method so that a point 100 feet away is within 1 foot of the true perpendicular.

Measure elevations consisting of abrupt changes or breaks in the ground with a rod and level. Use a metallic tape to measure all distances from the center line. In rough country, you can use the hand level to obtain cross sections if the center-line elevations have been determined by an engineer's level.

Cross-section leveling is usually done with a hand level after the profile run has been made, the profile run has been established, and the center-line elevation at each station is known. The method is as follows.

Suppose cross-section elevations at 10-foot intervals for 40 feet on either side of the center line are needed. To find these elevations, first determine the vertical distance from the ground to the line of sight through the hand level while standing erect with the level to your eye. The best way to do this is to sight on a level rod held plumb in front. Suppose the vertical distance is 5.5 feet. Then the HI at any center-line station is the center line elevation (obtained in the profile level run) plus 5.5 feet.

At station 0 + 00, as shown in *Figure 15-22*, the elevation is 122.53 feet. The HI is 122.53 + 5.5 = 128.03 feet. With the elevation rounded off to the nearest 0.1 foot, the elevation is 128.0

As rodman, if you hold a rod 40 feet to the left of the center line at station 0 + 00 and read 1.9 feet on the rod, then the elevation of the point plumbed by the rod is 128.0 - 1.9 = 126.1 feet.

Now if you move on to a point 30 feet from the center line at station 0 + 00 and read 3.3 feet on the rod, the elevation of the point is 128.0 - 3.3 = 124.7 feet.

This process is used to determine the elevations at all the required points on the cross section. This same process is repeated for each cross section.

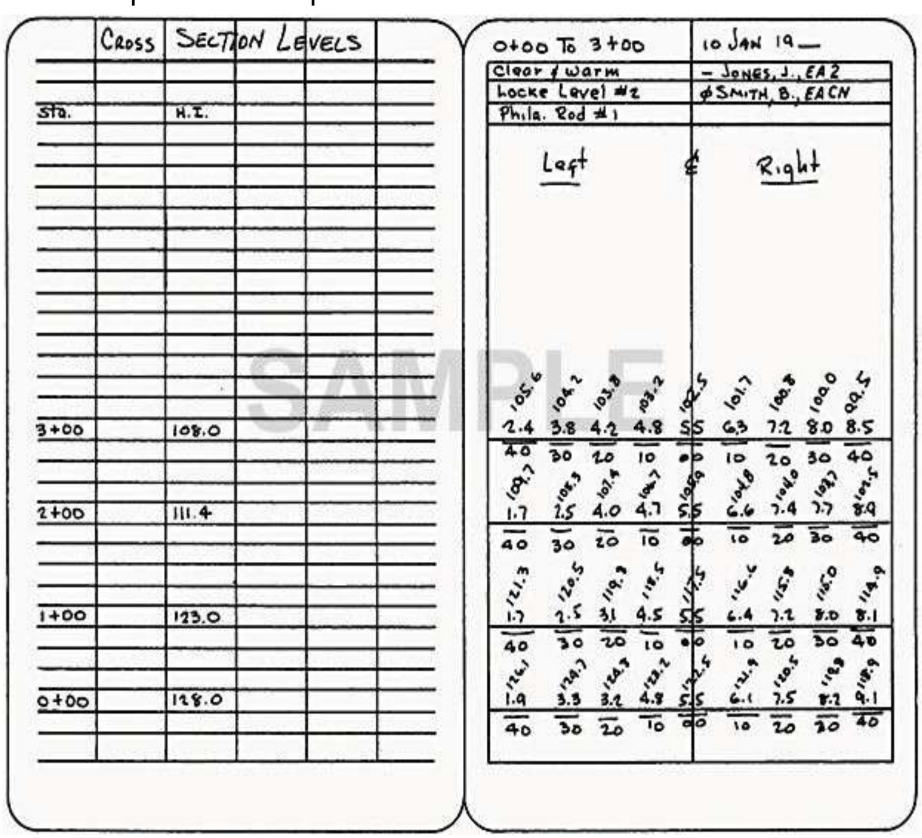

Figure 15-22 -Sample field notes from cross-section leveling at first three stations shown in figure 15-20.

Cross section notes are recorded in the field book using two basic methods. The first, and often preferred, method begins at the bottom of the page and is read upward, as shown in *Figure 15-22*. This method helps to keep orientation in the direction the line runs and helps to prevent confusion as to which is the right or left side of the line. It reduces the possibility of recording readings on the wrong side of the center line.

With the second method, notes are recorded in the conventional manner of reading from top to bottom of the page. Whichever method is used, the recorder must stand facing the direction in which the line runs; left and right in the notebook must correspond to left and right in the field.

Figure 15-22 shows field notes for cross-section levels taken on the first three stations shown in *Figures 15-19* and *15-20*. On the data side, only the station and the HI need to be listed. On the remarks side, each entry consists of a point elevation, written over the distance of the point from the center line. The computed elevation, determined by subtracting the rod reading from the HI, is written in above. Note the rod reading at the center line is the 5.5-foot vertical distance from the line of sight to the ground. Also, notice the center-line elevation written in at each station is obtained in the profile level run. The HI for each station is calculated by adding the two figures together.

3.3.4 3.3.4 Double Rodding

Double rodding is a form of differential leveling in which a continuous check is maintained on the accuracy of the leveling procedure. Double rodding is typically done by two rodmen; however, it is possible to carry out the procedure using only one rodman.

In double rodding, the HI is determined at each setup point by backsights taken on two different TPs. If no mistake or large error has been made, the result will be two HIs that differ slightly from each other. Elevations computed this way will also differ slightly. In each case, the average is taken as the elevation.

Figure 15-23 shows double-rodded level notes for a run from one BM to another by way of three intermediate TPs. In each case, a "higher" TP (TP_1) and a "lower" (TP_{1L}) were used, resulting in two different HIs for each. Computed by way of the higher HIs, the elevation of BM_2 came to 851.98 feet. Computed by way of the lower HIs, it came to 852.00 feet. The mean (average) of 851.99 feet was taken as the correct elevation.

Figure 15-23 - Sample field notes from double-rodded levels.

3.3.5 Indirect Leveling

Indirect methods of leveling include both trigonometric and ***barometric leveling***. Trigonometric leveling uses vertical angles and a horizontal distance to compute the difference in elevation. Barometric leveling uses the difference in atmospheric pressures that are observed by a barometer or an altimeter to determine the elevation differences. Indirect methods of leveling are discussed at the EA2 level.

Test Your Knowledge (Select the Correct Response)

10. The original level run is rapidly rerun as a check in what type of leveling procedure?

    A. Three-wire
    B. Cross-section
    C. Profile
    D. Flying

11. Simultaneous-reciprocal leveling requires which of the following level party personnel?

    A. One levelman and one rodman
    B. One levelman and two rodmen
    C. Two levelmen and one rodman
    D. Two levelmen and two rodmen

12. At what point(s) along a proposed highway are cross sections taken?

    A. Every 25 feet
    B. Every 50 feet
    C. At regular stations only
    D. At regular stations at any point where there is a break on the ground, or at any interval desired

13. What is a form of differential leveling in which a continuous check is maintained on the accuracy of the leveling procedure?

    A. Three-wire
    B. Double rodding
    C. Cross-section
    D. Profile

4.0.0 PRECISION in LEVELING; MISTAKES and ERRORS in LEVELING

Like all other surveying operations, leveling is carried out by following a prescribed order of precision. This means the instruments must be properly handled and the methods used to survey must be followed in order to achieve specific standards of accuracy.

4.1.1 Precision in Leveling

First-order leveling is used to establish the main level network for an area and provides basic vertical control for the extension of level networks of the same, or lower, accuracy in support of mapping projects, cadastral (recording property boundaries, subdivision lines, buildings, etc.), and local surveys. Level lines must start and end on proven, existing BMs of the same order. New levels must be run between the starting BM being used and at least one other existing BM and must show there is no change in their relative elevations.

Second-order leveling is used to subdivide nets of first-order leveling and provides basic control for the extension of levels of the same, or lower, accuracy in support of mapping projects and local surveys. Second-order levels are divided into two classes: Class I and Class II. Class I is used in remote areas where the line must be longer than 25 miles because routes are unavailable for the development of additional or higher order networks and for spur lines. Class II levels are used for the development of nets in more accessible areas. Class I leveling, requires that all lines start and close on previously established BMs of first or second order. New levels have to be run between the existing BM being used and at least one other existing BM to prove they have not changed their relative elevations. The criteria for Class II are the same as for Class I, except Class II lines are run in one direction only.

Third-order leveling is used to subdivide an area surrounded by first- and second-order leveling and to provide elevations for the immediate control of cadastral, topographic, and construction surveys for permanent structures. The following criteria should be observed in third order leveling:

1. All lines start from and close on two previously established BMs of third or higher order of accuracy if the new leveling indicates they have not changed in their relative elevations.
2. In the United States, third-order lines should not be extended more than 30 miles from BMs of first or second order. In foreign or remote areas, the distance may be extended according to the evaluation of the existing control and the situation. They may be single-run (one direction) lines but should always be loops or circuits that close upon BMs of an equal or a higher order.
3. When a line from previously established third-order marks is extended, the maximum length of the new line is greatly reduced. The distance and allowable error are carried back through the existing line to the nearest tie BM of the second or higher order.
4. Balanced sights should not be greater than 300 feet. BS and FS distances may be measured by pacing and approximately balanced between BMs.
5. Rod readings are read to thousandths and the rod waved for extended rod readings.
6. The bubble is checked to make sure it is centered before each sighting and reading.
7. Turning point pins or plates or well-defined points on solid objects are used for TPs.

Fourth-order leveling is used to subdivide an area within a third-order network. This method is used in connection with the location and construction of highways, railroads, and other engineering works that concern Seabees in advanced base projects.

In practice, trying to shoot for a higher degree of accuracy is advantageous if it does not affect work progress. The following criteria should be observed in fourth-order leveling:

1. All lines start from and close on previously established BMs of the third or fourth order of accuracy.
2. Maximum sight distance is about 500 feet.
3. Rod readings are read to hundredths of a foot. BS and FS distances are roughly balanced only when lines of great lengths are run, either uphill or downhill.
4. TPs are taken on solid or any well-defined, firm objects.

The instruments commonly used in third- and fourth-order leveling are the engineer's level and the Philadelphia rod. The adjustments of these instruments should always be checked before use.

4.1.1 Order of Precision

The precision of a level run is usually prescribed in terms of a maximum error of closure. Maximum error of closure is obtained by multiplying a constant factor by the square root of the length of the run in miles or in kilometers, depending upon the system of measurement being used. The Federal Bureau of Surveying and Mapping specifies certain requirements and the maximum closing errors, such as those shown in *Figure 15-24*. Refer to this standard if the order of precision is not specified for a particular survey project.

REQUIREMENTS	FIRST ORDER	SECOND ORDER Class I	SECOND ORDER Class II	THIRD ORDER	FOURTH ORDER
Spacing of lines and crosslines -------------	40-56 km or 25-35 miles	40-56 km or 25-35 miles	10 km or 6 miles; 10km or 6 miles	Not specified	None
Average spacing of permanently marked BMs along, not to exceed -----------------	2 km or 1 mile	2 km or 1 mile	2 km or 1 mile	5 km or 3 miles	None
Length of Sections --------	1-2 km or 1/2-1 mile	1-2 km or 1/2-1 mile	1-2 km or 1/2-1 mile	Not specified	None
Check between forward and backward running between fixed elevations or loop closure not to exceed -----------------------	$4mm\sqrt{k}$ or $0.017 ft \sqrt{M}$	$8.4mm\sqrt{k}$ or $0.035 ft \sqrt{M}$	$8.4mm\sqrt{k}$ or $0.035 ft \sqrt{M}$	$12mm\sqrt{k}$ or $0.05 ft \sqrt{M}$	0.6 m for lines up to 20 km or $0.1 ft \sqrt{M}$

k = the distance in kilometers.
M = the distance in miles.
*In areas outside the U.S. this criteria may be changed to conform with the situation.

Figure 15-24 - Federal Bureau of Surveying and Mapping requirements.

4.1.2 lculating Error of Closure

A level run that begins at a particular BM and is carried back to the same BM is called a level loop. A run that does not close on the initial BM is called a level line. A level line closes on another BM. However, when a level line is carried back to its origin, it becomes a level loop. A level line is usually carried back to the initial BM to determine the error of closure.

Error of closure is simply the difference between the known elevation of the initial BM and the elevation of the same BM as computed in a level run.

The allowable error of closure depends on the precision required (first, second, or third order). The permissible (or allowable) error of closure in accuracy leveling is expressed in terms of a coefficient and the square root of the horizontal length of the actual route over which the leveling was done.

Most differential leveling (plane surveying) is third-order work. In third-order leveling, the closure is usually made on surveys of higher accuracy without doubling back to the old BM at the original starting point of the level circuit. The length of the level circuit, therefore, is the actual distance leveled. For third-order leveling, the allowable error is

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

After adding the sight distances in the sixth and seventh columns of the differential level circuit shown in *Figure 15-14*, the length of the level circuit is 2,140 feet. The length in miles is 2140 / 5280 = 0.405.

The allowable error of closure is

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

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

First- and second-order levels usually close on themselves. The leveling party runs a line of levels from an old BM or station to the new BM or station, and then doubles back to the old BM for closure. The actual distance leveled is twice the length of the level circuit.

For second-order leveling, the allowable error is

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

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

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

4.2.0 Mistakes and Errors in Leveling

The terms "mistakes" and "errors" are not synonymous in surveying. Leveling operations, like other survey measurements, are susceptible to both. Mistakes can be avoided by a well-arranged system of operation and an attention to detail by all of the survey party members. Checking and rechecking, as described in some of the operations, eliminate many mistakes. While errors cannot be completely eliminated, errors can be minimized so their effect on survey accuracy is small and within allowable tolerances.

4.2.1 Identifying Leveling Mistakes

The leveling mistakes discussed here are not intended to include all possibilities but rather to list examples of commonly occurring mistakes. The survey party personnel should be aware of these possibilities and should be careful to avoid them. Some of the common mistakes are as follows:

1. **Not setting the rod on the same point for an FS and the following BS.** Using a turning pin, pedestal, or stake, or marking the location with chalk on hard surfaces helps to recover the identical point.
2. **Neglecting to clamp the target or the rod when extended.** Any slippage can pass unnoticed and result in an incorrect reading which may require an entire rerun of the line to discover the mistake. The rodman should watch the rod or target for any movement as the clamp is tightened. The rod extension or target should be read again after the clamp has been set.
3. **Reading the wrong mark.** The figures on a rod may be obscured by brush or may fall in a position in the field of view so that the instrumentman cannot see two consecutive numbers. Under these conditions, the instrumentman may read the wrong mark or even read in the wrong direction. This is particularly true when an inverting eyepiece is being used. Another possibility is miscounting the number of divisions. There is no way to check or discover these mistakes except to be aware of their possibility and to read carefully.
4. **Recording a reading in the wrong column.** In leveling, readings are not entered into the notebook in a normal sequence such as left to right across the page. There is always a chance that one or more values may be recorded in the wrong column. The recorder must be alert to avoid making this mistake.
5. **Reading the wrong angle sign in trigonometric leveling.** The instrumentman can accidentally call out a wrong sign in reading the angle. This mistake can be eliminated by the recorder watching the telescope as a pointing is made on the rod. If the wrong reading is called out, both the recorder and the instrumentman can resolve it immediately.
6. **Recording the wrong sign.** The sign varies depending on whether the rod reading is a BS or an FS, and whether the angle is a depression or an elevation. Also, the difference in elevation computation requires a sign reversal if the angle is read for the BS, but not for the FS. These variations can be confusing. The recorder has to be careful to avoid mistakes. This is done by recording the angle and rod reading signs as read. The sign conversion, if needed, shows up when the DE is computed. Examining the computations to see if all BS DEs have a sign opposite to the angle sign is simple.
7. **Subtracting the BS or adding the FS in differential leveling.** If the BS or FS is recorded properly (see Number 4 above), the mistake can be discovered when the BS column and the FS columns are added for a computation check.
8. **Using the wrong horizontal cross hairs.** This occurs on an instrument provided with stadia hairs.

4.2.2 fying Leveling Errors

Generally, errors cannot be completely eliminated; however, they can be contained within acceptable tolerances. Minimizing errors requires using prescribed methods and instruments. Reducing errors may also include applying mathematical corrections. Some of the conditions that produce errors are listed below.

1. **Instrument not properly adjusted.** A small amount of residual error exists in any adjustment. For the more accurate surveys, the residual error is minimized by using BS and FS balancing and, in trigonometric leveling, by taking direct and reverse (circle left and circle right) readings for the angles.
2. **Instrument not leveled properly.** Unlike the residual adjustment error that affects the readings one way consistently, this is a random or accidental error. It may affect the line of sight differently at each setup. This error is minimized only by careful leveling of the instrument each time it is set up and by re-centering the bubble before each reading.
3. **Telescope not focused properly**. Mis-focusing and parallax in the eyepiece create accidental errors that cannot be corrected. Proper focusing at each setup can minimize, even eliminate this error. The instrumentman should check and clear the parallax before the first sighting and should not readjust it until all sightings from the setup are complete.
4. **Rod improperly plumbed.** This is caused by a rodman not paying attention. The instrumentman can call attention to plumbing if it is at a right angle to the line of sight, but cannot see it in the direction of line of sight. The use of a rod level or waving the rod will avoid this error.
5. **Unstable object used for a TP.** The rodman causes this error by selecting a poor point of support, such as loose rocks or soft ground. As the rod is turned between sights, the weight of the rod can shift a loose rock or sink into soft ground. The elevation of the TP used for the next BS can change markedly from the value that had been computed from the previous FS. This error is avoidable by using the turning pin or pedestal when the ground is unstable.
6. **Rod length erroneous.** This error results in either too long or too short rod readings at each point. This error accumulates particularly over sloped areas. The rod length should be checked with a steel tape at intervals to locate the error.
7. **Unbalanced BS and FS distances.** The unbalanced distances do not cause the error. It is caused by the effect on the line of sight from residual adjustment and leveling errors, and the effect of curvature and refraction errors. Long distance readings are more susceptible to greater error than short distance readings. The unbalance may not be critical on one setup. However, unbalancing can compound into a considerable errors if it continues over several setups. Balancing sight distances at each instrument setup reduces the probability of errors.
8. **Earth's curvature.** Curvature produces an error only on unbalanced sights in leveling. When the BS distances are constantly greater than FS distances, or vice versa, a greater systematic error results, especially with long sites. To eliminate this error, maintain a balanced sight distance in every BS and FS reading, not just their sum total between BMs. Note that this type of error is directly related to the square of the distance from the instrument to the rod.

9. **Atmospheric refraction.** The effect of atmospheric refraction is only one-seventh of that caused by the earth's curvature. In first- and second-order leveling, the effect of refraction is minimized by taking the BS and FS readings in quick succession and avoiding readings near the ground. (They should be taken at least 2 feet from the ground.)
10. **Variation in temperature.** If a portion of the telescope is shaded while other parts are exposed to the sun's rays, it produces some warping effect on the instrument that may affect its line of sight. This effect is negligible in ordinary leveling. However, in leveling of higher precision, the effect may produce appreciable error. This is one of the reasons why surveyors use an umbrella to shield the instrument when doing more refined work.

Test your Knowledge (Select the Correct Response)

14. Recording a rod reading in the wrong column in a field book is classified as a

A. mistake.
B. standard error.
C. personal error.
D. natural error.

15. Between errors and mistakes, the most importance difference, if any, is that

A. errors can be avoided.
B. errors are caused by human negligence.
C. mistakes can be avoided.
D. there is no difference; the terms are synonymous.

5.0.0 BASIC ENGINEERING SURVEYS and CONSTRUCTION SITE SAFETY

An engineering survey forms the first of a chain of activities which ultimately leads to a completed structure of some kind, such as a building, a bridge, or a highway. An engineering survey is usually subdivided into a design-data survey and a construction survey.

This section discusses the basic engineering surveys commonly performed by an EA survey party in support of military construction activities. Various types of occupational hazards relating to specific surveying operations are also presented here, together with the precautions or applicable abatement procedures that must be carried out to deter injury to the survey crew and/or damage to surveying equipment or material.

5.1.0 Highway Surveys

Surveys for roads and streets involve both field work and office work. The extent of each type of work depends on the magnitude and complexity of the job. Some phases of the work may be done in the field or in the office. The decision as to which procedures are to be followed is influenced by the number of personnel available and by the experience and capabilities of the individuals involved.

5.1.1 Design-Data Survey

The design-data survey is conducted to collect information essential for planning an engineering project or development and estimating its cost. A typical design-data survey, for example, is a route survey required in the design and construction of a particular road or highway. The initial activities included in a route survey are a reconnaissance survey, a preliminary location survey, and a final location survey.

5.1.1.1 Reconnaissance Survey

A reconnaissance survey provides data that enables design engineers to study the advantages and disadvantages of a variety of routes in order to determine the most feasible one. Reconnaissance begins by finding all existing maps showing the area to be reconnoitered. In reconnaissance, studying existing maps is as important as the actual fieldwork. Studying maps and aerial photographs, if any exist, often eliminates an unfavorable route from further consideration, thus saving the reconnaissance field party considerable time and effort.

Contour maps provide essential information about area relief. Aerial photographs provide a quick means for preparing valuable sketches and overlays for the field party. Direct aerial observation provides an overview of an area that speeds up later ground reconnaissance if the region has already been mapped.

Begin the study of a map by marking the limits of the area to be reconnoitered and the specified terminals to be connected by the highway. Note whether or not there are any existing routes. Note ridgelines, water courses, mountain gaps, and similar control features. Look for terrain that permits moderate grades without too much excavating. Use simplicity in alignment and have a good balance of cuts and fills. Use a profile arrangement that makes it possible to fill depressions with the cut taken from nearby high places.

From the map study, determine grades, estimate the amount of clearing required, and locate routes that keep excavation to a minimum by taking advantage of terrain conditions. Mark stream crossings and marshy areas as possible locations for fords, bridges, or culverts.

The reconnaissance field party should follow the route or routes marked earlier during the map study. Field reconnaissance is an opportunity for checking the actual conditions on the ground and for noting any discrepancies in the maps or aerial photographs. Make notes of soil conditions, availability of construction materials such as sand or gravel, unusual grade or alignment problems, and requirements for clearing and grubbing. Take photographs or make sketches of reference points, control points, structure sites, terrain obstacles, landslides, washouts, or other unusual circumstances.

The reconnaissance survey party usually carries lightweight non-precision instruments. A compass is used to determine direction and angles. An aneroid barometer or altimeter is used to determine approximate elevations. An Abney hand level (clinometer) is used to estimate elevations and to project level lines. Other useful items to carry include pocket tapes, binoculars, pedometer and pace tallies, cameras, watches, maps, and field notebooks.

Keep design considerations in mind while running a reconnaissance survey. Remember that future operations may require further expansion of the route system. Locate portions of the new route, whenever possible, along preexisting roads or trails. Locate routes on stable, easily drained, high-strength-bearing soils. Avoid swamps, marshes, low-bearing-strength soils, sharp curves, and routes requiring large amounts of earthmoving.

Keep the need for bridges and drainage structures to a minimum. When the tactical situation permits, locate roads in forward combat zones in concealed areas and protected from enemy fire.

After the field work is complete, a reconnaissance survey report is generated. The completed report provides data used to select the most feasible route or routes.

5.1.1.2 Preliminary Survey

A preliminary survey is a more detailed study of one or more routes tentatively selected on the basis of a reconnaissance survey report. It consists of surveying and mapping a strip of land along the center line of a tentatively selected route. Some of the activities associated with preliminary survey include running a traverse (sometimes called a P-line or survey baseline), establishing BMs, running profiles, and taking cross sections. For many projects, the preliminary survey is conducted by a transit-tape party alone. Other projects may require a level party and a topographic party.

Normally, the data gathered from a preliminary survey is plotted while the party is in the field. This practice gives a more accurate representation of the terrain, reduces the possibility of error, and assists in resolving any doubtful situations while actually observing the terrain.

5.1.1.3 Final Location Survey

The final location survey, also called the location, is a continuous operation that goes on from the start of the project through to the end of the actual construction. The final location survey consists of establishing the approved layout in the field, such as providing the alignment, grades, and locations to guide the construction crew.

The EAs tasked with the final location survey normally start (in both time and distance) ahead of the construction crew in order to save construction time and to avoid delay of scheduled activities. Their activities include setting stakes to mark the limits of final earthmoving operations, locating structures, and establishing final grades and alignment.

The final location in the field is carefully established by the transit party, using the paper location prepared from the preliminary survey. The center line may vary from the paper location because of objects or conditions that were not previously considered. If variations are detected and changes are required, the changes must be approved by the engineering officer.

5.1.2 Office Work

After the type and general location of a highway are decided and the necessary design data is obtained in the field, a number of office tasks must be performed. The tasks include the following:

1. Plotting the plan view
2. Plotting the profile
3. Plotting the alignment
4. Designing the gradients
5. Plotting the cross sections

6. Determining end areas
7. Computing the volumes of cut and fill

Repeat these operations one or more times as trial designs are developed and revised. Plot a highway plan and profile view on the same sheet. *Figure 15-25* shows a plotted highway plan and profile view.

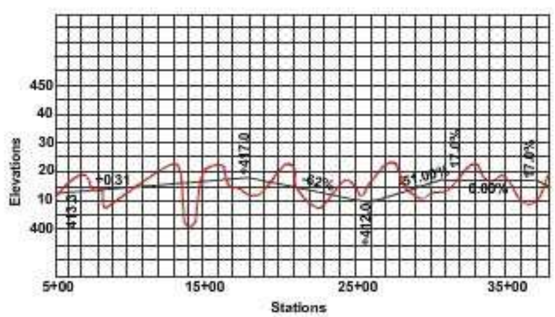

Figure 15-25 - Profile of highway.

5.1.2.1 Plotting the Plan View

Plotting the plan view of a highway is similar to a traverse except for the introduction of topographic details, curves, and curve data.

5.1.2.2 Profile Plotting

Profile plotting is done on regular profile paper that has ruled horizontal and vertical parallel lines, as shown in *Figure15-25*. The vertical lines are spaced 1/4 or 1/2 inch apart and the horizontal lines are spaced 1/20 or 1/10 inch apart.

The first consideration when conducting profile plotting is the selection of suitable horizontal and vertical scales for the profile paper. The selection of the scale varies with the character of the ground and other factors. In *Figure 15-25*, the horizontal scale used was 1 inch = 400 feet, and the vertical scale used was 1 inch = 20 feet. Normally, choose scales that are proportional numbers in multiples of ten.

To plot a profile, use profile level notes or use the elevations obtained from the contour lines. For the example in *Figure 15-25*, assume the profile level notes indicate the center line elevations at the indicated stations from 5 + 00 through 15 + 00.

Also for this example, the notes would show an elevation was taken at every full station and also at every station where a significant change in elevation occurs. This is true for station 8 + 75 where a significant elevation change occurs. If an elevation had not been taken at 8 + 75, the drop that exists between 8 + 00 and 9 + 00 would be indicated on the profile.

Notice at listed elevations that each was plotted as a point located where a vertical line that indicates the station intersected a horizontal line indicating the elevation of that station. Also note that usually stations are labeled where the line crosses highways, streams, and railroads.

Besides the profile of the existing terrain, the vertical tangents of the proposed highway center line are also plotted in *Figure15-25*. The end elevation for each of these (the elevations of points of vertical intersection (PVI) was determined by the design engineers. Various circumstances were considered when developing the proposed highway center line. One of the important considerations was the filling of each depression with an approximately equal volume of cut taken from a nearby hump or from two nearby humps.

The gradient, in terms of percentage of slope (total rise or fall in feet per 100 horizontal feet), is marked on each of the vertical tangents, as shown in *Figure15-25*. The percentage of slope is computed for a tangent as follows.

For the tangent running from station 6 + 00 to station 18 + 00, the total rise is the difference in elevation, or

$$417.0 - 413.3, \text{ or } +3.7 \text{ feet.}$$

The horizontal distance between the stations is 1,200 feet. The percentage of slope, then, is the value of *x* in the equation

$$\frac{1200.00}{3.7} = \frac{100}{x} = 0.31 \, or \; 31\%$$

For a tangent running from station 18 + 00 to station 26 + 00, the total slope downward is the difference in elevation, or

$$412.0 - 417.0, \text{ or } -5.0 \text{ feet.}$$

The distance between the stations is 800 feet. The percentage of slope then is the value of *x* in the equation

$$\frac{800}{5.0} = \frac{100}{x} = \; 0.62 \, or \;\; 62\%$$

5.1.2.3 2.3 Types of Cross Sections

Figure 15-26 shows information found in a typical design cross section including the materials to be used along with their thicknesses.

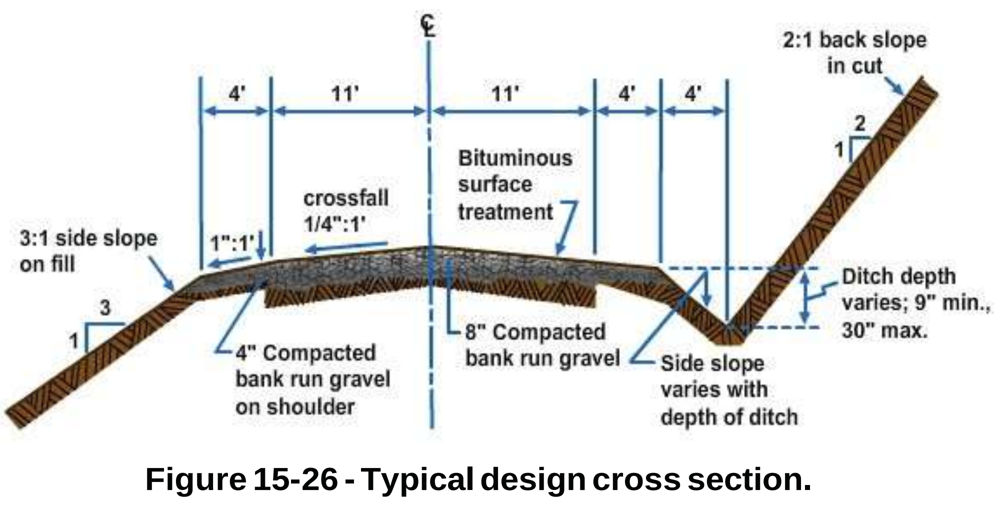

Figure 15-26 - Typical design cross section.

For the purpose of staking out and for earthmoving calculations, the cross-section line of the existing ground at each successive station must be plotted. After each station is plotted, the design-data cross section (typical section of the highway) is then superimposed.

Figure 15-27 shows a designed cross section of a 40-foot-wide road taken from a station or point along the road center line. The elevation of the existing surface is 237.4 feet all the way across, which makes it a level section. The finished grade for the highway at the station is 220.4 feet. The prescribed side-slope ratio is 1.5:1, or a 1.5 horizontal unit for every one unit of vertical rise.

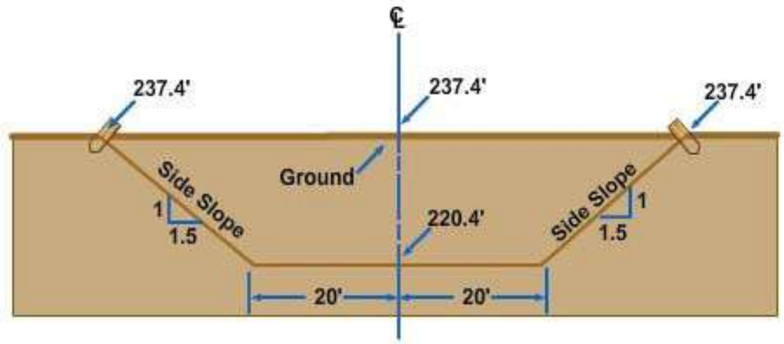

Figure 15-27 - Level section in cut.

Because the ground line across the cross section is level and the side-slope ratio is the same on both sides, the horizontal distance from the center line to the point where the side slope meets the natural surface is the same on both sides. Slope stakes are used to guide the earthmovers. The horizontal distance from the center line to a slope stake can be computed by methods that will be explained later.

In the case of this designed cross section, the data available includes the following:

1. Width of the highway
2. Slide-slope ratio
3. Proposed finished grade

Because the elevation of the level section in *Figure 15-27* is the same on both sides, only a single-level shot elevation is needed. This type of section is called a one-level section, or a level section. Because the entire sectional area consists of material to be excavated or cut, it is called a section in cut.

In the section shown in *Figure 15-28*, the ground line across the section is sloping. To plot this section, three different elevations are needed: one for the left slope stake, one for the center-line grade stake, and one for the right slope stake. If these three levels are taken, the section is called a three-level section in cut. If additional levels are taken midway between the center line and the slope stake on either side, it is called a five-level section in cut. It is a section in cut because the entire cross-sectional area consists of cut. Level, three-level, and five-level sections are called regular sections.

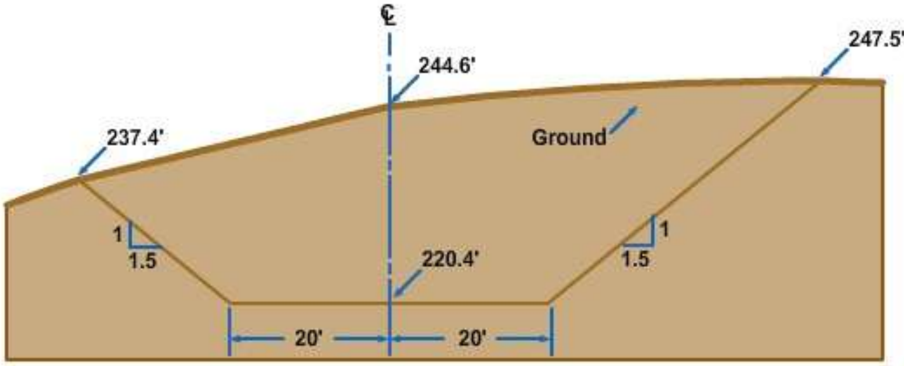

Figure 15-28 - Three-level section in cut.

Figure 15-29 shows a level section in fill. *Figure 15-30* illustrates a three-level section in fill. The section shown in *Figure 15-31* consisting of a cut and a fill is called a side hill section.

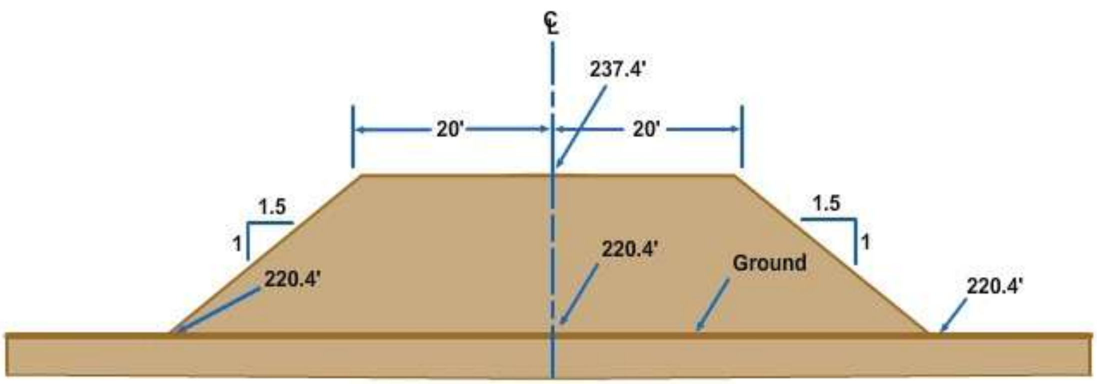

Figure 15-29 - Level section in fill.

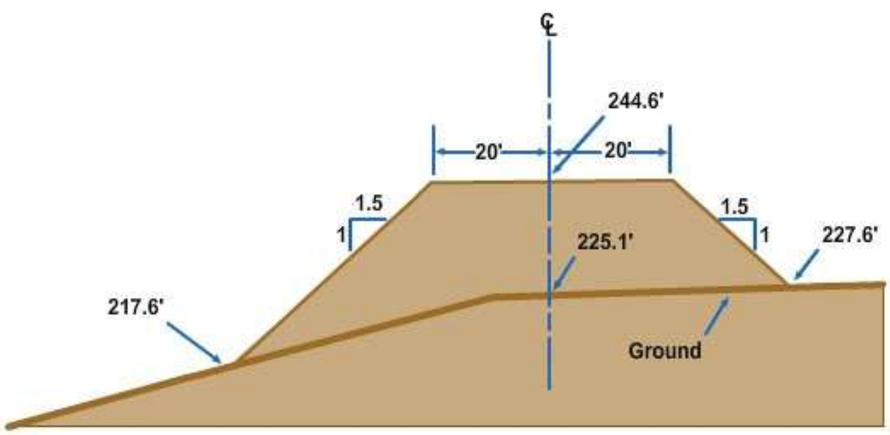

Figure 15-30 - Three-level section in fill.

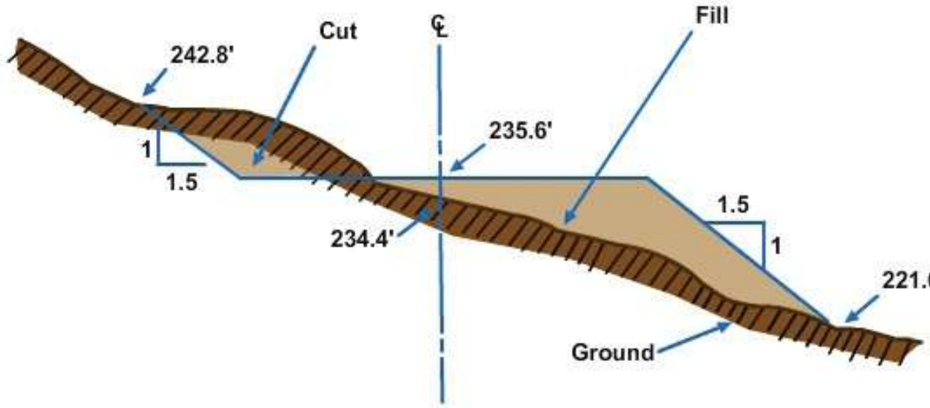

Figure 15-31 - Side hill section.

Cross sections may be preliminary or final. Preliminary cross sections are irregular sections plotted before the finished grade is determined. Preliminary cross sections may be identified by levels run in the field or by elevations found on the contour lines of a topographic map.

Final cross sections are sections of the final road design. They may be prepared in the same manner as preliminary sections, or they may be regular sections plotted from field data obtained after the finished grade is set. The term "final cross section" is also applied to as-built sections taken after construction is completed.

5.1.2.4 Plotting Cross Sections

Cross sections are usually plotted on cross-section paper. Commonly called 10 x10-inch paper, it is ruled into 1-inch squares with heavy orange or green lines, and with lighter lines into 1/10-inch squares.

Each cross section is plotted separately. The station number appears below each cross section. The first cross section is placed at the top of a sheet and continued downward until all sections are plotted. Two or more sections may be plotted on the same sheet. For a major highway project, the cross sections can be plotted on a continuous roll of cross-section paper. Some surveyors prefer to plot the cross sections from the bottom to the top of the paper. They may also prefer to record cross-section notes in the same manner. If you follow these methods of plotting and recording, you are properly oriented with the actual direction of the highway. This means your left is also towards the left of the highway. It is also to the left of the cross section notes and the plotted cross section. It does not matter which method is used as long as proper orientation is maintained.

Unlike profile plotting, in cross-section plotting, the same scale is often used for both the vertical and the horizontal distance. Common scales are 1 inch = 5 feet and 1 inch = 10 feet. When sections are shallow, it is best to exaggerate the vertical scale, making it from two to ten times the horizontal scale.

For the center line for a row of sections, use one of the heavier vertical lines on the paper far enough away from the margin so plotted points will not run off the paper. Note the depths indicated for the first section to be plotted, and select a horizontal line for the base approximately centered between the top and bottom margins. Mark this with the base elevation. Then lay off the horizontal distances of the section surface elevations on either side of the center line, and plot the elevations by using the level data. Finally, connect the plotted points by using a straightedge or by drawing freehand lines.

In *Figure 15-32*, cross-section notes are shown for the existing ground along a proposed road. In *Figure 15-33*, the sections at stations 11 + 00 and 11 + 43 have been plotted.

CROSS-SECTION NOTES
County Road, Ferndale, Mass.
Proj. 5-52

Sta.	BS	HI	FS	Elev.	
B.M. 3	4.71	76.70	–	72.49	
10+00					
11+00					
+43					Brook Valley
12+00					
T.P. 1	10.84	85.22	2.52	74.38	
13+00					
+67					Summit
14+00					
B.M. 4			6.32	78.90	78.92 Established Elev.

Winslow EA2 ⊼
Rankin EA3
Ludlam CN
Right of Way 80 ft Oct. 30, 19

Left ℄ Right

Figure 15-32 - Cross section notes.

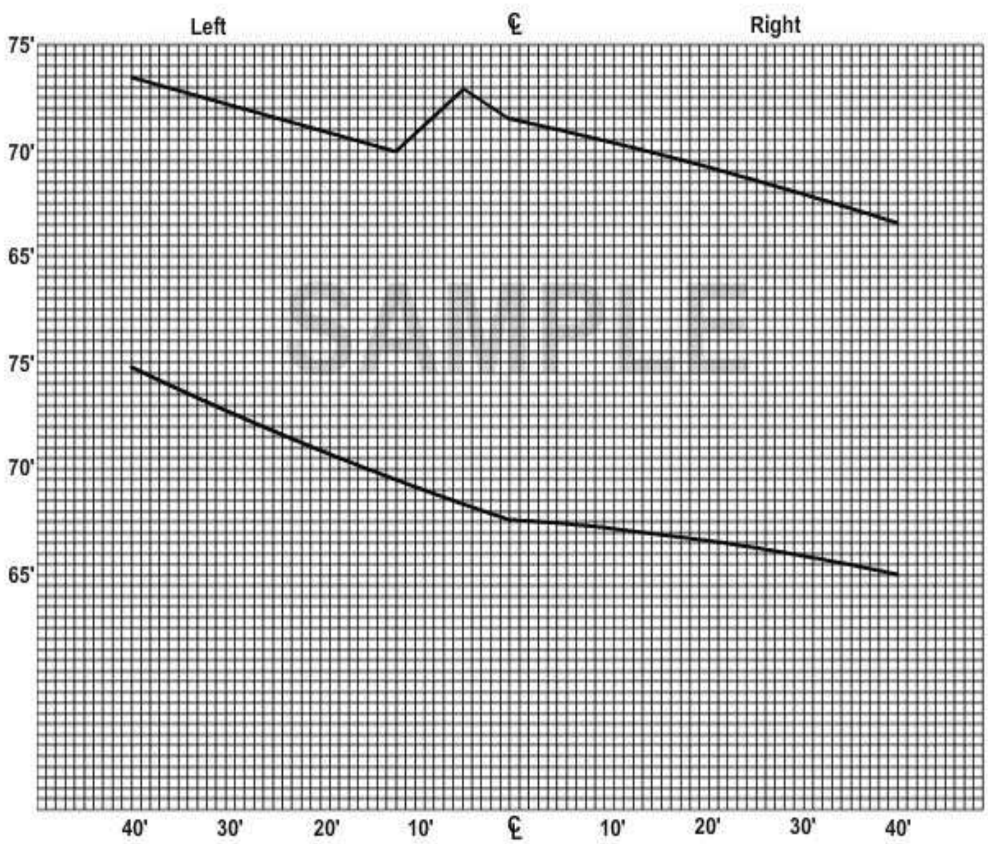

Figure 15-33 - Cross section plotted.

For each station the field party took the ground elevation 40 feet to the right and to the left of the center line. For each station, however, the center-line distance of the intermediate elevations varies making these irregular sections.

The HI for both plotted stations is 76.70 feet. For the point 6 feet left of the center line at station 11 + 00, note the 4.2 written below the 6. This reading was obtained from a rod held on this point. The number 72.5 shown in the parentheses right below the number 4.2 is the elevation of this point. You obtain the elevation by subtracting from the HI, the rod reading FS: 76.70 - 4.20, or 72.50

This point is plotted 6 feet to the left of the center line at an elevation of 72.5 feet, as shown in *Figure 15-33*. Notes are reduced in the office. The general practice is to print the elevations in RED. The elevation just computed (72.5) appears in red in the cross-section notes, as shown in *Figure 15-32*.

After the road gradients, either preliminary or final, are designed, plot the design-data cross section on the existing ground line section plot at each station to complete the picture of the end-area as it will be in the finished highway. Obtain the finished grade elevation for each station from the profile. Plot the finished grade point, usually located on the center at each cross section. Then draw in the outline of the pavement surface, ditches, and cut or fill slopes as they show on the typical design section. Plotting may be done with triangles. However, a faster method uses templates made of plastic, thin wood, sturdy cardboard, or other suitable material. Prepare templates for a cut section, a fill section, and a side hill section that may be flipped over to accommodate the direction of hillside slope.

The procedures just described are the most common and pertain to irregular sections. If regular sections are taken in the field after the gradients have been designed, then both the existing and the finished surfaces are plotted. Field notes for simplified three-level sections on a highway are shown in *Figure 15-34*. On the data side, the profile elevation and the grade elevation at each station are listed. In the columns headed Left and Right on the remarks side, the upper numbers and letter symbols (C for cut, F for fill) indicate the amount of material to be removed or added. The numbers under the lines indicate the distance measured out from the center line. These points also indicate slope stake locations. If a five-level or irregular section is being recorded, additional points must be written between those for the center and for the slope stakes to indicate the changing elevations.

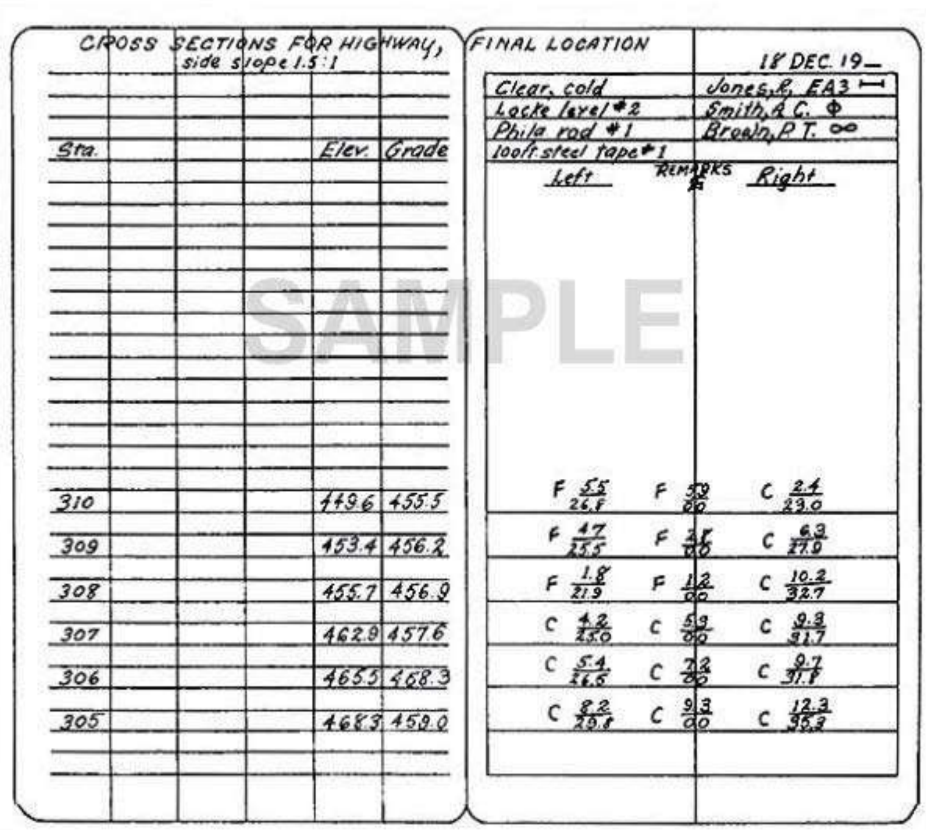

Figure 15-34 – Field notes for three-level cross section.

5.1.3 ayout/Stakeout Procedures

The design-data survey is followed by the construction survey, which consists of the layout or stakeout survey and the as-built survey. In a layout survey, both horizontal and vertical control points are located and marked to guide the construction crews. *Figure 15-35* illustrates a typical arrangement of stakes and hubs used in highway or road construction. The functions of the stakes and hubs include the following:

1. **Center-line stakes** indicate the exact center of the roadway construction.
2. **Shoulder stakes** indicate the inside edge of the roadway shoulders. These stakes are set opposite each center-line stake.
3. **Reference stakes**, as the name implies, provide a reference for other stakes or aid in establishing or reestablishing other stakes.
4. **Slope stakes** mark the intersection of side slopes with the natural ground surface. They indicate the earthwork limits on each side of the center line.
5. **Right-of-way stakes** indicate the legal right of passage and outmost bounds of construction.
6. **Grade stakes** indicate required grade elevations to the construction crews. During the final grading stage of construction, hubs called "blue tops" are used in lieu of stakes. The blue tops are driven so that the top of the hub is set at the required grade elevation.

7. **Guard stakes** identify and protect hubs. The face of the stake is marked with station identification and placed so the stake faces the hub it identifies. Sometimes more than one guard stake is used to protect a hub.
8. **Offset stakes** are additional stakes that are offset a known distance from other stakes that will likely be disturbed during construction. The offset stake is marked with the same information as the stake it offsets. It is also marked to show the offset distance. Often, stakes are offset a known distance from their true location. This eliminates the requirement for additional stakes.

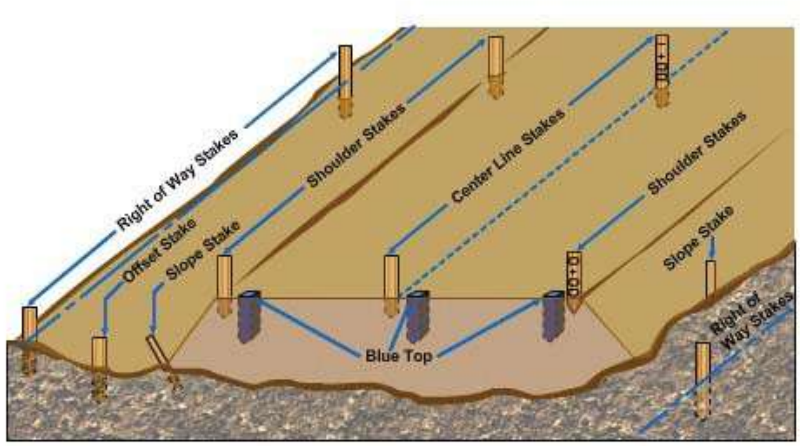

Figure 15-35 – Typical arrangement of hubs and stakes on a road section (final grading).

5.1.3.1 Center-Line Layout

The first major step in highway construction is usually the rough grading or earthmoving which brings the surface up to or down to the approximate elevation prescribed for the sub-grade. The sub-grade is the surface of natural soil, or the place where the pavement will be laid. The sub-grade elevation, therefore, equals the grade (finished surface) elevation minus the thickness of the pavement.

In rough grading, the equipment operators are usually guided by grade stakes set along the center line by the transit-tape survey party at center-line stations. The center-line stations (stakes) are usually set at intervals of 100 feet or more on straight-line stretches and intervals of 50 feet or less on roads with horizontal and vertical curvatures. On a small-radius, street-corner curve, a center-line hub stake might be set at the center of the circle of which the curve is a part. This is done so the construction crew may outline the curve by swinging the radius with a tape. Reference stakes or hubs are also set on one or both sides of the center line to reestablish the center line at any time.

Each center-line stake is marked with the vertical depth of cut or fill required to bring the surface to grade elevation. The surveyor must indicate the station markings and the cut and fill directions on stakes. The starting point is the first station in the survey is numbered 0 + 00. The next station is normally 100 feet farther and is marked 1 + 00; the third station is another 100 feet farther and is marked 2 + 00, and so on. On sharp curves or on rough ground, the stakes may be closer together, as shown in *Figure 15-*

36. Generally, the station markings face the starting point. The mark on the side facing the starting point is used to indicate the stake is a center-line stake.

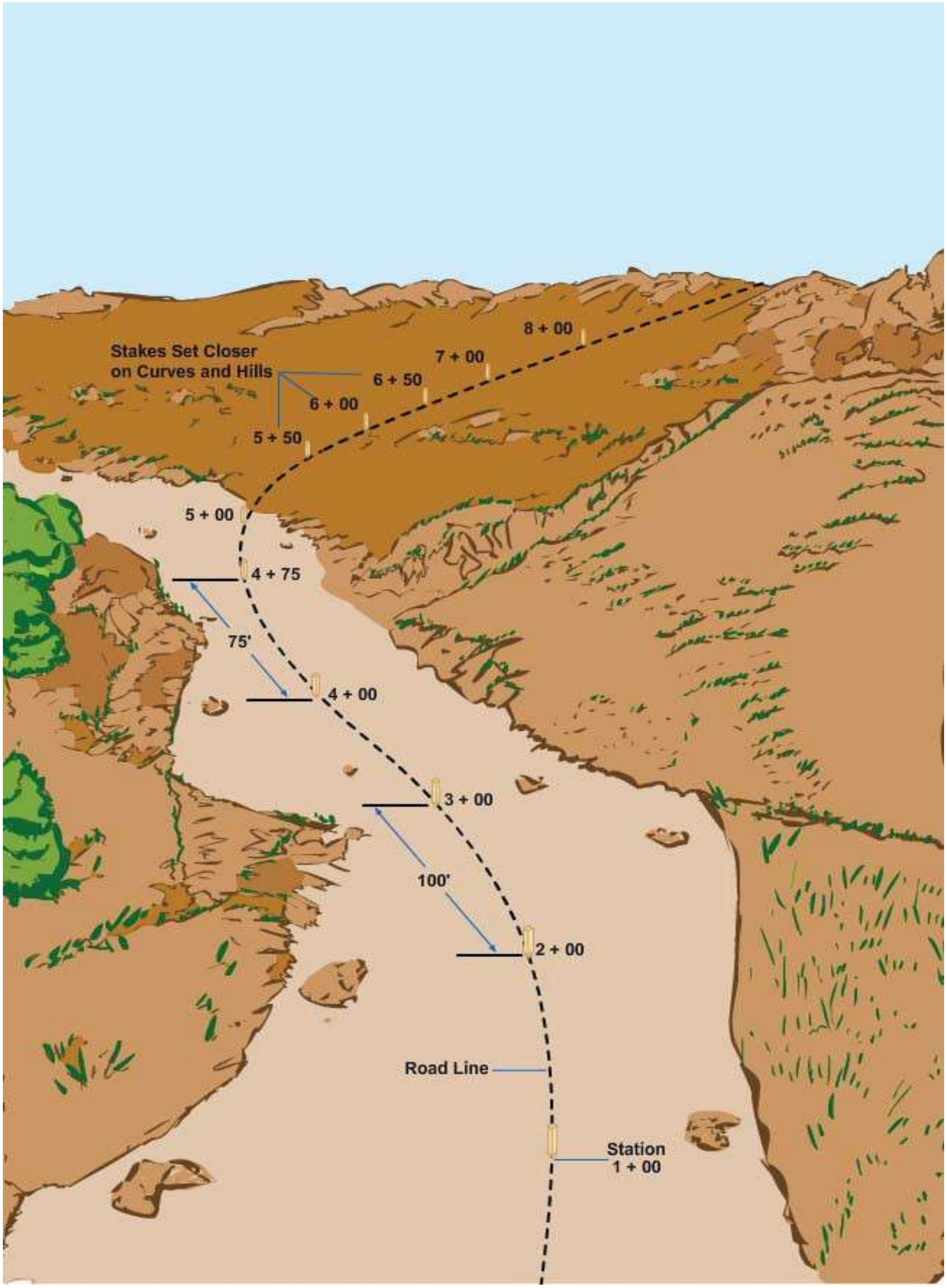

Figure 15-36 - Center-line layout.

The A cut is designated by the letter C, and the fill is indicated by the letter F. Numerals follow the letters to indicate the amount that the ground should be cut or filled. The symbol C1$^{\underline{5}}$ indicates the existing ground should be cut 1.5 feet, as measured from the reference mark. During rough grading, the cut and fill are generally carried just up to the nearest half foot. Exact grade elevations are later marked with hubs (blue tops).The mark V is called a crowfoot. The apex of the V indicates the direction of the required change in elevation; so a cut is indicated by V, and a fill is indicated by upside down V. In some cases, surveyors mark the grade stake only with a negative or a positive number and the crowfoot, indicating the cut or fill.

Figure 15-37 shows a cut stake which is also a center-line marker. Note the station mark is written on the front of the stake and the construction information on the back. On grade stakes other than the center-line stakes, the construction information should be written on the front and the station marked on the back.

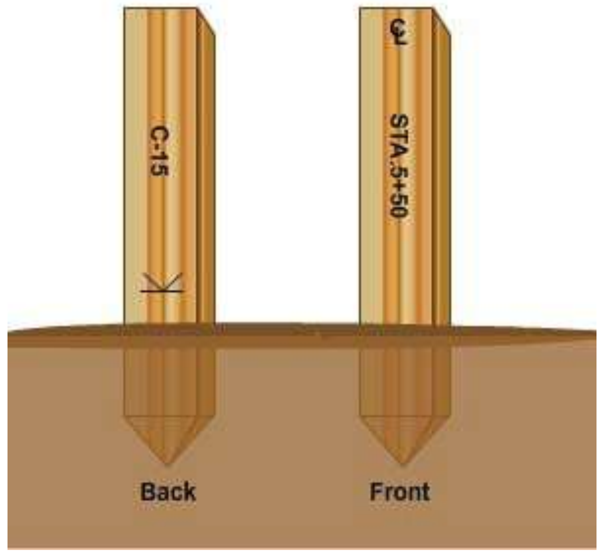

Figure 15-37 - Cut stake.

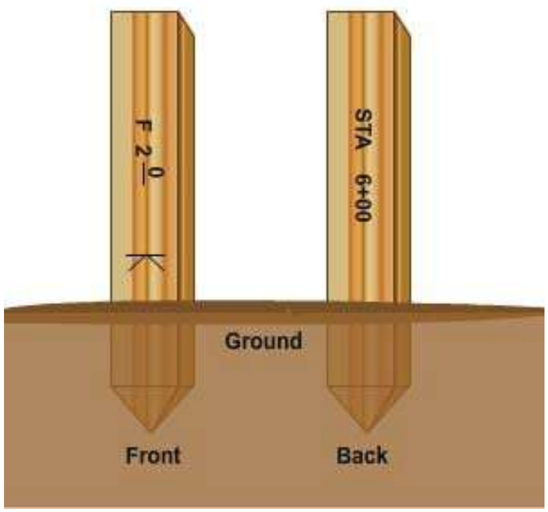

Figure 15-38 – Fill stake (not on center line).

The stake shown in *Figure 15-38* indicates fill is required. The letter F at the top of the stake stands for fill. The numerals indicate 2 feet of fill are required to bring the construction up to grade.

Some stakes indicate that no cutting or filling is required. *Figure 15-39* illustrates a grade stake on a proper grade on a center line. The word GRADE (or GRD) is on the back of the stake, and the crowfoot mark may not be indicated. Some surveyors prefer to use a crowfoot mark on all grade stakes. If this grade stake was not a center-line stake, the GRD mark would be written on the front of the stake.

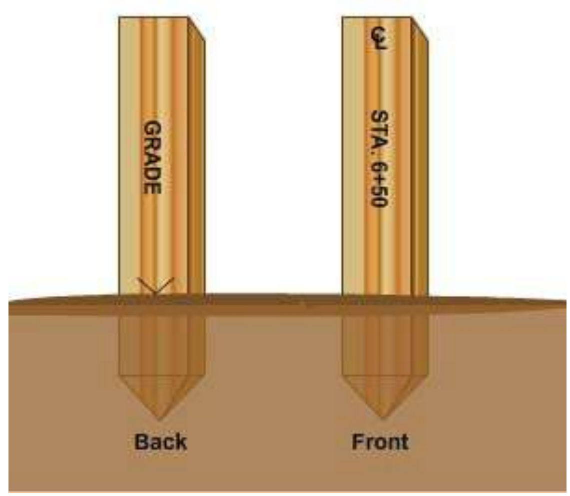

Figure 15-39 - Stake on proper grade.

5.1.3.2 Setting Grade Stakes

Points with the same ground and grade elevation are set by grade stakes. They are usually set after the center line is laid out and marked with hubs and guard stakes. They can be reestablished if the markers are disturbed. Elevations are usually determined by an engineer's level and level rod. One procedure used for setting grade stakes is as follows:

1. From BMs, turn levels on the center-line hubs or on the ground next to a grade stake at each station.
2. Reduce the notes to obtain hub-top or ground elevation.
3. Obtain the finished grade elevation for each station from the construction plans.
4. Compute the difference between the finished grade and the hub or ground elevation to determine the cut or fill at each station.
5. Go back down the line and mark the cut or fill on each grade stake or guard stake.

The elevations and the cuts or fills may be recorded in the level notes, or they may be set down on a construction sheet, as explained later in this chapter.

Another procedure may be used that combines the method listed above so that the computations may be completed while at each station. The cut or fill can be marked on the stake immediately.

As before, levels are run from BMs. The procedure at each station is as follows:

1. Determine the ground elevation of the station from the level notes to obtain HI.
2. Obtain the finished grade for the station from the plans.
3. Compute the difference between the HI and the finished grade. This vertical distance is called grade rod.
4. Read a rod held on the hub top or ground point for which the cut or fill is desired. This rod reading is called the ground rod.
5. Determine the cut or fill by adding or subtracting the grade rod and the ground rod, according to the circumstances, as shown in *Figure 15-40.*
6. Mark the cut or fill on the stake.

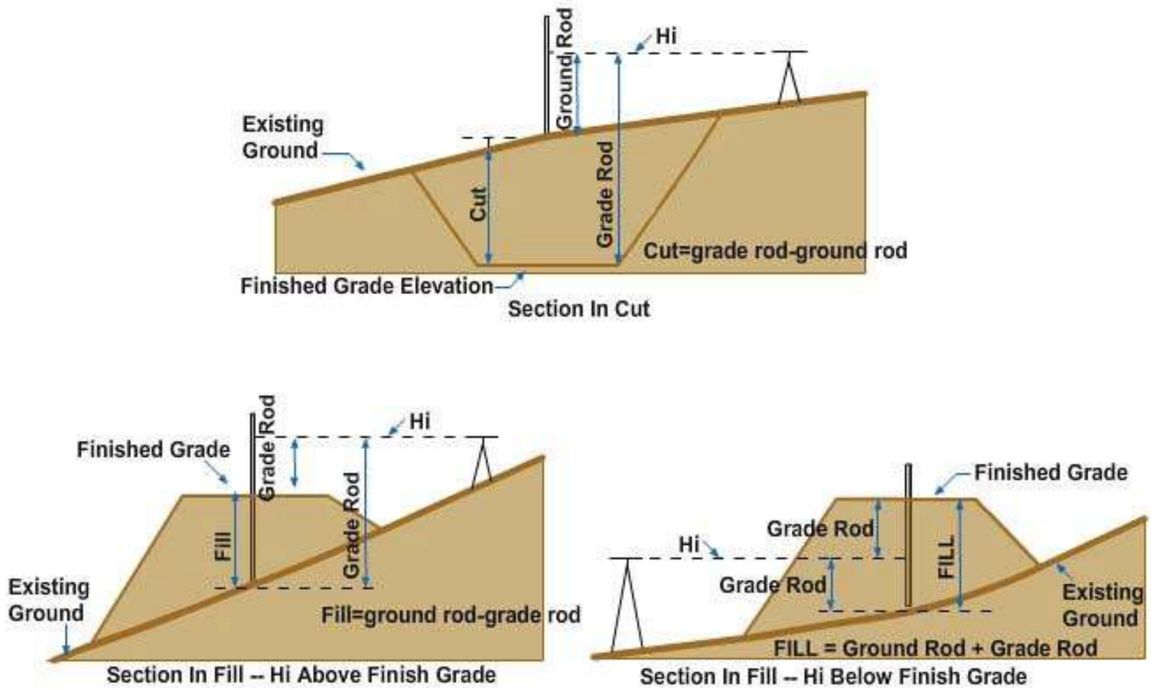

Figure 15-40 – Determining cut or fill from grade rod and ground rod.

Blue top hubs are used during the final grading. These hubs are driven into the ground until the top is at the exact elevation of the finished grade as determined by the surveying crew. When the top of the stake is at the desired finish grade elevation, it is colored with blue lumber crayon (keel) to identify it as a finished grade stake. Other colors may be used, but be consistent and use the same color keel throughout the project so as not to confuse the equipment operators. Blue tops are normally provided with a guard stake to avoid displacement during construction work. The guard stake usually shows the station and the elevation of the top of the hub. Setting blue tops is primarily conducted during final grading operations. The procedure is as follows:

1. Study the construction plans and center-line profiles for each station to determine the exact profile elevation and the horizontal distance from center line to the edge of the shoulder.
2. Measure the horizontal distance from the center line to the shoulder edge at each station, and drive a grade stake at this point on each side. It is advisable to offset the stakes a few feet to avoid displacement during construction.
3. Set the top of the stake even with the grade elevation, using both the level and the rod. This is accomplished by measuring down from the HI a distance equal to the grade rod (determined by subtracting grade elevation from the HI). The target on the rod is set at the grade-rod reading and the rod is held on the top of the stake. After a few trials, the stake is driven into the ground until the horizontal hair of the level intersects the rod level indicated by the target. Then color the top of a stake with blue crayon (keel).
4. Where the tops of stakes cannot be set to grade because grade elevation is too far below or above the ground line, set in ordinary grade stakes marked with the

cut or fill as in rough grading. However, for final grading, it is usually possible to set most of the blue tops.

Where grade stakes cannot be driven, for example in hard coral or rock areas, use ingenuity to set and preserve grade markings. Markings may often be made on the rock with a chisel or a keel.

5.1.3.3 Setting Slope Stakes

Slope stakes are driven at the intersection of the ground and each side slope or offset a short distance. They indicate the earthwork limits on each side of the center line. The minimum areas to be cleared and grubbed extend outward about 6 feet from the slope stakes.

Refer back to *Figure 15-31* and take a close look at the position of the slope stakes. The horizontal distance of a slope stake from the center line varies. Three variables must be known to determine this distance:

1. The width of the roadbed, including widths of shoulders and ditches, if any
2. The side-slope ratio (expressed in units of horizontal run in feet per foot of vertical rise or fall)
3. The difference in elevation between the grade for the road and the point on the natural ground line where the slope stake will be set

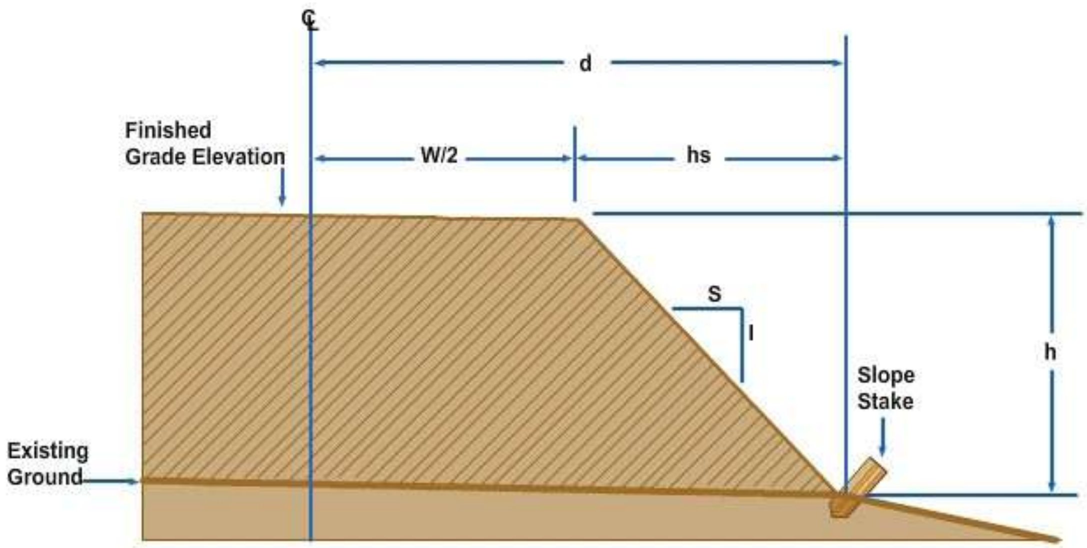

Figure 15-41 - Fill section level.

