Online-PDH©

Online Continuing Education for Professional Engineers
Since 2009

Engineering and Land Surveying

PDH Credits:

6 PDH

Course No.:

ELS101

Publication Source:

US NAVY

Engineering Aid Basics
“Engineering and Land Survey – Chapter 2”
Pub. # NAVEDTRA 14336A

1265 San Juan Dr. - Merritt Island, FL 32952
Phone: 321-501-5601

Chapter 2

Engineering and Land Surveys

Topics

1.0.0 Engineering Surveys

2.0.0 Airfield Surveys

3.0.0 Waterfront Surveys

4.0.0 Land Surveying

5.0.0 Map Projection

To hear audio, click on the box.

Overview

This chapter discusses important aspects of engineering surveying presented from the viewpoint of the party chief. Included in the discussion are design- data surveys, such as route surveys, and construction surveys that include stakeout and as-built surveys.

This chapter also addresses land surveying, which is a special type of surveying performed for the purpose of establishing or reestablishing land boundaries, preparing legal property descriptions, and subdividing tracts of land. Although a complete coverage of land surveying is beyond the scope of this NRTC, you will become acquainted with the procedures and some of the legal aspects involved.

Objectives

When you have completed this chapter, you will be able to do the following:

1. Describe the different types of engineering surveys.
2. Describe the different types of airfield surveys.
3. Describe the different types of waterfront surveys.
4. Describe the different procedures for conducting land surveys.
5. Describe the different methods of map projections.

Prerequisites

None

This course map shows all of the chapters in Engineering Aid Advanced. The suggested training order begins at the bottom and proceeds up. Skill levels increase as you advance on the course map.

Time Designation and Triangulation	ENGINEERING AID ADVANCED
Soil Stabilization	
Mix Design: Concrete and Asphalt	
Soils: Surveying and Exploration/Classification/Field Identification	
Materials Testing	
Specifications/Material Estimating/Advance Base Planning	
Project Drawings	
Horizontal Construction	
Construction Methods and Materials: Electrical and Mechanical Systems	
Construction Methods and Materials: Heavy Construction	
Electronic Surveying Equipment	
Horizontal and Vertical Curves	
Engineering and Land Surveys	
Engineering Division Management	

Features of this Manual

This manual has several features which make it easy to use online.

- Figure and table numbers in the text are italicized. The figure or table is either next to or below the text that refers to it.
- The first time a glossary term appears in the text, it is bold and italicized. When your cursor crosses over that word or phrase, a popup box displays with the appropriate definition.
- Audio and video clips are included in the text, with an italicized instruction telling you where to click to activate it.
- Review questions that apply to a section are listed under the Test Your Knowledge banner at the end of the section. Select the answer you choose. If the answer is correct, you will be taken to the next section heading. If the answer is incorrect, you will be taken to the area in the chapter where the information is for

review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

- Review questions are included at the end of this chapter. Select the answer you choose. If the answer is correct, you will be taken to the next question. If the answer is incorrect, you will be taken to the area in the chapter where the information is for review. When you have completed your review, select anywhere in that area to return to the review question. Try to answer the question again.

1.0.0 ENGINEERING SURVEYS

In previous chapters you learned that engineering surveys are subdivided into design-data surveys and construction surveys. A design-data survey is an orderly process of obtaining data that is needed for the planning and design of an engineering project. The activities involved in design-data surveying vary according to the type and complexity of the engineering or construction project. For example, the activities might include simply obtaining topographic data for a proposed building site, or they may include extensive route surveying and soils investigation for a highway. Construction surveying is divided into (1) the layout, or stakeout, survey and (2) the as-built survey. The layout, or stakeout, survey consists of locating and marking (staking) horizontal and vertical control points to guide construction crews, and giving line and grade as needed to establish additional control points and to reestablish disturbed stakes. The as-built survey includes making measurements to verify the locations and dimensions of completed elements of a new structure and to determine the amount of work accomplished up to a given date. The following section begins the discussion of route surveying.

1.1.0 Route Surveys

A route survey details the route or course a highway, road, or utility line will follow. While the end product of a route survey for a highway differs from that for a utility line, it may nevertheless be said that the purposes of any route survey are these:

1. To select one or more tentative general routes for the roadway or utility
2. To gather enough information about the general route to make it possible for designers to select the final location of the route
3. To mark this final location

Consistent with these purposes, a route survey is usually divided into reconnaissance, preliminary and final-location survey phases that satisfy, respectively, each of the purposes given above. Sometimes, however, circumstances may preclude the requirement to perform all three phases. For example, if a new road or utility line is to be constructed on a military installation having well marked vertical and horizontal control networks and up-to-date topographic maps and utility maps, then the reconnaissance and preliminary survey phases may not be required. Chapter 12 through 19 of the EA Basic NRTC discusses each phase of route surveying applicable to roads and highways.

Aside from roads and highways, other uses of route surveys are for aboveground utility lines, most commonly power and communication lines, and for underground utilities, such as power, communication, sewer, water, gas, and fuel lines. The character of the route survey for a utility can vary. A sanitary sewer, a water distribution line, or an electrical distribution line in an urban area generally follows the streets on which the buildings it serves are located.

Since these areas most likely have other existing utilities, existing utilities maps can be used to design the new utility lines. Consequently, reconnaissance and preliminary surveys are seldom necessary. On the other hand, a power transmission line or other utility running through open country on a large military installation may require reconnaissance and preliminary surveys in addition to the final location survey.

1.1.1 Route Surveys for Overhead Electrical Distribution and Transmission Lines

The reconnaissance survey for electrical power lines employs many of the same principles and practices used for highway work; however, the design considerations are different. For a power line, the design engineer considers principles of Horizontal Control and Direct Leveling to select one or more tentative routes over which the line will pass. These principles include:

1. Selecting the shortest possible route
2. Following the highways and roads as much as possible
3. Following the farmers' property or section lines
4. Routing in the direction of possible future loads
5. Avoiding going over hills, ridges, swamps, and bottom lands
6. Avoiding disrupting the environment

During the reconnaissance phase, all available maps of the area should be studied to gain a general understanding of the landscape. If a portion of the line is off the military installation, determine the ownership of the lands through which the line will pass. It is necessary to obtain permission to run the line. Look for any existing utilities in the area. If there are existing utilities, then look for existing utilities maps. Visit the area to examine the terrain and look for any natural or man-made features that may hinder or help the construction. In short, gather all information the engineer will need to select one or more general routes for the power line.

With the tentative route or routes selected, a preliminary survey is conducted from which a map is prepared showing the country over which the line will pass. Since the final location is not known, a wide strip of land needs to be mapped. When running the preliminary survey, incorporate all pertinent topographic information into the field notes. Note any existing overhead or underground lines and indicate whether they are power or communications lines. Locate such features as hills, ridges, marshes, streams, forests, roads, railways, power plants, buildings, and adjacent military camps or bases.

When the preliminary mapping is completed, the engineer selects the final route. Again, the engineer considers the principles listed above to select the route.

1.1.1.1 Pole Line Surveys

When the route has been selected, a plan and profile are then plotted. The plan shows the route the line will follow and the significant topography adjacent to the route. The profile shows the ground elevation along the line and the top elevations of the poles. These elevations are set in accordance with minimum allowable clearances specified in the *National Electrical Safety Code* (NESC), ANSI C2, and the most recent edition of the *National Electrical Code® (NEC®).*

For distribution lines, poles should be placed on the side of the street free of other lines and trees. Use the same side of the road throughout the length of the line as much as possible. For straight portions of lines, the usual spacing between poles is about 125 feet (100 feet minimum and 150 feet maximum). However, to make the poles come in line with property lines or fences, the span length may need to be adjusted. The engineer will determine the spans. Along roads, poles should be placed 2 feet from the inside edge of the curb or 2 feet from the edge of the road surface where curbs do not exist. On open roadways or highways, poles should be set 18 inches from the outside of fences.

For transmission lines, poles should be located in high places so that shorter poles can be used and still maintain the proper ground clearance at the middle of the span. Avoid locating poles along the edge of embankments or streams where washouts can be expected. In rolling country, the grading of the line should be considered when determining pole locations. A well-graded line does not have any abrupt changes up or down the line and will appear nearly horizontal regardless of small changes in ground level. Sometimes, by shifting a pole location a few feet, a standard length pole can be used where otherwise an odd-sized pole would be needed. In addition, transmission line poles should be located at least 2 feet from curbs, 3 feet from fire hydrants, 12 feet from the nearest track of a railroad track, and 7 feet from railway sidings.

When staking pole locations, mark the center of each pole with a hub on the line. On the guard stake, indicate 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.

1.1.1.2 Tower Line Surveys

High-voltage lines are often supported by broad-based steel towers. For a tower line, construction economy requires that changes in direction be kept at a minimum because a tower located where a line changes direction must withstand a higher stress than one located in a straight direction part of the line. In general, tower construction is cheaper in level country than in broken country; however, the line may be run over broken country to minimize changes in direction, to make the distance shorter, or to follow a line where the cost of obtaining right-of-way is inexpensive. Lines should be located adjacent to existing roads whenever practical, to provide easier access for construction and future maintenance. When a change in direction in a tower line is unavoidable, it should be made gradually in as small-angular increments as possible. Suppose, for example, a change in direction of 90° is required. Instead of an abrupt change in direction of 90°, towers should be set so as to cause the line to follow a gradual curve in a succession of chords around an arc of 90°.

1.1.2 Route Surveys for Drainage

When man-made structures are erected in a certain area, it is necessary to plan, design, and construct an adequate drainage system. Generally, an underground drainage system is the most desirable way to remove surface water effectively from operating areas. An open drainage system, like a ditch, is economical; however, when not properly maintained, it is unsightly and unsafe. Sometimes, an open drainage system also causes erosion, thus resulting in failures to nearby structures. Flooding caused by an inadequate drainage system is the leading cause of road and airfield rapid deterioration. 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.

1.1.2.1 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, which is a downward slope toward the disposal point just steep enough to ensure a gravity flow of waste and water through the pipes. This gradient is calculated by the designing engineer.

1.1.2.1.1 Natural Drainage

To understand the controlling considerations affecting the location and other design features of a storm sewer, understanding the mechanics of water drainage from the earth's surface is important.

When rainwater falls on the earth's surface, some of the water is absorbed into the ground. The amount absorbed varies according to the physical characteristics of the surface. In sandy soil, for instance, a large amount will be absorbed, while on a concrete surface, absorption will be negligible.

Of the water not absorbed into the ground, some evaporates, and some, absorbed through the roots and exuded onto the leaves of plants, dissipates through a process called transpiration.

The water that remains after absorption, evaporation, and transpiration is technically known as runoff. This term relates to the fact that this water, under the influence of gravity, makes its way through natural channels to the lowest point it can attain. To put this in terms of a general scientific principle, water seeks its own level. Unimpeded water on the earth's surface seeks sea level, and rivers, most of which empty into the sea, are the earth's principal drainage channels. However, not all of the earth's runoff reaches the great oceans; some of it is caught in landlocked lakes, ponds, and other non-flowing inland bodies of water.

Consider a point high in the mountains somewhere. As rain falls in the area around the point, the runoff runs down the slopes of a small gully and forms a small stream, which finds a channel downward through the ravine between two ridges. As the stream proceeds on its course, it picks up more and more water draining in similar fashion from high points in the area through which the stream is passing. As a result of this continuing accumulation of runoff, the stream becomes larger until eventually it either becomes or joins a large river making its way to the sea, or it may finally empty into a lake or some other inland body of water.

In normal weather conditions, the natural channels through which this runoff passes can generally contain and dispose of all the runoff. However, during the winter in the high mountains, runoff is commonly interrupted by snow conditions, that is, instead of running off, the potential runoff accumulates in the form of snow. When this accumulated mass melts in the spring, the runoff often attains proportions that overwhelm the natural channels, causing flooding of surrounding areas. In the same fashion, unusually heavy rainfall may overtax the natural channels.

1.1.2.1.2 Artificial Drainage

When artificial structures are introduced into an area, the natural drainage arrangements of the area are altered. When, for example, an area originally containing many hills and ridges is graded off flat, the previously existing natural drainage channels are removed, and much of the effect of gravity on runoff is lost. When an area of natural soil is covered by artificial paving, a quantity of previously absorbed water is no longer absorbed, thus causing potential drainage problems.

When man-made structures such as bridges and buildings are erected in an area, it is usually necessary to design and construct an artificial drainage system to offset the altered natural drainage system. 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 runoff. The only real difference between a drainage ditch and a storm sewer is that the ditch lies on the surface and the storm sewer lies below the surface.

Similarly, there is no essential difference in mechanical principle between an artificial and a natural drainage system. Like a natural channel, an artificial channel must slope downward and 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, which is 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.

1.1.2.1.3 Ditches

A surface drainage system consists principally of ditches that form the drainage channels. A ditch may consist simply of a depression formed in the natural soil, or it may be a paved ditch. Where a ditch must pass under a structure (such as a highway embankment), 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.

1.1.2.1.4 Storm Sewers

An underground drainage system consists 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

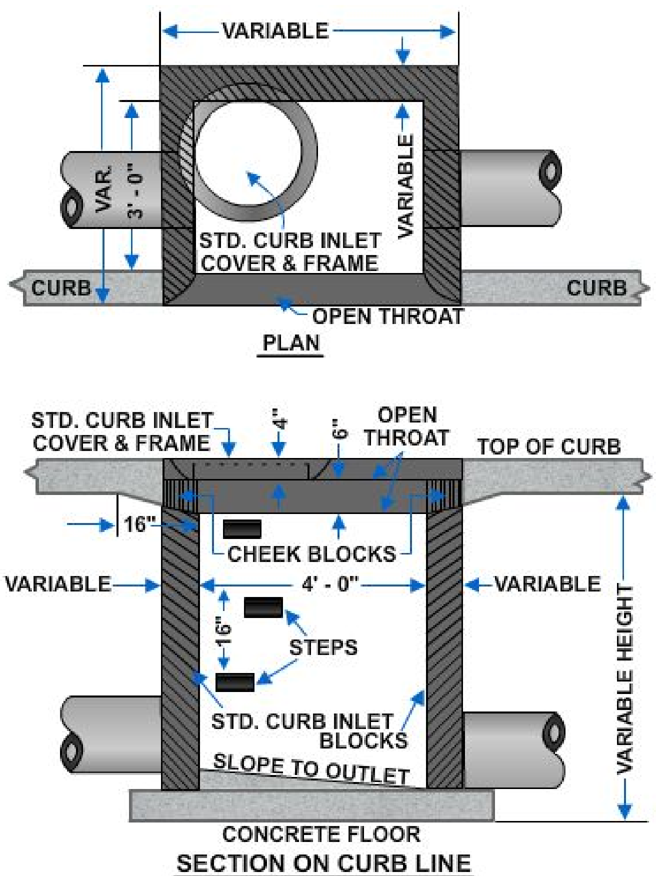

Figure 2-1 – Working drawing for typical curb inlet.

consists of a surface opening that admits the surface water runoff and an inner chamber called a box (sometimes called a catch basin). A box is usually rectangular but may be cylindrical. An inlet with a surface opening in the side of a curb is called a curb inlet. A working drawing of a curb inlet is shown in *Figure 2-1*. An inlet with a horizontal surface opening covered by a grating is called a grate (sometimes a drop) inlet.

1.1.2.1.5 Appurtenances

Technically speaking, the term "storm sewer" applies to the pipeline, while the inlets are called appurtenances. There are other appurtenances, the most common of which are manholes and junction boxes. A manhole is a box that is installed at a point where the trunk changes direction, gradient, or both. The term "manhole" originally related to the access opening at one of these points; however, a curb inlet and a junction box nearly always have a similar access opening for cleaning, inspection, and maintenance purposes. One of these openings is often called a manhole, regardless of where it is located. However, strictly speaking, the access opening on a curb inlet should be called a curb-inlet opening; and on a junction box, a junction-box opening. Distances between manholes are normally 300 feet, but this distance may be extended to a maximum of 500 feet when specified.

The access opening for a manhole, curb inlet, or junction box consists of the cover and a supporting metal frame. A frame for a circular cover is shown in *Figure 2-2*. Some covers are rectangular. The frame usually rests on one or more courses of adjusting blocks so that the rim elevation of the cover can be varied slightly to fit the surface grade elevation by varying the vertical dimensions, or the number of courses, of the adjusting blocks.

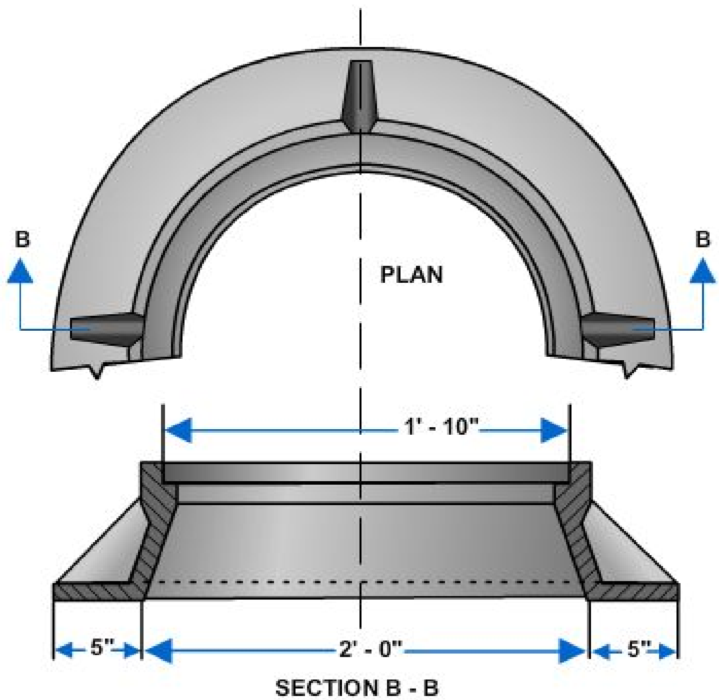

Figure 2-2 – Frame for access opening.

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.

1.1.2.2 Storm Sewer Route Survey

The character of the route survey for a storm sewer depends on the circumstances. The nature of the ground may indicate where the line must go. This is likely to be the case in a development area, that is, an area that will be closely built up and in which the lines of the streets and locations of the buildings have already been determined. In these circumstances, the reconnaissance and preliminary surveys may be said to be done on paper.

On the other hand, a line or parts of it often must be run for considerable distances over rough, irregular country. In these circumstances the route survey consists of reconnaissance, preliminary location, and final-location surveys. If topographic maps of the area exist, they are studied to determine the general area along which the line will be run. If no such maps exist, a reconnaissance party must select one or more feasible route areas, run random traverses through these, and collect enough topographic data to make the planning of a tentative route possible.

After these data have been studied, a tentative route for the line is selected. A preliminary survey party runs this line, making any necessary adjustments required by circumstances encountered in the field, taking profile elevations, and gathering enough topographic 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 2-3* shows a storm sewer plan and profile. The project here is the installation of 230 feet of 18-inch concrete sewer pipe (CSP) with a curb inlet (CI "A"). The computational length of sewer pipe is always given in terms of horizontal feet covered. The actual length of a section is, of course, greater than the computational length because of the slope.

The pipe in *Figure 2-3* is to run down slope from a curb inlet to a manhole in an existing sewer line. The reason for the distorted appearance of the curb inlet and manhole, which look much narrower than they would in their true proportions, is the exaggerated vertical scale of the profile. The appearance of the pipe is similarly distorted.

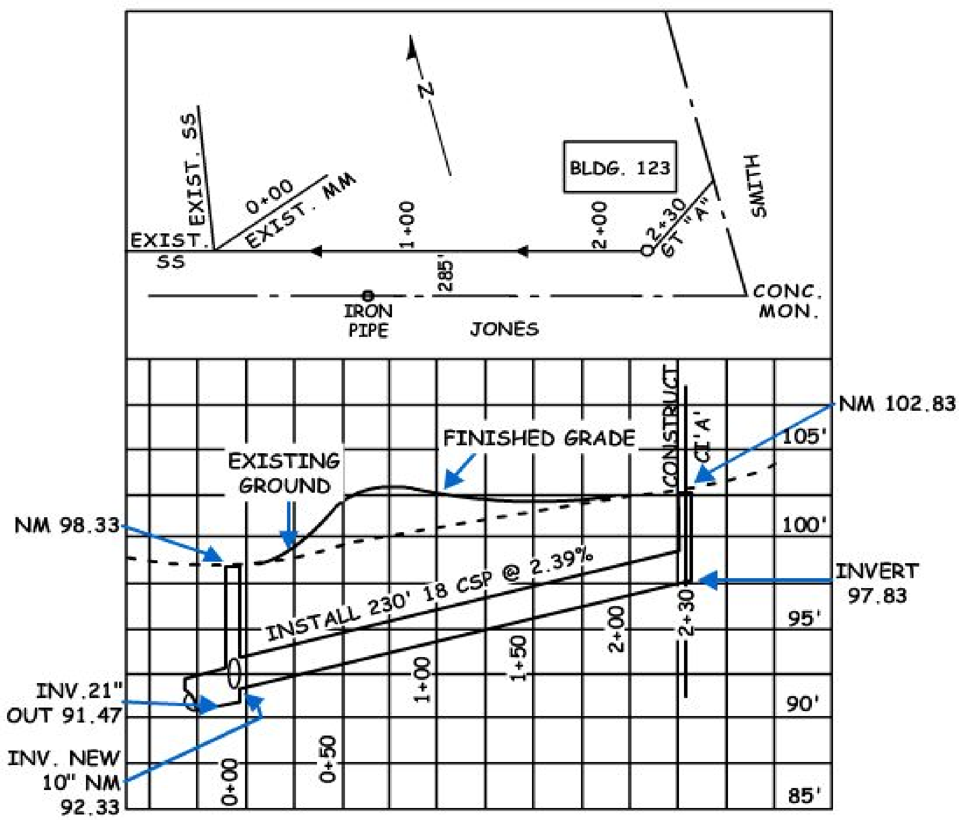

Figure 2-3 – Storm sewer plan and profile.

The pipe to be installed is to be placed at a gradient of 2.39 percent. The invert elevation of the outflowing 21-inch pipe at the manhole is 91.47 feet; that of the inflowing 18-inch pipe is to be 92.33 feet. Obviously, there is a drop here of 0.86 foot. Of this drop, 0.25 foot is because of the difference in diameters; the other 0.61 foot is probably because of structural and velocity head losses.

From the invert at the manhole, the new pipe will extend 230 horizontal feet to the invert at the center line of the curb inlet. The difference in elevation between the invert elevation at the manhole and the invert elevation at the curb inlet will be the product of 2.39 (the grade percentage) times 2.30 (number of 100-foot stations in 230 horizontal feet), or 5.50 feet. Therefore, the invert elevation at the curb inlet will be 92.33 feet (invert elevation at the manhole) plus 5.50 feet, or 97.83 feet. The invert elevation at any intermediate point along the line can be obtained by similar computation.

The plan shown in *Figure 2-3* is greatly simplified for the sake of clearness—it contains the bare minimum of data required for locating the new line. Plans used in actual practice usually contain more information.

The plan and profile constitute the paper location of the line. A final-location survey party runs the line in the field. Where variations are required because of circumstances discovered in the field (such as the discovery of a large tree or some similar obstruction lying right on the line), the direction of the line is altered (after receiving approval to do so) and the new line is tied to the paper location. The final-location party may simply mark the location of the line and take profile elevations, or it may combine the final-location survey and the stakeout (which is part of the construction survey, rather than the route survey) in the same operation.

1.1.3 Other Route Surveys

While highways and the various types of utilities have differing design requirements that must be considered when conducting route surveys, you have probably observed in your studies that much of route surveying is similar regardless of the type of construction being planned. This is especially true during the reconnaissance phase. Therefore, with a firm understanding of the preceding paragraphs and of the EA Basic NRTC discussion of route surveying, you should have little difficulty in planning and performing other types of route surveys. For roads and highways, however, you also must have an understanding of horizontal and vertical curves. Those will be discussed in the next chapter.

1.1.4 Earthwork Computations

Computing earthwork volumes is a necessary activity for nearly all construction projects and is often accomplished as a part of route surveying, especially for roads and highways. Suppose, for example, that a volume of cut must be removed between two adjacent stations along a highway route. If the area of the cross section at each station is known, you can compute the average-end area (the average of the two cross-sectional areas) and then multiply that average end area by the known horizontal distance between the stations to determine the volume of cut.

To determine the area of a cross section easily, you can run a planimeter around the plotted outline of the section. Counting the squares, explained in Chapter 15 of the EA Basic, is another way to determine the area of a cross section. Three other methods are explained below.

1.1.4.1 Area by Resolution

Any regular or irregular polygon can be resolved into easily calculable geometric figures, such as triangles and trapezoids. Then, by computing the area of each triangle and trapezoid and determining the sum of the areas, you obtain the area of the polygon.

