heat, power, water, and other utilities
4. design and upkeep of roads; pavement and surface drainage
5. collection and disposal of trash and sewage
6. waterfront work and dredging
7. mass transportation
8. upkeep of transportation equipment

A PWC, because of its organization, saves money for the Government by the elimination of duplicate facilities and staffing, and by provision of necessary skills where and when they are needed. The net overall result to be sought when a PWC is established is improved efficiency and reduction in cost to the Department of the Navy as a whole.

The Norfolk Naval Base provides a good example. With a number of separate command organizations stationed at this base, appreciable economies can be effected by having public works functions performed by a single organizations, rather than divided among a number of small organizations. The combined workload justified the installation of equipment, and the employment of trained supervisory personnel, not readily available to a small shop at an individual activity. In this way, effective results are obtained at lower cost.

NAVFAC FIELD DIVISIONS

In discussing the functions, technical responsibilities, and administrative duties of a Public Works Department, frequent mention was made of the field divisions and activities of NAVFAC. One of the major functions of the Command itself and the primary function of the field divisions is to provide assistance to the Public Works Officers stationed at the various Navy activities and installations. NAVFAC provides assistance by promulgating policies and issuing directives concerning programs, management procedures, and so forth.

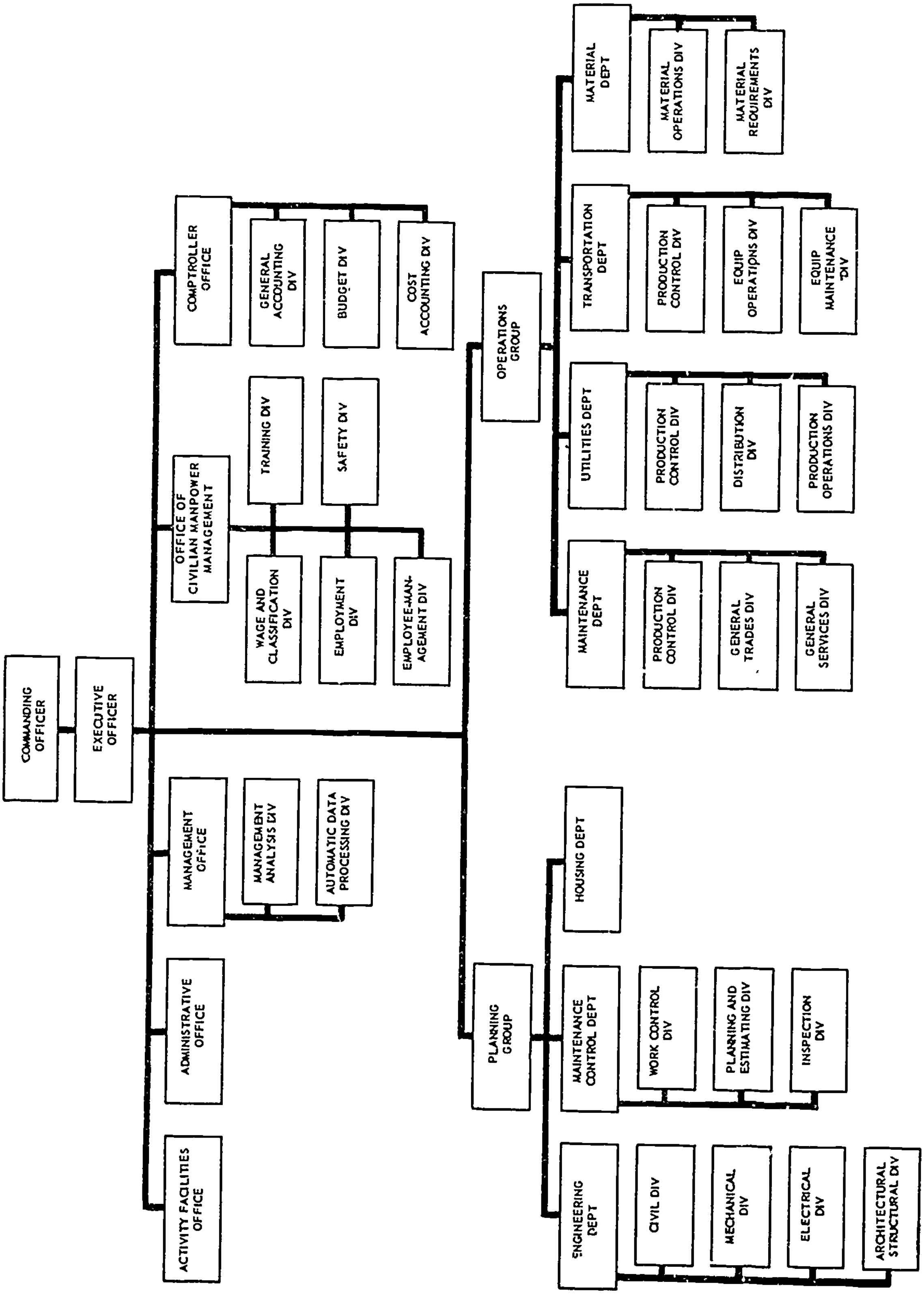
Field divisions work more directly with the individual activities, in that they help in implementing NAVFAC policies and programs, and also help the Public Works Departments in solving their particular problems. In the event that a field division is not able to render required assistance to an activity, then the field activity may request assistance from the NAVFACENGCOM Headquarters in solving the specific problem.