In *Figure 15-41*, *d* is the horizontal distance from the center line to the slope stake, W/2 is the horizontal distance from the center line to the top of the slope, *h* is the difference in elevation between the finished grade and the ground at the slope stake, and *s* is the slope ratio. The product of *h* x *s* gives the run of the slope or the horizontal distance the slope covers. The horizontal distance (*d*) of the slope stake from the center line, then, equals the sum of W/2 plus *hs*. For example, suppose W/2 is 20 feet, *h* is 10 feet, and the bank is a 4:1 slope.

Then

$$hs = 10 \times 4, \text{ or } 40$$

and

$$d = 20 \text{ feet} + 40 \text{ feet, or } 60 \text{ feet}$$

In practice other factors must be considered, such as a transverse slope or the crossfall of the pavement (sometimes called the crown), ditches, and other factors. In *Figure 15-42*, for example, there is a crossfall (*h*=) across W/2 so that the run (horizontal distance covered) of the bank ($h_b s$) is the product of $s \times h_b$ instead of *hs*, as in *Figure 15-37*, *view A*. The crossfall is usually constant and may be obtained from the typical design sect ion shown on the plans.

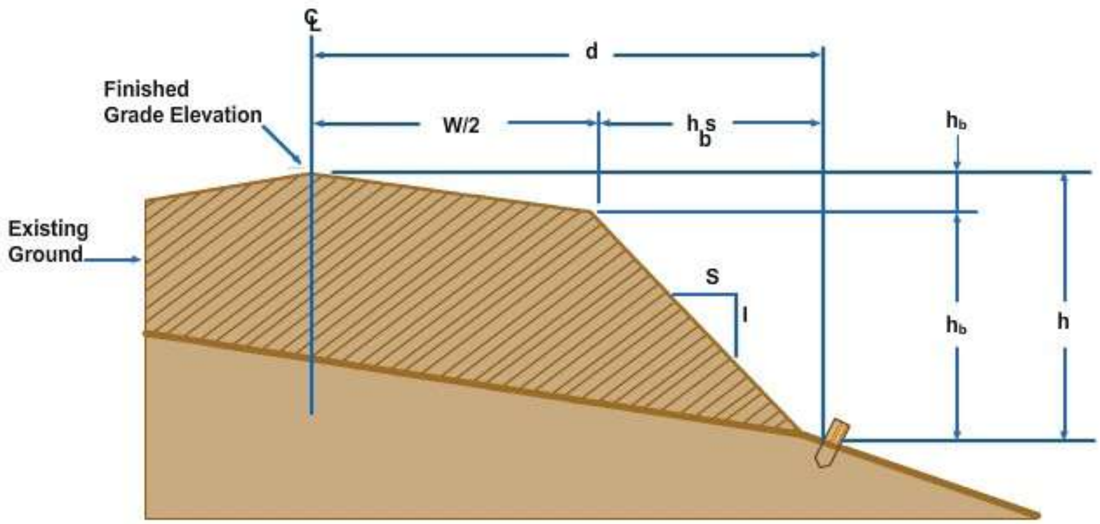

Figure 15-42 - Fill section with cross fall.

Figure 15-43 shows a cut section in which W/2 varies with crossfall, side slope, ditch depth, and back slope. For example, assume that the distance from the center line to the beginning of the side slope is 20 feet, the cross fall totals 1 foot, the ditch depth is 1.5 feet, and both the side slope and back slope ratios are 2:1. The distance W/2, then, comprises horizontal segments as follows:

1. From the center line to the top of the slope, which is 20 feet
2. Then to the ditch flow line, which equals the product of slope ratio 2 times ditch depth (1.5), or 3 feet.
3. Then to the point on the back slope that is level with the finished center line, which equals slope ratio 2 times the difference in elevation crossfall plus ditch depth, 2(1 + 1.5), or 5 feet.
4. The total distance of W/2, is the sum of 20 + 3 + 5 or 28 feet.

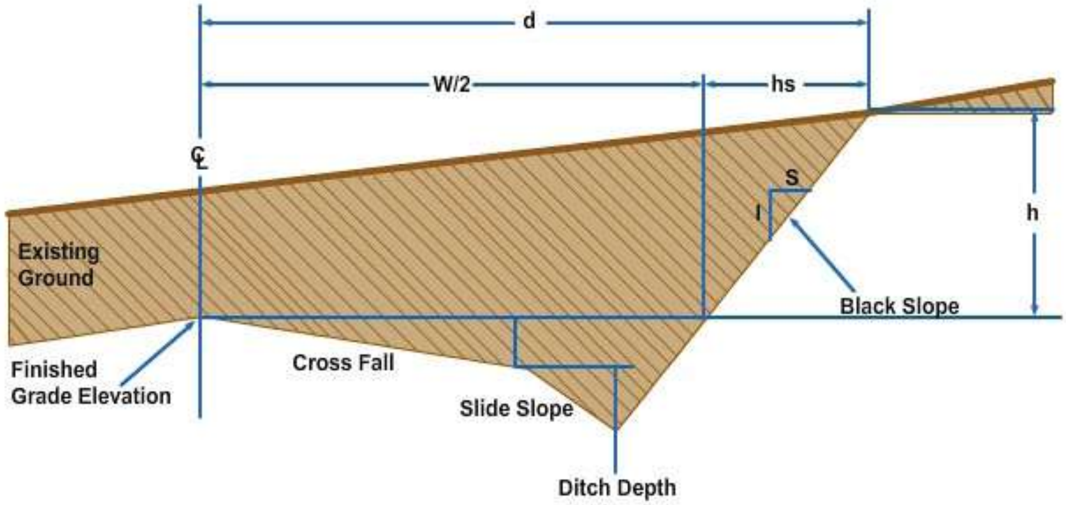

Figure 15-43 - Cut section.

5.1.3.4 Slope-Stake Procedure

Slope stakes are usually set with an engineer's or automatic level, a level rod, and a metallic or nonmetallic tape. In rough terrain, a hand level is generally used instead of an engineer's level. If the engineer's level is used, three crew members are generally employed for fieldwork. The three crew members include the instrumentman, the rodman, and one person to hold the zero end of the tape at the center line. When a hand level is used, two persons can do the job. The instrumentman uses the hand level and holds the zero end of the tape and is positioned at the center-line station as the rod reading is taken. The procedure is a trial and error process. Under field conditions, the rodman is at times as much as 200 or 300 feet away from the instrumentman. If power equipment is operating nearby or a wind is blowing, oral instructions cannot be given to the rodman about where to take trial shots. In other instances there may not be a clear view of the ground slope at the station being worked.

Consequently, the rodman must know as much as the instrumentman does about the theory and practice of setting slope stakes. The speed and efficiency of the party depend on the rodman more than on any other member. The rodman must always be mentally alert.

The most practical field procedure requires the rodman to know the value of W/2 and of *s* (the slope ratio). This is not difficult, since these values are usually constant for several stations, and the rodman can be informed when they change. A typical procedure for setting slope stakes is as follows:

1. The instrumentman computes the center-line cut or fill, using the HI, finished grade, and the existing ground elevation. Refer back to *Figure 15-36*.
2. The instrumentman calls or signals the center-line cut or fill to the rodman.
3. The rodman mentally computes the approximate value of *d* by multiplying *h* x *s* and adding W/2. The rodman pulls the tape taut while holding the tape at the computed distances.
4. Noting the approximate rise or fall of the ground, the rodman adjusts the approximate value of *d*, moves to the *d* point, and sets up the rod for a trial shot.

5. The instrumentman quickly calculates the cut or fill at this point and calls the value to the rodman.
6. The rodman compares the information with the estimated cut or fill. The rodman should be fairly close and should know at once whether to move toward or away from the center line. Having a much shorter distance over which to estimate ground slope, the rodman again estimates new cut or fill and *hs* + W/2, and moves the rod to the new d value.
7. The instrumentman again gives the cut or fill; if the value checks, the rodman calls or signals back the cut or fill and the distance.
8. The instrumentman quickly checks the two values mentally, and if the values are correct, records the values in the field book, signaling "Good" to the rodman.
9. The rodman marks and drives the stake.

With practice and on fairly smooth ground, a good rodman will seldom miss the first trial by more than 0.2 foot vertically and will, quite often, hit the correct value on the first trial.

Figure 15-44 shows the application of these procedures to an actual situation. The following data is known for this slope-stake stakeout:

1. The station is 15 + 00.
2. The W/2 (from the typical design section) is 20 feet.
3. The slope ratio is 1:1; therefore, *s* = 1.
4. The existing ground elevation at the center line (from the previously run profile) is 364.00 feet.
5. The HI is determined to be 369.30 feet at that setup.

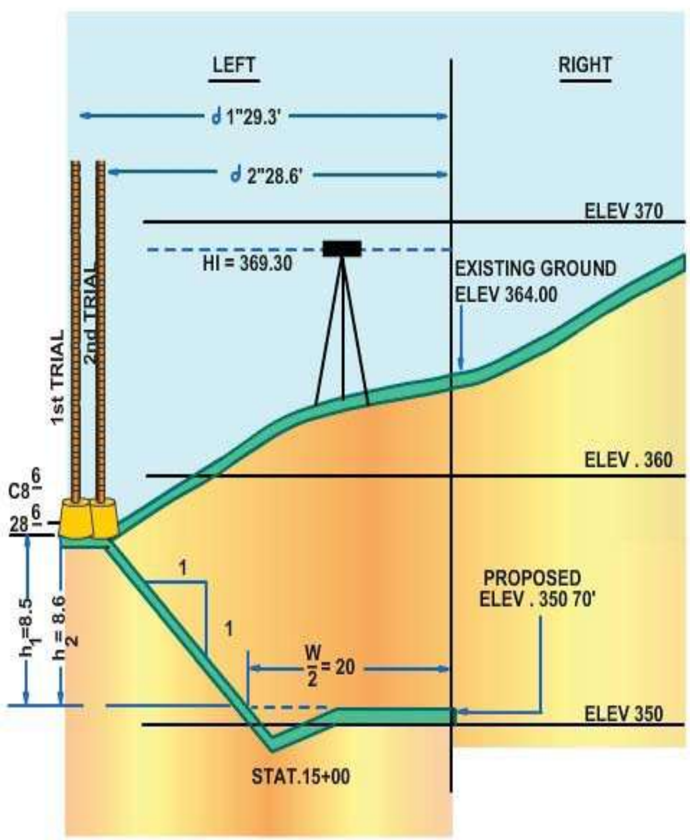

Figure 15-44 - Setting slope stakes.

The steps taken by the instrumentman and the rodman are as follows:

1. The instrumentman determines the center-line cut by subtracting 350.7 feet from 364.0 feet to get the cut, or 13.3 feet.
2. The rodman holds at the center line for a check. The rod should read 369.3 (the HI) minus 364.0, or 5.3 feet.
3. The instrumentman calls to the rodman, "Cut 13.3 feet."
4. The rodman computes *d*= 20+(1 x 13.3) = 33.3 while walking to the left.
5. As the rodman approaches about 30.0 feet from the center line, he/she estimates that the ground has a fall of 4 feet, and therefore computes the new cut as 13.3 - 4.0, or 9.3 feet. This means a new *d* of 20 + (1 x 9.3) = 29.3 feet.
6. The rodman sets up the rod 29.3 feet from the center line, as measured by metallic tape.
7. The instrumentman reads 10.1 on the rod and computes the new cut as 369.3 - (350.7 + 10.1), or 8.5 feet.

Note that the grade rod and ground rod values can be used here as explained earlier; the new cut then will be 18.6 - 10.1 = 8.5 feet.

Refer back to *Figure 15-36*.

8. The instrumentman calls, "Cut 8.5," to the rodman.
9. The rodman computes *d* = 20 + (1 x 8.5) = 28.5 feet. The rodman knows, therefore, that 29.3 feet from the center line is too far out.
10. Figuring that the ground rises about 0.1 foot between 29.3 left and 28.5 left, the rodman calculates that the more nearly correct cut will be 8.5 + 0.1, or 8.6 feet.
11. By using this cut, the rodman calculates the new *d* as 20 + (1 x 8.6), and sets the rod at 28.6 feet left.
12. The instrumentman reads and computes the new cut as 369.3 - (350.7 + 10.0) = 10.0 on the rod 8.6 feet.
13. The instrumentman calls, "Cut 8.6," to the rodman.
14. The rodman sees that the actual cut of 8.6 feet agrees with his estimated cut of the same, and calls, "Cut 8.6 at 28.6," to the instrumentman.
15. The instrumentman checks *d* = 20 + (1 x 8.6) = 28.6, signals the rodman, "Good," and makes the following entry into the field book:

$$\frac{c8^{6}}{28}$$

16. The rodman marks a stake with 15 + 00 and C86 and drives it in the ground at 28.6 feet left.

More often, slope stakes may be set by using a hand level. The distances out are generally measured to the nearest half or tenth of a foot. If a slope stake is placed in an offset position, the offset distance is also marked on the stake so the equipment operator is not confused about its actual location. Slope stakes are seldom used in areas requiring less than 2 feet of cut or fill.

5.1.4 Curb and Gutter Stakeout

Generally curbs and gutters are usually constructed before the finish grading is done. The curb constructors acquire their line and grade from offset hubs like those described previously. Guided by the offset hubs, the earthmovers make the excavation for the curb, form-setters set the forms, and the concrete crew members pour, finish, and cure the curb.

After the curb is constructed, shaping the sub-grade to the correct sub-grade elevation and laying the pavement to correct finished grade is simply a matter of measuring down the correct distance from a cord stretched from the top of one curb to the top of the opposite curb.

5.1.5 Pavement Stakeout

Pavement stakeout depends on the type of paving equipment used. The steps commonly used for paving concrete highways are as follows:

1. Set a double line of steel side forms, equipped with flanges that serve as tracts for traveling paving equipment.
2. Fill the space between the forms with concrete poured from a concrete paving machine (commonly called a paver).
3. Spread the concrete with a mechanical spreader that travels on the flanges of the side forms.
4. Finish the surface with a finisher, a machine that also travels on the side forms.

The line-and-grade or layout/stakeout problem consists principally of setting the side forms in line with the upper edges of the flanges for the prescribed highway grade. If the finished grade shown on the plans is the center-line grade, then the forms are set with tops at the center-line grade less the crossfall. If the design elevations are shown for points other than those on the center line, the form elevation is related to the design points as indicated by the typical section.

Concrete paving is also done by the slip form method, which uses a sliding or traveling section of formwork to spread and finish the concrete. The machinery is kept on line and the pavement is finished at grade by a control device or devices. The line control device usually follows a wire stretched between rods offset from the pavement edge.

Forms are not usually used in asphalt paving. Asphalt paving equipment, in general, is designed to lay the pavement at a given thickness, following the fine-graded sub-grade surface.

5.2.0 Structural Surveys

A structural survey is part of the chain of human activities that brings a structure such as a building, a bridge, or a pier into existence.

5.2.1 Earthwork

The first major step in highway construction is usually the rough grading or earthmoving which brings the surface up to, or down to, the approximate elevation specified for the rough grade.

The stakeout for rough grading is commonly done by the grid method. The area to be graded and the prescribed finish grade elevation on the site or plot plan are laid off in 25-, 50-, or 100-foot grid squares. The elevation at each corner point is determined by the following process:

- The difference between the existing grade and the prescribed grade elevation is computed.
- A grade stake is marked with the depth of cut or fill.
- The stake is driven into the ground at the point.

5.2.2 Stakeout

The next major step after the rough grading is completed is the building stakeout. Building stakeout involves locating and staking the main horizontal control points of a building. These are usually the principal corner points plus any other points of intersection between building lines.

Figure 15-45 shows a simple building stakeout. The site plan shows a 40 x 20-foot rectangular structure, with one of the long sides parallel to, and 35 feet away from, a base line. The base line is indicated at the site and on the plans by Monuments A and B.

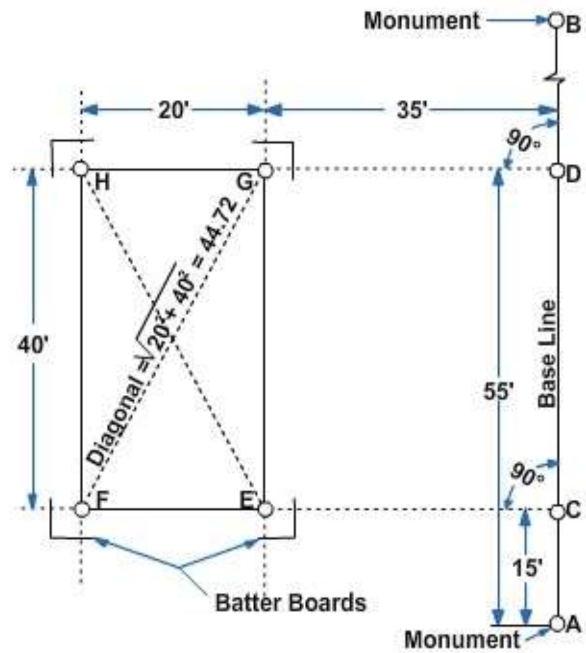

Figure 15-45 - Building stakeout.

One of the short sides of the building lies on a line running from *C*, a point on *AB* 15 feet from *A*, perpendicular to *AB*. The other short side lies on a similar line running from *D*, a point on *AB* 40 feet from *C* and therefore 40 + 15, or 55 feet from *A*, perpendicular to *AB*.

The steps in the stakeout procedure are as follows:

1. Set up the transit at Monument A. Train the telescope on a marker held on Monument B. Then drive hubs on the line of sight, one at *C* 15 feet from *A*, the other at *D* 55 feet from *A* and 40 feet from *C*.
2. Shift the transit to *C*, train on *B,* match the zeros, and turn 90^0 left. Measure off 35 feet from *C* on the line of sight and drive a stake to locate *E*. Measure off 55 feet from *C* (or 20 feet from *E*) and drive another stake to locate *F*.
3. Shift the transit to *D* and repeat the procedure described in Step 2 to locate and stake points *G* and *H*.

The accuracy of a rectangular stakeout can be check by measuring the diagonals of the rectangle.

The diagonals should be equal. The correct length of each diagonal can be checked by applying the Pythagorean Theorem, as shown in *Figure 15-45*.

For a large rectangle, checking the accuracy of the stakeout by angular measurement with the transit may be more convenient. For example: Determine the correct size of angle *GEH* in *Figure 15-45* by a convenient right-triangle solution, such as

$$\tan a = \frac{20}{40} = 0.50000$$

The angle with tangent 0.50000 measures (to the nearest minute) 26°34·. Therefore, angle *FEH* should measure

$$90^\circ 00' - 26^\circ 34', \text{or } 63°26'.$$

The corresponding angles at the other three corners should have the same dimensions. If the sizes as actually measured vary at any corner, the stakeout is inaccurate.

Batter boards are marks placed for use as references or guides during the initial excavation and rough grading of building and/or a sewer line construction. Batter boards are temporary devices used to support stretched cords that mark the outline and grade of the structure.

Batter boards consist of 2 x 4-inch stakes driven into the ground. Each stake has a crosspiece of 1 x 6-inch lumber nailed to it. The stakes are driven approximately 3 to 4 feet away from the building line where they will not be disturbed by the construction. They are driven far enough apart to straddle the line to be marked. Note in *Figure 15-46*, only three stakes are driven on outside corners because one is a common post for two directions. The length of the stakes is determined by the required grade line. They must be long enough to accept the 1 x 6-inch crosspiece to mark the grade.

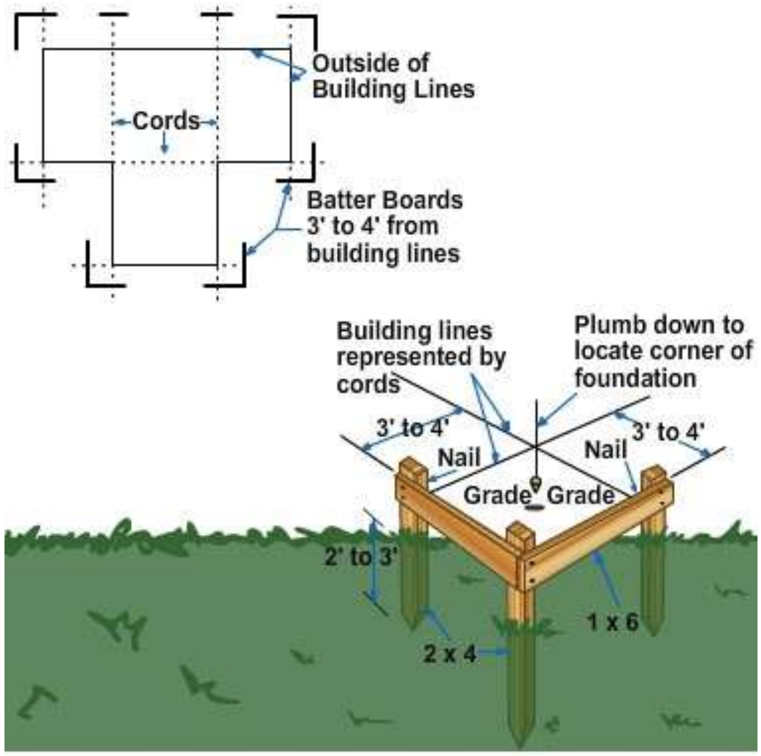

Figure 15-46 - Batter boards.

The 1 x 6-inch crosspiece is cut long enough to join both stakes and is nailed firmly to them after the grade has been established. The top of the crosspiece becomes the mark from which the grade will be measured. All batter boards for one structure are set to the same grade or level line. A transit is used to locate the building lines and to mark them on the top edge of the crosspiece. A nail is driven at each of these marked points, or a V notch is carved at the top outer edge of the crosspiece towards the marked point and the nail is driven on the outer face of the board.

When a string is stretched over the top edge of the two batter boards and is held against the nails or against the bottom of the notch, the string defines the outside building line and grade elevation.

Batter boards are set and marked as follows:

1. After laying out the corner stakes, drive 2 x 4-inch stakes 3 to 4 feet outside of each corner. These are selected to bring all crosspieces to the same elevation.

2. Mark the stakes at the grade of the top of the foundation or at some whole number of inches or feet above or below the top of the foundation. Use a level to mark the same grade or elevation on all stakes.
3. Nail 1 x 6-inch boards to the stakes so the edges of the boards are flush with the grade marks.
4. Locate the prolongation of the building lines on the batter boards by using a transit or by using a line and plumb bob.
5. Drive nails into the top edges of the batter boards or notch the boards to mark the building line.

5.3.0 Utilities Stakeout

Utilities is a general term applied to pipelines such as sewer, water, gas, and oil pipelines, and communications lines such as telephone or telegraph lines and electric power lines.

5.3.1 Above-ground Utilities

For an above-ground utility, such as a pole-mounted telephone or power line, the survey problem consists of locating the line horizontally and marking the stations where poles or towers are to be erected. Often, the directions of guys and anchors maybe staked. Occasionally, pole height for vertical clearance of obstructions is determined.

5.3.2 5.3.2 Underground Utilities

For an underground utility, often both line and grade must be determined. For pressure lines, such as water lines, it is usually necessary to stake out only the line, since the only grade requirement is that the prescribed depth of soil cover be maintained. However, staking elevations may be necessary for any pressure lines being installed in an area that is to be graded downward or has conflicting underground utilities.

Gravity flow lines, such as storm sewer lines, require staking for grade to be sure the pipe is installed at the design elevation and gradient (slope) needed for gravity flow through the pipe.

Grade for an underground sewer pipe is given in terms of the elevation of the invert. The invert of the pipe is the elevation of the lowest part of the inner surface of the pipe. *Figure 15-47* illustrates a common method of staking out an underground pipe. Both alignment and elevation are facilitated by a line of batter boards and battens (small pieces of wood) set at about 25- to 50-foot intervals. The battens, nailed to the batter boards, determine the horizontal alignment of the pipe when placed vertically on the same side of the batter boards and with the same edges directly over the center line of the pipe. The alignment of the battens must be checked as work progresses. Use a sighting cord, stretched parallel to the center line of the pipe at a uniform distance above the invert grade, to transfer line and grade into the trench. The center line of the pipe should be directly below the cord, and the sewer invert grade should be at the selected distance below the cord. A measuring stick, also called a grade pole, is used to transfer the grade from the sighting cord to the pipe, as shown in *Figure 15-47*. The grade pole, with markings of feet and inches, is placed on the invert of the pipe and held plumbed. The pipe is then lowered into the trench until the mark on the grade pole is on a horizontal line with the cord.

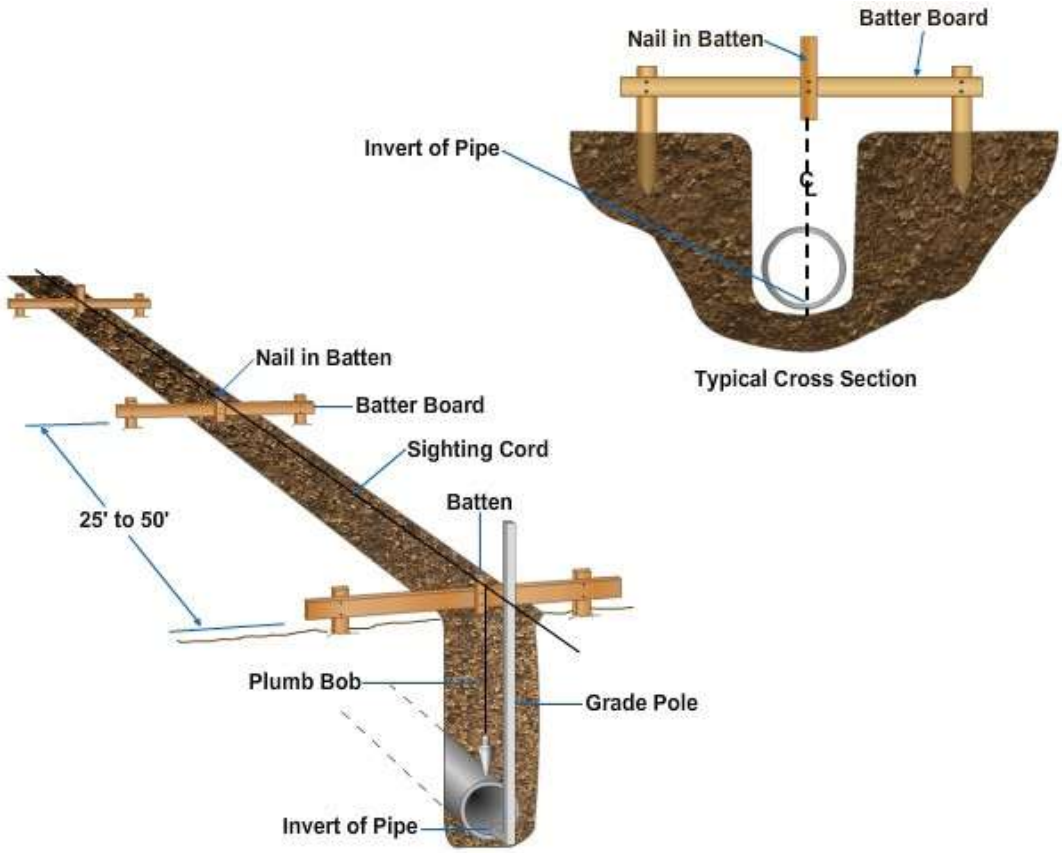

Figure 15-47 - Use of batter boards (with battens) for utility stakeout.

Figure 15-48 shows another method of staking out an underground sewer pipe without the use of battens. Nails are driven directly into the tops of the batter boards so a string stretched tightly between them defines the pipe center line. The string or cord can be kept taut by wrapping it around the nails and hanging a weight on each end. Similarly, the string (or cord) gives both line and grade.

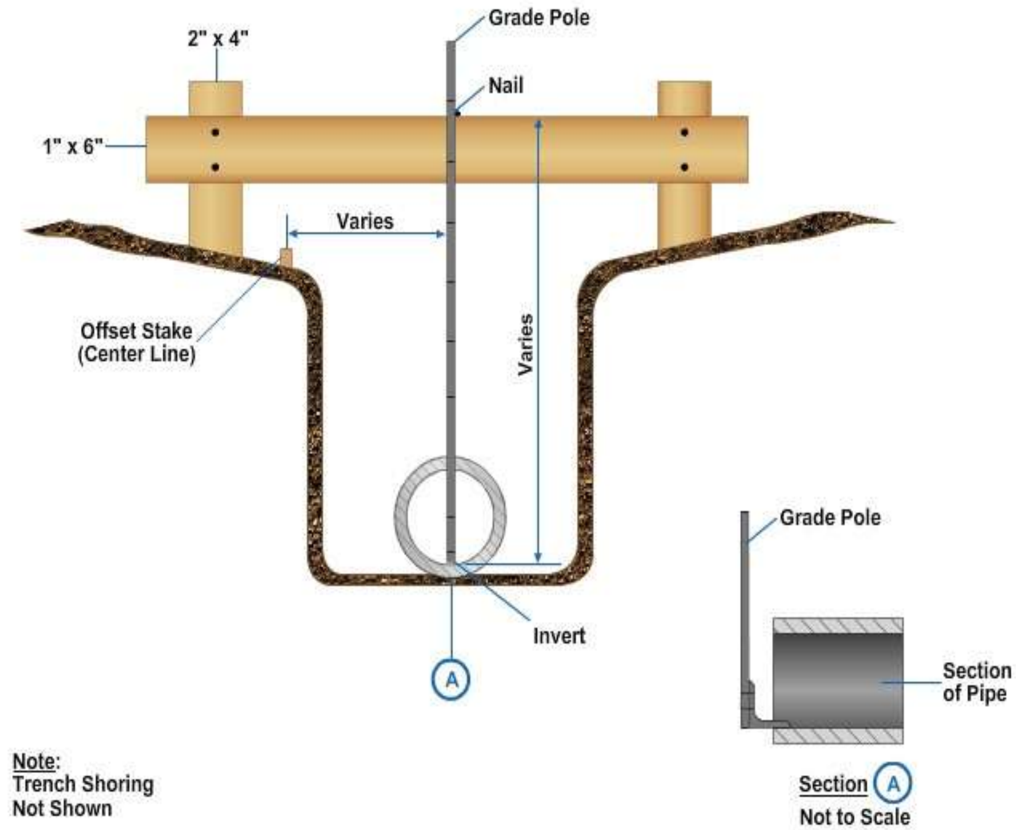

Figure 15-48 - Batter boards (without battens) for utility stakeout.

5.4.0 As-Built Survey

A finished structure seldom matches to the original plans in every detail. Unforeseeable difficulties often make variations from the plans necessary.

The purpose of an as-built survey is to record the variations. The as-built survey begins as soon as it becomes feasible. This means the actual horizontal and vertical locations of features in the completed structure should be determined as soon as the features are erected.

At times, variations from the original plans are recorded on new tracings of the working drawings. When differences are identified, the as-built data is recorded in the place of the original design data. Sometimes, reproductions of the original drawings are used with variations recorded by crossing out the original design data and writing in the as-built data.

In either case, the term "as-built survey," together with the date of revision, is written in or near the title block.

5.5.0 Construction Site Safety

WARNING

A survey party working at a construction site is always in a dangerous situation.

Where blasting or logging is going on, inform the powder crew or logging crew of the location of the area where surveyors are working. Also, instruct the individual crew members of the survey party to be alert at all times-particularly listening for the warning signal given by a crew using powder to set off a charge or a logger felling a tree.

When surveying near highways, railroads, or airstrips, use red flagging generously. Do not use flagging in a combat area, however. Place flagging on the legs of the surveying equipment and at a few places along the measuring tape. Put flags on rods and range poles. Attach flagging to hats and to the back of shirts or jackets.

Constantly think of personal safety when working near heavy construction equipment. Inform equipment operators when surveyors are in the vicinity. Alert the surveying crew that an equipment operator's vision is often obscured by dust or by the equipment itself.

Do not climb directly behind another crew member when ascending steep, rocky slopes. If the crew member were to fall, loosen a rock, or drop something, serious injury could result to the crew below.

5.5.1 Excavations

WARNING

When work involves excavation, observe precautions to prevent accidents.

To avoid slides or cave-ins, support the sides of the excavations 5 feet or more deep by substantial bracing, shoring, or sheet piling if the sides are steeper than the angle of repose. The angle of repose is the maximum angle at which material will repose without sliding. Trenches in partly saturated or otherwise highly unstable soil should be stabilized with vertical sheet piling or suitable braces. Shore, brace, or underpin foundations of structures adjacent to excavations as long as the excavation remains open. Do not allow excavated or other material to accumulate closer than 2 feet from the edge of an excavation. In a traffic area use barricades, safety signs, danger signals, red lights, or red flagging on at least two sides.

Walk at least 2 feet away from the edge of a vertical excavation. Near thoroughfares or walkways, excavations should have temporary guardrails or barricades and if permissible, depending on combat conditions, red lights or torches should be illuminated from sunset to sunrise.

Do not enter a manhole until certain it is free from dangerous gases. Do not guess. Wait for clearance from a competent authority if there is any question as to whether a sewer is free of gas. Do not smoke in manholes. If illumination is required, use a safety flashlight or lantern.

Avoid contact with all electric wiring. Never throw a metal tape across electric wires. Use breaking chain if crossing wiring is required. Avoid placing your body over wiring to reduce the likelihood of falling onto dangerous wiring.

5.5.2 5.5.2 Tree Climbing

Before climbing a tree, ensure it is safe to climb, and carefully check the condition of the branches that you might use for standing. Different kinds of wood vary greatly in strength. Oak, hickory, and elm trees are strong, flexible wood safe for climbing. Limbs of all trees become brittle at low temperature, and have a tendency to break easier in cold weather. Dead branches or those containing many knots or fungus are weaker.

When standing on a limb, place your feet as close to the parent trunk as possible. Climb with care when limbs are wet or icy. To prevent an eye injury, wear goggles when working in bushy trees.

WARNING

Before climbing a tree, be sure there are no overhead wires passing through its foliage. If you must take a position in a tree within reach of live wire, place some sort of insulating safety equipment between yourself and the wire. Do not allow tree limbs to contact live wires. Moisture in a limb may cause a short circuit.

When cutting tools are required to clear a working space in a tree, raise and lower them with a hand line. Never throw tools up into a tree or down onto the ground.

5.5.3 Overhead Lines

When a structure has an access opening and is below the street, such as a manhole or a transformer vault, it should be protected by a barrier or other suitable guard when the cover to the access opening is removed.

5.5.4 Crossing Ice

Make certain ice will support your weight before crossing. The thickness and the nature of ice are important in determining its carrying capacity.

Because part of the supporting power of ice is derived from the water below it, a layer of ice that is in contact with the water surface is safer than one that has no contact with the water surface.

An ice layer usually becomes thinner over current, near banks of streams or lakes, over warm springs, and over swampy ground. Rotten ice identifiable by its dull color and honeycomb texture has little supporting power.

Test your Knowledge (Select the Correct Response)

16. Fieldwork on the construction of a road being built on a 5-year-old naval air station would very likely begin with what type of survey?

    A. Final location
    B. Topographic
    C. Reconnaissance
    D. As-built

17. Direct air observation of an area to be reconnoitered offers what main advantage?

    A. Acquiring information about the relief of the area
    B. Providing a quick means of preparing sketches of the area
    C. Speeding subsequent ground reconnaissance of the area
    D. Providing a quick means of preparing maps of the area

18. Which of the following tasks in constructing a highway is part of the preliminary survey?

    A. Establishing final grades and alignments
    B. Computing the highway right-of-way
    C. Running the traverse
    D. Setting grade stakes

19. Which of the following details must be shown on a plan view of a proposed highway?

    A. Curve design data
    B. Gradient
    C. Spot elevations
    D. Typical cross section of the highway

20. On the cross-section paper most widely used in surveying offices, the horizontal lines are spaced how far apart?

    A. 1/20 inch
    B. 1/10 inch
    C. 1/5 inch
    D. 1/4 inch

21. The batter boards should be placed how many feet from the building lines so as not to interfere with construction?

    A. 1 to 2
    B. 2 to 3
    C. 3 to 4
    D. 4 to 5

22. Red flagging should be used on the legs of your instrument when you are surveying in the vicinity of which of the following areas?

    A. Airstrips
    B. Excavations
    C. Logging operations
    D. Blasting operations

Summary

This chapter addressed the leveling operations used to determine elevations of points or the differences in elevation between points on the earth's surface. The data gathered from leveling operations is used for engineering designs, mapping, and construction projects.

This chapter discussed the basic principles of and the methods used in direct leveling. The duties and responsibilities of the leveling crew were also addressed. Finally, the chapter included a general description of basic engineering surveys and the various construction-site hazards commonly associated with conducting a survey.

Review Questions (Select the Correct Response)

1. To be used as elevation references in the development or expansion of a permanent naval station, you should establish monument BMs in which of the following locations?

   A. On all important structures, such as buildings and piers
   B. At all road intersections
   C. In a grid system 1 mile apart
   D. In a grid system 1/2 mile apart

2. Mean sea level (MSL) differs from mean tide level (MTL) in what way?

   A. MSL is the mean of tides observed in the open sea; MTL is the mean of inland tidewater observations.
   B. MSL is the result of averaging tabulated tide readings; MTL is taken from the tidal curve.
   C. MSL is the mean of a large number of points along a tidal curve; MTL is the mean of only the high and low points along the tidal curve.
   D. MSL is the datum used primarily in hydrographic surveys; MTL is used as a datum in any type of survey.

3. The correct way to obtain the MSL value for a month's tide tabulated record is to add all daily sums for the month and to divide this total by the sum of what specific units of time in that month?

   A. Minutes
   B. Days
   C. Hours
   D. Weeks

4. Assume you are engaged in a hydrographic survey of the water approaches to Naval Air Station, Adak, Alaska. Your soundings should refer to what datum?

   A. MLLW
   B. MWL
   C. MTL
   D. MLWS

5. The proper way to remove an engineer's level from its carrying case is to grasp it firmly by what part(s)?

   A. The telescope
   B. The footplate
   C. The leveling head
   D. The wye rings

6. You are setting up an engineer's level on a concrete surface. You mount the instrument on a tripod placed inside a floor triangle. This precaution will protect the tripod from which of the following accidents?

   A. Turning
   B. Moving laterally
   C. Tipping over
   D. Collapsing

7. The whole foot numbers on a Philadelphia rod are what color?

   A. Red
   B. White
   C. Black
   D. Yellow

8. In leveling, which of the following statements best defines height of instrument (HI)?

   A. The elevation of the horizontal line of sight
   B. The vertical distance from the horizontal axis of the telescope to a point on the ground directly below the instrument
   C. The vertical distance between the reference datum and the horizontal line of sight
   D. The elevation of the reference datum minus the backsight rod reading

9. By using the technique of balancing shots, you can eliminate which of the following effect(s) in differential leveling?

   A. Instrumental error
   B. Curvature of the earth's surface
   C. Atmospheric refraction
   D. All of the above

10. In profile leveling, rod readings taken from points that are neither BMs nor TPs are entered under what heading in the field notebook?

   A. BS
   B. FS
   C. IFS
   D. Remarks

11. You are doing cross-section leveling for a highway road survey. The profile center-line elevation at station 25 + 00 is 112.5 feet and eye height is 5.3 feet. On a rod held 20 feet from the center line you read 11.2 feet. What is the elevation, in feet, at this point?

   A. 96.0
   B. 106.6
   C. 118.4
   D. 129.0

12. In third-order leveling, the starting and closing BMs must be of which of the following orders accuracy?

    A. First
    B. Second or higher
    C. Third or higher
    D. Fourth or higher

13. What is the first step in a reconnaissance survey?

    A. A field trip to the desired location
    B. A study of existing maps and aerial photographs
    C. An instrument survey of the desired location
    D. An inventory of available construction equipment

14. A field reconnaissance party follows the route previously marked on a map to verify actual conditions on the ground. Which of the following conditions, relative to an engineering study, should be noted?

    A. Soil conditions and washout areas
    B. Vegetation and obstacles
    C. Quarry sites and sand or gravel deposits
    D. All of the above

15. Your survey party is assigned the task of completing a reconnaissance survey of a 3-mile road in hilly, wooded terrain. For this survey, your party should carry which of the following equipment?

    A. Lensatic compass
    B. Brush hook
    C. Hand level
    D. All of the above

16. As the lead surveyor laying out the final location of a roadway center line, you suspect that the preliminary survey was in error regarding the exact location of the center line. Which of the following actions should you take?

    A. Lay out the center line according to the preliminary data.
    B. Lay out the center line the way you know it should be.
    C. Lay out the center line and then report the reason for making the necessary change.
    D. Report the problem and receive authorization before making the location change.

17. After the surface elevations have been plotted on the cross-section paper, the points should be connected in which of the following ways?

    A. By freehand curves
    B. By freehand straight lines
    C. By lines drawn with a straightedge
    D. Either B or C

18. In the plotting of cross sections, the vertical scale relates to the horizontal scale in which of the following manners?

    A. The vertical scale must be equal to the horizontal scale.
    B. The vertical scale must be exaggerated from the horizontal scale.
    C. The vertical scale may be equal to the horizontal scale, or it may be exaggerated for clarity.
    D. The vertical scale is usually less than the horizontal scale, but it may be equal or exaggerated for clarity.

19. During what stage of a road construction project are "blue tops" used?

    A. Rough grading
    B. Clearing and grubbing
    C. Final grading
    D. Paving

20. What term is used for the natural earth surface below the pavement of a highway?

    A. Final grade
    B. Finish grade
    C. Rough grade
    D. Sub-grade

21. In curb construction, construction crews should obtain line and grade from which of the following sources?

    A. Center-line stakes
    B. Blue tops
    C. Shoulder stakes
    D. Offset hubs

22. Pavement stakeout is primarily dependent upon which of the following factors?

    A. Type of instruments used to perform the stakeout
    B. Type of equipment used for paving
    C. Finish grade elevations
    D. Directions from the construction crew leader

23. The invert elevation of an underground sewer pipe is taken at what point on the pipe?

    A. Lowest outside surface
    B. Highest inside surface
    C. Lowest inside surface
    D. Highest outside surface

24. For any construction project, what is the optimum time for the as-built survey to begin?

    A. During the layout survey
    B. As soon as stakeout is completed
    C. Upon final project completion
    D. During construction as the individual features are completed

25. Which of the following actions should you take when you are running a tape-transit traverse that crosses electric wires?

    A. Stretch the tape above the wires.
    B. Ground one end of the tape.
    C. Break chain at the wires.
    D. Wear rubber gloves.

26. Excavations that are what minimum depth, in feet, must be suitably braced and shored to prevent cave-ins?

    A. 2
    B. 3
    C. 4
    D. 5

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.

Elementary Surveying, 6th ed, Brinker, R. C. and P. R. Wolf, Harper & Row, Publishers, NY, 1977.

Construction Surveying, FM 5-233, U.S. Department of Defense, Headquarters, Department of the Army, Washington, DC, 1985.

Topographic Surveying, FM - 34.331, U.S. Department of Defense, Headquarters, Department of the Army, Washington, DC, 2001.

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Chapter 16

Materials Testing: Soil and Concrete

Topics

To hear audio, click on the box.

Overview

Natural earth is the ultimate foundation for any road, airfield, building, or other structure. Regardless of their designated purpose, all structures are supported by one of the earth's construction materials: soil. Because soil is the ultimate foundation for any project, it may be the most important of all building materials. Just as a poorly constructed and weak concrete foundation will not support a building, neither will a poorly "constructed" and weak soil foundation support a well-constructed concrete foundation.

This chapter will offer the definition of soil, and introduce you to the different types of soil you may encounter during the wide range of projects Seabees undertake.

It will also present the basic properties and characteristics of soil and explain the importance those characteristics play in determining adequacy and classification for use as a construction material.

As an EA, you will be responsible for collecting soil samples and performing certain testing .This chapter will provide guidance on those procedures as well as explain their importance in properly and correctly identifying and classifying the many types of soil that exist in nature.

Finally, this chapter will also acquaint you with various tests for concrete and explain their purposes and importance as well. You will learn how to perform certain tests yourself and how to prepare concrete samples for other tests that will be performed by EAs that are more senior.

Whether the project is a structure with concrete or a road or revetment without concrete, soil is the foundation, and you as an EA, must gain the skills to determine its usefulness.

Objectives

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

1. Identify the different types of soil origins.
2. Identify the physical characteristics of soils.
3. Describe the different classifications of soil.
4. Describe the procedures associated with soil sampling.
5. Describe the procedures associated with soil testing.
6. Describe the procedures associated with concrete testing.

Prerequisites

None

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

Topographic Surveying and Mapping	↑	ENGINEERING AID BASIC
Indirect Leveling/Level and Traverse Computations		
Care and Adjustment of Survey Equipment		
Materials Testing: Soil and Concrete		
Direct Leveling and Basic Engineering Surveys		
Horizontal Control		
Direct Linear Measurements and Field Survey Safety		
Surveying: Elements and Equipment		
Construction Drawings		
Electrical: Systems and Plans		
Mechanical: Systems and Plans		
Concrete and Masonry		
Wood and Light Frame Structures		
Drafting: Projections and Sketching		
Drafting: Geometric Construction		
Drafting: Fundamentals and Techniques		
Drafting: Equipment		
Mathematics and Units of Measurement		
Engineering Aid Rating		

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 SOIL ORIGIN

One entry in Merriam-Webster's Online Dictionary defines soil as "the upper layer of earth that may be dug or plowed and in which plants grow." While that may be one correct definition and perfectly satisfactory to many groups of people, it does not address the precision required by civil engineers and soil technicians.

For engineering and construction purposes, a more precise definition is this one, found in Maintenance and Operation Manual 330 (MO-330) "Soil is a heterogeneous aggregation of uncemented or weakly cemented mineral grains enclosing voids of various sizes. These voids may contain air, water, organic matter, or different combinations of these materials." As you progress through this chapter, the aptness of this definition for construction will become obvious, but let us consider where soil comes from first.

1.1.1 Soil Formation

Soil formation is a continuous and evolutionary process still in action today. The Earth's crust consists of rock, which geologists classify into three groups:

- Igneous — formed by cooling from a molten state
- Sedimentary — formed by the accumulation and cementing of the particles and remains of plants and animals
- Metamorphic — formed from existing rocks that have been subjected to heat and pressure

Exposed to the atmosphere, rock undergoes a physical and chemical process called ***weathering,*** which decomposes the rock into a loose, incoherent mixture of gravel, sand, and finer material. This process over a sufficient length of time disintegrates the three rock types and produces soils of various designations.

1.2.0 Residual Soil

Residual soil is any soil that remains in place during the weathering process. A mantle of residual soil will reflect the characteristics of the underlying parent rock from which it was derived.

1.3.0 Transported Soil

Transported soil is any soil that moved to a place other than its original location during the weathering process. Transported soils often bear properties induced by its mode of transportation such as water, wind, ice, and the force of gravity.

1.3.1 Alluvial Soil

Alluvial [*uh*-**loo**-vee-*uh*l] soil is formed when a river or stream with decreasing velocity gradually loses its soil-transporting capacity. As a river's velocity diminishes, it does not have sufficient power to keep the large soil particles in suspension, and they settle to the riverbed.

Typically, over time this further decreases the river's velocity, which causes smaller particles to settle. As the river becomes slow and sluggish (as in the lowlands where the gradient becomes small), it transports only the extremely fine particles in suspension. These finite particles settle at the mouth of the river where they form deltas of fine-grained soil. Prime examples of this are the Mississippi, Nile, Ganges, and Mekong Deltas. (*Figure 16-1*)

Figure 16-1 - Example of alluvial soils transported to form deltas.

1.3.2 Marine Soil

Marine soil is also formed from materials carried into the seas by streams, but it includes material eroded from the beaches by the tidal action of the waves. This tidal and wave action carries part of the marine soil material out into deep water deposits while another part of it is heaped back upon the beaches along the coast.

1.3.3 Lacustrine Soil

Lacustrine [l*uh*-**kuhs**-trin] soils are transported soils deposited in freshwater lakes. They are typically fine-grained soils, the result of being brought into freshwater lakes by streams or rivers.

1.3.4 Aeolian Soil

Aeolian [ee-**oh**-lee-*uh*n] soils are transported by wind rather than water. The build up of heavier sand grain deposits from wind are called “dunes,” and the finer particles (generally transported farther) are deposited to form a material called loess [**loh**-es]. Dune deposits seldom contain material larger than sand size while loess is a fine-grained, unstratified accumulation of clay and silt.

1.3.5 Glacial Soil

Glacial soil (or drift) is material transported by an advancing ice sheet. It could have been pushed ahead, carried upon, or carried within the ice. As glaciers melt, deposits of various forms occur, such as these:

- Moraine [m*uh*-**reyn**] — a mass of till (boulders, pebbles, sand, and mud) deposited by a glacier, often in the form of a long ridge. Moraines typically form because of the plowing effect of a moving glacier.
- Kame [**keym**] terrace — an irregularly shaped hill or mound composed of sand, gravel and till that accumulates in a depression on a retreating glacier.
- Esker [**es**-ker] — a long, narrow, steep-sided ridge of coarse sand and gravel deposited by a stream flowing in or under a melting sheet of glacial ice.
- Outwash plane — a glacial outwash plain formed of sediments deposited by melting water at the terminus of a glacier.

1.3.6 Colluvial Soil

Colluvial [k*uh*-**loo**-vee-*ahl*] soil consists of mixed loose earth material that has accumulated at the base of a hill through the action of gravity, such as piles of talus, avalanche debris, and sheets of detritus moved by soil creep or frost action.

Test your Knowledge (Select the Correct Response)

1. What source provides a more precise definition of soil for engineering and construction purposes?

   A. Merriam-Webster's Online Dictionary
   B. American Society for Testing and Materials
   C. Maintenance and Operation Manual 330
   D. American Society of Civil Engineers

2.0.0 PHYSICAL CHARACTERISTICS OF SOILS

The physical characteristics of soils aid in determining their engineering characteristics and are the basis of any soil classification system. In North America, the most common engineering classification systems for soils are the Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO).

The Seabees, the military in general, and civilian engineering each use a system of soil classification to identify and determine the suitability of soils for both vertical and horizontal construction projects.

As an EA, your knowledge of these physical characteristics will aid in determining the degree to which local soils can be used in engineering projects to support traffic loads or to serve as a subgrade or foundation material.

2.1.0 Particle Size

The size of the particle grains in the soil mass determines how the soils are divided into groups. An EA identifies the particle grain sizes by using sieves.

A sieve is a screen attached across the end of a shallow cylindrical frame. (*Figure 16-2*) The screen permits particles smaller than the openings to fall through while retaining larger ones. When sieves of different sizes are stacked so the largest screen openings are at the top and the smallest at the bottom, soil can be separated into particle groups based on size.

Figure 16-2 – Typical sieves used for particle size identification.

The amount remaining on each sieve can then be measured and described as a percentage by weight of the entire sample.

Table 16-1 shows only four of many size groups used in the Unified Soil Classification System.

Finer particles passing the No. 200 sieve that exhibit plasticity and strength when dry are called clays; those exhibiting non-plasticity and little strength when dry are called silt.

Table 16-1 - Sample of Four Size Groups Used in the Unified Soil Classification System (USCS).

Size groups	Sieve Size	
	Passing	Retained on
Cobbles----------------	No Maximum size*---------------	3 in.
Gravels-----------------	3 in.-----------------------------------	No. 4
Sands-------------------	No. 4---------------------------------	No. 200
Fines--------------------	No. 200------------------------------	No minimum size
*In military engineering, maximum size of cobbles is accepted as 40 inches, based upon maximum jaw opening of the crushing unit.		

2.2.0 Particle Shape

The shape of the particles influences the strength and stability of a soil. Bulky and platy (*Figure 16-3*) are two general shapes recognized in the USCS and they may be located within the same geological area.

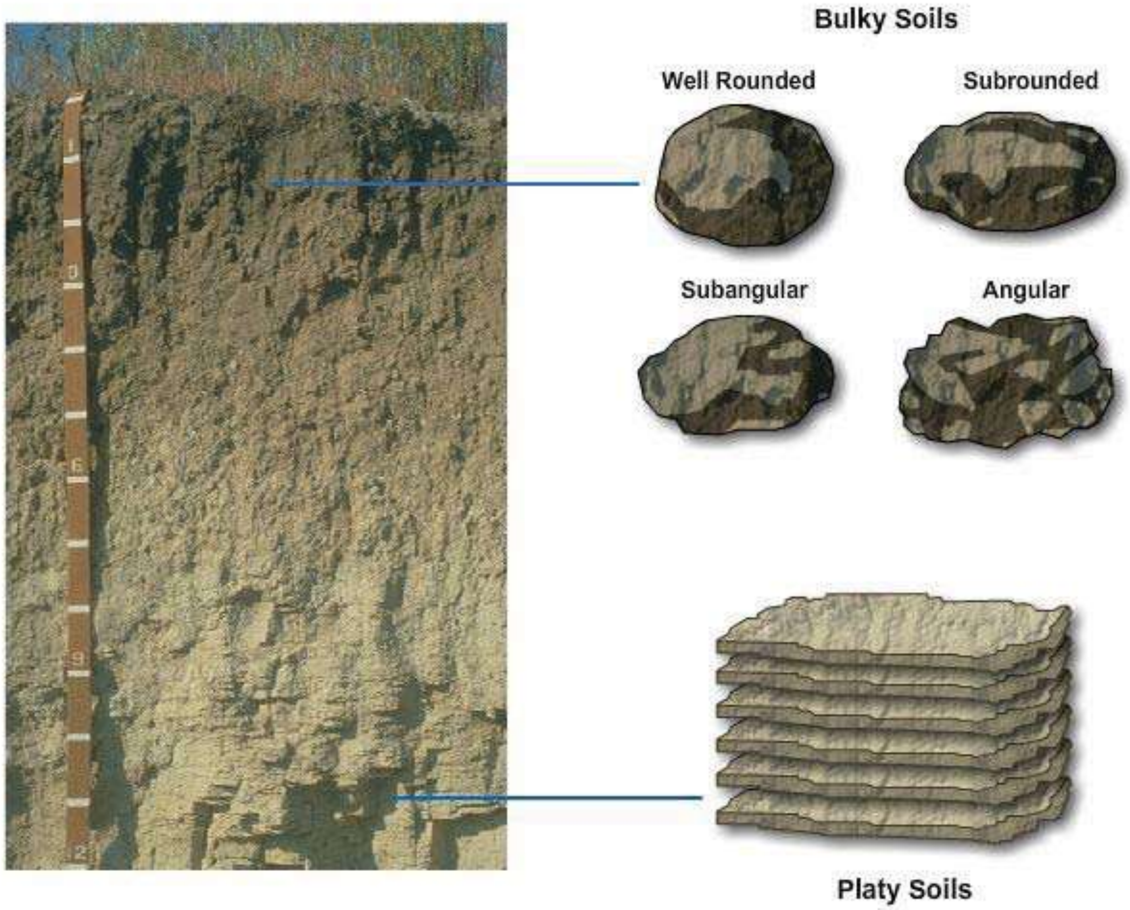


Figure 16-3 - Examples of bulky and platy particle shapes.

2.2.1 Bulky

Cobbles, gravel, sand, and silt particles cover a large range of sizes; however, they are all bulky in shape. The term “bulky” is confined to particles that are relatively large in all three dimensions, as contrasted to platy particles, in which one dimension is small as compared to the other two.

The bulky shape has the following four subdivisions listed in descending order of desirability for construction:

- Angular —recently broken up particles characterized by jagged projections, sharp ridges, and flat surfaces. Seldom found in nature because of weathering, angular gravels and sands are generally the best materials for construction because of their interlocking characteristics but must usually be produced artificially by crushing.
- Subangular — particles that have been weathered to the extent that the sharper points and ridges have been worn off.
- Subrounded — particles that have been further weathered and are still somewhat irregular in shape but have no sharp corners and few flat areas. Frequently found in streambeds, if composed of hard, durable particles, subrounded material is adequate for most construction needs.

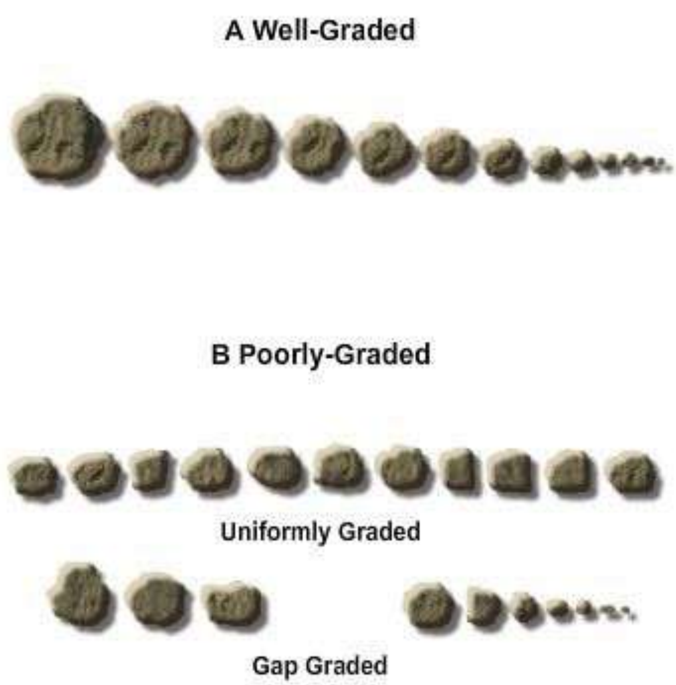
- Rounded — particles weathered to the point that all projections have been removed, with few irregularities in shape remaining. Usually found in or near streambeds or beaches, they resemble spheres of varying sizes.

2.2.2 Platy

Platy (or flaky) particles have flat, plate-like grains with two dimensions much larger than the third. Clay is a common example. Because of their shape, platy particles have a greater contact area for moisture and are undesirable for construction purposes.

2.3.0 Gradation

The sizes and shapes of soil particles deal with properties of the individual grains in a soil mass. Gradation describes the distribution of the different size groups within a soil sample. (*Figure 16-4*)



The soil may be well-graded, or poorly-graded.

Well-graded soils (*Figure 16-4, view A*) must have a good range of all representative particle sizes between the largest and the smallest. All sizes must be represented, and no one size should be either overabundant or missing.

Poorly-graded soils (*Figure 16-4, view B*) contain a narrow range of particle sizes or lack some intermediate sizes.

Figure 16-4 - Examples of well-graded and poorly-graded graduations.

Uniformly graded soils are those with a limited range of particle sizes. Soils with some intermediate sizes not well represented or missing are called gap, step, or skip graded.

2.4.0 Compactness

Compactness refers to how closely a mass of soil particles are packed together; for a given unit of volume, the closer the packing, the greater its compactness and weight.

In a dense structure with a high degree of compactness, closely packed soil particles interlock with smaller grains filling the voids between the larger particles. With each particle closely surrounded by other particles, grain-to-grain contact is increased. This lessens the tendency for individual grain displacement under load, and the soil is capable of supporting heavier loads. Usually, well-graded coarse materials are dense and exhibit strength and stability under load.

In a loose structure, the particles lack compactness and are not packed as closely together as possible. Loose, open structures have voids, which will lead to foundation settlement or to road disintegration when traffic loads are applied.

2.5.0 Specific Gravity

Specific gravity, designated by the symbol G_s is defined as the ratio between the weight per unit volume of a material and the weight per unit volume of water at a stated temperature—usually 20°C. Using the system international (SI) (metric) system, you can determine specific gravity by the following formula:

$$\text{Specific gravity } G_s \quad \frac{weight\ of\ sample\ in\ air\ (g)}{weight\ of\ sample\ in\ air\ (g)\quad weight\ of\ sample\ submerged\ (g)}$$

Specific gravity varies between 2.60 and 2.80 for most inorganic soils. While tropical, iron-rich ***laterite*** [**lat**-*uh*-rahyt], as well as some other lateritic soils, can have a specific gravity of 3.0 or more, sand particles (composed of quartz) have a specific gravity of about 2.65 and clays can have values as high as 3.50.

The solids of soil particles are composed of minerals with a specific gravity greater than 2.60. Any specific gravity values smaller than that are an indication of the possible presence of organic matter.

2.6.0 Soil Moisture

A soil's moisture content is often the most important factor affecting its engineering characteristics. Water may enter from the surface or move through the subsurface layers by gravitational pull, capillary action, or absorption. Moisture to some degree is present in most cases and it influences the various soils differently. Moisture probably has the greatest effect upon soil behavior when the soil is subjected to loading.

2.6.1 Sources of Water in Soils

Soil moisture may come from surface or subsurface water, gravity, capillary action, or absorption.

- Surface water — from precipitation or runoff, which enters the soil through openings between particles. It may adhere to the particles or penetrate the soil to some lower layer.
- Subsurface water — collected or held in pools or layers beneath the surface by a restricting layer of soil or rock and constantly acted upon by one or more external forces.
- Gravity-controlled water — seeks a lower layer and moves through the voids or spaces until it reaches some restriction such as bedrock or an impervious layer of soil with openings or voids are so small it prevents water passage.
- Capillary moisture — voids or spaces form continuous tunnels or tubes causing the water to rise in the tubes by capillary action; the smaller the tube, the stronger the capillary action. Water rises higher in finer soils which have smaller interconnected voids. The area of moisture above a free water layer or pool is called the capillary fringe.
- Atmosphere absorption moisture — moisture evaporates from the soil surface, which draws more moisture from the soil below that also evaporates. This process continues until the soil is in an air-dry condition (the moisture in the soil

is in equilibrium with the moisture vapor in the air). In an air-dry state, the moisture in the soil is in the form of thin films of water surrounding individual soil particles. This is called hydroscopic moisture. Hydroscopic moisture is the result of naturally occurring electrical forces binding the water molecules to the soil particles. This moisture may be removed from air-dried soil by heating the material in an oven at a controlled temperature for 24 hours or until attaining a constant weight.

The term "moisture content" (symbol W) is used to define the amount of water present in a soil sample. It is the ratio of the weight of water to the weight of the solid mineral grains (weight of dry soil) expressed as a percentage.

Moisture content $W \quad \dfrac{weight\,of\,water}{weight\,of\,dry\,soil}\,x\,100$

When a wet soil is air-dried in the laboratory without the use of controlled heating, the amount of hydroscopic moisture remaining in the air-dried soil is called the hydroscopic moisture content, also expressed as a percentage of the weight of the dry soil.

2.6.2 Plasticity

Plasticity is a property of the fine-grained portion of a soil that allows it to be deformed beyond the point of recovery without cracking or changing volume appreciably. Some minerals (quartz powder for example) cannot be made plastic no matter how fine the particles or how much water is added.

On the other hand, all clay minerals are plastic and can be rolled into thin threads at certain moisture contents without crumbling. Since practically all fine-grained soils contain some clay, most of them are plastic and the degree of plasticity is a general index to the clay content of a soil.

"Fat" and "lean" are terms sometimes used to distinguish between highly plastic and slightly plastic soils. For example, fat clay is highly plastic while lean clay is only slightly plastic.

Plasticity is determined by observing the different physical states that a plastic soil passes through as moisture conditions change. The boundaries between the different states (described by the moisture content at the time of change) are called consistency limits or ***Atterberg*** limits.

The liquid limit (LL) is the moisture content corresponding to the arbitrary limit between the liquid and plastic state of a soil. Above this value, the soil is presumed to be a liquid and behaves as such by flowing freely under its own weight. Below this value, provided the soil exhibits a plastic state, it deforms under pressure without crumbling.

The plastic limit (PL) is the moisture content corresponding to the arbitrary limit between the plastic and semisolid state. Above this value, the soil is no longer pliable and crumbles under pressure.

The plasticity index (PI) is the numerical difference in moisture content between the two limits, or the plastic range. It defines the range of moisture content within which the soil is in a plastic state. The equation is $PI \quad LL \quad PL$.

The shrinkage limit (SL) is the water content boundary where further loss of moisture will not result in any more volume reduction. Beyond this point, further drying does not reduce the volume but may cause cracking.

2.6.3 Effects of Soil Moisture

Moisture affects coarse-grained soils much less than fine-grained soils. Coarser soils have larger void openings, which drain more rapidly, and capillary action is practically nonexistent in gravels and sands containing few fines. If coarse soils are above the groundwater table, they will not retain large amounts of water.

Also, since the particles in gravelly and sandy soils are relatively large (compared to clay and silt particles), they are heavy in comparison to the films of moisture that might surround them.

On the other hand, moisture in the voids of fine-grained soil has considerable effect on the light, small, sometimes microscopic, particles. Clays often undergo large volume changes with variations in moisture content, as the shrinkage cracks in a dry lakebed can demonstrate. Consequently, unpaved clay roads that may be solid enough when sun-baked will often lose stability and turn into slick mud during rainy weather. (*Figure 16-5*)

Figure 16-5 - Examples of clay road under dry and wet conditions.

Besides swelling and losing stability when wet, clays retard water drainage due to their flat, platy shapes and small size. Since drainage is of the greatest importance, especially in horizontal construction such as airfield pavement for example, design engineers must know if subsurface clay exists at the project site. As addressed earlier, plasticity is the characteristic by which you can identify clay in the project's soil particles.

2.7.0 Organic Soils

Organic soils contain mineral grains but with a conspicuous admixture of vegetable matter. Soils of organic origin are formed by the growth and subsequent decay of plant life, by an accumulation of inorganic particles such as skeletons or shells of organisms, or by a combination of both. An organic soil may be organic silt, organic clay, or it may be a highly organic soil, such as peat or meadow mat with little silt or clay particles.

Organic soils are most often black in color, and usually have a characteristic musty odor. Organic soils are usually easily compressible with poor load-bearing properties.

2.8.1 Effects of Soil Characteristics

Soil characteristics are a definitive measure of the soil's suitability to serve some intended construction purpose. An understanding of these characteristics is essential for determining the first step in preparing the earth's foundation for a structure's foundation, or the subgrade for road or other horizontal project.

1. Dense, solid soil withstands greater applied loads (has greater load-bearing capacity) than loose soil.
2. Particle size has a definite relation to load-bearing capacity. Coarse-grained soils can be compacted to a greater density than fine-grained soils because the smaller particles tend to fill the spaces between the larger ones.
3. The shape of the grains affects the bearing capacity. Angular particles tend to interlock, form a denser mass, and become more stable than rounded particles, which can roll or slide past one another.
4. Well-graded soils with a good range of particle sizes minimize voids. Poorly-graded soils, with their lack of one or more sizes, leave more or greater voids and comprise a less dense mass.
5. Moisture content and consistency limits aid in describing the suitability of a soil. Typically, coarse-grained sandy or gravelly soil has good drainage characteristics for use in its natural state. Fine-grained clayey soil with a high plasticity index may require considerable treatment, especially if used in a moist location.

Test your Knowledge (Select the Correct Response)

2. What initially determines how soils are divided into groups?

   A. Gradation of the soil particles
   B. Moisture of the soil particles
   C. Shape of the soil particles
   D. Size of the particle grains in the soil mass

3.0.0 SOIL CLASSIFICATION

Soil type is an important factor when selecting the proper location on which to construct any structure or facility, or when determining any necessary soil import amendment to a predetermined location.

With the existing soil accurately identified and described, its suitability as foundation material or for supporting traffic as a subgrade base can be determined, or it can be evaluated for use as an aggregate, filler, or binder for an engineered compaction mixture.

3.1.0 Classifying Soils

The Unified Soil Classification System (USCS) is a common soil classification and reference system that has a universal interpretation. In this system, all soils are divided into three major divisions.

3.1.1 Coarse-Grained Soils

Coarse-grained soils have a soil mass where at least half of the material, by weight, is larger than (retained on) a No. 200 sieve. (*Table 16-2*) This division is further divided as gravels and sands. If more than half of the coarse fraction, by weight, is retained on a

No. 4 sieve, it is classified as a gravel. If less than half is retained on a No. 4 sieve, then it is a sand. Gravels and sands are further subdivided into additional categories dependent upon the amount and characteristics of any plastic fines the soil sample contains.