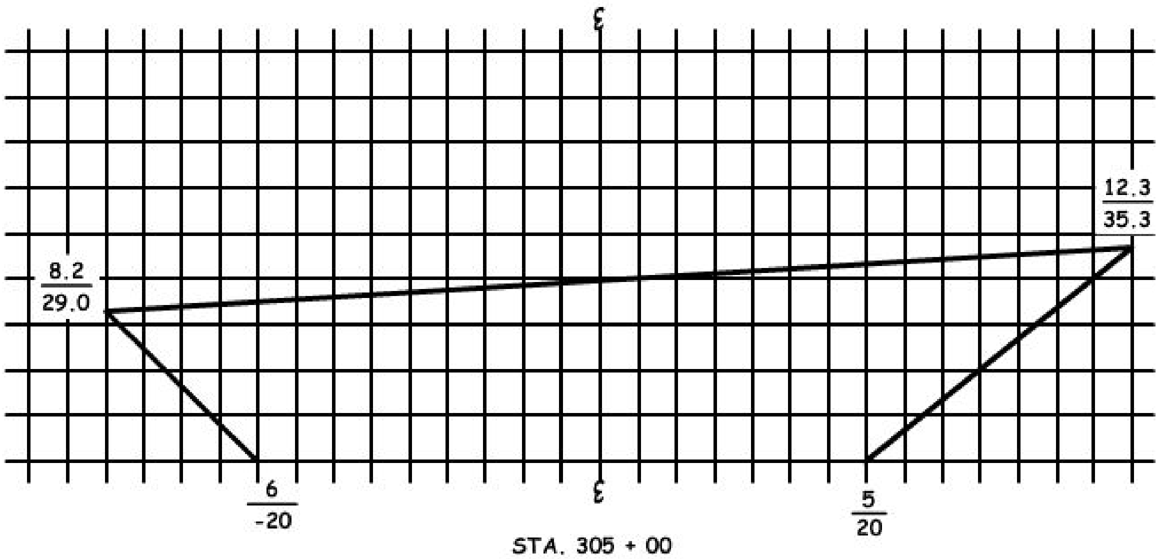

Figure 2-4 – A cross section plotted on cross-section paper.

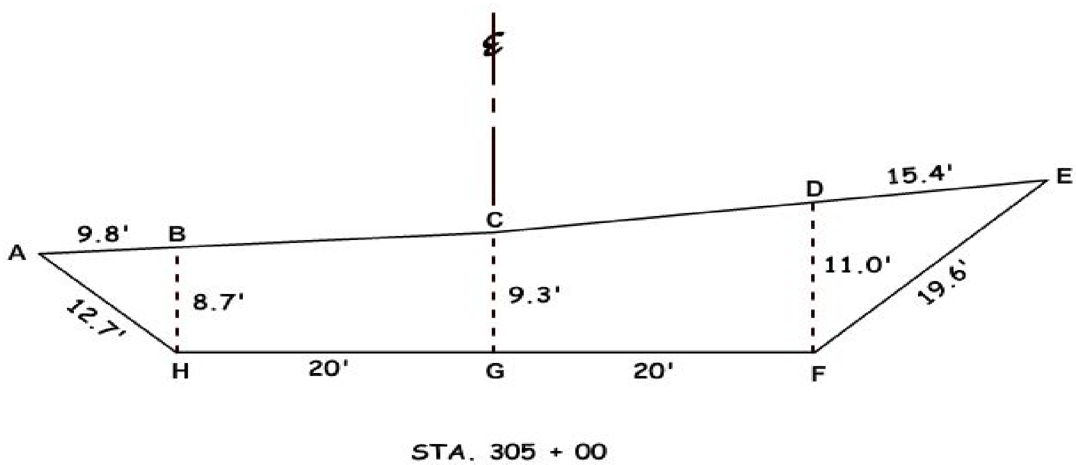

Figure 2-5 – Cross section resolved into triangle and trapezoids.

Take, for example, the plot of station 305 + 00 shown in *Figure 2-4*. *Figure 2-5* illustrates how this figure can be resolved into two triangles, *ABH* and *DFE,* and two trapezoids, *BCGH* and *CGFD.* For each of these figures, the approximate dimensions have been determined by the scale of the plot. From your knowledge of mathematics, you know that the area of each triangle can be determined using the following formula:

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

Where:

a, b, and c = sides of the triangle

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

s = one half of the perimeter of the triangle, and that for each trapezoid, you can calculate the area using the formula:

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

When the above formulas are applied and the sum of the results is determined, the total area of the cross section at station 305 is calculated at 509.9 square feet.

1.1.4.2 Area by Formula

A regular section area for a three-level section can be more exactly determined by applying the following formula:

$$A = \frac{W}{4}(h_l + h_r) + \frac{C}{2}(d_l + d_r)$$

In this formula, *W* is the width of the highway; *hl* and *hr* are the vertical distances of the left and right slope stakes above grade; *dl* and *dr* are the center-line distances of the left and right slope stakes; and *c* is the depth of the center-line cut or fill. Applying the formula for station 305 + 00 (*Figure 2-4*), you get the following results:

A = (40/4) (8.2+ 12.3) + (9.3/2)(29.8+ 35.3)= 507.71 square feet.

1.1.4.3 Area of Five-Level or Irregular Section

Figures 2-6 and *2-7* are the field notes and plotted cross sections for two irregular sections. To determine the area of sections of this kind, you should use a method of determining area by coordinates.

For explanation purpose, let's consider station 305 (*Figure 2-6*). First, consider the point where the center line intersects the grade line as the point of origin for the coordinates. Vertical distances above the grade line are positive *Y* coordinates; vertical distances below the grade line are negative *Y* coordinates. A point on the grade line itself has a *Y* coordinate of 0. Similarly, horizontal distances to the right of the center line are positive *X* coordinates; distances to the left of the center line are negative *X* coordinates, and any point on the center line itself has an *X* coordinate of 0.

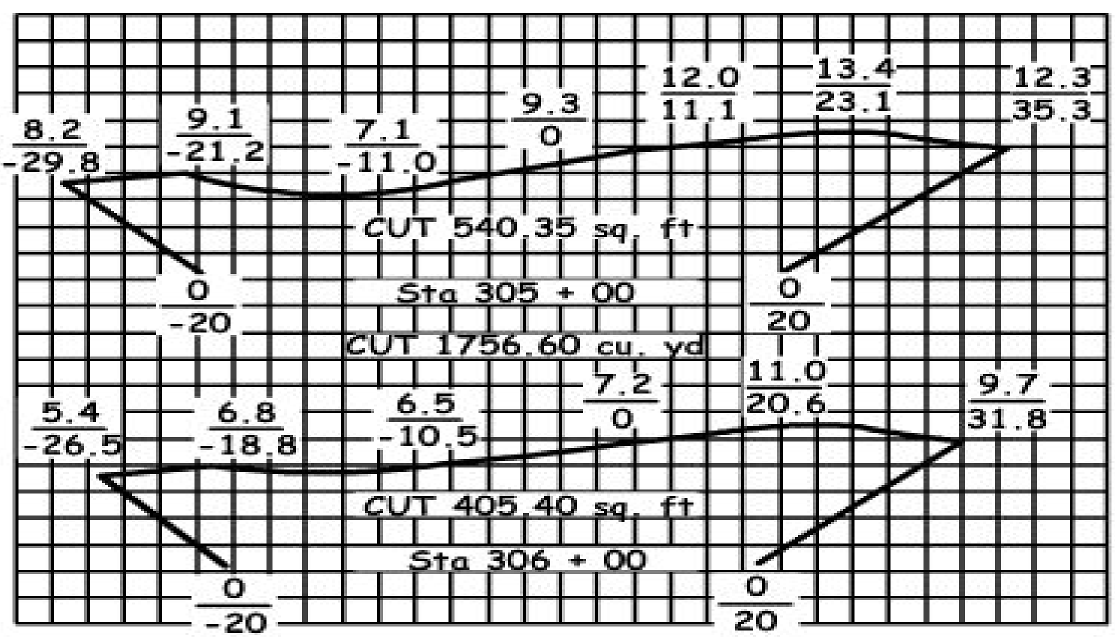

Figure 2-6 – Field notes for irregular sections.

Plot the cross section, as shown in *Figure 2-7,* and be sure that the *X* and *Y* coordinates have their proper signs.

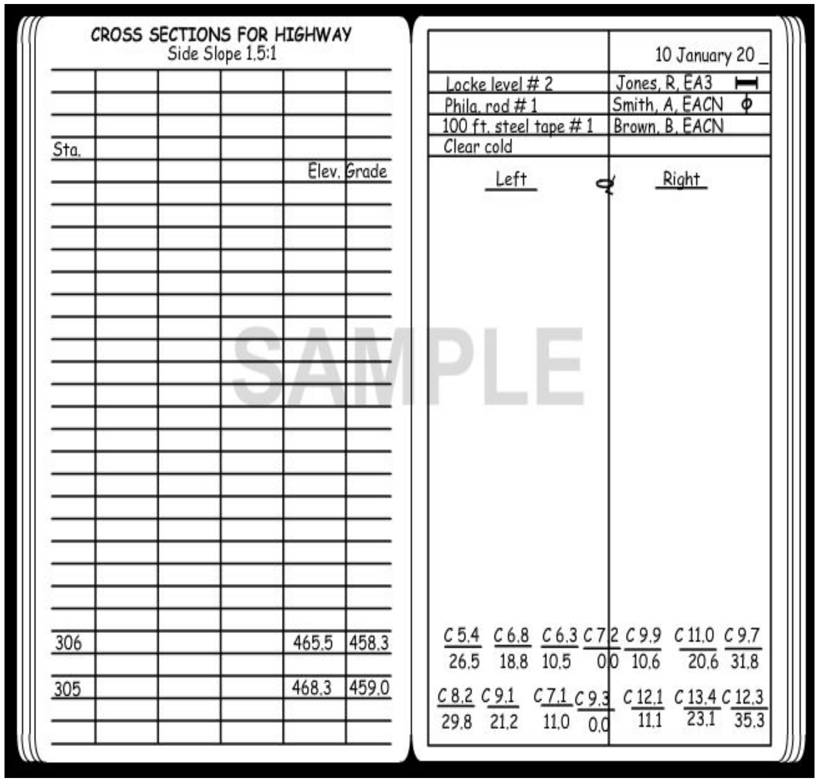

Figure 2-7 – Cross Section plot.

Then, starting at a particular point and going successively in a clockwise direction, write down the coordinates, as shown in *Figure 2-8*.

Figure 2-8 – Coordinates for cross-section station 305 shown in *Figure 2-7*.

After writing down the coordinates, you then multiply each upper term by the algebraic difference of the following lower term and the preceding lower term, as indicated by the direction of the arrows (*Figure 2-8*). The algebraic sum of the resulting products is the double area of the cross section. Proceed with the computation as follows:

8.2[-21.2 – (-20.0)]	=		-9.8
9.1[-11.0 – (29.8)]	=	+171.1	
7.1[0 – (21.2)]	=	+150.5	
9.3[11.1 – (-11.0)]	=	+205.5	
12.0[23.1 – 0]	=	+277.2	
13.4[35.3 – 11.1]	=	+324.3	
12.3[20.0 – 23.1]	=	______	-38.1
		+1128.6	-47.9
		-47.9	
		1080.7	

Since the result (1,080.70 square feet) represents the double area, the area of the cross section is one half of that amount, or 540.35 square feet.

By similar method, the area of the cross section at station 306 (*Figure 2-8*) is 408.40 square feet.

1.1.4.4 Earthwork Volume

As discussed previously, when you know the area of two cross sections, you can multiply the average of those cross-sectional areas by the known distance between them to obtain the volume of earth to be cut or filled. Consider *Figure 2-9* which shows the plotted cross sections of two side hill sections. For this figure, when you multiply the average end area (in fill) and the average end area (in cut) by the distance between the two stations (100 feet), you obtain the estimated amount of cut and fill between the stations. In this case, the amount of space that requires filling is computed to be approximately 497.00 cubic yards and the amount of cut is about 77.40 cubic yards.

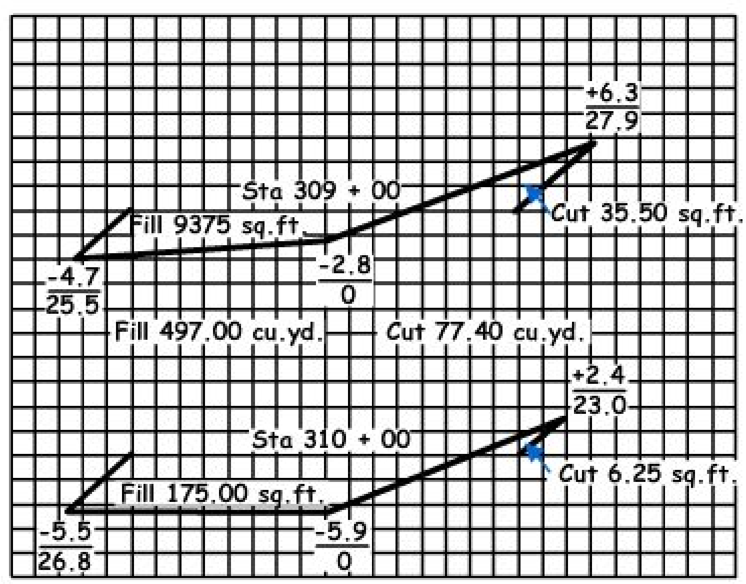

Figure 2-9 – Plots of two side hill sections.

1.1.4.5. Mass Diagrams

A concern of the highway designer is economy on earthwork. The designer wants to know exactly where, how far, and how much earth to move in a section of road. The ideal situation is to balance the cut and fill and limit the haul distance. A technique for balancing cut and fill and determining the economical haul distance is the mass diagram method.

A mass diagram is a graph or curve on which the algebraic sums of cuts and fills are plotted against linear distance. Before these cuts and fills are tabulated, the swells and compaction factors are considered in computing the yardage. Earthwork that is in-place will yield more yardage when excavated and less yardage when being compacted. An example of this is sand: 100 cubic yards in-place yields 111 cubic yards loose and only 95 cubic yards when compacted. *Table 2-1* lists conversion factors for various types of soils. These factors should be used when you are preparing a table of cumulative yardage for a mass diagram. Cuts are indicated by a rise in the curve and are considered positive. Fills are indicated by a drop in the curve and are considered negative. The yardage between any pair of stations can be determined by inspection. This feature makes the mass diagram a great help in the attempt to balance cuts and fills within the limits of economic haul.

Table 2-1 - Soil Conversion Factors (Conversion Factors for Earth-Volume Change)

Soil Type	Soil Condition	Converted to		
		In-place	Loose	Compacted
Sand	In-place	1.00	1.11	0.95
	Loose	.90	1.00	.86
	Compacted	1.05	1.17	1.00
Loam	In-place	1.00	1.25	0.90
	Loose	.80	1.00	.72
	Compacted	1.11	1.39	1.00
Clay	In-place	1.00	1.43	0.90
	Loose	.70	1.00	.63
	Compacted	1.11	1.39	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	0.67	1.00	.87
	Compacted	0.77	1.15	1.00

The limit of economic haul is reached when the cost of haul and the cost of excavation become equal. Beyond that point it is cheaper to waste the cut from one place and to fill the adjacent hollow with material taken from a nearby borrow pit. The limit of economic haul will vary at different stations on the project, depending on the nature of the terrain, the availability of equipment, the type of material, accessibility, availability of manpower, and other considerations.

The term “free-haul distance” means a distance over which hauling material involves no extra cost. This distance is usually taken to be about 500 feet, meaning that it is only for hauls longer than 500 feet that the limits of economic haul need to be considered.

1.1.4.5.1 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 2-2*. Under End Areas, put the cross-sectional area at each station—sometimes this is cut, sometimes fill, and sometimes (as at stations 9 + 00 and 15 + 00) part cut and part fill. Under Volumes, put the volumes of cut or fill between stations, computed from the average end areas and the distance between sections in cubic yards. Note that, besides the sections at each full station, sections are taken at every plus where both the cut and the fill are zero. Note also that cut volumes are designated as plus and fill volumes as minus.

Table 2-2 – Table of Cumulative Yardage.

CUMULATIVE YARDAGE					
STATION	END AREAS (FT^2)		VOLUMES (YD^3)		ALGEBRAIC SUMS, VOLUMES, CUMULATIVE
	CUT	FILL	CUT	FILL	
0 +00	186	0	---	---	0
1 + 00	65	0	+465	---	+465
2 + 00	44	0	+202	---	+667
3 + 00	22	0	+122	---	+789
3 + 50	0	0	+20	---	+809
4 + 00	0	22	---	-20	+789
5 + 00	0	44	---	-122	+667
6 + 00	0	65	---	-202	+465
7 + 00	0	186	---	-465	0
8 + 00	0	119	---	-563	-563
9 + 00	35	46	+65	-305	-803
9 + 80	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 + 70	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

Under Algebraic Sums Volumes, Cumulative, 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.

1.1.4.5.2 Plotting Mass Diagram

Figure 2-10 shows the values from the table of cumulative yardage plotted on a mass diagram. The vertical coordinates are cumulative volumes, plus or minus, from a line of zero yardage, each horizontal line representing an increment of 200 cubic yards. The horizontal coordinates are the stations, each vertical line representing a full 100-foot station.

As you can see, the mass diagram makes it possible for you to determine by inspection the yardage of cut or fill lying between any pair of stations. Between station 0 + 00 and station 3 + 50, for example, there are about 800 cubic yards of cut. Between station 3 + 50 and station 7 + 00, there are about 800 cubic yards of fill (descending curve).

Between station 7 + 00 and station 10 + 50, there are about 850 cubic yards of fill (curve still descending), and so on.

Remember that sections where the volume (yardage) changes from cut to fill correspond to a maximum in the mass diagram curve, and sections where it changes from fill to cut correspond to a minimum. The peaks and the lowest points of the mass diagram that represent the maximum or minimum yardage occur at or near the grade line on the profile.

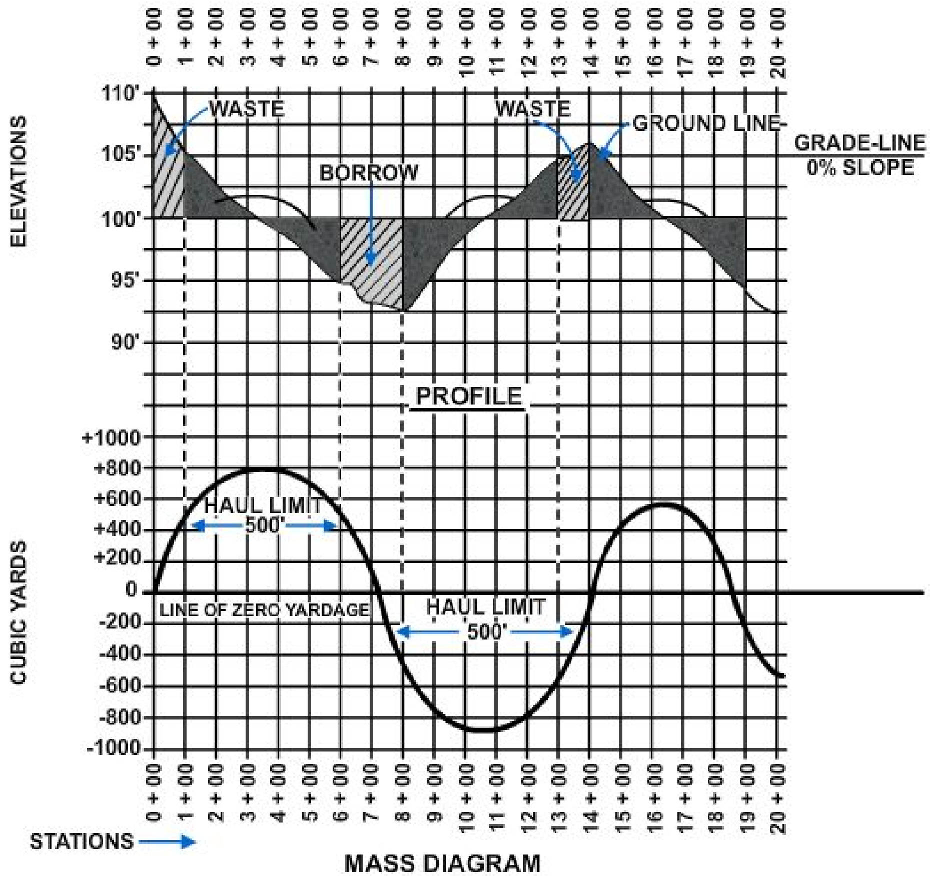

Figure 2-10 – Profile and mass diagram.

1.1.4.5.3 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, examine *Figure 2-10*. Here the profile of a road, from stations 0 + 00 to 20 + 00, has been plotted above the mass diagram. You can see that they are plotted on the same horizontal scale. The labeled sections and arrows on the profile show relatively what is to be done to the cuts and fills, and where the limit of economical haul is exceeded, the cut is wasted, and the fill is borrowed.

In *Figure 2-10*, a 500-foot haul-limit line has been inserted into the mass diagram curve above and below the lines of zero yardage. (The 500-foot distance is laid out to scale horizontally parallel to the line of zero yardage.) The terminal points of these haul-limit distances were projected to the profile curve, as indicated. You can see that the cut lying between stations 1 + 00 and 3 + 50 can be hauled economically as far as station 6 + 00; that the cut lying between stations 10 + 50 and 13 + 00, as far as station 8 + 00; and that the cut lying between stations 14 + 00 and 16 + 50, as far as station 19 + 00. This leaves the cut between stations 0 + 00 and 1 + 00, the fill between stations 6 + 00 and 8 + 00, the cut between stations 13 + 00 and 14 + 00, and the fill between stations 19 + 00 and 20 + 00.

As indicated in *Figure 2-10*, the cut between stations 0 + 00 and 1 + 00, lying outside the limit of economical haul distance, would be wasted, that is, dumped into a nearby spoil area or ravine. The cut between stations 1 + 00 and 3 + 50 would be dumped into the adjacent fill space between stations 3 + 50 and 6 + 00. The fill space between stations 6 + 00 and 8 + 00 would be filled with borrow, that is, material taken from a nearby borrow pit. The fill space between stations 8 + 00 and 10 + 50 would be filled with the cut between 10 + 50 and 13 + 00, and the space between stations 16 + 50 and 19 + 00 would be filled with the cut lying between stations 14 + 00 and 16 + 50. 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 2-10* is only about 400 feet, then instead of wasting the cut between stations 13 + 00 and 14 + 00, you would use that to fill the hollow between stations 19 + 00 and 20 + 00. The surplus cut remaining would be wasted after allowing for shrinkage in the filled spaces.

1.2.0 Construction Surveys

In this section we will discuss construction surveying as it pertains to the stakeout of various types of construction, such as bridges and culverts, sewer lines, airfield runways, and waterfront structures. For a refresher of stakeout surveys for other types of construction, such as buildings and pavements, you should review Chapters 12 through 15 of the EA Basic NRTC. As mentioned early in this chapter, as-built surveying is performed for two purposes: (1) to determine the horizontal and vertical location of points as they are actually constructed in the field and (2) to determine the amount of work accomplished up to a given date. Towards the first of those purposes, little can be said that is not adequately covered in the EA Basic NRTC; therefore, the following discussion of as-built surveying is geared towards the second purpose.

First, however, let's consider an aspect of both as-built and stakeout surveying that is of particular significance to the party chief, that is, that the party chief must maintain close liaison with the other crews working on the project. Survey parties work independently on many types of surveys, such as establishing horizontal and vertical control, running preliminary lines, shooting topo, and gathering engineering data. But in stakeout, the survey party is an integral part of the construction team. Timing and scheduling are important. When line and grade stakes are not set at the right place and at the right time, the work of entire construction crews is delayed. The party chief must also be constantly aware of the need for replacing stakes that have been knocked out by accident or design. Frequently, changes in grade and alignment will be authorized in the field to best meet the conditions encountered. These field-change orders will, in many cases, require immediate computations in the field and revisions to the stakeout. It is best to obtain as-built data as soon as a section of the work is complete. This is particularly true if field changes have been made, since the press of further construction may prevent a timely return to the job to obtain the as-built data. When these data are not obtained, users of the plans may be seriously misled in supposing that the construction conformed to the original drawings.

1.2.1 As-Built Surveys for Monitoring Construction Progress

In the Seabees, the percentage of completion for construction projects is based on a work in place (WIP) concept. To explain this, consider a simple example in which Charlie Company is required to paint out three rooms totaling 1,100 square feet of wall and ceiling surface. When half of the total square footage is completed, the work in place is 550 square feet and the painting work is 50 percent complete. When all surfaces have been painted, the work is 100 percent complete.

Now assume a construction battalion is tasked with the construction of 15 miles of bituminous-paved road. As you know from your study of the EA Basic NRTC, the construction of this road includes many construction activities, such as clearing, excavation for base and sub-base courses, installation of drainage structures, placement of base and sub-base courses, prime coating, and laying the bituminous-surface course. Each of those activities represents a certain percentage of the total project. Assume the construction activity for clearing is estimated to be 5 percent of the total project and that this activity involves the removal of 528,000 square yards of brush and overburden. When all of the clearing is completed and no other work has been accomplished, the project is 5 percent complete; however, if only 130,000 square yards have been removed and no other work has been accomplished, then approximately 25 percent of the clearing activity has been completed and the project is .05 x .25 = 1 percent complete.

For projects such as this, the EA surveyor is often required to perform as-built surveys to determine the work in place for each of the construction activities. These surveys are usually performed on a periodic basis, such as biweekly or monthly. The results of these surveys are then used to determine the completion percentage of the project.