The Field Divisions exercise middle management responsibilities for the Commander, NAVFACENGCOM in the latter's capacity as the single executive responsible for the maintenance of buildings, grounds, and structures (Class I and Class II property) and the operation of utilities at naval installations. To enable the Field Divisions to discharge these responsibilities, an organization, together with assigned functions for major components, has been developed.

MISSION

Activities formerly titled District Public Works Offices and Area Public Works Offices are identified in this manual as Engineering Field Divisions (EFD) of the NAVFACENGCOM. As specifically approved by SecNav, their responsibilities are expressed by the following mission statement:

"To accomplish the planning, design, and construction of public works, public utilities and special facilities, including acquiring and dispos-



16.5

Figure 16-8.—Public Works Center organization chart.

ing of real estate for the Navy and other Federal agencies and offices, to direct and administer the maintenance of facilities and operation of utilities; to direct and administer the operation and maintenance of family housing, to administer the assignment, replacement, disposal, maintenance, and utilization of transportation, weight-handling, and construction equipment under the cognizance of the NAVFACENGCOM, to assist activities in the application of the programs which are assigned to NAVFAC for technical guidance or primary support; and to perform such other functions as may be directed by the NAVFAC Commander, NAVFACENGCOM."

The mission statement as it applies to an individual field division is delineated in greater detail by issuance of NAVFAC directives and instructions.

TASKS AND FUNCTIONS

The basic functions of a Field Division are as follows:

1. Provides technical facility planning service, conducts readiness planning, and provides technical and engineering guidance and assistance in connection with mobilization and emergency plans for all commands and activities.
2. Provides architectural and engineering design of public works and public utilities.
3. Provides for construction of public works and public utilities.
4. Prepares, awards, and administers contracts for planning, architectural and engineering services, utilities, and construction, supervises the contractual practices, procedures, performance, and staffing of subordinate contracting offices, designates Resident Officers in Charge of Construction (ROICC), and establishes local ROICCs to service an activity or group of activities.
5. Determines, manages, and disposes of real estate according to requirements generated by command or activity missions.
6. Represents NAVFAC in coordination, development, and reporting of requirements for acquisition, operation, maintenance, repair, and improvement of family housing.
7. Represents NAVFAC in performance of single executive responsibilities for facilities maintenance, utilities, and transportation operation.
8. Provides consulting services and technical assistance to all shore activities.

Because of their professional and technical backgrounds, the personnel of the Field Divisions can render valuable assistance to an activity in building up the Public Works Department's professional technical capacity at the activity.

The Engineering Field Division is available for consultation in matters relating to the organization of Public Works Departments at the individual activities. For small activities, it can render services similar to those provided by a well-staffed Engineering Division at a larger activity. For example, its staff can furnish designs for public works and utilities, prepare specifications in connection with these designs, and make engineering investigations into specialized fields.

When a Public Works Officer has need of a technical engineering review and approval of proposed plans or specifications, he should request the assistance of the cognizant Engineering Field Division.

INDEX

S

☆U.S. GOVERNMENT PRINTING OFFICE: 1974-640-701/34