Table 16-2 - USCS Classification for Coarse-Grained Soils.

Coarse grained soils At least 50% retained on No.200 (0.075 mm) sieve	Gravel > 50% of coarse fraction retained on No.4 (4.75 mm) sieve	clean gravel <5% smaller than #200 Sieve
		gravel with >12% fines
	Sand < 50% of coarse fraction retained No.4 (4.75 mm) sieve	clean sand
		sand with >12% fines

3.1.2 Fine-Grained Soils

Fine-grained soils have a soil mass where more than half of the material, by weight, is smaller than (passes) a No. 200 sieve. (*Table 16-3*) The fine-grained soils are not classified by grain size distribution but according to plasticity and compressibility.

Table 16-3 - USCS Classification for Fine-Grained Soils.

Fine grained soils More than 50% passes No.200 (0.075 mm) sieve	silt and clay liquid limit < 50	inorganic
		organic
	silt and clay liquid limit ;: 50	inorganic
		organic

3.1.3 Highly Organic Soils

Highly organic soils, such as peat, have too many undesirable characteristics for consideration as foundations or use as construction material. The USCS has reserved a special classification for these soils but without any further laboratory criteria.

These soils are usually readily identifiable in the field by their distinctive color, odor, spongy feel, and frequently fibrous textures from their common components: decomposed or decomposing leaves, grass, branches, or other fibrous vegetable matter.

3.2.0 Classification Tests

These three basic classifications, or divisions, are not the complete description of the USCS or the methods used to classify soils. There are further and more detailed descriptors of soils within the Unified Soil Classification System and in the American Society for Testing and Materials (ASTM) International ASTM D2487 - 06e1, and ASTM D2488. However, as an EA, you will be performing some of the basic tests (sieve analysis and Atterberg limits) and you need to understand why you are performing the tests and how the results are used. You must also know the importance of ensuring that your test results are correct and reliable. Additional soil testing information is available in EA Advanced, NAVFAC MO-330, *Materials Testing,* or one of numerous commercial publications on soil mechanics.

Test your Knowledge (Select the Correct Response)

3. **(True or False)** Existing project site soil may be identified for its construction suitability or for use as an engineered compaction mixture.

   A. True
   B. False

4.1.1 SOIL SAMPLING

In construction, for both the planning and building phases, it is vital to have as much engineering information as possible about the subsurface conditions at the site area.

That information includes:

- Location, extent, and condition of the soil layers
- Elevation of the groundwater table and bedrock
- Drainage characteristics of the surface and subsurface soils
- Location of possible borrow areas from which soil and other mineral-product materials may be “borrowed” for a construction operation

This information is gathered through soil survey exploration of the proposed area.

These multifaceted surveys consist of:

- Collecting soil samples
- Soil testing by laboratory or field procedures, or both
- Soil classification
- Development of soil profiles

In the full scope of soil surveying, your primary concern, as an EA, is gathering soil samples and conducting certain of the laboratory soils tests.

4.1.1 Sampling Methods

Collecting soil samples in the field for testing is called soil sampling.

There are three principal methods of soil sampling. They include taking samples from:

1. the surface
2. already existing excavations
3. test pits and test holes

Depending on the project’s scope, expediency, and permanency, available time for soil sampling will determine which method is used and the extent to which sampling is done.

Soil sampling from test pits provides the most satisfactory results for studying the natural soil conditions as well as collecting undisturbed soil samples.

A test pit is an open excavation large enough for a person to enter. (*Figure 16-6*) Usually dug by hand, digging can be expedited by power equipment (clamshell, dragline, bulldozer, backhoe, power-driven auger) when available.

Excavations below the groundwater table require using caissons or lowering the water table.

Excavations to 5 feet or more may require shoring and bracing to prevent cave-ins.

Load-bearing tests can also be performed on the soil in the bottom of the pit.

Figure 16-6 – Example of a soil sampling test pit.

The most common method of test hole exploration is by hand auger. (*Figure 16-7*) Best suited to cohesive soils, it can also be used on less cohesive soils above the water table providing the individual aggregate diameter is smaller than the auger's bit clearance.

Usually used for work at shallow depths, with pipe extensions a powered earth auger may be used to a depth of about 30 feet in relatively soft soils.

These samples are completely disturbed but satisfactory for determining soil profile, classification, moisture content, compaction capabilities, and similar soil properties.

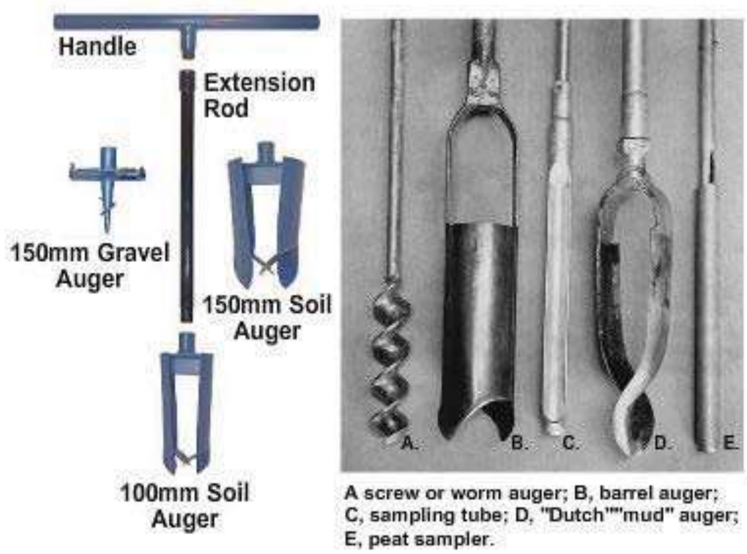


Figure 16-7 – Examples of hand augers for test hole soil sampling.

In a hasty soil survey, under expedient conditions or limited time, the number of test pits and test holes is kept to a minimum by using existing excavations for soil sampling.

In a deliberate survey, where time and conditions allow a more thorough soil sampling operation, test holes are used extensively and augmented by test pits, governed by the judgment of the engineering officer.

Table 16-4 shows various methods of soil exploration and sampling in a condensed form.

Table 16-4 - Methods of Soil Exploration and Sampling.

Common name of method	Materials in which used	Method of advancing the hole	Method of sampling	Value for foundation purposes
Auger boring	Cohesive soils and less cohesive soils above groundwater elevation	Augers rotated until filled with soil and then removed to surface	Samples recovered from material brought up in augers	Satisfactory for highway exploration at shallow depths
Well drilling	All soils, rock, and boulders	Churn drilling with power machine	Bailed sample of churned material or clay socket	Clay socket samples are dry samples. Bailed samples are valueless.
Rotary drilling	All soils, rock, and boulders	Rotating bits operating in a heavy circulating liquid	Samples recovered from circulating liquid	Samples are of no value.
Test pits	All soils. Lowering of groundwater may be necessary.	Hand digging or power excavation	Samples taken by hand from original position in ground	Materials can be inspected in natural condition and place.

4.2.1 Tagging Samples

For gathering information and compiling an accurate interpretation of the collected soil data, you must label your soil samples correctly and systematically. Review the following scenario for soil in a given area that is to be tested (such as a proposed structure's site).

The officer in charge of soil exploration decides how many soil sampling points are needed and where they must be located to produce a representative test of the soil in the area. This information is recorded in a sketch like the one shown in *Figure 16-8*. Refer to this figure often to follow the scenario.

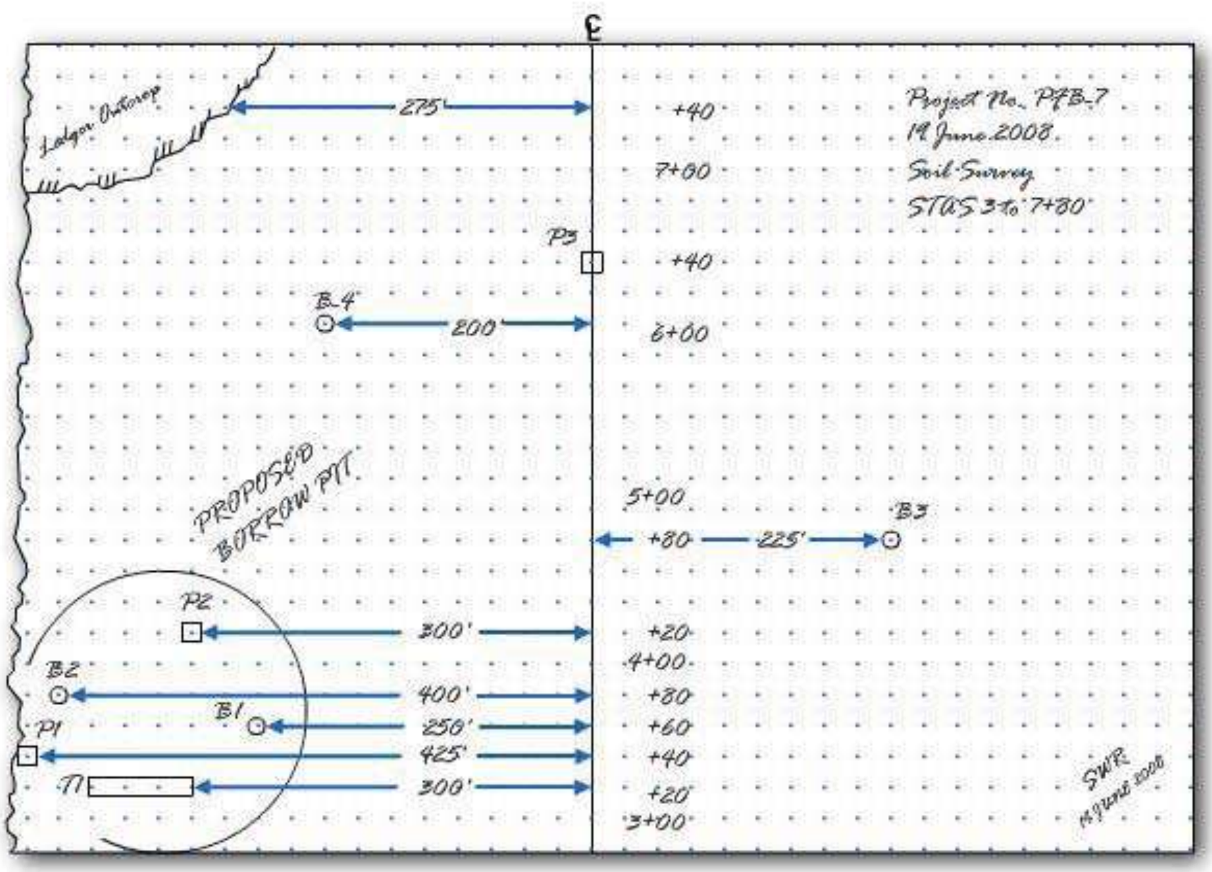


Figure 16-8 - Example of a sketch identifying soil sampling points.

This sketch shows the locations of the designated exploratory points along a highway's centerline with the point locations referenced by the centerline stations and the distances from the centerline.

Left of the centerline, between stations 2 + 80 and 4 + 60, there is a proposed borrow pit from which soil will be taken for fill.

Five samples are taken from there.

- Trench T1, a 75-foot trench located at station 3 + 20, 300 feet left of the highway centerline
- Pit P1, a 20-foot-square pit at station 3 + 40, 425 feet left of the centerline
- Boring B1 at station 3 + 60, 250 feet left of the centerline
- Boring B2 at station 3 + 80, 400 feet left of the centerline
- Pit P2, a 20-foot-square pit at station 4 + 20, 300 feet left of the centerline

In addition to the borrow pit exploration, the officer in charge of the soil exploration designated other locations.

- Boring B3 at station 4 + 80, 225 feet to the right of the centerline
- Boring B4 at station 6 + 00, 200 feet to the left of the centerline
- Pit P3, a 20-foot-square pit at station 6 + 40 on the centerline

Each sample is tagged according to the location from which it was taken and the locations are given in consecutive numbers.

For the scenario in *Figure 16-8*, the numbers might run from the bottom up, with T1 being No. 1; P 1 as No. 2; B1 as No. 3; and so on. A sample is tagged with the project symbol (in this case PFB 7) and the location symbol such as T1, P2, or B4, for example.

If more than one sample is taken from the same location, you need to use additional numbers. For example, a sample taken from B2 may be tagged ‘‘PFB 7-B2-4, bag 1 of 6.” This means the soil sample came from Boring pit No. 2, at location No. 4, as the first of six bags.

The sample’s identification should be printed on two tags with a marking pencil or pen, one placed inside the bag, the other tied on the outside. Gummed labels may be similarly used to identify samples placed in moisture content boxes, cylinders, or jars.

4.3.0 Disturbed Samples

Disturbed samples are those taken by hand scoops, auger borings, shovels, or any other convenient hand tool but with no attempt to obtain or maintain the material in its natural state of structure or density.

Figure 16-9 — California Bearing Ratio (CBR) test equipment.

These samples can be used for mechanical analysis, plasticity, specific gravity, frost susceptibility, compaction, and laboratory compacted ***California Bearing Ratio (CBR)*** tests. (*Figure 16-9*) The size of the sample taken will depend upon the tests to be performed.

4.3.1 Individual Samples

When taking individual samples from a pit, trench, or exposed face, first shave off any loose and dried soil to obtain a fresh surface and clearly expose any soil variations. (*Figure 16-10*)

Then take a typical sample of each type of soil or any soil requiring additional investigation while being sure to label the sample number by layer.

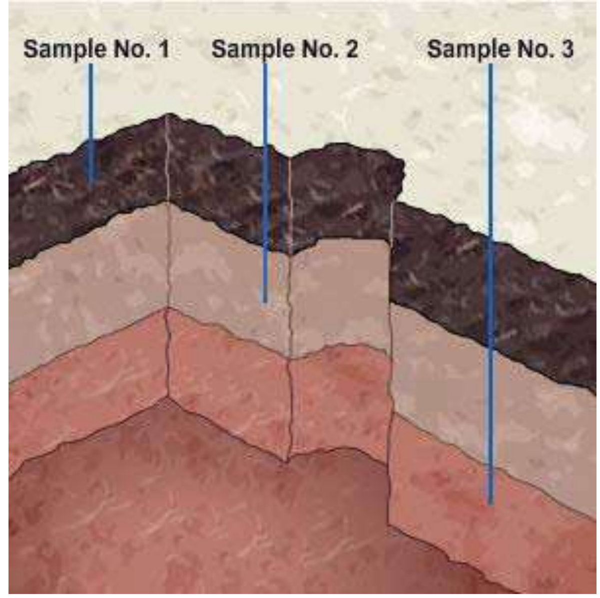


Figure 16-10 — Example of collecting soil samples from an exposed face.

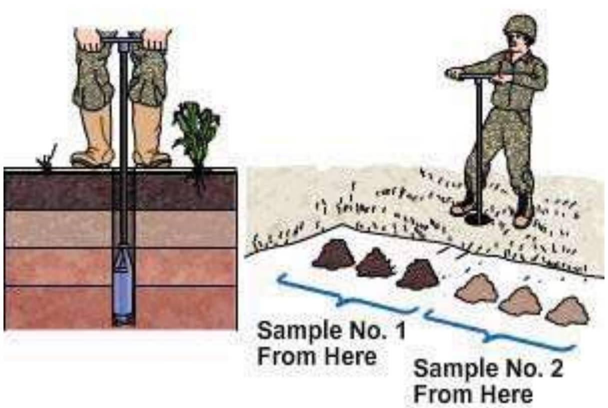


Figure 16-11 — Example of collecting individual soil samples with a hand auger.

When taking individual samples from hand auger holes, place typical portions of the collected soil along a row in the correct order according to depth and retrieval, as shown in *Figure 16-11*.

4.3.2 Composite Samples

A composite sample is a representative mixture of all soil within:

- A soil mass to be investigated
- An existing stockpiled material
- A windrow of soil excavated from a trench

A test sample is taken in the laboratory from a composite sample by quartering, which will be explained later in this chapter.

To take composite samples from test pits, trenches, or power shovel cuts, take the following steps:

1. Remove any overburden or surface soil intended for waste.
2. Shave off any loose and dried soil to obtain a fresh surface for taking the sample.
3. Excavate a channel of uniform cross section from top to bottom, depositing the soil onto a quartering cloth, canvas, or tarpaulin, as shown in *Figure 16-12.*

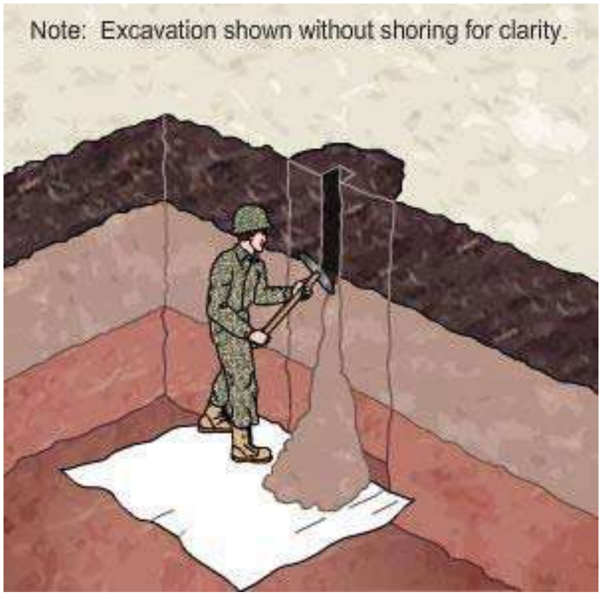


Figure 16-12 – Example of taking a composite soil sample from an exposed face.

Collect and bag all the removed material to ensure that the sample contains the correct cross sectional proportions.

To take composite samples from auger holes, remove the overburden and then collect all the material excavated from the hole without bothering to “place typical portions of the collected soil along a row” as done for individual soil sampling.

To take composite samples from stockpiles or windrows, take particular care.

When excavated material is placed in piles or rows, the coarse material tends to roll to the bottom, leaving the finer material on the top.

To compensate for this in a stockpile, after clearing the surface, take the sample from a full height strip.

To collect a sample from a small windrow, excavate and bag material from a short section, as shown in *Figure 16-13*.

Figure 16-13 – Example of taking a composite soil sample from a windrow.

4.3.3 Moisture Content Samples

To draw a complete soil profile and accurately ascertain the physical properties of soils obtained from test borings or pits, planners need to know the natural moisture content of the soil samples.

The natural moisture content is determined from samples taken in the field and placed in a container, which is then sealed to prevent loss of moisture by evaporation.

Generally, 100 grams of soil are enough to determine the moisture content of fine-grained soils, but soils containing gravel require larger samples.

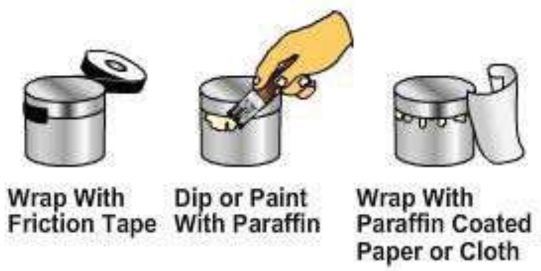


Figure 16-14 – Example of sealing a sample container to retain moisture content.

Normally, moisture content samples are placed in metal dishes (canisters) with tight-fitting covers. However, any clean, sealable container may be used.

If the moisture content test will be performed within 1 day of the sample collection, sealing the container is not required.

If a longer interval will elapse between sampling and testing, the containers should be sealed. (*Figure 16-14*)

4.4.1 Undisturbed Samples

Soil samples that are cut, removed, and packed with the least possible disturbance are termed “undisturbed samples.” (*Figure 16-15*)

As carefully as possible, these samples are taken in their natural structures with layers, void ratio, and moisture content preserved.

Figure 16-15 - Example of undisturbed soil sample with surface layer.

Undisturbed samples are used for determining the in-place density (unit weight) and investigating the strength by the CBR (or unconfined compression) tests in the laboratory. These samples may be shipped to more completely equipped laboratories for shear, consolidation, or other strength tests.

An undisturbed sample can be taken as a:

- chunk sample — cut by hand with a shovel and knife
- cylinder sample — obtained by a CBR mold equipped with a sampling cutter, or by using a cylindrical sampler in an alternate expedient method

The method chosen will depend on the available equipment, the tests required, and the type of soil being sampled. Frequently it will require a great deal of ingenuity in adapting the sampling devices and their usage to the job conditions.

Cohesionless samples must be kept in the sample container (cylinder method whenever possible) and handled without jarring or vibration until ready for testing. However, some soils are too hard or contain too many stones to permit cylinder sampling and can be taken only by cutting out chunk samples by hand.

Whatever method is used, all undisturbed samples must be handled with care. The sample must be packed in the container for shipment without allowing its structure to change, including its moisture content during sampling and shipment

4.4.1 Chunk Samples

The chunk sample is the simplest type of undisturbed sample. However, chunk samples can be obtained only from soils that will not deform, break, or crumble while being removed. *Figure 16-16* shows the process of taking a chunk sample from a level surface, such as a subgrade or the bottom of a test pit.

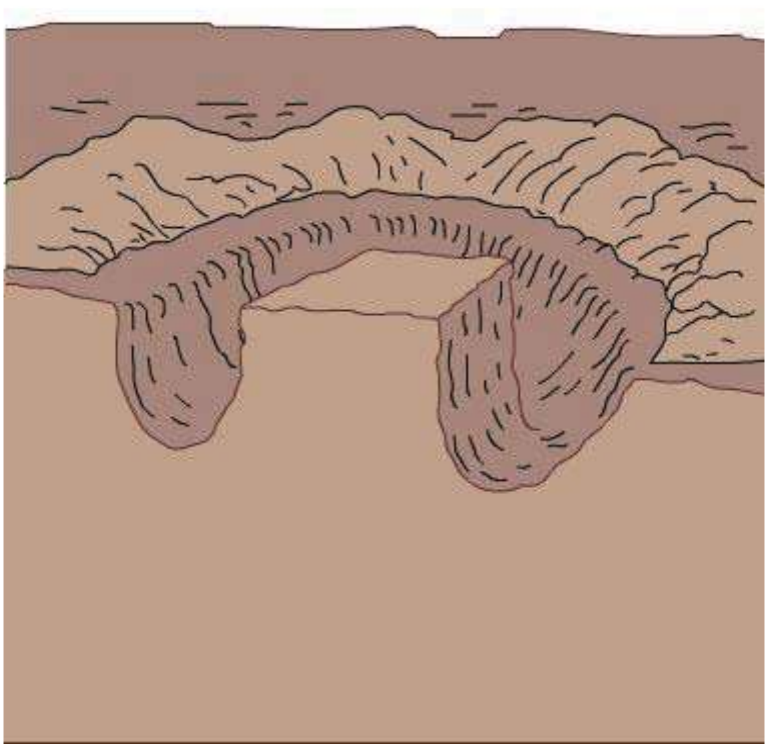


Figure 16-16 – Example of taking a chunk sample from a level surface.

After smoothing the ground surface and marking the outline of the chunk, the first step is to excavate a trench around the chunk.

Then deepen the excavation and trim the sides of the chunk with a knife.

Finally, using a knife, trowel, or hacksaw blade, cut off the chunk at the bottom and carefully remove it from the hole.

When taking a chunk sample from the vertical face of a test pit or trench, the process is similar except for the extra work effort and care needed to remove the soil from behind the intended sample. (*Figure 16-17*)

Smooth the surface of the face and mark the chunk outline.

Excavate the soil from the top, sides, and back of the chunk.

Shape the chunk with a knife

Cut it off and carefully remove it.

Figure 16-17 – Example of taking a chunk sample from a vertical surface.

After removing a chunk sample from a hole or wall, you need to seal it.

Figure 16-18 - Example of applying paraffin layers in coats.

One method is to apply three coats of melted paraffin. (*Figure 16-18*)

Allow each coat to cool and become firm before applying the next coat.

This gives adequate protection for strong samples that will be used within a few days.

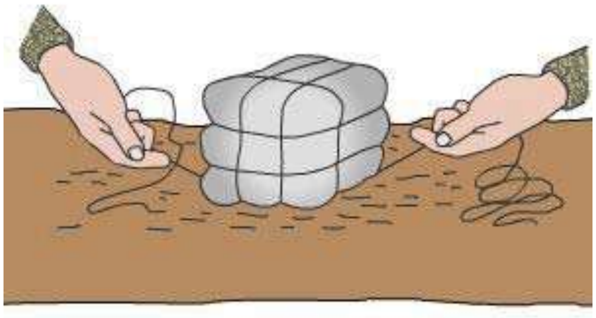


Figure 16-19 – Example of applying additional cloth and twine protection.

For chunk samples that are weak, or may not be used within a few days, additional protection is required.

Wrap them with cheesecloth or other soft cloth, and then seal them with paraffin. (*Figure 16-19*)

If no cloth is available, reinforce the sample with several loops of friction tape or twine, taking extra precautions in this operation so the sample is not damaged.

Then apply three additional coats of paraffin.

After wrapping the sample and applying the first brush coat, as an alternative to applying the three additional coats of paraffin, you can dip the entire sample in melted paraffin. (*Figure 16-20*)

Of course, this requires a larger container and more paraffin, but this method also provides a more uniform coating that can be built up to 1/8 inch or more in thickness by repeatedly dipping the sample.

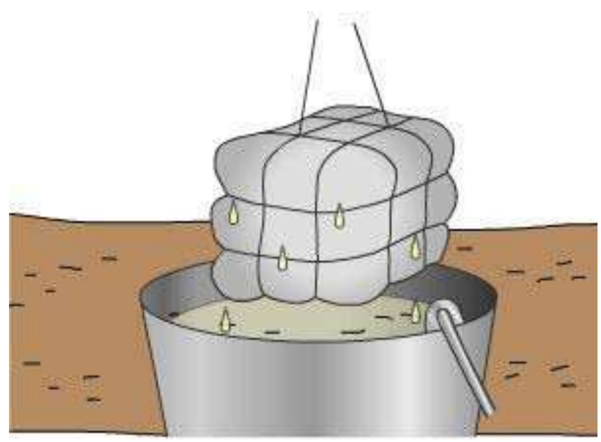


Figure 16-20 – Example of applying layers of paraffin protection by dipping.

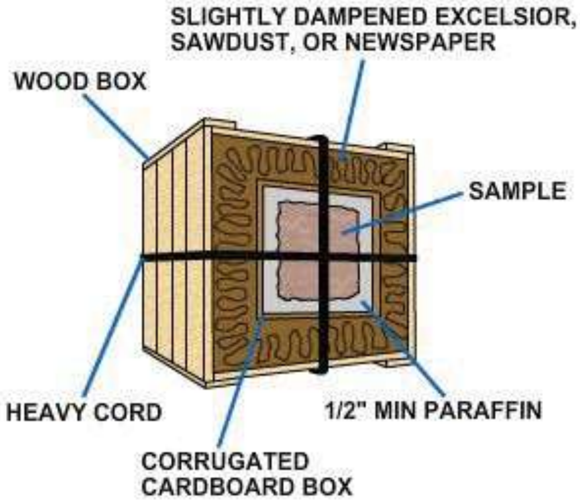


Figure 16-21 – Example of packaging a chunk sample for shipment to a laboratory.

For shipping a chunk sample to a laboratory, for example from a battalion's remote detail site to the main body site, still further protection is required.

This can be accomplished by applying multiple layers and coats of cloth and paraffin or by packing the paraffin-thickened chunk sample in a cardboard box with excelsior or sawdust and shipping it in a wooden box. (*Figure 16-21*)

4.4.2 Cylinder Samples by CBR Mold

To collect undisturbed samples for CBR or density tests, the cylinder method may be used for samples from soft, fine-grained soils. A CBR compaction mold is fitted with an extension collar, a sampling collar, and a cutting edge. (*Figure 16-22*)

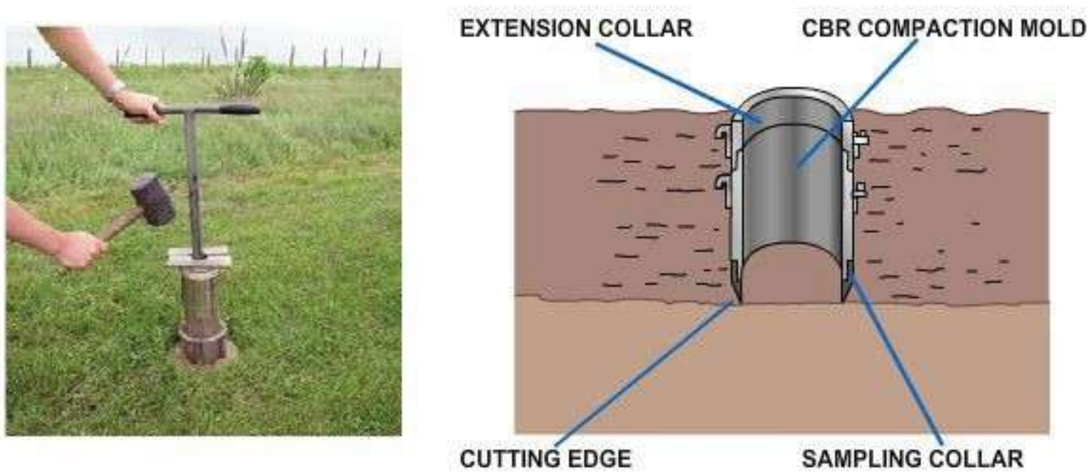


Figure 16-22 - Example of a cylinder CBR compaction mold.

Figure 16-23 demonstrates how to obtain a cylinder sample by using the CBR mold.

- Smooth the ground surface, and press the sampling collar and mold into the soil with moderate pressure.
- Excavate a trench around the cylinder and press the mold down over the soil again using a hand driver or loading bar if necessary. (Improvise a loading bar from any suitably sized piece of timber.)
- Carefully trim the soil away from the sampling collar with a knife, cutting downward and outward to avoid cutting into the sample. The sampling collar does the actual cutting to size. You can use the field CBR jack to force the sampler down, but it has only about 2 inches of travel, so if available, you would do better to use a truck jack. In either case, do not force the sampler down ahead of the trimming on the outside of the cylinder.
- Excavate the trench deeper and repeat the process until the soil penetrates well into the extension collar.
- Cut off the sample at the bottom of the mold with a shovel, knife, or wire, and remove the mold and sample from the hole.

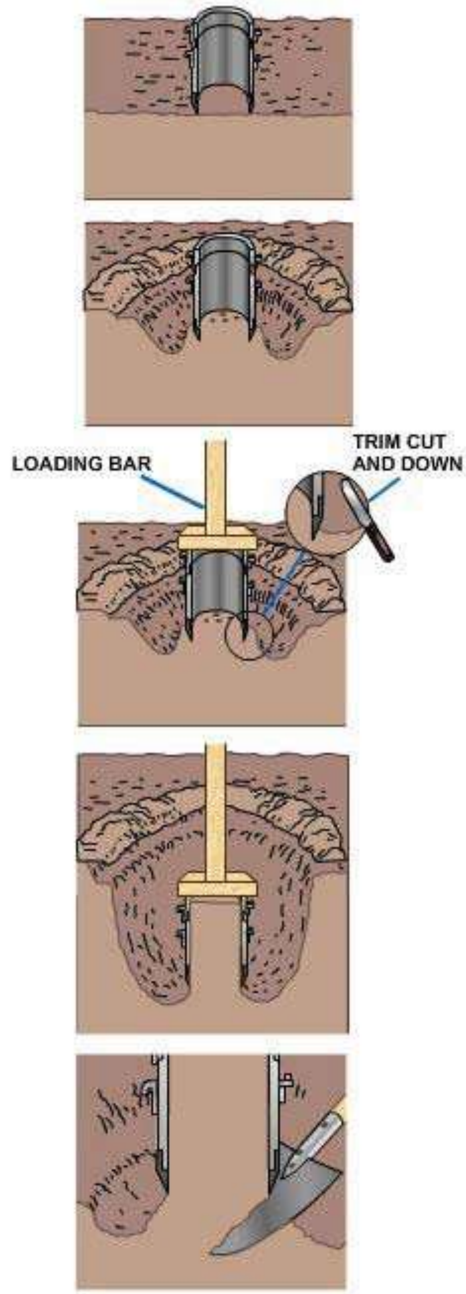
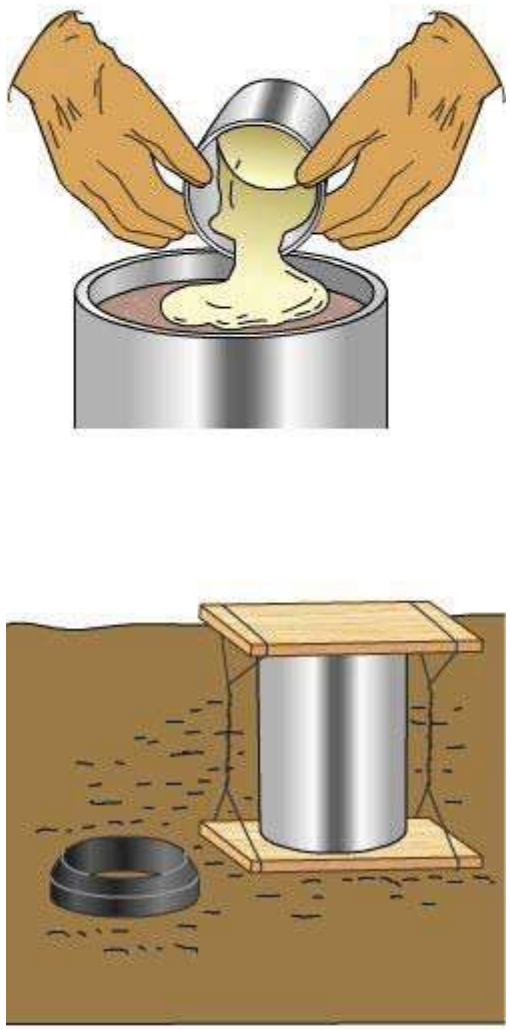


Figure 16-23 - Example of collecting an undisturbed cylinder sample by CBR compaction mold.

Undisturbed samples taken by cylinder method need to be protected similar to the chunk samples. (*Figure 16-24*)



- Remove the mold and sample from the hole.
- Remove the upper collar of the mold and trim the top surface of the sample down to approximately 1/2 inch from the top of the mold.
- Fill this recess with paraffin to seal the end of the sample.
- Turn the mold over and remove the cutting edge, creating a similar recess in the bottom of the sample.
- Fill this recess with paraffin. If the sample is to be handled a great deal, you should overfill the ends with paraffin and trim them exactly flush using a straightedge.
- Place boards over both ends and clamp in place, using bolts, string, or wire.

If the samples are to be transported some distance or handled quite a bit before testing, wrap the cylinders in cloth and soak them in paraffin layers.

Figure 16-24 – Example of sealing and protecting a CBR cylinder mold.

4.5.0 Quartering Samples

Quartering is the process of ensuring a soil sample's representation while reducing it to a convenient size or dividing it into two or more smaller samples for testing. The objectives are the same, but the procedures vary somewhat, depending upon the size of the sample.

4.5.1 Samples Weighing Over 100 Pounds

To quarter a sample of over 100 pounds, using a shovel, pile and thoroughly mix the sample on a canvas. (*Figure 16-25*)

- Place each new shovelful on the top-center of the preceding one so that the soil will be distributed evenly in all directions.
- Flatten the sample into a circular layer of approximately uniform thickness.
- Insert a stick or length of pipe under the canvas and then lift it at both ends to divide the sample into two equal parts.
- Remove the stick, leaving a fold in the canvas, and then reinsert it under the sample at right angles to the first division.
- Lift the stick again dividing the sample into four parts.
- Discard two diagonally opposite quarters taking care to clean the fines from the canvas.
- Remix the remaining material by taking an alternate shovelful from each quarter.
- Repeat the quartering process as necessary to reduce the sample to the desired size.

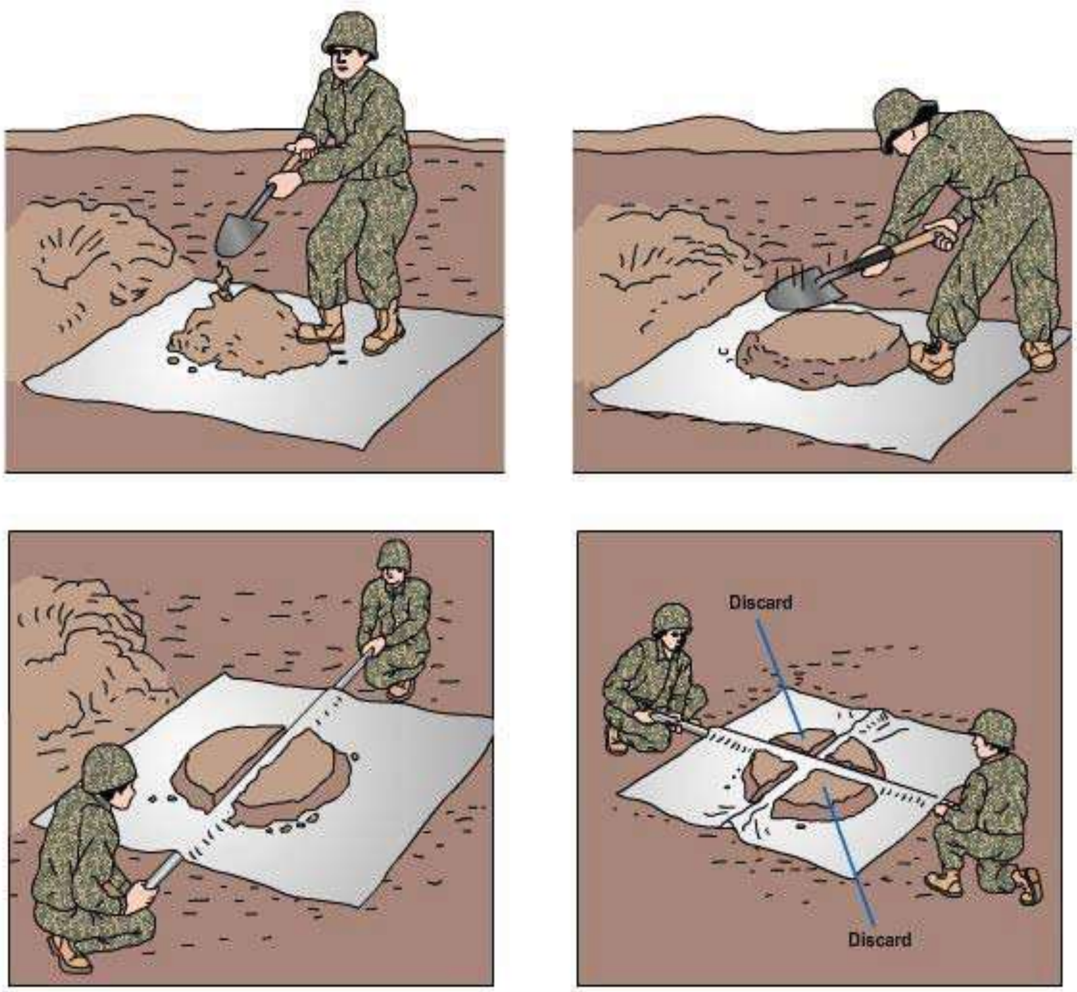


Figure 16-25 - Example of quartering and reducing a large sample to desired size.

4.5.2 Samples Weighing Between 25 and 100 Pounds

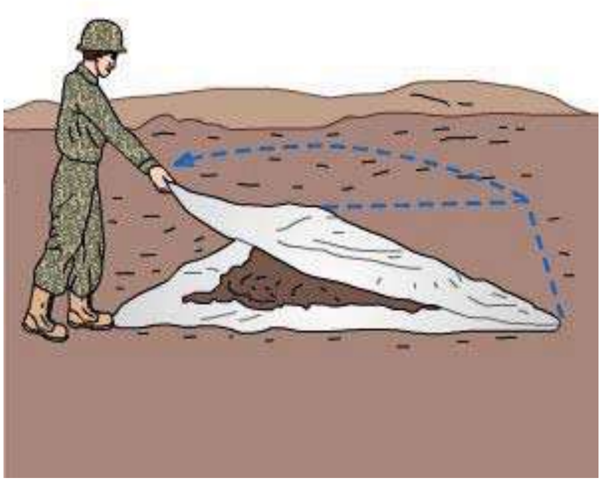


Figure 16-26 – Example of quartering a soil sample of 25-100 pounds.

In quartering a sample between 25 and 100 pounds, you can pile the soil on the canvas and mix it by alternately lifting the corners of the canvas and pulling the sample over as if preparing to fold the canvas diagonally. (*Figure 16-26*)

Flatten and quarter the sample as done with the larger, over 100-pound example.

Repeat until the sample is the desired size.

4.5.3 Samples Weighing Less Than 25 Pounds

For samples less than 25 pounds, the process is the same but on a smaller scale. (*Figure 16-27*)

Place the sample on canvas or a clean sheet of paper.

With a trowel, mix it thoroughly, form it into a conical shape, and flatten it.

Divide the sample into quarters, and discard two diagonally opposite quarters.

Remix the remaining material and repeat the process until the sample is the size needed for the test.

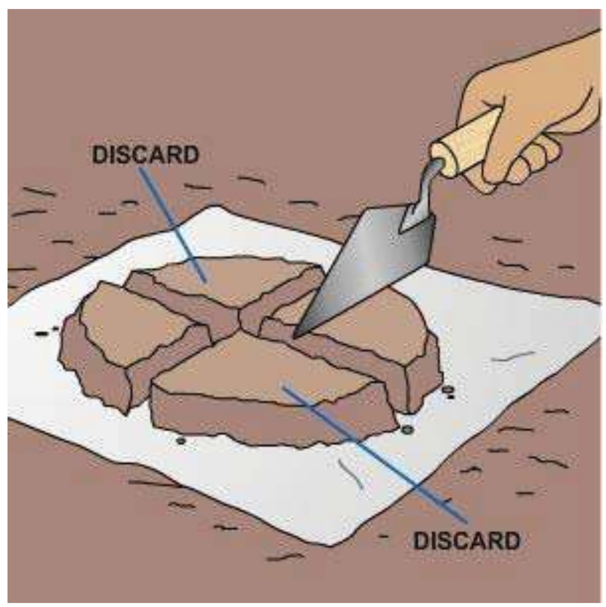


Figure 16-27 – Example of quartering a soil sample of less than 25 pounds.

Test your Knowledge (Select the Correct Response)

4. **(True or False)** Only soil samplings taken from test pits and holes are valid.

   A. True
   B. False

5.1.1 SOIL TESTING

To test the representative soil samples, disturbed or undisturbed, the Navy follows procedures laid down by the American Society for Testing Materials (ASTM). A complete soil test typically proceeds according to the following steps:

1. Determine moisture content.
2. Determine soil particle sizes (grains) and the percentage distribution of sizes with a mechanical analysis.
3. Determine specific gravity.
   - Specific gravity is expressed in terms of ratio: the weight of a given volume of substance relative to the weight of an equal volume of water. A cubic foot of water weighs 62.43 pounds.
     - For soil, determine the absolute specific gravity, that is, determine the ratio of the weight of a dense volume, which is a volume exclusive of air spaces.
     - For example, a cubic foot of dry sand weighs about 100 pounds, but with air exhausted, a cubic foot of sand weighs about 165.44 pounds. Therefore, the specific gravity of sand equals 165.44 divided by 62.43 (1 ft.^{3} water), or about 2.65.
4. Determine Atterberg limits if the soil is clay or a similar fine-grained soil.
   - A fine-grained soil remains plastic over a certain range of moisture content. The upper moisture content is called the liquid limit; the lower is called the plastic limit. Above the range, the soil becomes fluid; below the range, the soil becomes semisolid.
5. Determine moisture-density relationship.
   - Compaction is used to determine the moisture-density relationship; in other words, with a given compaction energy, determining what moisture content will result in the maximum compaction. Compaction testing is not included in this course but will be discussed in EA Advanced.
6. Determine by field control testing:
   - the field moisture content (with an eye to reducing or increasing it to the optimum, if feasible).
   - the point at which the specified density has been obtained by compaction.

Field control testing is not included in this course but will be discussed in EA Advanced.

5.1.0 Determining Moisture Content

A soil's moisture content (also referred to as water content) is an indicator of the amount of water present. By definition, moisture content in a sample is the ratio of the weight of water to the weight of solids (oven-dried), expressed as a percentage (w).

$$w = \frac{W_w}{W_s} x\,100$$

Where:

w moisture content of the soil (expresses as a percentage)

W_w weight of water in the soil sample

W_s weight of oven-dried solids in the sample

With many soils, close control of moisture content during compaction is necessary to develop a required density and strength in the soil mass. The amount of compaction effort to obtain a specified density depends on having the moisture content at or very close to optimum.

Specified density is expressed in terms of dry unit weight, so moisture content must be determined with a wet unit weight to determine whether moisture must be added or removed from the soil mass at the construction site to achieve the optimum moisture content (OMC) for compaction.

There are several methods for determining moisture content of soil but the most accurate is the oven-drying method with an electric or portable gasoline oven to dry the samples.

The calcium carbide gas pressure method is a more expedient method, but it is less accurate and should always be approved by your supervisor.

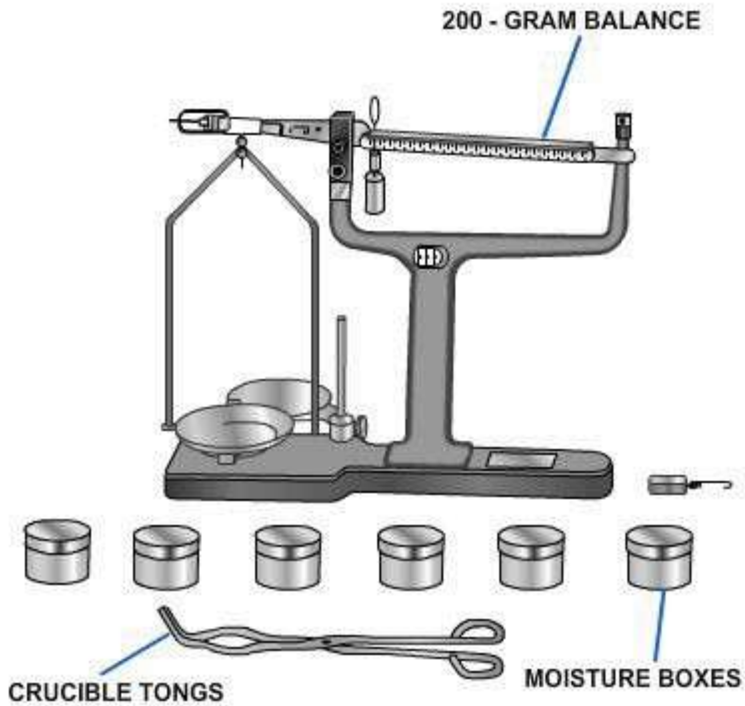
The Nuclear Moisture-Density Meter method is a third option, but it requires special training, along with operator certification, and will not be covered in this course.

5.1.1 Oven-drying Method

To use the oven-drying method (ASTM D 2216-05), again the most accurate method, use the following apparatus and procedures.

5.1.1.1 Apparatus

Figure 16-28 shows the laboratory apparatus needed for determining moisture content.



- A balance for weighing material to 0.01 grams (453.6 g = 1 pound)
- Several small circular moisture boxes (called cans) for placing samples in to weigh and dry
- An electric oven or a portable gasoline oven to dry samples
- Crucible tongs

Figure 16-28 - Apparatus for determining moisture content in the oven-drying method.

If an electric or gasoline oven is not available, the materials can be dried in a frying pan held over an ordinary stove or hot plate. However, the frying pan substitute has a disadvantage. Whereas the electric oven thermostat can be set to a desired temperature, with a frying pan, the temperature is hard to control and any organic material in the sample may be burned causing a slight to moderate inaccuracy in the result.

5.1.1.2 Procedure

Perform the following steps to determine the moisture content. Refer to *Figure 16-29* for entries on DD Form 1205.

- Record all identifying sample information (blocks 1 - 5).
- Label and weigh clean, dry, moisture boxes (cans); record as *Weight of Tare* (block d).
- Place required soil sample in can and cover with lid.
  - When conducting this test as part of another test method, use the specimen mass stated in that test method.
  - When conducting this test with no minimum specimen mass provided, use the values provided in *Table 16-5*, depending on the degree of accuracy of the reported water content.
- Weigh soil sample and tare to the nearest 0.01 gram; record as *Weight of Tare + Wet Soil* (block a).
- Oven-dry sample, with lid removed, at 110°C ± 5° until sample weight becomes constant.

- Oven-drying time will vary depending on the type of soil, the size of the sample, and other factors. For routine water-content determination, oven-dry a sample of clean sands and gravel for a minimum of 4 hours. For most other soils, a minimum drying time of 16 hours is adequate.

- Remove sample from oven; replace lid and allow to cool until it can be handled comfortably with bare hands.
- Weigh dried soil sample and tare; record as *Weight of Tare + Dry Soil* (block b).
- Determine weight of water (W_w) by subtracting *Weight of Tare + Dry Soil* (block b) from *Weight of Tare + Wet Soil* (block a); record as Weight of Water (W_w) (block c).
- Determine weight of dry soil (W_s) by subtracting *Weight of Tare* (block d) from *Weight of Tare + Dry Soil* (block b); record as *Weight of Dry Soil* (W_s) (block e).
- Determine water content (w), in percent, and record it using the formula:

$$w \quad \frac{W_w}{W_s} x\,100$$

When determining the average water content, the individual tests must be within ± 1 percent. Any individual tests that do not meet this requirement will not be used. If none of the individual tests meet this requirement, then additional testing is required. Refer again to *Figure 16-29* to note an invalidated test.

SOIL MOISTURE-CONTENT DETERMINATION

1. PROJECT		2. DATE
ENGINEER CENTER EXPANSION		1 Dec
3. JOB NUMBER	4. TEST SITE	5. SAMPLE NUMBER
16-P-T	North Comer	5-C-I

TEST Bag 1 AVERAGE %						
RUN NUMBER	1	2	3	4		
TARE NUMBER	1-1	1-2	1-7	1-41		
a. WEIGHT OF TARE + WET SOIL			32.46	32.26		2.6
b. WEIGHT OF TARE + DRY SOIL	33.31	37.. /tf'	31.84	31.68	MEAN=	3.6 (+/-1)
c. WEIGHT OF WATER, W w (a - b)	0.61	0.64	0.62	0.58		4.6
d. WEIGHT OF TARE	16.48	18.82	15.02	15.13		
e. WEIGHT OF DRY SOIL, W s (b - d)	16.83	18.36	16.82	16.55		
WATER CONTENT, w (c/e x 100)	3.6 %	3.5 %	3.7 %	3.5 %	%	%

TEST Bag 2 AVERAGE 9.9 %						
RUN NUMBER	1	2	3	4		
TARE NUMBER	2-1	2-2	2-3	2-4		
a. WEIGHT OF TARE + WET SOIL						8.9
b. WEIGHT OF TARE + DRY SOIL					MEAN=	9.9 (+/-1)
c. WEIGHT OF WATER, W w (a - b)			/.f/8'	..'.L		10.9
d. WEIGHT OF TARE	/ .31	I g, S0	15.93	15.81		
e. WEIGHT OF DRY SOIL, W s (b - d)	22.91	24.26	22.13	25.55		
WATER CONTENT, w (c/e x 100)	9.2 %	12.8 %	8.5 %	8.9 %	%	%

TEST AVERAGE %						
RUN NUMBER						
TARE NUMBER						
a. WEIGHT OF TARE + WET SOIL						
b. WEIGHT OF TARE + DRY SOIL						
c. WEIGHT OF WATER, W w (a - b)						
d. WEIGHT OF TARE						
e. WEIGHT OF DRY SOIL, W s (b - d)						
WATER CONTENT, w (c/e x 100)	%	%	%	%	%	%

TEST AVERAGE %						
RUN NUMBER						
TARE NUMBER						
a. WEIGHT OF TARE + WET SOIL						
b. WEIGHT OF TARE + DRY SOIL						
c. WEIGHT OF WATER, W w (a - b)						
d. WEIGHT OF TARE						
e. WEIGHT OF DRY SOIL, W s (b - d)						
WATER CONTENT, w (c/e x 100)			%	%		

6. REMARKS

WATER CONTENT $w = \frac{W_w}{W_s} \times 100$

Tare if 2-2 not used. Not within +/- 1% of MEAN
Probable error in recording weights of this sample

SAMPLE

7. TECHNICIAN (Signature)	8. COMPUTED BY (Signature)	9. CHECKED BY (Signature)
EA2 Johnson	EA2 Johnson	EA1 Barnes

DD FORM 1205, DEC 1999 PREVIOUS EDITION IS OBSOLETE. Adobe Professional 7.0

Figure 16-29 - Example of data sheet for soil moisture content. DD Form 1205.

Table 16-5 - Recommended Minimum Test Specimen for Reporting Water Content.

Maximum Particle Size(100% Passing)	Standard Sieve Size	Minimum Moist Mass for Reporting to ± 0.1%	Minimum Moist Mass for Reporting to ± 1%
2.0 mm or less	No. 10	20.0 g	20 g*
4.75 mm	No. 4	100.0 g	20 g*
9.50 mm	3/8 in	500.0 g	50 g
19.00 mm	3/4 in	2.5 kg	250 g
37.50 mm	1 1/2 in	10.0 kg	1 kg
75.00 mm	3 in	50.0 kg	5 kg
*** To be representative, not less than 20 grams shall be used.**			

5.1.2 Calcium Carbide Gas Pressure Method (AASHTO T 217-1986)

CAUTION

The chemical reaction of calcium carbide with water produces acetylene gas, which is extremely flammable. Exercise extreme caution to avoid open flame when releasing the gas from the speedy moisture tester. Perform the test in a well-ventilated area, as asphyxiation could occur if performed in a confined area.

A typical Calcium Carbide Gas Pressure method uses a 26 gram, SPEEDY® moisture tester to determine the moisture content of soils, fine aggregates, sand, and clay.

Determination can be made in the laboratory or field to within ± 0.5 percent, in from 45 seconds to 3 minutes depending upon the material being tested. If another tester is to be used, consult the user’s manual for the tester before conducting the moisture-content determination.

The tester operates on the principle of introducing a calcium carbide reagent (reactive agent) to the free moisture of the soil sample inside a sealed then shaken chamber. The resulting chemical reaction creates a gas that is contained in the sealed chamber. The resulting gas pressure is displayed on a built-in gas pressure gauge.

5.1.2.1 Apparatus

The SPEEDY® Moisture Tester set (*Figure 16-30*) includes:

- SPEEDY® tester
- Balance
- Half-weight reagent
- Measuring scoop
- Brushes
- Cleaning cloth
- Two 1 1/4-in. steel balls

Figure 16-30 – Example of a SPEEDY® Moisture Tester.

5.1.2.2 Procedure

- Weigh a specified gram sample of soil (26g on SPEEDY® Moisture Tester model).
- Place soil sample and two 1 1/4-inch steel balls in large chamber.
- Hold pressure vessel in a horizontal position to prevent soil from contacting reagent before tester is sealed.
- Place three scoops (24g) of reagent in cap. While still horizontal, insert cap into pressure vessel and tighten clamp to seal cap.
- Raise moisture tester to a vertical position so reagent falls into vessel.
- Return tester to horizontal and vigorously shake with a rotating motion for 10 seconds to put steel balls into orbit around inside circumference to break down soil.
  - Rest for 20 seconds; repeat shake-rest cycle for a total of 3 minutes.
  - Do not allow steel balls to fall against either cap or orifice leading to the dial; this may cause damage.
- Hold the tester horizontal at eye level, read and record dial reading as percent of moisture by wet mass.
- Point cap away and release gas pressure slowly.
- Empty pressure vessel and examine for lumps. If soil sample is not completely broken down, retest another sample and increase time limit (shaking unit) by 1 minute.

   - The limit of the tester is 12 percent moisture for aggregate, or 20 percent moisture for soil. If the limit is exceeded, then the test must be run again using a half-sized sample (13 grams) and the dial reading must be multiplied by 2.

- Determine percentage of moisture by dry mass (oven-dry moisture percentage), by converting direct wet mass reading into a calibration curve supplied with test set.

5.2.0 Mechanical Analysis

Determining grain sizes and the percentage distribution of each size is done with mechanical analysis. A complete mechanical analysis is accomplished in two parts: sieve analysis and ***hydrometer*** analysis.

5.2.1 Sieve Analysis

Sieve analysis applies to soils that are larger than the No. 200 sieve or contain small amounts of material passing the No. 200 sieve.

Sieve analysis can be done on the entire sample or on the sample after the fines are removed by prewashing. To conduct a mechanical analysis, use the following apparatus and procedures.

5.2.1.1 Apparatus

A typical sieve analysis apparatus includes:

Figure 16-31 - Typical sieve set apparatus.

- Gram weighing balance
- Sieves with apertures of varying sizes used to determine grain sizes (*Figure 16-31*)
- Sieves may be:
   - Circular sifter type (usually about 8 inches in diameter)
   - Rocker type, a rocker frame in which screens with apertures of various sizes can be placed

The sieve used for analysis is the so-called standard sieve. A standard sieve has a square aperture.

Sieve screen sizes have two types of identifying systems:

- A sieve with fewer than four apertures to the linear inch is designated by the size of an aperture, for example, a 1/4-inch, 1/2-inch, 3/4-inch, or 1-inch sieve.
- A sieve with four or more apertures to the linear inch is designated by a number representing the number of apertures per linear inch. A No. 4 sieve has four apertures to the linear inch; No. 6 has six apertures; and so on. The finest sieve used is a No. 200, which is slightly smaller than $\frac{1}{200^{th}}$ of an inch square.

To conduct a sieve analysis, you also need an electric or hand-operated sieve shaker. (*Figure 16-32*)

Shakers come in a variety of styles and functional operation.

Figure 16-32 – Example of types of sieve shakers.

5.2.1.2 Procedure-Sieve Analysis, Dry

To conduct a mechanical dry sieve analysis you must have a minimum amount of soil sample. (*Table 16-6*)

Table 16-6 - Minimum Amount of Soil Sample for Grain-Size Analysis.

<table>
<tr><td>Maximum particle size (sieve opening)</td><td>Minimum dry weight of test specimen</td><td rowspan="7">The minimum sample weight depends on the maximum particle size in the sample.</td></tr>
<tr><td>3 in.</td><td>5,000 g</td></tr>
<tr><td>2 in.</td><td>4,000 g</td></tr>
<tr><td>1 1/2 in.</td><td>3,000 g</td></tr>
<tr><td>1 in.</td><td>2,000 g</td></tr>
<tr><td>3/4 in.</td><td>1,000 g</td></tr>
<tr><td>3/8 in. (No. 4)</td><td>500 g</td></tr>
</table>

Samples are analyzed by the following procedure. Refer to *Figure 16-33* for entries on DD Form 1206.

Samples that contain cohesive soils such as clays or silts, which form hard lumps, must be prewashed. Look for the 4 additional operations.

GRAIN-SIZE ANALYSIS (SIEVE METHOD)

1. PROJECT ENGINEER CENTER EXPANSION		2. DATE 1 Dec
3. JOB NUMBER 16-P-T	4. EXCAVATION 5-C	5. DATE COMPLETED 5 Dec
6. NOTES ABOUT SAMPLE/DESCRIPTION Red in color, very fine sands		7. SAMPLE NUMBER 5-C-1
		8. ORIGINAL SAMPLE WEIGHT 4,405
9. PREWASHED [X] YES [ ] NO	10. + #200 SAMPLE WEIGHT, WASHED 2,814	11. - #200 SAMPLE WEIGHT, WASHED 1,570

12. SIEVE SIZE	13. SIEVE WEIGHT	14. SIEVE-SAMPLE WEIGHT	15. WEIGHT RETAINED	16. CUMULATIVE WEIGHT RETAINED	17. PERCENT RETAINED	18. PERCENT PASSING
2"	585	585	0	0	0	100
1 1/2"	714	797	84	84	1.9	98.1
3/4"	577	738	161	245	3.7	94.4
1/4"	540	1,168	628	873	14.3	80.1
#4	507	625	118	[illegible]	2.7	77.4
#16	404	827	[illegible]	[illegible]	9.5	67.9
#30	596	820	[illegible]	1,633	5.1	62.7
#40	402	634	[illegible]	1,865	5.3	57.4
#60	534	966	433	2,298	9.9	47.6
#80	351	655	[illegible]	2,602	6.9	40.6
#100	265	[illegible]	[illegible]	2,665	1.5	39.2
#200	347	[illegible]	114	1,779	2.6	36.6

19. TOTAL WEIGHT RETAINED IN SIEVES (Sum of column 15)	2,779	24. ERROR (8-23) 23	25. ERROR IN PERCENTAGE $\left(\frac{24}{8}\right)$ X 100 = 0.5
20. WEIGHT SIEVED THROUGH #200 (Weight in pan)	33		
21. WASHING LOSS - [10+ 11])	21		
22. TOTAL WEIGHT PASSING #200 SIEVE (20+ 11)	1,603		
23. TOTAL WEIGHT OF FRACTIONS (19+ 22)	4,381		

26. PERCENT GRAVEL (% G)	27. PERCENT SAND (% S)	28. PERCENT FINES (% F)	29. DECIMAL FINES (% F÷ 100)
22.6	40.8	36.6	0.366

30. REMARKS
USCS SC W/GRAVEL

31. TECHNICIAN (Signature)	32. COMPUTED BY (Signature)	33. CHECKED BY (Signature)
EA2 Johnson	EA2 Johnson	EA1 Barnes

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SAMPLE

Figure 16-33 - Example of grain-size analysis. DD Form 1206.

- Prepare sample.
  - Spread out and air dry.
  - Break up aggregate with fingers or mortar and pestle (usually a part of the laboratory apparatus). Take care not to crush individual grains. The object is to separate aggregations of clustering grains.
- Obtain representative size. (*Table 16-6*)
- Record identifying sample information on form (blocks 1 through 7).
- Oven-dry material at 110°C ± 5° until a constant weight is obtained; allow cooling.
- Weigh oven-dried sample to the nearest gram; record as original weight on form (block 8).
- If only a dry sieve is to be performed, check “No” in block 9 and enter 0 in blocks 10 and 11 and proceed with selecting sieves.
  - If sample will be prewashed, check “Yes” in block 9 and add the following 4 operations:
    1. Place sample in clean container; cover completely with water; allow soaking until any adhering and lumpy particles are completely disintegrated, 2 to 24 hours.
    2. Wash sample over a No. 200 sieve into a 2 x 2 foot concrete pan until all –200 materials have been washed through.
       a. If sample contains an appreciable amount of coarse particles, combine No. 4 and No. 200 sieves.
       b. Take care not to overload No. 200 sieve. If necessary, transfer sample in increments. (This process may take up to 6 different pans and as long as 8 hours.)
    3. Process +200 material.
       a. Oven-dry washed + 200 material at 110°C ± 5° until constant weight is obtained and allow cooling.
       b. Weigh to nearest tenth of a gram, record + *#200 Sample Weight, Washed* (block 10).
    4. Process –200 material.
       a. Allow the –200 material to settle in pan until surface water becomes clear (16 to 24 hours).
       b. Decant surface water (use siphon or syringe) ensuring settled material is not disturbed.
       c. Use a trowel to transfer as much material as possible from pan to pudding pans.
       d. Rinse remainder of material from 2 x 2 pans to pudding pans with as little water as possible.
       e. Oven-dry washed –200 material and determine weight to nearest tenth of a gram; record as — *#200 Sample Weight, Washed* (block 11).

- Retain material from these 4 additional steps for prewashed material for use in hydrometer analysis.

- Select a nest of sieves to accommodate largest particle size of soil; ensure all material will pass through largest sieve.
- Record weight of each selected sieve (to nearest tenth of a gram) on form (column 13).
  - Sieve selection varies according to type of soil being tested. The following is recommended as a minimum:

Stack (nest) sieves on top of each other with the largest sieve on top.

The coarsest sieve recorded is the sieve above the first one that retains any material.

The “retained” weight recorded for this sieve is 0 g.

The passing weight recorded through this sieve is the total weight of the sample.

2 inch
1 1/2 inch
1 inch
3/4 inch
3/8 inch
No. 4
No. 10
No. 16
No. 30
No. 40
No. 50
No. 100
No. 200

- Weigh and place a pan on bottom.
- Cover sample.
  - If sample was prewashed, place only +200 material onto top sieve of nest and cover.
  - If sample was not prewashed, place entire sample on top sieve of nest and cover.
- Place nest of sieves in sieve shaker and shake for 5 to 15 minutes.
  - Shaking interval depends on quantity of fine material.
    - Five minutes-for most coarse-grained soils.
    - Fifteen minutes-for most fine-grained soils.
- Remove cover and sieves from shaker in descending order.
- Weigh each sieve-sample and record on form (column 14).

- Determine weight of material retained on each sieve by subtracting weight of sieve (column 13) from weight of sieve and retained sample (column 14); record as weight retained (column 15).
- Add weights retained on all sieves and record as total weight retained in sieves (block 19).
- Weigh pan with material passing No. 200 sieve; subtract weight of pan; record as weight sieved through No. 200 (block 20).
- Complete form blocks 21 through 25 using formulas provided on sheet; if error percentage is 1 percent or greater, rerun test.
- Compute cumulative weight retained (column 16) for each sieve by adding weight retained (column 15) to the previous cumulative weight retained (column 16) with starting point being 0.
- Compute percent retained (column 17) for each sieve by dividing weight retained by total weight of fractions as follows:

$$\frac{column\,15}{block\;23}\,x\,100$$

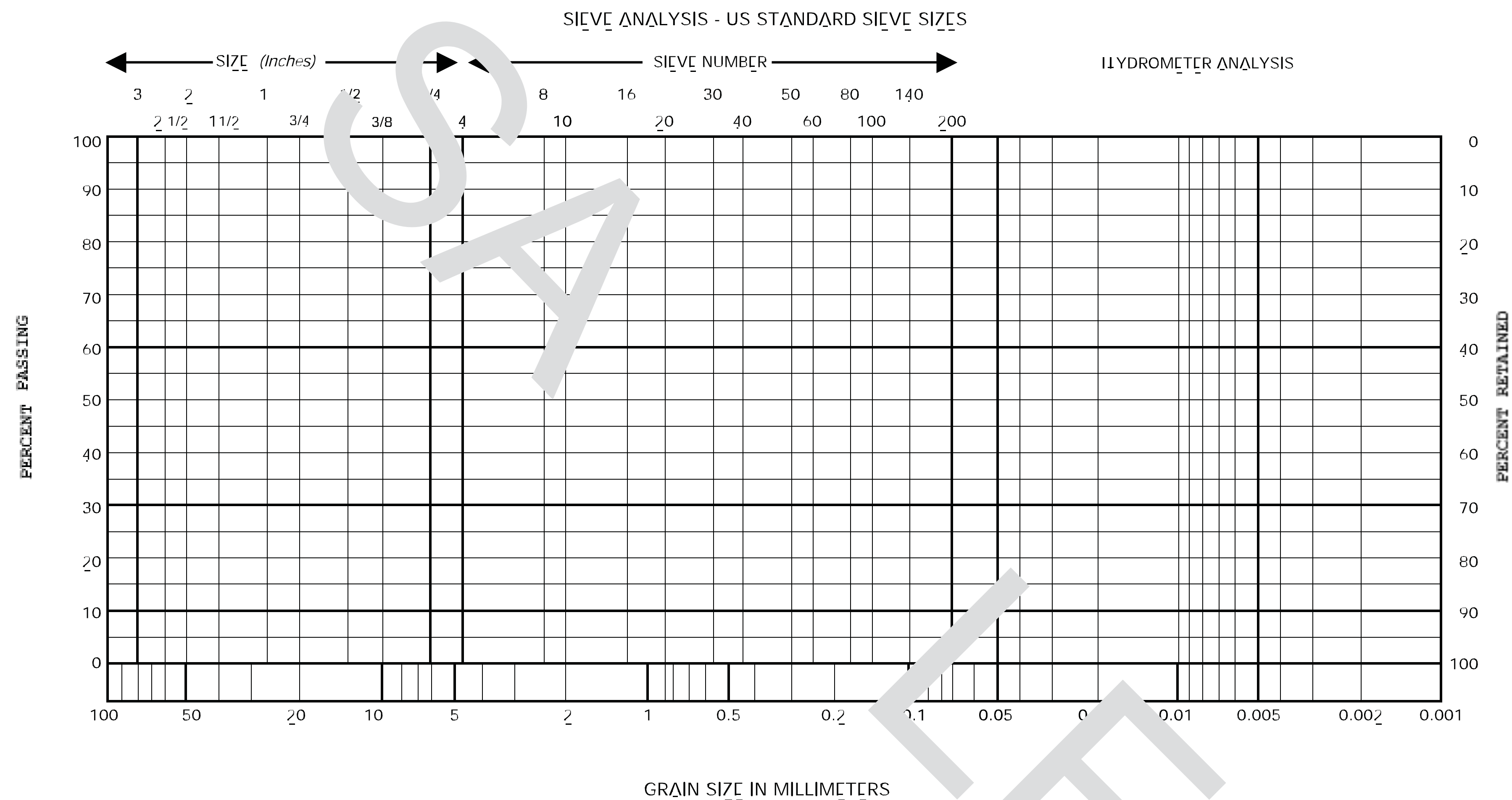
- Compute percent passing for each sieve size by subtracting cumulative weight retained (column 16) from total weight of fractions (block 23) and dividing by total weight of fractions as follows:

$$Column18 \quad \frac{block\,23 \quad column\,16}{block\;23}\,x\,100$$

- Determine percentages for gravel, sand, and fines; record as:
  - Gravel is material retained on No. 4 sieve (block 26).
  - Sand is material passing No. 4 sieve, retained on No. 200 sieve (block 27).
  - Fines are material passing No. 200 sieve (block 28).
- Prepare Grain-Size Distribution graph, DD Form 1207. (*Figure 16-34*)
  - Record identifying sample information in remarks blocks.
  - Use sieve-analysis data to plot sieve size and percentage passing sieve.
  - Use a french curve to connect plotted points forming a smooth, free-flowing curve (grain-size distribution curve).