When doing as-built surveys for the purpose of monitoring and reporting progress, the techniques or methods used are not unique. Use the method that is best suited for the job at hand. Also, for this type of as-built surveying, extreme accuracy is usually not required.

1.2.2 Culverts and Bridges

As in other types of layout for construction, the stakeout of culverts and bridges generally includes providing line and grade. The procedures and precision required will vary with the magnitude and complexity of the job.

1.2.2.1 Ditches and Culverts

For minor open drains or outfall ditches a few feet deep, a single line of stakes will serve for both alignment and grade. By running profile levels, the elevations of the tops of the stakes can be determined. As a guide for the construction workers, mark the cut on each stake to show the depth of drain below each station.

For deep drains, cross section the line and set slope stakes. The grade for a ditch is measured along the bottom of the ditch, also referred to as the flow line.

When pipe culverts without wing walls and aprons are staked, only the alignment and invert grade are required; however, when head walls, wing walls, and aprons are used to intercept drainage water, to retain earthwork, and to prevent erosion, grade stakes, as well as horizontal alignment stakes, are required. Large bridge culverts and box culverts require stakes and hubs for batter board alignment similar to those required for a building layout.

Figure 2-11 illustrates the stakeout of a box culvert that crosses below an airfield taxiway. The angle at which the culvert crosses below the taxiway may be written on the plans, or it may be taken from the plans.

Assume that this angle is 84°30´, as shown. To run the center line of the culvert, setup the transit at *A* and turn the 84°30´ angle from the center line of the taxiway.

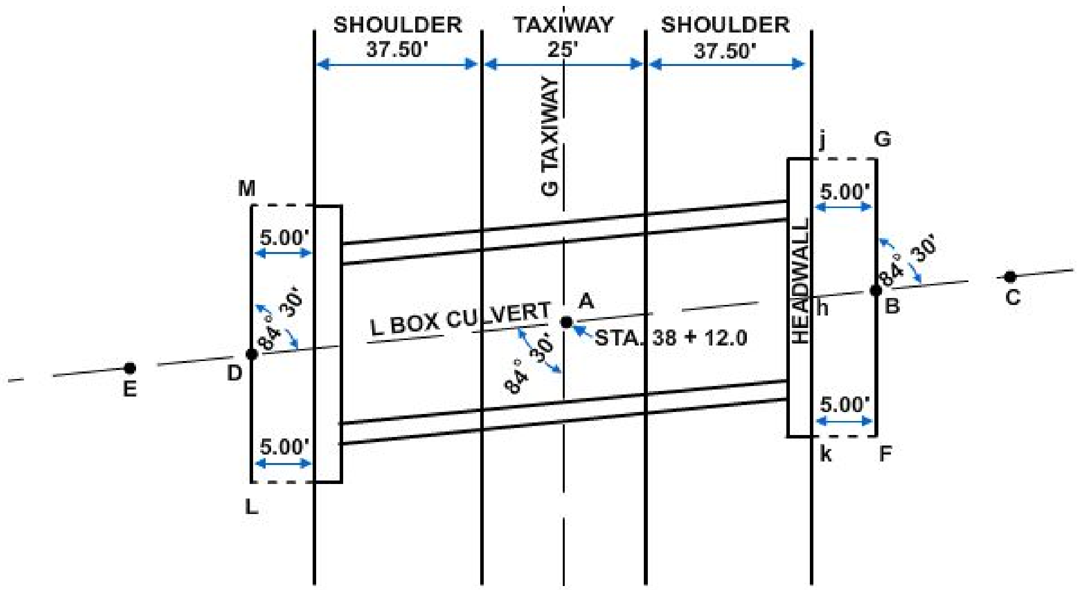

Figure 2-11 – Stakeout of a box culvert.

Place reference stakes at *B, C, D,* and *E* along the culvert center line far enough beyond the limits of the culvert to make sure they are not disturbed by the construction work. In this case, points *B* and *D* are set arbitrarily at 5 feet (measured at right angles) from the location of the outside face of the culvert headwalls.

To facilitate the stakeout, set a stake at point *h.* From *h* the locations of points *j* and *k* may be measured and staked. The distance used is one half of the length of the headwall as that length is shown on the design plans. Set stakes at points *F* and *G* directly opposite and on lines at right angles to the ends of the headwalls. Set stakes similarly at *L* and *M.* Set grade stakes near *B* and *D* for the invert or flow line of the culvert.

The stakes set in this way are sufficient to locate the forms for the headwalls and for the barrel of the culvert. *Figure 2-12* illustrates one type of pipe inlet and culvert configuration. The type shown is suitable for picking up side-surface drains adjacent to a landing strip or roadway embankment. Stakes for both horizontal alignment and elevations are required.

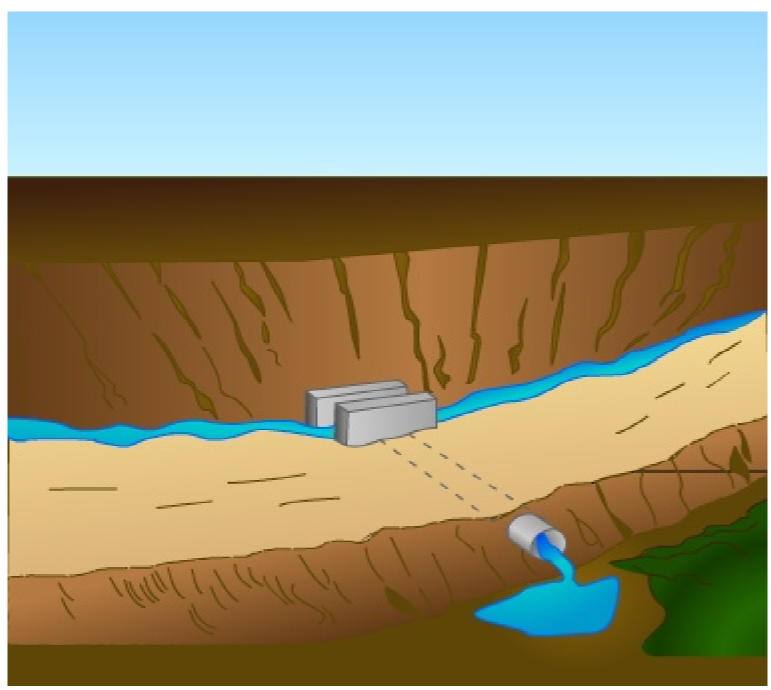

Figure 2-12 – Ditch inlet and pipe culvert.

Figure 2-13 shows the stakeout of a pipe culvert, wing wall, and apron.

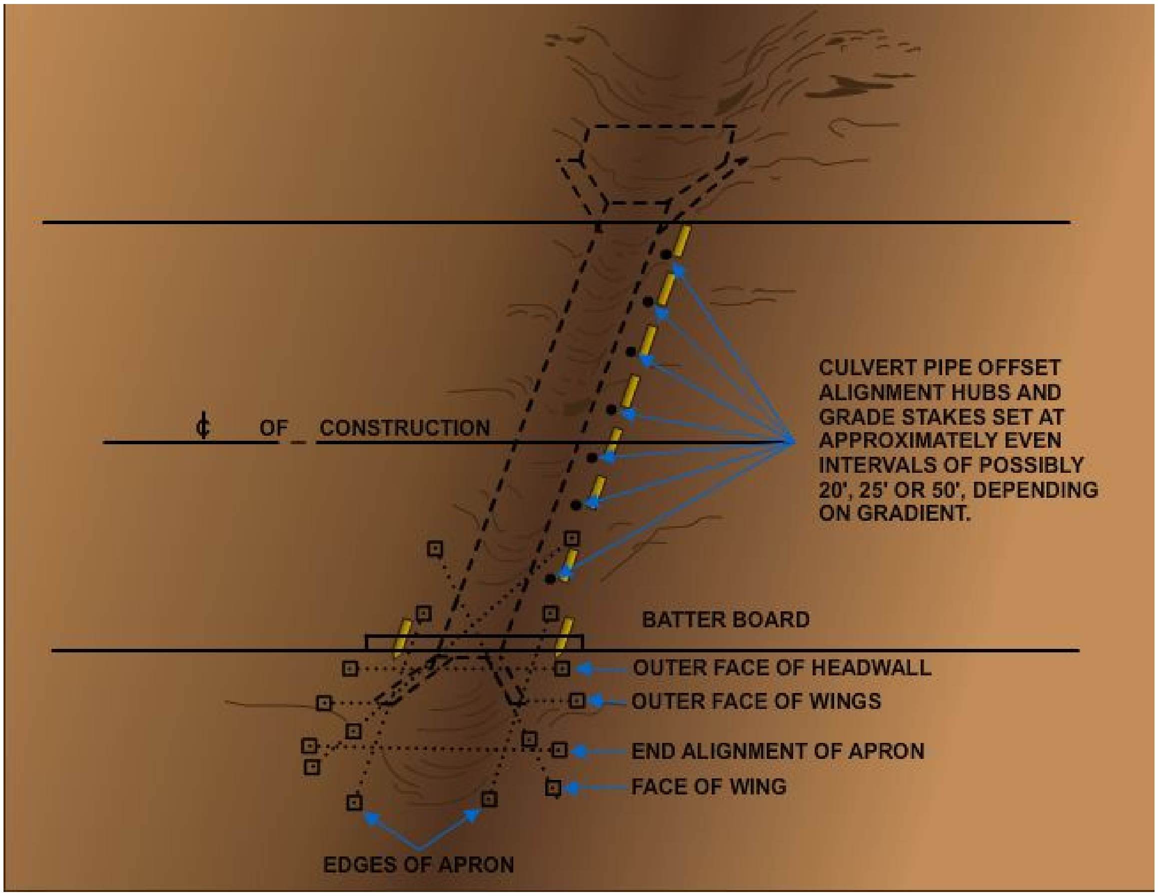

Figure 2-13 – Stakeout of a pipe culvert, wing wall, and apron.

1.2.2.2 Bridge Substructures

As you know from the EA Basic NRTC, the substructure of a fixed bridge consists of the end and intermediate supports and their foundations. Bridge substructures are divided into two main types of supports: end supports called abutments and intermediate supports called bents or piers.

1.2.2.2.1 Abutments

The ground support at each end of a bridge is called an abutment. Construction plans will show the details of the abutments. Check the layout after excavation and before pouring the concrete. You must check abutment elevations, and when concrete is used, establish lines for setting forms. Abutments must be staked by following the construction plans, and abutment stakes should be tied to the horizontal control system to meet accuracy requirements.

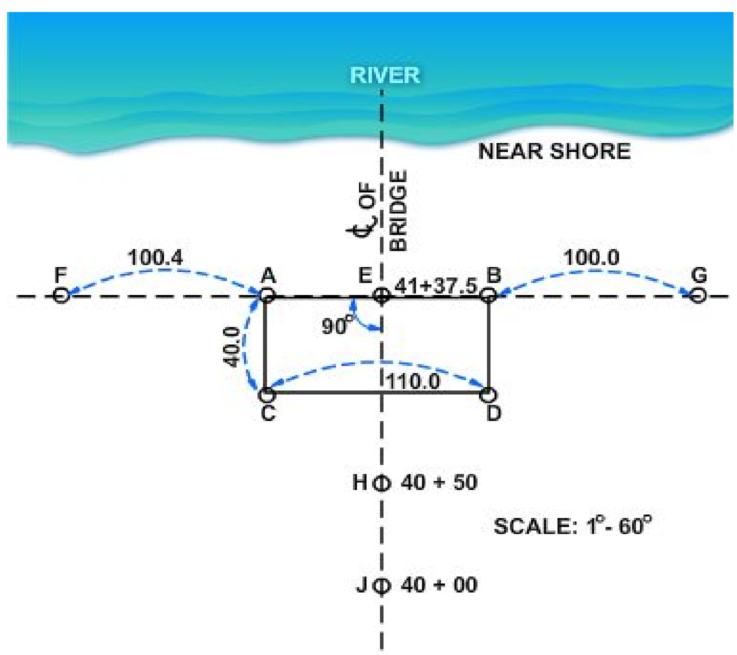

Figure 2-14 – Staking a right-angle abutment.

The following is a typical procedure for surveying an abutment that is to be at right angles to the center line of the bridge. In *Figure 2-14*, the foundation of a concrete abutment, *ABDC,* is shown in the plan. *AB* is the face of the abutment foundation. Establish two convenient points, *H* and *J,* near the abutment *CD,* on the bridge center line. Set a stake at *E* (station 41 + 37.50)—the station designated on the plan for the abutment face.

Set up the transit at *E,* train on *H,* match the zeros, and turn 90° angles to locate *A* and *B* at the correct distance from *E.* Reference the line *AB* by setting stakes at *F* and *G* at the indicated distances from *A* and *B.* Set temporary stakes at *C* and *D* to mark the other corners of the foundation.

Sometimes the alignment of a bridge is not at right angles to the center line of the stream or road it crosses. When this occurs, the abutment is askew (other than a right angle) to the center line of the stream or road. Then slight modifications are necessary to stake out an askew abutment.

Figure 2-15 shows the plan for an askew near-side abutment of a railroad bridge over a highway. The outside line of the foundation is *ABCD.* The ***"neat" line*** of the face of the abutment is *MN.* Set stakes to define the direction of *MN* and ends *AD* and *BC.* The stakes *P, S, U, R, V,* and *T* are offset from the abutment so they will not be disturbed by foundation excavating. The general procedure is as follows:

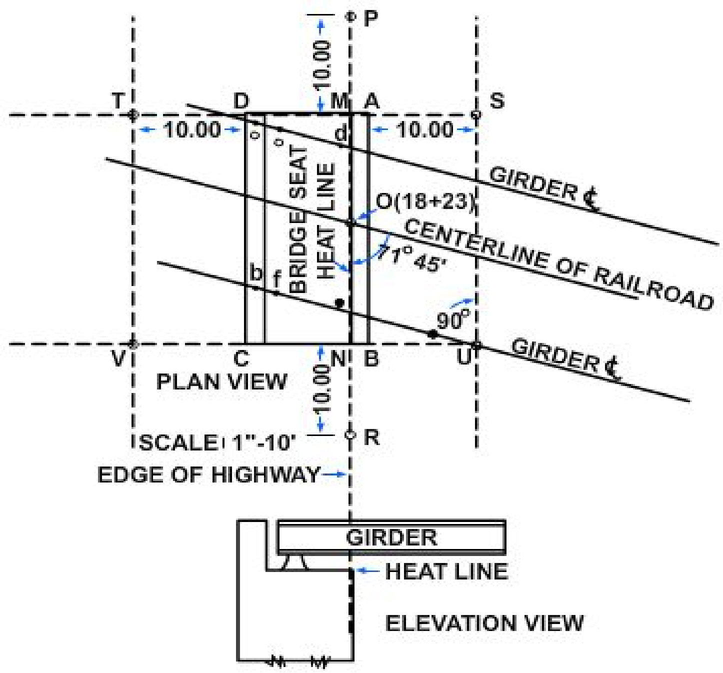

Figure 2-15 – Staking an askew abutment.

1. Take the dimensions for setting necessary stakes from the abutment plans. Set the temporary point *O* at the station location indicated.
2. With the instrument at *O,* sight along the center line of the railroad, turn the skew angle (71°45´), set the permanent stakes *P* and *R,* and set points *M* and *N.*
3. With the instrument at *M,* sight *R,* turn 90°, and set permanent stakes *S* and *T.*
4. With the instrument at *N,* sight *P,* turn 90°, and set permanent stakes *U* and *V.*

The face of the abutment is defined by *P* and *R.* Stakes *S, T, U,* and *V* define the face of the end forms. When construction begins, set stakes at *A, B, C,* and *D* by measuring from the offset stakes. (These stakes are knocked out as the excavation progresses.)

Concrete for the foundation is poured into the excavation. If forms are needed for the foundation, measure the distances from the reference offset stakes. Set the elevations of the top and bottom of the foundation from bench marks outside the excavation area.

When the foundation has been poured to grade and has had a day to set, mark temporary points on the top at *M* and *N* by measuring 10 feet plus the distance *AM* and *BN* from the offset stakes *S* and *U.* Check the forms by measuring the equal diagonals *MC* and *ND.* Mark points denoting elevation directly on the forms and give the data to the petty officer in charge of the construction project.

After the bridge seat is poured, mark point *O.* After the rear wall has been poured, mark points defining the girder center lines: *a, b, c, d, e,* and *f.* These points will be used for the accurate location of the bearing plates that will support the girders.

1.2.2.2.2 Abutment Wing Walls

Figure 2-16 illustrates the stakeout of abutment wing walls. A typical procedure is as follows:

1. Set up the instrument at B; turn the wing angle from *G;* set reference stakes *H* and *I;* measure distances *BH* and *BI.* Set up at *A* and repeat this procedure to establish *J* and *K.* Use reference lines *FG, BH,* and *AJ* to set temporary stakes marking the corners of the excavation for the foundation. Then the method described earlier for abutments is followed. If abutment or wing-wall faces are battered (inclined, rather than vertical), lines are established for both top and bottom.

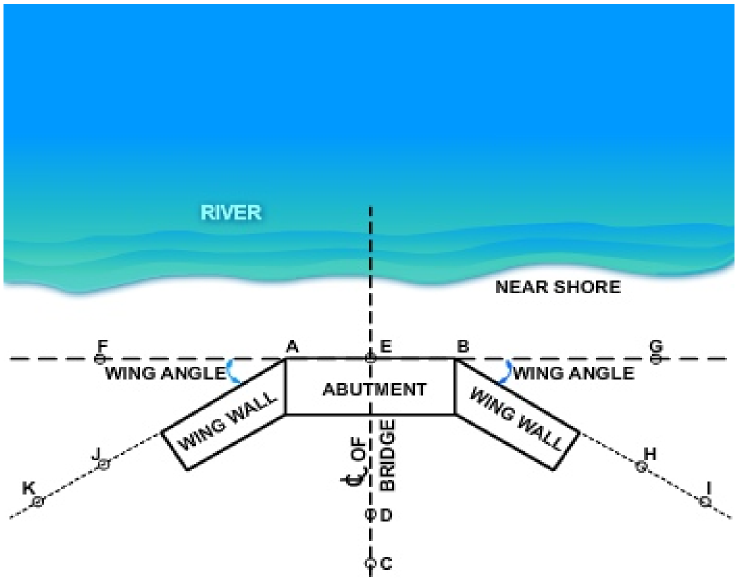

Figure 2-16 Staking out abutment wing walls.

2. To stake out wing walls for askew abutments to the center line of a bridge, follow the procedure described for askew abutments. Set up the instrument over *N* (*Figure 2-15*); sight on *R;* turn the wing angles; set reference stakes to establish the wing line from *N.* Establish the wing line from *M* in the same manner.

1.2.2.2.3 Piers

After the center line of the bridge is established, locate the piers by chaining, if possible. If chaining is impractical, locate the piers by triangulation. Set stakes establishing the center line on each side of the river. Lay out *CD* and *EF* approximately at right angles to the center line, as shown in *Figure 2-17*. For well proportioned triangles, the length of the base lines should equal at least one-half *CE.* To locate piers at *A* and *B,* you may use the following procedure:

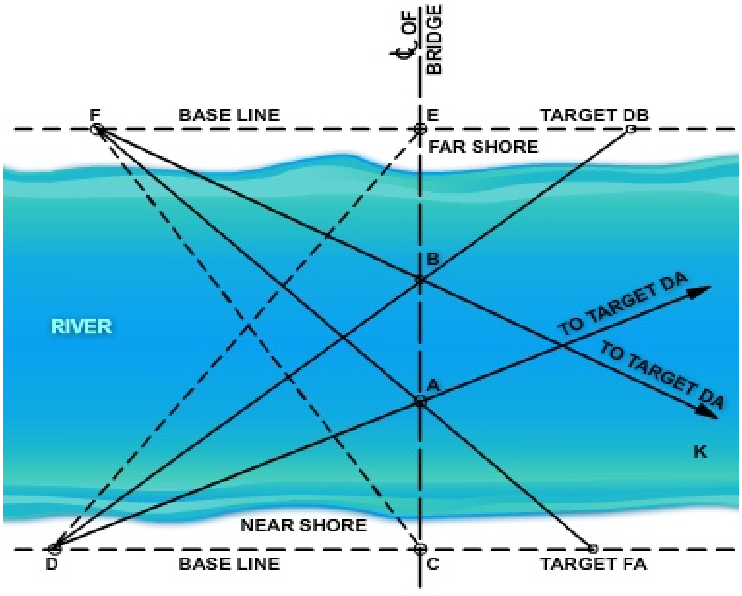

Figure 2-17 – Method of locating piers.

1. Establish base lines *CD* and *EF* and carefully reference them.
2. Measure the length of each base line with a degree of accuracy suitable for the required accuracy of the line *CE.*
3. Measure all angles of the triangles *CDE* and *EFC.*
4. Compute the distance *CE* from the triangle *CDE* and check against the same distance computed from triangle *EFC.* The difference in computed lengths must be within the prescribed limits of error.
5. Compute angles *BDC, ADC, BFE,* and *AFE.*
6. Draw a triangulation diagram, showing computed angles and distances and measured angles and distances.
7. Turn the computed angles *BDC, ADC, BFE,* and *AFE.*
8. Set targets *DA* and *DB* on the far shore and *FB* and *FA* on the near shore so that the intersecting lines can be reestablished without turning angles. Carefully reference these points.

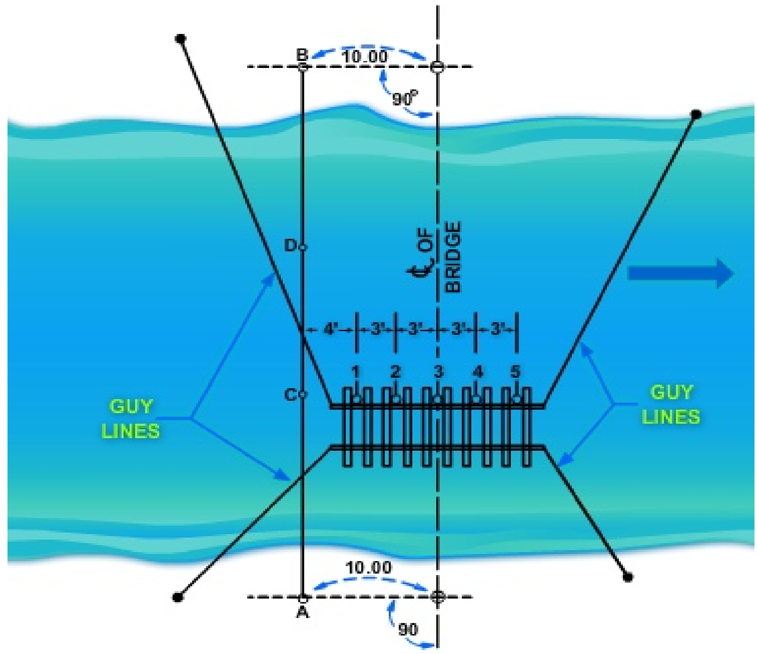

Figure 2-18 – Method of positioning piles.

9. Use two instruments to position piers. Occupy two points, such as *C* and *D,* simultaneously, using the intersection of sights *CE* and *DA* to locate the pier. Check the locations of points *A* and *B* if they are within the limits of error by sighting along the center line, *CE.*

1.2.2.2.4 Piles

You may be required to position piles, record pile-driving data, and mark piles for cutoff. *Figure 2-18* shows points *A* and *B* established as a reference line 10 feet from the center line of a bridge. Stretch a wire rope between points *A* and *B* with a piece of tape or a wire rope clip at each pile-bent position (such as *C* or *D).*

Locate the upstream pile (pile No. 1) by measuring an offset of 4 feet from the line *AB* at *C.* A template is then floated into position and nailed to pile No. 1 after it is driven. The rest of the piles are positioned by the template.

If it is impractical to stretch a wire rope to the far shore, set up a transit at a convenient distance from the center line of the bridge. Position the piles by sighting on a mark located the same distance from the center line of the template. Before driving piles, you must measure the length of the piles. Measure the distance between the piles by chaining.

During pile driving, keep a complete record of the following: location and number of piles, dimensions, kind of woods, total penetration, average drop of hammer, average penetration under last five blows, penetration under last blow, and amount of cutoff.

Mark elevations on the two end piles by nailing two 3- by 12-inch planks to guide the saw in cutting the piles to the specified height.

1.2.2.3 Bridge Grade Stakes

Elevations are taken from bench marks set in or near the construction area. Consider permanency, accessibility, and convenience when setting bench marks. Set grade stakes for a bridge site in the same manner as the grade stakes on any route survey. Make sure that the senior petty officer in charge of the job has sufficient information so that the exact method being used to designate the grade can be understood.

1.2.3 Sewer Stakeout

To stake out a sewer, you obtain data from a plan and profile that shows:

1. The horizontal location of each line in the system
2. The horizontal location and character of each manhole
3. The invert elevations at each manhole
4. The gradient of each line

You will also have detail drawings of each type of appurtenance. If manholes in the same category are of different types, you may identify them by letter symbol, as CI “A,” and so on. In addition, identification of a particular appurtenance may be by consecutive number, as CI “A” #3.

The stakeout consists of setting hubs and stakes to mark the alignment and indicate the depth of the sewer. The alignment may be marked by a row of offset hubs and stakes or by both offset hubs and a row of 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 center-line stakes guide the backhoe operator or ditcher operator. The cuts are usually shown to tenths and 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.