GRAIN SIZE DISTRIBUTION GRAPH - AGGREGATE GRADATION CHART

1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION 16-P-T	6 Dec



EXCAVATION NUMBER	SAMPLE NUMBER	LL	PL	PI	Cu (D_{60}/D_{10})	Cc $(D_{30})^2/(D_{60} \times D_{10})$	SOIL DESCRIPTION/REMARKS	CLASSIFICATION (USCS)
5-c	5-C-1	20	10	10	N/A	N/A	Red in color, very fine sands	SC

3. TECHNICIAN (Signature)	4. PLOTTED BY (Signature)	5. CHECKED BY (Signature)
EA2 Johnson	EA2 Johnson	EA1 Barnes

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Figure 16-34 – Example of grain-size distribution graph. DD Form 1207.

5.2.1.3 Procedure-Sieve Analysis with Prewashing (recap)

If grain-size sample will be prewashed, and “Yes” in block 9 of DD Form 1206 (*Figure 16-33*) is checked, perform the following 4 operations:

- Place sample in clean container; cover completely with water; allow soaking until any adhering and lumpy particles are completely disintegrated, 2 to 24 hours.
- Wash sample over a No. 200 sieve into a 2 x 2 foot concrete pan until all –200 materials have been washed through.
  - If sample contains an appreciable amount of coarse particles, combine No. 4 and No. 200 sieves.
  - Take care not to overload No. 200 sieve. If necessary, transfer sample in increments. (This process may take up to 6 different pans and as long as 8 hours.)
- Process + 200 material.
  - Oven-dry washed + 200 material at 110°C ± 5° until constant weight is obtained and allow cooling.
  - Weigh to nearest tenth of a gram, record as + *#200 Sample Weight, Washed* (block 10).
- Process — 200 material.
  - Allow the — 200 material to settle in pan until surface water becomes clear (16 to 24 hours).
  - Decant surface water (use siphon or syringe) ensuring settled material is not disturbed.
  - Use a trowel to transfer as much material as possible from pan to pudding pans.
  - Rinse remainder of material from 2 x 2 pans to pudding pans with as little water as possible.
  - Oven-dry washed — 200 material and determine weight to nearest tenth of a gram; record as — *#200 Sample Weight, Washed* (block 11).
- Retain material from these 4 additional steps for prewashed material for use in hydrometer analysis.

5.2.2 Hydrometer Analysis

The determination of grain size distribution by sieve analysis is limited to materials larger than the No. 200 (0.074-mm) sieve. For soil classification, this is sufficient since grain size distribution is not used to classify fine-grained soils that pass through the No. 200 sieve. However, when appropriate to the geographical area, an analysis of the distribution of particles smaller than the No. 200 sieve is necessary for frost susceptibility. Frost susceptibility should always be considered in areas subject to substantially freezing temperatures, since repeated freezing and subsequent thawing of water in the soil can seriously affect the ability of the soil to support a structure. A soil is considered frost susceptible if it contains 3 percent or more by weight of particles smaller than 0.020 mm in diameter, and hydrometer analysis is the test used to determine the grain size distribution of soils passing the No. 200 sieve.

Figure 16-35 shows an example of a grain-size analysis using the hydrometer method.

GRAIN-SIZE ANALYSIS (HYDROMETER METHOD)

1. PROJECT	2. DATE
ENGINEER CENTER EXPANSION	6 Dec

3. BORING NUMBER	4. SAMPLE OR SPECIMEN NUMBER	5. CLASSIFICATION
5-C	5-C-l	SC
6. DISH NUMBER '-1-A	7. GRADUATE NUMBER #3	8. HYDROMETER NUMBER/TYPE *(151H/152/-/J* 359557
9. DISPERSING AGENT USED Sodium Hexametaphosphate		10. QUANTITY 15 ML
11. COMPOSITE CORRECTION O . .S-	12. DECIMAL FINES *(Block 29, DD Form 1206)* O. '3 "	13. SPECIFIC GRAVITY OF SOLIDS *(Block 6n, DD Form 1208)* Gs =

14. TIME	15. ELAPSED TIME. *(T)* *minutes*	16. ACTUAL HYDROMETER READING *(R1)*	17. CORRECTED READING *(R)*	18. TEMP °C	19. TEMPERATURE AND SPECIFIC GRAVITY CONSTANT *(K)*	20. EFFECTIVE DEPTH *(L)*	21. PARTICLE DIAMETER *(D)*, mm	22. PERCENT FINER a. PARTIAL	22. PERCENT FINER b. TOTAL
0930	0								
0931	1	l./S:D	'l-S: S'	{)._(p	001:J... 7)..	<6.<?	0.0377	Cf 3.3	3.l/- l
0932	2	43- D	'-13..S--	::J (,,	o.01;L 7	q.J	/'J, O:l."11	gcf .:l_	3;),-
0935	5	3g>•.,s''	39.o	:Lb	0.01 I :J.	CJ.er	a.o r1R	79,ff:/	a,<;.
0945	15	:J..3·6-	:J.. ·O		/). 01fl 7:J..	I'J..,AJ	t:>.o 11._r	1-J<f :J.	1'20
1000	30	/ g',J	/'1 10	,:l,s'	CJ,ol {J.J:>f,	13.;)...	o.ooetf	38.	!/-./ l
1030	60	15,0	1.s-,5'	().$'	o.o/ ag'&,	13.7	0.{)()f:,o	31,	lf.(p
1130	120	1 3.0	13•.)	J	o-ol:l<;/	/J.f. ,O	0.003	:J.7.1	It>./
1330	240	,,,0	11,s	f)S'	O-0JJ..f:?(,o	11.1,3	0.00"3 J	.:13.	<i/l t,.
0930	1440	/!?._ ·	9.o	/}.I/	O,!)/_=l O/	I L/ ,g	D.oo l.l...	I .'l	C:,,7

WEIGHT *(Grams)*		
	23. DISH + DRY SOIL	j ;)_'i-,'7o
	24. DISH	j. 7-S'.b;l
	25. DRY SOIL *(Ws)*	'1,J.

The particle diameter (D) is calculated from Stokes' equation using the corrected hydrometer reading. Use the following formula to solve for particle diameter (D):

D = K VLJT

Corrected hydrometer reading (R) = actual hydrometer reading (Rj + composite correction

Ws = Oven-dry weight (in grams} of soil used for hydrometer analysis

Hydrometer graduated in scific gravity: (151H) J

Hydrometer graduated in grams er liter (152H}

Partial Percent Finer = $\frac{Gs}{Gs - 1} \times \frac{100{,}000}{Ws} (R - 1)$

$\frac{(R)(a)}{Ws} \times 100$

(a = specific gravity of solids cotTection factor)

Tar.al Percent Finer = Partial Percent Finer x Decimal fines (Block 12}

O. 3b6

q::. l.Ol

26. REMARKS

Red in color, very fme sands.

FROST GROUP: F4

27. TECHNICIAN *(Signature}*	28. COMPUTED BY *(Signature)*	29. CHECKED BY *(Signature}*
EACN Pineda	EACN Pineda	EA2 Johnson

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Figure 16-35 - Grain-size analysis (Hydrometer Method). DD Form 1794.

Hydrometer analysis is based on Stokes' law, which relates the terminal velocity of a free-falling sphere in a liquid to its diameter.

The relation is expressed by the following equation:

$$V = \frac{G_s - G_w}{18n} x D^2$$

Where:

V terminal velocity

G_s specific gravity of solids

G_w specific gravity of the liquid in which the sphere is falling

n viscosity of the liquid

D diameter of the sphere

Larger particles settle more rapidly than smaller ones and it is assumed that Stokes' law can be applied to a mass of dispersed soil particles of various shapes and sizes.

The hydrometer analysis is an application of Stokes' law that permits the calculation of grain size distribution in silts and clays. For the analysis, the soil particles are given the sizes of equivalent spherical particles as in Stokes' Law.

The density of a soil-water suspension depends upon the concentration and specific gravity of the soil particles. If the suspension is allowed to stand, the particles will gradually settle out of the suspension, and the density will be decreased.

A hydrometer is an instrument used to measure the density of the suspension at a known depth below the surface. The density measurement, together with knowledge of the specific gravity of soil particles, determines the percentage of dispersed soil particles in suspension at the time and depth of measurement.

Stokes' law is used to calculate the maximum equivalent particle diameter for the material in suspension (at depth and elapsed time of settlement). A series of density measurements (at known depth of suspension and times of settlement) gives the percentages of particles finer than the diameters given by Stokes' law.

Thus, the series of readings will reflect the amount of different sizes of particles in the fine-grained soils. The particle diameter (D) is calculated from Stokes' equation using corrected hydrometer readings and a ***nomographic chart***. Hydrometer analysis procedures are not discussed in this course but are contained in ASTM D 422.

5.3.1 Specific Gravity Testing

Specific gravity is the ratio of the weight of a solid substance to the weight of an equal volume of water. In dealing with soils, determining specific gravity is necessary for certain tests, such as hydrometer analysis, and for computations involving volume and weight relationships.

The specific gravity of solids is normally applied only to soil that passes the No. 4 sieve. Generally, geotechnical engineers need a soil's specific gravity to perform additional testing of that particular soil.

In some cases though, there may be different soil fractions used when performing this test. For example, a –10 sample's resulting specific gravity is applicable to hydrometer analysis, while determining the zero-air-voids curve in soils-compaction testing (laboratory) uses the –4 sample's specific gravity.

A soil's specific gravity largely depends on the density of the minerals making up the individual soil particles. Some typical specific gravity values for specific soil types are:

- Solid substance of most inorganic soils — 2.60 to 2.80
- Tropical iron-rich laterite, as well as some lateritic soils — 2.75 to 3.0 +
- Sand particles composed of quartz — 2.65 to 2.67
- Inorganic clays — 2.70 to 2.80
- Soils with large amounts of organic matter or porous particles (such as diatomaceous earth) — 2.00 to 2.60

There are three different formats for expressing the specific gravity of a soil mass.

- Specific Gravity of Solids (G_s) — the ratio of the weight in air of a given volume of *soil particles* to the weight of an equal volume of distilled water, both at a stated temperature.
  - The specific gravity of solids is applied only to that fraction of a soil that passes a No. 4 sieve.
- Apparent Specific Gravity (G_a) — the ratio of the weight in air of a given volume of *the impermeable portion of soil particles* to the weight in air of an equal volume of distilled water, both at a stated temperature.
  - The impermeable portion of a porous material, such as most large soil grains, includes the solid material plus impermeable pores or voids within the particles.
- Bulk Specific Gravity (G_m) — the ratio of the weight in air of a given volume of *permeable material (including permeable and impermeable voids)* to the weight of an equal volume of distilled water, both at a stated temperature.

5.3.1 Sample Selection

For specific gravity tests, soil samples may be disturbed or undisturbed. However, take care to ensure that a sample is a representative sample.

When selecting a sample containing both large and small particles, separate it on a No. 4 sieve; discard any particles not passing.

It is easier to begin the test with an oven-dried sample. However, some soils, particularly those with high organic content, should be tested at their natural water content with the oven-dried weight determined at the end of the test.

5.3.2 Specific Gravity of Solids

As presented earlier, determining the specific gravity of solids applies only to soil that passes a No. 4 sieve. However, when used in conjunction with a hydrometer analysis, specific gravity is determined only on the fraction that passes a No. 200 sieve.

5.3.2.1 Apparatus

- 500-milliliter (ml) volumetric flask
  - For course discussion, assume the flask has been calibrated; the weight of the flask and water has been calibrated over a range of temperatures likely encountered in the laboratory. Calibration procedures are located in ASTM D 854.
- Balance, 2,000-gram capacity
- Balance, 200-gram capacity
- Cans, moisture content
- Dishes, evaporating
- Funnel
- Mortar and pestle
- Pump, vacuum (optional)
- Stirrer, soil dispersion (optional)
- Thermometer, general laboratory

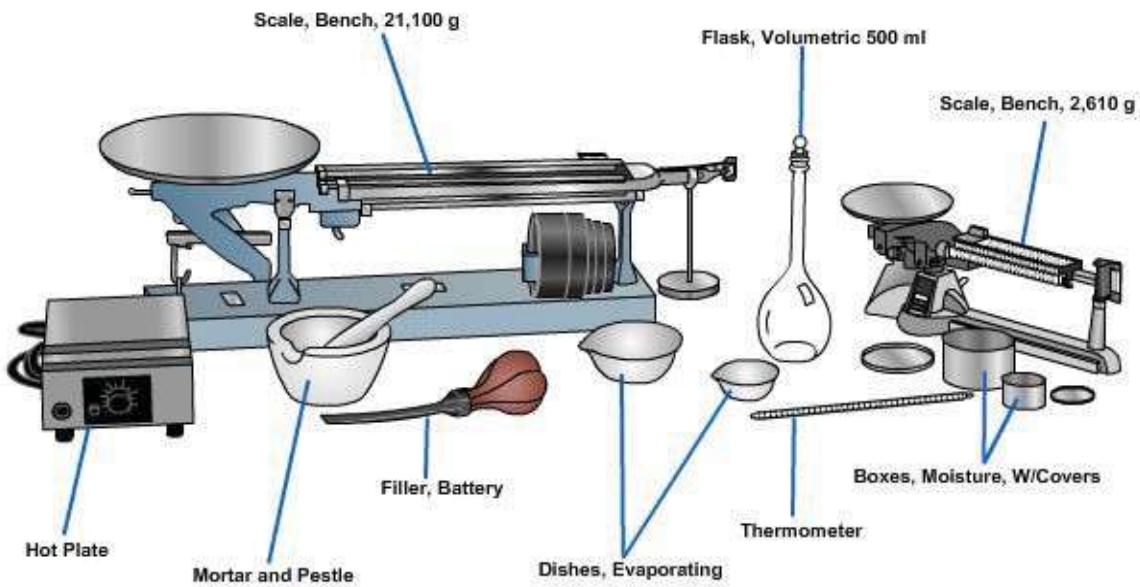

Figure 16-36 - Example of apparatus for determining specific gravity.

5.3.2.2 Procedure

To perform a specific gravity of solids test, use the following procedures. Refer to *Figure 16-37* for entries on DD Form 1208.

SPECIFIC-GRAVITY TESTS

1. PROJECT ENGINEERJNG CENTER EXPANSION		2. DATE I Dec
3. BORING NUMBER 5-C-I	4. JOB NUMBER 16-P-T	5. EXCAVATION NUMBER 5-C

6. SPECIFIC GRAVITY OF SOLIDS (Gs)

FLASK CALIBRATION DATA	a. FLASK NUMBER	b. CLEAN, DRY WEIGHT, Wb	c. FLASK + WATER WEIGHT. Wbw	d. OBSERVED TEMPERATURE, Ti
	#2A	171 Grams	668 Grams	25 o C

e. SAMPLE OR DETERMINATION NUMBER		5-C-1		
f. DISH NUMBER		2A		
g. WEIGHT OF DISH + DRY SOIL	Grams	308		
h. WEIGHT OF DISH	Grams	270		
i. WEIGHT OF DRY SOIL, Ws	Grams	38		
j. WEIGHT OF FLASK + WATER + IMMERSED SOIL, Wt>ws	Grams	692		
k. TEMPERATURE OF WATER, Tx	C	23		
l. CALCULATED WEIGHT OF FLASK + WATER AT Tx, W11w	Grams	668		
m. CORRECTION FACTOR FOR Tx, K		I		
n. SPECIFIC GRAVITY OF SOLIDS	$Gs = \frac{WsK}{Ws + Wow - Wt>ws}$	3		

DETERMINATION DATA

7. APPARENT (Ga) AND BULK (Gm) SPECIFIC GRAVITY

a. SAMPLE OR SPECIMEN NUMBER			
b. TEMPERATURE OF WATER AND SOIL (°C) (must be within 23 ±_1°C)			
c. TARE + SATURATED SURFACE DRY SOIL			
d. TARE			
e. SATURATED SURFACE ·DRY SOIL, (8)			
f. (WIRE BASKET + SOIL) IN WATER			
g. WIRE BASKET IN WATER			
h. SATURATED SOIL IN WATER, (C)			
i. TARE AND DRY SOIL			
j. TARE			
k. DRY SOIL, (A)			

DETERMINATION DATA

l. APPARENT SPECIFIC GRAVITY — G. = {A)I (A • C)

m. BULK SPECIFIC GRAVITY — Gm "" (A)I (8 ·C)

n. BULK SPECIFIC GRAVITY, SATURATED SURFACE DRY (SSD) — Gm = (8)I (8 - C)

8. REMARKS

9. TECHNICIAN *(Signature)*	10. COMPUTED BY *(Signature)*	11. CHECKED BY *(Signature)*
EACN Pineda, AP	EACN Pineda, AP	EA 2 Johnson

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NAVEDTRA eLIf\§ — **Example of data sheet for specific gravity. DD Form 1208.** 16-51

- Calibrate volumetric flask (for course discussion, flask has been calibrated).
  - Record basic sample information and flask number (blocks 1-5; 6a).
  - Weigh clean, dry, flask to nearest 0.01 gram; record as Clean, Dry Weight W_b (block 6b).
  - Fill flask with room-temperature distilled water; ensure bottom of meniscus is even with calibration mark.
  - Weigh flask plus water; record as *Flask + Water Weight* W_{bw} (block 6c).
  - Determine water temperature to nearest whole degree, record as *Observed Temperature* T_i (block 6d).
  - Create graph or table for flask being used if additional specific-gravity determinations are to be made. (NAVFAC MO 330 provides additional guidance).
- Obtain soil sample for testing.
  - Separate sample over No. 4 sieve to obtain 100-gram sample passing sieve, or over No. 10 sieve to obtain 20-gram sample.
  - Discard material retained on sieve.
- Prepare sample for testing.
  - Record identifying sample information (blocks 6e, 6f).
  - Place – 4 or –10 sample into evaporating dish.
  - Perform following procedures for soil at natural water content or moisture; otherwise, go to next procedure for oven-dried sample:
    - Add distilled water to sample and mix to slurry.
    - Transfer slurry to flask and add distilled water until about three-fourths full.
  - Perform following procedures for oven-dried soil sample:
    - Oven-dry sample to a constant weight at temperature of 110°± 5°C.; allow cooling and weigh to nearest 0.01 gram; record as *Weight of Dish + Dry Soil* (block 6g).
    - Transfer dried sample to volumetric flask; avoid any particle loss.

      Fill flask three-fourths full with distilled water and allow to soak for 12 hours.
    - Weigh empty, dry evaporating dish; record as *Weight of Dish* (block 6h).
- Process sample through test method.
  - Remove entrapped air by bringing solution to a slow, rolling boil for 10 minutes, occasionally rolling flask to assist in air removal (ensure no loss of material occurs while boiling); cool to room temperature.
  - Fill flask with distilled water until bottom of meniscus is level with calibration mark.
  - Dry outside; thoroughly remove any moisture adhering to neck.

- Weigh flask and contents to nearest 0.01 gram; record as *Weight of Flask + Water + Immersed Soil* (W_{bws}) (block 6j).
- Shake flask immediately after weighing (put contents in suspension); determine water temperature at mid-depth to nearest degree; record as *Temperature of Water* (T_x) (block 6k).
- Determine dry unit weight for soil processed at natural moisture content:
  - Transfer soil solution from flask to pre-weighed pudding pan; record as *Weight of Dish* (block 6h). Use care when transferring all grains.
  - Oven-dry to constant weight at temperature of 110° ± 5°C; allow cooling; record as *Weight of Dish + Dry Soil* (block 6g).

• Compute results on DD Form 1208.(*Figure 16-37*)

- Compute weight of dry soil (W_s) by subtracting weight of dish (block 6h) from weight of dish + dry soil (block 6g); record as *Weight Of Dry Soil* W_s (block 6i).
- Determine weight of flask and water (W_{bw}) by plotting temperature of water (T_x) (block 6k) on calibration curve; record as *Calculated Weight of Flask + Water at* T_x**,** W_{bw} (block 6L). (If the calibration curve and graph were not produced, use the formula as indicated and record the result on the form.)

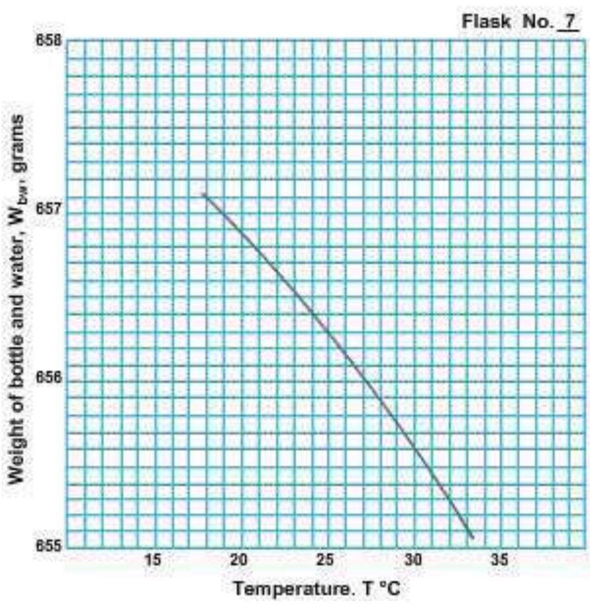


Figure 16-38 - Example of calibration curve for a volumetric flask.

$$W_{bw} = \left[\frac{P_w(T_x)}{P_w(T_i)} x \left(W_{bw} \ at\ T_i - W_b \right) \right] + W_b$$

Where:

$P_w(T_x)$ density of water identified by temperature (T_x)

$P_w(T_i)$ density of water identified by temperature (T_i)

W_{bw} weight of flask and water in grams

W_b weight of flask in grams

T_i observed/recorded temperature of water in ºC

T_x any other desired temperature, in ºC

- Determine correction factor (K).
  - Locate temperature of water (T_x) (block 6k) in *Table 16-7*.
  - Read across to correction factor column; record as *Correction Factor for* T_x, K (block 6m).

Table 16-7 - Relative Density of Water and Correction Factor (K) at Various Temperatures.

TEMP oC	RELATIVE DENSITY	CORRECTION FACTOR, K	TEMP oC	RELATIVE DENSITY	CORRECTION FACTOR, K	TEMP oC	RELATIVE DENSITY	CORRECTION FACTOR, K
18.0	0.99862	1.0004	23.0	0.99756	0.9993	28.0	0.99626	0.9980
18.5	0.99852	1.0003	23.5	0.99744	0.9992	28.5	0.99611	0.9979
19.0	0.99843	1.0002	24.0	0.99732	0.9991	29.0	0.99597	0.9977
19.5	0.99833	1.0001	24.5	0.99720	0.9990	29.5	0.99582	0.9976
20.0	0.99823	1.0000	25.0	0.99707	0.9988	30.0	0.99567	0.9974
20.5	0.99813	0.9999	25.5	0.99694	0.9987	30.5	0.99552	0.9973
21.0	0.99802	0.9998	26.0	0.99681	0.9986	31.0	0.99537	0.9971
21.5	0.99791	0.9997	26.5	0.99668	0.9984	31.5	0.99521	0.9970
22.0	0.99780	0.9996	27.0	0.99654	0.9983	32.0	0.99505	0.9968
22.5	0.99768	0.9995	27.5	0.99640	0.9982	32.5	0.99490	0.9967

- Compute specific gravity of solids to two decimal places using the following formula; record as *Specific Gravity of Solids* G_s (block 6n).

$$G_s \quad \frac{W_s K}{W_s + W_{bw} \quad W_{bws}}$$

Where:

W_s dry weight of the sample

K correction factor based on the density of water at 20ºC Obtain the factor by selecting the correction factor corresponding the recorded temperature. (*Table 16-6*)

W_{bw} weight of the flask filled with water only at test temperature

Obtain this value from a calibration curve, or table, previously prepared for the flask used.

W_{bws} weight of the flask, water, and sample at test temperature

5.3.3 Bulk and Apparent Specific Gravity

The specific gravity of solids is not applied to coarse particles because they normally contain voids from which air cannot be displaced unless the particles are ground into finer particles so as to eliminate the voids. Thus, when dealing with coarser particles, it is more convenient to work with the apparent specific gravity of the particle mass or to determine the bulk specific gravity.

To recap the definitions of Apparent Specific Gravity (G_a) and Bulk Specific Gravity (G_m):

Apparent Specific Gravity (G_a) — the ratio of the weight in air of a given volume of ***the impermeable portion of soil particles*** to the weight in air of an equal volume of distilled water, both at a stated temperature.

- The impermeable portion of a porous material, such as most large soil grains, includes the solid material plus impermeable pores or voids within the particles.

Bulk Specific Gravity (G_m) — the ratio of the weight in air of a given volume of *permeable material (including permeable and impermeable voids)* to the weight of an equal volume of distilled water, both at a stated temperature.

The following applies to the determination of both bulk and apparent specific gravity. Bulk specific gravity is usually determined for the coarser materials retained on a No. 4 sieve. Large stones may be determined individually.

For aggregates used in Portland-cement concrete, measure to determine the bulk specific gravity of the aggregates in a saturated, surface dry (SSD) condition. This is the condition in which the pores in each aggregate particle are filled with water and no excess water is on the particle surface.

This test method covers the specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as apparent specific gravity, bulk specific gravity, bulk specific gravity SSD.

5.3.3.1 Sample Preparation

Prepare a representative sample by washing the material over the No. 4 sieve to remove dust and coatings and obtain a sample size; approximately 2 kilograms are required. Ensure the sample is representative.

5.3.3.2 Apparatus

- Balance, sensitive to 0.5 gram, capable of suspending the sample container in water from the center of the weighing platform or pan of the weighing device
- Wire sample basket or a bucket with a 4- to 7-liter capacity for 1 1/2-inch or smaller aggregate and a larger basket or bucket for larger aggregate sizes.
- Water tank large enough to hold the basket
- Volumetric Flask, 2 to 3 cubic feet
- Heat source (oven or hot plate)
- Metal sample container
- Metal spatula
- Absorbent towel

5.3.3.3 Procedure

Perform the test in the following order, recording weights to the nearest 0.5 gram. Refer to *Figure 16-37* again.

- Obtain representative sample.
- Record basic sample information (block 7a).
- Dry the sample to a constant weight at 110°C + 5°.
- Weigh container and record as *Tare* (block 7j).
- Weigh container and dry sample; record as *Tare and Dry Soil* (block 7i).

- Determine weight of dry soil by subtracting *Tare* (block 7j) from *Tare and Dry Soil* (block 7i); record as Dry Soil (A) (block 7k).
- Allow cooling to 50°C; immerse in water; soak at room temperature for 24 hours.
- Remove sample from water and roll in a large, absorbent cloth until all visible films of water are removed.
    - The surfaces of the particles will still appear to be slightly damp. The larger fragments may be wiped individually. When saturated surface is dry, the surface may still appear damp but take care to avoid excessive evaporation during the surface drying.
    - The aggregate sample is now in an SSD condition.
- Weigh saturated surface dry container and record as *Tare* (block 7d).
- Weigh container with saturated surface dry sample; record as *Tare + Saturated Surface Dry Soil* (block 7c).
- Determine weight of saturated surface dry sample by subtracting *Tare* (block 7d) from *Tare + Saturated Surface-Dry Soil* (block 7c); record as *Saturated Surface-Dry Soil (B)* (block 7e).
- Weigh wire basket in water; record as Wire Basket In Water (block 7g).
- Place sample in basket and immerse in water; hang basket and sample from balance and support so it hangs freely in water; record as *(Wire Basket + Soil) in Water* (block 7f).
- Determine weight of saturated soil sample by subtracting Wire Basket In Water (block 7g) from *(Wire Basket + Soil) in Water* (block 7f); record as *Saturated Soil in Water (C)* (block 7h).
- Measure temperature of water and soil; record in (block 7b).
- Compute Apparent Specific Gravity using following formula; record as *Apparent Specific Gravity* G_a (block 7l). $G_a = \dfrac{A}{A - C}$
- Compute Bulk Specific Gravity using following formula; record as *Bulk Specific Gravity* G_m (block 7m). $G_m = \dfrac{A}{B - C}$
- Compute Bulk Specific Gravity (SSD) using following formula; record as *Bulk Specific Gravity, Saturated Surface Dry (SSD)* G_m (block 7n). $G_m = \dfrac{B}{B - C}$
- Where : $\begin{array}{l} A = weight\ of\ dry\ soil\ in\ air \\ B = weight\ of\ SSD\ sample\ in\ air \\ C = weight\ of\ SSD\ sample\ in\ water \end{array}$

5.3.4 Specific Gravity of Composite Sample

After determining the specific gravity of solids (G_s) and the apparent specific gravity (G_a), the specific gravity of an entire soil sample (both larger and smaller than a No. 4 sieve) can be calculated with the following formula:

$$G = \frac{100}{\frac{\%Passing\ No.4\ sieve}{G_s} + \frac{\%Retained\ on\ No.4\ sieve}{G_a}}$$

Enter this composite specific gravity, along with the percent of materials retained on, or passed through the No. 4 sieve, in the remarks block of the data sheet.

5.3.5 Comment Regarding Correction Factor (K)

Refer again to *Figure 16-37*. There you will see the (K) value used *(0.9993)* from *Table 16-6* and the results obtained by using the correction factor in calculating G_s (block 6n). Carried to four decimal places, $G_s = 2.6256$.

If you were to disregard (K) and recalculate, you would obtain $G_s = 2.6238$.

The value obtained without the correction factor is hardly different from the value obtained with the correction factor. Therefore, unless unusually accurate precision is required, you may disregard the correction factor.

5.4.0 (Atterberg Limits) Liquid Limit, Plastic Limit, Plasticity Index Determination (ASTM 4318-95A)

If the proper amount of water is present, clays and some other fine-grained soils exhibit plasticity. A plastic soil can be deformed beyond the point of recovery without cracking or exhibiting a change in volume and be remolded.

The liquid limit (LL) is that point at which the material contains the greatest water content and remains plastic; additional water causes it to become a thick liquid.

The plastic limit (PL) is that point at which the material contains the lowest water content and remains plastic; less water causes it to become brittle and break into fragments if remolding is attempted.

The plasticity index (PI) is the numerical difference between the LL and the PL, expresses as:

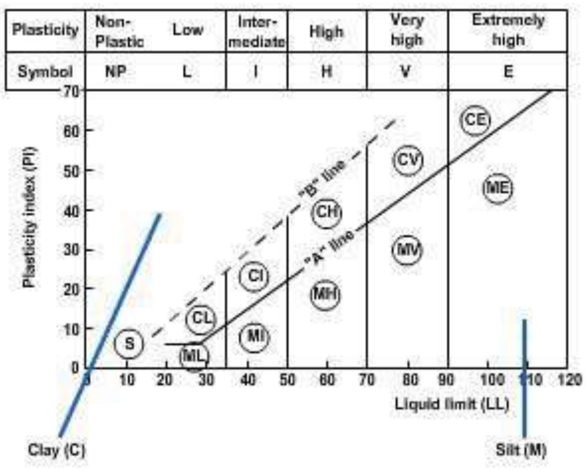
$$PI = LL - PL$$

A large PI indicates a very plastic soil; a small PI denotes a soil with little plasticity.

As water content decreases below the PL, the soil mass shrinks and becomes stiffer. The shrinkage limit (SL) is that point at which, with further drying, shrinkage stops.

No sharp distinction identifies the liquid, plastic, and solid brittle states of consistency, so standardized procedures have been established for determining the LL and PL. These consistency limits, as well as the shrinkage limit, are called the Atterberg limits, named for Albert Atterberg, a Swedish chemist who did the initial work on soil plasticity.

However, since tests in this course determine only the LLs and PLs and not the SLs, they are not identified as the Atterberg limits.



Research with large numbers of clay soils established the soil plasticity chart for laboratory classification of fine-grained soils, an example of which is shown in *Figure 16-39*.

The LL and PI values are coordinates that locate a particular soil sample on the chart.

The region on the chart in which the sample falls gives the classification based on the behavioral characteristics of the particular soil.

Figure 16-39 – Example of a plasticity chart.

Take particular care when performing tests. Some soils, particularly those with a high organic content, can provide inconsistent readings or drastic differences between an oven-dried sample and a sample at natural moisture content.

Conduct the following tests on samples of natural moisture content. Determine the moisture content at the end of the test.

5.4.1 Apparatus-Test Equipment

A Liquid Limit testing device consists of a brass bowl mounted on a box type apparatus with a crank. (*Figure 16-40*) When the crank is turned, the device elevates and drops the bowl (containing a sample) a specific distance onto a hard rubber anvil centered under the bowl. Each drop is called a “blow.”

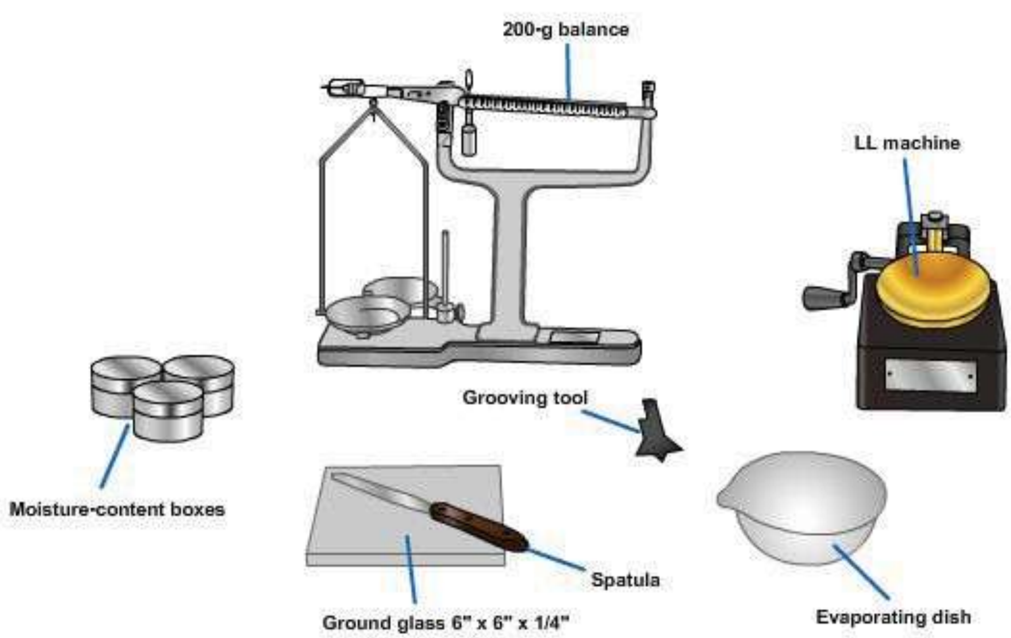


Figure 16-40 – Example of apparatus for LL & PL testing.

The test requires the standard support equipment of scale, moisture-content (tare) cans, and evaporating dish, as well as the LL device. *Figure 16-41* provides a more detailed description of an LL device.

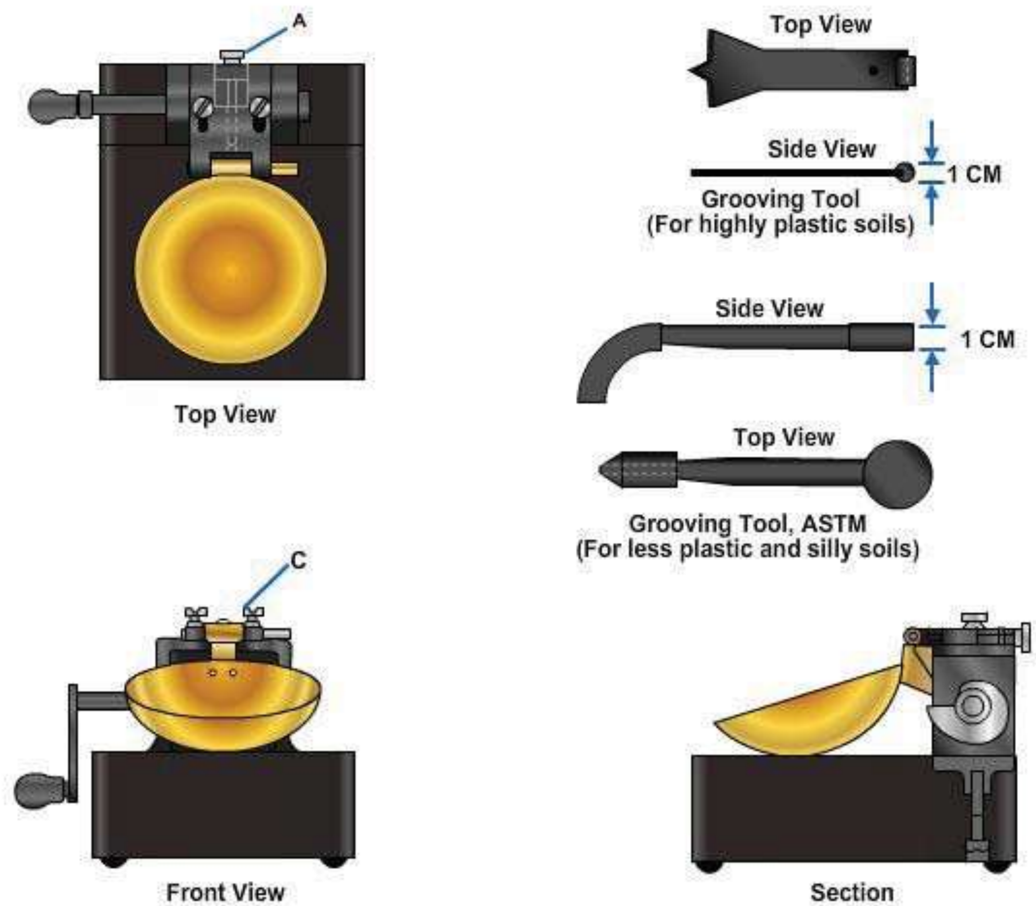


Figure 16-41 - Example of Liquid Limit device with grooving tools.

5.4.2 Procedure (Liquid Limit LL)

- Prepare soil sample.
  - Sieve soil sample (at natural moisture content) over No. 40 sieve; obtain at least 250 grams.
  - If little or no material is retained on No. 40 sieve:
    - Collect 200 to 250 grams of –40 material for testing.
    - Mix material with distilled water until water content is slightly below LL, about peanut butter consistency. (The goal is to have the material fall in the 25- to 35-blow range for the first test.)
    - Place mixture in airtight plastic bag for at least 16 hours (overnight) so moisture content can become consistent throughout; remix material thoroughly before testing.
  - If material is retained on No. 40 sieve:
    - Place –40 material in airtight plastic bag to maintain natural moisture content.

- Soak coarse material retained on No. 40 sieve. (Soaking time is variable.)
- Rub ***colloidal*** [*kuh*-**loid**-l] material from surfaces of large particles until clean, placing fines in suspension.
- Pour off suspended fines slowly into another pan; be careful not to pour off coarse material.
- Add clean water to coarse material and repeat wash process until poured off water is sufficiently clear to indicate majority of fines in suspension have been poured off.
- Remove excess water from pan containing suspended fines after fines have settled by decantation and evaporation. (Do not oven-dry or add chemical substances to speed dry or hasten the settlement.)
- Oven-dry coarse material that was soaked and washed.
- Sieve oven-dried coarse material over No. 40 sieve.
- Combine –40 material obtained from plastic bag, decanted and evaporated fines, oven dried material sieved over No. 40.
  - If combined material is too moist, air-dry until water content is slightly below LL.
  - If combined material is too dry, add small quantities of water until water content is slightly below LL (peanut butter consistency).
- Place combined mixture in airtight plastic bag for at least 16 hours (overnight) so the moisture content can become consistent throughout; remix material thoroughly before testing.

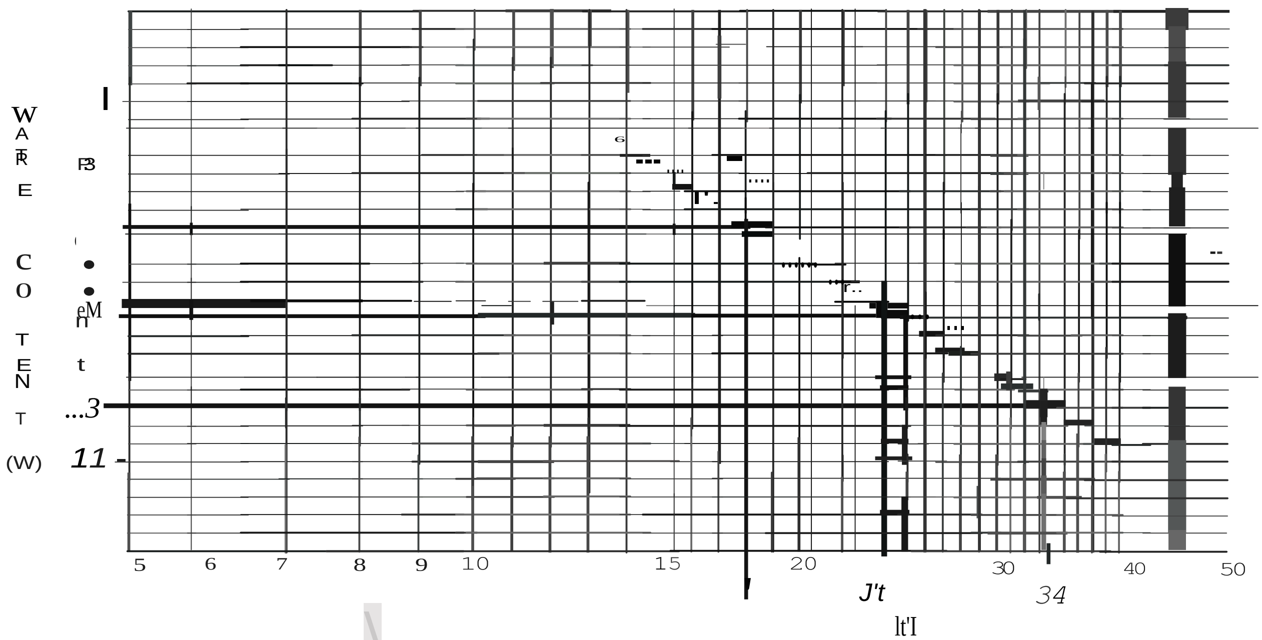
- Inspect LL device.
  - Ensure pin connecting cup is not worn permitting side play.
  - Ensure screws connecting cup to hanger arm are tight.
  - Check cup for wear; if grooved from use, replace it.
  - Check contact between cup and base; if flat on cup or dent in base can be felt, replace or repair.
  - Check grooving tool for wear.
  - Check cup drop height so point on cup meeting base (not lowest point of the cup) rises to a height of 1 centimeter; use gauge on handle of grooving tool to assist. (The height of the drop must be 1 centimeter. Use the thumbscrew at the rear of the device to make an adjustment.)
- Perform LL test. Refer to *Figure 16-42* DD Form 1209.
  - Obtain about 50 grams of 200- to 250-gram prepared sample; place in airtight container for use in PL test.
  - Record all identifying sample information on DD Form 1209 (blocks 1-5).

LIQUID- AND PLASTIC-LIMITS DETERMINATION

1. PROJECT		2. DATE
ENGINEER CENTER EXPANSION		3 Dec
3. EXCAVATION NUMBER	4. JOB NUMBER	5. SAMPLE NUMBER
5-C	16-P-T	5-C-l

6. LIQUID LIMIT, LL

RUN NUMBER	1	2	3		
TARE NUMBER	J-L.	.!J -1-	:J-J.,..		
a. WEIGHT OF WET SOIL + TARE	111!.>. "3	d-3· S-	r.01		
b. WEIGHT OF DRY SOIL + TARE	..0€	4')QI ,.;I	013,: ,,,		
c. WEIGHT OF WATER $W_w = a - b$	0(, 13	l •A./ J	l.£f 1		
d. WEIGHT OF TARE	1 7.'IJP	1r.()A.f.	/t..30		
e. WEIGHT OF DRY SOIL $W_s = b - d$	I I.Q.1.	7 , I R	7.3.		
WATER CONTENT $w = \frac{W_w}{W_s} \times 100$	1q.'3	19 q	.'?		
NUMBER OF BLOWS	:'3	ll.'I	/ !/'		



7. PLASTIC LIMIT, PL

RUN NUMBER	5	6	7	8		
TARE NUMBER	li'-JO	l> . p	;-p	i?-P		
a. WEIGHT OF WET SOIL + TARE	l\...;ll i>•f	;).. 3- ;).7	..11-j ,07	LS"'i		ff,J
b. WEIGHT OF DRY SOIL + TARE	1. c1L	Ot , (p/	.IJ ""l#	6t , t:/ S'	/t/EAN :	".o3 (+/_ t'
c. WEIGHT OF WATER $W_w = a - b$	./"'l'I-	(B	o. ,,,	Q, />/		(-
d. WEIGHT OF TARE						
e. WEIGHT OF DRY SOIL $W_s = b - d$	,.n._/	IP'• trI	'd.:> fr	(,,t:Jb		
WATER CONTENT $w = \frac{W_w}{W_s} \times 100$	V7.1,	9.7	11. 3 /O.O	/_q J.. 10./		
PLASTIC LIMIT, PL (Average w)	et.Cf					

8. REMARKS		
Fines=CL	LL =	20
PLASTIC LIMIT TARE 5-P NOT USED. POSSIBLE ERROR NOT +/- 1%	PL =	10
	PI =	10

9. TECHNICIAN (Signature)	10. COMPUTED BY (Signature)	11. CHECKED BY (Signature)
EA2 Billings	EA2 Billings	EA1 Barnes

DD FORM 1209, DEC 1999 PREVIOUS EDITION IS OBSOLETE. Adobe Professional 7.0

Figure 16-42 -Example of data sheet for LL & PL determinations. DD Form 1209.

- Label and pre-weigh three empty moisture-determination tares (boxes); record as *Weight of Tare* (block 6d).

- Place 20 to 25 grams of thoroughly mixed sample into brass cup, and level it off with a maximum depth of 1 centimeter. *(Figure 16-43*)

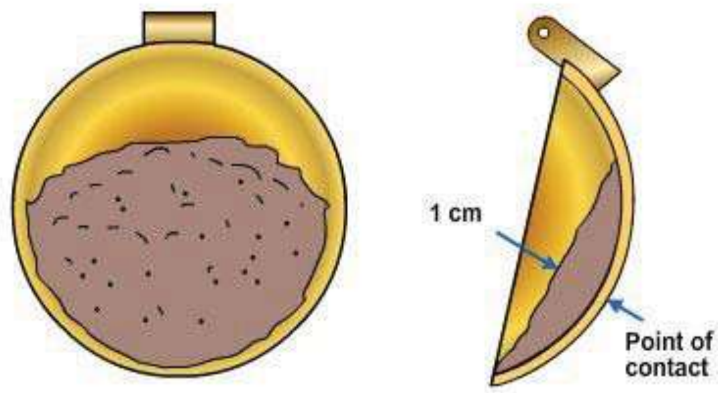


Figure 16-43 – Example of leveling LL sample into cup.

- Divide sample in cup with grooving tool so a clean, sharp groove is formed. *(Figure 16-44*)

Hold cup with cam follower upward and draw grooving tool (beveled edge forward) through specimen downward away from cam follower.

Use more than one stroke but no more than six; clean grooving tool's cutting edge after each stroke.

Avoid tearing side of groove; replace sample and regroove if side tears.

Figure 16-44 – Example of cup and grooving tool.

With some sandy and highly organic soils, it is impossible to draw the grooving tool through the specimen without tearing the sides of the groove. In such cases, the groove should be made with a spatula, using the grooving tool only for a final check of the groove). (*Figure 16-45)*

Figure 16-45 - Example of cutting groove with spatula in sandy soil.

- Attach cup to device; ensure height of drop is 1 centimeter.

- Turn crank of LL device at two revolutions per second; count blows until sample's halves make contact at bottom of groove along a distance of 13 millimeters (1/2 inch.) *(Figure 16-46)*

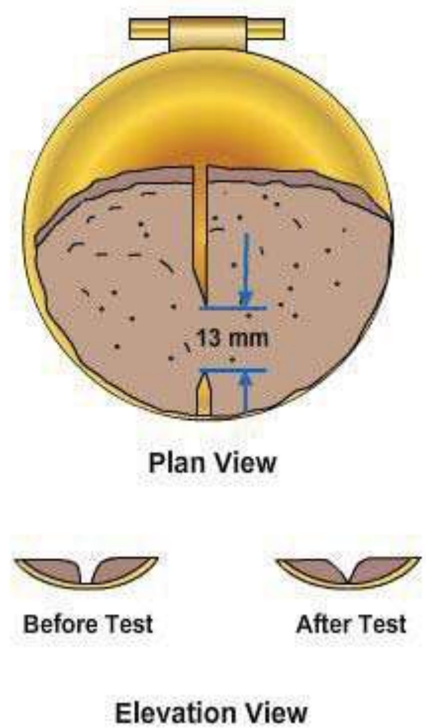


Figure 16-46 - Example of sample contact.

- Record number of blows to close groove 13 millimeters.

- Obtain 5 to 10 grams from cup to determine moisture content; take sample perpendicular to groove from edge of cup through portion that has closed in bottom of groove, as shown in *Figure 16-47*. Place in pre-weighed box; cover with lid; weigh and record as *Weight of Wet Soil + Tare* (block 6a).

Figure 16-47 - Example of removing sample for moisture determination.

- Transfer remaining cup soil to mixing dish; wash and dry cup and grooving tool.
- Remix entire soil specimen; add a little water to increase water content of sample and decrease number of blows required to close groove. Repeat steps for at least two additional trials, producing successively lower number of blows to close groove.
- Oven-dry moisture-determination samples (3 minimum); allow to cool, reweigh and record as *Weight of Dry Soil + Tare* (block 6b).
- Determine weight of water (W_w) by subtracting *Weight of Dry Soil + Tare* (block 6b) from *Weight of Wet Soil + Tare* (block 6a); record as *Weight of Water* $W_w \quad a \quad b$ (block 6c).
- Determine weight of dry soil (W_s) by subtracting *Weight of Tare* (block 6d) from *Weight of Dry Soil + Tare* (block 6b); record as *Weight of Dry Soil* $W_s \quad b \quad d$ (block 6e).
- Determine and record water content for each specimen by computing following formula:

$$W \quad \frac{W_w}{W_s} x100$$

- Plot water-content points on Form 1209 semilog graph (water versus number of blows); draw a straight line (flow line) representative of sample (3 minimum) points.

- Determine LL by interpreting the graph where the flow line intersects the 25-blow line. Record LL to nearest whole number (block 8 LL).

5.4.3 Procedure (Plastic Limit PL)

The PL of a soil is the water content, expressed as a percentage of weight of oven-dried soil, at which the soil begins to crumble when rolled into a thread millimeters in diameter. About 50 grams of material are required for the PL test.

Perform the following steps to determine the PL. Refer again to *Figure 16-42* DD Form 1209

- Label and pre-weigh two empty moisture-determination tares (boxes); record as *Weight of Tare* (block 7d).
- Obtain 50-gram sample set aside during LL test; reduce water content (if required) to obtain consistency whereby the sample can be rolled without sticking to hands while spreading or mixing continuously on glass plate. Drying process may be accelerated by air-drying only.
- Select about 2 grams (marble size) from 50-gram mass; form test specimen into ellipsoidal mass; roll on a finely ground glass plate with fingers or palm of hand to a uniform thread diameter of 3.2 millimeters (1/8 inch), taking no more than 2 minutes. *(Figure 16-48*)
    - Rolling rate should be 80 to 90 strokes per minute; count a stroke as one complete motion forward and back to starting position; rate may have to decrease for very fragile soil.

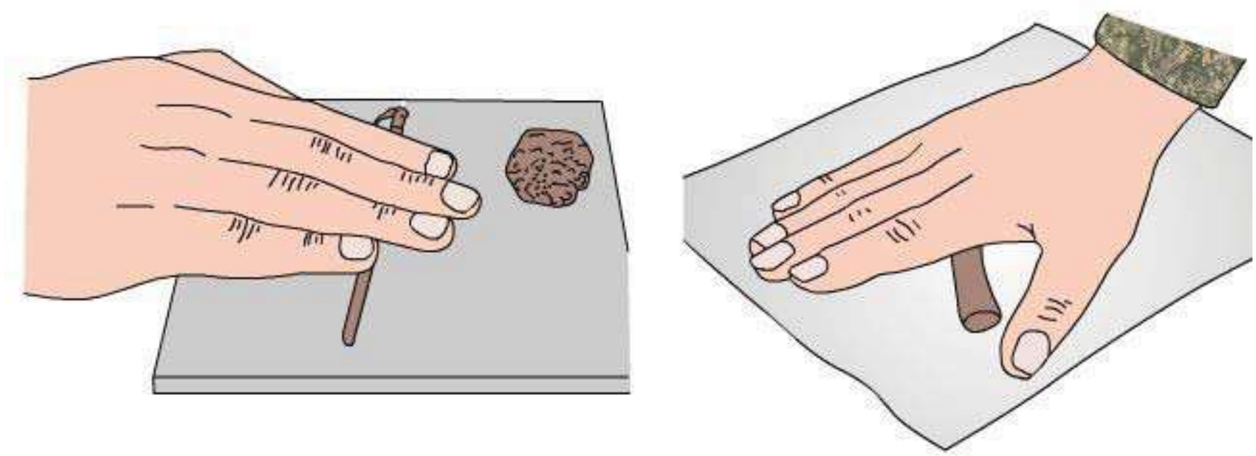


Figure 16-48 - Example of rolling Plastic Limit (PL) sample by fingers or palm.

- Remold and roll again to 3.2 millimeters diameter; repeat until total sample crumbles before reaching the 3.2-millimeters-diameter thread*. (Figure 16-49*)
    - Rolled sample may not crumble at same time; if thread breaks into smaller lengths, roll each length to 3.2 millimeters; continue until sample can no longer be remolded and rolled to 3.2-millimeter thread without total break-up.

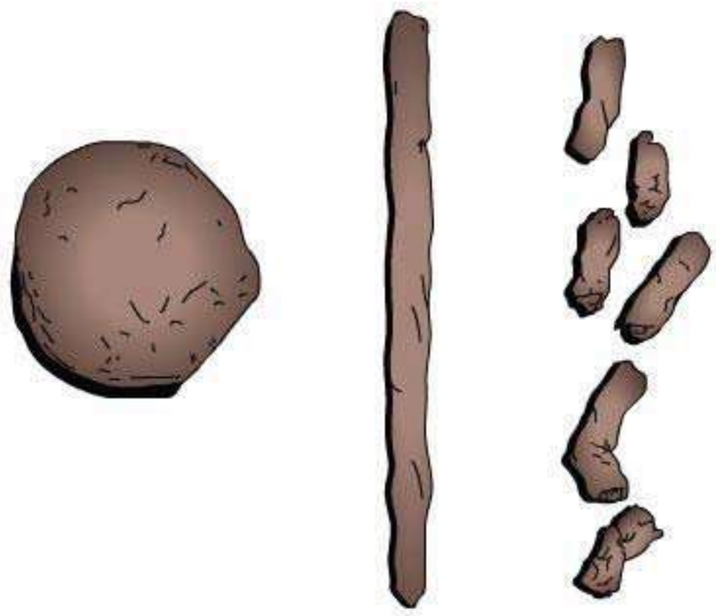


Figure 16-49 - Example of PL sample roll/thread test before and after crumbling.

- Collect and place crumbled portions into pre-weighed moisture-determination box and cover with lid.
- Repeat until crumbled threads in box weigh at least 6 grams.
- Repeat steps to obtain a second box of at least 6 grams of material.
- Weigh boxes with crumbled threads; record as *Weight of Wet Soil + Tare* (block 7a).
- Determine water content by following steps of LL test.
    - Oven-dry moisture-determination samples (2 minimum); allow to cool, reweigh and record as *Weight of Dry Soil + Tare* (block 7b).
    - Determine weight of water (W_w) by subtracting *Weight of Dry Soil + Tare* (block 7b) from *Weight of Wet Soil + Tare* (block 7a); record as *Weight Of Water* $W_w \quad a \; b$ (block 7c).
    - Determine weight of dry soil (W_s) by subtracting *Weight of Tare* (block 7d) from *Weight of Dry Soil + Tare* (block 7b); record as *Weight of Dry Soil* $W_s \quad b \; d$ (block 7e).
    - Determine and record water content for each specimen by computing following formula:

$$W \quad \frac{W_w}{W_s} x100$$

- Determine average water content of samples and record to nearest tenth as PL.

- o When determining average water content, individual tests must be within ± 1 percent of mean; any individual test not meeting this requirement will not be used (*Figure 16-42 Tare Number 5-P*); if no individual test meets this requirement, additional testing is required

5.4.4 Plasticity Index (PI) Determination

- Compute plasticity index using following formula:

$$PI \quad LL \quad PL$$

  - Record as $(LL \quad PL) \quad PI$ (block 8 PI)

- Classify soil by plotting LL versus PI on plasticity chart as follows, referring to *Figure 16-50*.
  - Material plotted on or above A line is classified as clay; material plotted below A line is classified as silt.
  - Material plotted on or right of 50 percent line has a high LL (H); material plotted left of 50 percent line has a low LL (L).
  - Upper, or U, line is an approximate upper boundary; although not impossible, any results plotted above U line should be considered suspect and tests rechecked.

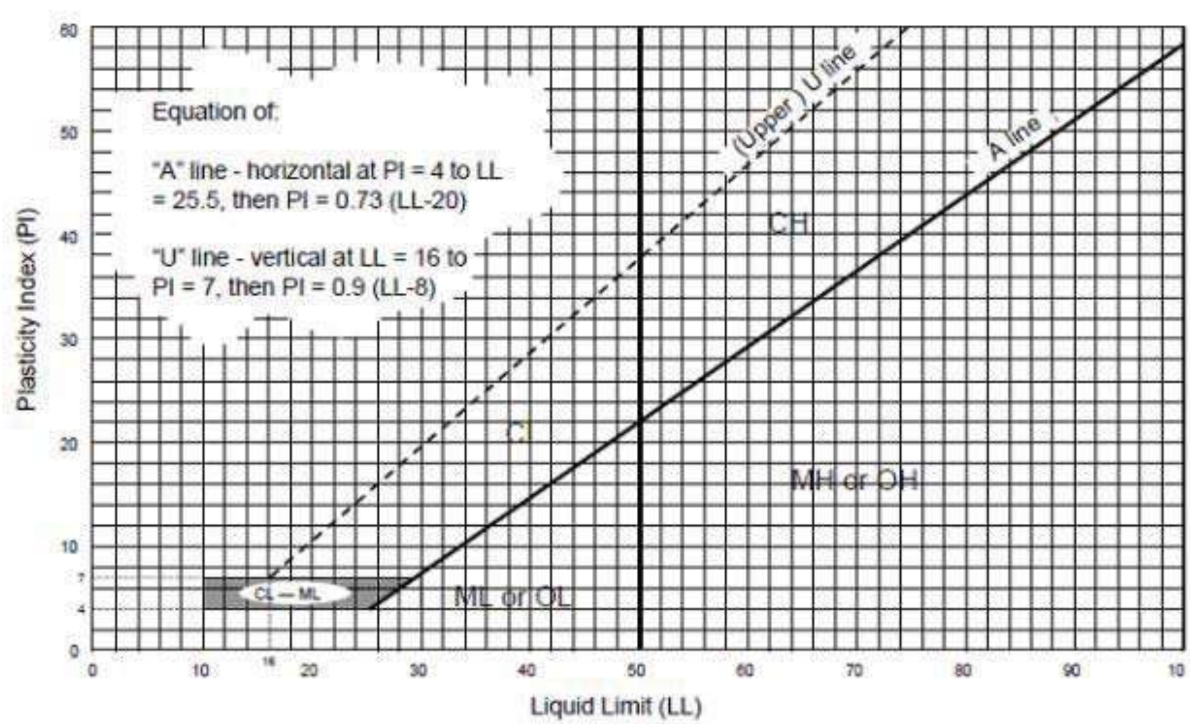


Figure 16-50 - Example of USCS Plasticity Index chart for soil classification.

Test your Knowledge (Select the Correct Response)

5. The Navy follows______procedures to test representative soil samples.

   A. American National Standards Institute (ANSI)
   B. National Institute for Standards and Technology (NIST)
   C. National Standards Body (NSB)
   D. American Society for Testing Materials (ASTM)

6.1.1 CONCRETE TESTING

Chapter 8 of this course provides information about concrete and its use in the construction industry. You may recall that concrete is one of the most economical, versatile, and universally used construction materials, as well as one of the few building materials that a user can produce directly on the job to meet the specific requirements.

To combine the ingredients correctly (on the job site or nearby), you must know the required physical properties of both the plastic and the hardened concrete. The hardened concrete must have the following:

• Strength	• Workability	• Uniformity
• Durability	• Watertightness	• Consistency

The quality and character of the hardened concrete is greatly influenced by the properties of the mix when it is plastic. To attain optimum quality, the plastic mix must be uniform, consistent, and workable while meeting the specified requirements.

Concrete testing is directed toward those properties and specified requirements.

6.1.0 Concrete Tests

In concrete testing, as in soils testing, no single test can provide all of the required information. Therefore, an array of tests must be performed to gather specific data.

The following describes common tests that you may perform as an Engineering Aid.

6.1.1 Aggregate Tests

An aggregate must provide maximum strength and durability in a concrete mixture. Fineness, coarseness, and aggregate gradation are factors considered when deriving the correct concrete mix for a specific construction purpose. Specific gravity, absorption, and moisture also affect the aggregate’s ability to bind well with cement and water in a concrete mix.

The components of the final mix (cement, water, and aggregate) must bond adequately for structural strength and must resist weather and loads.

Correct aggregate selection also reduces the project’s cost. An engineering analysis determines the aggregate best suited for a particular purpose. *(Table 16-8*)

Table 16-8 - Example of Maximum Recommended Sizes of Coarse Aggregate.

Structure	Minimum Dimension (Inches)			
	2 1/2 to 5	**6 to 11**	**12 to 29**	**30 or More**
Reinforced walls, beams, and columns	1/2 to 3/4	3/4 to 1 1/2	1 1/2 to 3	1 1/2 to 3
Unreinforced walls	3/4	1 1/2	3	6
Slabs, heavily reinforced	3/4 to 1	1 1/2	1 1/2 to 3	1 1/2 to 3
Slabs, lightly reinforced	3/4 to 1 1/2	1 1/2 to 3	3	3 to 6
NOTE: Maximum size not to exceed 1/5 of minimum dimension of a wall or similar structure, 1/3 of slab thickness for horizontal slab, or 3/4 of minimum clear spacing between reinforcing bars.				

In order to provide the strongest and most durable concrete, the aggregate contained in the mixture must be the best possible in terms of gradation, shape, strength, and cleanliness. Testing allows the best selection.

These include tests for stockpile sampling, gradation, specific gravity, absorption, and surface moisture. These tests are not included in this course, but you can learn more about aggregate testing in NAVFAC MO-330 *Materials Testing.*

6.1.2 Slump Tests

"Workability" describes the relative ease or difficulty of placing and consolidating concrete. During placing, concrete should be as stiff as possible as a homogeneous, voidless mass. However, too much stiffness makes it too difficult or impossible to work into forms and around reinforcing steel. Too fluid a mixture is also detrimental.

The measure of concrete's workability is its slump, which is a design consideration inversely proportional to the stiffness of the mix.

As shown in *Table 16-9*, recommended values for slump vary for different types of construction.

Table 16-9 - Recommended Slumps for Various Types of Construction.

Types of construction	Slump, inches*	
	Maximum	**Minimum**
Reinforced foundation walls and footings	5	2
Plain footings, caissons, and substructure walls	**4**	**1**
Reinforced slabs, beams, and walls	**6**	**3**
Building columns	**6**	**3**
Pavements	**3**	**2**
Heavy mass construction	**3**	**2**
Bridge decks	**4**	**3**
Sidewalks, driveways, and slabs on ground	**6**	**3**
*When high-frequency vibrators are used, the values may be decreased approximately one-third; in no case should the slump exceed 6 inches.		

To measure this designed inverse proportion between stiffness and workability, testers typically perform slump tests during project preparation as concrete mix trial batches and as quality control during construction. Procedures for performing slump tests will be explained later in this chapter.

6.1.3 Strength Tests

Engineers, by a combination of concrete design mix and reinforcing (if necessary), must balance the strength of concrete (compressibility) with its weakness (flexibility). A project's design mix must meet the structure's intended force loading on a given element.

Often, trial batches are prepared for a mix design test and as the project progresses, for a quality control (QC) measure to ensure that concrete mixed on site or delivered to the field satisfies those specified strengths. These mix design and QC trial batches are then subjected to the following tests.

6.1.3.1 Compression Test (ASTM C39 / C39M)

Compression tests are conducted to determine a mix design's ability to resist a crushing force.

In a standard compression test, a load is applied *parallel to the longitudinal axis* of a pre-molded and properly cured concrete cylinder of a specified standard size. (*Figure 16-51*)

A properly conducted test calculates the maximum compression load in pounds per square inch (psi) that the mix design, or QC sample, can obtain at the point the cylinder ruptures.

Figure 16-51 - Example of concrete cylinder compression test.

The test procedures themselves will be covered in EA Advanced, but the procedures for preparing the cylinders for testing will be discussed later in this chapter.

6.1.3.2 Flexural Strength Test (ASTM C 78)

Flexural strength (modulus of rupture) tests are conducted to determine a concrete's ability to resist a breaking force.

In a standard flexural test, a load is applied *perpendicular to the longitudinal axis* of a standard size, pre-molded, and properly cured concrete beam. (*Figure 16-52*)

From this test, the flexural strength, expressed in terms of modulus of rupture and given in psi, can be readily calculated.

Figure 16-52 - Example of flexural strength test.

As with the compression test, only the procedures to prepare the test beams will be discussed in this course.

6.2.0 Slump Tests

The slump test is performed on newly mixed concrete.

To perform the test, you need a slump cone and a tamping rod. *(Figure 16-53*)

The slump cone should be galvanized steel, 12 inches in height, with a base opening 8 inches in diameter and top opening 4 inches in diameter.

The top and bottom openings are perpendicular to the vertical axis of the cone.

The tamping rod is a straight steel rod 5/8 inches in diameter and approximately 24 inches in length.

One end of the rod is rounded to a diameter of 5/8 inches. (Do not substitute a piece of rebar.)

Figure 16-53 - Example of sump test equipment.

6.2.1 Sampling Procedures (ASTM C172)

Obtaining a concrete sample for a slump test should be accomplished according to ASTM C172 *Standard Practice for Sampling Freshly Mixed Concrete*.

This course will present only the procedure for sampling from a revolving drum transit mixer (TM) or agitator. If you ever need to obtain a sample from a paving mixer, open-top truck mixer, or other type of equipment, refer to the most recent ASTM C 172.

Samples taken for the test specimens must be representative of the entire batch. Accomplish this by taking partial samples at two or more regularly spaced intervals during discharge of the middle portion of the batch.

Pass a scoop or pail repeatedly through the entire discharge stream and combine the partials into one sample for testing purposes.

Be sure the first and last portions of the combined samples are taken as quickly as possible while still representing the entire batch, but never exceeding 15 minutes to gather the combined samples.

If it is necessary to transport samples away from the mixer to another location where the slump test is to be performed, combine the samples and remix them with a shovel to ensure uniformity.

6.2.2 Testing Procedures (ASTM C 143)

Perform slump tests according to ASTM C143 / C143M *Standard Test Method for Slump of Hydraulic-Cement Concrete.* Be sure to start the test within 5 minutes after obtaining the final portion of the composite sample.

Perform the following steps to determine the slump:

- Moisten inside of slump cone and place it on a flat, moist, nonabsorbent (rigid) surface. Hold in place during filling by standing on two foot pieces.

NOTE: Complete the following steps in an elapsed time of no more than 2 1/2 minutes.

- Fill slump cone to one-third volume (2 5/8 inches high) with plastic concrete.
- Rod concrete by applying 25 evenly distributed strokes; penetrate full depth of first layer.
- Add second layer until two-thirds volume filled (about 6 1/8 inches high).
- Rod second layer as first with rod just penetrating underlying first layer.
- Add third and last layer; overfill if possible.
- Rod third layer as second with rod just penetrating underlying second layer; if height subsides below top of cone, add concrete to keep above top of mold.
- Strike off excess concrete with tamping rod in screeding and rolling motion so cone is completely filled.
- Remove slump cone from concrete.
    - Place hands on handles and press downward.
    - Step off footholds.
    - Raise cone carefully and quickly in vertical direction.
        - Raise cone a distance of 12 inches within 5 to 7 seconds by a steady upward lift with no lateral or twisting motion.

- Place cone directly beside slumped concrete.
  - At this point, about 2 1/2 minutes should have elapsed since start of filling.

- Measure and record slump immediately, as shown in *Figures 16-54 and 16-55*.
  - Place tamping rod along top of cone so it projects over concrete.
  - Measure slump from bottom of rod to top center of concrete with a ruler.
  - Record slump to nearest ¼ inch.

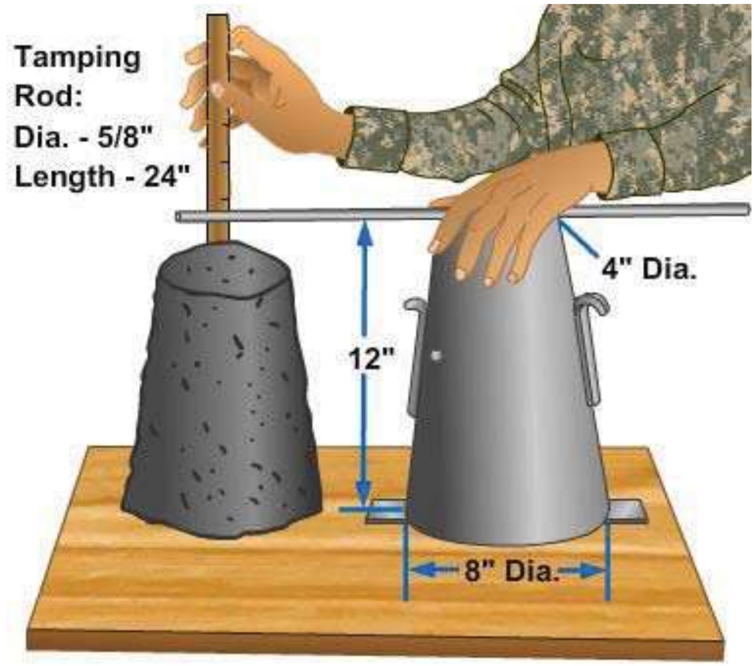


Figure 16-54 - Example of measuring slump.

Figure 16-55 - Seabee performing slump test.

If a decided falling away or shearing off occurs from one side or portion of the specimen mass, disregard the measurement and make a new test on another portion of the sample.

If two consecutive tests show falling away or shearing off, the concrete probably lacks the necessary plasticity and cohesiveness for the slump test to be applicable.

After measuring and recording to the nearest ¼ inch, the slump test is complete. However, as a supplementary procedure, tap the sides of the specimen gently with the tamping rod. The reaction of the concrete will indicate its cohesiveness and workability.

A well-proportioned, workable mix gradually slumps to lower elevations and retains its original identity. A poor mix crumbles, segregates, and falls apart.

If a slump test is for a mix design's trial batch, then too little or too much slump indicates the need for a new trial batch with revised mix proportions.

When the test is for a quality control measure, the slump obtained by testing will be compared to the slump specified for that particular project or element of that project. If QC testing reveals too little or too much slump, the quality control inspector or other appropriate authority will need to determine whether to accept or reject the concrete.

6.3.0 Preparation of Concrete Specimens

Concrete specimens representative of a distinct batch of concrete must be sampled and analyzed for quality control. The number of specimens tested depends on the job specifications. If no requirement is listed in the specifications, a minimum of 2 will be molded for each test age for each 100 cubic yards, or fraction thereof, of each class of concrete placed in any one day.

A third specimen may be taken to assist in determining when forms may be removed. The test specimens must remain on site and undisturbed for an initial curing period (the first 16 to 48 hours after molding). Normally the test ages are 7 and 28 days for compressive strength tests.

6.3.1 Cylinder Specimens

Concrete cylinder specimens are taken to perform tests evaluating the compressive strength of the concrete. (*Figure 16-56*)

Compressive strength is defined as the average of the strengths of all cylinders of the same age made from a sample taken from a single batch of concrete.

At least two cylinders are required to constitute a test. Therefore, a minimum of four specimens are required if tests are to be made at 7 and 28 days.

The test results will be the average of the strengths of the two specimens tested at 28 days.

The standard cylindrical specimen is 6 inches in diameter by 12 inches long.

Figure 16-56 - Typical concrete cylinder mold.

6.3.1.1 Standards for Cylinder Molds

Figure 16-57 - Seabee making typical concrete cylinder molds.

Cylinder molds should be made of steel, cast iron, or other nonabsorbent material that does not react with concrete containing Portland cement or other hydraulic cements.

Molds should hold their dimensions and shapes under severe use.

They should hold water poured into them without leakage. (*Figure 16-57*)

6.3.1.2 Filling Cylinder Molds

Place the molds on a level, rigid surface, free of vibration or other disturbances, at a place as near as possible to the location where they are to be stored for the first 24 hours.

Perform the following steps to produce and label a concrete cylinder for testing:

- Prepare mold.
  - Clean and dry.
  - Oil lightly.
  - Assemble.
- Make cylinder.
  - Fill mold one-third full with fresh concrete.
  - Consolidate concrete by applying 25 evenly distributed strokes over mold's surface area with tamping rod; rod must totally penetrate layer.
  - Tap side of mold 8 to 10 times with tamping rod.
  - Add concrete to two-thirds full.
  - Apply 25 evenly distributed strokes to mold's surface area using rounded end of tamping rod; rod must pass through second layer and 1 inch into first layer.
  - Tap side of mold 8 to 10 times with tamping rod.
  - Add concrete to slightly overfill.

- Apply 25 strokes; rod must pass entirely through and 1 inch into second layer.
    - Tap side of mold 8 to 10 times with tamping rod.
    - Trowel off concrete so it is flush with top of mold and smoothly finished.
- Label mold; as a minimum, label should include:
    - Specimen number.
    - Date cylinder was made.
    - Project or placement concrete came from.
        - The system of labeling is optional. The information should be recorded on a paper tag or gummed label and attached to the mold.
- Cover cylinder with plastic or wet burlap to maintain moisture; covering should be tight around cylinder but not make contact with fresh concrete.
- Allow cylinder to cure undisturbed for 24 hours.
- Remove covering and mold from cylinder after 24 ($\pm$8) hours.
- Transfer label from mold to concrete cylinder; label may be transferred or information recorded directly on cylinder with grease pencil.
- Cure cylinder.

6.3.1.3 Curing and Storing Cylinders

During the initial curing period of test specimens, be sure to take precautions to prevent the evaporation and loss of water in the specimens. After an initial curing period of16 to 48 hours, remove specimens from the job site that are intended for checking the strength of trial design mixtures or QC of field concrete.

Take them to the testing laboratory, moist-cure them at 73.4°F, and store them in moist rooms, damp sand or sawdust, or limewater to maintain free water on all surfaces of the specimen at all times.

Occasionally, some test specimens are made in the field to determine when forms may be removed. These specimens are in addition to the required number of specimens formed for strength determination. Give these specimens (as much as possible) the same protection as the specimens for compression testing. Store them in or on the structure as near as possible to the point of use. Test them in the moist condition resulting from the specified curing treatment.

Specimens intended for testing to determine when a structure may be put into use are removed from the molds at the same time the forms are removed from the structure.

To ship specimens to a laboratory, pack them in a sturdy wooden box or other suitable container surrounded by wet sawdust or wet sand. Provide protection from freezing during storage or shipment. Moist curing is continued when the specimens are received in the laboratory.

6.3.1.4 Capping Cylinders

To prepare cylinders for testing, plane the ends of compression-test specimens within 1.2 inch and within 0.5 degree of being perpendicular to the axis of the cylinder.

- 2 to 4 hours after molding, cap specimens formed in strong metal molds having accurately flat baseplates.

- Make a stiff paste of Portland cement and water at time cylinder is molded so capping mixture will shrink before application.
- Remove any free water or laitance (layer of fine particles on surface) from end of specimen.
- Apply paste to top of concrete and work with a flat plate until smooth and level with top of mold.

Grind hardened concrete specimens to smooth the ends or cap them with a material having greater compressive strength than the concrete.

- Prepared mixtures of sulfur and granular materials, special high-strength gypsum plasters, and neat high-early strength cement are satisfactory capping materials.
- Ordinary low-strength plaster of paris, compressible rubber, or fibrous materials are not suitable for caps.
- Apply selected material in a plastic state and finish to desired plane surface by applying glass or metal plates and squeezing out excess material to provide a cap that is as thin as possible.

Apply sulfur caps in time to harden at least 2 hours before testing. Plaster caps cannot be stored over 4 hours in the moist room. Age neat cement caps 6 days or more in the moist room (2 days when Type II cement is used).

During capping, protect moist-cured specimens against drying by covering them with wet burlap.

There are numerous alternatives to sulfur caps listed in ASTM C 617 *Standard Practice for Capping Cylindrical Concrete Specimens*. If you must use sulfur caps, ensure that sulfur vapors are not inhaled while heating the capping compound. Ensure there is adequate ventilation and respiratory protection is used. Used sulfur capping compound is a hazardous material and must be properly disposed of.

6.3.2 Beam Specimens

The flexural strength of hardened concrete is measured by using a simple concrete beam and third-point loading mechanism. The flexural strength is determined by calculating measured breaks of the beam and is expressed as a modulus of rupture in psi.

The standard beam specimen is 6 x 6 x 21 inch (152 x 152 x 532 mm.) for concrete in which the maximum size of the coarse aggregate is 2 in. (50 mm). When the maximum size of the coarse aggregate exceeds 2 in. (50 mm), the smaller cross-sectional dimension is to be increased to at least three times the nominal maximum size of the coarse aggregate.

All beam specimens prepared in the field are to be the standard beam size (6 in. wide by 6 in. deep by 21 in. long) unless required otherwise by project specifications.

6.3.2.1 Standards for Beam Molds

Beam molds are to be smooth on all interior surfaces and free from warpage. The molds are to produce specimens that do not exceed the required cross-sectional dimensions by 1/8 inches. The length of a specimen is not to be more than 1/16 inches shorter than the specified length, but may exceed that length.

6.3.2.2 Rodding

Assemble a standard 6- x 6- x 21-inch concrete-beam mold and lightly oil the inside. Fill the mold with two layers of concrete from the production batches, each about 3 inches deep. Consolidate each layer by rodding, using one stroke per 2 square inches (63 per layer), evenly distributed over the layer's surface.

Tap the sides lightly 10 to 15 times with a rubber mallet to close the voids left by rodding. Lightly spade the concrete along the mold's sides with a trowel to help remove surface voids. When rodding the second layer, penetrate the first layer about 1/2 inch. Strike off the top surface with a straightedge, finish it with a wood or magnesium float.

6.3.2.3 Curing

Place a suitable identifying label on the finished surface of the specimens. Cover the entire specimens—still in the mold—with a double thickness of wet burlap. Ensure that the specimens remain on site and are undisturbed for an initial curing period (the first 16 to 48 hours after molding).

After this curing period, move them to the testing laboratory and remove them from the molds for further curing. The most satisfactory curing range for concrete is 68° to 86°F, with 73.4°F being the most favorable temperature. Moist-cure the beams in saturated lime water, totally submerged in a wet-tank humidity room, or keep them wet until they are tested.

When transporting specimens from the field to the laboratory, be sure they are sufficiently cushioned to protect them from damage by jarring. Additional measures are required to prevent damage by freezing temperatures and moisture loss. You can prevent moisture loss by covering the specimens with plastic or surrounding them by wet sand or wet sawdust.

Summary

Engineering Aids are part of a project from its initial stages. (*Figure 16-58*) Proper testing and analysis of local soil and available aggregate can determine the feasibility of a project at a proposed site. As an EA, the data and information you garner will allow design engineers to make decisions about the foundation (earth) under a foundation, and determine the viability of aggregate use in a concrete mix design. Each decision has its associated cost impact, so your accurate calculations are important in multiple ways.

Figure 16-58 - Materials testing applies to soils, aggregate, and concrete.

Review Questions (Select the Correct Response)

1. Soil is a mixture of mineral grains enclosing various sizes of voids that contain _____.

   A. air (or other gases)
   B. water
   C. organic matter
   D. air (or other gases), water, and organic matter

2. Into how many groups do geologists classify rock?

   A. Two
   B. Three
   C. Four
   D. Five

3. What classification of rock is formed by cooling from a molten state?

   A. Igneous
   B. Sedimentary
   C. Metamorphic
   D. Organic

4. What classification of rock is formed by accumulation of particles and remains of plants and animals?

   A. Igneous
   B. Sedimentary
   C. Metamorphic
   D. Organic

5. What classification of rock is formed by pressure and heat applied to existing rock?

   A. Igneous
   B. Sedimentary
   C. Metamorphic
   D. Organic

6. What is the term for the physical and chemical process that transforms rock into a loose, incoherent mixture?

   A. Atmospheric exposure
   B. Decomposition
   C. Disintegration
   D. Weathering

7. **(True or False)** Transported soil will reflect the characteristics of the underlying parent rock from which it was derived.

   A. True
   B. False

8. Examples of alluvial soil can be found in______.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

9. Examples of lacustrine soil can be found in______.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

10. Examples of aeolian soil can be found in______.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

11. Examples of glacial soil can be found in______.

   A. mouths of river deltas
   B. freshwater lakes and rivers
   C. dunes
   D. eskers, kames, and moraines

12. What is the term for fine particles that pass the No. 200 sieve and exhibit plasticity and strength?

   A. Marine soil
   B. Clay
   C. Silt
   D. Colluvial soil

13. What is the term for fine particles that pass the No. 200 sieve and exhibit little plasticity and strength?

   A. Marine soil
   B. Clay
   C. Silt
   D. Colluvial soil

14. According to the Unified Soil Classification System, materials retained on a 3-inch sieve are classified as______.

A. sands
B. fines
C. gravels
D. cobbles

15. Which bulky particle shape is considered the most desirable for construction purposes?

A. Angular
B. Subangular
C. Rounded
D. Subrounded

16. Well-graded soils consist of______particle sizes.

A. uniformly graded large
B. uniformly graded small
C. uniformly graded intermediate
D. a good representation of all

17. In a dense structure with a high degree of compactness,______.

A. closely packed soil particles interlock with smaller grains
B. uniformly graded large particles compact together
C. uniformly graded small particles compact together
D. uniformly graded intermediate particles compact together

18. What is the minimum-maximum specific gravity range of most inorganic soils?

A. 2.60 -- 2.65
B. 2.60 -- 2.80
C. 2.65 – 3.00
D. 3.00 -- 3.50

19. Which soil property has the greatest effect on soil when subject to loading?

A. Specific gravity
B. Gradation
C. Moisture Content
D. Plasticity

20. Which of the following best describes the term “hydroscopic moisture”?

A. Soil water absorbed by the atmosphere
B. Absorbed moisture in soil at any time
C. Absorbed moisture in air-dried soil
D. Thin films of water surrounding soil particles

21. Which of the following factors does the term “moisture content” (symbol W) refer to?

A. The amount of free water in a soil sample
B. The proportion of the weight of water to the weight of wet soil expressed as a percentage
C. The amount of hydroscopic moisture in a soil sample
D. The proportion of the weight of water to the weight of dry soil expressed as a percentage

22. Which of the following properties of fine-grained soil permits clay to be rolled into thin threads at certain moisture contents without crumbling?

A. Liquidity
B. Consistency
C. Plasticity
D. Cohesiveness

23. Which of the following terms is used to describe the boundary where further loss of moisture does not change a soil’s volume?

A. Liquid Limit
B. Plastic Limit
C. Plasticity Index
D. Shrinkage Limit

24. Which of the following terms is used to describe the moisture content corresponding to the arbitrary limit between the liquid and plastic state of a soil?

A. Liquid Limit
B. Plastic Limit
C. Plasticity Index
D. Shrinkage Limit

25. Which of the following terms is used to describe the moisture content corresponding to the arbitrary limit between the plastic and semisolid state?

A. Liquid Limit
B. Plastic Limit
C. Plasticity Index
D. Shrinkage Limit

26. Which of the following constructions would be least affected by soil moisture?

A. An asphaltic-cement road laid on a sand-clay admixture
B. A concrete building foundation laid on a base of fine-grained soil
C. A concrete building foundation laid on a gravel base
D. An asphaltic-cement runway laid on a gravel-clay admixture

27. What soil classification often undergoes large volume changes with variations in moisture content?

A. Gravel
B. Sand
C. Silt
D. Clay

28. According to the United Soil Classification System, what are the three major divisions of soil classifications?

A. Course-grained, Fine-grained, Organic
B. Course-grained, Fine-grained, Sand
C. Course-grained, Peat, Organic
D. Cobble, Fine-grained, Organic

29. What is the soil classification when less than half of the coarse-grained portion of a soil sample is retained on a No. 4 sieve?

A. Gravel
B. Sand
C. Clay
D. Silt

30. When samples are taken by test holes with the hand auger, the samples may be completely disturbed, but they are satisfactory for determining which of the following information?

A. Compaction capabilities
B. Moisture content
C. Soil profile
D. All of the above

31. From which of the following locations was a soil sample tagged CB-P3-1 taken?

A. Project CB, bag No. P3, pit No. 1
B. Project CB, pit No. 3, location No. 1
C. Construction battalion pit No. 3, area No. 1
D. Construction borrow pit No. P3, bag No. 1

32. For which of the following tests are disturbed samples satisfactory for use?

A. Mechanical analysis
B. Frost susceptibility
C. Specific gravity
D. All of the above

33. How large a sample is enough to determine the moisture content of fine-grained soils?

A. 50 grams
B. 75 grams
C. 100 grams
D. 200 grams

34. A moisture content sample taken at 0730 will not be tested until 1430. At a minimum, what action, if any, should be taken to prevent the evaporation of moisture from the soil?

A. Seal the canister with friction tape.
B. Dip the canister in paraffin.
C. Wrap the canister with a paraffin-coated cloth.
D. None, since the test will be performed within 1 day.

35. For which of the following soil properties are undisturbed soil samples tested?

A. In-place density
B. Shear strength
C. Compressive strength
D. All of the above

36. For which of the following soil types would an undisturbed chunk sample be best suited for sampling?

A. Highly plastic
B. Cohesionless
C. Slightly plastic
D. Moderately cohesive

37. Which of the following steps should be taken next after removing a CBR mold and undisturbed sample from a hole?

A. Remove the cutting edge.
B. Coat the top of the sample with paraffin.
C. Remove the upper collar and trim a ½-inch recess in the top of the mold.
D. Place boards over both ends.

38. Which of the following methods is one way to be certain that a soil sample is representative of the whole sample?

A. Soaking
B. Straining
C. Quartering
D. Halving

39. What quarter(s) should you discard when quartering a sample?

A. Any single quarter
B. Two adjacent quarters
C. Two diagonally opposite quarters
D. Any three quarters

40. What is the identified sequence of a complete soil test as laid down by the American Society for Testing Materials (ASTM)?

A	Determine specific gravity
B	Determine moisture content
C	Determine moisture-density relationship
D	Determine grain size and distribution
E	Determine the field moisture content
F	Determine Atterberg limits

A. A, B, F, C, E, D
B. B, C, A, D, F, E
C. B, D, A, F, C, E
D. B, D, C, A, E, F

Refer to Figure PC 16-1 for questions 41-44
Table of Values from DD Form 1205
Compute water content for each run.

Test	**Natural Soil Moisture Content**					
Run Number	1	2	3			
Tare Weight	6	7	9			
A. Weight of Tare + Wet Soil	196.4	187.3	209.6			grams
B. Weight of Tare + Dry Soil	176.8	169.9	190.2			grams
C. Weight of Water, $W_w \quad (A \;\; B)$						grams
D. Weight of Tare	43.6	44.0	46.4			grams
E. Weight of Dry Soil, $W_s \quad (B \;\; D)$						grams
Water Content, $w \quad \frac{W_w}{W_s} x100$	%	%	%			

Figure PC 16-1

41. What is the dry weight in grams of the soil in run number 1?

A. 176.8
B. 152.8
C. 143.6
D. 133.2

42. What is the weight of water in grams in run number 2?

A. 17.4
B. 17.6
C. 18.4
D. 18.6

43. What is the water content of run number 3?

A. 13.0%
B. 13.2%
C. 13.5%
D. 17.4%

44. What is the average moisture content of the three runs?

A. 13.4%
B. 14.0%
C. 31.1%
D. 41.9%

45. Sieve analysis applies to soils that are larger than the______sieve.

A. ½ inch
B. No.4
C. No.40
D. No. 200

46. When is it necessary to prewash a sample before proceeding with a normal dry sieve analysis?

A. When the sample is too dry
B. When the sample has an undesirable water content
C. When the sample contains too little superfine materials
D. When the sample contains cohesive soil forming hard lumps

47. _____retain on a No. 4 sieve.

A. Sands
B. Fines
C. Gravels

48. _____pass a No. 4 sieve and retain on a No. 200 sieve.

A. Sands
B. Fines
C. Gravels

49. _____pass a No. 200 sieve.

A. Sands
B. Fines
C. Gravels

50. During a sieve analysis, 2% of the material passed the No. 200 sieve. What subsequent test should you perform on the sample to determine this soil's susceptibility to frost?

A. Hydroscopic moisture content
B. Hydrometer analysis
C. Specific gravity
D. Moisture-density relationship

51. Which of the following materials should you test for specific gravity of solids after a sieve analysis has been performed?

A. Only those larger than the No. 40 sieve
B. Only those retained on the No. 4 sieve
C. Only those passing the No. 4 sieve
D. Materials passing the No. 200 sieve

52. Which factor in the calculation for Specific Gravity of Solids has the least impact on the outcome? $G_s \quad \frac{W_s K}{W_s + W_{bw} \quad W_{bws}}$

A. W_s dry weight of the sample
B. K correction factor based on the density of water at 20ºC
C. W_{bw} weight of the flask filled with water only
D. W_{bws} weight of the flask, water, and sample

53. How should the surface of a saturated-surface-dry (SSD) sample appear?

A. Very wet
B. Very dry
C. Damp
D. Pitted

54. The______is the point at which the material contains the greatest water content and remains plastic.

A. plasticity index (PI)
B. plastic limit (PL)
C. liquid limit (LL)
D. shrinkage limit (SL)

55. The______is the point at which the material contains the lowest water content and remains plastic.

A. plasticity index (PI)
B. plastic limit (PL)
C. liquid limit (LL)
D. shrinkage limit (SL)

56. The______is the point at which, with further drying, shrinkage stops.

A. plasticity index (PI)
B. plastic limit (PL)
C. liquid limit (LL)
D. shrinkage limit (SL)

57. Beyond what limit should you consider results suspect when entering data on a USCS Plasticity Chart?

A. Below 50 LL
B. Above 51 LL
C. Below A line
D. Above U line

58. What property of concrete does the slump test measure?

A. Compressibility
B. Workability
C. Durability
D. Strength

59. From which portion of a batch should a slump test be taken at 2 or more regularly spaced intervals?

A. First and middle
B. Middle only
C. First and last
D. Middle and last

60. How many times is each layer of a slump test rodded?

A. 10
B. 15
C. 25
D. 30

61. For a slump test, what should the elapsed time be from beginning of fill to lifting the cone?

A. 2 ½ minutes
B. 5 minutes
C. 7 ½ minutes
D. 10 minutes

62. What are the dimensions of a standard concrete cylinder specimen?

A. 6 in. diameter by 6 in. long
B. 6 in. diameter by 12 in. long
C. 8 in. diameter by 6 in. long
D. 8 in. diameter by 12 in. long

63. A standard size cylinder specimen should be filled in______layers and rodded _____times at each layer.

A. 2, 25
B. 2, 50
C. 3, 25
D. 3, 50

Trade Terms Introduced in this Chapter

Atterberg	Albert Mauritz Atterberg (1846–1916). Swedish chemist and agricultural scientist who created the Atterberg limits commonly referred to by geotechnical engineers and engineering geologists.
California Bearing Ratio (CBR)	A penetration test for evaluation of the mechanical strength of road subgrades and basecourses.
Colloidal	Of a mixture in which very small particles of one substance are distributed evenly throughout another substance. The particles are generally larger than those in a solution and smaller than those in a suspension.
Hydrometer	An instrument used to measure the specific gravity (or relative density) of liquids, that is, the ratio of the density of the liquid to the density of water.
Laterite	A red, porous, claylike soil formed by the leaching of silica-rich components and enrichment of aluminum and iron hydroxides.
Nomographic chart	A chart representing numerical relationships.
Weathering	The physical disintegration and chemical decomposition of earth materials at or near the earth's surface.

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.

Materials Testing, FM 5-472 Ch.2 /NAVFAC MO 330/AFJMAN 32-1221(I) Headquarters, Department of the Army, Washington, DC, 1 July 2001

Standard Method for Particle-Size Analysis of Soils, ASTM D422-63, American Society for Testing and Materials, Philadelphia, Pa., 2007.

Standard Practice for Capping Cylindrical Concrete Specimens, ASTM C617 - 98(2003), American Society for Testing and Materials, Philadelphia, Pa., 2003.

Standard Practice for Making and Curing Concrete Test Specimens in the Field, ASTM C31 / C31-8b, American Society for Testing and Materials, Philadelphia, Pa, 2008.

Standard Practice for Sampling Freshly Mixed Concrete, ASTM C172-08, American Society for Testing and Materials, Philadelphia, Pa., 2008.

Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM D2487 - 06e1, American Society for Testing and Materials, Philadelphia, Pa., 2006.

Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass ASTM D2216 – 05, American Society for Testing and Materials, Philadelphia, Pa., 2005.

Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils, ASTM D4318 – 05, American Society for Testing and Materials, Philadelphia, Pa, 2005.

Standard Test Method for Slump of Hydraulic Cement Concrete, ASTM C143 / 143M - 08, American Society for Testing and Materials, Philadelphia, Pa, 2008.

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Chapter 17

Care and Adjustment of Survey Equipment

Topics

1.0.0 Care of Instruments

2.0.0 Instrument Adjustments and Repairs

To hear audio, click on the box.

Overview

The accuracy and quality of any survey will depend upon the skills and abilities of the survey crew. However, the underlying foundation for a crew's accurate survey is the quality and condition of the surveying equipment. Equipment that has not been cared for and maintained becomes inaccurate, and inaccurate equipment will negatively affect a survey regardless of the skills of the crew.

Taking proper care of your survey equipment cannot be overemphasized; therefore, the first part of this chapter will address proper instrument handling, stowing, and maintenance practices.

The second part of this chapter will address instrument adjustment and repair. As used in this chapter, the term "adjustment" means bringing the various fixed parts of an instrument into proper relationship with one another. It is different from the ordinary operations of leveling the instrument, aligning the telescope, and so forth.

As an EA, you need to be able to correctly maintain the equipment and adjust the fixed elements into sync as a matter of routine.

Objectives

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

1. Describe the care and maintenance of surveying equipment.
2. Describe the methods for conducting instrument adjustment and repairs.

Prerequisites

None

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

Topographic Surveying and Mapping		ENGINEERING AID BASIC
Indirect Leveling/Level and Traverse Computations		
Care and Adjustment of Survey Equipment		
Materials Testing: Soil and Concrete		
Direct Leveling and Basic Engineering Surveys		
Horizontal Control		
Direct Linear Measurements and Field Survey Safety		
Surveying: Elements and Equipment		
Construction Drawings		
Electrical: Systems and Plans		
Mechanical: Systems and Plans		
Concrete and Masonry		
Wood and Light Frame Structures		
Drafting: Projections and Sketching		
Drafting: Geometric Construction		
Drafting: Fundamentals and Techniques		
Drafting: Equipment		
Mathematics and Units of Measurement		
Engineering Aid Rating		

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 CARE of INSTRUMENTS

A user's manual accompanies every survey instrument in the Table of Allowance (TOA).

Each manual provides information on the appropriate care and maintenance of a specific instrument as well as instructions on the functions, operations, and adjustments of its various components.

You should thoroughly study each user's manual, such as the one shown in *Figure 17-1*, before you attempt to use that instrument.

Some suggestions for the care and maintenance of surveying equipment are discussed in the following paragraphs.

Figure 17-1 — Typical theodolite user's manual.

1.1.0 Handling, Carrying, and Stowing

When you handle any surveying instrument, such as the transit, level, theodolite, or plane table, always exercise great care. Each is a precision instrument intended for operation in the robust world of construction.

CAUTION

NEVER leave an instrument unattended while set up on a street, near construction work, or in any other place where it can be damaged.

CAUTION

NEVER grasp the telescope to remove an instrument from its carrying case. Wrenching the telescope could damage a number of delicate parts.

When you set up an instrument, make sure it is securely fastened to the tripod head. However, only tighten the various clamp screws, leveling screws, and adjustment screws to a firm bearing; overtightening could strip the threads, twist off the screw, bend the connecting part, or place undue stresses on the instrument.

When you carry an instrument, ensure that all clamp screws are only lightly clamped so that the parts will move if the instrument is struck.

When you carry a tripod-mounted instrument, place it on one shoulder with the tripod legs pointing forward, and hold them together with your hand and forearm. If you are walking on the side of a hill, carry the instrument on the downhill shoulder; this leaves the uphill arm and hand free to catch yourself if you trip or stumble.

Do not carry an instrument on your shoulder through doorways or beneath low-hanging branches; under those circumstances, carry it under your arm with the head of the instrument to the front.

If you need to climb over a fence, first place the instrument on the other side with the tripod legs well spread.

Figure 17-2 — Examples of typical instrument cases.

Every transit, theodolite, or level comes equipped with a carrying box or case so the instrument and its accessories can be stowed in a manner that ensures a minimum of motion during transportation.
Always stow an instrument in its carrying case when not in use. (*Figure 17-2*)

For carrying stakes and hubs, canvas bags with shoulder straps are usually provided. They closely resemble a newsboy's bag.

In fact, a newsboy's bag makes an excellent carrying bag for stakes and hubs, as does a Navy seabag equipped with a shoulder strap. (*Figure 17-3*)

Figure 17-3 — Typical bags for stakes and hubs.

Also provided are various other types of leather or canvas bags and sheaths for items such as chaining-pin quivers, plumb-bobs, and Abney and Locke levels. Most of these can be attached to the belt.

In addition, leather pouches, also usually attachable to the belt, are available for carrying small hand tools, marking equipment, turning-point pins, and the like.

In time, you will learn various conveniences, such as carrying your supply of surveyor's tacks by sticking them in a rubber ball or a piece of softwood attached to your belt.

1.2.0 Cleaning and Lubrication

You must clean all surveying instruments, equipment, or tools immediately after you use them. Dust off the transit or theodolite and wipe it dry before you place it back in its case. Remove all dust with a soft brush before wiping dirty components with a clean cloth. If the instrument becomes wet, remove it from its carrying case and dry it thoroughly at room temperature once you get back to your workstation.

CAUTION

NEVER leave a wet instrument stored in the carrying case.

CAUTION

NEVER rub the lenses of a telescope with your fingers or a rough cloth. Use a lint-free soft cloth or clean chamois leather instead.

Occasionally, you may need to clean the lenses with a soft cloth dampened with a mixture of equal parts water and alcohol.

Immediately after each use, always remove mud and dirt from tripods, range poles, leveling rods, and so forth, especially when the surveying gear is made of a material susceptible to rust or decay.

When lubricating instruments, always use the right lubricant recommended for the climatic condition in your area. For instance, in sub-zero temperatures, graphite is the recommended lubricant for a transit's moving parts, while a light film of oil (preferably watch oil) is the recommendation in warmer climates.

If you are ever in doubt, before doing anything to an instrument, consult the manufacturer's manual or your senior EA.

2.0.0 INSTRUMENT ADJUSTMENTS and REPAIRS

Properly maintaining equipment to inspection standards facilitates quality work and accurate surveys. As part of their tasking, Engineering Aids make minor adjustments and repairs to surveying instruments, that is, those that can generally be done in the field using simple tools. Major adjustments and major repairs generally need to be done in the factory.

If the instrument's defect cannot be corrected by a minor adjustment or minor repair, do not attempt to disassemble it; instead, arrange to send the instrument to the manufacturer. Most surveying instruments are precision instruments that require special skills and tools for major adjustments and recalibration. Only the instrument company or its subsidiaries can provide these.

2.1.1 Instrument Adjustments

As stated previously, in this chapter, adjustment means the process of bringing the various parts of an instrument into proper relationship with one another. To be a qualified surveyor, you must have the ability to make these adjustments.

To make proper adjustments, a qualified surveyor must:

1. Be familiar with the principles upon which the adjustments are based.
2. Know the methods or tests used to determine if an instrument is out of adjustment.
3. Know the procedure and sequence for making adjustments.
4. Be able to tell what effect an adjustment of one element will have on other parts.
5. Understand the effect of each adjustment when it is actually used for measurement.

Generally, instrument adjustments involve the level tubes, the telescope, and the ***reticle*** [**ret**-i-k*uh*l]; for example, if one or both of the plate-level bubbles of an engineer's transit are centered when the plate is, in fact, not level, the instrument is out of adjustment.

An optical instrument equipped with vertical and horizontal cross hairs is out of adjustment if the point of intersection between the cross hairs does not coincide with the optical axis. If the reflected bubble on a Locke or Abney level is centered when the optical axis is other than horizontal, the instrument is out of adjustment.

Adjustment chiefly involves a step or a sequence of steps necessary to bring a bubble to center when it should be at center, or bring a crosshair point of intersection into coincidence with the optical axis.

Instrument manufacturers publish handbooks detailing recommended adjustment procedures, usually as small pamphlets, obtainable free of charge.

The following topics are intended to give you a general overview of instrument adjustment procedures. However, for adjusting a particular instrument, you need to follow the appropriate manufacturer's instructions.

2.1.1 General Adjustment Procedures

Carefully check your instruments periodically to determine whether they need adjustment. A modern adage advises, "An instrument should be checked frequently but adjusted rarely." The basis for this saying lies in the fact that modern quality instruments get out of adjustment much less frequently than generally believed. The need for an adjustment is often caused by a previous adjustment that was unnecessary but occurred because of errors in checking.

Before assuming that adjustment is necessary, you must positively ascertain that maladjustment actually exists.

In general, apply the following procedures to all tripod-mounted optical instruments: (*Figure 17-4*)

1. Check the instrument on a cloudy day, if possible.
2. Ensure that the tripod shoes are tight and that the instrument is screwed all the way down on the tripod.
3. Set the tripod up on firm ground in the shade but in a good light where you can sight at least 200 feet in opposite directions.
4. Spread the tripod feet well apart and place them so that the plate is approximately level. Press the shoes in firmly, or set them in cracks or chipped depressions if on a hardened surface. (Avoid setting up on asphalt pavement in warm weather.)

Figure 17-4 — Typical surveyor's tripod.

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

6. Level the instrument with particular care, then loosen all level screws slightly (again to release residual friction) and relevel. Tighten all screws with equal firmness but do not over tighten. Too much tightness will eventually deform the centers, causing both friction and play.
7. Carry out all checks in the prescribed sequence for the instrument. Repeat the check sequence at least three times but do NOT make an adjustment unless the same check indicates the same amount of error every time.
8. Remember that most tests show an error that is double the actual displacement error in the instrument.

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

Before making an adjustment, consider whether any error discovered will have a material effect on field results. Make any adjustments in a prescribed order. After making an adjustment, retighten the adjusting parts firmly but not too tightly, then repeat the original check, and readjust if necessary.

After making all contemplated adjustments, repeat the entire round of checks in the proper order. This will indicate whether an initial adjustment has been disturbed by a subsequent adjustment.

The following sections will address field tests and adjustments for the engineer's level and the transit.

While the principles of performing adjustments are nearly the same for one manufacturer's level or transit as compared to another manufacturer's, there are some differences in detail. Therefore, when preparing to adjust an instrument, always consult the operator's manual for that particular instrument.

When a particular surveying requires a high degree of accuracy, the level or transit you use must be in perfect adjustment. In this event, you must perform the tests presented in the following sections and make any necessary adjustments. However, when the survey can tolerate lower accuracy, you can usually compensate for maladjustment until a proper adjustment can be made.

Following each of the next instrument-adjustment discussions, a note will present a method of compensating for maladjustment. Keep in mind, however, that if you frequently check your instruments and keep them in good adjustment, these compensations should seldom be necessary.

2.1.2 Self-Leveling Level Adjustments

The self-leveling level (also called automatic level) shown is *Figure 17-5* is a precise, time-saving development in leveling instruments. It did away with the tubular spirit level, whose bubble takes time in centering as well as in resetting its correct position from time to time during operation.

The self-leveling level is equipped with a small bull's-eye level and three leveling screws. The leveling screws, which are on a triangular foot plate, are used to center the bubble of the bull's-eye level approximately. The line of sight automatically becomes horizontal and remains horizontal as long as the bubble remains approximately centered. A prismatic device called a compensator makes this possible. The compensator is suspended on fine, nonmagnetic wires. The action of gravity on the compensator causes the optical system to swing into the position that defines a horizontal sight. This horizontal line of sight is maintained despite a slight out of level of the telescope or even when a slight disturbance occurs on the instrument.

Figure 17-5 – Example of self-leveling level.

2.1.3 te

A theodolite is essentially a transit of high precision. Theodolites come in different sizes and weights and from different manufacturers. Although theodolites may differ in appearance, they are basically alike in their essential parts and operation. Some of the models currently available for use in the military are WILD® (Herrbrugg), BRUNSON®, K&E® (Keuffel & Esser), PATH®, and Trimble® theodolites.

To give you an idea of how a theodolite differs from a transit, we will discuss some of the most commonly used theodolites in the U.S. Armed Forces.

2.1.3.1 One-Minute Theodolite

The one-minute directional theodolite is essentially a directional type of instrument. This type of instrument can be used, however to observe horizontal and vertical angles as a transit does.

The theodolite shown in *Figure 17-6* is a compact, lightweight, dustproof, optical reading instrument. The scales read directly to the nearest minute or 0.2 mil and are illuminated by either natural or artificial light. The main or essential parts of this type of theodolite are discussed in the next several paragraphs.

- **Horizontal Motion –** Located on the lower portion of the alidade, and adjacent to each other, are the horizontal motion clamp and tangent screw used for moving the theodolite in azimuth. Located on the horizontal circle casting is a horizontal circle clamp that fastens the circle to the alidade. When this horizontal (repeating) circle clamp is in the lever-down position, the horizontal circle turns with the telescope. With the circle clamp in the lever-up position, the circle is unclamped and the telescope turns independently. This combination permits use of the theodolite as a repeating instrument. To use the theodolite as a directional type of instrument, you should use the circle clamp only to set the initial reading. You should set an initial reading of 0°30' on the plates when a direct or reverse (D/R) pointing is required. This will minimize the possibility of ending the D/R pointing with a negative value.
- **Vertical Motion –** Located on the standard opposite the vertical circle are the vertical motion clamp and tangent screw. The tangent screw is located on the lower left and at right angles to the clamp. The telescope can be rotated in the vertical plane completely around the axis (360°).
- **Levels –** The level vials on a theodolite are the circular, the plate, the vertical circle, and the telescope level. The circular level is located on the tribrach of the instrument and is used to roughly level the instrument. The plate level, located between the two standards, is used for leveling the instrument in the horizontal plane. The vertical circle level (vertical collimation) vial is often referred to as a split bubble. This level vial is completely built in, adjacent to the vertical circle, and viewed through a prism and 45° mirror system from the eyepiece end of the telescope. This results in the viewing of one-half of each end of the bubble at the same time. Leveling consists of bringing the two halves together into exact coincidence, as shown in *Figure 17-7*. The telescope level, mounted below the telescope, uses a prism system and a 45° mirror for leveling operations. When a telescope is plunged to the reverse position, the level assembly is brought to the top.

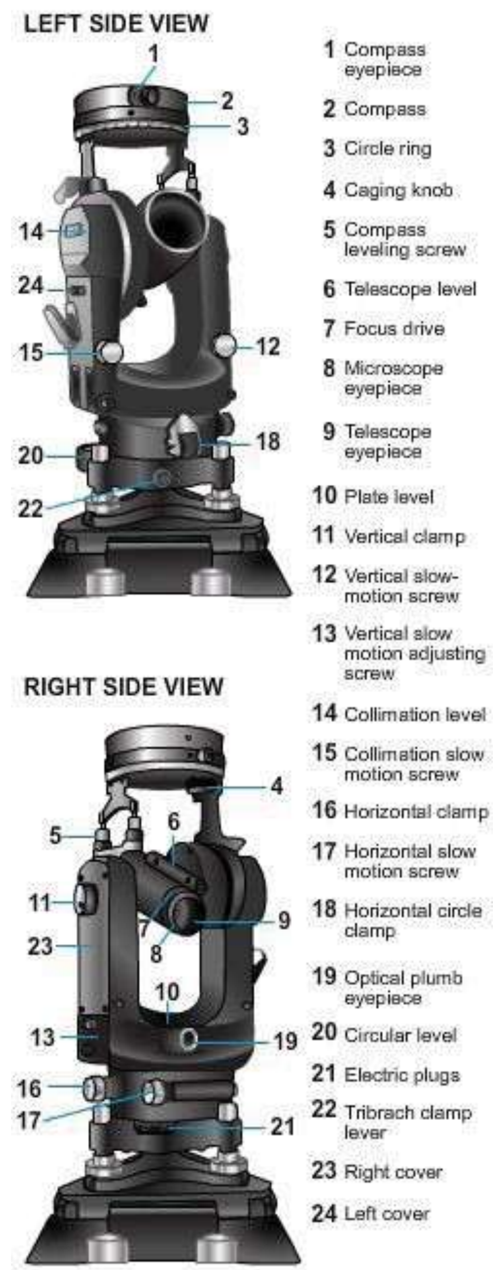

Figure 17-6 — Wild® one-minute theodolite.

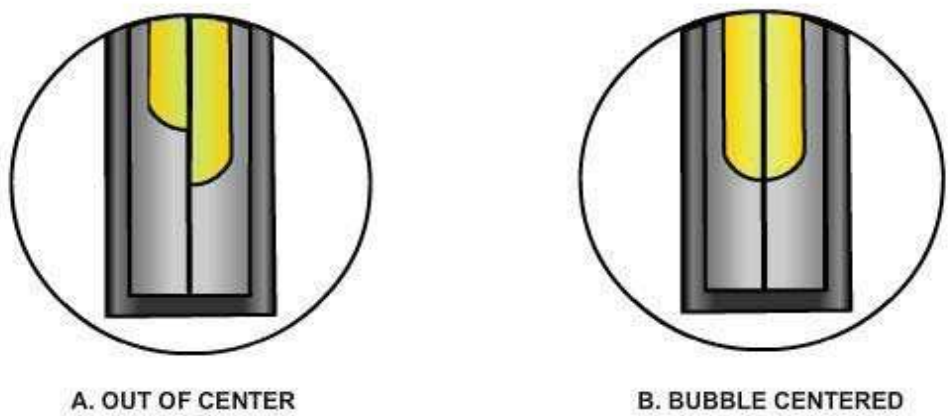

Figure 17-7 – Coincidence type level.

- **Telescope –** The telescope of a theodolite can be rotated around the horizontal axis for direct and reverse readings. It is a 28-power instrument with the shortest focusing distance of 1.4 meters.
- The cross wires are focused by turning the eyepiece; the image, by turning the focusing ring. The reticle has horizontal and vertical cross wires, a set of vertical and horizontal ticks (at a stadia ratio of 1:100), and a solar circle on the reticle for making solar observations (*Figure 17-8).* This circle covers 31 min of arc and can be imposed on the sun's image (32 min of arc) to make the pointing refer to the sun's center. One-half of the vertical line is split for finer centering on small distant objects. The telescope of the theodolite is an inverted image type. Its cross wires can be illuminated by either sunlight reflected by mirrors or by battery source. The amount of illumination for the telescope can be adjusted by changing the position of the illumination mirror.

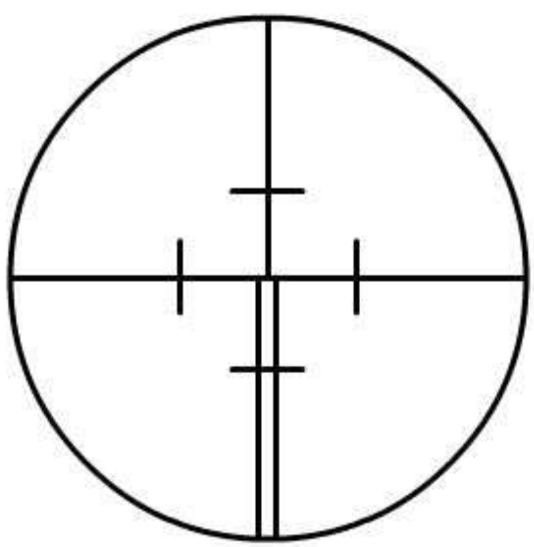

Figure 17-8 – Theodolite reticle.

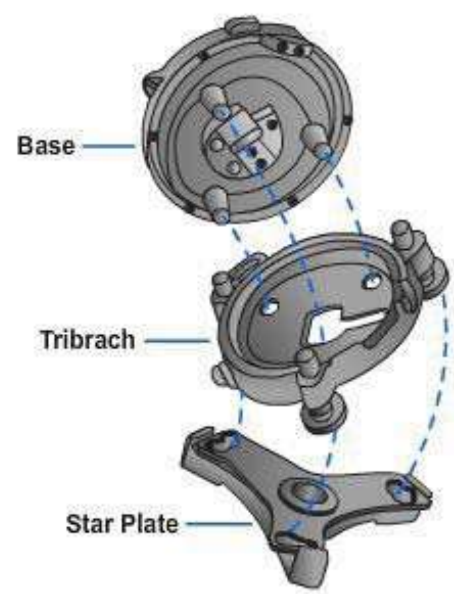

Figure 17-9 – Three-screw leveling head.

- **Tribrach –** The tribrach assembly found on most makes and models is a detachable part of the theodolite that contains the leveling screw, the circular level, and the optical plumbing device (*Figure 17-9*). A locking device holds the alidade and the tribrach together and permits interchanging of instruments without moving the tripod. In a "leapfrog" method, the instrument (alidade) is detached after observations are completed. It is then moved to the next station and another tribrach. This procedure reduces the amount of instrument setup time by half.
- **Circles –** The theodolite circles are read through an optical microscope. The eyepiece is located to the right of the telescope in the direct position, and to the left, in the reverse. The microscope consists of a series of lenses and prisms that bring both the horizontal and the vertical circle images into a single field of view. In the degree-graduated scales the images of both circles are shown as they would appear through the microscope of the one-minute theodolite (*Figure 17-10*). Both circles are graduated from 0° to 360° with an index graduation for each degree on the main scales. This scales graduation appears to be superimposed over an auxiliary that is graduated in minutes to cover a span of 60 min (1°). The position of the degree mark on the auxiliary scale is used as an index to get a direct reading the degrees and minutes. If necessary, these scales can be interpolated to the nearest 0.2 min of arc.

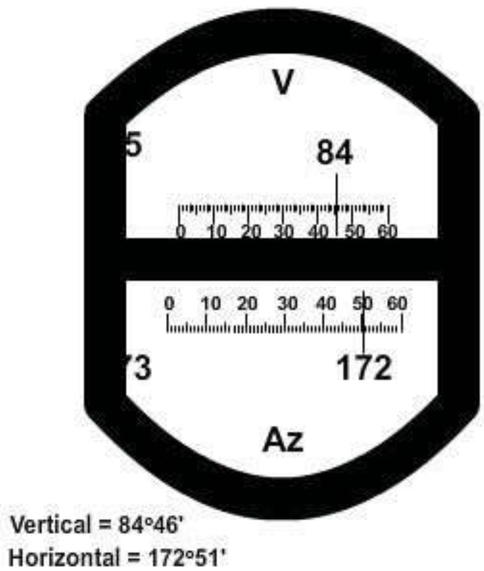

Figure 17-10 – Degree-graduated scales.

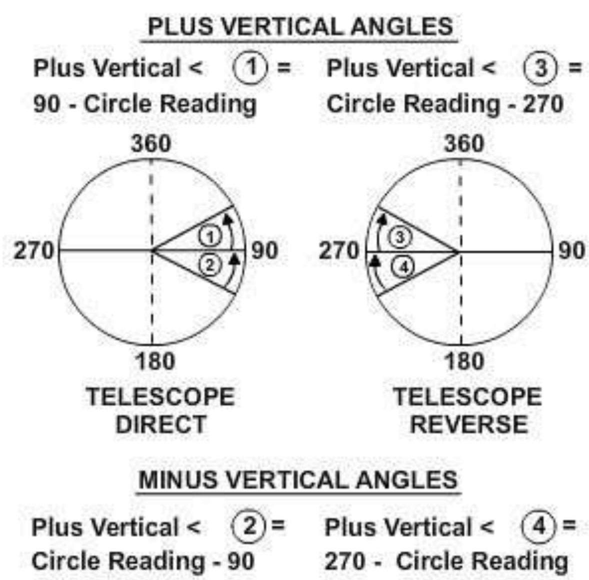

Figure 17-11 – Converting zenith distances into vertical angles (degrees).

The vertical circle reads 0° when the theodolite's telescope is pointed at the zenith and 180° when it is pointed straight down. A level line reads 90° in the direct position and 270° in the reverse. The values read from the vertical circle are referred to a zenith distances and not vertical angles. *Figure 17-11* shows how these zenith distances can be converted into vertical angles. In the mil-graduated scales, the images of both circles are shown as they would appear through the reading microscope of the 0.2-mil theodolite (*Figure 17-12).* Both circles are graduated from 0 to 6,400 mils. The main scales are marked and numbered every 10 mils, with the last zero dropped. The auxiliary scales are graduated from 0 to 10 roils in 0.2-mil increments. Readings on the auxiliary scale can be interpolated to 0.1 mil. The vertical circle reads 0 mil when the telescope is pointed at the zenith, and 3,200 mils when it is pointed straight down. A level line reads 1,600 roils in the direct position and 4,800 roils in the reverse. The values read are zenith distances. These zenith distances can be converted into vertical angles as shown in *Figure 17-13*.

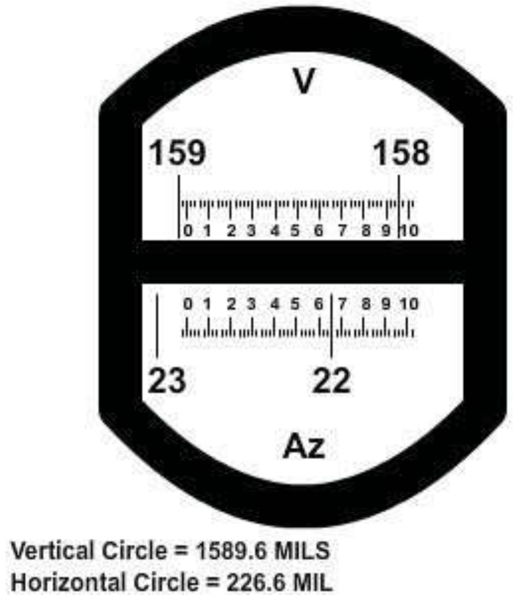

Figure 17-12 – Mil-graduated scales.

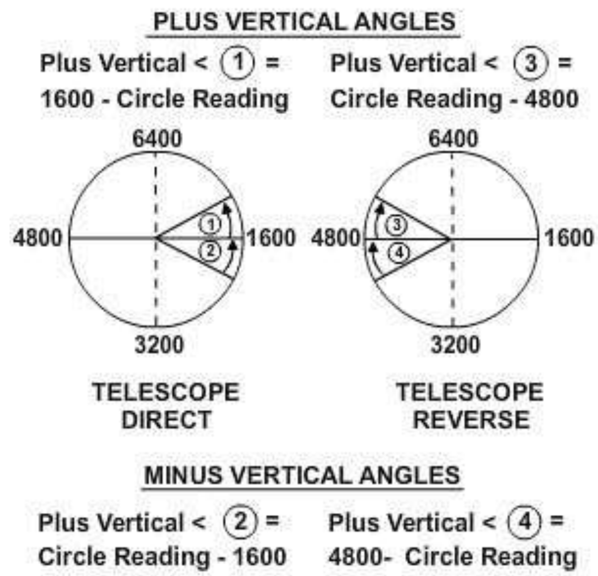

Figure 17-13 – Vertical angles from zenith distances (mils).

2.1.3.2 One-Second Theodolite

The one-second theodolite is a precision direction type of instrument for observing horizontal and vertical directions. This instrument is similar to, but slightly larger than the one-minute theodolite. The WILD® theodolite is compact, lightweight, dustproof, optical reading, and tripod-mounted (*Figure 17-14)*. It is one spindle, one plate level, a circular level, horizontal and vertical circles read by an optical microscope directly to 1 sec (0.002 roil), clamping and tangent screws for controlling the motion, and a leveling head with three foot screws. The circles are read using the coincidence method rather than the direct method. There is an inverter knob for reading the horizontal and vertical circles independently. The essential parts of a one-second theodolite are very similar to that of the one-minute theodolite, including the horizontal and vertical motions, the levels, the telescope, the tribrach, and the optical system shown in *Figure 17-15.* The main difference between the two types, besides precision, is the manner in which the circles are read. The circle to be viewed in the one-second theodolite is selected by turning the inverter knob on the right standard. The field of the circle-reading microscope shows the image of the circle with lines spaced at 20-min intervals, every third line numbered to indicate a degree, and the image of the micrometer scale on which the unit minutes and seconds are read *Figure 17-16*. The numbers increase in value 0° to 360°, clockwise around the circle. The coincidence knob on the right side of, and near the top of, the right standard is used in reading either of the circles. The collimation level and its tangent screw are used when the vertical circle is read.

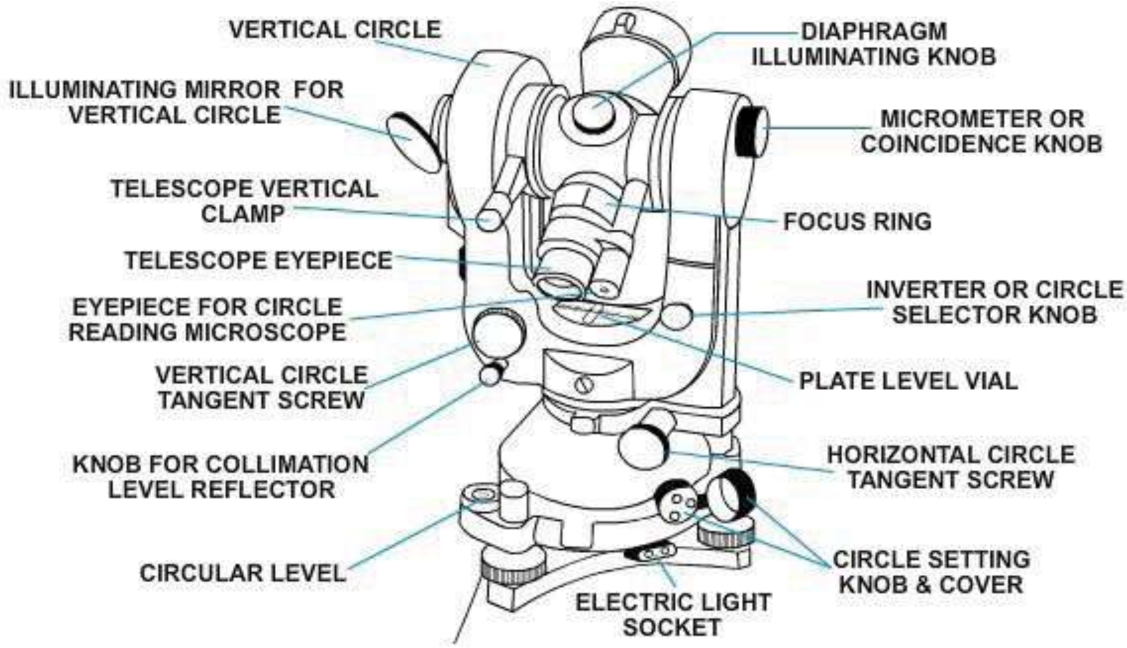

Figure 17-14 — One-second theodolite.

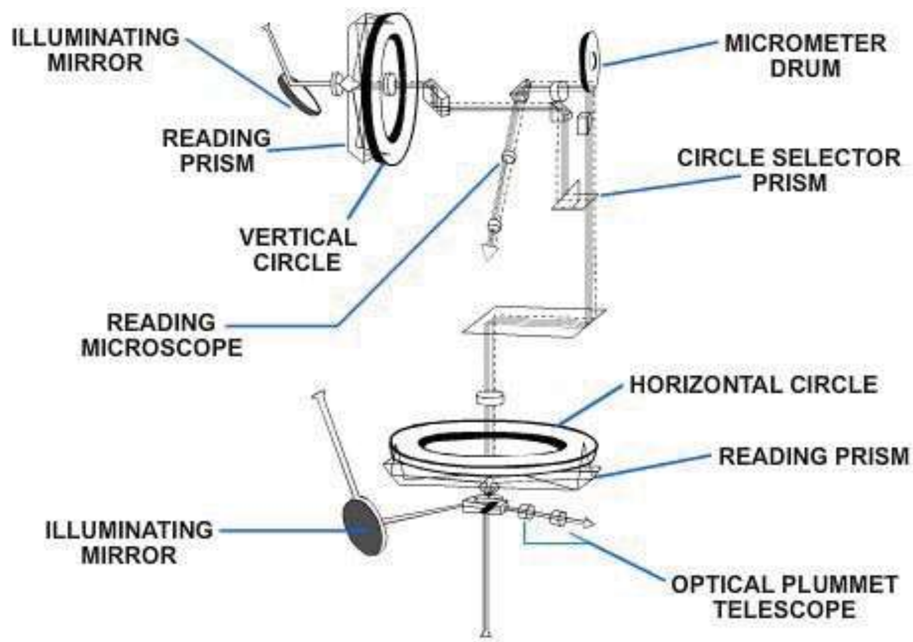

Figure 17-15 — Circle-reading optical system.

The circles of the theodolite are read by the coincidence method in which optical coincidence is obtained between diametrically opposite graduations of the circle by turning the micrometer or coincidence knob. When this knob is turned, the images of the opposite sides of the circle appear to move in opposite directions across the field of the circle-reading microscope. The graduations can be brought into optical coincidence and appear to form continuous lines crossing the dividing line. An index mark indicates the circle graduations that are to be used in making the coincidence. The index mark will be either in line with a circle graduation or midway between two graduations. The final coincidence adjustment should be made between the graduations in line with the index mark or when this index mark is halfway between the two closest graduations.

- **Horizontal Circle –** To read the horizontal circle, turn the inverter or circle-selector knob until its black line is horizontal. Adjust the illuminating mirror to give uniform lighting to both sections of the horizontal circle; the micrometer scale is viewed through the circle reading microscope. Focus the microscope eyepiece so that the graduations are sharply defined. The view through the microscope should then be similar to *Figure 17-16, view A*. From this point continue the following way:

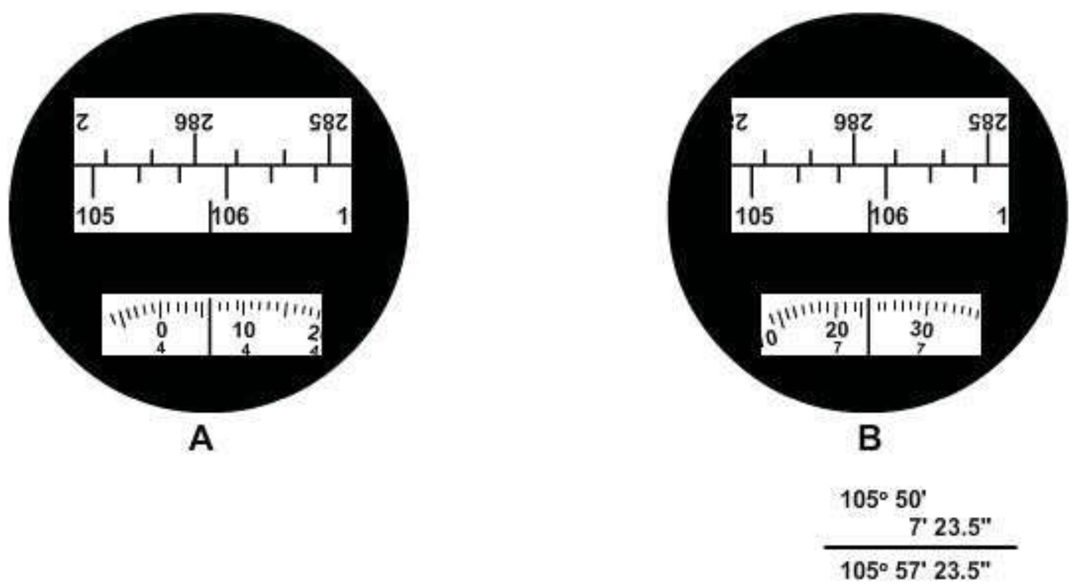

Figure 17-16 — View of a one-second theodolite circle.

  - Turn the coincidence knob until the images of the opposite sides of the circle are moved into coincidence. Turning this knob also moves the micrometer scale. The view through the microscope now appears as shown in *Figure 17-16, view B*.
  - Read the degrees and tens of minutes from the image of the circle. The nearest upright number to the left of the index mark is the number of degrees (105). The diametrically opposite number (the number ± 180°) is 285. The number of divisions of the circle between the upright 105 and inverted 285 gives the number of tens of minutes. In *Figure 17-16, view B*, there are five divisions between 105 and 285; and the reading, therefore, is 105°50'. The index may also be used for direct reading of the tens of minutes. Each graduation is treated as 20 min. Thus, the number of

graduations from the degree value to the index mark multiplied by 20 min is the value. If the index falls between graduations, another 10 min is added when the tens of minutes is read directly.

- Read the unit minutes and seconds below from the image of the micrometer scale. This scale has two rows of numbers below the graduations; the bottom row is the unit minutes and the top row, seconds. In *Figure 17-16, view B*, the unit minutes and seconds are read as 7'23.5".
- Add the values determined in steps 2 and 3 above. This gives 105°57'23.5" as the final reading.

- **Vertical Circle –** When reading the vertical circle, turn the circle-selector knob until its black line is vertical. Adjust the mirror on the left standard and focus the microscope eyepiece. You then go on in the following way:

  - Use the vertical circle tangent screw to move the collimation level until the ends of its bubble appear in coincidence in the collimation level viewer on the left standard (*Figure 17-17).*
  - Read the vertical circle and micrometer scale as described before. Be sure to have proper coincidence before you take the reading.
  - The vertical circle graduations are numbered to give a 0° reading with the telescope pointing to the zenith. Consequently, the vertical circle reading will be 90° for a horizontal sight with the telescope direct and 270° for a horizontal sight with the telescope reversed. *Figure 17-17* shows the view in the circle-reading microscope for direct and reversed pointings on a target. These readings are converted to vertical angles as follows:

	Telescope Direct	Telescope Reversed
Circle Reading	86°17'43.5"	273°42'21.5"
Zenith Distance	86°17'43.5"	86°17'38.5"
Mean Zenith Distance	86°17'41.0"	
Mean Vertical Angle	+ 3°42'19.0"	

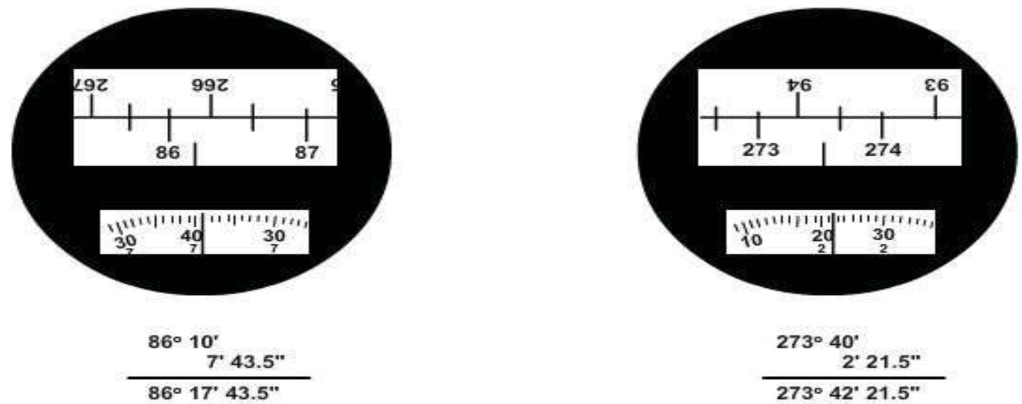

Figure 17-17 – View of a vertical circle for direct and reversal pointings.

There are two separate occasions for setting the horizontal circle of the theodolite. In the first case, the circle is set to read a given value with the telescope pointed at a target. With the theodolite pointed at the target and with the azimuth clamp tightened, the circle is set as follows: Set the micrometer scale to read the unit minutes and the seconds of the given values. Then, with the circle-setting knob, you turn the circle until coincidence is obtained at the degree and tens of minutes value of the given reading. This setting normally can be made accurately to plus or minus 5 sec. After the circle is set in this manner, the actual reading should be determined.

In the second case, the circle is set to a value of a given angle. When a predetermined angle is measured, you first point the instrument along the initial line from which the angle is to be measured and read the circle. Add the value of the angle to the circle reading to determine the circle reading for the second pointing. Set the micrometer scale to read the unit minutes and the seconds of the value to be set on the circle. Then, you turn the instrument in azimuth and make coincidence at the degrees and tens of minutes value that is to be set. The predetermined value can usually be set on the circle in this way to plus or minus 2 sec.

2.1.4 tal Station (Trimble® 5600) Adjustment

The Trimble® 5600 Total Station when used with the Trimble® Alphanumeric Control Unit (ACU) and Trimble® Integrated Survey Rover (ISR) gives you the best and most productive measuring method available today for every measuring situation. In this section you will be introduced to the components of the Total Station and their adjustments. The Trimble® 5600 Total Station, Trimble® ACU, and ISR are used with the Terramodel programs which are loaded to a base computer and can be downloaded to the ACU for known or unknown control points. Upon completion of your survey or measurements the data can be downloaded from the Trimble® ACU back to the base computer for creation of linework or other layout as desired (*Figure 17-18*).

Figure 17-18 – Data flow using Trimble® 5600 Total Station.