If the survey party stakes only the offset hubs, then the construction crew usually sets center-line stakes for line only and uses the hubs as a guide for the depth of excavation. The extent of the stakeout and computations performed by the survey party and the work done by the construction crew depend on the capabilities and the availability of personnel and the work load. In any case, hubs and/or stakes are generally set at 25-foot intervals, though 50-foot and even 100-foot intervals have been known to suffice.

Sewer hubs are usually offset from 5 to 8 feet from the center line. Before entering the field, compute from the profile the invert elevation at every station where a hub will be set. Consider *Figure 2-19*, for example. This is a plan showing a line running from a curb inlet through two manholes to an outfall. The dotted lines are offsets (greatly exaggerated for clearness) to points where you will set the hubs. Note that at stations 5 + 75 and 1 + 70.21, you set two hubs, one for the invert in and the other for the invert out.

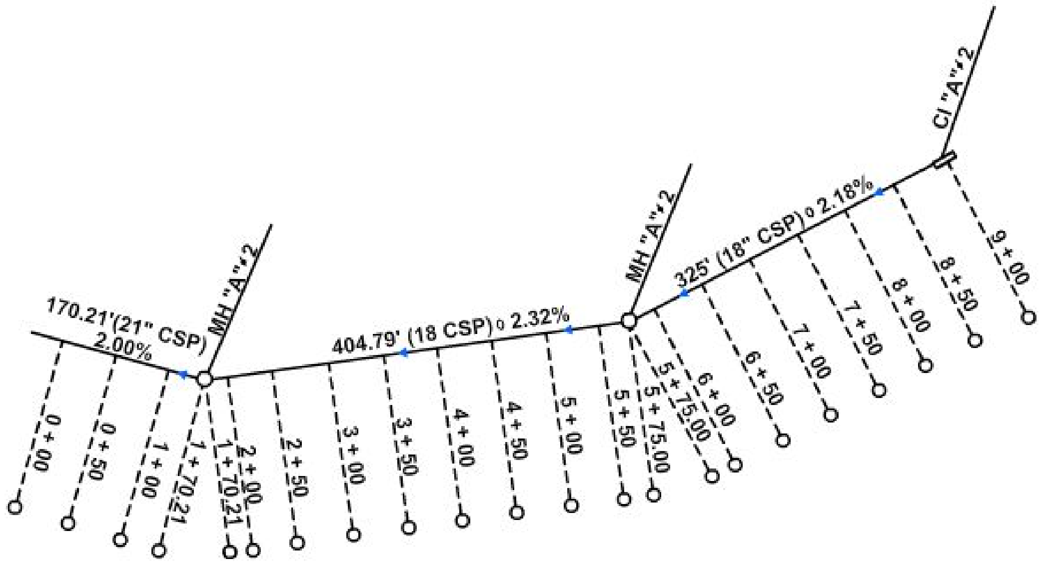

Figure 2-19 – Sewer stakeout plan.

The invert elevations at the manhole (MH) are given on the profile. Suppose that the invert out at CI “A” #2 is 122.87 feet. The gradient for this pipe is 2.18 percent. Station 8 + 50 lies 0.50 station from CI “A” #2; therefore, the invert elevation at station 8 + 50 is 122.87 feet minus (0.50 x 2.18), or 122.87 feet minus 1.09, or 121.78 feet. You compute the invert elevations at the other intermediate stations in the same manner.

Suppose now that you are starting the stakeout at CI “A” #2. The final-location party left a center-line stake at this station. You occupy this point, turn 90 degrees left from the line to MH “A” #1, and measure off the offset, for example, 8 feet. This is presuming that, if the ground slopes across the line, the high side is the side on which the hubs are placed in *Figure 2-19*. Hubs are always placed on the high side to prevent them from being covered by earth dozed off to form a bench for the trench-digging rig.

You drive a hub 8 feet offset from station 9 + 00 and determine the elevation of the top of the hub. The vertical distance from the top of the hub to the invert at station 9 + 00 is the difference between the invert elevation and the elevation of the top of the hub. The invert elevation at station 9 + 00 is 122.87 feet. Suppose the elevation of the top of the hub is 126.94 feet. Then you would mark the guard stake for this hub, CI “A” #2 inv. C 4.07´. Suppose the elevation of the top of the hub driven at station 8 + 50 is 127.33. The invert elevation at this station is 121.78; therefore, you would mark the guard stake for this station, 8 + 50, C 5.55´.

The manner in which the construction crew will use these hubs to dig the trench to grade will vary according to the preference of the supervisor for one of several methods. One method involves the erection of a batter board across the trench at each hub. The top of each board is placed on the posts at a set distance above invert elevation, for example, 10 feet. *Figure 2-20* illustrates this method.

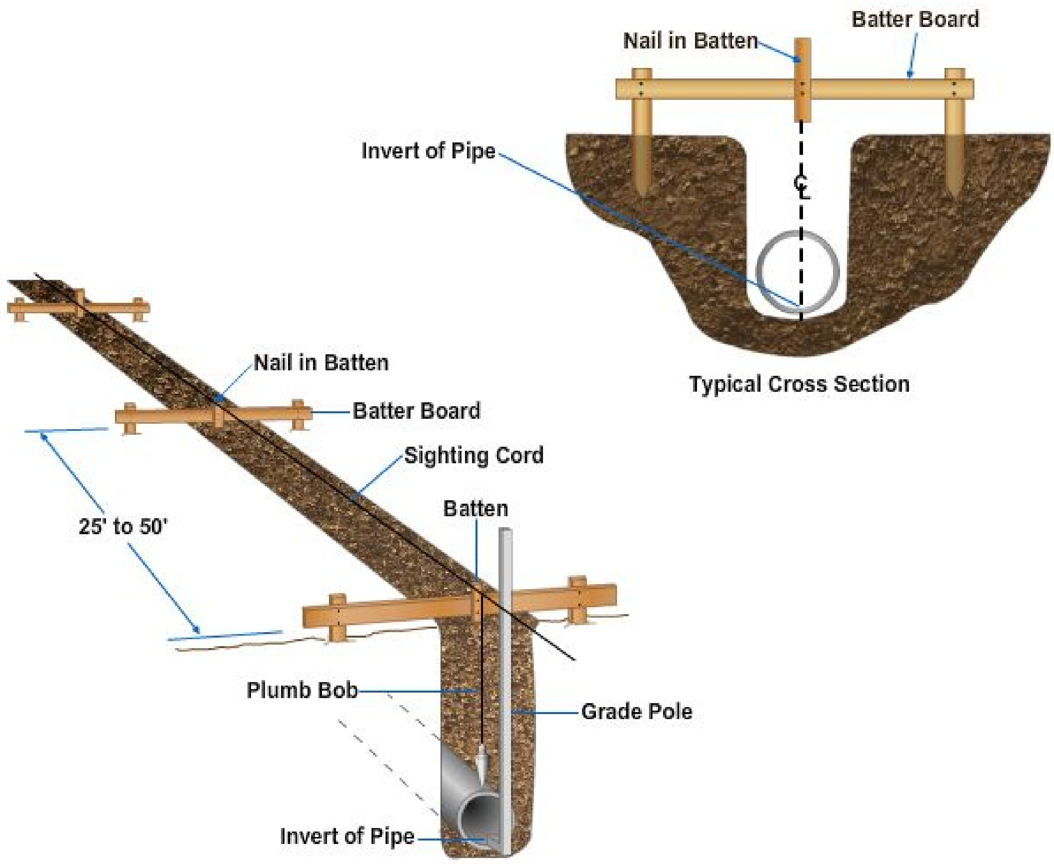

Figure 2-20 – Setting sewer line to grade.

Take station 9 + 00 in *Figure 2-19,* for example. The elevation of the top of the hub is 126.94 feet and the invert elevation is 122.87 feet. To be 10 feet above invert elevation, the top of the batter board must be placed on the post 5.93 feet above the top of the hub. To get this distance, the field constructor would simply subtract the specified cut from 10 feet. At station 8 + 50, for example, the height of the top of the batter board above the top of the hub would be 10 – 5.55, or 4.45 feet.

The offset is measured off from a point directly above the hub along the batter board; a mark here is directly over the center of the pipeline. Battens are nailed on the batter board to indicate sewer center-line alignment. A string is stretched and tacked along these battens. The string indicates the horizontal location of the line and follows the gradient of the line, but at a distance of 10 feet above the invert. The amount of cut required to be taken out at any point along the line can be determined by setting a measuring pole alongside the string. If the string indicates 8.5 feet, for example, another 1.5 feet of cut must be taken out.

Corners of rectangular manhole boxes are staked out much as building corners are staked out. For a box located where a line changes direction, it may be desired that the center line of the box bisect the angle between the lines. The box for a curb inlet must be exactly located with respect to a street curb to be constructed in the future; therefore, curb inlets are usually staked out with reference to the street plan, rather than with reference to the sewer plan.

1.2.4 Laser Method of Laying Pipe

Another useful device for controlling pipeline excavations and laying pipe is the laser. So many applications are being found for the laser that it may eventually be the only tool needed for the layout and control of construction projects. It can be quickly, accurately, and economically used for purposes such as distance measurement, alignment for tunnel borings, setting of pipes with desired grades, and setting of line and grade for many types of construction.

The laser is an intense light beam that can be concentrated into a narrow ray, containing only one color (red) or wavelength of light. The resulting beam can be projected for short or long distances and is clearly visible as an illuminated spot on a target. It is not disturbed by wind or rain, but it will not penetrate fog. A laser can be set up on a bracket or even attached to a transit telescope. The beam is aligned in the proper direction at the desired grade and can be left relatively unattended.

Today, instead of using batter boards and strings, lasers can be used to control the alignment for excavating trench and setting a pipe. The laser can be set so that it shines on the boom of a backhoe so that the equipment operator can clearly see the illuminated spot. By its position, the operator can closely control the depth of digging. For laying the pipe, the laser is set in the proper direction at the desired distance above the pipe invert. With the aid of the L-shaped pole or template, as shown in *Figure 2-21*, the workers can control the invert elevation. It may also be possible to direct the laser beam from the inside of manholes through the pipes being laid and to control the grade without any interference from the backhoe operations. This can be done even if the pipes are too small for human access.

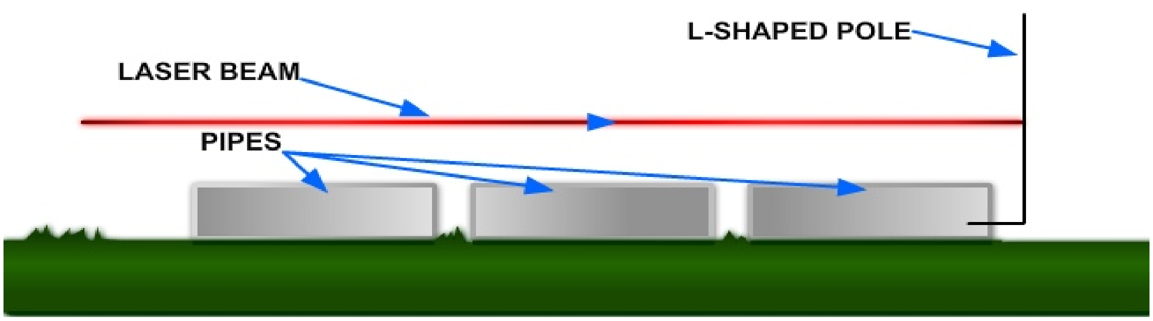

Figure 2-21 – Pipe laying with laser.

1.2.5 Underground Duct System Layout

The stakeout for an underground power line 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 feet below the bottoms of the incoming and outgoing ducts. Power and communications manholes are often combined; *Figure 2-22* shows plan and section views of a combination power and communications manhole.

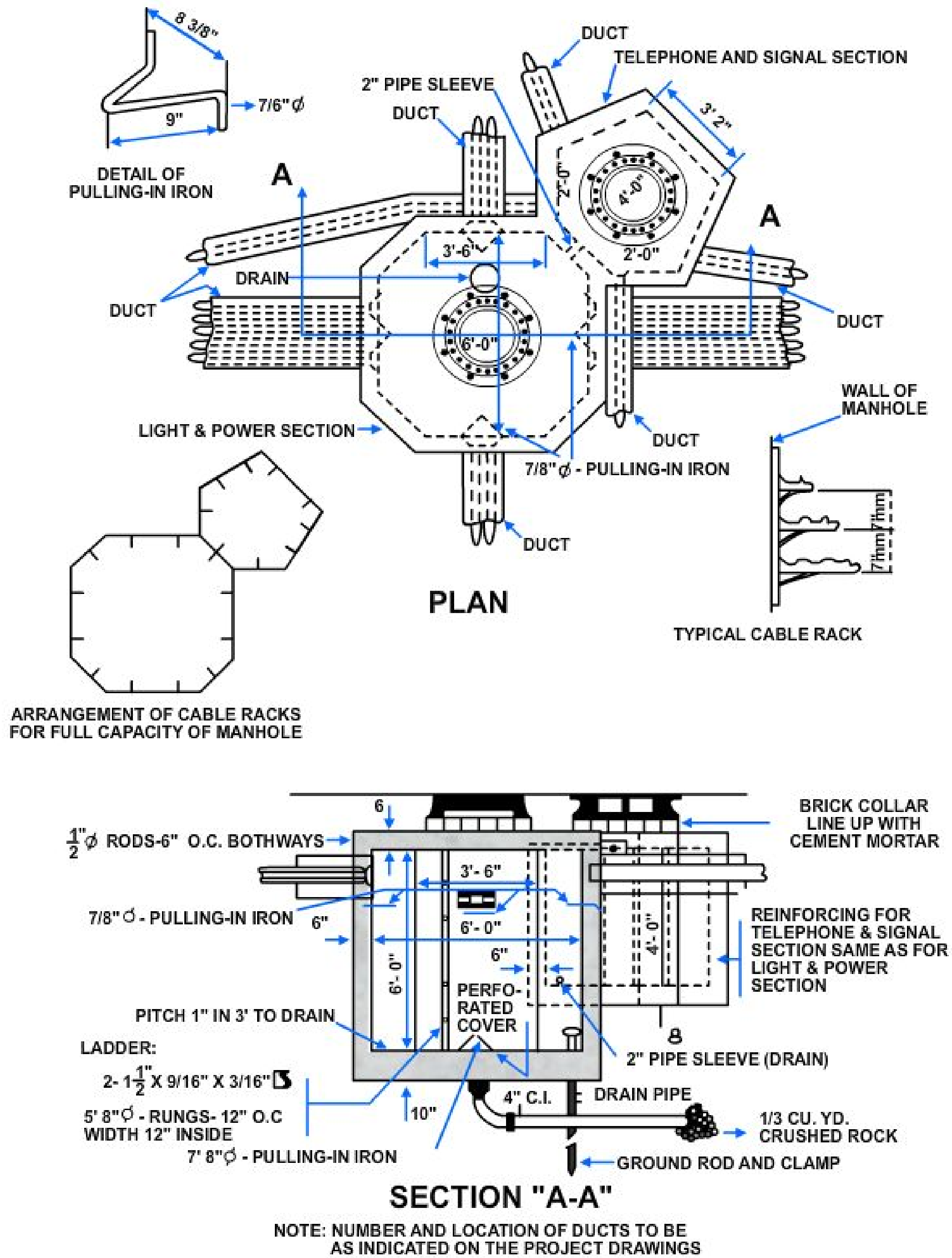

Figure 2-22 – Combination power and communication manhole.

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 2-23* shows plan and section views of a handhole.

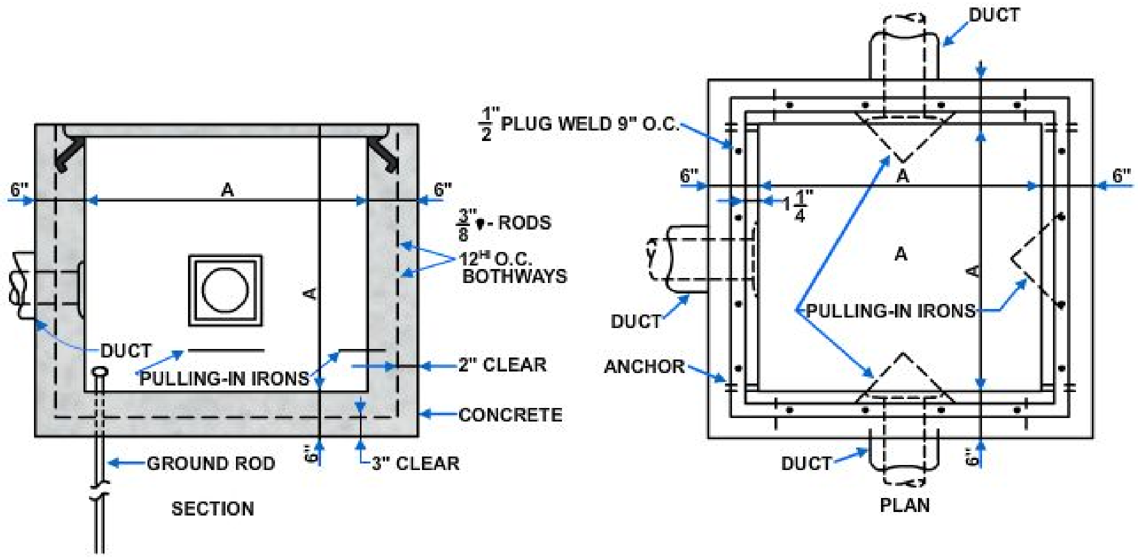

Figure 2-23 – Handhole.

1.2.6 Construction Sheets

Several construction situations have been mentioned in which line and grade for construction are obtained from a line (or perhaps from two lines) of offset hubs. A guard stake adjacent to one of these hubs usually gives the station and elevation of the hub, grade for the structure at this station, and the vertical distance between the top of the hub and grade, marked C or F.

This information is often recorded on a construction sheet (familiarly known as a cut sheet) like the shown in *Figure 2-24*. One advantage of the use of a cut sheet is that the information applicable to each hub is preserved in the event that guard stakes are displaced. Another advantage is that reproductions of the cut sheet can be given to construction supervisors so that they may always have access to all the essential construction data.

CONSTRUCTION SHEET

PROJECT : MEMQ Area
CONSTRUCTION : Storm sewer
LOCATION : MH #2 out to MH #3 in
HUB OFFSET : 10' from ℄ sewer
GRADE TO : invert

BY:Brown,M.EAZ Date: 29 Feb.20_

STATION	HUB ELEY.	GRADE	CUT OR FILL	REMARKS
0+00(MH#2out)	286.23	280.00	C 6.23	
0+50	286.40	279.50	C 6.90	
1+00	285.97	279.00	C 6.97	
1+50	284.33	278.50	C 5.83	
2+00	284.35	278.00	C 6.35	hub offset 8'
2+50	283.08	277.50	C 5.58	
2+87(MH#3in)	283.11	277.13	C 5.98	

Figure 2-24 – Typical construction sheet.

Test Your Knowledge (Select the Correct Response)

1. Which of the following elements of a route survey must always be performed?

   A. Reconnaissance survey
   B. Preliminary survey
   C. Both A and B
   D. Final-location survey

2. **(True or False)** The reconnaissance survey for electrical lines is performed by guidelines unique to that survey.

   A. True
   B. False

3. When the route for the distribution line has been selected, a plan and profile are plotted. Which of the following elevations is/are shown?

   A. Finish grade
   B. Existing grade
   C. Top of the poles
   D. Both A and B

4. What type of drainage system is the most desirable way to remove surface water?

   A. Underground
   B. Open ditch
   C. Collection ponds
   D. French drain

5. What does the term “runoff” mean in relation to drainage?

   A. The amount of rainfall not absorbed
   B. Water attempting to attain the lowest point due to gravity
   C. Only the water collected in collection ponds
   D. Water carried by the storm sewer system

6. What appurtenance for a storm sewer system is located where trunk lines converge?

   A. Manhole
   B. Box
   C. Junction box
   D. Grate

7. Area by resolution involves dividing the area into what type of figures for ease of calculation?

   A. Irregular polygons
   B. Trapezoids
   C. Triangles
   D. Both B and C

8. What distance, in feet, is normally considered the free-haul distance?

   A. 400
   B. 500
   C. 750
   D. 1,000

9. The term “balance line” refers to the point on a mass diagram where…….

   A. a cut becomes a fill
   B. a fill becomes a cut
   C. the haul limit is exceeded
   D. the volume of fill equals the volume of cut

10. When you stake out culverts, the detail of the work is based upon what factor?

   A. Complexity of the culvert
   B. Length of the culvert
   C. Depth of the culvert
   D. Location of the culvert

11. What term is used to refer to the abutment when a bridge does not align at right angles to the road or stream?

    A. Near-side
    B. Far-side
    C. Askewed
    D. Misaligned

12. After the first pile is driven, a template is attached to it. What is the purpose of the template?

    A. To assist in positioning other piles
    B. To assist in positioning the guy lines
    C. To aid in marking piles for length
    D. To aid in measuring the distance between piles

13. The use of a laser to control the alignment for excavating a trench and setting a pipe also eliminates the need for what other equipment?

    A. Batter boards only
    B. Batter boards and hubs
    C. Hubs and strings
    D. Batter boards and strings

14. Which of the following aids assists the worker in controlling the invert elevation of the pipes being laid with a laser?

    A. L-shaped pole
    B. Laser beam
    C. Hubs
    D. String line and plumb bob

2.0.0 AIRFIELD SURVEYS

Airfield construction is of a special kind; for this reason, it is discussed here under a separate heading.

2.1.0 Airfield Route Surveys

The route for an airfield is the horizontal location of the runway center line; if there is more than one runway, there is, of course, more than one route. The principal consideration regarding the direction of a runway center line is the average direction of the prevailing wind in the area, since planes must take off into the wind. The azimuth of the center line will be as nearly as possible the same as the average azimuth of the prevailing wind. A study of the meteorological conditions is therefore a part of the reconnaissance survey. Other data gathered on this survey (which may be conducted on foot, by ground surface vehicle, by plane, or by all three) include the land formation, erosional markings, vegetation, configuration of drainage lines, flight hazards, approach zone obstructions, and soil types.

From the reconnaissance data, one or more preliminary center lines are selected for location by preliminary survey. For quick preliminary stakeout, there may be two parties, working away from station 0 + 00 located at the approximate midpoint of the center line.

In such cases, stations along the azimuth may be designated as plus and those along the back azimuth as minus.

Level parties follow immediately behind the transit parties, taking profile levels and cross sections extending the width of the strip, plus an overage for shoulders and drainage channels. From the preliminary survey data, a plan and profile are made of each tentative location, and from these, a selection of a final location is made.

2.2.0 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.

An approach zone is a trapezoidal area beyond the end zone at each end of a runway. It must be free of obstruction not only on the ground but also off the ground at a specific glide angle. The size of the approach zone depends on the type and stage of development of the field. For permanent naval air stations, the trapezoidal area might be 10,000 feet long with a width of 4,000 feet at the outer end. For purposes of explanation only, we will assume that these are the dimensions of the approach zone for which you are surveying.

The glide angle for most types of aircraft is 2 percent, usually given as 50:1, or a rise (or drop) of 1 vertical for 50 horizontal. *Figure 2-25* shows, in plan, profile, and isometric, an approach zone and its adjacent transition surfaces and end of runway. You must stake out this approach zone and check it for clearance by the following procedure:

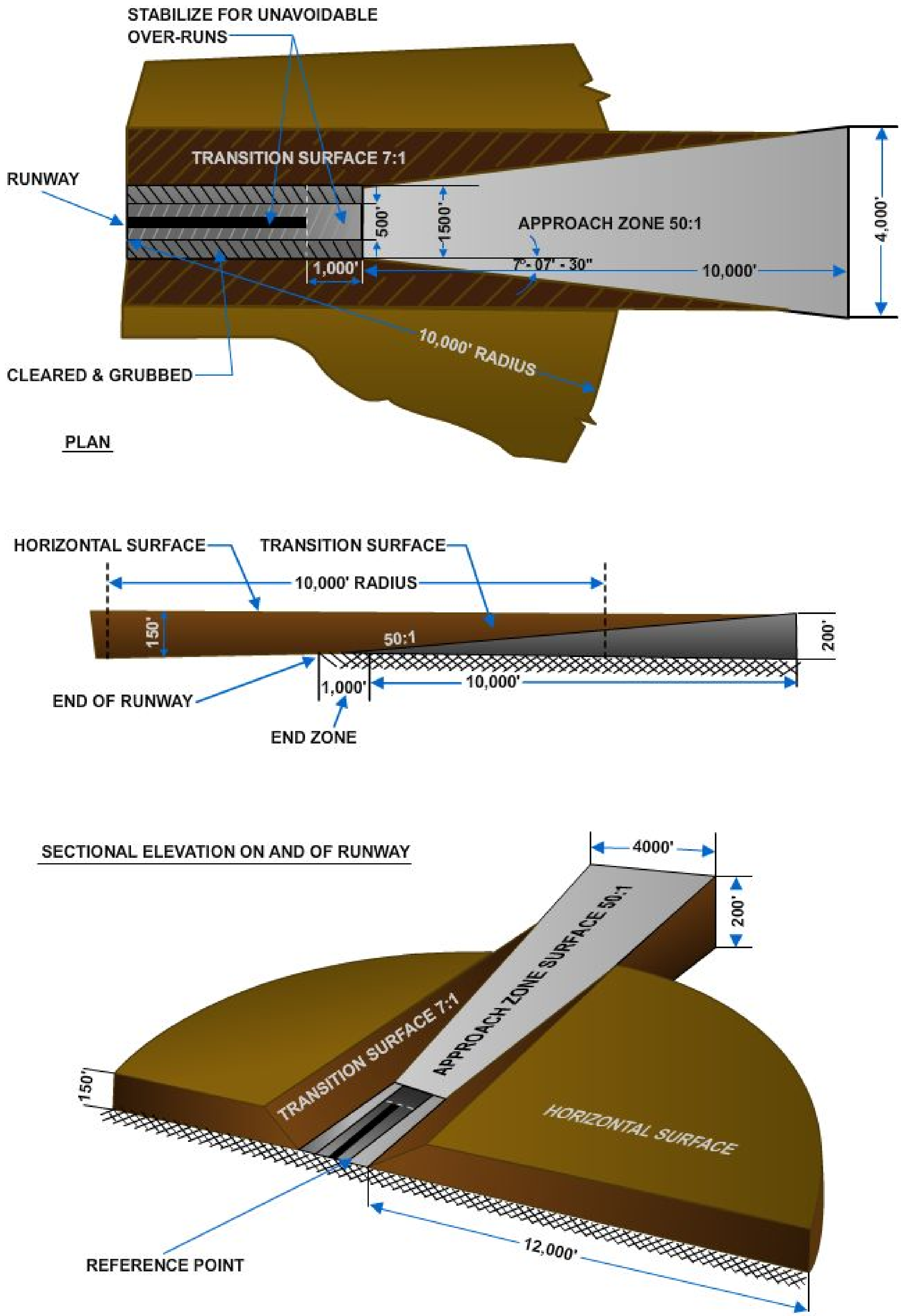

Figure 2-25 – Runway approach zone.