2.1.4.1 4.1 Tripod Adjustment

The following steps are to be followed when setting up the tripod over a control point and making adjustments:

- Unwrap the tripod and extend its legs so that the tripod head is at approximately chin level (higher is better for more precise work, so that you can get maximum leg spread). Spread the tripod legs over the initial occupied point so that the tripod head is approximately level. Make sure the legs are spread as widely as practical for maximum stability.
- Attach the instrument tribrach to the tripod head and ensure that the tribrach's leveling foot screws are centered half way between their range of movement (for ease of leveling). Hand tighten the bayonet screw at the base of the tribrach. Step or "set" one leg into the ground securely (usually the leg opposite the sight on your tribrach), sight through the optical plummet, and pick up and move the other two tripod legs until the cross hairs are centered over your occupied point nail or marker. (You can place the toe of your shoe near the point for reference.)

NOTE

If the tribrach crosshairs are out of focus, adjust the crosshairs ring first until the crosshairs appear clear and crisp. Then, adjust the focus ring until the image is in focus. To check for parallax, slowly move your head around while looking through the optical plummet. You should see not movement between the crosshairs and the focused background (this is known as being out of parallax), nor should the crosshairs move apart.

- Once the crosshairs are within one centimeter of the point (1/2"), step the remaining two legs into the ground.
- Precisely position the tribrach crosshairs over the point by using the leveling foot screws on the tribrach.
- Level the bull's-eye bubble on the tribrach by using two tripod legs. Do NOT level using the tribrach foot screws. At this point you are leveling the tripod head. When the bubble is within the circle of the bull's-eye. Use the tribrach leveling foot screws to precisely center the bubble.
- Once the bull's-eye bubble is precisely level, look through the optical plummet to ensure that the crosshairs are over the point or at least within a couple of centimeters (1"). Center the crosshairs precisely over the point by loosening the tripod bridge screw and gently slide the tribrach and adapter over the point. Be sure not to rotate the tribrach. When the crosshairs are centered on the point, tighten the tripod head screw. If the tribrach overhangs the tripod head, return to the step where the tripod legs were spread over the initial occupied point and adjust.

NOTE

You can check the set up and calibration of your tribrach by attaching a plumb bob to the tripod head screw so it hangs over the point. It should hang precisely over the point ± the plumb bob string width. If the wind is blowing, you may want to perform this tribrach check indoors.

- Check the level bubble. If the level is out just a little, return to the step where the bubble is within the circle of the bull's-eye and use the tribrach leveling foot screws to precisely center the bubble. If it is out more than a couple of millimeters, redo the step where you precisely positioned the tribach crosshairs over the point by using the leveling foot screw on the tribach.

2.1.4.2 Attaching and Leveling the Trimble®/Geodimeter Total Station

The following steps should be followed when attaching and leveling the Trimble®/Geodimeter Total Station (*Figure 17-19)*:

- Remove the instrument from its case and loosen the horizontal motion lock. Rotate the base of the instrument until the RS-232 port aligns with the notch in the tribrach. Gently place the instrument in the tribrach and be sure to lock it in place by turning the tribrach locking knob clockwise until it stops.
- Check the bubble on the optical plummet and re-level if needed. Then, recheck to be sure the crosshair of

Figure 17-19 – Trimble®/Geodimeter Total Station with ACU.

the optical plummet is still centered over the point. If required, loosen the bayonet screw of the tribrach and move it over the point (again, taking care not to rotate the tribrach as you move it). Rotate the instrument so its keyboard is parallel to two of the tribrach foot screws.

- Turn on the instrument by pressing the power key at the lower left corner of the keyboard.
- Use the tribrach's two foot screws to center the cursor between the two of the display lines. Remember that the bubble goes in the direction of your left thumb. Without rotating the instrument, use the third foot screw to center the top cursor between the other two display lines. When both cursors are centered, the instrument is correctly leveled in coarse mode.
- Press the Aim/Measure (A/M) button. The instrument will now automatically adjust and engage its dual axis compensator. You should have a prompt of "Temp =. Use your thermometer and input the current temperature. At the "Press =" prompt, use your barometer and input the correct barometric pressure. At the "Offset =" prompt, input 0 (zero) if you are using standard Geodimeter/Trimble® glass of prisms. Use an offset of 2mm or 0.00656 feet for a 360° prism.
- At the "HA Ref =" prompt, simply press the Enter (ENT) key. You will most likely be inputting an actual value.
- The instrument is now in Program 0 mode and the top of the display should read STD P0 TIME and is ready for fine leveling, collimation, or to run a program.
- Adjust the display contrast for the best possible viewing for current lighting conditions by using the Menu (MNU 13) Key.

NOTE

Continue with the next steps only if you are going to do a precise survey. If you are just running a topo survey, for example, you are finished with this setup procedure.

- For a precise survey you would turn the instrument so it is parallel to two of the tribrach foot screws and fine level it by pressing the fine level button which is marked with a level symbol; which is the same key as button "N" in alpha mode.
- Once the indicators are both centered, using the fine leveling, press the fine level button again. As long as your measurement units are correct and the instrument has been collimated, you are now ready to begin collecting survey data by running precise survey programs which will be discussed later.

2.1.4.3 Trimble® Alphanumeric Control Unit (ACU)

If you want to switch between using the Trimble® ACU and another control unit Trimble® strongly recommends that before each switch you perform the following adjustments which are described in detail in the Trimble® 5600 user manual:

- Horizontal collimation
- Vertical collimation
- Compensator run center

The internal battery of the Trimble® ACU can provide up to one hour of stand-by time to avoid any potential data loss should your external power source expire. The internal battery powers the Trimble® ACU only. It does not power any device that may be connected. The Trimble® ACU is configured by default not to run on internal battery power for users with the Windows CE operating system version 4.0.9 or later. To enable the Trimble® ACU to run from internal battery power perform the following steps:

- From the start menu, select "Settings/Control Panel" and then click the power icon.
- In the "Run On Battery" tab, select the "Enable running on Internal Battery" check box.
- Now the Trimble® ACU will run from internal battery power.

NOTE

Under no circumstances should you rely on the internal battery for extended periods, especially during data collection. When the Trimble® ACU is running on its internal battery (when enabled), Trimble® recommends that you connect an external power source immediately. External power sources include the Trimble® ACU mains charger, the Trimble® 5600 Total Station and the CU holder for robotic surveying.

To toggle the backlight on and off, press the "Shift" button, and then press the "Trimble®" button. To access the backlight settings, from the "Start" menu select "Settings/Control Panel" and then click on the "Display" icon.

Use the "Alpha" key to enter alphabetic characters on the Trimble® ACU. Press this key to switch between alpha and numeric modes. To enter an upper case character in the preview panel, press the "Shift" key while in alpha mode.

To use the Trimble® ACU with a Trimble® 5600 Total Station, the instrument must have firmware version 696-03.05 or later installed. To start the system, use the following procedure:

- Set up the instrument and ensure that the Trimble® ACU is turned off, and then attach it to the front of the instrument. Connect a power suppkly to the foot-connector of the instrument.
- Press the green power button on the Trimble® ACU to start the system. The instrument should beep indicating that it has been turned on. You will then be able to use the survey application software installed on the Trimble® ACU to connect to the instrument and start your survey.

To use the Trimble® ACU with a Trimble® Integrated Survey Rover (ISR) (*Figure 17-20)* the following procedures should be used:

- Attach the Trimble® 5800 RTK Rover and the Trimble® ACU holder to the rod. Insert a freshly charged battery in the Trimble® 5800 GPS Rover, and then press the green power button to turn it on.
- Attach two freshly charged batteries to the Trimble® ACU holder. Ensure that the Trimble® ACU is turned off,

Figure 17-20 – Trimble® 5800 RTK Rover with ACU

and then attach it to the Trimble® ACU holder.

- Press the green power button on the Trimble® ACU to start the system. You will then be able to use the survey application software installed on the Trimble® ACU to connect to the receiver and start your survey.

2.2.0 Minor Repairs and Replacement Procedures

Minor repairs to surveying instruments and equipment are those that can be done in the field with the use of simple tools. Major repairs must be done by instrument specialists generally employed by the manufacturers of the instruments. Never attempt to make a major repair yourself.

2.2.1 Repair It or Replace It?

Whether you or someone else in the unit should attempt to repair a damaged item of equipment will depend on the nature of the damage and the character of the item. For example, you can easily splice a broken tape, but should you attempt to straighten a bent compass needle? That decision would depend on the type of compass: an ordinary pocket compass, perhaps yes, the compass on a transit, probably no.

Damage to articles such as range poles, tripod legs, and the like may be easily repaired in a battalion or PWD shop, and minor damage to instruments may be repaired occasionally as well. However, major repairs to instruments, if economically worthwhile, should be done by manufacturers, their authorized representatives, or competent Navy instrument repairmen.

If the senior EA or engineering officer deems an instrument beyond economical repair, it must be surveyed (properly disposed of) using standard survey procedures. Then a replacement instrument can be ordered through the Navy supply system. Expendable items are procured in the same manner.

2.2.2 Supply System

The Navy supply system lists, identifies by a stock number, and describes in a stock catalog each item of equipment or supply that is available.

A battalion allowance list identifies items that may be drawn from supply, and indicates the maximum number permissible.

When a battalion's inventory falls short of the allowance due to expenditure, wear, casualty, loss, or some other type of attrition, the shortage must be replaced.

The battalion or PWD shop personnel may be able to replace some items such as range poles, chaining pins, bull-points, turning-point pins, targets, stake bags, equipment boxes, and the like, but most items are replaced by supply from the nearest available naval supply depot.

To replenish an item, you must order it by stock number and follow a prescribed procedure. To learn the correct procedures, contact one of the supply petty officers in the unit or study the chapters on the Navy supply system in Military Requirements for Petty Officers Third and Second Class, NAVEDTRA 14504.

2.2.3 NMCB Surveyor’s Kit

Every NMCB is outfitted with adequate surveying supplies and equipment. They are listed in the NMCB Table of Allowance (TOA) and contained in Surveyor Kit #80010. Normally, four complete kits are carried in the battalion allowance and available for checkout to the surveyor section supervisor or the senior EA.

Each survey party chief is responsible for making sure the kit assigned to the crew is complete. In addition, the kits must be inventoried during turnover and at twice-monthly intervals throughout deployment.

The purpose of these inventories is to ensure both 100% accountability and a proper state of good repair of the items in the kit. Remember, if you have custody of the kit, you can be held financially accountable for items missing or damaged through negligence.

Most consumable items in the kit, such as pencils, pencil leads, lumber crayon, and surveyor's flagging, are stocked in the battalion supply department for kit replenishment. Additional supplies and equipment are also stocked in the engineering office surveyor's locker to supplement the kits.

Summary

Seabees operate in many different environments under a wide range of circumstances while upholding the "Can Do" motto. The engineering survey is often the first step in beginning a project, and the quality of the survey will depend on the skill of the survey crew functioning with properly maintained and adjusted equipment. As an Engineering Aid, being familiar with equipment maintenance and comfortable with adjustments after a thorough systematic check will enable you to support both your unit and the tradition. (*Figure 17-21*)

Figure 17-21 — Seabees operating multiple survey equipment under varied environments.

Review Questions (Select the Correct Response)

1. Which of the following definitions best describes "adjustment" as presented in Chapter 17?

   A. Aligning the fixed parts of the instrument
   B. Aligning the telescope for leveling work
   C. Aligning the instrument for a level run
   D. Aligning a transit scope for use with a level

2. Which, if any, of the following items comes with an instrument to assist you with care and maintenance?

   A. A tool kit to repair the instrument
   B. A prepaid shipping box to return it to the manufacturer for repairs
   C. A user's manual
   D. None of the above

3. Which of the following situations should you avoid when handling or caring for your instrument?

   A. Setting up the instrument in a street
   B. Removing the instrument from the case by the telescope
   C. Tightening the instrument to the tripod head during setup
   D. Tightening all screws to a firm bearing

4. What is the preferred method for carrying an instrument on a sidehill?

   A. On the uphill shoulder
   B. In front of you with the tripod legs extended
   C. Under the arm on the downhill side
   D. On the downhill shoulder

5. **(True or False)** All clamp screws should be firmly tightened when an instrument is transported.

   A. True
   B. False

6. In what manner should you store an instrument when not in use?

   A. In the carrying case
   B. On a shelf in the survey locker
   C. Mounted on the tripod
   D. Any place that is convenient

7. Which of the following bags may be used to carry stakes and hubs?

   A. Canvas bag with a shoulder strap
   B. Newsboy's bag
   C. Seabag
   D. All of the above

8. What is the recommended method for carrying surveyor's tacks?

   A. In the tack box
   B. In a pocket on the surveyor's bag
   C. Stuck in a rubber ball or piece of soft wood
   D. In your shirt pocket for quick access

9. **(True or False)** You should NEVER carry any equipment in sheaths or pouches, or on your belt.

   A. True
   B. False

10. You have been surveying and caught in the rain. What should you do with the instrument upon return to the office?

   A. Store the instrument in the carrying case.
   B. Blow-dry the instrument with a hair dryer.
   C. Wipe it down with a cloth.
   D. Remove it from the case and dry the instrument at room temperature.

11. **(True or False)** You should clean the lens of the telescope with a chamois or lint-free cloth only.

   A. True
   B. False

12. What type of lubricant is recommended for lubricating transits in subzero temperature?

   A. Watch oil
   B. Whale oil
   C. Graphite
   D. 10W-30

13. Which of the following sources should you consult before doing anything to an instrument?

   A. Tech library
   B. Senior EA
   C. Manufacturer's manual
   D. Either B or C

14. Why is it important to clean mud and dirt from your equipment after use?

    A. To prevent rust or decay
    B. To ensure neatness
    C. To keep the Chief happy

15. Why is it important to take good care of your equipment?

    A. For inspection purposes
    B. For quality work and accurate surveys
    C. Both A and B above
    D. For safety

16. **(True or False)** Major repairs and major adjustments are among the responsibilities of the EA.

    A. True
    B. False

17. Recalibration should be done by whom?

    A. Senior EA
    B. Manufacturer
    C. Supply department
    D. Instrumentman

18. Which of the following skills should the surveyor possess in order to make proper adjustments?

    A. Ability to tell the effect of the adjustment on other parts
    B. Ability to perform tests used to determine when the instrument is out of adjustment
    C. Knowledge of the proper sequence for making adjustments
    D. All of the above

19. Which of the following instrument parts is/are used to make instrument adjustments for levels?

    A. Tripod head
    B. Cross hairs
    C. Level tubes
    D. Both B and C above

20. The cross hairs on a telescope are out of adjustment when they fail to align with ________.

    A. the object being sited
    B. one another
    C. the optical axis
    D. the alignment points

21. How do you determine if an Abney or Locke level is out of adjustment?

    A. Check the reflected bubble with the instrument in a horizontal plane.
    B. Check the reflected bubble with the instrument in a vertical plane.
    C. Check the plate level bubbles.

22. What is a general rule regarding the frequency of adjustment?

    A. Check and adjust often.
    B. Check rarely and adjust rarely.
    C. Check often and adjust rarely.
    D. Check rarely and never adjust.

23. You feel your instrument is out of adjustment. Which of the following procedures should you do before making any adjustments?

    A. Ensure the instrument is screwed down on the tripod.
    B. Set the instrument up in the shade.
    C. Repeat the checks at least three times.
    D. All of the above

24. What type of surface should you use to set up an instrument for adjustment?

    A. Asphalt
    B. Chipped hardened surface
    C. Sand
    D. Plywood

25. What purpose, if any, does retightening the wing nuts on the tripod legs accomplish?

    A. To prevent a possible shifting of the legs
    B. To ensure the nuts did not loosen themselves
    C. To keep the tripod head from moving
    D. None

26. What amount of the actual displacement error do most tests show an error equal to?

    A. Half the actual error
    B. Double the actual error
    C. Equal to the actual error
    D. Three times the actual error

27. What is creep in relation to the instrument?

    A. Position shift due to heat
    B. Settlement of the instrument
    C. Position shift due to cold
    D. All of the above

28. **(True or False)** The operator's manual is your first source of information when instruments need adjustment.

A. True
B. False

29. You are performing a survey requiring a high degree of accuracy. Which, if any, of the following procedures should be one of the first steps you perform?

A. Check your instrument for maladjustment.
B. Figure the compensation for adjustments to the instrument.
C. Oil the tripod head.
D. None of the above

30. You are assigned to a survey party. You get the level along with your other equipment. What procedure, if any, should you perform on the instrument before starting work?

A. Check the instrument for proper adjustment.
B. Adjust all the bubble tubes to the maximum angle.
C. Perform a two-peg test.
D. None

31. **(True or False)** When adjusting a level, you should follow an exact order for making all the adjustments.

A. True
B. False

32. You have found the level tube out of adjustment on a level. You set the instrument up and then level the bubble over each set of leveling screws. What is your next step?

A. Rotate the instrument 90° and adjust the bubble half the distance to the center of the tube.
B. Rotate the instrument 180°, check the bubble, and adjust the bubble to the center of the tube.
C. Rotate the instrument 180° and adjust the bubble half the distance to the center of the tube.
D. Rotate the instrument 180°, loosen the capstan screws, and rotate the reticle until the bubble is half the distance of the tube.

33. In what order should adjustments on a level be made?

A. Vertical cross hair, level tube, and line of sight
B. Horizontal cross hair, line of sight, and level tube
C. Level tube, line of sight, and horizontal cross hair
D. Level tube, horizontal cross hair, and line of sight

34. **(True or False)** The telescope of the one-minute theodolite is an inverted image type.

A. True
B. False

35. The tribrach assembly found on most one-minute theodolite units contains which of the following parts?

A. Leveling screw
B. Circular level
C. Optical plumbing device
D. All of the above

36. What degree does the vertical circle read when the theodolite's telescope is pointed straight down?

A. 0°
B. 90°
C. 180°
D. 270°

37. What method of reading the circles is used on the one-second theodolite?

A. Direct
B. Coincidence
C. Horizontal
D. Vertical

38. Which of the following activities may perform minor repairs?

A. Navy cal lab
B. Local PWD
C. Battalion machine shop
D. All of the above

39. When a piece of equipment is damaged beyond repair, it must be replaced. From what source may you obtain a replacement?

A. PWD
B. Equipment manufacturer
C. Army/Navy surplus store
D. Navy supply system

40. What source/reference determines the maximum number of any item allowed in a battalion?

A. Supply department
B. Table of Allowance
C. Authorization list
D. Naval supply depot

41. Which of the following sources should you refer to when checking on the quantity of surveying kits in a battalion?

A. Table of Allowance
B. 80010 inventory list
C. *Military Requirements for Petty Officer Third Class*
D. NAVFAC P-315

Trade Terms Introduced in this Chapter

Reticle	A grid or pattern placed in the eyepiece of an optical instrument, used to establish scale or position.

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.

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

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Chapter 18

Indirect Leveling/Level and Traverse Computations

Topics

1.0.0 Indirect Leveling

2.0.0 Level and Traverse Computations

To hear audio, click on the box.

Overview

Leveling is the surveying operation that determines the difference in elevation between points on the earth's surface. The operation is divided into two major categories: direct leveling and indirect leveling. From your study of the other chapters, you should be familiar with the methods and procedures used in direct leveling. This chapter introduces the theory and basic procedures used in indirect leveling.

You also learned in the other chapters that perfect closure in level nets and traverses is seldom, obtained. Typically, a certain amount of linear or angular error occurs. When this error exceeds a prescribed amount, the level net or traverse must be rerun. However, when the error is within the specified allowable limits, then certain adjustments can be made.

This chapter provides information on the adjustments and the calculations needed to make the adjustments for the methods used to determine the area of traverses.

Objectives

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

1. Describe the different types of indirect leveling.
2. Describe the methods for conducting level and traverse computations.

Prerequisites

None

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

Topographic Surveying and Mapping	↑	ENGINEERING AID BASIC
Indirect Leveling/Level and Traverse Computations		
Care and Adjustment of Survey Equipment		
Materials Testing: Soil and Concrete		
Direct Leveling and Basic Engineering Surveys		
Horizontal Control		
Direct Linear Measurements and Field Survey Safety		
Surveying: Elements and Equipment		
Construction Drawings		
Electrical: Systems and Plans		
Mechanical: Systems and Plans		
Concrete and Masonry		
Wood and Light Frame Structures		
Drafting: Projections and Sketching		
Drafting: Geometric Construction		
Drafting: Fundamentals and techniques		
Drafting: Equipment		
Mathematics and Units of Measurement		
Engineering Aid Rating		

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 INDIRECT LEVELING

Indirect methods of leveling include barometric leveling and trigonometric leveling. These methods are discussed in the following paragraphs.

1.1.0 Barometric Leveling

Barometric leveling makes use of the fact that differences in elevation are proportional to differences in the atmospheric pressure. Therefore, when the atmospheric pressure of a barometer is read at various points on the earth's surface, you have a measurement of the relative elevation of these points. A mercurial barometer, aneroid barometer, or sensitive altimeter may be used for this purpose. However, the mercurial barometer is too cumbersome to take out into the field. Barometric leveling is used mostly in reconnaissance surveys where differences in elevations are large, such as in mountainous regions. Elevations determined by barometric leveling are typically several feet in error even after they are corrected for the effects of temperature and humidity. These errors are caused by day-to-day pressure fluctuations, even by fluctuations from hour to hour. Because of these fluctuations, barometric observations are usually taken at a fixed station during the same period that observations are made on a second barometer that is carried from point to point in the field. The use of two barometers enables you to correct for atmospheric disturbances that could not be readily detected if only one barometer were used. This method is not normally used in construction surveying, except when a construction surveyor may need to run his or her own preliminary topographic control.

Barometric or altimeter surveys are run by one of three methods: the single-base, the two-base, and the leapfrog.

The single-base method requires a minimum number of observers and the least equipment. However, this method needs a series of corrections and is neither as practical nor as accurate as the other two.

The two-base method is generally accepted as the standard method for accuracy and is the one most widely used. It requires fewer corrections than the single-base method.

The leapfrog method uses the same type of corrections as the single-base, but the altimeters are always in close relationship to each other and are operating under reasonably similar atmospheric conditions. The results of the leapfrog method are more accurate than the single-base method and compare favorably with the two-base method.

There are several factors and limitations that must be observed in barometric leveling which are beyond the scope of this training manual. For actual barometric leveling, consult the instruction manual for the instrument being consulted. The theory of two-base barometric leveling is explained below.

The two-base method is described here only to provide an idea of how the system works. This method uses at least three altimeters, one at each lower and upper base where elevations are initially known, and one or more roving where elevations are needed between the upper and lower base elevations. In this operation, points of unknown elevations to be determined must lie within the range of the elevations of the lower and upper base stations. The readings of the altimeters at the unknown elevations are taken at the same instant that both the upper and the lower base altimeters are read. If radio communication is not available, a timepiece is needed for each altimeter.

All of the timepieces need to be synchronized and the altimeter readings taken at prearranged intervals.

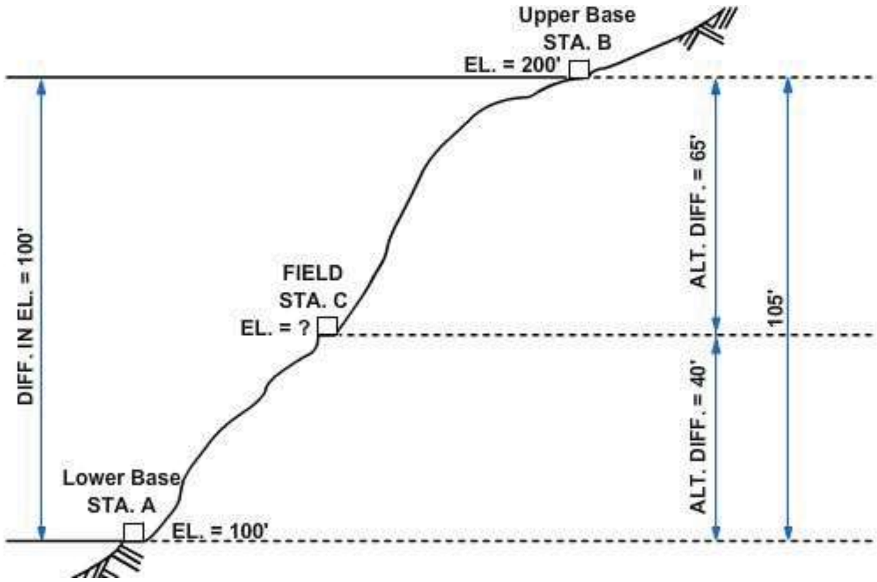


Figure 18-1 – Diagram of a two-base altimeter survey.

Figure 18-1 shows a diagram of the two-base method using three altimeters. The figure shows the known elevations of the lower (Sta. A) and upper (Sta. B) base stations. Altimeter readings at each of the base stations and at field station C are shown. The difference in elevation is computed by direct proportion, using either the lower base or the upper base as reference. For example, to find the differences in elevation between Sta. A and Sta. C, perform the following steps:

$$\frac{Diff.El.AC}{100} \quad \frac{40}{105}$$

$$Diff.El.AC \quad \frac{40 \times 100}{105} \quad 38 \; feet$$

Then the result is added to the elevation of Sta. A, as seen below:

Elevation C = 100 + 40/105 x 100 = 100 + 38 = 138 feet

When the upper base is used as a reference, compute the difference in elevation by using the same method.

However, to compute from Sta. B, subtract the result, as shown below:

Elevation C = 200 - 65/105 x 100 = 200 - 62 = 138 feet

For a more accurate result, do not make altimeter surveys on days when there is not much variation in barometric pressure. Avoid windy days with rapidly moving detached clouds, as the alternating sunlight and shade over the survey area can cause fluctuations in the altimeter reading. Steady barometric pressures generally occur on days with gentle winds and an overcast sky. The recommended time for observations is 2 to 4 hours after sunrise and 2 to 4 hours before sunset. When possible, avoid midday observations. Remember to shade the instrument at all times, and avoid jarring the instrument suddenly during its transfer from one station to another.

1.2.1 Trigonometric Leveling

When the vertical angle and either the horizontal or slope distance between two points is known, the fundamentals of trigonometry can be applied to calculate the difference in elevation between points. This is the basic principle of trigonometric leveling. This method of indirect leveling is particularly adaptable to rough, uneven terrain where direct leveling methods are impracticable or time-consuming. As in any survey, the equipment used in trigonometric leveling depends on the precision required. For most trigonometric-leveling surveys of ordinary precision, angles are measured with a transit, or alidade, and distances are measured either with a tape or by stadia. On reconnaissance surveys the vertical angles may be measured with a ***clinometer***, and distances may be obtained by pacing. The method used in trigonometric leveling is described in the following paragraphs:

In *Figure 18-2*, a transit is set up and leveled at *A,* which is also point *O*. The rodman holds the rod at point *B.* The instrumentman trains the telescope on *C,* which is an easily read value (usually a full foot) on the rod. With the telescope trained on *C*, the vertical angle (a) is read. Then either the horizontal distance or the slope distance between the instrument and the rod is determined. Now one side and one angle of the right triangle (*OCD*) are known. From your knowledge of trigonometry, you know that the other sides and angle can be computed. However, in trigonometric leveling, you are concerned only with determining the length of the side opposite the measured angle (side *CD*). The length of this side is the difference in elevation (DE). As seen in *Figure 18-2* the DE is the distance between the height of instrument (HI) and the intersection of the line of sight with the rod (point *C*). Computing the DE consists of multiplying the measured distance by the proper trigonometric function of the measured angle: sine, when slope distance (*OC*) is measured; tangent, when horizontal distance (*OD*) is measured.

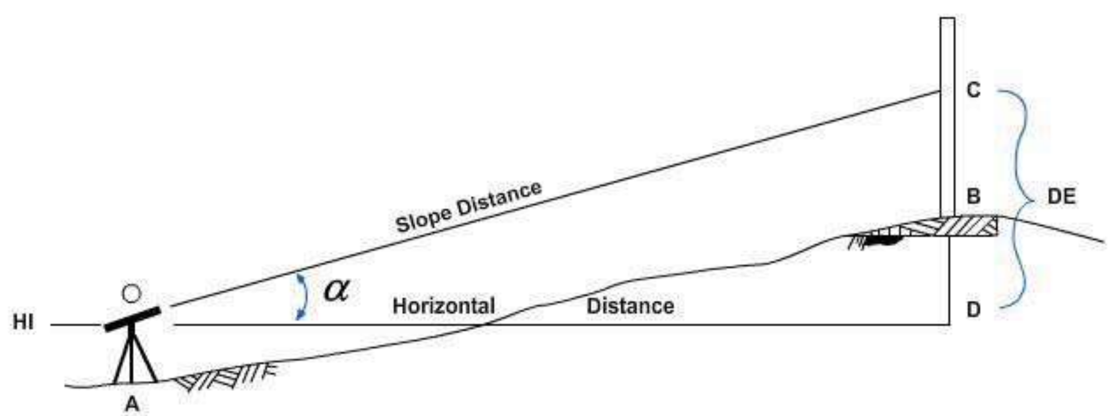


Figure 18-2 - Difference in elevation in trigonometry leveling.

The following paragraphs discuss typical situations encountered in trigonometric leveling.

1. Depression angle backsight, shown in *Figure 18-3*. The rod is on point *B* below the instrument. The measured vertical angle (a) is a depression (minus) angle. To compute the HI, the rod reading RB and the DE are added to the elevation of *B*, or

$$HI = RB + DE + Elev.\ B.$$

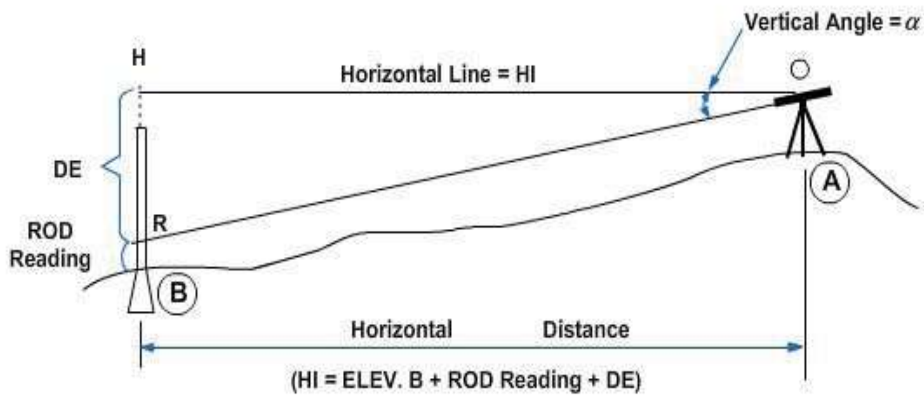


Figure 18-3 - Backsight Depression (Minus) Angle.

2. Depression angle foresight, shown in *Figure 18-4*. The rod is below the instrument, and the vertical angle is minus. The elevation at *C* equals the HI minus the DE and minus the rod reading RC, or

$$Elev.\ C = HI - DE - RC.$$

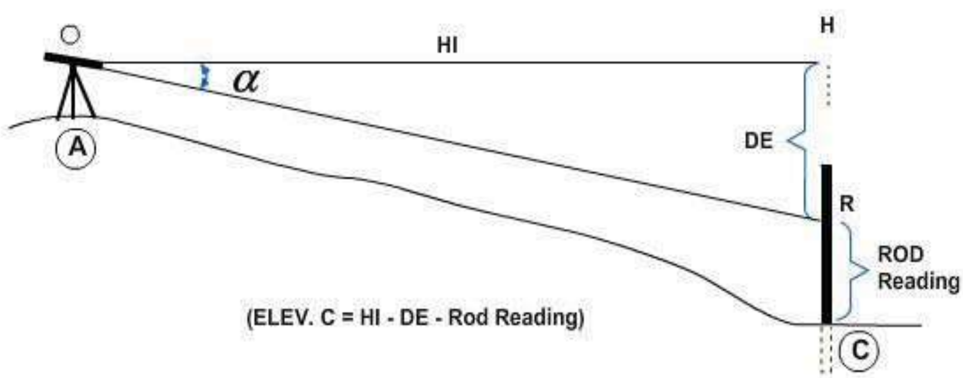


Figure 18-4 - Foresight Depression (Minus) Angle.

3. Elevation angle backsight, shown in *Figure 18-5*. The rod is above the instrument, and the vertical angle is plus. The HI at *F* equals the elevation at *C* plus the rod reading (RC) and minus the DE, or

$$HI = Elev.\ C + RC - DE.$$

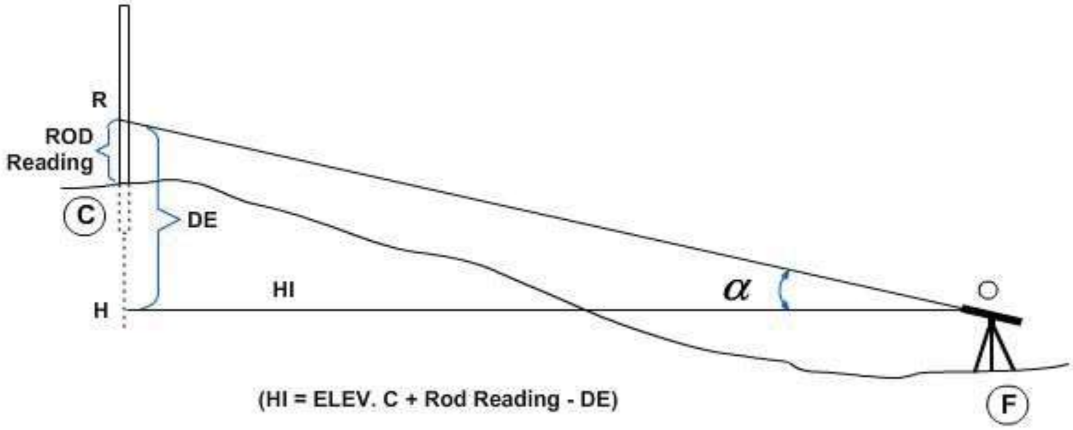


Figure 18-5 - Backsight Elevation (Plus) Angle.

4. Elevation angle foresight, shown in *Figure 18-6*. The rod is above the instrument and the angle is plus. The elevation of *G* equals the HI plus the DE and minus the rod reading (RG), or

$$Elev.\ G = HI + DE - RG.$$

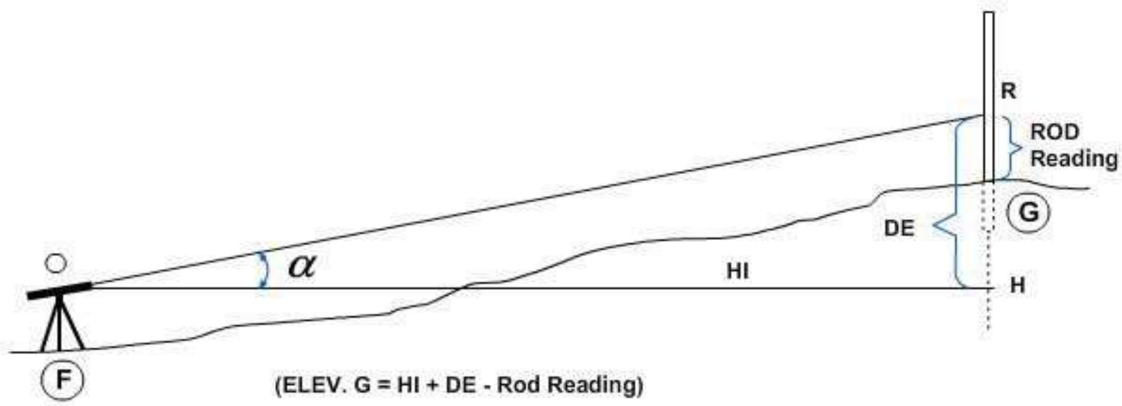


Figure 18-6 - Foresight Elevation (Plus) Angle.

As mentioned earlier in this section, the horizontal or slope distances used for calculating the DE may be obtained using various methods. For each method, there are requirements and limitations, which are discussed below.

1. Measured distances obtained by horizontal chaining should be corrected for standard error, temperature, and sag before computing the DE. These corrections are discussed in Chapter 12 of this NRTC. Under ordinary circumstances in the Seabees, corrections for earth curvature and refraction are not necessary. However, methods to perform these corrections can be found in commercial publications, such as *Surveying Theory and Practice* by Davis, Foote, Anderson, and Mikhail.
2. Measured distances obtained by slope chaining also should be corrected as discussed above. In addition, the slope distance must be converted to a horizontal distance before computing the DE. As an aid in computations, tables have been developed that provide the following data:
    a. Inclination corrections for 100-foot tape

b. Differences in elevation for given horizontal distances and gradients from 0° to 45°

c. Differences in elevation for given slope distances and gradients from 0° to 45°

d. Horizontal distances for given slope distances and gradients from 0° to 45°

3. When using stadia, refer to the stadia procedures and formulas described in Chapter 12 of this NRTC. With practice, these provide a rapid means of determining horizontal distances and elevations.

4. Electronic distance-measuring devices measure the straight-line horizontal or slope distance between instruments. When the same setups slopes is used, replace the electronic equipment with a theodolite and either a target or a rod to measure the vertical angle. The measured vertical angle can be used to convert the measured slope distance to DE by multiplying by the sine of the vertical angle.

Test your Knowledge (Select the Correct Response)

1. Barometric leveling computes the difference in elevations by which of the following measurements?

   A. Slope angle
   B. Atmospheric pressure
   C. Slope distance
   D. Vertical offset

2. Barometric leveling is used mostly in which of the following types of surveys?

   A. Layout
   B. Route
   C. Reconnaissance
   D. Navigational

3. Barometric leveling should be performed at what time of day?

   A. Midday
   B. 2 to 4 hours before sunrise or 2 to 4 hours after sunset
   C. 2 to 4 hours after sunrise or 2 to 4 hours before sunset
   D. 2 to 4 hours before sunset or 2 to 4 hours after sunset

4. When the horizontal or slope distance is measured by chaining, which of the following must be computed before you determine the difference of elevation?

   A. Repair adjustment, sag, and temperature
   B. Standard error, sag, and tension
   C. Sag, temperature, and standard error
   D. Tension, heat, and number of movements

2.0.0 LEVEL and TRAVERSE COMPUTATIONS

This section contains information on procedures used in making level and traverse computations. This section also discusses methods of differential leveling, including steps to follow in checking level notes and information on adjusting intermediate bench marks as well as level nets. In addition, this section addresses several methods of plotting horizontal controls used in determining the bearing of the traverses. These methods include plotting angles by protractor and scale, plotting angles from tangents, and plotting by coordinates. Additional information includes the common mistakes an EA may encounter in making or checking computations.

2.1.0 Preliminaries to Computations

Before starting computations, closely check the field data for completeness and accuracy. This includes checking the field notes to ensure they accurately reflect what was actually measured.

A field measurement may itself require transformation (called reduction**)** before it can be applied as a value in computations. For example, field notes may show plate readings for two-, four-, or six-time angles. Each of these must be reduced to the mean angle, as explained earlier. In another example, field notes may show a succession of chained slope distances. Unless the order of precision of the survey permits slope corrections to be ignored, each of these slope distances must be reduced to the corresponding horizontal distance.

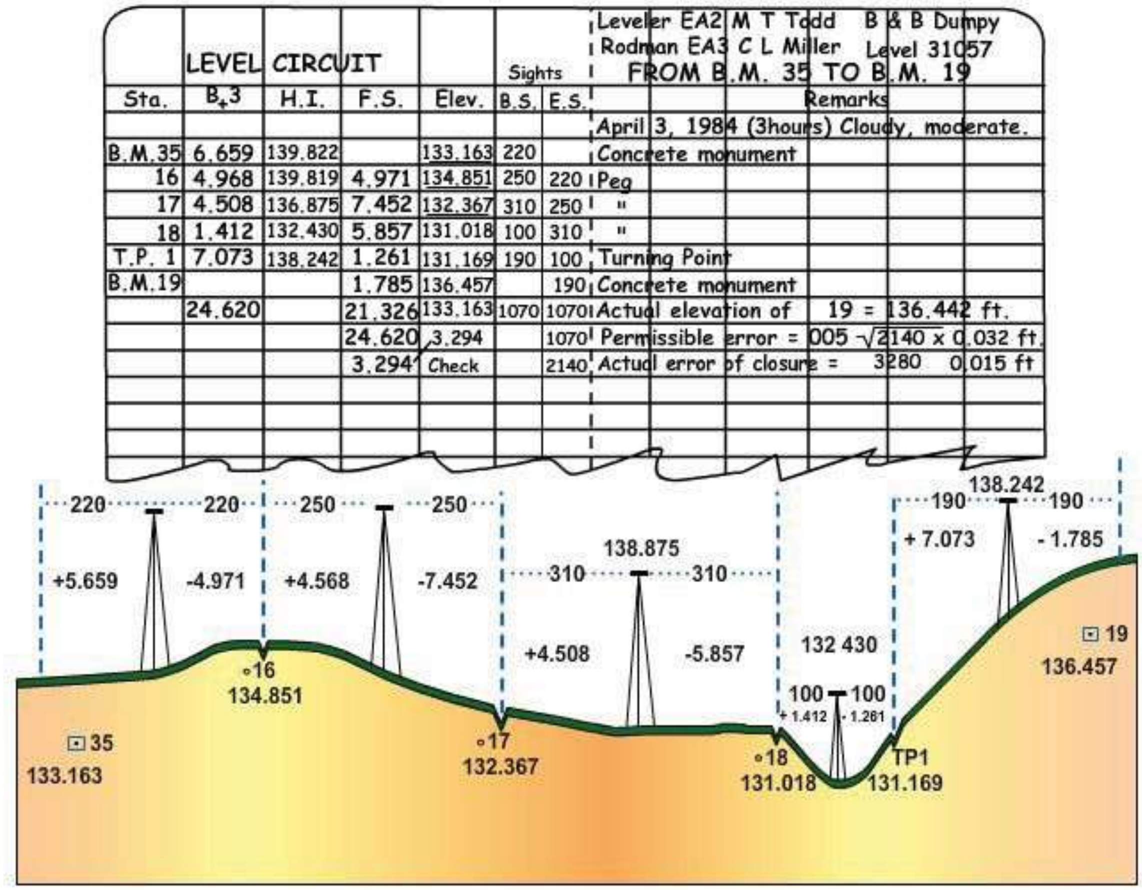
In a closed traverse you must attain a ratio of linear error of closure and a ratio of angular error of closure that are within the maximums specified for, or implied from, the nature of the survey.

An error that is within the maximum allowable is eliminated by "adjustment," which means the equal distribution of a sum total of allowable error over the separate values that contribute to the total. Suppose, for example, that for a triangular closed traverse with interior angles approximately equal in size, the sum of the measured interior angles comes to 179°57'. The angular error of closure is 03'. Because there are three interior angles about equal in size, 01' would be added to the measured value of each angle.

2.2.0 Level Computations

In making level computations, be sure to check the notes for a level run by verifying the beginning bench mark (BM). This checking includes making sure the correct BM was used and its correct elevation was properly recorded. Then check the arithmetical accuracy to ensure backlights are added and foresights are subtracted. The difference between the sum of the foresights taken on BMs or turning points (TPs) and the sum of the backlights taken on BMs or TPs should equal the difference in elevation between the initial BM or TP and the final BM or TP. This fact is shown in *Figure 18-7*.

This procedure only checks the arithmetic. It does not indicate the accuracy of the measurement made in the field.



	LEVEL	CIRCUIT			Sights		Leveler EA2 M T Todd B & B Dumpy Level 31057 Rodman EA3 C L Miller FROM B.M. 35 TO B.M. 19
Sta.	B.S.	H.I.	F.S.	Elev.	B.S.	E.S.	Remarks
							April 3, 1984 (3hours) Cloudy, moderate.
B.M.35	6.659	139.822		133.163	220		Concrete monument
16	4.968	139.819	4.971	134.851	250	220	Peg
17	4.508	136.875	7.452	132.367	310	250	"
18	1.412	132.430	5.857	131.018	100	310	"
T.P. 1	7.073	138.242	1.261	131.169	190	100	Turning Point
B.M.19			1.785	136.457		190	Concrete monument
	24.620		21.326	133.163	1070	1070	Actual elevation of 19 = 136.442 ft.
			24.620	3.294		1070	Permissible error = 005 √2140 x 0.032 ft.
			3.294	Check		2140	Actual error of closure = 3280 0.015 ft

Figure 18-7 – Differential-level circuit and notes for differential leveling.

2.2.1 Adjusting Intermediate Bench Mark Elevations

Level lines that begin and end on points that have fixed elevations, such as bench marks, are often called level circuits. When leveling is accomplished between two previously established bench marks or over a loop that closes back on the starting point, the elevation determined for the final bench mark is seldom equal to its previously established elevation. The difference between these two elevations for the same bench mark is known as the error of closure**.** The remarks column in *Figure 18-7* indicates the actual elevation of BM 19 is known to be 136.442 feet. The elevation found through differential leveling was 136.457 feet. The error of closure of the level circuit is 136.457 - 136.442 = 0.015 feet.

Assume that errors have occurred progressively along the line over which the leveling was conducted. To adjust for this error, the error is equally distributed along the line as shown by the following example. Refer to *Figure 18-7*, and notice the total distance between BM 35 and BM 19, over which the line of levels was run, is 2,140 feet. The elevation on the closing BM 19 is found to be 0.015 foot greater than its known elevation. Therefore adjustments must be made for the intermediate BMs 16, 17, and 18.

The amount of correction is calculated as follows:

Correction = Error of closure [*distance between the starting BM and the intermediate BM]*

distance between the starting and closing BM

BM 16 is 440 feet from the starting BM. The total length distance between the starting and closing BMs is 2,140 feet. The error of closure is 0.015 foot. By substituting these values into the above formula, the correction is as follows:

$$\textit{Correction}\ \ 0.015 \times \frac{440}{2140} \quad 0.003\ ft$$

Since the observed elevation of the closing BM is greater than its known elevation, the adjustments are subtracted from the intermediate BMs. Therefore, for BM 16, the adjusted elevation is 134.851 - 0.003 = 134.848. The adjustments for intermediate BMs 17 and 18 are made in a similar manner.

2.2.2 Calculating the Allowable Error

The allowable error of closure depends on the precision required (first, second, or third order). The allowable error of closure in leveling is expressed in terms of a coefficient times the square root of the horizontal length of the actual route over which the leveling was accomplished.

Most differential leveling (plane surveying) is third-order work. In third-order leveling, the closure is usually made on surveys of higher accuracy without doubling back to the bench mark at the original starting point of the level circuit. The length of the level circuit, therefore, is the actual distance leveled. For third-order leveling, the allowable error is:

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

Refer again to *Figure 18-7*. By adding the sight distances in the sixth and seventh columns of the figure, you will find that the length of the level circuit is 2,140 feet (or 0.405 miles). The allowable error of closure, then, is

$$0.050\ \ ft\ \sqrt{0.405}\ \ \ 0.050(0.64)\ \ \ 0.032\, ft$$

Since the actual error is only 0.015 foot, the results are sufficiently accurate for third-order precision.

First- and second-order levels usually close on themselves. This means the leveling party runs a line of levels from an old BM or station to the new BM or station, and then doubles back to the old BM for closure. The actual distance leveled is twice the length of the level circuit.

For second-order leveling, the allowable error is

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

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

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

2.2.3 Adjusting Level Nets

When a level survey system covers a large area, you, in turn, adjust the interconnecting network in the whole system. Adjustment of an interconnecting network of level circuits consists of adjusting, in turn, each separate figure in the net, with the adjusted values for each circuit used in the adjustment of adjacent circuits. This process is repeated for as many cycles as necessary to balance the values for the whole net. Within each circuit the error of closure is normally distributed to the various sides in proportion to their lengths. *Figure 18-8* represents a level net made up of circuits *BCDEB*, *AEDA*, and *EABE*.

Along each side of the circuit is shown the length of the side in miles and the observed difference in elevation in feet between terminal BMs. The difference in elevation (plus or minus) is in the direction indicated by the arrows. Within each circuit is shown its total length (L) and the error of closure (Ec) which is determined by summing up the differences in elevation in a clockwise direction.

Figure 18-9 shows the computations required to balance the net. The circuits, sides, distances (expressed in miles and in percentages of the total), and differences in elevation (DE) are listed.

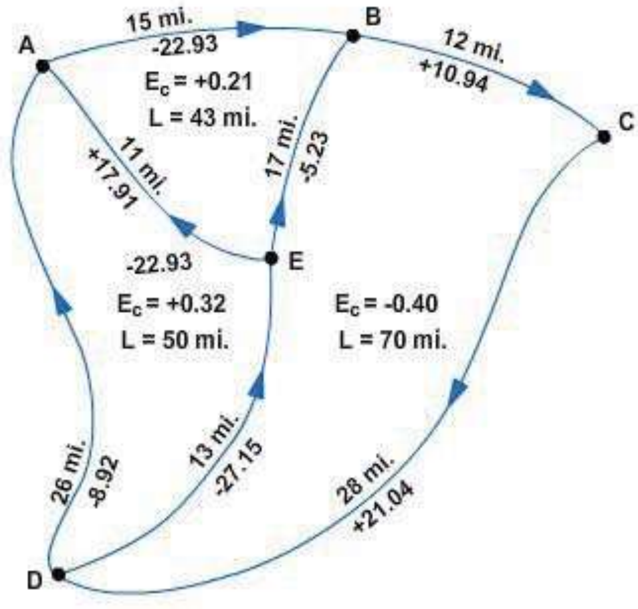


Figure 18-8 - Adjustment of level nets.

Circuit side	Distance		Cycle I			Cycle II			Cycle III			Cycle IV		
	Mi	%	DE	Corr	Corr DE	DE	Corr	Corr DE	DE	Corr	Corr DE	DE	Corr	Corr DE
BCDEB														
BC	12	17	+ 10.94	+ 0.07	+ 11.01	+ 11.01	- 0.02	+ 10.99	+ 10.99	- 0.01	+ 10.98	+ 10.98	0	+ 10.98
CD	28	40	+ 21.04	+ 0.16	+ 21.20	+ 21.20	- 0.05	+ 21.15	+ 21.15	- 0.01	+ 21.14	+ 21.14	- 0. 01	+ 21.13
DE	13	19	- 27.15	+ 0.07	- 27.08	- 27.02	- 0.03	- 27.05	- 27.03	- 0.01	- 27.04	- 27.03	0	- 27.03
EB	17	24	- 5.23	+ 0.10	- 5.13	- 0.03	- 0.03	- 5.09	- 5.07	- 0.01	- 5.08	- 5.08	0	- 5.08
Total.	70	100	- 0.40	+ 0.40	0	+ 0.13	- 0.13	0	+ 0.40	- 0.40	0	+ 0.01	- 0.01	0
AEDA														
AE	11	22	- 17.91	- 0.06	- 17.97	- 17.93	- 0.01	- 17.94	- 17.93	0	- 17.93	- 17.93	....	....
ED	13	26	+ 27.08	- 0.06	+ 27.02	+ 27.05	- 0.02	+ 27.03	+ 27.04	- 0.01	+ 27.03	+ 27.03	....	....
DA	26	52	- 8.92	- 0.13	- 9.05	- 9.05	- 0.04	- 9.09	- 9.09	- 0.01	- 9.10	- 9.10	....	....
Total.	50	100	+ 0.25	- 0.25	0	+ 0.07	- 0.07	0	+ 0.02	- 0.02	0	0	....	....
EABE														
EA	11	26	+ 17.97	- 0.04	+ 17.93	+ 17.94	- 0.01	+ 17.93	+ 17.93	0	+ 17.93	+ 17.93	....	....
AB	15	35	- 22.93	- 0.06	- 22.99	- 22.99	- 0.01	- 23.00	- 23.00	- 0.01	- 23.01	- 23.01	....	....
BE	17	39	+ 5.13	- 0.07	+ 5.06	+ 5.09	- 0.02	+ 5.07	+ 5.08	0	+ 5.08	+ 5.08	....	....
Total.	43	100	+ 0.17	- 0.17	0	+ 0.04	- 0.04	0	+ 0.01	- 0.01	0	0	....	....

Figure 18-9 - Computations required to balance the level net.

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

$$0.40 \times \frac{12}{70} \;\; 0.07 \; feet$$

Notice that the sign is opposite to that of the error of closure. The correction of +0.07 foot is entered on the first line of the column headed CORR and is added to the difference in elevation (10.94 + 0.07 = +11.01). The sum is entered on the first line under the heading CORR DE (corrected difference in elevation). The same procedure is followed for the remaining lines *CD*, *DE*, and *EB* of circuit *BCDEB*.

The sum of the corrections must have the opposite sign and be equal to the error of closure. The algebraic sum of the corrected differences in elevation must equal zero. The lines in circuit *AEDA* are corrected in the same manner as *BCDEB*, except that the corrected value of *ED* (+27.08 instead of +27.15) is used. The lines of *EABE* are corrected using the corrected value of *EA* (+17.97 instead of +17.91) and *BE* (+5.13 instead of +5.23). In the column Cycle II, the procedure of Cycle I is repeated. You should always list the latest corrected value from previously adjusted circuits before computing the new error of closure. The cycles are continued until the corrections become zero. The sequence in which the circuits are taken is immaterial as long as they are repeated in the same order for each cycle. Computations may be based on corrections rather than differences in elevation.

2.3.0 Traverse Computations

Traverse operations are conducted for mapping large construction projects, such as a military post or an air base, road railroad and pipeline alignment projects, and for many other projects. A traverse is always classified as either a closed traverse or an open traverse. A closed traverse starts and ends at the same point or at points whose relative horizontal positions are known. An open traverse ends at the station whose relative position is previously unknown and, unlike a closed traverse, provides no check against mistakes and large errors. In the Chapter 12, you studied field procedures for laying out traverses. In this chapter you will study computations that are necessary for adjusting and determining the areas of traverses.

2.3.1 and Reducing Angles

The beginning traverse computations start with checking to make sure all the required angles (including closing angles) were turned and that the notes correctly indicate their sizes. For deflection angles, check to make sure that angles marked *L* or *R* were actually turned and have been turned in those directions. Check to make sure sketches agree with your field notes. Next, reduce repeated angles to mean angles using the procedures learned in Chapter 12.

2.3.2 and Reducing Distances

Check to make sure that all required linear distances have been chained. Reduce slope distances when needed. If you broke chain on the slopes, check to make sure that the sums of break distances were correctly added. Finally, apply standard error, tension, and temperature corrections if needed.

2.3.3 Adjusting Angles

From your study of the Chapter 14, you should recall the following three conditions for a closed traverse:

1. The theoretical or geometrical sum of the interior angles is 180° x (n - 2), n being the number of angles measured.
2. The sum of the exterior angles is 180° x (n + 2), where n = number of angles measured.
3. The difference between the sum of the right deflection angles and the sum of the left deflection angles is 360°. Any discrepancy between one of these sums and the actual sum of the angles as turned or measured constitutes the angular error of closure.

You adjust the angles in a closed traverse by distributing an angular error of closure that is within the allowable maximum equally among the angles. *Figure 18-10* shows a traverse in which one of the deflection angles was turned to the left, all others to the right. The sum of the right deflection angles is 444°59'. By subtracting the left deflection angle (85°01'), the angular error of closure of 02' is determined, which is an average of 20" per deflection angle. This average angular error of closure is then added to each right deflection angle and subtracted from each left deflection angle. After applying this adjustment to each deflection angle in this example, you find, then, that the sum of the adjusted angles to the right equals 445°00'40" and that the sum of the left angles (of which there is only one) is 85°00'40". The difference between these values is 360°00'00", as it should be.

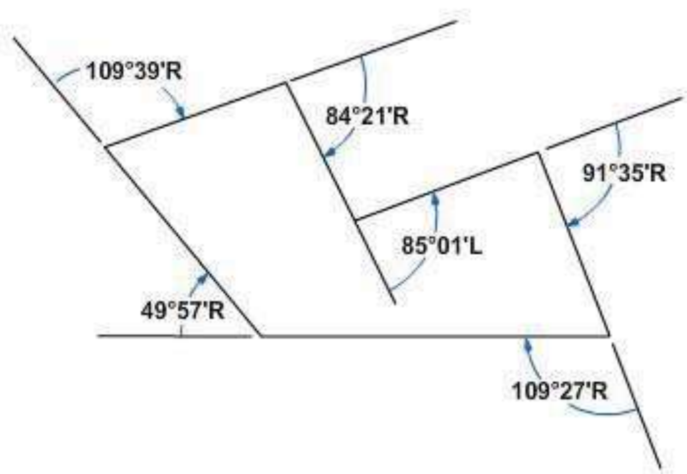


Figure 18-10 - Close traverse by deflection-angle method.

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

2.3.4 Adjusting for Linear Error of Closure

The procedure for distributing a linear error of closure (one within the allowable maximum) over the directions and distances in a closed traverse is called balancing or closing the traverse. However, before this information can be calculated you must understand the concept of latitude and departure.

2.3.4.1 Latitude and Departure

Latitude and departure are values used in the method of locating a point horizontally by its plane coordinates. In the plane coordinate system, a point of origin is arbitrarily selected for convenience. The location of a point is given in terms of its distance north or south and its distance east or west of the point of origin. The plane coordinate system will be explained later in this chapter.

The latitude of a traverse line means the length of the line as projected on the north-to-south meridian running through the point of origin. The departure of a traverse line means the length of the line as projected on the east-to-west parallel running through the point of origin, as shown in *Figure 18-11)*. The point of origin is at *O*. The line *NS* is the meridian through the point of origin, and the line *EW* is the parallel through the point of origin. The latitude of *AB* is the length of *AB* as projected on *NS* and the departure of *AB* is the length of *AB* as projected on *EW*. If a traverse line was running due north and south, the latitude would equal the length of the line and the departure would be zero. For a line running due east and west the departure would equal the length of the line and the latitude would be zero.

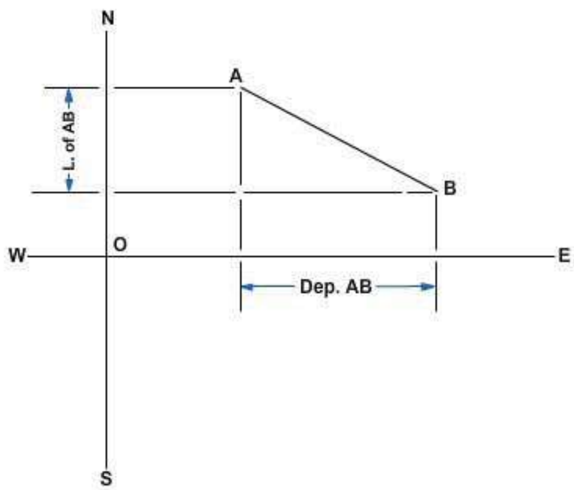


Figure 18-11 - Latitude and departure.

Now, for a line running other than north to south or east to west, the latitude or departure can be determined by simple triangle solution. *Figure 18-12* shows a traverse line 520.16 feet long bearing S61°25'E. To determine the latitude, you solve the triangle *ABC* for the length of the side *AC*. From the bearing, you know that the size of angle *CAB* (the angle of bearing) is 61°25'. The triangle is a right triangle; therefore

AC = 520.16 cos 61°25' = 248.86 feet.

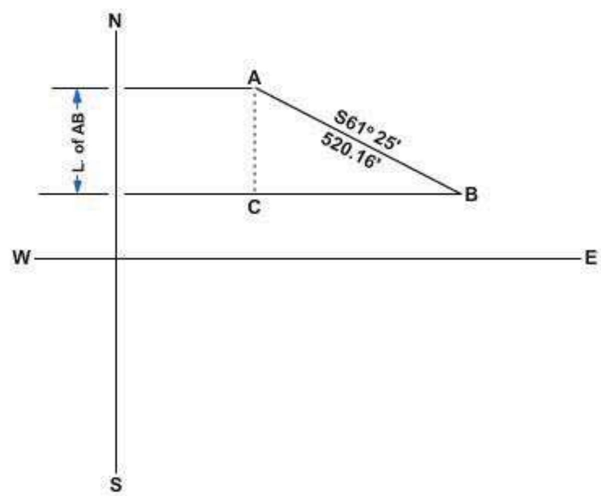


Figure 18-12 - Latitude equals length of traverse line times cosine of angle of bearing.

The latitude of a traverse line, then, equals the product of the length of the line times the cosine of the angle of bearing.

To determine the departure, solve the length of the side *CB* shown in *Figure 18-13.*

CB = 520.16 sin 61°25' = 456.76 feet.

The departure of a traverse line, then, equals the length of the line times the sine of the angle of bearing.

The latitude of a traverse line is designated north or south and the departure is designated east or west following the compass direction of the bearing of the line. A line bearing northeast, for example, has a north latitude and east departure. In computations, north latitudes are designated plus and south latitudes minus; east departures are designated plus and west departures minus.

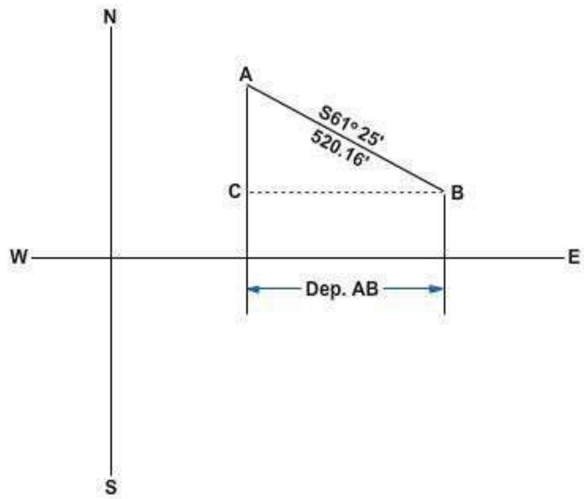


Figure 18-13 - Departure equals length of traverse line times sine of angle of bearing.

Figure 18-14 demonstrates that in a closed traverse, the algebraic sum of the plus and minus latitudes is zero and the algebraic sum of the plus and minus departures is zero. The plus latitude of *CA* is equal in length to the sum of the two minus latitudes of *AB* and *BC*. The minus departure of *BC* is equal in length to the sum of the two plus departures of *CA* and *AB*.

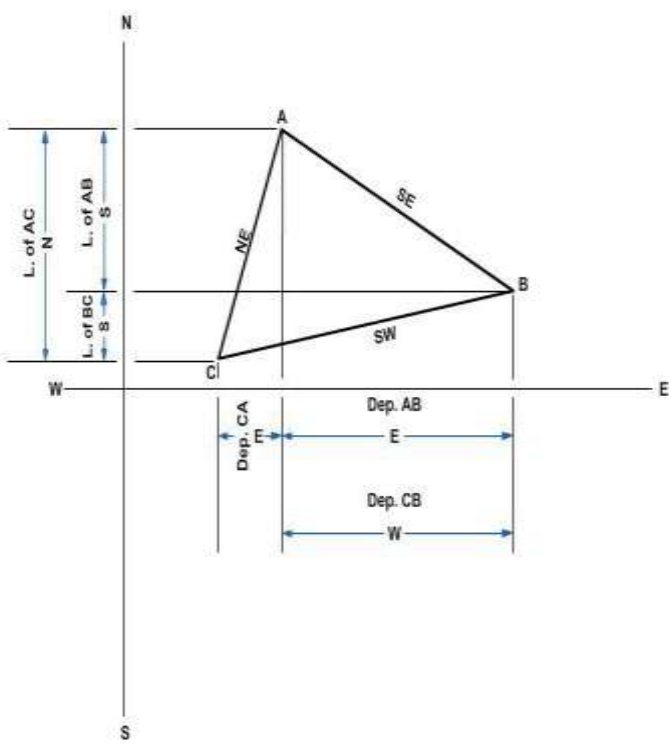


Figure 18-14 - Graphic solution of a closed traverse by latitude and departure.

2.3.4.2 Linear Error of Closure

In practice, the sum of the north latitudes usually differs from the sum of the south latitudes. The difference is called the error of closure in latitude. Similarly, the sum of the east departures usually differs from the sum of the west departures. The difference is called error of closure in departure.

From the error of closure in latitude and the error of closure in departure, the linear error of closure can be determined. This is the horizontal linear distance between the location of the end of the last traverse line (as computed from the measured angles and distances) and the actual point of beginning of the closed traverse.

For example, you come up with an error of closure in latitude of 5.23 feet and an error of closure in departure of 3.18 feet. These two linear intervals form the sides of a right triangle. The length of the hypotenuse of this triangle constitutes the linear error of closure in the traverse. By the Pythagorean Theorem, the length of the hypotenuse equals approximately 6.12 feet. Suppose the total length of the traverse was 12,000.00 feet. Then your ratio of linear error of closure would be 6.12:12,000.00, which approximately equates to 1:2,000.

2.3.4.3 Closing a Traverse

A traverse is closed or balanced by distributing the linear error of closure (one within the allowable maximum, of course) over the traverse. There are several methods of doing this, but the one most generally applied is based on the compass rule**.** This rule adjusts the latitude and departure of each traverse line as follows:

1. Correction in latitude equals the linear error of closure in latitude times the length of the traverse line divided by the total length of traverse.
2. Correction in departure equals the linear error of closure in departure times the length of the traverse line divided by the total length of traverse.

Figure 18-15 shows a closed traverse with bearings and distances notes.

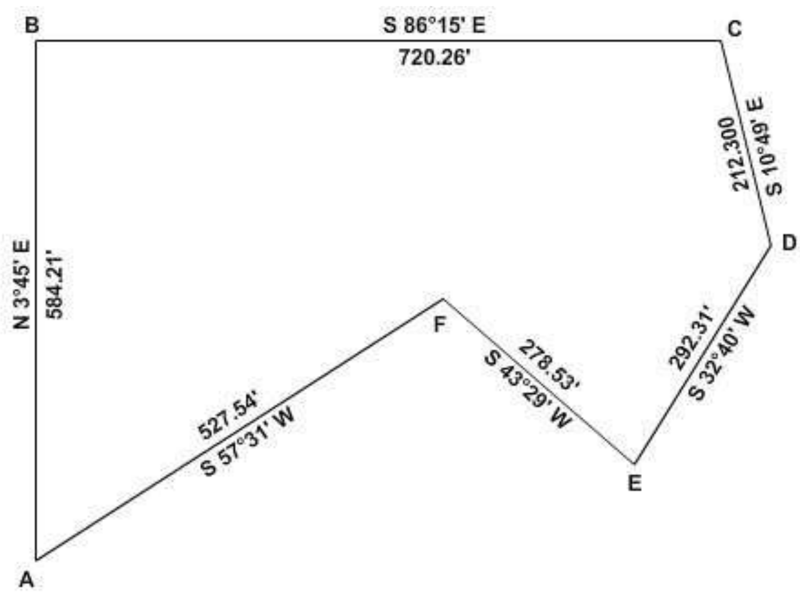


Figure 18-15 - Closed traverse by bearings and distance.

Figure 18-16 shows the computation of the latitudes and departures for the traverse entered on the form commonly used for this purpose. As you can see, the error in latitude is +0.33 foot, and the error in departure is +2.24 feet. The linear error of closure, then, is

$$\sqrt{(0.33^2 + 2.24^2)}\ \ 2.26\ \ feet$$

Station	Bearing	Distance	Function		Latitude		Departure	
			Cohne	.sine	North	South	East	West
A								
	N 3°45' E	584.21	.99786	.06540	582.95		38.20	
B								
	S 86°15' E	720.26	.06540	.99786		47.10	718.72	
C								
	S 10°49' E	212.00	.98223	.18767		208.23	39.77	
D								
	S 32° 40' W	292.31	.84182	.53975		246.07		157.77
E								
	N 43° 29' W	278.53	.72557	.68814	202.09			191.67
F								
	S 57° 31' W	527.54	.53705	.84335		283.31		445.01
A								
	TOTAL	2614.85		TOTALS	785.04	784.71	796.69	794.45
					-784.71		-794.45	
					+.33		2.24	

Figure 18-16 - Form for computing latitudes and departures.

The total length of the traverse is 2614.85 feet; therefore, the ratio of error of closure is 2.26:2614.85, or about 1:1157.

Assume this ratio is within the allowable maximum. Proceed now to adjust the latitudes and departures by the compass rule. Set down the latitudes and departures on a form like the one shown in *Figure 18-17* with the error of closure in latitude at the foot of the latitudes column and the error of closure in departure at the foot of the departures column.