Figure 2-26 shows the approach zone in plan. The dotted line *BC* lies 750 feet from the center line. The angle at *B* can be determined by solving the triangle *CBD,* tan *B* = 1,250/10,000, or 0.125000; therefore, angle *B* measures 7°7´30´´. Determining the distance from the dotted line to the edge of the approach zone at any station is similarly a simple right-triangle solution. Suppose that *AB* is located at station 0 + 00. Then at station 1 + 00, the distance from the dotted line to the edge of the approach zone is 100 tan 7°7´30´´, or 12.5 feet; therefore, the distance between the center line and the edge of the approach zone at this station is 750 + 12.5, or 762.5 feet.

To check for obstructions, set up a transit at the narrow end of the approach zone, then set the telescope at a vertical angle equal to the one that the glide plane makes with the horizontal, and take observations over the whole approach zone, as indicated in *Figure 2-27*. Determining the vertical angle is a simple right-triangle solution. If the glide angle is 50:1, then the tangent of the vertical angle is 1/50, or 0.020000, and the angle measures 1°8´45´´.

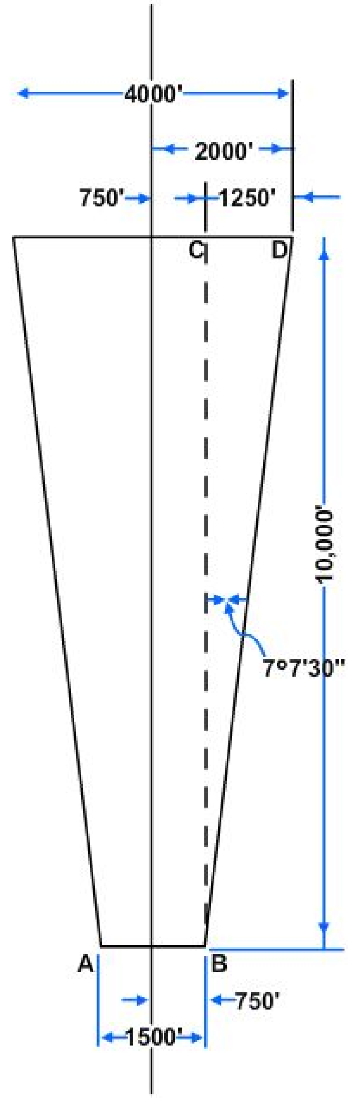

Figure 2-26 – Plan view of approach zone.

Figure 2-27 shows how the exact vertical location of the glide plane varies with the character of the surface of the end zone.

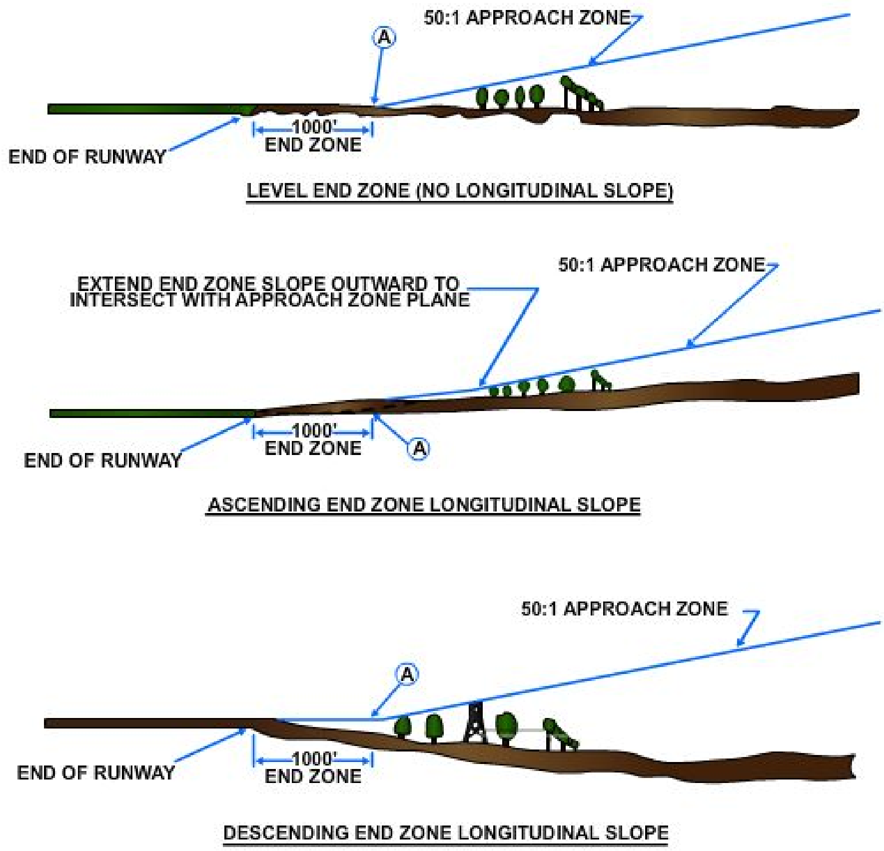

Figure 2-27 – Approach clearance for different types of end zones.

Test Your Knowledge (Select the Correct Response)

15. When laying out a runway, you must consider what factor?

    A. Landing area
    B. Parking apron
    C. Direction of the prevailing wind
    D. Drainage

3.0.0 WATERFRONT SURVEYS

Under some circumstances it is possible to chain distances over the water; however, it is usually more convenient to shore base triangulate to determine offshore distances from a base line. No matter how you get offshore distances, however, offshore points cannot be marked like ground points with hubs or stakes. Therefore, in the location of offshore points, there must usually be coordination between a survey party on the beach and a party afloat.

3.1.0 Offshore Pile Location by Chaining

Figure 2-28 shows a situation in which offshore locations of piles for a wharf were determined by chaining. We will call each series of consecutive piles running offshore a line and each series running parallel to the shore a row. Alignment for each line was obtained by transit—set up on a shore base line offset from the inboard row of piles. In each line the distance from one pile to the next was chained, as shown.

In *Figure 2-28* the lines are perpendicular to the base line, which means that the angle turned from the base line was 90° and the distance from one transit setup to the next was the same as the prescribed distance between lines. If the lines were not perpendicular to the base line, both the angle turned from the base line, the distance from one transit setup to the next, and the distance from the base line to the first offshore pile in each line would have to be determined.

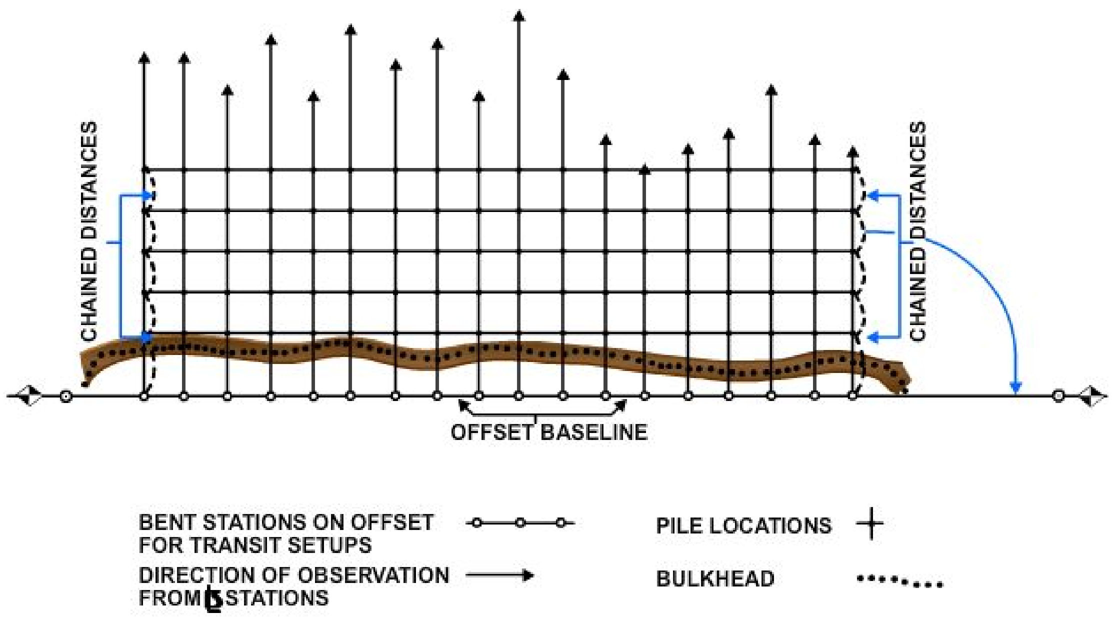

Figure 2-28 – Offshore location by chaining.

In *Figure 2-29* the wharf design involves an angle between each line of piles and the base line which is 60°40´. You can determine the chaining distance between transit setups by solving the triangle *JAB* for *AB, JA* being drawn from transit setup *B* perpendicular to the first line of piles. The offshore location of the next line of piles is determined by the chain distance on the base line from the first pile line transit setup *A* through piles 1, 2, 5, 10, 16, and 25 and the oblique 60°40´angle. *AB* measures 50/sin 60°40´, or 57.35 feet. This, then, is the distance between all adjacent transit setups on the base line.

The distance from the base line to the first offshore pile in any line also may be determined by right-triangle solution. For pile No. 1 this distance is prescribed as 50 feet. For pile 2, first solve the triangle *A2L* for *2L,* which is 100/tan 29°20´, or 177.95 feet. The distance from 2 to *Q* is 150 feet; therefore, *QL* measures 177.95 – 150, or 27.95 feet. *QD* amounts to 27.95/tan 60°40´, or 15.71 feet. Therefore, the distance from transit setup *D* to pile No. 8 is 50 + 15.71, or 65.71 feet.

Use the same process of solving for the right triangle distances determine the distance to first pile points *F15, G22,* and *H23* by solving the right triangle *AN10* and proceeding as before. For pile No. 24, the distance *I24* amounts to 50 tan 29°20´, or 28.10 feet.

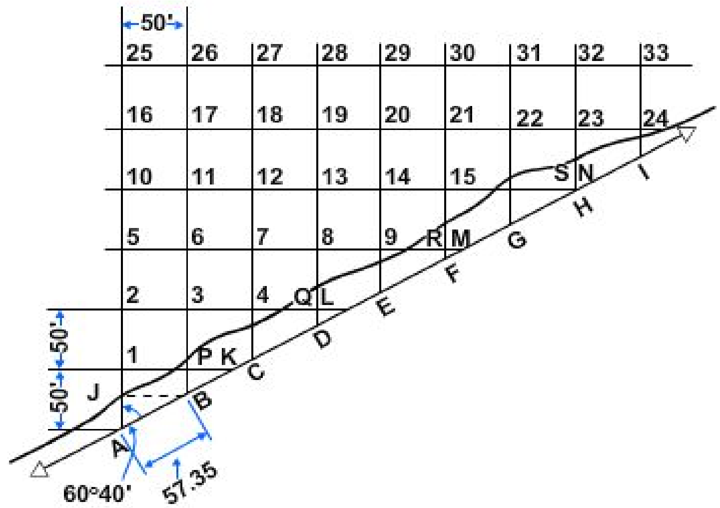

Figure 2-29 – Offshore location of pile lines oblique to the base line.

3.2.0 Offshore Location by Triangulation

For piles located farther offshore, the triangulation method of location is preferred. A pile location diagram is shown in *Figure 2-30*. It is presumed that the piles in section *X* will be located by the method just described, while those in section *Y* will be located by triangulation from the two control stations shown.

The base line in *Figure 2-30* measures (1,038.83 – 433.27), or 595.56 feet, from control station to control station. The middle line of piles runs from station 7 + 41.05, making an angle of 84° with the base line. The piles in each bent are 10 feet apart; bents are identified by letters, and piles by numbers. The distance between adjacent transit setups in the base line is 10/sin 84°, or 10.05 feet.

Bents are located 20 feet apart. The distance from the center-line base line transit setup at station 7 + 41.05 to pile No. 3 is 70 feet. The distance from station 7 + 51.10 to pile No. 2 is 70 + 10 tan 6°, or 70 + 1.05, or 71.05 feet. The distance from station 7 + 61.15 to pile No. 1 is 71.05 + 1.05, or 72.10 feet. The distance from station 7 + 31.00 to pile No. 4 is 70 - 1.05, or 68.95 feet; and from station 7 + 20.95 to pile No. 5 is 68.95 – 1.05, or 67.90 feet.

You can determine the angle you turn, at a control station, from the base line to any pile location by triangle solution. Consider pile No. 61, for example. This pile is located 240 + 72.10, or 312.10 feet, from station 7 + 61.15 on the base line. Station 7 + 61.15 is located 1,038.83 – 761.15, or 277.68 feet, from control station 10 + 38.83. The angle between the line from station 7 + 61.15 through pile No. 61 and the base line measures 180°- 84°, or 96°. Therefore, you are dealing with the triangle *ABC* shown in *Figure 2-31*. You want to know the size of angle A. First solve for *b* by the law of cosines, in which *b2 = a2 + c2- 2ac* cos *B,* as follows:

$$b^2 = 312.102 + 277.682- 2(312.10)(277.68) \cos 96°$$

$$b = 438.89 \text{ feet}$$

Knowing the length of *b,* you can now determine the size of angle *A* by the law of sines. Sin *A* = 312.10 sin 96°/438.89, or 0.70722. This means that angle *A* measures, to the nearest minutes, 45°00´.

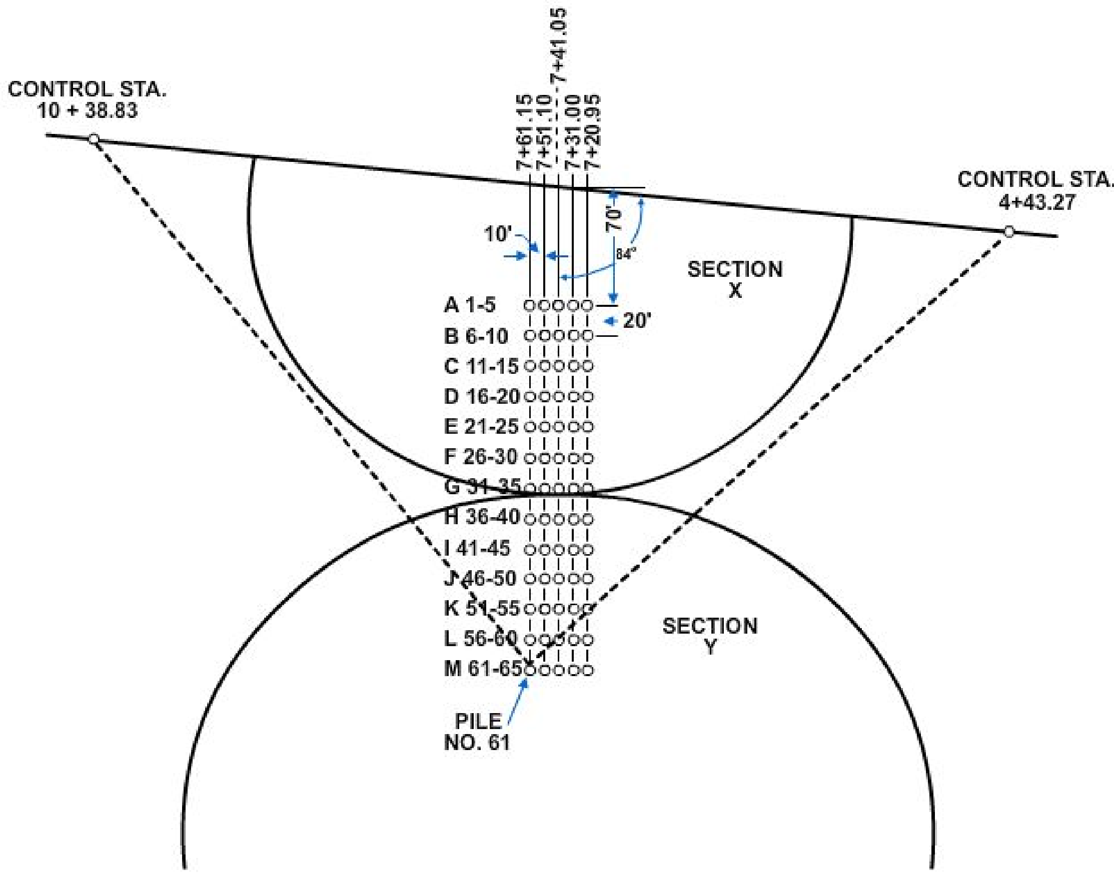

Figure 2-30 – File location diagram.

To determine the direction of this pile from control station 4 + 43.27, you would solve the triangle *DBC* shown in *Figure 2-31*. You do this in the same manner as described above. First solve for *b* using the law of cosines and then solve for angle *D* using the law of sines. After doing this, you find that angle *D* equals 47°26´.

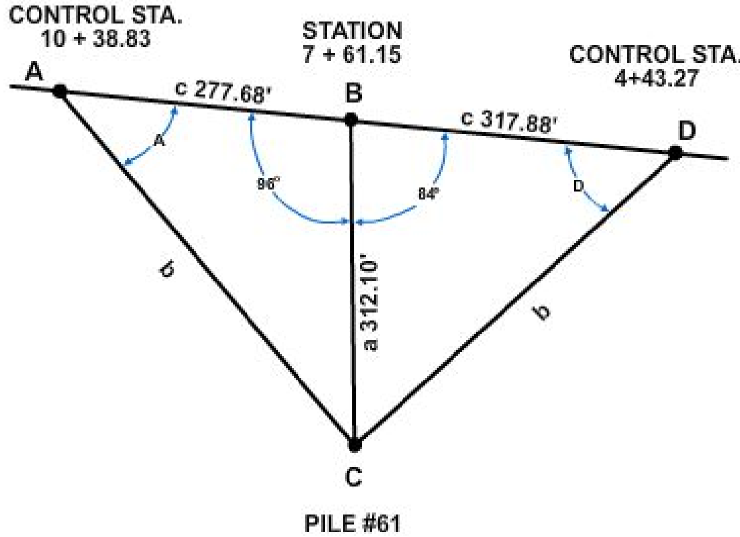

Figure 2-31 – Trigonometric solution for Pile No. 61.

It would probably be necessary to locate in this fashion only the two outside piles in each bent; the piles between these two could be located by measuring off the prescribed spacing on a tape stretched between the two. For the direction from control station 10 + 38.83 to pile No. 65 (the other outside pile in bent M), you would solve the triangle shown in *Figure 2-32*. Again, you solve for *b* using the law of cosines and then use the law of sines to solve for angle *A.*

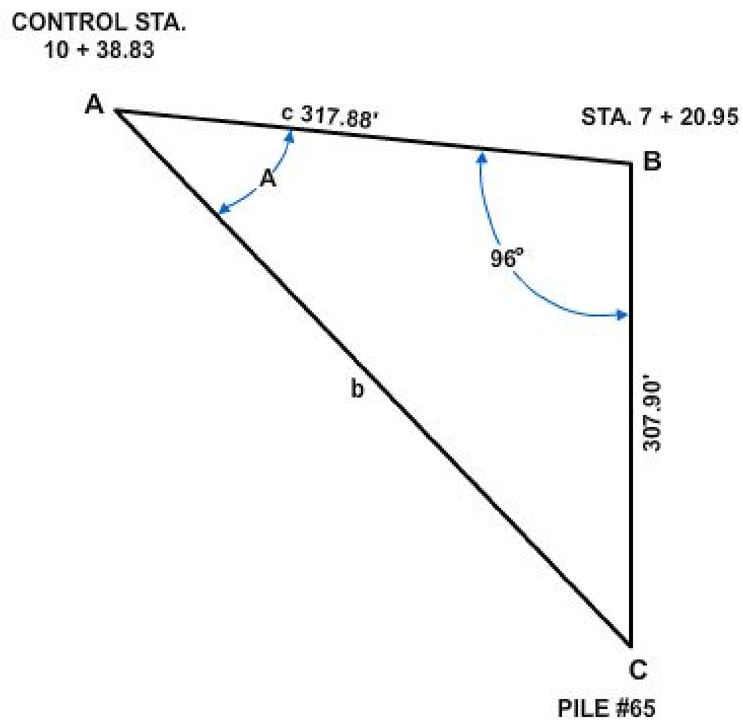

Figure 2-32 – Trigonometric solution for Pile No. 65.

For each control station, a pile location sheet like the one shown in *Figure 2-33* would be made up. If desired, the direction angles for the piles between No. 61 and No. 65 could be computed and inserted in the intervening spaces.

Table 2-3 – File location sheet.

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

3.3.0 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 a known location on the beach, or by some other piloting method. Many times, however, dredges are positioned by survey triangulation. The method of determining direction angles from base line control points is the same as the method just described.

Test Your Knowledge (Select the Correct Response)

16. When locating piles by triangulation, you would normally locate how many piles?

    A. As many as possible
    B. Half of each bent
    C. The two outside piles of each bent
    D. Two

4.0.0 LAND SURVEYING

Land surveying includes surveys for locating and monumenting the boundaries of a property; preparation of a legal description of the limits of a property and of the area included; preparation of a property map; resurveys to recover and remonument property corners, and surveys to subdivide property.

It is sometimes necessary to retrace surveys of property lines, to reestablish lost or obliterated corners, and to make ties to property lines and corners; for example, a retracement survey of property lines may be required to assure that the military operation of quarry excavation does not encroach on adjacent property where excavation rights have not been obtained. Similarly, an access road from a public highway to the quarry site, if it crosses privately owned property, should be tied to the property lines that are crossed so that correctly executed easements can be obtained to cross the tracts of private property.

EAs may be required to perform 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, knowledge of these principles enable the EA to conduct the survey in a manner required by the property laws of the nation concerned.

In the United States, land surveying is a survey conducted for the purpose of ascertaining the correct boundaries of real estate property for legal purposes. In accordance with federal and states laws, the right and/or title to landed property in the United States can be transferred from one person to another only by means of a written document, commonly called a deed. To constitute a valid transfer, a deed must meet a considerable number of legal requirements, some of which vary in different states. In all the states, however, a deed must contain an accurate description of the boundaries of the property.

A right in real property need not be complete, outright ownership (called fee simple). There are numerous lesser rights, such as leasehold (right to occupancy and use for a specified term) or easement (right to make certain specified use of property belonging to someone else). But in any case, a valid transfer of any type of right in real property usually involves an accurate description of the boundaries of the property.

As mentioned previously, the EA may be required to perform various land surveys. As a survey team or crew leader, you should have a knowledge of the principles of land surveys in order to plan your work accordingly.

4.1.0 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.

4.1.1 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 old method of describing land that still forms the basis for the majority of deed descriptions in the eastern states of the United States and in many foreign lands. A good metes-and-bounds description starts at a point of beginning that should be monumented and referenced by ties or distances from well established monuments or other reference points. The bearing and length of each side is given, in turn, around the tract to close back on the point of beginning. Bearing may be true or magnetic grid, preferably the former. When magnetic bearings are read, the declination of the needle and the date of the survey should be stated. The stakes or monuments placed at each corner should be described to aid in their recovery in the future. Ties from corner monuments to witness points (trees, poles, boulders, ledges, or other semi-permanent or permanent objects) are always helpful in relocating corners, particularly where the corner markers themselves lack permanence. In timbered country, blazes on trees on or adjacent to a boundary line are most useful in reestablishing the line at a future date. It is also advisable to state the names of abutting property owners along the several sides of the tract being described. Many metes-and-bounds descriptions fail to include all of these particulars and are frequently very difficult to retrace or locate in relation to adjoining ownerships.

One of the reasons why the determination of boundaries in the United States is often difficult is that early surveyors often provided minimal description. Today, good practice requires a land surveyor to include all relevant information in the 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 2-33* is given below.

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

Figure 2-33 – Lot plan by metes and bounds.

> "All that certain tract or parcel of land and premises, hereinafter particularly described, situate, lying and being in the Township of Maplewood in the County of Essex and State of New Jersey and constituting lot 2 shown on the revised map of the Taylor property in said township as filed in the Essex County Hall of Records on March 18, 1944."
>
> "Beginning at an iron pipe in the northwesterly line of Maplewood Avenue therein distant along same line four hundred and thirty-one feet and seventy- one-hundredths of a foot northeasterly from a stone monument at the northerly corner of Beach Place and Maplewood Avenue; thence running (1) North forty-four degrees thirty-one and one-half minutes West along land of. . ."

Another form of a lot description maybe presented as follows:

> "Beginning at the northeasterly corner of the tract herein described; said corner being the intersection of the southerly line of Trenton Street and the westerly line of Ives Street; thence running S6°29´54´´E bounded easterly by said Ives Street, a distance of two hundred and twenty-seven one hundredths (200.27) feet to the northerly line of Wickenden Street; thence turning an interior angle of 89°59´16´´ and running S83°39´50´´W bonded southerly by said Wickenden Street, a distance of one hundred and no one-hundredths (100.00) feet to a corner; thence turning an interior angle of. . ."

You will notice that in the above example, interior angles were added to the bearings of the boundary lines. This will be another help in retracing lines.

4.1.2 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.

4.1.3 By Plane Coordinates

For many years the triangulation and traverse monuments of various domestic and foreign survey agencies have been defined by their latitudes and longitudes. Property corners might be definitely fixed in position in the same way. The computations can be 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 which form a 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. 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. The *Y*-coordinate is always positive. The *X* –coordinates increase in size, numerically, from west to east and the *Y* -coordinates increase in size from south to north. All *X* -coordinates in an area represented on a state grid are made positive by assigning the origin of the coordinates: $X = 0$ plus a large constant. For any point, then, the *X* -coordinate equals the value of *X* adopted for the origin, plus or minus the distance *(X´)* of the point east or west from the central meridian *(Y* -axis); and the *Y* -coordinate equals the perpendicular distance to the point from the *X* -axis. The linear unit of the state coordinate systems is the foot of 12 inches defined by the equivalence: 1 international meter = 39.37 inches exactly.

The linear distance between two points on a state coordinate system, as obtained by computation or scaled from the grid, is termed the "grid length" of the line correcting those points. The angle between a line on the grid and the *Y* -axis, reckoned clockwise from the south through 360°, is the grid azimuth of the line. The computations involved in obtaining a grid length and a grid azimuth from grid coordinates are performed by means of the formulas of plane trigonometry.

A property description by metes and bounds might include points located by coordinates as follows:

> "Commencing at U.S. Coast and Geodetic Survey Monument 'Bradley, Va', having coordinates y = 75,647.13 ft and x = 35,277.48 ft, as based on the Virginia Coordinate System, North Zone, as are all the coordinates, bearings, and distances in this description; thence S 36°30´E, 101.21 ft to the intersection

of Able Street and Baker Avenue, whose coordinates are y = 75,565.77 ft and x = 35,337.45 ft, ..."

4.1.4 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 detailing the location and boundaries of each major subdivision and of each of the lots it contains. The map book is filed in the county or city recorder's office, and henceforward, in deeds or other instruments, a particular lot is described as, for example, "Lot 72 of Tract 5417 as per map recorded in book 72, pages 16 and 17, of maps, in the office of the county/city recorder of [named] county/city"; or as "Lot 32 of Christopher Hills Subdivision as per. . . ."

4.2.0 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. Accept liability 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. If required, 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. Seek additional evidence when original monuments cannot be recovered with certainty from the data contained in the deed description. Such evidence must be substantial in character and must not be merely personal opinion.
9. Seek agreement between adjourning owners as to a mutually acceptable location in the absence of conclusive evidence as to the location of a boundary; possibly serve as an arbiter in relocating the boundary according to prevailing circumstances and procedures set forth by local authority.
10. Appear as an expert witness when a boundary dispute is carried to the courts.
11. Respect the laws of trespass. The right to enter upon property in conducting public surveys is provided by law in most localities. In a few political subdivisions, recent laws make similar provision with respect to private surveys. Generally, the military surveyor should request permission from the owner before entry on private property. When the surveyor lacks permission from an adjoiner, it is usually possible to make the survey without trespassing on the adjoiner's land,

but such a condition normally adds to the difficulty of the task. The surveyor is liable for actual damage to private property resulting from his/her operations.

A primary responsibility of a land surveyor is to prepare boundary data that may be submitted as evidence in a court of law in the event of a legal dispute over the location of a boundary. The techniques of land surveying do not vary in any essential respect from those used in any other type of horizontal-location surveying—you run a land survey boundary traverse, for example, just as you do a traverse for any other purpose. The thing that distinguishes land surveying from other types of surveying is that a land surveyor is often required to decide the location of a boundary on the basis of conflicting evidence.

For example, suppose you are required to locate, on the ground, a boundary line that is described in a deed as running, from a described point of beginning marked by a described object, N26°15´E, 216.52 feet. Suppose you locate the point of beginning, run a line there from the deed distance in the deed direction, and drive a hub at the end of the line. Then you notice that there is, a short distance away from the hub, a driven metal pipe that shows signs of having been in the ground a long time. Let's say that the bearing and distance of the pipe from the point of beginning are N26°14´E, 215.62 feet.

You can see that there is conflicting evidence here. By deed evidence the boundary runs N26°15´E, 216.52 feet, but the evidence on the ground seems to indicate that it runs N26°14´E, 215.62 feet. Did the surveyor who drove the pipe drive it in the wrong place, or 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, must possess the knowledge, experience, and judgment to select the best evidence when the existing situation is conflicting.

There are no specific rules that can be consistently followed. In the case mentioned, the decision as to the best evidence might be influenced by a number of considerations. The pipe is pretty close to the deed location of the end of the boundary. This might, everything else being equal, be a point in favor of considering the pipe bearing and distance, rather than the deed bearing and distance, to be correct. If the pipe were a considerable distance away, it might even be presumed that it was not originally intended to serve as a boundary marker. Additionally, the land surveyor would consider the fact that, if the previous survey was a comparatively recent one done with modern equipment, it would be unlikely that the measured bearing to the pipe would be off by much more than a minute or the distance to the pipe off by much more than a tenth of a foot. However, if the previous survey was an ancient one, done perhaps with compass and chain, larger discrepancies than these would be probable.

Further considerations would have to be weighed as well. If the deed said, "From [point of beginning] along the line of Smith N26°15'E, 216.52 feet," and you found the remains of an ancient fence on a line bearing N26°15'E, these remains would tend to vouch for the accuracy of the deed bearing regardless of a discrepancy in the actual bearing of the pipe or other marker found.

To sum up, in any case of conflicting evidence, you should (1) find out as much as you can about all the evidential circumstances and conditions, using all feasible means, including questioning of neighboring owners and local inhabitants and examining deeds and other documents describing adjacent property, and (2) select the best evidence on the basis of all the circumstances and conditions.

As in many other professions, the primary—in this case, the surveyor—may be held liable for incompetent services rendered. For example, if the surveyor has been given, in advance, the nature of the structure to be erected on a lot, he/she may be held liable for all damages or additional costs incurred as a result of an erroneous survey, and pleading in defense that the survey is not guaranteed will not stand up in court. Since civilian professional surveyors must be licensed before they can practice their profession, they must show that degree of prudence, judgment, and skill reasonably expected of members of their profession.

4.3.0 Land Survey General Procedure

As there are no universal rules for the weighing of evidence, so there are no universal, unvarying rules for land-survey procedures. The typical problem, however, usually breaks down into the following major action phases:

1. The location, study, and (when necessary) interpretation of all the available deeds, contracts, maps, wills, or other documents that contain a description of the boundaries. The principal repository for most of this information resides in the city or county records office. It is not unusual to uncover conflicting documentation describing the same property in different ways. Or you may find a document in which some of the language may bear more than one interpretation. In this last case you apply a legal maxim to the effect that an ambiguous document should be given the sense that the maker of the document may be reasonably presumed to have intended.
2. The determination, after study of all the documents and related evidence, of what the true property description may be presumed to be, and from this a determination of what physical evidence of the boundary location exists in the field. Physical evidence means for the most part monuments. In land-surveying speech, a monument is any identifiable object that occupies a permanent location in the field and serves as a reference point or marker for a boundary. A monument may be a natural monument, such as a rock, a tree, or the edge of a stream. It may be an artificial monument, such as a pipe or a concrete monument. Do not use perishable markers for monuments, such as a wooden marker that decays easily.
3. The location, in the field, of the existing physical evidence of the boundaries.
4. The establishment of the boundary involving those decisions previously mentioned as to the best evidence. It also involves the setting, referencing, and marking of points that should have been marked in previous surveys but were not or that were marked with markers that have since disappeared.
5. The preparation of the property description.

4.4.0 Plats of Surveyed Lands

The official plat of a township or other subdivision is the drawing on which is shown the direction and length of each line surveyed, established, retraced, or resurveyed; the relationship to adjoining official surveys; the boundaries, designation, and area of each parcel of land; and, insofar as practical, a delineation of the topography of the area and a representation of the culture and works of man within the survey limits. A subdivision of the public lands is not deemed to have been surveyed or identified until the notes of the field survey have been approved, a plat prepared, the survey accepted by the Director of the Bureau of Land Management as evidenced by a certification to that effect on the plat, and the plat has been filed in the district land office. Plats are drawn on sheets of uniform size, 19 inches by 24 inches in trimmed dimensions, for convenience in filing. The usual scale is 1 inch = 40 chains, equivalent to a representative fraction of

1:31,680. Where detail drawings of a portion of the survey area are required, scales of 1 inch = 20 chains or 1 inch = 10 chains may be used. A detail of a small area may be 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. Features other than survey lines are quite extensive; color printing is used. Survey lines, numbers, lettering, and railroads are printed in black; topographic relief, roads, highways, trails, culture, alkali flats, sandy-bottom draws, and sand dunes are shown in brown; rivers, lakes, streams, and marshes are shown by conventional symbols in blue, and timbered areas are indicated in green. Where such a green overprint might obscure other details, the presence of timber may be indicated.

A property plat plan must contain the following:

1. Directional orientation, usually indicated by a north arrow.
2. Bearing and distance of each boundary.
3. Corner monuments.
4. Names of adjacent owners, inscribed in areas of their property shown.
5. Departing property lines. A departing property line is one that runs from a point on one of the boundaries of the surveyed lot through adjacent property. It constitutes a boundary between areas belonging to two adjacent owners.
6. Names of any natural monuments that appear on the plat (such as the name of a stream), or the character of any natural monuments (such as “10-inch oak tree”) that have no names.
7. Title block, showing name of owner, location of property, name of surveyor, date of survey, scale of plat, and any other relevant data.

The preceding items are those that usually appear on any plat. Some land surveyors add some or all of the following as well:

1. Grid lines or ticks (a grid tick is a marginal segment of a grid line, the remainder of the line between the marginal ticks being omitted), when determinable.
2. On a plat on which grid lines or ticks are shown, comer locations by grid plane coordinates.
3. Streams, roads, wooded areas, and other natural features, whether or not they serve as natural monuments.
4. Surveyor’s certificate. This is a statement (required by law in many states) in which the surveyor makes a personal affidavit as to the accuracy of the survey. A typical certificate might read as follows: I, (surveyor’s name), registered land surveyor, hereby certify that this plat accurately shows property of (owner’s name), as acquired in Deed Book 60, page 75, of the land record of (named) County, State of (name).
5. The area of the property.

4.5.0 Land Survey Precision

Most land surveying of tracts of ordinary size is done by using transit-tape methods. For a large tract, however (such as a large government reservation), 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 $1 million per acre), would be surveyed with considerably higher precision than would a rural tract.

Again there are no hard-and-fast rules. However, the prescribed order of precision for surveying the boundaries of a naval station might require the following:

1. Plumb bobs used for alignment and for transferring chained distances to the ground
2. Tape leveled by a Locke level
3. Tension applied by spring balance
4. Temperature correction made
5. Angles turned four times

If you turn angles four times with a 1-minute transit, you are measuring angles to approximately the nearest 15 seconds. The equivalent precision for distance measurement would be measurement to the nearest 0.01 foot. Four-time angles might be precise enough for lines up to 500.00 feet long. For longer lines, a higher angular precision (obtained by repeating six or eight times) might be advisable.

Test Your Knowledge (Select the Correct Response)

17. What type of survey determines the boundaries and areas of a property?

    A. Geodetic
    B. Hydrographic
    C. Land
    D. All of the above

18. All real estate deeds written in the United States must contain what information?

    A. Leasehold
    B. Easement
    C. Accurate boundary description
    D. Judge’s signature

19. When property is transferred, what laws must be followed when the description and plan are recorded?

    A. Federal
    B. State
    C. County
    D. City

20. Which of the following types of data is contained in the map books that are filed in the recorder’s office?

    A. Subdivision boundaries and locations
    B. Map history
    C. Bench mark locations
    D. Listing of all the pertinent maps for a subdivision

21. What is a primary responsibility for a land surveyor making surveys on property boundaries?

    A. To ensure the establishment of blocks, tracts, and subdivision
    B. To meet the requests of the property owners
    C. To prepare data that may be submitted as evidence for property disputes
    D. To verify previous surveys so property may be transferred

22. How do land surveys differ from other types of surveys?

    A. The surveyor may be required to make boundary decisions from conflicting evidence.
    B. More experience is required to perform land surveys.
    C. The accuracy required for land surveys is more precise.
    D. Methods for determining horizontal locations are different.

23. What is the final step, required by law in some states, to be completed by the land surveyor before a plat is filed in the district land office?

    A. Certification of the plat
    B. Preparation of the property description
    C. Preparation of the plat and a recheck of the accuracy
    D. Approval of the field survey notes

5.0.0 MAP PROJECTION

Map and chart projection includes the characteristics and development of various types of projections. A paper cylinder (without ends) and a paper cone can be cut along the side and flattened out without distortion. For this reason, the two most common basic projection methods are the ***Mercator***, in which the earth's surface is projected onto a cylinder, and the conic, in which the surface is projected onto a cone. A third method is the ***gnomonic*** method, in which the earth's surface is projected onto a plane placed tangent to a particular point. For a polar gnomonic chart, this point is one of the earth's geographical poles.

5.1.0 Mercator Projection

To grasp the concept of Mercator projection, imagine the earth to be a glass sphere with a strong light at the center. Imagine, also, that the geographical meridians and parallels are inscribed as lines on the sphere at a given interval (for example, every 15 degrees). Now imagine a paper cylinder placed around the sphere, tangent to the equator, as shown in *Figure 2-34*.

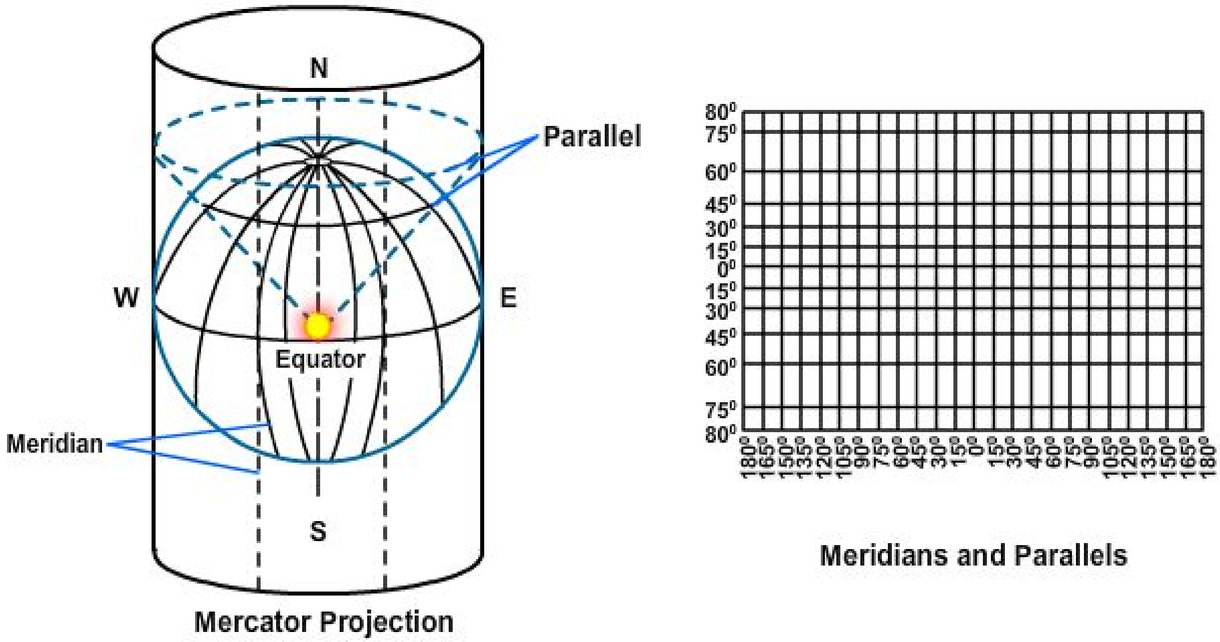

Figure 2-34 — Mercator Projection.

The shadow images of the meridians will appear on the paper as equally spaced, parallel, vertical lines. The shadow images of the parallels will likewise appear as straight lines running perpendicular to the shadow images of the meridians. The parallels are not actually equally spaced, however; instead, the distance between adjacent parallels will progressively increase as latitude (distance north or south of the equator, the line of tangency) increases.

You can see that there are two elements of distortion here, each of which progressively increases with latitude. One is the fact that the meridians, which on the earth itself converge at each of the poles, are parallel (and therefore equidistant) for their entire length on the cylinder. The other is the fact that the parallels, which are actually equidistant on the sphere itself, become progressively farther apart as latitude increases.

These two elements produce the familiar distortion that is characteristic of a Mercator map of the world. On such a map the island of Greenland, which has an area of only about 46,740 square miles, is considerably larger in outline than the continental United States, which has an area (excluding Alaska) of about 2,973,776 square miles.

Figure 2-34 Also depicts the meridians and parallels at 15-degree intervals of the earth's surface on a Mercator projection. Note that the parallels extend only to 80 degrees north and south. Because the cylinder has no ends, Mercator projection of regions in latitudes higher than about 80 degrees is impossible. Note, also, that although the distance along a meridian between (for example) 15°N and 30°N and between 60°N and 75°N is the same on the ground, these distances are much different on a Mercator projection. Still another characteristic to note is the fact that a meridian is perpendicular to all parallels it intersects and that all the meridians are parallel to each other.

5.1.1 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 degrees from this position to bring it tangent to a meridian. *Figure 2-35* shows the appearance of the meridians and parallels on the transverse Mercator world projection when the cylinder is flattened out. In this case, the cylinder was placed tangent to the meridian running through 0-degrees and 180-degrees longitude.

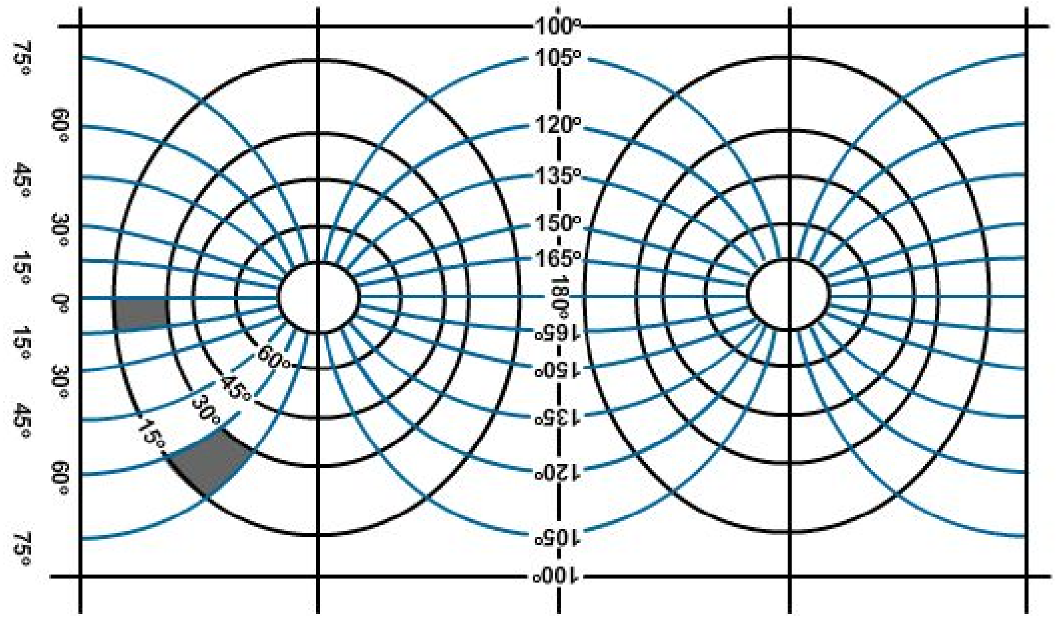

Figure 2-35 — Transverse Mercator Projection.

You can see that, in general, a transverse Mercator projection has less distortion than a Mercator projection does. You also can see that, unlike distortion on a Mercator projection, distortion on a transverse Mercator increases with longitude as well as with latitude away from the meridian of tangency. This is indicated by the shaded areas shown in *Figure 2-35*. These areas are the same size on the ground. Since they lie in the same latitude, they would have the same size on a Mercator projection. On the transverse Mercator projection, however, the area in the higher longitude would be larger.

The important thing to note about the transverse Mercator, however, is the fact that in any given area the distortion is about the same in all directions. It is this fact that makes the transverse Mercator the most feasible projection for use with the military grid reference system.

A ***rhumb line*** is a curve on the surface of a sphere that cuts all meridians at the same angle. A mathematical navigational device, developed to plot the Mercator-projected maps, makes the rhumb line a straight line on the chart, thus preserving the same angle of bearing with respect to the intersected meridians as does the track of a vessel under a true course. On the globe the parallels become shorter toward the poles, and their length is proportionate to the cosine of latitude. In the Mercator projection the parallels are equally long. This means that any parallel is increased by 1/cos q, or sec q, where q is the latitude in degrees. To have the same scale along the parallels as along the meridians, you must increase each degree of latitude by the secant of the latitude. In this mathematical transformation, the tangent cylinder concept was not employed, nor is it ever employed, in the Mercator projection. A Mercator projection table is used to plot the ***meridional distances***. For intensive study on elements of map projection, you may refer to special publications published by the U.S. Coast and Geodetic Survey that deal with this subject.

5.1.2 Universal Transverse Mercator and Military Grid Reference System

An extensive application of the transverse Mercator projection is in a grid reference system for military maps called the Universal Transverse Mercator (UTM) Military Grid Reference System (MGRS). In this system a reference plane grid, like those used in U.S. state grid systems, is imposed on Transverse Mercator projections of relatively small areas. The MGRS is an alpha-numeric system for expressing UTM / UPS coordinates. A single alpha-numeric value references an area that is unique for the entire earth.

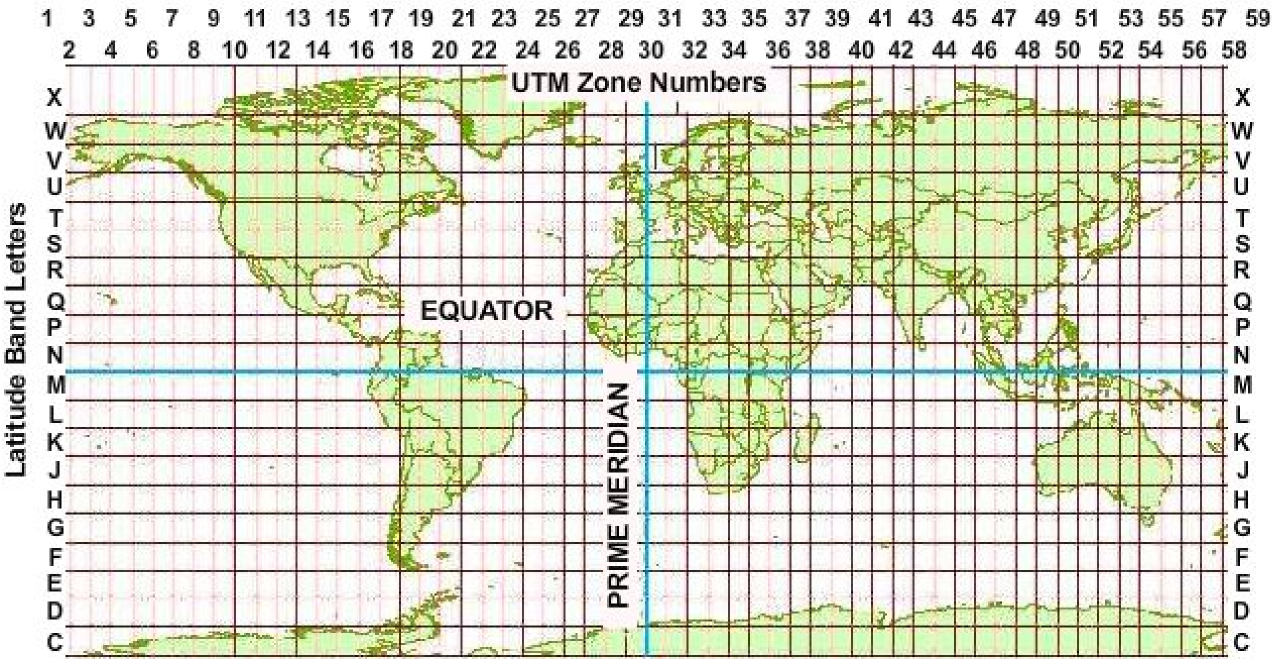

Figure 2-36 — MGRS Grid Zones.