Next, use the compass rule to determine the latitude correction and departure correction for each line. For all, the latitude correction equals

$$0.33 \text{ x } \frac{584.21}{2614.85}\ \ 0.07\ \ feet$$

The error of closure in latitude is plus; therefore, the correction is minus.

Note that the sum of the applied latitude corrections equals the error of closure in latitude and the sum of the applied departure corrections equals the error of closure in departure. The corrections, however, are opposite in sign to the error of closure.

2.3.5 Traverse Tables/Adjusting Bearings and Distances

In computing latitudes and departures, arithmetical calculations can be greatly expedited by the use of a traverse table. The latitudes and departures for any bearing and distance can be determined mostly by using the tables.

Line	Latitude	Departure	Lat. Correction	Dep. Correction	Adj. Latitude	Adj. Departure
AB	+582.95	+38.20	-0.07	-0.50	+582.88	+37.70
BC	-47.10	+718.72	-0.09	-0.62	-47.19	+718.1
CD	-208.23	+39.77	-0.03	-0.18	-208.26	+39.59
DE	-246.07	-157.77	-0.04	-0.25	-246.11	-158.02
EF	+202.09	-191.67	-0.03	-0.24	+202.06	-191.91
FA	-283.31	-445.01	-0.07	-0.45	-283.38	-445.46
	+0.33	+2.24	-0.33	-2.24	0.00	0.00

Figure 18-17 - Form for adjusting latitudes and departures.

Figure 18-18 shows sample pages from a table that gives angle-of-bearing values to the nearest quarter degree (15'). More precise tables give angular values to the nearest 01'.

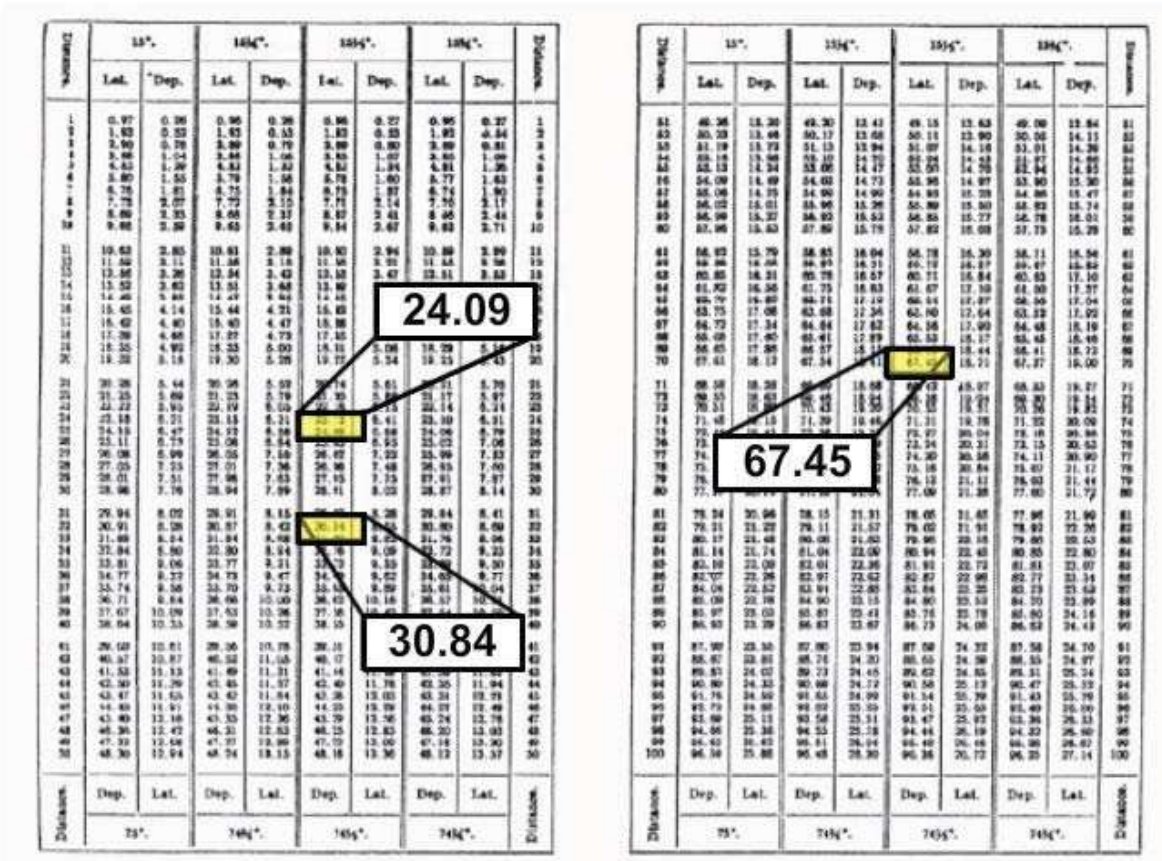


Figure 18-18 – Sample pages from traverse table.

Under each of the bearing values at the head of the page, a double column gives latitudes and departures for distances of from 1 to 100 feet. For a particular traverse line, you determine the latitudes and departures by breaking down the distance, moving decimal points, and adding up results as in the following example.

Suppose you want to determine the latitude and departure for a traverse line 725.32 feet long, bearing N15°30'E. Perform the following steps to find the latitude. In the latitude column 15 1/2°, identify the latitude for 70 feet. You read 67.45 feet. If the latitude for 70 feet is 67.45 feet, the latitude for 700 feet is 674.50 feet. Note this in your notes.

Next, you look up the latitude for 25 feet under the same 15 1/2° latitude column, which is 24.09 feet. The latitude for 725 feet, then, is

$$674.50 + 24.09 = 698.59 \text{ feet.}$$

Finally, for the 0.32 foot, look up the latitude for 32 feet, which is 30.84 feet. If the latitude for 32 feet is 30.84 feet, the latitude for 0.32 foot must be 0.3084 foot, which rounds off at 0.31 foot. The numerical value of the latitude then is 698.59 + 0.31 = 698.90 feet. Because the line *AB* bears northeast, the latitude is positive.

Departure is calculated in the same way by using the departure column.

Finally, enter the adjusted latitudes and adjusted departures in the last two columns. Determine the values in each case by applying the correction to the original latitude or departure. Note that the negative latitudes now equal the positive latitudes and the negative departures equal the positive departures. This indicates the errors of closure have been entirely distributed.

With the adjusted latitudes and departures, you can now adjust the original bearings and distances by the method called inversing**.** Inversing simply means computing the bearing and length of a traverse line from the latitude and departure. Again the process is one of simple triangle solution. *Figure 18-19* shows traverse line *AB* with the adjusted latitude and departure noted. To determine the adjusted angle of bearing, you solve the triangle *AA'B* for angle *A'AB* as follows:

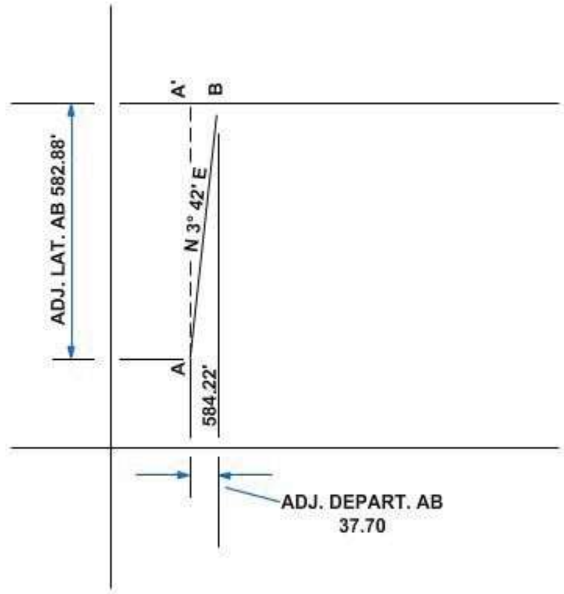


Figure 18-19 - Adjusted bearing and distance from adjusted latitude and departure.

$$\tan A'AB \quad \frac{37.70}{583.88} \quad 0.06468$$

$$A'AB \; 3042'$$

The adjusted bearing of *AB,* then, is N3°42'E. For the adjusted distance, solve the triangle for *AB* as follows:

$$AB \quad \frac{37.70}{\sin 3042'} \quad \frac{37.70}{0.06453} \quad 584.22 \; feet$$

The adjusted length of *AB*, then, is 584.22 feet.

2.3.6 Plane Coordinates

The location of a point by plane coordinates means to describe the location of the point in terms of its distance north or south and east or west from a point of origin.

Figure 18-20 shows how coordinate distances are measured on an axis (called the Y axis) running north to south through the point of origin. East to west coordinates are measured on an X axis running east to west through the point of origin. Values on the Y axis north of the point of origin are plus and values south of the point of origin are minus. Values on the X axis east of the point of origin are plus and values west of the point of origin are minus.

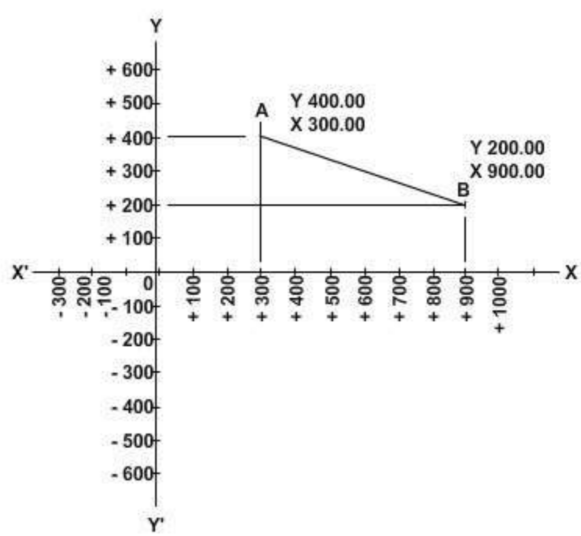


Figure 18-20 - Location by plane coordinates.

2.3.6.1 Plane Coordinates from Latitude and Departure

Figure 18-20 also shows the relationship between the plane coordinates of the end stations on a traverse line and the latitude and departure of the line. You can see the difference between the Y coordinate of *A* and the Y coordinate of *B* (which is 200.00 feet) equals the latitude of *AB.* You can also see the difference between the X coordinate of *A* and the X coordinate of *B* (which is 600.00 feet) equals the departure of *AB.* Therefore, if you know the coordinates of one of the stations in a traverse, you can determine the coordinates of the others from the latitudes and departures.

Figure 18-21 shows a closed traverse with adjusted latitudes and departures notes. You want to assign plane coordinates to the traverse stations. To avoid the necessity of working with negative coordinates, you select as point of origin a point *O* that is west of the most westerly traverse station and south of the most southerly traverse station.

You determine the bearing and length of dotted line *OD* and compute from these values the latitude and departure of *OD*. You can see that the Y coordinate of station D must equal the latitude of *OD*, or 150.70 feet. Also the X coordinate of D must equal the departure of *OD* or 556.30 feet.

The Y coordinate of station A equals the Y coordinate of D plus the latitude of *AD* or

150.70 + 591.64 = 742.34 feet.

The X coordinate of station A equals the X coordinate of D minus the departure of *AD* or 556.30 - 523.62 = 32.68 feet.

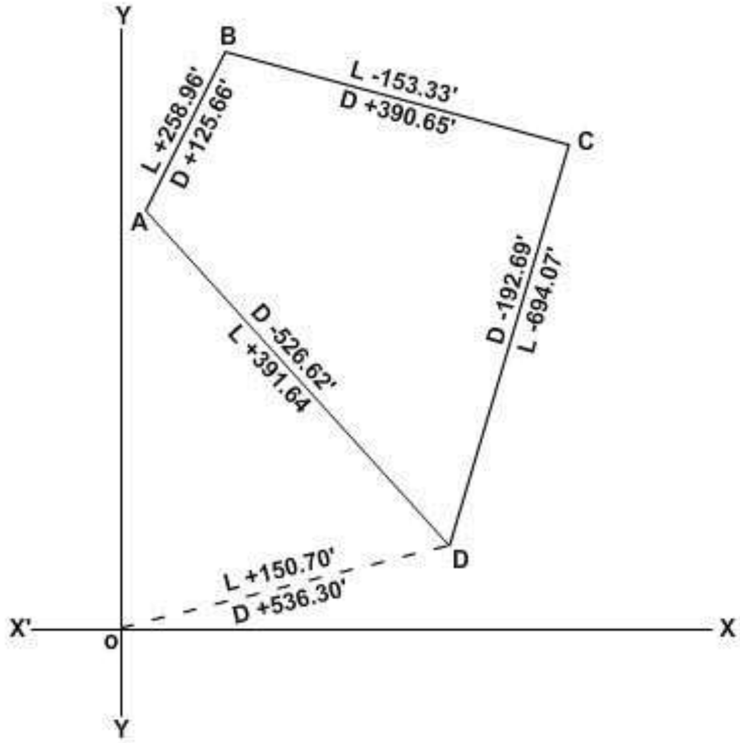


Figure 18-21 - Closed traverse with adjusted latitudes and departures.

The Y coordinate of station B equals the Y coordinate of station A plus the latitude of *AB* or 742.34 + 255.96 = 998.30 feet.

The X coordinate of station B equals the X coordinate of station A plus the departure of *AB* or

32.68 + 125.66 = 158.34 feet.

The Y coordinate of station C equals the Y coordinate of station B minus the latitude of C or

998.30 - 153.53 = 844.77 feet.

The X coordinate of station C equals the X coordinate of station B plus the departure of BC or

158.34 + 590.65 = 748.99 feet.

The Y coordinate of station D equals the Y coordinate of station C minus the latitude of CD or

$$844.77 - 694.07 = 150.70 \text{ feet.}$$

The X coordinate of station D equals the X coordinate of station C minus the departure of CD or

$$748.99 - 192.69 = 556.30 \text{ feet.}$$

These are the same coordinates originally computed for station D, a fact that serves as a check on accuracy.

You enter these values on a form that is similar to the one shown in Figure 18-22. In actual practice, however, a wider form is used on which all values and computations from the original station through bearing and distance, latitude and departure, and coordinates can be entered.

Station	Latitude		Departure		Coordinates	
	NORTH	SOUTH	EAST	WEST	Y	X
A					742.34	32.68
	255.96		125.66			
B					998.30	158.34
		153.53	590.65			
C					844.77	748.99
		694.07		192.69		
D					150.70	556.30
	591.64			523.62		

Figure 18-22 - Form for computing coordinates.

2.3.6.2 Latitude and Departure from Plane Coordinates

The numerical values of latitude and departure of a traverse line are easily computed from the coordinates of the end stations of the line. For traverse line *AB*, for example, the numerical value of latitude equals the difference between the Y coordinate of *A* and the Y coordinate of *B*, while the numerical value of departure equals the difference between the X coordinate of *A* and the X coordinate of *B*.

To determine whether a latitude or departure computed this way is positive or negative, the best method is to examine a sketch of the traverse to determine the compass direction of the bearing of the line in question. If the line bears northeast, the latitude is positive, or north, and the departure is positive, or east. If the line bears southwest, both latitude and departure are negative.

2.3.7 Areas

Various methods are used in computing areas. Some of the common methods are discussed below.

2.3.7.1 Area by Double Meridian Distance

The meridian distance of a traverse line is equal to the length of a line running east to west from the midpoint of the traverse line to a reference meridian. The reference meridian is the meridian that passes through the most westerly traverse station.

In *Figure 18-23*, the dotted lines indicate the meridian distances of the traverse lines to which they extend from the reference meridians. You can see that the meridian distance of the initial line *AB* equals one half of the departure of *AB*. The meridian distance of the next line *BC* equals the meridian distance of *AB*, plus one half of the departure of *AB*, plus one half of the departure of *BC*.

Figure 18-23 shows that the meridian distance of *CD* equals the meridian distance of *BC*, plus one half of the departure of *BC*, minus one half of the departure of *DC.* Similarly, the meridian distance of *AD* equals the meridian distance of *DC*, minus one half of the departure of *DC*, minus one half of the departure of *AD*.

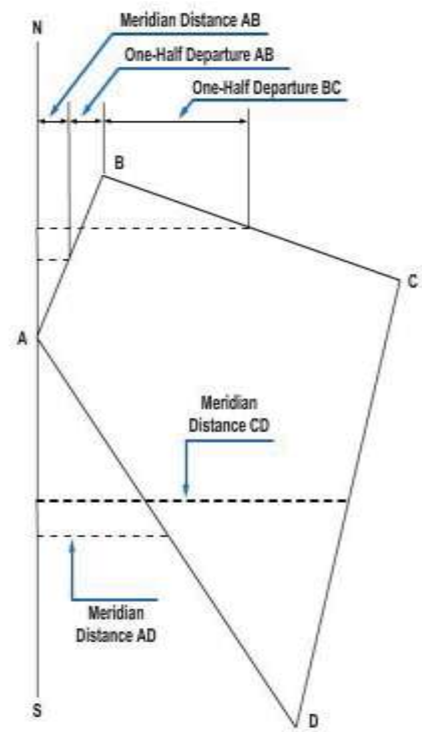


Figure 18-23 - Meridian distances.

You should now understand the basis for the following rules for determining meridian distance:

1. For the initial traverse line in a closed traverse, the meridian distance equals one half of the departure.

2. For each subsequent traverse line, the meridian distance equals the meridian distance of the preceding line, plus one half of the departure of the preceding line, plus one half of the departure of the line itself. However, it is the algebraic sum that results-meaning that plus departures are added but minus departures are subtracted.

It is customary to use double meridian distance (DMD) rather than meridian distance in calculations. When the meridian distance of the initial traverse line in a closed traverse equals one-half of the departure of the line, the DMD of the line equals its departure. Again, from the rule for meridian distance of the next line, the DMD of that line equals the DMD of the preceding line, plus the departure of the preceding line, plus the departure of the line itself.

It can be shown geometrically that the area contained within a straight-sided closed traverse equals the sum of the areas obtained by multiplying the meridian distance of each traverse line by the latitude of that line. Again the result is the algebraic sum. If you multiply a positive meridian distance (when the reference meridian runs through the most westerly station, all meridian distances are positive) by a plus or north latitude, you get a plus result that you add. If you multiply a positive meridian distance by a minus or south latitude, however, you get a minus result that you subtract.

Therefore, if you multiply for each traverse line the double meridian distance by latitude instead of meridian distance by latitude, the sum of the results will equal twice the area, or the double area. To get the area, divide the double area by 2.

Figure 18-24 shows entries for the computations of the DMD of the area of the traverse *ABCD*. Because *AB* is the initial traverse line, the DMD of *AB* equals the departure. The DMD of *BC* equals the DMD of *AB* (125.66), plus the departure of *AB* (125.66), plus the departure of *BC* (590.65), or 841.97 feet. The DMD of *CD* equals the DMD of *BC* (841.97), plus the departure of *BC* (590.65), plus the departure of *CD* (which is minus 192.69, and therefore is subtracted), or 1239.93 feet. The DMD of *DA* equals the DMD of *CD* (1239.93), plus the departure of CD (-192.69), plus the departure of DA (-523.62), or 523.62 feet. Note that the DMD of this last traverse line equals the departure of the line, but with an opposite sign. This fact serves as a check on the computations.

The double area for *AB* equals the DMD times the latitude or

$$125.66 \times 255.96 = 32{,}163.93 \text{ square feet.}$$

The double area for *BC* equals 841.97 (the DMD) times minus 153.53 (the latitude), or minus 129,267.65 square feet. The double area of *CD* is

$$1{,}239.93 \times (-694.07) = -860{,}598.21 \text{ square feet.}$$

The double area of *DA* is 523.62 x 591.64 = 309,794.54 square feet.

The difference between the sum of the minus double areas and the sum of the plus double areas is the double area which is 647,907.39 square feet. The area is one half, or 323,953.69 square feet. Land area is generally expressed in acres. There are 43,560 square feet in 1 acre; therefore, the area in acres is $\frac{323953.69}{43560}\ 7.44A.$

Course	Latitude		Departure		DMD	Double Area	
	+	–	+	–		+	–
AB	+255.96		+125.66		+125.66	+32163.93	
BC		-133.53	+590.63		+341.97		-129267.65
CD		-694.07		-192.69	+1239.93		-860598.21
DA	+591.64			-523.62	+523.62	+309794.54	
						341958.47	989565.86
							341958.47
						2)	647907.39
							323953.69
			Area = 323,953.69 Sq. Ft. = 7.44 Acres				

Figure 18-24 - Area from double meridian distances.

2.3.7.2 Area by Double Parallel Distance

The accuracy of the area computation of a DMD can be checked by computing the same area from double parallel distances (DPD).

As shown in *Figure 18-25*, the parallel distance of a traverse line is the north-to-south distance from the midpoint of the line to a reference parallel. The reference parallel is the parallel passing through the most southerly traverse station.

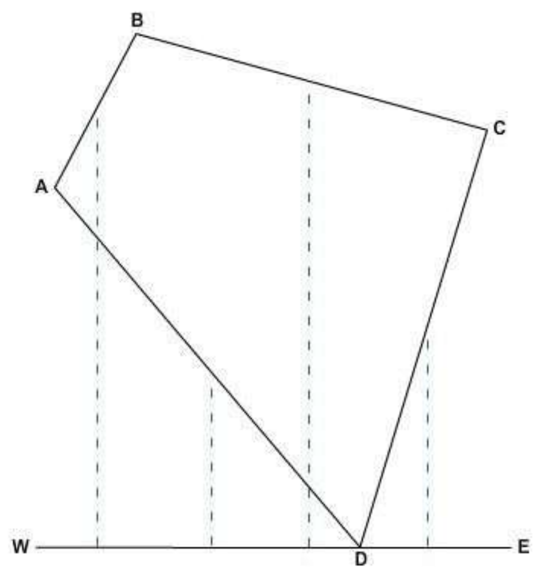


Figure 18-25 - Parallel distances.

The solution for parallel distance is the same as the one used for meridian distance, except that to compute parallel distance, the latitude is used instead of departure. The parallel distance of the initial traverse line (which is *DA* in this case) equals one half of the latitude. The parallel distance of the next line, *AB,* equals the parallel distance of the preceding line, *DA,* plus one half of the latitude of the preceding line *DA,* plus one half of the latitude of line *AB* itself.

It follows from the above that the DPD of the initial traverse line *DA* equals the latitude of the line. The DPD of the next line, *AB*, equals the DPD of the preceding line, *DA*, plus the latitude of the preceding line, *DA*, plus the latitude of the line *AB* itself. The solution for area is the same as for area by meridian distance except that, for the double area of each traverse line, you multiply the DPD by the departure instead of multiplying the DMD by the latitude.

Figure 18-26 shows entries for the computation of the area of DPD for the traverse *ABCD*. Note that the result is identical to that obtained by the computation of the DMD.

Course	Latitude		Departure		DPD	Double Area	
	+	−	+	−		+	−
DA	+591.64			-523.62	+591.64		-309794.54
AB	+255.96		+125.66		+1439.24	+180854.90	
BC		-153.53	+590.65		+1541.67	+910387.38	
CD		-694.07		-192.69	+694.07		-133740.35
						+1091442.28	-443534.89
						-443534.89	
						2) 647907.39	
						323953.69	
			Area = 323,953.69 Sq. Ft. = 7.44 Acres				

Figure 18-26 - Area from double parallel distances.

2.3.7.3 Area from Coordinates

Before we explain the method of computing area from coordinates, let us set coordinates for the stations of the traverse *ABCD*. To avoid using negative coordinates, we will measure Y coordinates from an X axis passing through the most southerly station and X coordinates from a Y axis passing through the most westerly station, as shown in *Figure 18-27*.

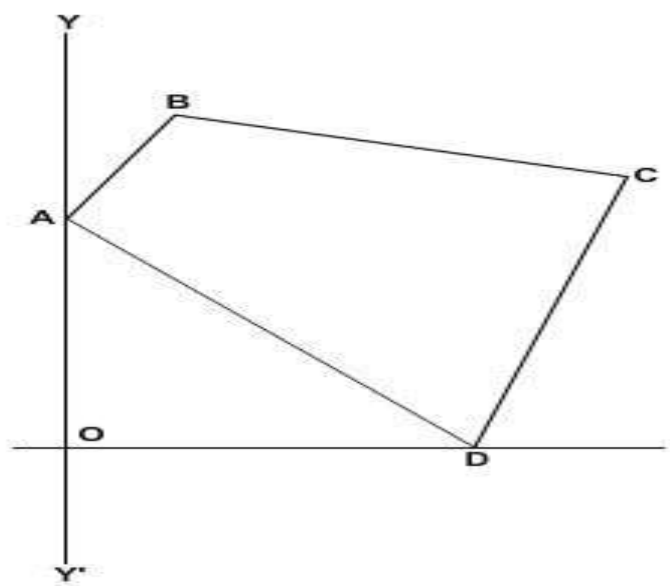


Figure 18-27 - Closed traverse by coordinate method.

Figure 18-28 shows the coordinate entries. It shows that the Y coordinate of *A* equals the latitude of *DA*, or 591.64 feet, and the X coordinate of *A* is zero. The Y coordinate of *B* equals the Y coordinate of *A* plus the latitude of *AB* or 591.64 + 255.96 = 847.60 feet.

Station	Latitude		Departure		Coordinates	
	+	-	+	-	Y	X
A					591.64	0
	+255.96		+125.66			
B					847.60	125.66
		-153.53	+590.65			
C					694.07	716.31
		-694.07		-192.69		
D					0	523.62
	+591.64			-523.62		
A					591.64	0

Figure 18-28 - Coordinate entries for computation of Figure 18-27.

The X coordinate of *B* equals the departure of *AB*, or 125.66 feet. The Y coordinate of *C* equals the Y coordinate of *B* minus the latitude of *BC* or 847.60 - 153.53 = 694.07 feet.

The X coordinate of *C* equals the X coordinate of *B* plus the departure of *BC* or 125.66 + 590.65 = 716.31 feet.

The Y coordinate of *D* obviously is zero; however, it computes as the Y coordinate of *C* minus the latitude of *CD* of 694.07 - 694.07, which serves as a check. The X coordinate of *D* equals the X coordinate of *C* minus the departure of *CD* or 716.31 - 192.69 = 523.62 feet. This is the same as the departure of *DA*, but with an opposite sign-a fact which serves as another check.

Figures 18-29 and *18-30* show the method of determining the double area from the coordinates. First, multiply pairs of diagonally opposite X and Y coordinates, as shown in *Figure 18-29*, and determine the sum of the products. Then, multiply pairs diagonally in the opposite direction, as shown in *Figure 18-30*, and determine the sum of the products. The difference between the sums (shown in *Figure 18-29*) is the double area or 1,044,918.76 - 397,011.37 = 647,90.39 square feet. The symbol shown beside the sum of the coordinate products is the capital Greek letter (L) sigma. In this case, it means sum.

Station	Coordinates	
	Y	X
A	591.64	0
B	847.60	125.66
C	694.07	716.31
D	0	523.62
A	591.64	0

591.64 X 125.66 = 74,345.48

847.60 X 716.31 = 607,144.35

694.07 X 523.62 = 363.428.93

0 X 0 = 0

Σ 1,044,918.76

Figure 18-29 - First step for tabulated computation of Figure 18-27.

Station	Coordinates	
	Y	X
A	591.64	0
B	847.60	125.66
C	694.07	716.31
D	0	523.62
A	591.64	0

0 X 847.60 = 0

125.66 X 694.07 = 87,216.84

716.31 X 0 = 0

523.62 X 591.64 = 309794.53

Σ 397,011.37

Figure 18-30 - Second step for tabulated computation of Figure 18-27.

2.3.7.4 Area by Trapezoidal Formula

It is often necessary to compute the area of an irregular figure, when one or more of its sides do not form a straight line. For illustration purposes, assume *Figure 18-31* is a parcel of land in which the south, east, and west boundaries are straight lines perpendicular to each other, but the north boundary is a meandering shoreline.

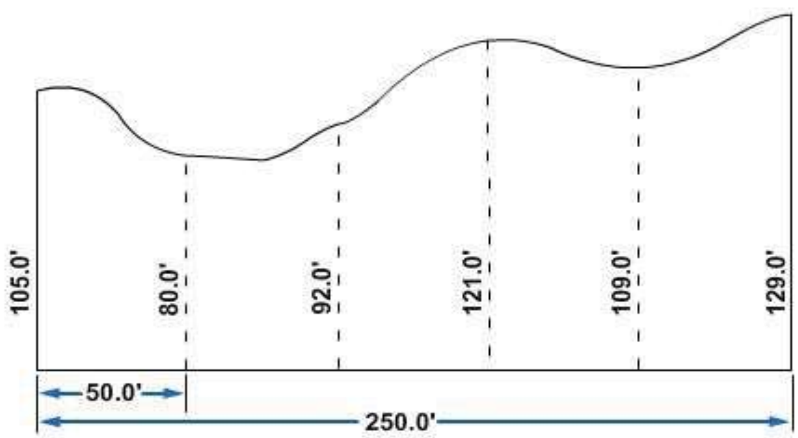


Figure 18-31 - Area of irregular figure by trapezoidal rule.

To determine the area of this figure, first lay off conveniently equal intervals (in this case, 50.0-foot intervals) from the west boundary and erect perpendiculars as shown. Measure the perpendiculars. Call the equal interval "d" and the perpendiculars (beginning with the west boundary and ending with the east boundary) h_1 through h_6.

You can see that for any segment lying between two perpendiculars, the approximate area, by the rule for determining the area of a trapezoid, equals the product of "d" times the average between the perpendiculars. For the most westerly segment, for example, the area is

$$d\left(\frac{h_1+h_2}{2}\right).$$

The total area equals the sum of the areas of the segments. Therefore, since "d" is a factor common to each segment, the formula for the total area may be expressed as follows:

$$A = d\left(\frac{h_1+h_2}{2}+\frac{h_2+h_3}{2}+\frac{h_3+h_4}{2}+\frac{h_4+h_5}{2}+\frac{h_5+h_6}{2}\right)$$

This works out to

$$A = d\left(\frac{h_1+2h_2+2h_3+2h_4+2h_5+2h_6}{2}\right)$$

In turn, this reduces to

$$A = d\left(\frac{h_1+h_6}{2}+h_2+h_3+h_4+h_5\right)$$

Substituting in the formula the data from *Figure 18-31*, you have

$$A = 50\left(\frac{105+129}{2}+80+92+121+109\right)$$

When the calculation is completed the result is 25,950 square feet or approximately 0.6 acre.

2.3.7.5 Area by Counting the Squares

Another method of computing the area of an irregular figure is to plot the figure on a sheet of graph paper. The area is then determined by counting the squares within the figure outline and multiplying the result by the area represented by each square.

Figure 18-32 shows the same figure shown in *Figure 18-31* but plotted to scale on a sheet of graph paper on which each of the small squares is 5 feet x 5 feet or 25 square feet. When squares within the outline are counted, they total 1,038 squares which means

1,038 x 25 = 25,950 square feet.

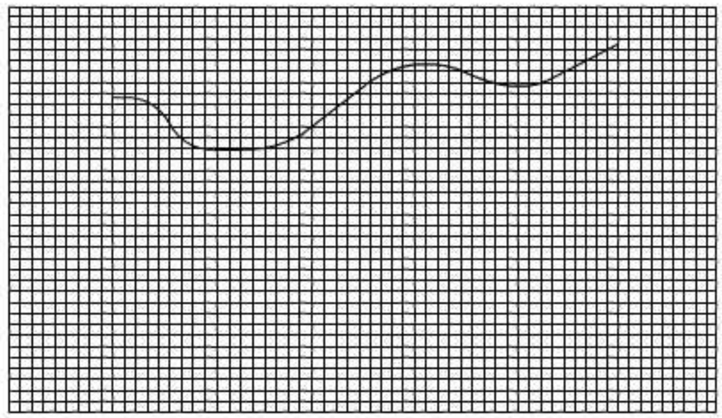


Figure 18-32 - Computing area by counting the squares.

2.3.7.6 Parcels That Include Curves

Not all parcels of land are bounded entirely by straight lines. It is often necessary to compute the area of a construction site that is bounded in part by the center lines or edges of curved roads or the right-of-way lines of curved roads.

Figure 18-33 shows a construction site with a shape similar to the traverse used in the previous examples. In this site, however, the traverse lines *AB* and *CD* are the chords of circular curves, and the boundary lines *AB* and *CD* are the arcs intercepted by the chords. The following sections explain the method of determining the area lying within the straight-line and curved-line boundaries.

The data for each of the curves is inscribed on *Figure 18-33*, that is, the radius R, the central angle �, the arc length A, the tangent length T and the chord bearing and distance C_H.

The crosshatched areas lying between the chord and arc are called segmental areas. To determine the area of this parcel, you must take the following steps.

1. Determine the area lying within the straight-line and chord (also straight-line) boundaries.
2. Determine the segmental areas.
3. Subtract the segmental area for Curve 1 from the straight-line boundary area.
4. Add the segmental area for Curve 2 to the straight-line boundary area.

The method of determining a segmental area was explained in the EA Basic Chapter 2. The straight-line area may be determined by the coordinate method, as explained in this chapter. For *Figure 18-33*, the segmental area for Curve 1 works out to be 5,151 square feet; for Curve 2, it is 29,276 square feet.

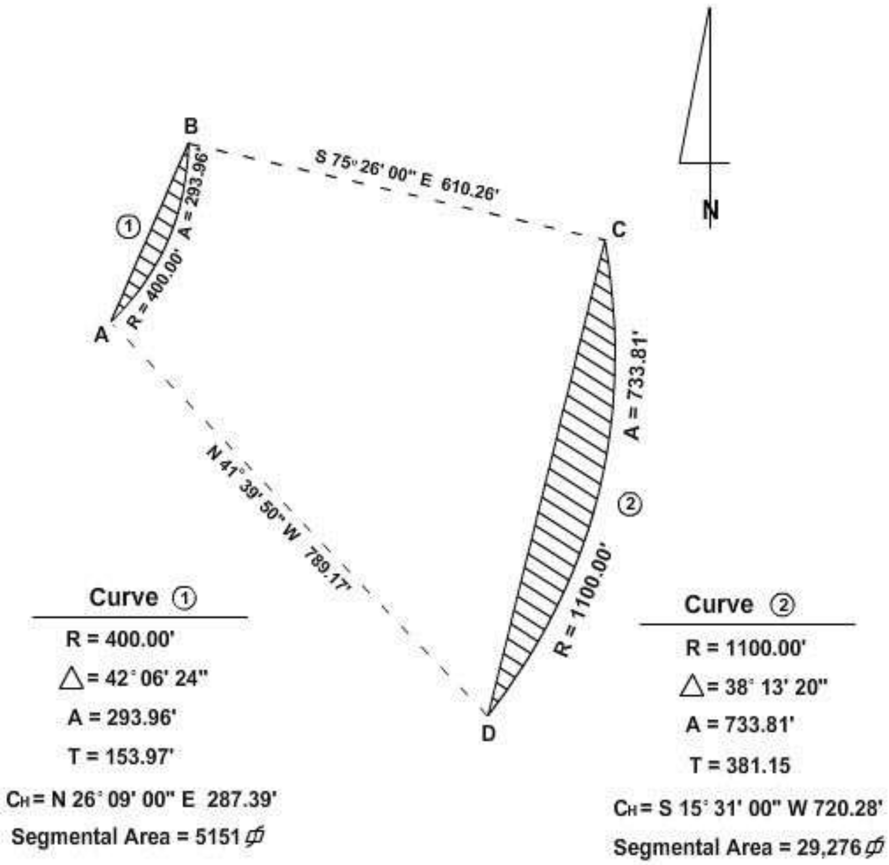


Figure 18-33 - Area within straight-line and curved-line boundaries (curved segments).

Figure 18-34 shows a typical computation sheet for the area problem shown in *Figure 18-33*. Included with the station letter designations in the station column are designations (Chord #1 and Chord #2) showing the bearings and distances that constitute the chords of Curves 1 and 2. The remainder of the upper part of the form shows the process (with which you are now familiar) of determining latitudes and departures from the bearings and distances, coordinates from the latitudes and departures, double areas from cross multiplication of coordinates, double areas from the difference between the sums of north and sums of east coordinates, and areas from half of the double areas. As you can see in *Figure 18-34*, the area within the straight-line boundaries is 324,757 square feet. From this area, segmental area No. 1 is subtracted. Then segmental area No. 2 is added.

To calculate the area of the parcel as bounded by the arcs of the curves, add or subtract the segmental areas depending on whether the particular area in question lies inside or outside of the actual curved boundary. In *Figure 18-33*, the segmental area for Curve 1 lies outside and must be subtracted from the straight-line area, while Curve 2 lies inside and must be added. With the segmental areas accounted for, the area comes to 348,882 square feet or 8.01 acres.

STATION	BEARING	DIST.	FUNCTION		LAT	DEP	COORDINATES	
			COS	SIN	N+;S-	E+;W-	NORTH	EAST
A							740.33	31.68
Chord #1	N 26°09' 00" E	287.39	89764	44072	+257.97	+126.66		
B							998.30	158.34
	S 75° 26' 00" E	610.26	25151	96786	-153.49	+590.65		
C							844.81	748.99
Chord #2	S 15° 31' 00" W	720.28	96355	26752	-694.03	-192.69		
D							150.78	556.30
	N 41° 39' 50" W	789.17	74705	66477	+589.55	-524.68		
A							740.33	31.68
							Σ \	1,339,685.1
							Σ /	- 690,171.7
							2A =	649.513.4
							A =	324,757
					Less Segmental Area #1			- 5,151
					Plus Segmental Area #2			+ 29,276
								348,882 ø
								8.0092 Ac.

Figure 18-34 - Computation of area which includes curve segments.

The second method of determining a curved boundary area uses the external areas rather than the segmental areas of the curves, as shown in *Figure 18-35*. The straight-line figure is defined by the tangents of the curves, rather than by the chords. This method may be used as an alternative to the chord method or to check the result obtained by the chord method.

The computation sheet shown in *Figure 18-36* follows the same pattern as *Figure 18-34*. However, there are two more straight-line boundaries, because each curve has two tangents rather than a single long chord.

The coordinates of *A, B, C,* and *D* are the same as in the first example, but the coordinates of the points of intersection (PIs) must be established from the latitudes and departures of the tangents. The computations for determining the tangent bearings are shown in the lower left of *Figure 18-36*. When the chord bearing is known, the tangent bearing can be computed by adding or subtracting one-half of delta (�) as appropriate. The angle between the tangent and the chord equals �2.

After setting coordinates on the PIs, cross-multiply, accumulate the products, subtract the smaller from the larger, and divide by 2, as before, to get the area of the straight-line figure running around the tangents. Then add or subtract each external area as appropriate. In *Figure 18-35*, the external area for Curve 1 is inside the parcel boundary and must be added, while Curve 2 is outside and must be subtracted. The area comes to 348,881 square feet, which is an acceptable check on the area calculated by using the segmental areas.

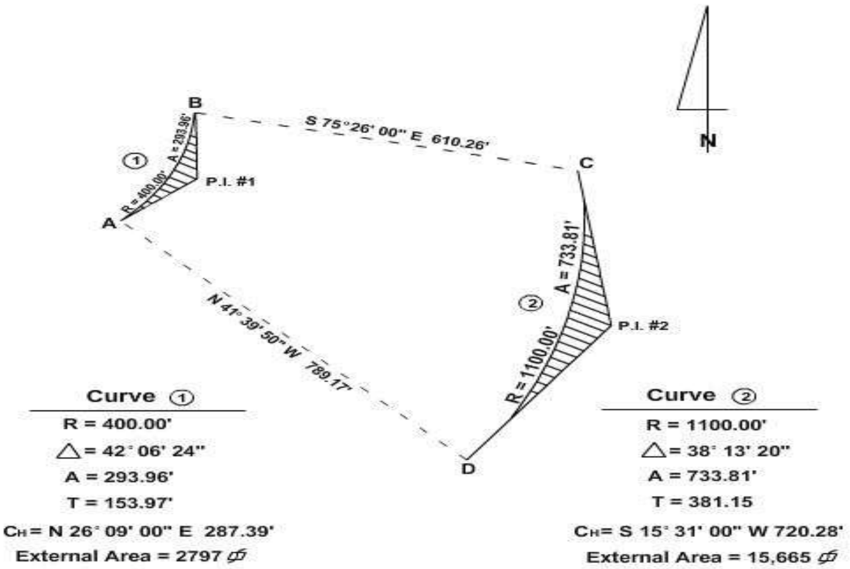


Figure 18-35 - Area within the curve and its tangents.

STATION	BEARING	DIST.	FUNCTION COS	FUNCTION SIN	LAT N+;S-	DEP E+;W-	COORDINATES NORTH	COORDINATES EAST
A							740.33	31.68
Tangent	N 47° 12' 12" E	153.97	67940	73377	+104.61	+112.98		
P.I. #1							844.94	144.66
Tangent	N 5° 05' 48" E	153.97	99605	08884	+153.36	+13.68		
B							998.30	158.34
C							844.81	748.99
Tangent	S 3° 35' 40" E	381.15	99803	06269	-380.40	+23.89		
P.I. #2							464.41	772.88
Tangent	S 34° 37' 40" W	381.15	822.86	568.24	-313.63	-216.58		
D							150.78	556.30
A							740.33	31.68

①	②		
$\Delta/_2$ = 21° 07' 12"	$\Delta/_2$ =19° 01' 40"	Σ\	1,904,665.4
		Σ\	-1,181,167.9
CHB = N 26° 09' 00" E	CHB = S 15° 31' 00" W	2A =	723,497.5
+ $\Delta/_2$ = +21° 03' 12"	+ $\Delta/_2$ = +19° 06' 40"	A =	361,749
tanB = N 47° 12' 12" E	tanB = S 34° 37' 40" W	Plus External Area #1 =	+2,797
		Less External Area #2 =	-15,665
CHB = N 26° 09' 00" E	$\Delta/_2$ = +19° 06' 40"		348,881 ⌀
- $\Delta/_2$ - = +21° 03' 12"	- CHB = S 15° 31' 00"	or	8,009.2 Ac.
tanB = N 5° 05' 48" E	tanB = S 3° 35' 40" E		

Figure 18-36 - Computation of area which includes external area of curves.

2.3.8 ntal Control

Computations for horizontal control become clarified when a plot or scaled graphic representation of the traverse can be viewed. For example, looking at a plot can tell you whether you should add or subtract the departure or the latitude of a traverse line in computing the departure or latitude of an adjacent line or in computing the coordinates of a station.

For linear distances that are given in feet and decimals of feet, use the correct scale on an engineer's scale for laying off linear distances on a plot. For plotting traverses, there are three common methods: by protractor and scale, by tangents, and by coordinates.

2.3.8.1 Plotting Angles by Protractor and Scale

The adjusted bearings and distances for closed traverse *ABCD* are as follows:

Traverse Line	Bearing	Distance
AB	$N26009'E$	285.14 *feet*
BC	$S75026'E$	610.26 *feet*
CD	$S15031'W$	720.28 *feet*
DA	$N41031'W$	789.96 *feet*

Figure 18-37 shows the plotting method of traverse *ABCD* using a scale and protractor. First select a scale that will make the plot fit on the size of the paper. Select a convenient point on the paper for station A and draw a light line *NS,* representing the meridian through the station.

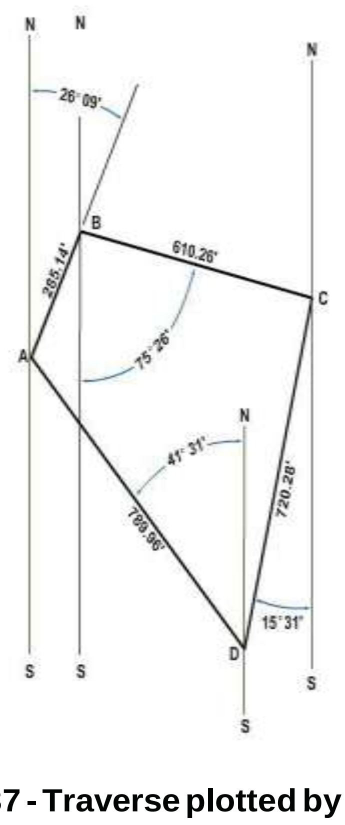


Figure 18-37 - Traverse plotted by protractor and scale method.

AB bears N26°9'E. Set the protractor with the central hole on *A* and the 00 line at *NS*, and lay off 26°09'E. The minutes must be estimated. Draw a line in this direction from *A*, and on the line measure off the length of *AB* (285.14 feet) to scale.

This locates station B on the plot. Draw a light line *NS* through *B* parallel to *NS* through *A*, representing the meridian through station B. *BC* bears S75°26'E. Set the protractor with the central hole on *B* and the 00 line on *NS*, lay off 75°26' from the S leg of *NS* to the E, and measure off the length of *BC* (610.26 feet) to scale to locate *C*. Proceed to locate *D* in the same manner. This procedure produces a number of light meridian lines through stations on the plot. *Figure 18-38* illustrates a procedure that eliminates these lines. A single meridian *NS* is drawn clear of the area of the paper on which you intend to plot the traverse. From a convenient point *O*, lay off each of the traverse lines in the proper direction. Then transfer the directions to the plot by one of the methods for drawing parallel lines.

2.3.8.2 Plotting Angles from Tangents

Sometimes instead of having bearing angles to plot from, you might want to plot the traverse from deflection angles turned in the field. The deflection angles for the traverse are as follows:

AB to *BC*	78°25'R *BC*
to *CD*	90°57'R
CD to *DA*	122°58'R
DA to *AB*	67°40'R

You could plot from these angles by protractor. Lay off one of the traverse lines to scale. Then lay off the direction of the next line by turning the deflection angle to the right of the first line extension by protractor and so on.

However, the fact that you can

read a protractor directly to only the nearest 30 minutes presents a problem. When you plot from bearings, the error in estimation of minutes applies only to a single traverse line. When you plot from deflection angles, however, the error carries on cumulatively all the way around. For this reason, you should use the tangent method when you are plotting deflection angles.

Figure 18-39 shows the procedure of plotting deflection angles larger than 45°. The direction of the starting line is called the meridian, following a conventional procedure that the north side of the figure being plotted is situated toward the top of the drawing paper. In doing this, you might have to plot the appropriate traverse to a small scale using a protractor

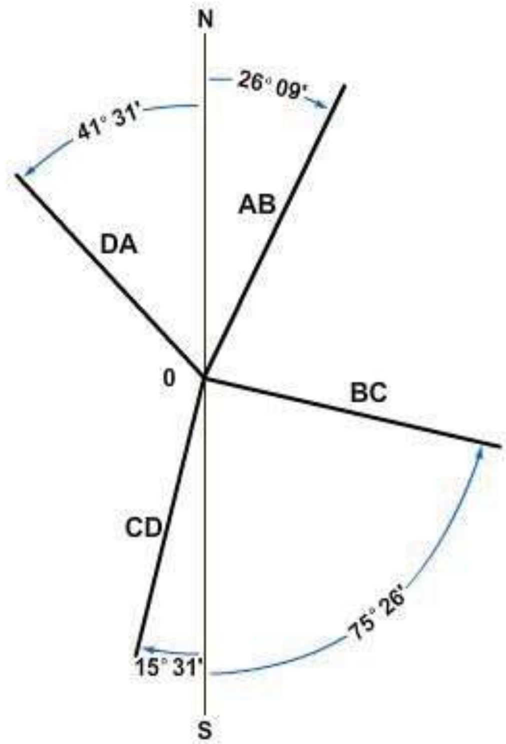


Figure 18-38 – Plotting traverse lines by parallel method from a single meridian.

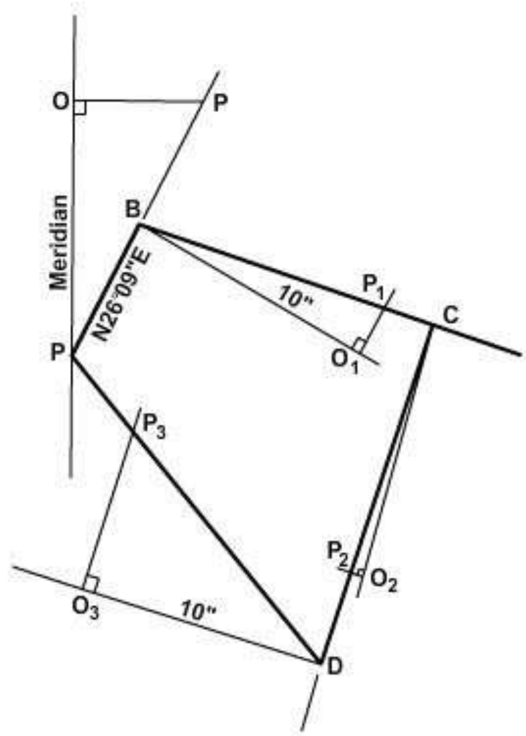


Figure 18-39 – Plotting by tangent-offset method from deflection angles larger than 45 degrees.

and an engineer's scale, just to have a general idea of where to start. Make sure that the figure will fit proportionately on the paper of the desired size. Starting at point *A*, you draw the meridian line lightly. Then you lay off *AO,* 10 inches (or any convenient round-figure length) along the referenced meridian. Now, from *O* you draw a line *OP* perpendicular to *AO*. Draw a light line *OP* as shown. In a trigonometric table, look for the natural tangent of the bearing angle 26°90', which equals to 0.49098. Find the distance *OP* as follows:

$$OP = AO \tan 26°09' = 4.9098, \text{ or } 4.91 \text{ inches.}$$

You know that *OP* is equal to 4.91 inches. Draw *AP* extended and then lay off the distance *AB* to scale along *AP*. Remember that unless a closed traverse is plotted, it is always advantageous to start offsets from the referenced meridian, the reason being that, after you have plotted three or more lines, you can always use this referenced meridian line for checking the bearing of the last line plotted to find any discrepancy. The bearing angle, used as a check, should also be found by the same method (tangent-offset method).

To plot the directions of lines from deflection angles larger than 45°, the complementary angle (90° minus the deflection angle) must be used. To plot the direction of line *BC* in *Figure 18-39*, draw a light perpendicular line towards the right from point B. Measure off a length of approximately 10 inches, which represents *BOJ*. The complement of the deflection angle of *BC* is 90° - 78°25' = 11°35'.

The natural tangent value of 11°35' is equal to 0.20497. From O_1 draw O_1P_1 perpendicular to BO_1. Solving for O_1P_1, you will have

$$O_1P_1 = BO_1 \tan 11°35' = 2.0497, \text{ or } 2.05 \text{ inches.}$$

Now lay off the distance O_1P_1. Draw a line from *B* through P_1 extended; lay off the distance *BC* to scale along this line. The remaining sides, *CD* and *DA*, are plotted the same way. Make sure that the angles used for your computations are the correct ones. A rough sketch of your next line will always help to avoid major mistakes.

When the deflection angle is less than 45°, the procedure of plotting by tangent is as shown in *Figure 18-40*. Here you measure off a convenient round-figure length (say 500.00 feet) on the extension of the initial traverse line to locate point *O*, and from *O*, draw *OP* perpendicular to *AO*. The angle between *BO* and *BC* is, in this case, the deflection angle. Assume that 23°21'. The formula for the length of *OP* is this is

$$OP = BO \tan 23°21' = 500 \times 0.43170 = 215.85 \text{ feet.}$$

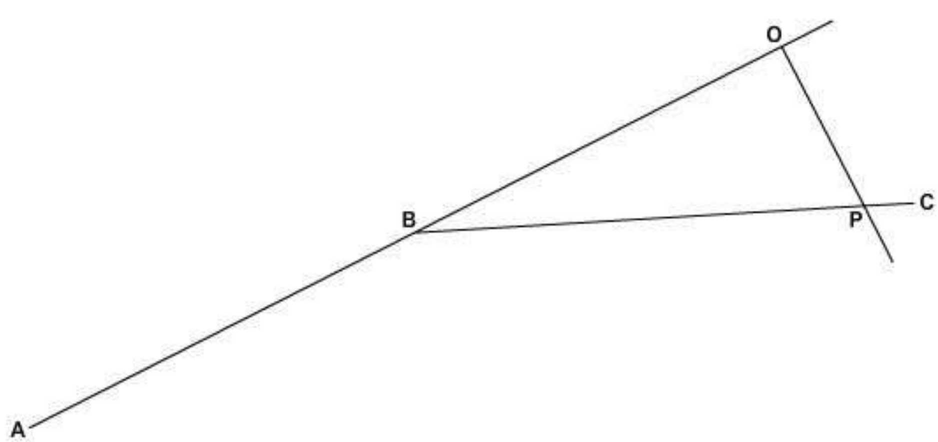


Figure 18-40 - Plotting by tangent-offset method from deflection angles smaller than 45 degrees.

2.3.8.3 Plotting by Coordinates

A common and accurate method of plotting by coordinates is shown in *Figure 18-41*. Each station is located by its coordinate and without angular measurements. To plot station B, for instance, you would lay off from *O* on the Y axis a distance equal to the Y coordinate of *B* (847.60 feet). Draw a light line from this point perpendicular to the Y axis, and measure off on this line a distance equal to the X coordinate of *B* (125.66 feet). The remaining points are plotted in the same way.

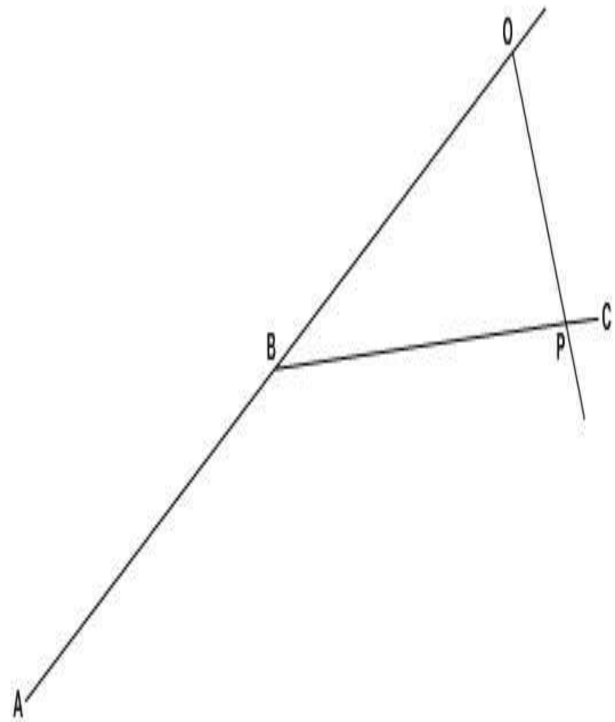


Figure 18-41 - Plotting by coordinates.

2.3.9 Mistakes in Computations

An involved computation, such as determining an area by DMDs, involves a large number of calculations and thus the possibility of a large number of errors. Some of the most common types of mistakes are discussed below.

2.3.9.1 Mistakes with Signs

Be careful to give a value such as a latitude or departure its correct sign (+ or -) and apply the sign correctly in addition, subtraction, multiplication, and division. To prevent not including the correct sign, do not write a value without including the sign. The practice of omitting plus signs is a correct procedure, but it is safer to write in the plus signs.

2.3.9.2 9.2 Wrong Column

A wrong column mistake may be an entry made in a wrong column or a reading taken from a wrong column. To avoid column mistakes, make both entries and readings with deliberation.

2.3.9.3 Wrong Quadrant

When you mistake the quadrant in which a line lies, you get a bearing that may have the correct angular value but that has the wrong compass direction. A common cause of this mistake is viewing the direction of a line from the wrong station. In *Figure 18-42*, the direction of *AB* is northeast and the direction of *BA* is southwest. However, *AB* and *BA* are the same traverse line. To minimize direction errors, place arrows on the diagram showing the direction of the line.

2.3.9.4 9.4 Wrong Azimuth

The same mistake that applies to quadrants also applies to azimuths. Suppose that the bearing of *AB* in *Figure 18-42* is N46°E. Then the azimuth of *AB* is (measured from north) 46°. While *AB* and *BA* are the same traverse line, the azimuth of *BA* is 226°.

2.3.9.5 Leaving Out a Traverse Line

A common source of mistakes is leaving out (commonly called dropping**)** a traverse line, either in the field notes or in computations. If an outsized angular and linear error of closure occurs, check to make sure one of the traverse lines has not been dropped.

2.3.9.6 Wrong Decimal Place

The incorrect placement of a decimal point is a common mistake. Suppose, for example, you are determining an approximate double area by multiplying a DMD of +841.97 feet by latitude of -153.53 feet. If the value of -1535.3 is used instead of the correct -153.53, the result will not be correct.

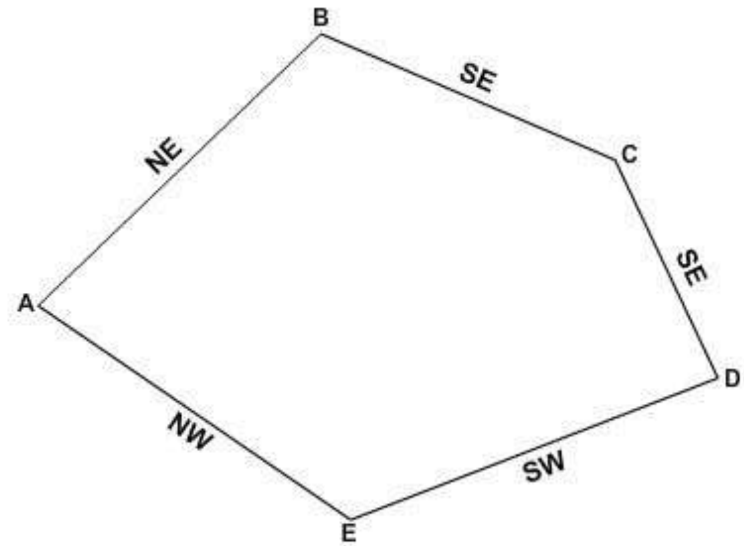


Figure 18-42 – Proper compass direction of a closed traverse.

2.3.10 ing Mistakes

If a mistake cannot be located and corrected, the whole traverse must be rerun to find the mistake. This may be avoided by using of the following solutions to identifying mistakes.

2.3.10.1 zed Angular Error of Closure

The size of an outsized angular error of closure may be a clue to the location of the particular mistake. Suppose, for example, that a six-sided closed traverse has the following measured interior angles:

90018′
118048′
1540142′
147018′
<u>1010</u> <u>128</u>′
612018′

The interior angles in a six-sided closed traverse should add up to 720°00'. The difference between 720°00' and 612°18' is 107°42'. This large difference suggests that measuring about 107°42' was dropped along the way. You should look for an angle of about this size in the traverse.

Suppose that in a four-sided traverse, the difference between the sum of the R-deflection angles and the sum of the L-deflection angles comes to 180°. For a four-sided traverse, this difference should be 360°. This large angle sum difference (180°) suggests one of the angles is the wrong direction. Look for an angle measuring about half the error of closure (in this case, measuring half of 180°, or 90°), and see whether this angle is the wrong direction.

If an angle has not been dropped, a large interior-angle error of closure probably means a large mistake in measuring or in recording the measuring of one of the angles. You may be able to locate the suspect angle by plotting the traverse from the measured angles. Then draw in the line of the linear error of closure and erect a perpendicular bisector from this line. The bisector may point to the suspect angle.

For example, in *Figure 18-43*, all the bearings are correct except the bearing of *CD*, which should be S15°31'W for closure, but inadvertently is S05°31'W. Because of this error, the traverse fails to close by the length of the dashed line *AA*'.

A perpendicular bisector from *AA′* points directly to the faulty angle C.

If a perpendicular bisector from the line of linear error of closure does not point at any angle, the faulty angle may lie at the point of the beginning of the traverse. In *Figure 18-44*, the bearings of all lines are correct for closure except that of the initial line *AB*. Line *AB* should be N29°09'E for closure but was plotted N16°09'E. A perpendicular from *AA′* does not point at any angle in the traverse.

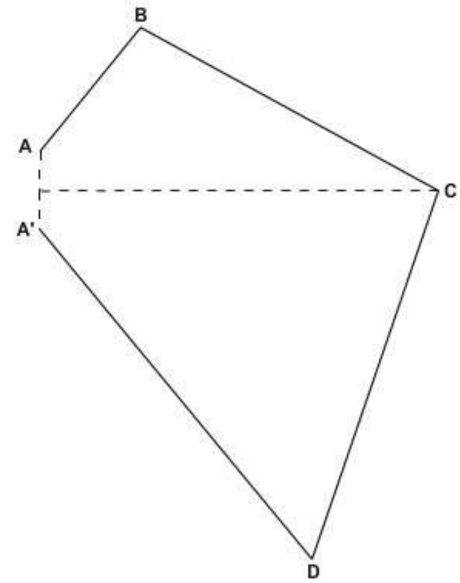


Figure 18-43 - Graphical method to locate angular mistakes in a closed circuit (angle C).

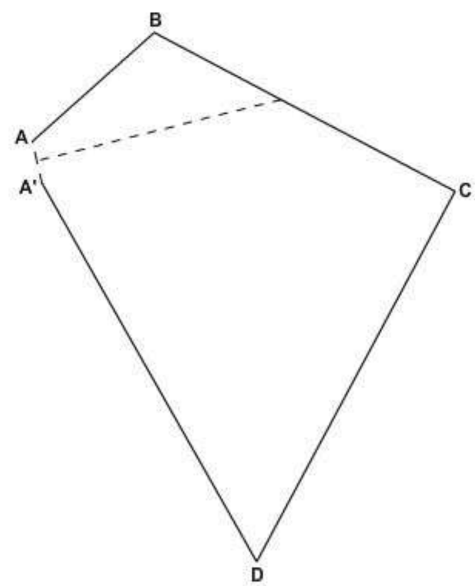


Figure 18-44 - Graphical method to locate angular mistakes in a closed circuit (angle A).

2.3.10.2 Outsized Latitude and/or Departure Error of Closure

When both the latitudes and departures fail to close by large amounts, there is probably a mistake in an angle or a distance.

When one closure is satisfactory and the other is not, a computational mistake is probably the cause of the outsized closure error.

2.3.10.3 Outsized Linear Error of Closure

Check for the following mistakes when an angular error of closure is within allowable limits and there is an outsized linear error of closure.

1. Ensure traverse lines have not been dropped.
2. Ensure each latitude and departure is in the correct column.
3. When computing latitudes and departures, ensure the correct cosine and correct sine are used. The latitude of a traverse line equals the product of the length

times the cosine of the bearing. The departure equals the product of the length times the sine of the bearing.

4. Ensure each bearing has the proper compass direction. Ensure the front bearing is used, not the back bearing.
5. Ensure all bearings and distances are copied correctly.
6. Ensure all cosines and sines are copied correctly.
7. Check for arithmetical errors.

If these procedures do not identify the mistake, the traverse will have to be rerun. If a rerun is required, examine the direction of the line of linear error of closure on the plot. Often, the traverse line that contains the mistake is parallel to this line. If there is a line that is parallel, start the rerun at that point.

Test your Knowledge (Select the Correct Response)

5. Before beginning computations based on your field notes, you should perform which of the following actions?

   A. Reduce slope measurements
   B. Reduce angles to mean angles
   C. Check notes for completeness
   D. All of the above

6. When you are discussing computations, the term "adjustment" refers to ________________.

   A. fudging of the numbers
   B. alignment of columns
   C. level computations
   D. equal distribution of the total error

7. **(True or False)** Level lines that begin and end on points that have fixed elevations, such as bench marks, are often called plane coordinates.

   A. True
   B. False

8. You have just completed a level circuit run of 2,640 feet. The error of closure was .021 feet. What order of precision is this leveling work?

   A. First
   B. Second
   C. Third
   D. Fourth

9. What is the first step in traverse computations?

   A. Calculating mean angles
   B. Checking notes for all data
   C. Correcting distance measurements
   D. Verifying the crew members

10. You are giving the location by plane coordinates of a point. In what terms should you give the location of that point in relation to the point of origin?

A. Its distance east
B. Its distance south
C. Its distance north or south and the distance east or west
D. Its distance south and west

11. A positive latitude and a negative departure characterize a traverse line bearing ______.

A. NE
B. NW
C. SE
D. SW

12. The term "inversing"refers to computing the ______.

A. latitude and departure of a traverse line from its bearing and length
B. bearing and length of a traverse line from its latitude and departure
C. ratio of linear error of closure of a traverse from its length and error of closure
D. latitude and departure from the corrected angles and distances

13. What is the initial step in finding the area of the figure by counting squares?

A. Plot it to scale on graph paper
B. Use a planimeter to determine the area
C. Divide it into 100-foot squares
D. Determine the bearings of the lines

14. A bearing that has the correct angular value, but the wrong compass direction is usually caused by which of the following surveying mistakes?

A. Viewing the direction of a traverse line from the wrong station
B. Dropping a traverse line
C. Taking a reading from a wrong column of a traverse table
D. Omitting the plus or minus sign of a written value

15. When you have an outsized error of closure for latitudes but not departures, what should you check?

A. Mistake in an angle
B. Mistake in a distance
C. Error in arithmetic
D. Dropped traverse line

Summary

This chapter introduced you to the theory and basic procedures used for indirect leveling, including barometric and trigonometric leveling. This chapter also detailed the procedures used to make level and traverse computations.

The section on level computations addressed the adjusting of intermediate bench mark elevations, calculating allowable error, and adjusting level nets. The traverse computations section addressed open and closed traverses and the procedures used for adjusting and determining the areas of traverses.

Finally, the chapter detailed some of the mistakes made when calculating the traverse areas.

Review Questions (Select the Correct Response)

1. What is the minimum number of altimeters required for a two-base method of barometric leveling?

   A. Five
   B. Two
   C. Three
   D. Four

2. **(True or False)** The basic principle of trigonometric leveling is when the vertical angle and either the horizontal or slope distance between two points is known, the fundamentals of trigonometry can be applied to calculate the difference in elevation between points.

   A. True
   B. False

3. In making level computations, be sure to check the notes for a level run by verifying the ____________.

   A. turning point
   B. beginning bench mark
   C. turning point and beginning bench mark
   D. none of the above

4. When the horizontal or slope distance is measured by chaining, which of the following corrections must be computed before you determine the difference of elevation?

   A. Repair adjustment, sag, and temperature
   B. Standard error, sag, and tension
   C. Sag, temperature, and standard error
   D. Tension, heat, and number of movements

5. When you do trigonometric leveling with an electronic distance-measuring device, what other instrument do you use to measure your angles?

   A. Transit
   B. Theodolite
   C. Level
   D. Alidade

6. What are you verifying by checking the difference in foresights and backsights?

   A. Balanced foresights and backsights
   B. Arithmetic accuracy
   C. Error of closure
   D. BM elevation

7. Most differential leveling (plane surveying) is order work.

   A. First
   B. Second
   C. Third
   D. Fourth

8. **(True or False)** When adjusting a level net, you adjust each leg only once, regardless of a leg being in more than one circuit.

   A. True
   B. False

9. The terms "elevation angle" and "depression angle" refer to which of the following situations?

   A. Rod location in relation to the instrument
   B. Value of the vertical angle
   C. Instrument location in relation to the rod
   D. All of the above

10. How is distribution of angular error of closure performed?

   A. Proportionally by angle size
   B. Proportionally by distance between angles
   C. Equally among all angles
   D. By subtracting the error from all angles

11. Traverse operations are conducted for mapping large construction projects, such as a

   A. military post
   B. grocery store
   C. school
   D. mall

12. **(True or False)** In computing latitudes and departures, calculations can be greatly expedited by the use of a traverse table.

   A. True
   B. False

13. The linear error of closure is determined by the .

   A. sum of the departures.
   B. difference in the departures and latitudes.
   C. error of latitude.
   D. use of the Pythagorean theorem with error of closure in latitude and departure.

14. What is the most common method of balancing a traverse?

    A. Rule of thumb
    B. Compass rule
    C. Closure rule
    D. Grid rule

15. Plane coordinates describe the location of a point in what manner?

    A. By a distance north or south and east or west from a point of origin
    B. By the bearing north or south and east or west from a point of origin
    C. By the bearing and distance from a point of origin
    D. By the line of sight from a point of origin

16. What is the major difference between the DMD method of determining area and the DPD method?

    A. The DPD of the initial traverse line is twice the departure.
    B. A reference parallel is used instead of a reference meridian.
    C. The distances are calculated using latitude instead of departure.
    D. Both B and C

17. After you have determined the segmental areas, what do you do with this information to find the area of the whole parcel?