Starting at the 180th meridian and progressing eastward by the compass, the earth's surface is divided into a succession of north-south zones, each extending for 6 degrees of longitude. These zones are numbered from 1 through 60. Between latitude 80°S and 84°N, each zone is divided into a succession of east-west rows, each containing 8 degrees of latitude, with the exception of the northernmost row, which contains 12 degrees of latitude. Rows are designated by the letters *C* through *X,* with the letters *I* and *O* omitted. The lettering system begins at the southernmost row and proceeds north. For a particular zone-row area, the designation consists of first, the zone number and next a row letter, such as 15S, which means row S in zone 15.

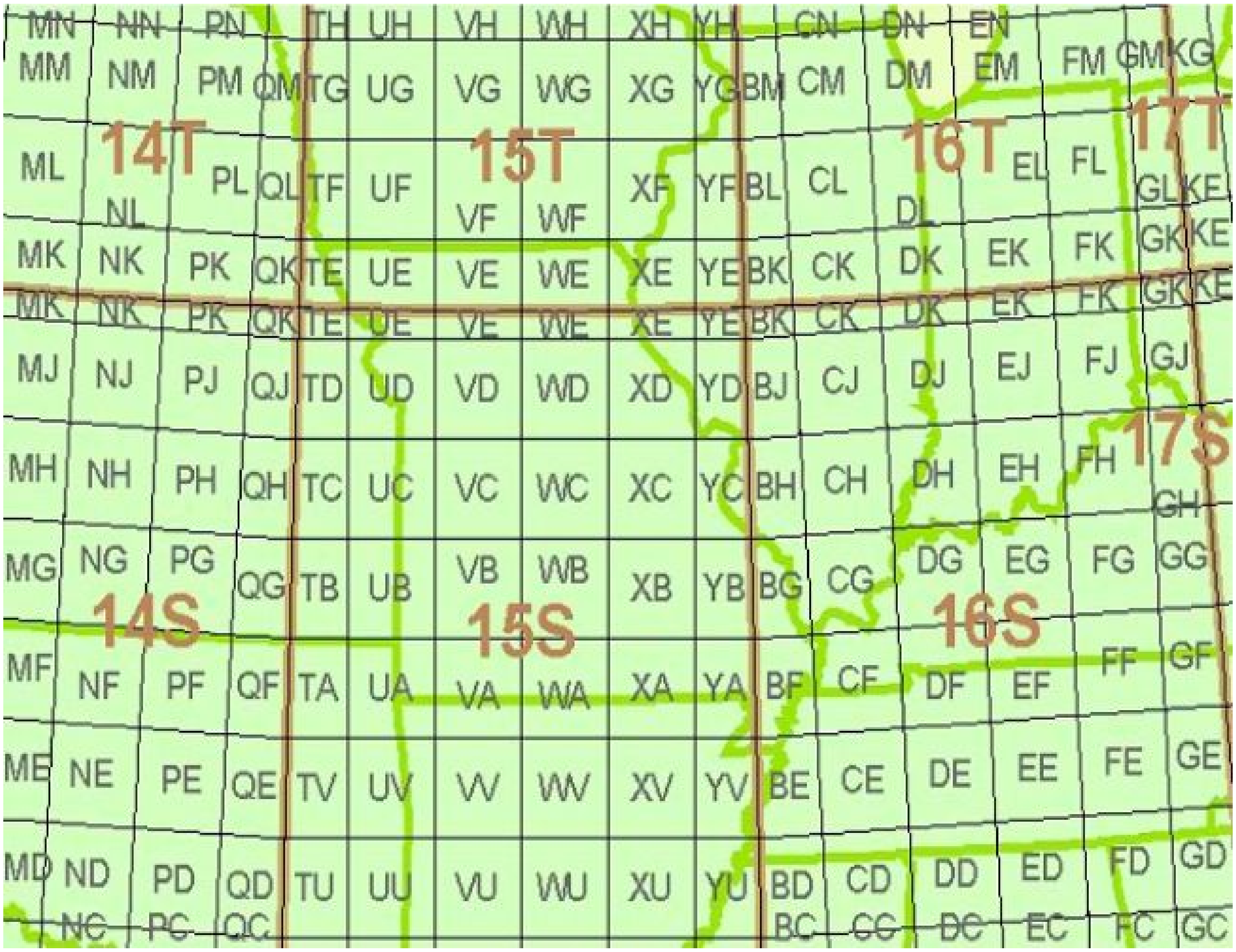

Figure 2-37 –MGRS Grid Zones Close in over the U.S.A..

The components of MGRS values are broken down as follows for the Example: 15SWC8081751205

The first two characters represent the 6° wide UTM zone.

- Leading zeroes are included in the 1st two characters so that Zone 8 is "08".
- For polar areas outside the UTM area, these characters are omitted.

The third character is a letter designating a band of latitude.

- Beginning at 80°S and preceding northward, the 20 bands are lettered C through X (Omitting I and O).
- The bands are all 8° high except band X, which is 12° high.
- Outside the UTM area, A and B are used near the South Pole, Y and Z near the North Pole.

The vertical UTM boundaries and horizontal latitudinal band boundaries form (generally) 6° X 8° Grid Zones. Hence, the first three letters of the MGRS value, e.g. "15S", are referred to as the ***Grid Zone Designation (GZD)***.

In the UTM Military Grid System, a particular point on the earth is further identified by the 100,000-meter square in which it happens to lie. Each of the 6-degree longitude by 8-degree latitude zone-row areas in the system is subdivided into squares measuring 100,000 meters on each side. Each north-south column of 100,000-meter squares is identified by letter as follows. Beginning at the 180th meridian and proceeding eastward, you will find six columns of full squares in each 6-degree zone. Besides the full columns, usually partial columns also run along the zone meridians. The partial columns and full columns in the first three zones are lettered from *A* through Z, again with the letters *I* and *O* omitted. In the next time zones, the lettering system begins over again.

Continuing with the example, "15SWC8081751205", the fourth and fifth characters are a pair of letters designating one of the 100,000-meter grid squares within the grid zone (or UPS area). In *Figure 2-37*, the Grid Zone Designators are shown in brown. The smaller gray letters are the 100,000-meter grid square designators. The example point "15SWC8081751205" is located in square "WC" near the center of the figure. The remaining characters consist of the numeric Easting and Northing values within the 100,000-meter grid square.

The MGRS coordinates may be truncated to reflect lesser precision level.

For example: 15SWC8081751205 is at one-meter refinement.

15SWC80815120 is at 10-meter refinement.

15SWC808512 is at 100-meter refinement.

15SWC8051 is at 1000-meter refinement.

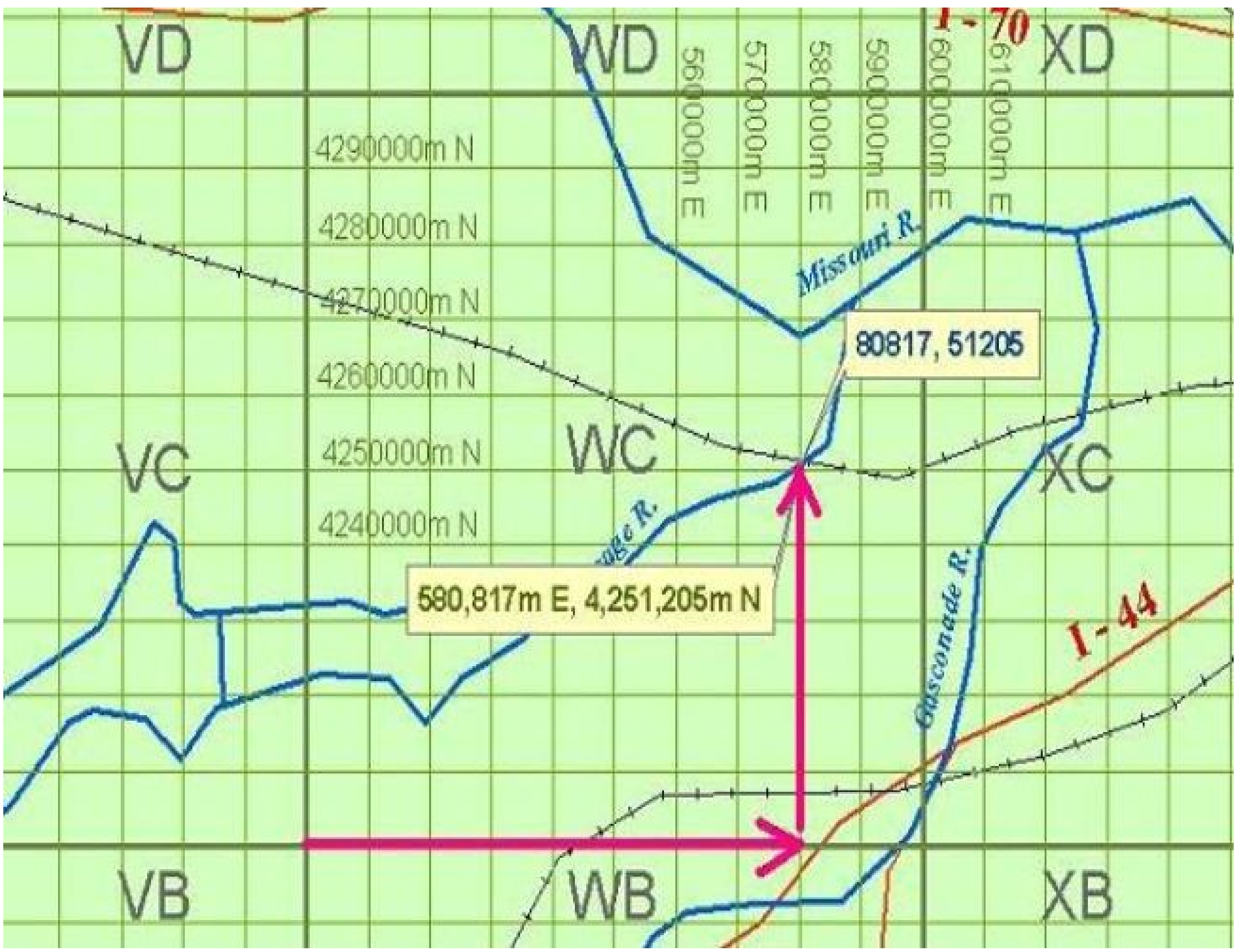

Figure 2-38 – MGRS Grid Zone Detail.

In *Figure 2-38*, the magenta arrows show how MGRS easting and northing values are determined from within the 100,000-meter grid square. The MGRS value of this position is 15SWC8081751205.

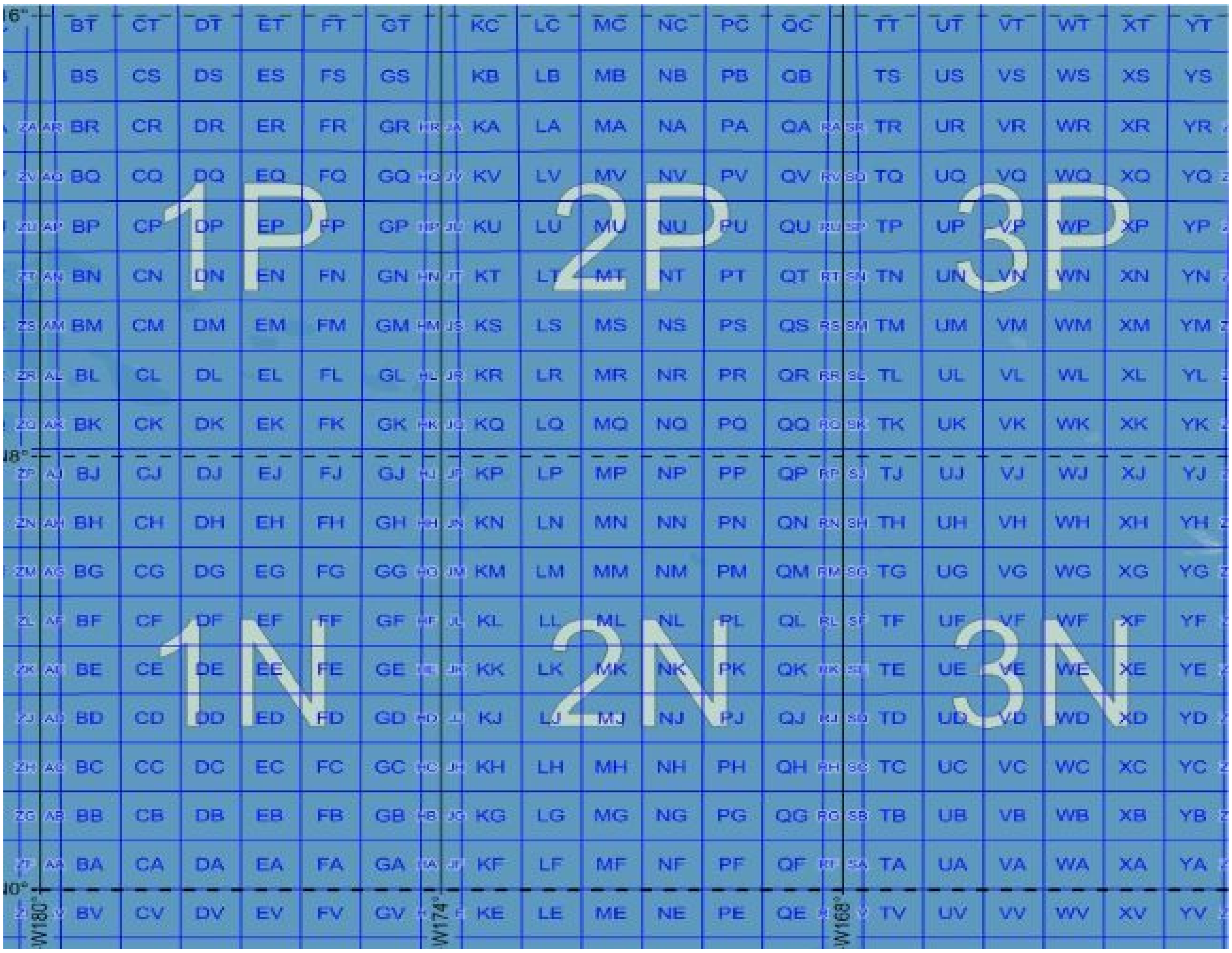

Figure 2-39 – UTM Example (Pacific Ocean).

Observe, for another example, *Figure 2-39*, which depicts the zone-row areas in 1N, 2N, and 3N, and 1P, 2P, and 3P. The zone meridians shown are 180°W, 174°W, 168°W, and 162°W; the zone-row parallels shown are the equator (0° latitude), 8°N, and 16°N. The first 100,000-meter-square column to the east of 180 degrees is the partial column A. Next comes six full columns: B, C, D, E, F, and G. Then comes partial column H, to the west of the zone meridian 174°W. The east-west rows of 100,000-meter squares are designated by the letters *A* through *V,* again with *I* and O omitted. For columns in the odd-numbered zones, the first row of squares north of the equator has the letter designation *A;* for columns in the even numbered zones, the first row of squares north of the equator has the letter designation *F.* Rows above and below this row are designated alphabetically. The first row south of the equator in the odd-numbered zones, for example, has the letter designation *V,* while the first row south of the equator in the even-numbered zones has the letter designation *E.* The complete designation for a particular 100,000-meter square consists of the number-letter, zone-row designation plus the two-letter, 100,000-meter-square designation. For example, the designation 1NBA means the first full square east of the 180th meridian and north of the equator (square BA) in zone-row 1N, as shown in *Figure 2-39*.

Figure 2-40 — Lat-Long Example (Pacific Ocean).

If you know the latitude and longitude of a certain point on the earth, you can determine the designation of the 100,000-meter square in which the point lies. Take Honolulu, Hawaii, for example, which lies approximately at latitude -158°00'00" W by 21°15'00" N longitude. You will find this latitude and longitude in *Figure 2-40*. The point lies in column 16, row S, and 100,000-meter square ES; therefore, the 100,000-meter-square designation for Honolulu, Hawaii, is 4QFJ15 as can be found in *Figure 2-41*.

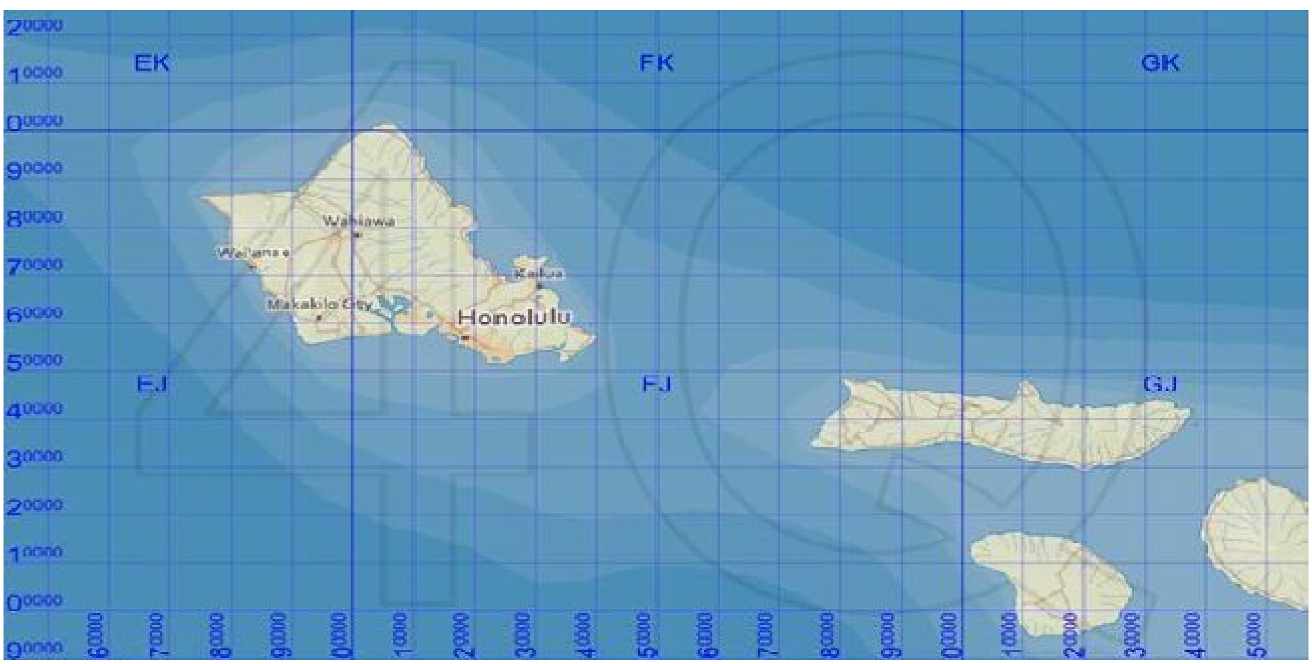

Figure 2-41 — 4Q Example (Pacific Ocean).

This process results in very large coordinate values when the coordinates are referenced to the point of origin. For example, for determining the location of a Seabee construction project to be built in As Samawah, Iraq, the coordinates of the lo-meter square in which the project is located are casting 527,500 meters, northing 3,460,500 meters; however, since the grid zone-row designation pins the coordinate down to a relatively small area, some of the digits of the coordinates are often omitted.

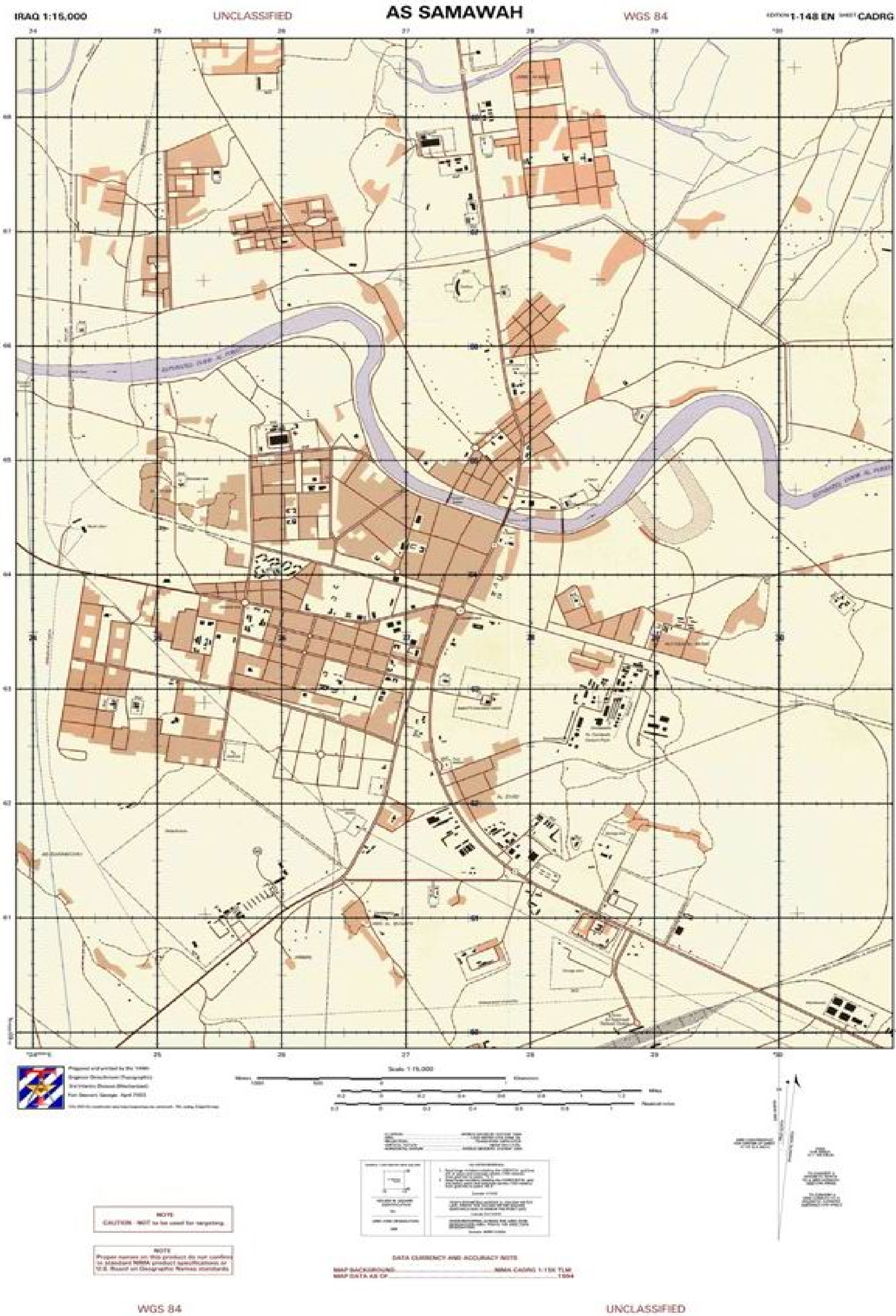

Figure 2-42 – Military Map Example.

Consider, for example, the part of a map shown in *Figure 2-42* (zoom in for detail). The grid squares on this map measure 1,000 meters on each side. Note that in the bottom left corner of the map the casting grid lines are identified by printed coordinates in which only the principal digits are shown, and of these, even the initial number 5 is in small type. The understood value of the number 275 is 527,500 meters. In setting down the coordinate for this line, even the 5 should be omitted and only the 275 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 construction project in the southern part of As Samawah may be given as 38RNV275605. This means zone-row 38R, 100,000-meter square NV, casting 275, northing 605. Actually, the casting is 527,500 and the northing 3,460,500.

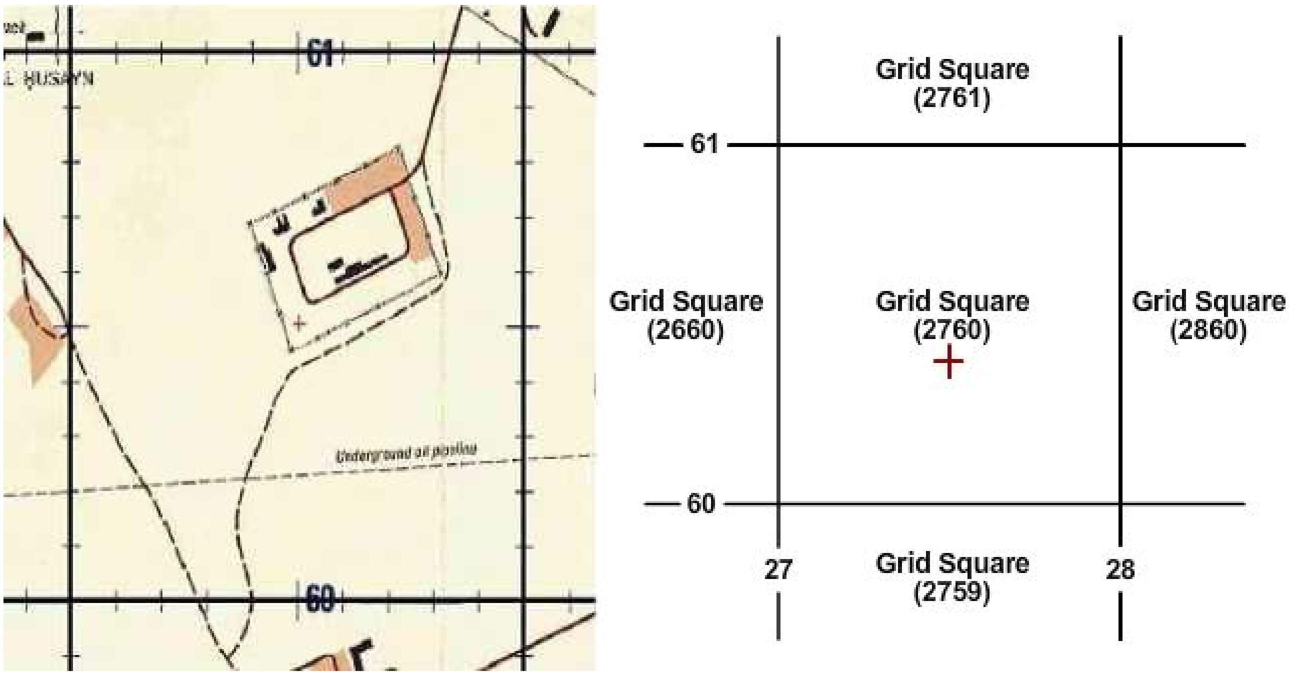

Figure 2-43 — Grid Square Detail.

If four digits are given in a coordinate element, the coordinates pin a point down to a particular 10-meter square. Consider *Figure 2-43*, for example. For the point +, the two-digit coordinates 2760 would mean that the point is located somewhere within the 1,000-meter-grid square 2760. To pin the location down to a particular 100-meter square within that square, you would have to add another digit to each coordinate element. The + lies five-tenths of 1,000 meters between line 27 and line 28; therefore, the casting of the 100-meter square is 275. By the same reasoning, the northing is 605 which makes the coordinate for the 100-meter square 275605. To pin the point down to a particular 10-meter square, you should add another pair of digits, these being determined by scale measurement on the map. It follows from all this that the coordinates previously given for the project (909993 15) locate this building with reference to a particular lo-meter square.

Figures 2-42 and *2-43* further depict 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. These indicate that the map covers parts of both. Note, too, that the direction of grid north (that is, the direction of the north-south grid lines in the map) varies from that of true north by 0°19’E (5.5 MILS) and from the magnetic north by l°15’E (55 MILS).

5.1.2.1 Universal Polar Stereographic (UPS) Coordinate System

The Polar Regions (that is, the areas above 84°N and below 80°S) have only two zones in each area and use the ***Universal Polar Stereographic (UPS)*** coordinate system which is used in conjunction with the UTM coordinate system. Like the UTM coordinate system, the UPS coordinate system uses a metric-based Cartesian grid laid out on a conformally projected surface. UPS covers the Earth's Polar Regions which are not covered by the UTM grids, plus an additional 30 minutes of latitude extending into UTM grid to provide an amount of overlap between the two systems. These lie on either side of the 0-degrees and 180-degrees meridian. In the North Polar Region, the half of the region that contains the west longitudes is zone Y; that containing the east longitudes is zone Z as depicted in *Figure 2-44*. No numbers are used with these designations. Similarly, in the South Polar Region, the half containing the west longitudes is zone A; that containing the east longitudes, zone B, as depicted in *Figure 2-45*.

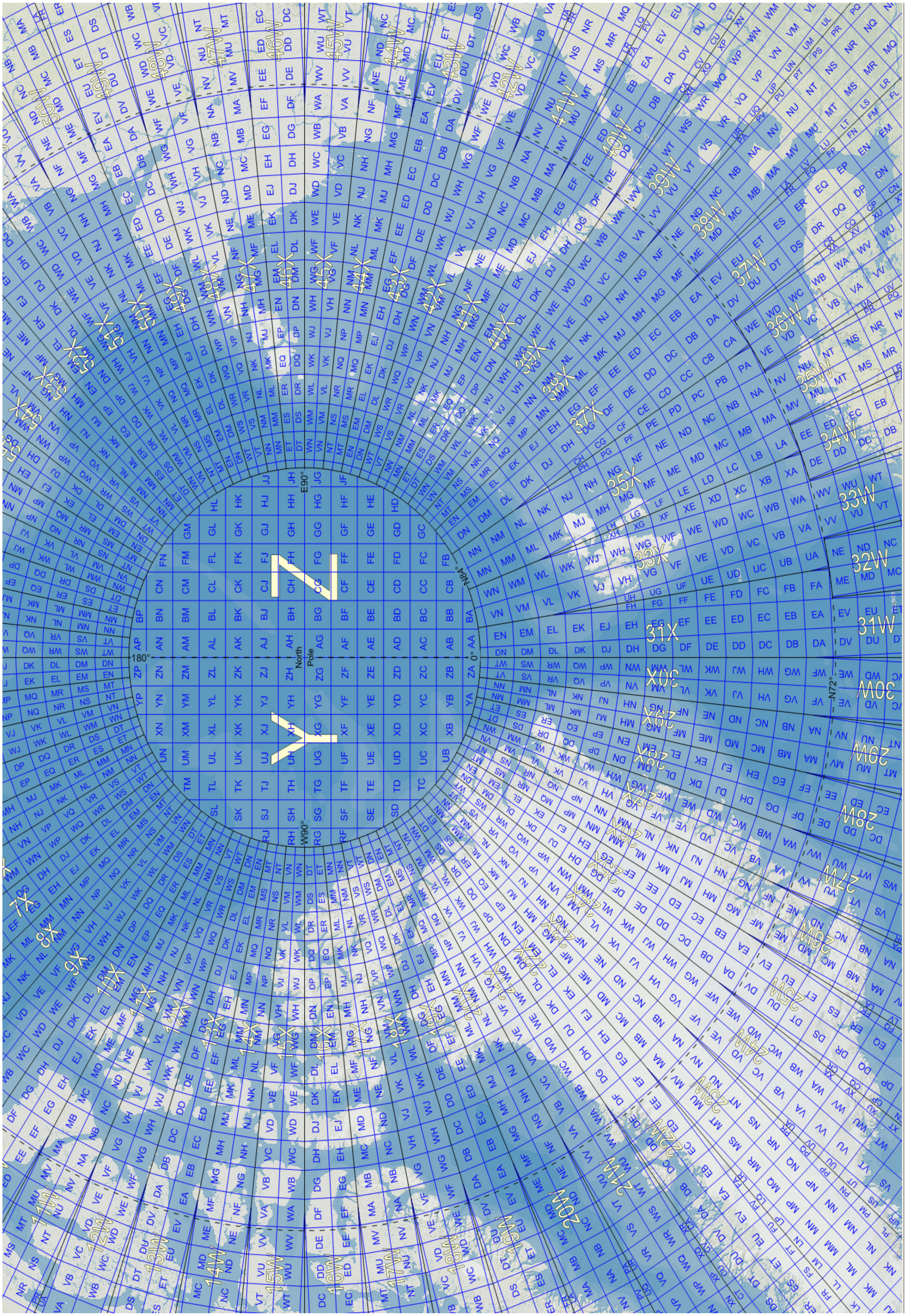

Figure 2-44 – UPS Grid of North Pole.

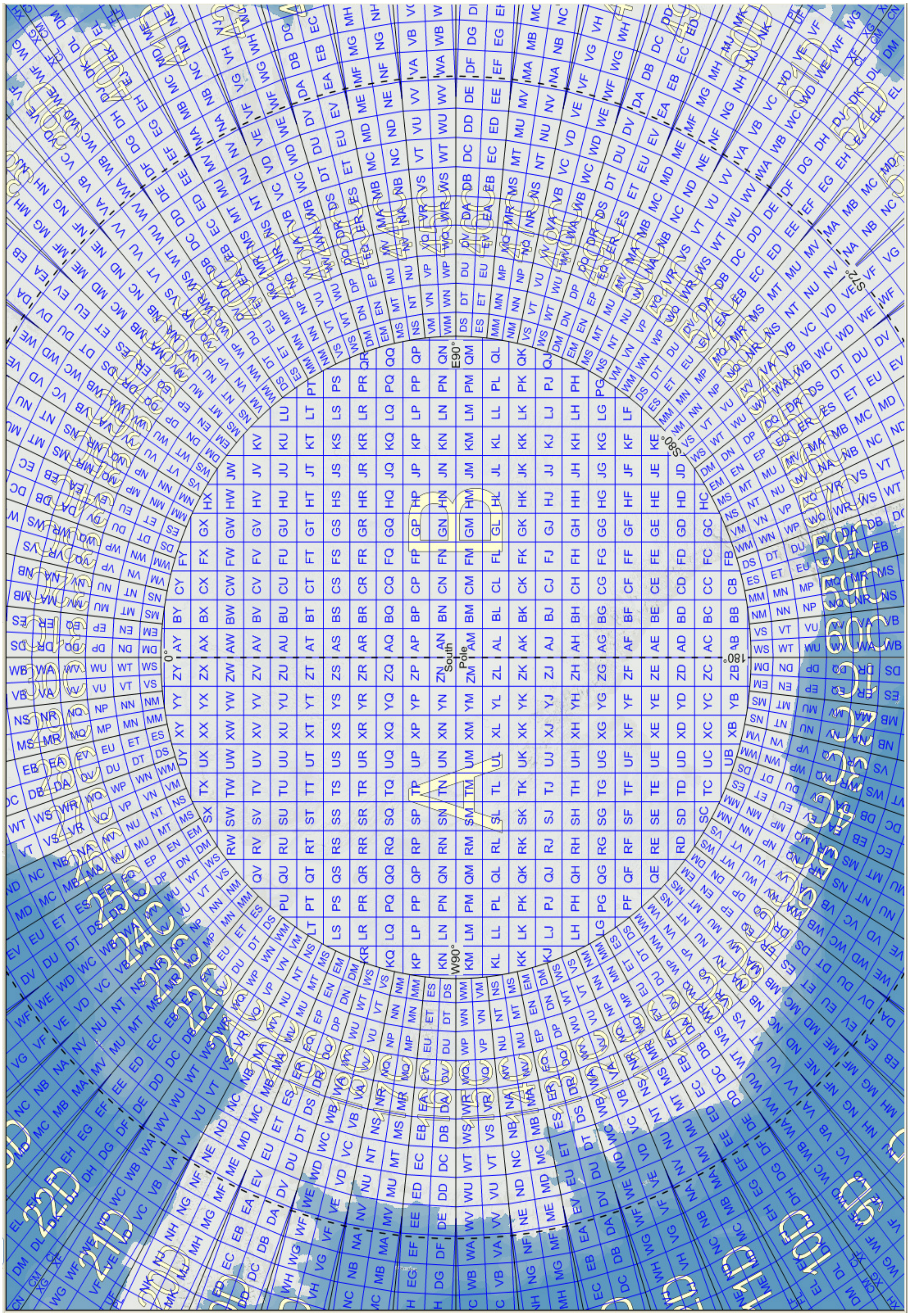

Figure 2-45 – UPS Grid of South Pole.

5.2.0 Conic Projection

To grasp the concept of conic projection, again imagine the earth as a glass sphere with a light at the center. Instead of a paper cylinder, image a paper cone placed over the Northern Hemisphere tangent to a parallel, as shown in *Figure 2-46*. The North Pole will be projected as a point at the apex of the cone. The meridians will radiate outward from the North Pole as straight lines. The parallels will appear as concentric circles, growing progressively smaller as latitude increases.

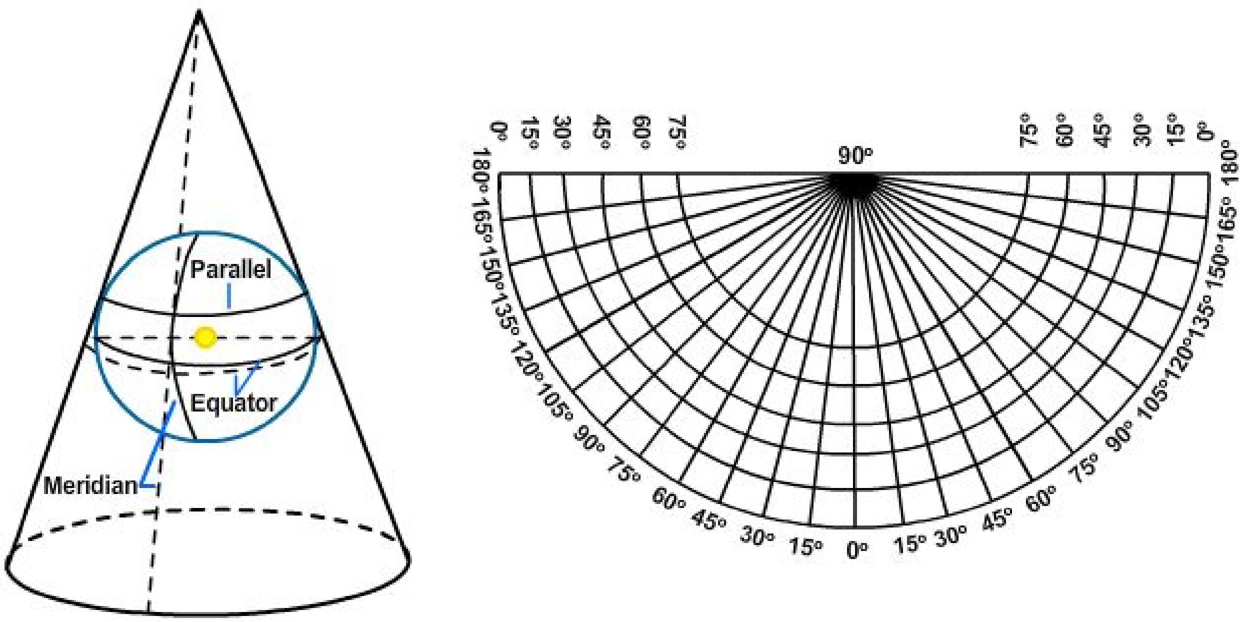

Figure 2-46 — Conic Projection.

When the cone is cut along a meridian and flattened out, the meridians and parallels will appear as shown in *Figure 2-46*. 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.

5.3.0 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 as in *Figure 2-47*.

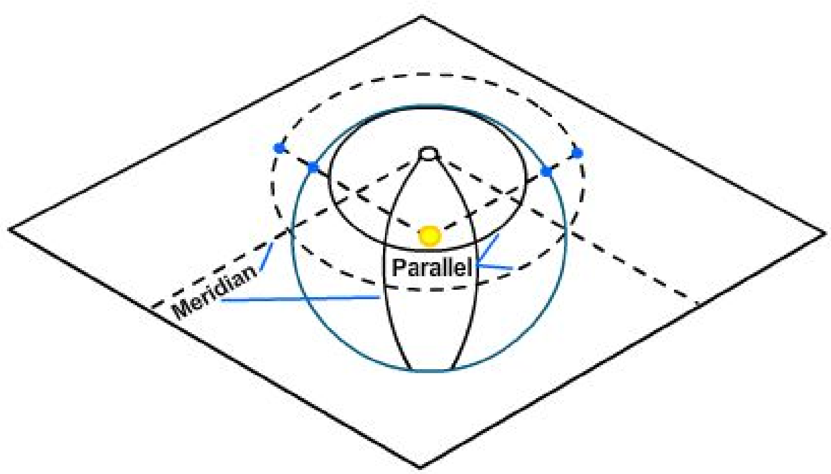

Figure 2-47 – Gnomonic Projection.

5.5.0 Polyconic Projection

In polyconic projection a near approach to direction conformality is obtained in relatively small area maps by projecting the area in question onto more than one cone. A central meridian on the map is straight; all the others are slightly curved and not quite parallel. Similarly, the parallels are slightly curved and not quite parallel; therefore, they are not precisely perpendicular to the meridians. An example of a polyconic map projection is shown in *Figure 2-48*.

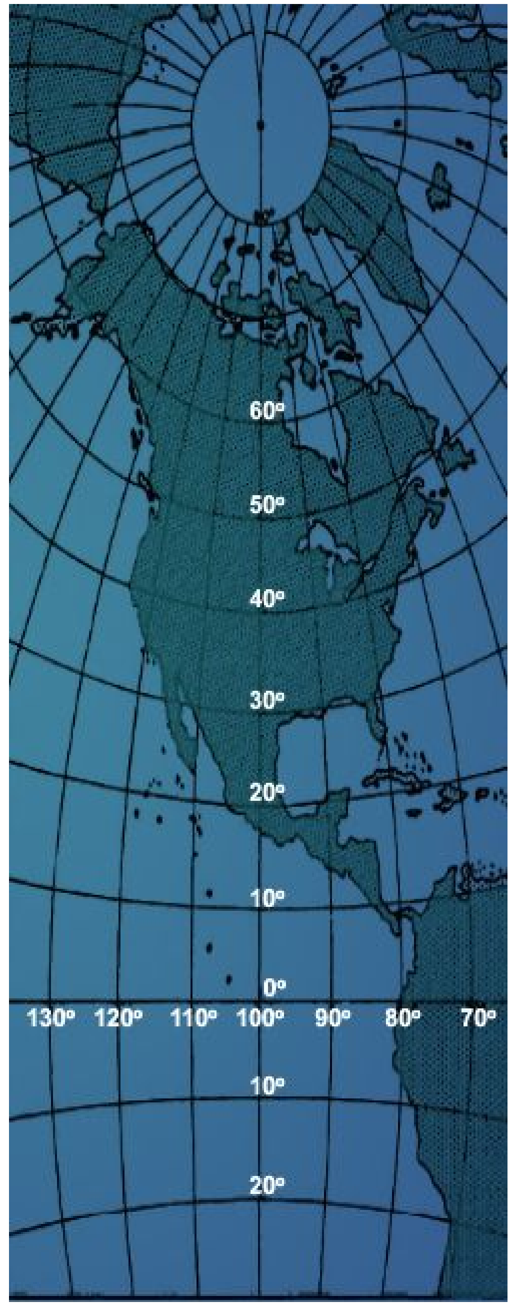

Figure 2-48 — Polyconic Projection.

Polyconic projection is extensively used for the ***quadrangle maps*** (familiarly called quad sheets) of areas of the United States published by the Geological Survey. For most of the built-up areas of the States, these maps are available on a scale of 1:24,000, showing areas extending for 7°30' of latitude and longitude. An index map is available, which gives you the quadrangle divisions and the name of the map that covers a particular area.

Being that polyconic projection is not conformal distance-wise is indicated by the fact that one of these quad sheets, though it shows an area that is square on the ground, is oblong rather than square. The vertical or latitudinal length of the map is always greater than the horizontal or longitudinal length. The reason is that latitude is measured along a meridian, which is always a great circle, while longitude is measured along a parallel; and every parallel other than the equator is less than a great circle. An understanding of the concept of the great circle is essential to a thorough understanding of map and chart projection. A great circle is any line on the earth's surface (not necessarily a meridian or the equator) that lies in a plane that passes through the earth's center. Any meridian lies in such a plane; so does the equator. But any parallel other than the equator lies in a plane that does not pass through the earth's center; therefore, no parallel other than the equator is a great circle.

Now, 1 minute of arc measured along a great circle is equal to 1 nautical mile (6076.115 ft) on the ground. But 1 minute of arc measured along a small circle amounts to less than 1 nautical mile on the ground. Therefore, a minute of latitude always represents a nautical mile on the ground, the reason being that latitude is measured along a meridian and every meridian is a great circle. A minute of longitude at the equator represents a nautical mile on the ground because, in this case, the longitude is measured along the equator, the only parallel that is a great circle. But a minute of longitude in any other latitude represents less than a nautical mile on the ground; and the higher the latitude, the greater the discrepancy.

5.6.0 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 2-49*. 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 that applies to the whole map is exact only at the standard parallels, as shown in *Figure 2-49*. Between the parallels the scale is a little too small; beyond them, it is a little too large. The discrepancy is small enough to be ignored in work of ordinary precision or less. For work of higher precision, there are correction factors that may be applied.

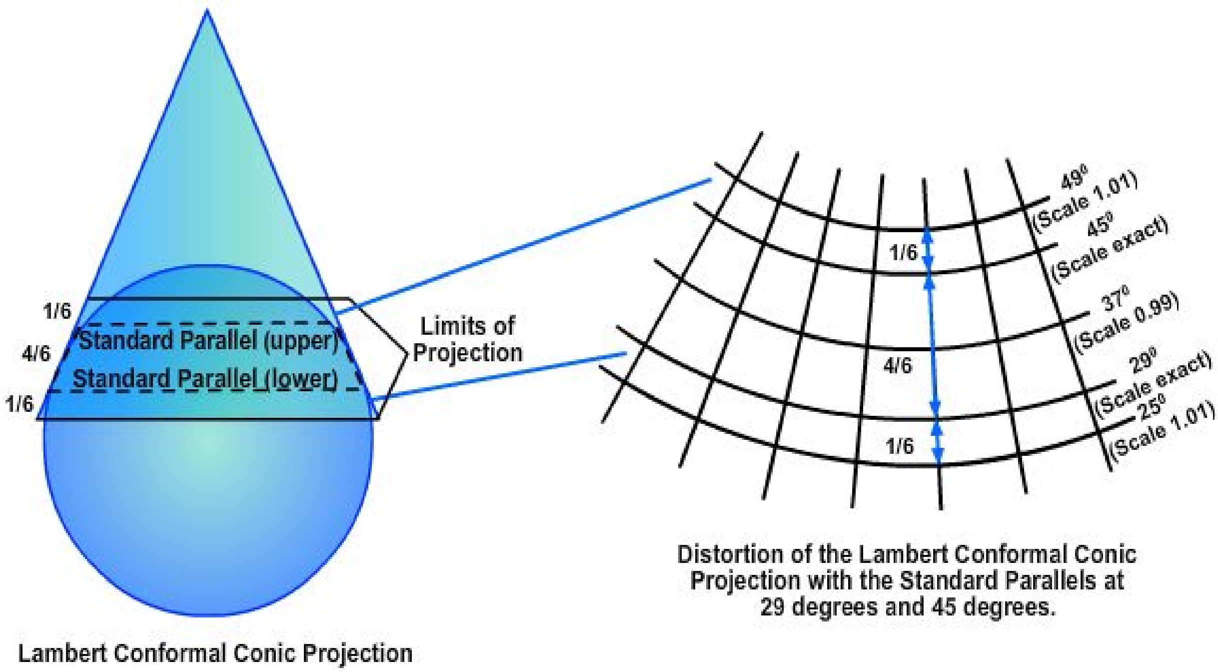

Figure 2-49 — Lambert Conformal Conic Projection.

The Lambert conformal conic projection is the base for the state coordinate systems devised by the Coast and Geodetic Survey for zones of limited north-south dimension and indefinite east-west dimension. For zones whose greater dimension is north-south, the Coast and Geodetic Survey uses the transverse Mercator projection.

Summary

This chapter discussed engineering surveying factors presented from the viewpoint of the party chief. This chapter included land surveying used to establish or reestablish land boundaries, preparing legal property descriptions, and subdividing tracts of land. This chapter also addressed procedures and the legal aspects involved in surveying. Finally, we explored map projection methods and took an in-depth look at Universal Transverse Mercator and Military Grid Reference System maps.

Trade Terms Introduced in this Chapter

"Neat" line	The line defining the limits of an aspect of construction, such as an excavation or a wall.
Mercator	A mathematical method of showing a map of the globe on a flat surface.
Gnomonic	A gnomonic map projection displays all great circles as straight lines.
Rhumb line	In navigation, a rhumb line is a line crossing all meridians of longitude at the same angle.
Meridional Distances	The distance or departure from the meridian, the easting or westing.
Grid Zone Designation (GZD)	The first three letters of the MGRS value, e.g. "15S", are referred to as the Grid Zone Designation (GZD).
Universal Polar Stereographic (UPS)	The UPS coordinate system covers the Earth's polar regions, specifically the areas north of 84°N and south of 80°S which are not covered by the UTM grids, plus an additional 30 minutes of latitude.
Conformal	A conformal map is a function which preserves angles.
Quadrangle Maps	Polyconic projection is extensively used for the quadrangle maps (familiarly called quad sheets) of areas of the United States published by the Geological Survey.
Standard Parallel	A parallel on a map or chart along which the scale is as stated for that map or chart.

Additional Resources and References

This chapter is intended to present thorough resources for task training. The following reference works are suggested for further study. This is optional material for continued education rather than for task training.

U.S. Department of the Army, *Construction Surveying*, FM5-233, Headquarters, Department of the Army, Washington, D.C., 1985.

Davis, Raymond E., Francis S. Foote, James M. Anderson, and Edward M. Mikhail, *Surveying Theory and Practice*, 6th ed., McGraw-Hill, New York 1981.

National Geodetic Survey http://www.ngs.noaa.gov/

National Geospatial-Intelligence Agency
http://earth-info.nga.mil/GandG/coordsys/grids/referencesys.html