    A. Always subtract the areas from the area of the parcel.
    B. Always add the areas to the area of the parcel.
    C. Determine if the segmental areas are inside or outside the parcel straight-line and chord boundaries, then add or subtract as required.

18. How may you prevent direction error?

    A. By placing directional arrows on the traverse diagram
    B. By quickly adding up the angles to ensure the traverse lines were not dropped
    C. By making both readings and field note entries with deliberation
    D. By never writing a value without including the appropriate sign

19. Which of the following errors uses the same prevention method as direction error prevention?

    A. Dropped signs
    B. Dropped traverse lines
    C. Wrong azimuths
    D. Missing decimal points

20. When you have an outsized linear error of closure, what should you check first?

    A. Accuracy of latitudes and departures
    B. A dropped traverse line
    C. Your arithmetic
    D. Bearings computations

21. After you check computations and ensure that no angle was dropped in the process, you still have a large error of closure. What further check, if any, should you attempt at this time?

A. See if an angle is exactly equal to the error of closure; if so, there is a deflection angle error.
B. Construct a perpendicular bisector from the line of the linear error of closure to indicate a possible erroneous measurement.
C. Construct a line parallel to the suspected erroneous line to find the error.
D. None; you must return to the field.

22. When you have an outsized linear error of closure but an acceptable angular error of closure, you should check to see whether you used the

.

A. sine of the bearing when finding the latitude of the course.
B. sine of the bearing when finding the departure of the course.
C. cosine of the bearing when finding the departure of the course.
D. tangent of the bearing when finding the latitude of the course.

23. You cannot locate your error and the traverse will not close; therefore, you must rerun the traverse. With which line should you begin?

A. Traverse line parallel to the linear error of closure
B. Initial traverse line
C. Final traverse line
D. Line perpendicular to the line of linear closure at its midpoint

Trade Terms Introduced in this Chapter

Clinometer	An instrument used to establish angles, usually on a hillslope and more rarely along bedding planes.

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.

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

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Chapter 19

Topographic Surveying and Mapping

Topics

1.0.0 Topographic Surveying

2.0.0 Topographic Mapping

To hear audio, click on the box.

Overview

Topography refers to the characteristics of the land surface. These characteristics include relief, natural and artificial (or man-made) features. Relief is the configuration of the earth's surface and includes such features as hills, valleys, plains, summits, depressions, trees, streams, and lakes. Man-made features are highways, bridges, dams, wharfs, buildings, and so forth.

This chapter introduces the methods and procedures used to perform topographic surveying and to prepare topographic maps. A ***topographic map*** is a drawing that shows the natural and artificial features of an area. A ***topographic survey*** is conducted to obtain the data needed for the preparation of a topographic map.

Objectives

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

1. Describe the different types of topographic surveying control mechanisms.
2. Describe the methods for conducting topographic mapping.

Prerequisites

None

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

Topographic Surveying and Mapping		ENGINEERING AID BASIC
Indirect Leveling/Level and Traverse Computations		
Care and Adjustment of Survey Equipment		
Materials Testing: Soil and Concrete		
Direct Leveling and Basic Engineering Surveys		
Horizontal Control		
Direct Linear Measurements and Field Survey Safety		
Surveying: Elements and Equipment		
Construction Drawings		
Electrical: Systems and Plans		
Mechanical: Systems and Plans		
Concrete and Masonry		
Wood and Light Frame Structures		
Drafting: Projections and Sketching		
Drafting: Geometric Construction		
Drafting: Fundamentals and techniques		
Drafting: Equipment		
Mathematics and Units of Measurement		
Engineering Aid Rating		

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.

1.1.1 TOPOGRAPHIC SURVEYING

The field work in a topographic survey has two aspects:

- The establishment of a basic framework of horizontally and vertically located control points (called instrument points or stations)
- The determination of the horizontal and vertical locations of details in the vicinity of each instrument point.

1.1.0 Topographic Control

Topographic control consists of two parts: horizontal control, which locates the horizontally fixed position of specified control points, and vertical control, which establishes the elevations of specified bench marks. This control provides the framework from which topographic details, such as roads, buildings, rivers, and the elevation of ground points, are located.

1.1.1 1.1.1 Horizontal Control

Locating primary and secondary horizontal control points or stations may be accomplished by traversing, by triangulation, or by the combination of both methods. On an important, large-area survey, there may be both primary control, in which a number of widely separated primary control points are located with a high degree of precision, and secondary control points, where stations are located with less precision within the framework of the primary control points.

The routing of a primary traverse should be considered carefully. It should follow routes that will produce conveniently located stations. Such routes might run along roads, ridges, valleys, edges of wooded areas, public land lines, or near the perimeter of tracts of land. This latter route is particularly important for small areas. When all the details in the area can be conveniently located from stations on the primary traverse, secondary traverses are not needed. However, the size or character of the terrain usually makes secondary traverses necessary. Consider, for example, the situation shown in *Figure 19 -1*. This figure shows a tract bounded on three sides by highways and on the fourth side by a fence. For simplification, the figure shows only the items to be discussed. An actual complete plan would include a title, date, scale, north arrow, etc.

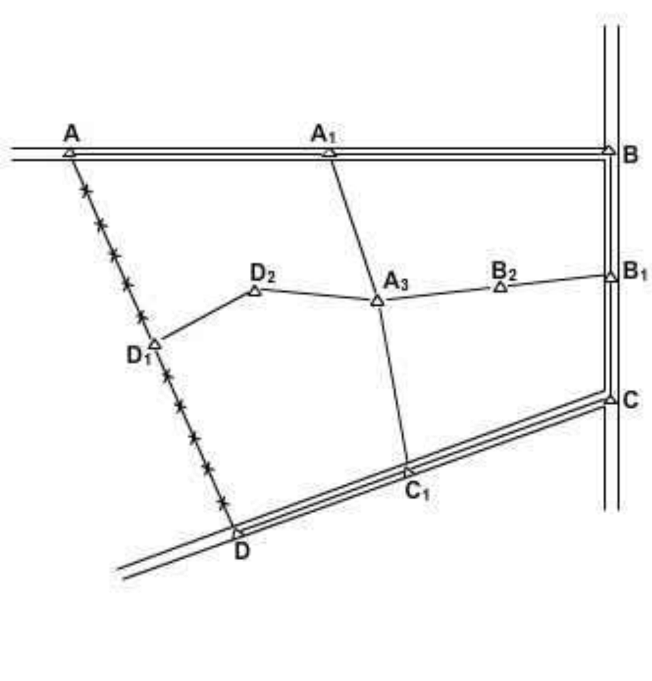


Figure 19-1 - Primary and Secondary Traverse.

The primary traverse *ABCD* runs around the perimeter of the tract. If this tract was sufficiently small and level, then details within the whole tract could be located from only the primary control points which includes stations *A, A1, B, B1, C, C1, D,* and *D 1.*

However, in this example the size or perhaps the character of the terrain made it necessary to establish additional control points inside the perimeter of the tract. The additional controls points are *D2, A2,* and *B2.* These points were established by running traverse lines (called crossties) across the area from one primary traverse station to another. It should be noted that, since each secondary traverse closes on a primary control point, errors cannot accumulate any farther than the distance between the primary stations.

Field notes for the survey sketched in *Figure 19 -1* must contain notes showing the horizontal locations of the stations and level notes for determining the elevations of the stations.

1.1.2 ertical Control

In topographic surveying, bench marks serve as starting and closing points for the leveling operations when locating details. Although for some surveys the datum may be assumed, it is preferable that all elevations be tied to bench marks which are referred to the sea-level datum. In many areas, particularly in the United States, series of permanent and precisely established bench marks are available. A surveyor must make an effort to tie surveys to these bench marks to ensure proper location and identification. Often, the established horizontal control marks are used as the bench marks because the level routes generally follow the traverse lines.

Vertical control is usually carried out by direct leveling; however, trigonometric leveling may be used for a limited area or in rough terrain. Topographic maps for construction projects must be based on accurate horizontal and vertical data. The degree of precision of a topographic map is related to the scale of the land area depicted in the map. When establishing the primary vertical control to use in a topographic survey for an intermediate-scale map, four degrees of precision are used as follows:

First - 0.05 foot distance in miles. This order is used as the standard for surveys in flat regions when the contour interval is 1 foot or less. It is also used to determine the gradient of streams or to establish the grades for proposed drainage and irrigation systems.

Second- 0.1 foot distance in miles. This order is used in a survey when the contour interval of the map is 2 feet.

Third- 0.3 foot distance in miles. This order is used for a contour interval of 5 feet.

Fourth- 0.5 foot distance in miles. This order is used for a contour interval of 10 feet and may be done by stadia leveling, a method that is very advantageous in hilly terrain. Stadia will be discussed later in this chapter.

The third or fourth order of precision is used for a large-scale map that generally has a contour interval of 1 or 2 feet. For an extensive survey of a large area, the third order is used. Surveys of smaller areas use the fourth order.

Once the topographic control has been established, the next major step in a topographic survey is to locate the details horizontally and vertically in the vicinity of each control point or station. These details consist of (1) all natural or artificial features that appear on the map and (2) enough ground points and spot elevations to make the drawing of contour lines possible.

The methods and the instruments used in topographic surveys depend upon the purpose of the survey, the degree of precision needed, the nature of the terrain to be covered, the map scale, and the contour interval. For a high degree of accuracy, azimuths should be located with a theodolite or transit. Horizontal distances should be measured with a chain or an electronic distance measurement (EDM) device. Elevations are determined with a level.

The following sections discuss two methods commonly used to locate topographic details.

1.2.1 Locating Details by Transit and Tape

In Chapter 14, you learned the procedures used to tie in and locate points using a transit and tape. These same procedures are used for tying in and locating topographic details.

To begin, determine the vertical location (or elevation) of the detail points by using direct or trigonometric leveling procedures. Then horizontally locate the details either by directions or distances or a combination of both. Use a method or a combination of methods that requires the least time in a particular situation. Directly measure the dimensions of structures, such as buildings, with tapes. When many details exist, assign each one a number in the sketch and key the detail to a legend to avoid overcrowding. For directions, use azimuths instead of deflection angles to minimize confusion. Locate details as follows:

1. Measure the angle and distance from transit stations.
2. Measure angles from two transit stations.
3. Measure distances from two known points.
4. Measure an angle from one station and distance from another station.
5. Measure swing offsets and range ties.

Detailing by transit and tape is a time-consuming process that requires chaining many distances and taking many level shots. This is necessary when a high degree of accuracy is required. For lower-precision (third and fourth order) surveys, a less time-consuming method is to locate the details by transit and stadia.

1.3.0 Locating Details by Transit and Stadia

Most of the topographic surveying conducted by an EA requires a lower degree of accuracy, and thus is well suited to the transit and stadia method. In this method, horizontal distances and differences in elevation are indirectly determined by using subtended intervals and angles observed with a transition and a leveling rod or stadia board. The following sections discuss the principles of stadia and then examine field procedures used in stadia work.

1.3.1 ia Equipment Terms, and Principles

This section addresses the equipment, terminology, and principles used in stadia surveying. Although the discussion of stadia surveying is included here,, as an EA, you should be aware that stadia can be used in any situation where horizontal distances and differences in elevation must be determined indirectly. The results, though, are of a lower order of precision than is obtainable by taping, EDM, or differential leveling. However, the results are adequate for many purposes, such as lower -order trigonometric leveling.

A thorough understanding of stadia is important to any surveyor. To supplement the knowledge gained from this section, read other books, such as *Surveying Theory and Practice,* by Davis, Foote, Anderson, and Mikhail.

1.3.1.1 Stadia Rods

Where sight distances do not exceed 200 feet, a conventional rod such as a Philadelphia rod is adequate for stadia work. A stadia rod is used for longer distances. Stadia rods usually have large geometric designs on them so they may be read at distances of 1,000 to 1,500 feet or even farther. Some rods do not have any numerals on them. From the geometric pattern on the rod, intervals of a tenth of a foot and sometimes a hundredth of a foot can be seen.

1.3.1.2 Stadia Hairs

The telescope of transits (as well as theodolites, plane-table alidades, and many levels) is equipped with two hairs (called ***stadia hairs***) that are in addition to the regular vertical and horizontal cross hairs. *Figure 19-2* shows two types of stadia hairs as viewed through a telescope. As shown in this figure, one stadia hair is located above and the other an equal distance below the horizontal (or middle) cross hair. On most equipment, the stadia hairs are not adjustable and remain equally spaced.

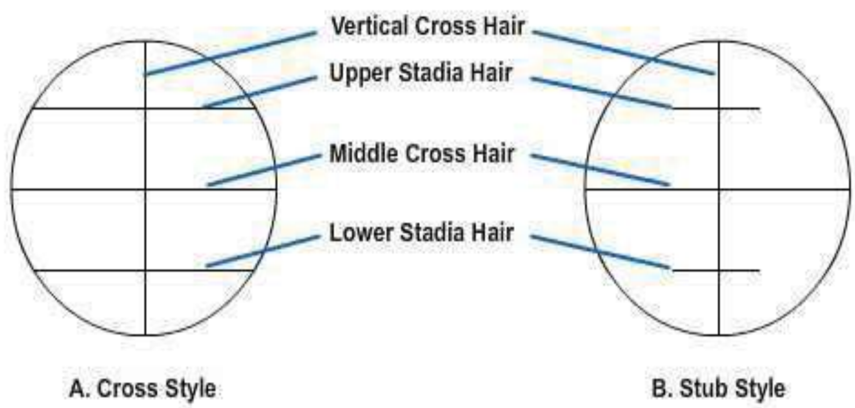


Figure 19-2 - Stadia Hairs.

1.3.1.3 Stadia Interval

When viewed through a transit telescope, the stadia hairs appear to intercept an interval on the stadia rod. The ***stadia interval*** or ***stadia reading*** is the distance on the rod between the apparent positions of the two stadia hairs.

Determine stadia intervals by sighting the lower stadia hair at a convenient foot mark and then observing the position of the upper stadia hair. For example, the lower hair might be sighted on the 2.00 foot mark and the upper hair might be in line with 6.37. After subtraction (6.37 -2.00), the stadia reading is 4.37.

When a stadia reading is more than the length of the rod, you should take the observed half-interval and multiply it by 2 to get the stadia reading.

1.3.1.4 Stadia Constant

Light rays that pass through the lens (objective) of a telescope come together at a point called the ***principal focus*** of the lens. Then these light rays continue in straight-line paths, as shown in *Figure 19-3*.

The distance between the principal focus and the center of the lens is called the ***focal length*** *(f)* of the lens. For any particular lens, the focal length does not change. Dividing the focal length by the distance between the stadia hairs *(i),* yields the ***stadia constant*** *(k).* The stadia constant is also called the stadia factor or stadia interval factor.

A convenient value to use for the stadia constant is 100. Stadia hairs are usually spaced so that the interval between them makes the stadia constant equal to 100.

1.3.1.5 Stadia Distance

The distance from the principal focus to the stadia rod is called the ***stadia distance***. As shown in *Figure 19-3*, this distance is equal to the stadia constant *(k)* times the stadia reading *(s).*

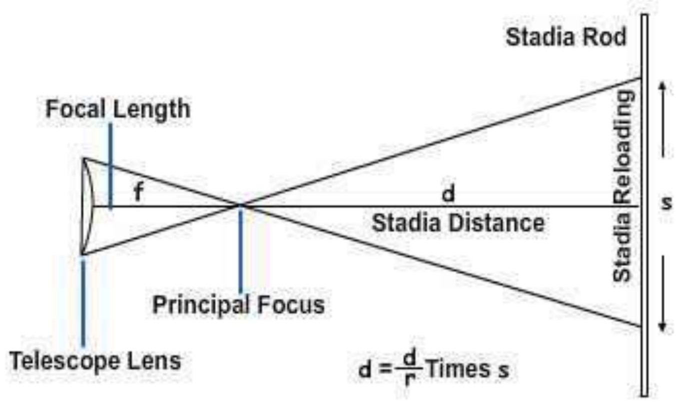


Figure 19-3 – Light rays converge at principal focus of a lens.

1.3.1.6 Instrument Constant

The distance from the center of the Transit telescope instrument to the principal focus is the ***instrument constant***. This constant is determined by the manufacturer of the instrument. This information is typically stated on the inside of the instrument box. Externally focusing telescopes are manufactured so that the instrument constant may be considered equal to 1. For internally focusing telescopes, the objective in the telescope is so near the center of the instrument that the instrument constant may be considered zero. This is a distinct advantage of internally focusing telescopes. Most modern instruments are equipped with internally focusing telescopes.

1.3.1.7 Stadia Reduction Formulas

Stadia work is concerned with finding two values:

1. The horizontal distance from the center of the instrument to the stadia rod
2. The vertical distance or difference in elevation between the center of the instrument and middle-hair reading on the rod.

Stadia reduction formulas are used to find these values.

1.3.1.7.1 ia Formula for Horizontal Sights

To calculate a horizontal sight, first determine the horizontal distance between the center of the instrument and the stadia rod. Find this distance by adding the stadia distance to the instrument constant as follows:

Write *ks* for the stadia distance and *(f + c)* for the instrument constant. Then the formula for computing horizontal distances when the sights are horizontal becomes the following:

$$h = ks + (f + c)$$

Where:

h = horizontal distance from the center of the instrument to a vertical stadia rod

k = stadia constant, usually 100

s = stadia interval

$f + c$ = instrument constant (zero for internally focusing telescopes, approximately 1 foot for externally focusing telescopes)

f = focal lengths of the lens

c = distance from the center of the instrument to the center of the lens

The instrument constant is the same for all readings. Using an externally focusing instrument with an instrument constant of 1.0 and a stadia interval of 1 foot, the horizontal distance would be as follows:

$$h = (100)\ (1) + 1 = 101 \text{ feet.}$$

If the stadia interval is 2 feet, the horizontal distance is as follows:

$$h = (100)\ (2) + 1 = 201 \text{ feet.}$$

If you are using an internally focusing instrument, the instrument constant is zero and can be disregarded. This is the advantage of an internally focusing telescope. So, if the stadia interval is 1 foot, the horizontal distance is simply the stadia distance, which is 100 feet. For a stadia reading of 2 feet, the horizontal distance is 200 feet.

Horizontal distance usually is stated to the nearest foot. Occasionally for short distances under 300 feet it may be specified that tenths of a foot be used.

1.3.1.7.2 Stadia Formulas for Inclined Sights

Since most often the sights needed in stadia work are not horizontal, it is necessary to incline the telescope upward or downward to acquire a vertical angle. This vertical angle (a) may be either an ***angle of elevation*** or an ***angle of depression***, as shown in *Figure 19-4*. When the line of sight is elevated above the horizontal, it is an angle of elevation. If the line of sight is below the horizontal, the vertical angle is an angle of depression.

In either case, use the following formulas to find the horizontal and vertical distances:

$$h = ks \cos^2 a + (f + c) \cos a$$

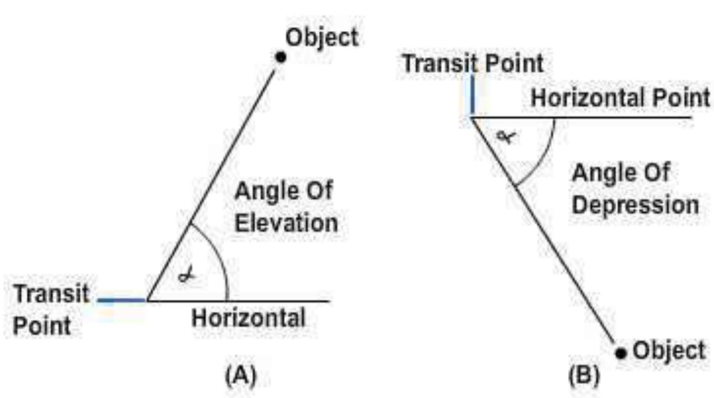


Figure 19-4 – (A) Angle of elevation and (B) Angle of depression.

$$v = 1/2\ ks\ sin\ 2a + (f + c)\ sin\ a$$

These two expressions are called the stadia formulas for inclined sights in which

h = horizontal distance

v = vertical distance

h = stadia distance

a = vertical angle

f + *c* = instrument constant

Refer to *Figure 19-5* for clarification of the terms in the stadia formulas for inclined sights.

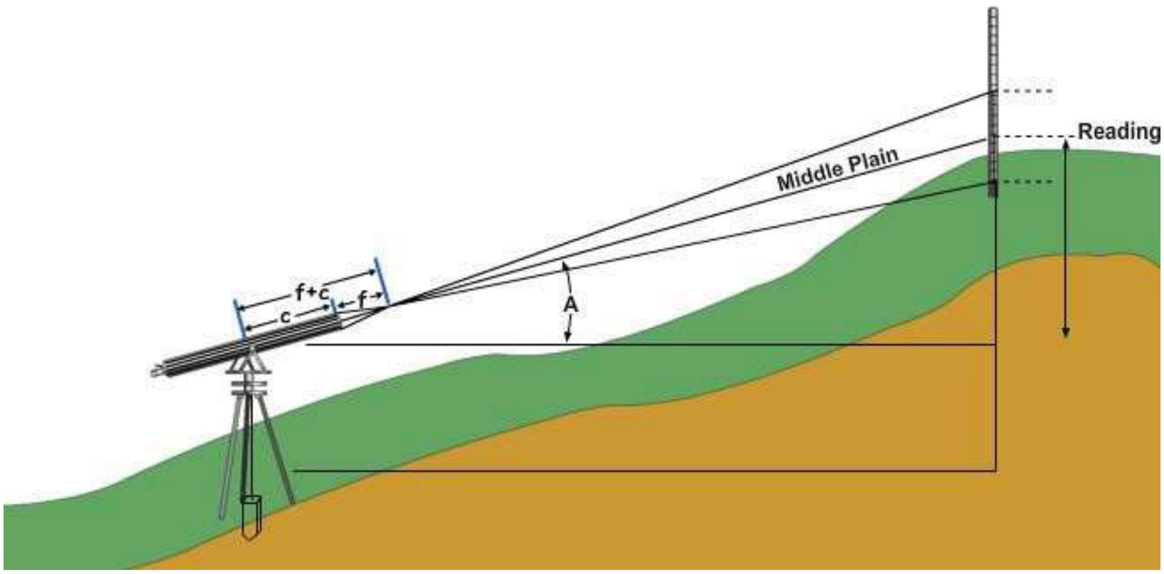


Figure 19-5 - Stadia interval - inclined sight.

1.3.1.8 Distance and Elevation for Inclined Sights

The following example describes the use of the stadia reduction formulas for inclined sights. Assume a stadia interval of 8.45 and an angle of elevation of 25°14', as shown in *Figure 19-6*. Let the instrument constant be 1.0.

Substituting the known values in the stadia formula for the horizontal distance yields the following:

$$h = ks\ cos2a + (f + c)\ cos\ a$$

$$h = 100\ (8.45)\ (0.90458)2 + (1)\ (0.90458) = 692.34$$

The horizontal distance is 692 feet.

Substituting the known values in the formula for the vertical distance yields the following:

$$v = 1/2\ ks\ sin\ 2a + (f + c)\ sin\ a$$

$$v = 50\ (8.45)\ (0.77125) + (1)\ (0.42631)$$

$$v = 326.28$$

The vertical distance to the middle-hair reading on the rod is 326.28 feet.

To find the elevation of the ground at the base of the rod, subtract the center-hair rod reading from this vertical distance and add the height of instrument (HI) as depicted in the example in *Figure 19-6*. If the HI is 384.20 feet and the center-hair rod reading is 4.50 feet, then the ground elevation is

326.28 - 4.5 + 384.20 = 705.98 feet.

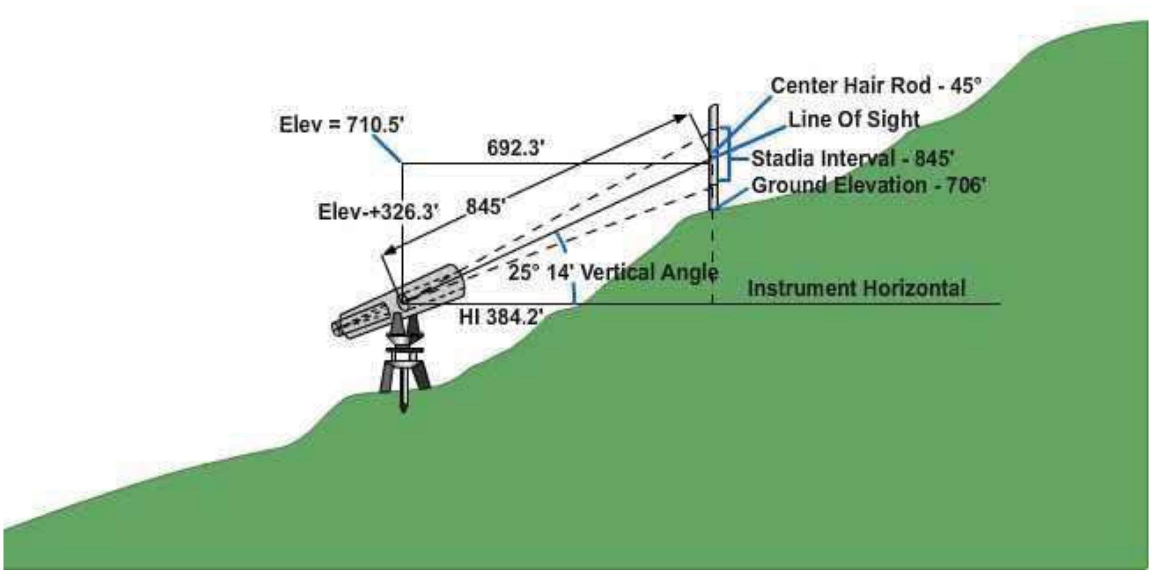


Figure 19-6 - Ground elevations - telescope raised.

If the angle of inclination was depressed, the center-hair rod reading is added to the vertical distance. The sum is then subtracted from the HI. Using this equation, the ground elevation of *Figure 19-7*, would be:

384.2 - (326.28 + 4.5) = 53.42 feet.

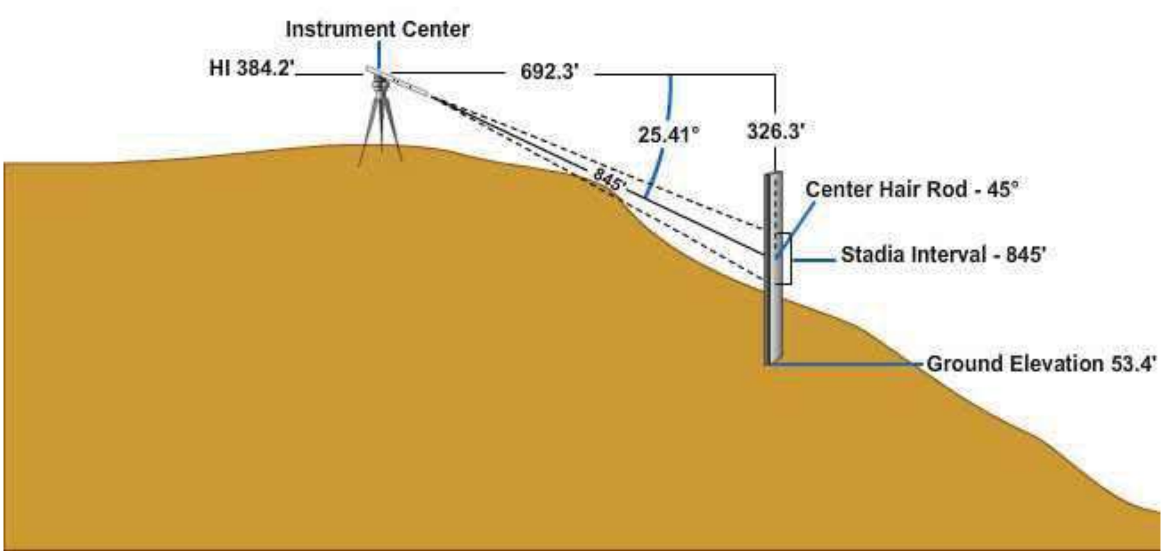


Figure 19-7 - Ground elevation - telescope depressed.

1.3.1.9 Stadia Tables

Horizontal distance and the vertical distance (difference in elevation between two points) can also be determined by using the stadia reduction tables. (*Table 19-1* is used for following example.)

Table 19-1 - Stadia reduction table for 24 - 27 minutes.

Minutes	24°		25°		26°		27°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
C=0.75	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
C=1.00	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
C=1.25	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

The values of 100 *cos2a* and 1/2(100) sin 2a are computed at 2-minute intervals for angles up to 30°. The values in the table are multiplied by the stadia reading, and then added to the value of the instrument constant given at the bottom of the page.

To find the values from the stadia table for the example previously discussed, read under 25° and opposite 14'. Under Hor. Dist. to find

$$100\ \mathrm{COS}^2\ 25°14' = 81.83.$$

Under Diff. Elev. to find

$$1/2\ (100)\ \sin 2\ (25°14') = 38.56.$$

The values of the term containing the instrument constant are given at the bottom of the page.

For:

$$(f + c) = C = 1.00$$

Find:

$$(f + c) \cos a = 0.90$$

Therefore:

$$(f + c) \sin a = 0.43$$

Using these values in the formulas, find:

$$h = 8.45\ (81.83) + .090$$

$$h = 692.4 \text{ or } 692 \text{ feet}$$

and

$$v = 8.45\ (38.56) + 0.43$$

$$v = 326.23 \text{ or } 326 \text{ feet}$$

1.3.1.10 Approximate Forms of Stadia Formulas

Because of the errors inherent in stadia surveying, it has been found that approximate stadia formulas are precise enough for most stadia work. Refer again to *Figures 19-5*, *19-6* and *19-7*, and notice that it is customary to hold the stadia rod plumb rather than inclined at right angles to the line of sight. Failure to hold the rod plumb introduces an error causing the observed readings to be longer than the true readings. Another error inherent in stadia surveying is caused by the unequal refraction of light rays in the layers of air close to the earth's surface. The refraction error is smallest when the day is cloudy or during the early morning or late afternoon hours on a sunny day. Unequal refraction also causes the observed readings to be longer than the true readings.

To compensate for these errors, topographers often regard the instrument constant as zero in stadia surveying of ordinary precision, even if the instrument has an externally focusing telescope. In this way, the last terms in the stadia formulas for inclined sights vanish, that is, become zero. Then the approximate expressions for horizontal and vertical distance are

$$h = ks \cos^2 a$$

$$v = 1/2ks \sin 2a$$

1.3.2 Field Procedures

Figure 19-8 illustrates a situation where the difference in elevation between an instrument station of known elevation and a ground point of unknown elevation needs to be determined. In *Figure 19-8*, (A) The elevation of instrument station *P* is known and the difference in elevation between *P* and the rod station P_1 needs to be determined. The horizontal center-line height of the instrument (H.I.) above point *P is* equal to *PA.* This H.I. is different than the H.I. typically used in direct leveling.

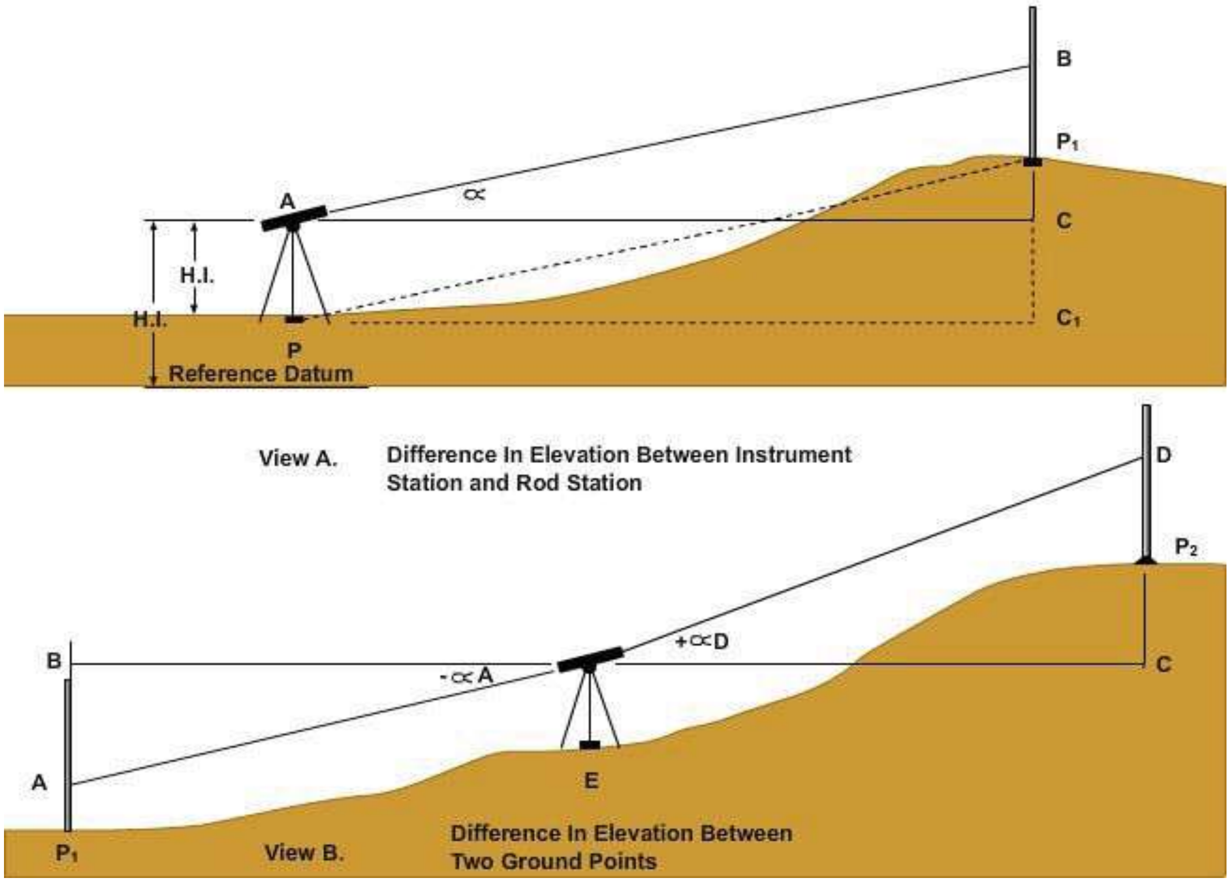


Figure 19-8 - Difference in elevation.

The rod reading is P_1B.

The difference in elevation *(DE)* between *P* and P_1 can be expressed as follows:

$$DE = PA = BC - P_1b$$

$$\text{or, } DE = h.i. = BC - P_1B$$

Therefore, the ground elevation at P_1 can be expressed as follows:

$$\text{Elev. } P_1 = \text{Elev. } P + (h.i. + BC - P_1B)$$

Now sight on the rod such that $P_1B = PA$ = h.i. In this case, a similar triangle (PC_1P_1) is formed at the instrument station *P.* From observation of these similar triangles, it be can seen that the $DE = P1C1 = BC$. Therefore, the ground elevation at P_1 can be expressed as follows:

$$\text{Elev. } P_1 = \text{Elev. } P + BC$$

This is an important concept to understand when shooting stadia from a station of known elevation. It illustrates that when the center cross hair is sighted on a rod graduation that is equal to the h.i. before reading the vertical angle, then calculating the difference in elevation is greatly simplified. However, if the line of sight is obstructed and you cannot sight on a rod graduation that is equal to the h.i., then you must sight on some other graduation.

In addition, in *Figure 19-8*, (B) The difference in elevation between two points on the ground (P_1 and P_2) from an instrument station (*E*) that is located between the two points needs to be determined.

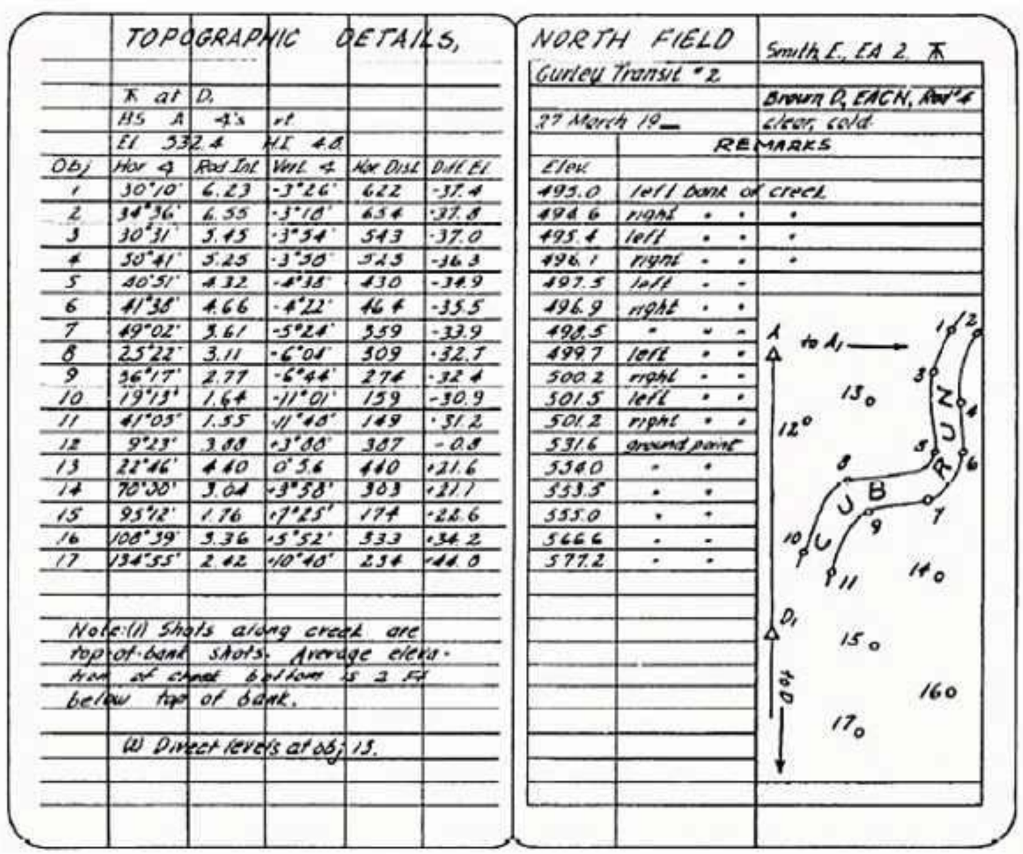
Assume in this case that a backsight is taken on a rod held at P_1 and then a foresight is taken to P_2. Now the difference in elevation *(DE)* between the two points can be written as follows:

$$DE = P_1A + AB + CD - P_2D$$

In reverse, if a backsight was taken to P_2 with a foresight to P_1, then the expression for *DE* can be written as follows:

$$DE = CD - P_2D - AB - P_1A$$

Figure 19-9 shows field notes for locating topographic details by transit and stadia. The details shown by numbers in the sketch on the Remarks side are listed on the data side by numbers in the column headed Obj. At the top of the page on the data side, control point D_1 was used as the instrument station. Immediately below this, from instrument station D_1, the transit was backsighted to point *A* and that all horizontal angles were measured to the right from the backsight on *A.*



TOPOGRAPHIC DETAILS, NORTH FIELD

Smith L. EA 2 ⊼

Gurley Transit #2

Brown D, EACN, Rod'4

27 March 19__ clear, cold

⊼ at D_1

BS A 4's rt

El 532.4 HI 4.8

Obj	Hor ∡	Rod Int	Vert ∡	Hor Dist	Diff El	Elev	REMARKS
1	30°10'	6.23	-3°26'	622	-37.4	495.0	left bank of creek
2	34°36'	6.55	-3°18'	654	-37.8	494.6	right " " "
3	30°31'	5.45	-3°54'	543	-37.0	495.4	left " " "
4	50°41'	5.25	-3°50'	523	-36.3	496.1	right " " "
5	40°51'	4.32	-4°38'	430	-34.9	497.5	left " "
6	41°38'	4.66	-4°22'	464	-35.5	496.9	right " "
7	49°02'	3.61	-5°24'	359	-33.9	498.5	" " "
8	25°22'	3.11	-6°04'	309	-32.7	499.7	left " "
9	36°17'	2.77	-6°44'	274	-32.4	500.2	right " "
10	19°13'	1.64	-11°01'	159	-30.9	501.5	left " "
11	41°05'	1.55	-11°48'	149	-31.2	501.2	right " "
12	9°23'	3.88	+3°80'	387	-0.8	531.6	ground point
13	22°46'	4.40	0°5.6	440	+21.6	554.0	" "
14	70°30'	3.04	+3°58'	303	+21.1	553.5	" "
15	95°12'	1.76	+7°25'	174	+22.6	555.0	" "
16	108°39'	3.36	+5°52'	333	+34.2	566.6	" "
17	134°55'	2.42	+10°48'	234	+44.0	577.2	" "

Note: (1) Shots along creek are top-of-bank shots. Average elevation of creek bottom is 2 Ft below top of bank.

(2) Direct levels at obj 13.

Figure 19-9 – Notes for locating topographic details by transit and stadia.

In the third line from the top on the data side, the known elevation of D_1 *is* 532.4 feet and the vertical distance (h.i.) from the point or marker at D_1 to the center of the instrument above D_1 is 4.8 feet. This vertical distance was carefully determined by measurement with a tape or rod held next to the instrument.

Begin with point 1 to see how each of the objective points was detailed. Remember, in this example D_1 is the instrument station from which all observations are made.

To determine the direction of point 1, train the transit telescope on *A* and match the zeros. Next, turn the telescope right to train on point 1 and read the horizontal angle (30°10').

For the horizontal distance and elevation of point 1, set a rod on the point, and train the lower stadia hair of the transit telescope on a whole-foot mark on the rod so the center hair is near the 4.8 graduation. (This is a common practice in stadia work that makes reading the stadia interval easier.) Then read and record the stadia interval (in this case 6.23 feet). Next, rotate the telescope about the horizontal axis until the center hair is on the 4.8 rod graduation. Lock the vertical motion and read and record the vertical angle (-3026'). Be sure to record each vertical angle correctly as plus or minus. While you are reading and recording the vertical angle, the rodman can be moving to the next point. This will help speed up the survey.

From the stadia interval and the vertical angle reading, the horizontal distance (entered in the fifth column of *Figure 19-11*) and the difference in elevation (in the sixth column) are determined from a stadia reduction table. *Table 19-2* shows the page from a stadia reduction table that applies to the data for point 1 in *Figure 19-9*.

Table 19-2 - Horizontal distances and elevations from stadia.

Minutes	0°		1°		2°		3°	
	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.	Hor. dist.	Diff. elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
C=0.75	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
C=1.00	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
C=1.25	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

For this point, the vertical angle is -3026', and the stadia interval is 6.23 feet. In the table under 3° and opposite 26', note that the multiplier for horizontal distance is 99.64, while the one for difference in elevation is 5.98. If the final distance is ignored, the horizontal distance is

$$6.23 \text{ X } 99.64 = 620.75 \text{ (or 621feet).}$$

The difference is elevation is

$$6.23 \text{ X } 5.98 = 37.3 \text{ feet.}$$

Add the corrections for focal distance given at the bottom of the page to these figures. For an instrument with a focal distance of 1 foot, add 1 foot to the horizontal difference (making a total horizontal distance of 622 feet) and 0.06 foot to the difference in elevation. This makes the difference in elevation round off to 37.4 feet, and since the vertical angle has a negative (-) sign, the difference in elevation is recorded as -37.4 feet.

In the first column on the remarks side of *Figure 19-9*, enter the elevation of each point, computed as follows. For point 1, the elevation equals the elevation of instrument station *D1* (532.4 feet) minus the difference in elevation (37.4 feet), or 495.0 feet. Subtract the difference in elevation, in this case, because the vertical angle you read for point 1 was negative. For a positive vertical angle (as in the cases of points 12 and 13 through 17 of your notes), add the difference in elevation.

The remainder of the points in this example are detailed in a similar manner except for point 13. When a detail point is at the same, or nearly the same, elevation as the instrument station, the elevation can be determined more readily by direct leveling. This is the case for point 13. As seen in the vertical-angle column of the notes, the vertical angle was 0° at a rod reading of 5.6 feet. Therefore, the elevation of point 13 is equal to the elevation of the instrument station (532.4 feet) plus the H.I. (4.8 feet) minus the rod reading (5.6 feet), or 531.6 feet.

In the above example the transit was initially backsighted to point *A* and the zeros were matched. This was because the azimuth of D_1A was not known. However, if you knew the azimuth of D_1A, you could indicate your directions in azimuths instead of in angles right from D_1A. Suppose, for example, that the azimuth of D_1A was 26°10'. You would train the telescope on *A* and set the horizontal limb to read 26°10'. Then when you train on any detail point, read the azimuth of the line from D_1 to the detail point.

Test your Knowledge (Select the Correct Response)

1. Which of the following elements is representative of topographic maps?

   A. Earth's surface.
   B. Earth's natural features
   C. Man-made features
   D. All of the above

2. By what manner are control points located?

   A. Triangulation only
   B. Traversing only
   C. Both A and B
   D. Indirect leveling

3. When topographic maps require a high degree of accuracy, what method of finding details is recommended?

   A. Transit and tape
   B. Transit and stadia
   C. Transit and trigonometric leveling
   D. EDM and level

4. Which of the following actions should you take to avoid overcrowding and confusion when sketching details during fieldwork?

   A. Use azimuths instead of deflection angles.
   B. Use numbers and legends for a large number of details.
   C. Both A and B
   D. Estimate distances and angles.

5. **(True or False)** Philadelphia rods should be used for stadia work for distances up to 1,500 feet.

   A. True
   B. False

6. When your stadia reading is more than the length of the rod, what procedure should you use?

   A. Read a half-interval using the middle cross hair; then multiply by 2.
   B. Hold two rods together.
   C. Make a rod in the BU shop that will be long enough.
   D. Shorten your sighting.

7. Unequal refraction caused by the sun's rays will affect your data by causing what differences in readings?

   A. Longer distances than actual.
   B. Shorter distances than actual
   C. Reversed vertical angles
   D. Smaller vertical angles than actual

2.0.0 TOPOGRAPHIC MAPPING

The following sections address how a draftsman prepares a topographic map. Additional field methods used by surveyors are also presented.

2.1.0 Representation of Relief

One of the purposes of a topographic map is to depict relief. Relief is the term for variance in the vertical configuration of the earth's surface. You have seen how relief can be shown in a plotted profile or cross section. These, however, are views on a vertical plane, but a topographic map is a view on a horizontal plane. On a map of this type, relief may be indicated by the following methods, shown in *Figure 19-10.*

A relief model is a three-dimensional relief presentation of a molded or sculptured model, developed in suitable horizontal and vertical scales, of the hills and valleys in the area.

Shading is a pictorial method of showing relief by the use of light and dark areas to suggest the shadows that would be created by parallel rays of light shining across the area at a given angle.

Hachures are a pictorial method similar to shading except that the light-and-dark pattern is created by short hachure lines drawn parallel to the steepest slopes. Relative steepness or flatness is suggested by varying the lengths and weights of the lines.

Contour lines are lines of equal elevation. Each contour line on a map is drawn through a succession of points that are the same elevation.

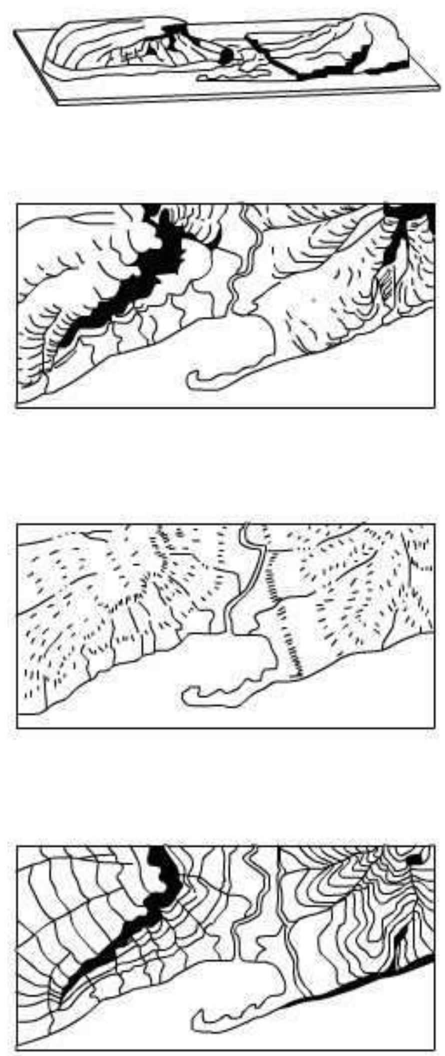


Figure 19-10 - Methods of indicating relief.

The contour-line method is the most commonly used topographic map.

2.2.0 Contour Lines

Contour lines indicate a vertical distance above or below a datum plane. Contours begin at sea level, normally the zero contour, and each contour line represents an elevation above (or below) sea level. The vertical distance between adjacent contour lines is known as the contour interval. Starting at zero elevation, the topographer draws every fifth contour line with a heavier line. These are known as index contours. At some place along each index contour, the line is broken and its elevation is given. The contour lines falling between index contours are called intermediate contours. They are drawn with a finer line than the index contours and usually do not have their elevations given. Examples of index contours and intermediate contours are shown in *Figure 19-11.*

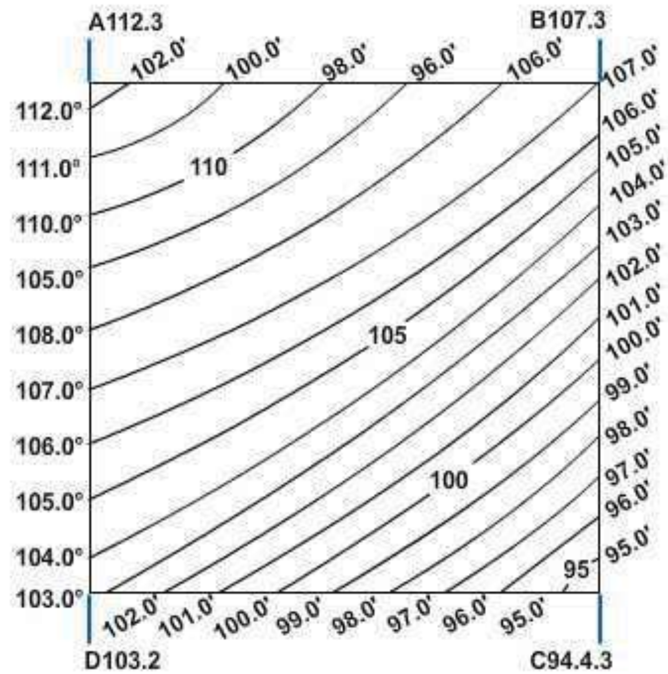


Figure 19-11 - Traverse with contour lines.

2.3.1 Ground Point Systems

The essential data for showing relief by contour lines consists of the elevation of a sufficient number of ground points in the area. Methods of determining the horizontal and vertical locations of these ground points are called ground point systems. The systems most frequently used are the following:

- Tracing contours
- Grids
- Control points
- Cross profiles

In practice, combinations of these methods may be used in one survey.

2.3.1 2.3.1 Tracing Contours

In the tracing contours system, points on a given contour are plotted on the map, and the contour line is drawn through the plotted points. The method may be illustrated by the following simple example.

Refer to the traverse shown in *Figure 19-11*. In this figure, assume that the traverse runs around the perimeter of a small field. The elevations at corners *A, B, C,* and *D* are as shown. The ground slopes downward from *AB* toward *DC* and from *AD* toward *BC.*

In this example the contour interval is 1 foot.

Therefore, the 112-foot contour line is plotted, the 111-foot contour line, the 110-foot contour line, and so forth.

Also in this example, assume that the required order of precision is low, as encountered in a reconnaissance survey, for example, and therefore a hand level is used.

The elevation of station A is determined to be 112.5 feet. Assume that the vertical distance from the level to the ground is 5.7 feet. Then, the H.I. at station A is

$$112.5 + 5.7 = 118.2 \text{ feet.}$$

If a level rod is set up anywhere on the 112.0-foot contour, the reading from station A would be

$$118.2 - 112.0 = 6.2 \text{ feet.}$$

Therefore, to determine the point where the 112.0-foot contour crosses *AB,* the rodman backs out from point *A* along *AB* until reaching the point where 6.2 feet is read on the rod. The point where the 112.0-foot contour crosses *AD* can be determined the same way. You can measure the distance from *A* to each point and then record the distance from *A* to the 112.0-foot contour on *AB* and *AD.*

When all of the contours have been located on *AB* and *AD,* shift to station C and carry out the same procedure to locate the contours along *BC* and *CD.* Now all the points are located where contours at a one-foot interval intersect the traverse lines. If the slope of the ground is uniform (as it is presumed to be *in Figure 19-11*), the contour lines can be plotted by simply drawing lines between points of equal elevation, as shown in the figure. If the slope has irregularities, send the rodman out along one or more lines laid across the irregular ground, to locate the contours on these lines as you located them on the traverse lines.

2.3.2 nate System

In the grid coordinate system, the area is laid out in squares of convenient size, and the elevation of each corner point is determined. While this method lends itself to use on relatively level ground, ridge or valley lines must be located by spot elevations taken along the lines. The locations of the desired contours are then determined on the ridge and valley lines and on the sides of the squares by interpolation. This gives a series of points through which the contour lines may be drawn. *Figure 19-12* illustrates this method.

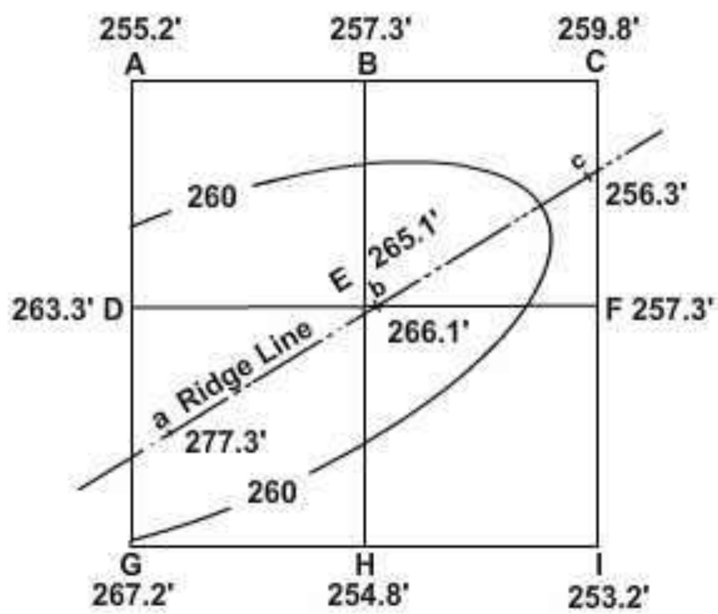


Figure 19-12 – Grid system of ground points.

Assume that the squares in *Figure 19-12* measure 200.0 feet on each side. Points *a, b,* and *c* are points on a ridge line, also 200.0 feet apart. You need to locate and draw the 260.0-foot contour line. By inspection, you can see that the 260.0-foot contour must cross *AD* since the elevation of *A* is 255.2 feet and the elevation of *D* is 263.3 feet. However, at what point does the 260.0-foot contour cross *AD?* This can be determined by using a proportional equation as follows.

Assume that the slope from *A* to *D* is uniform. The difference in elevation is 8.1 feet (263.3 - 255.2) for 200.0 feet. The difference in elevation between 255.2 and 260.0 feet (elevation of the desired contour) is 4.8 feet. The distance from *A* to the point where the 260.0-foot contour crosses *AD* is the value of *x* in the proportional equation: 8.1:200 = *4.8:x* or *x* = 118.5 feet. Lay off 118.5 feet from *A* on *AD* and make a mark.

In the same manner, you locate and mark the points where the 260.0-foot contour crosses *BE, EF, EH,* and *GH.* The 260.0-foot contour crosses the ridge between point *b* (elevation 266.1 feet) and point *c* (elevation 258.3 feet). The distance between *b* and *c* is again 200.0 feet. Therefore, you obtain the location of the point of crossing by the same procedure just described.

You now have six plotted points: one on the ridge line between *b* and *c* and the others on *AD, BE, EF, EH,* and *GH.* A line sketched by hand through these points is the 260.0-foot contour line. Note that the line is, in effect, the line that would be formed by a horizontal plane that passed through the ridge at an elevation of 260.0 feet. Note, too, that a contour line changes direction at a ridge summit.

2.3.3 Control Points

This explanation illustrates the fact that any contour line may be located by interpolation on a uniform slope between two points of known elevation a known distance apart. The example also demonstrates how a ridge line is located in the same manner.

By locating and plotting all the important irregularities in an area (ridges, valleys, and any other points where elevation changes radically), a contour map of an area can be drawn by ***interpolating*** the desired contours between the control points.

A very elementary application of the method is shown in *Figure 19-13*. Point *A* is the summit of a more or less conical hill. A spot elevation is taken here, and then also at points *B, C, D, E,* and *F,* which are points at the foot of the hill. It is desired to draw the 340.0-foot contour. Point *a* on the contour line is interpolated on the line from *A* to *B,* point *b is* interpolated on the line from *A* to *C,* point *c* is interpolated on the line from *A* to *D,* and so on.

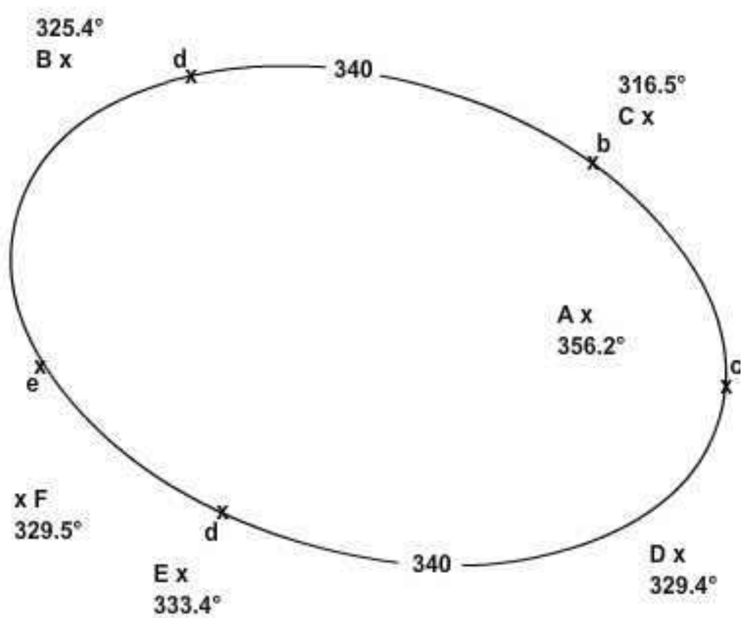


Figure 19-13 - Control point method of locating contour.

Figure 19-14 shows a more complicated example in which contours are interpolated and sketched between controlling spot elevations taken along a stream.

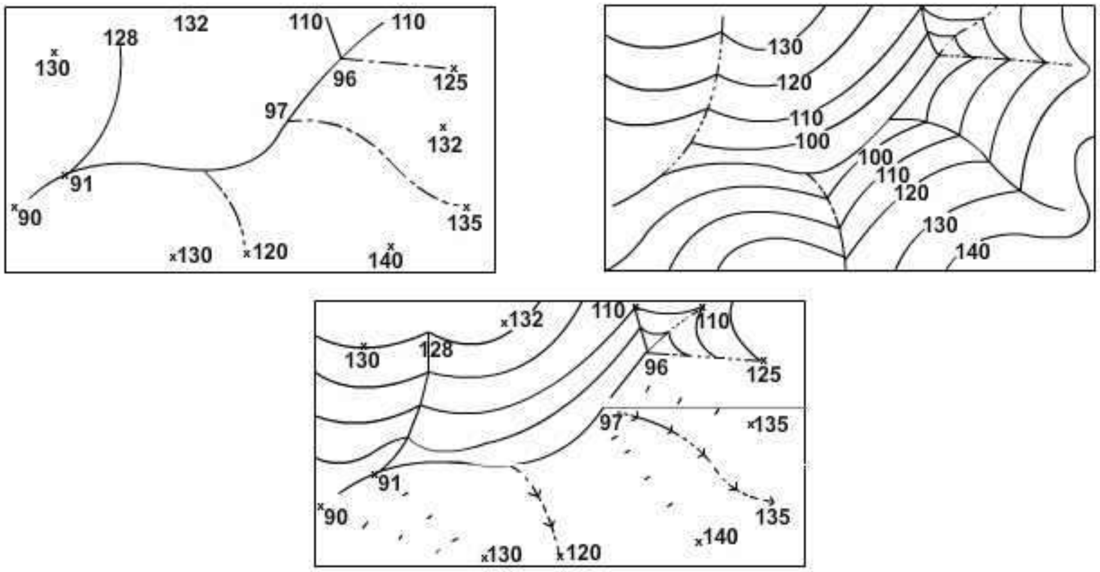


Figure 19-14 - Sketching contours by interpolation.

2.3.4 Cross Profiles

In the cross-profile system, elevations are taken along selected lines that are at right angles to a traverse line. Shots are taken at regular intervals or at breaks, or both, in the ground slope. The method is illustrated in *Figure 19-15*. The line *AB* is a traverse along which 100-foot stations are shown. On each of the dotted cross-section lines, contours are located. The particular contour located at a particular station depends on (1) the ground elevations and (2) the specified contour interval. In this instance, it is 2 feet. The method used to locate the contours is the one described earlier for tracing a contour system.

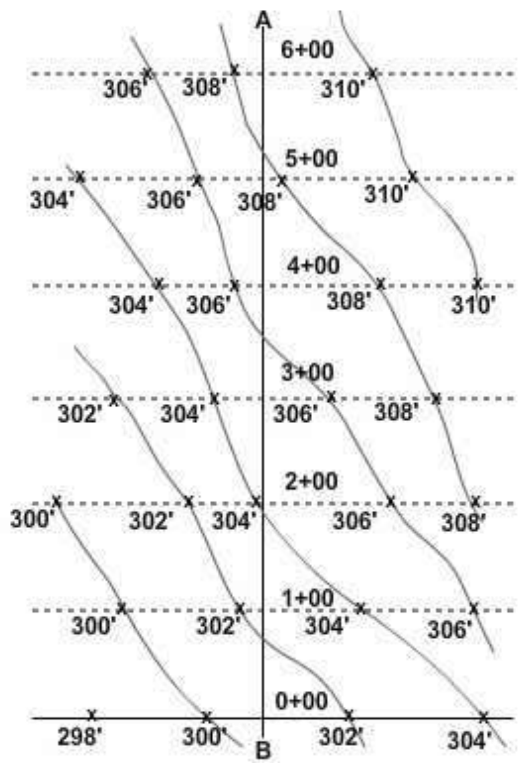


Figure 19-15 - Cross profiles.

When the even-numbered 2-foot interval contours are located on all the cross-profiles lines, the contour lines are drawn through the points of equal elevation.

2.4.0 Characteristics of Contour Lines

A contour line is a line of equal elevation; therefore, two different lines must indicate two different elevations. Two different contour lines cannot intersect or otherwise contact each other except at a point where a vertical or overhanging surface, such as a vertical or overhanging face of a cliff, exists on the ground. *Figure 19-16* shows an overhanging cliff. The segments of contour lines on the cliff are made as dotted (or hidden) lines. Aside from the exception mentioned, any point where two different contour lines intersect would be a point with two different elevations.

When you are forming a mental image of the surface configuration from a study of contour lines, it is helpful to remember that a contour line is a level line, that is, a line that would be formed by a horizontal plane passing through the earth at the indicated elevation.

A contour line must close on itself somewhere, either within or beyond the boundaries of the map. A line that appears on the map completely closed may indicate either a summit or a depression. If the line indicates a depression, this fact is sometimes shown by a succession of short hachure lines drawn perpendicular to the inner side of the line. An example of a depression is shown in *Figure 19-16*. A contour line marked in this fashion is called a depression contour.

On a horizontal or level plane surface, the elevations of all points on the surface are the same. Therefore, since different contour lines indicate different elevations, there can be no contour lines on a level surface. On an inclined plane surface, contour lines at a given equal interval will be straight, parallel to each other, and equidistant.

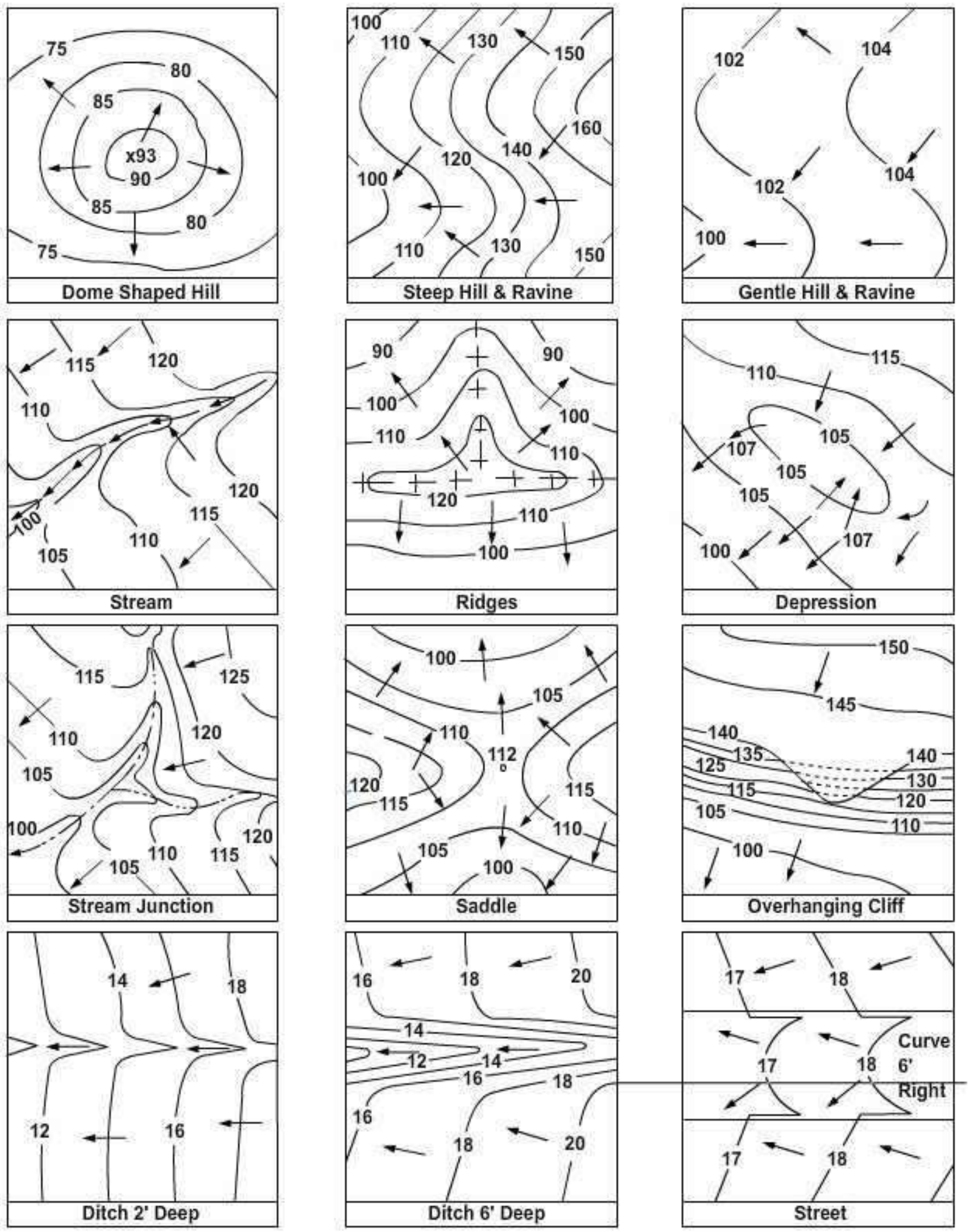


Figure 19-16 - Typical contour formations.

Generally, the spacing of the contour lines indicates the nature of the slope. Contour lines that are evenly spaced and wide apart indicate a uniform, gentle slope, as shown in *Figure 19-17*.

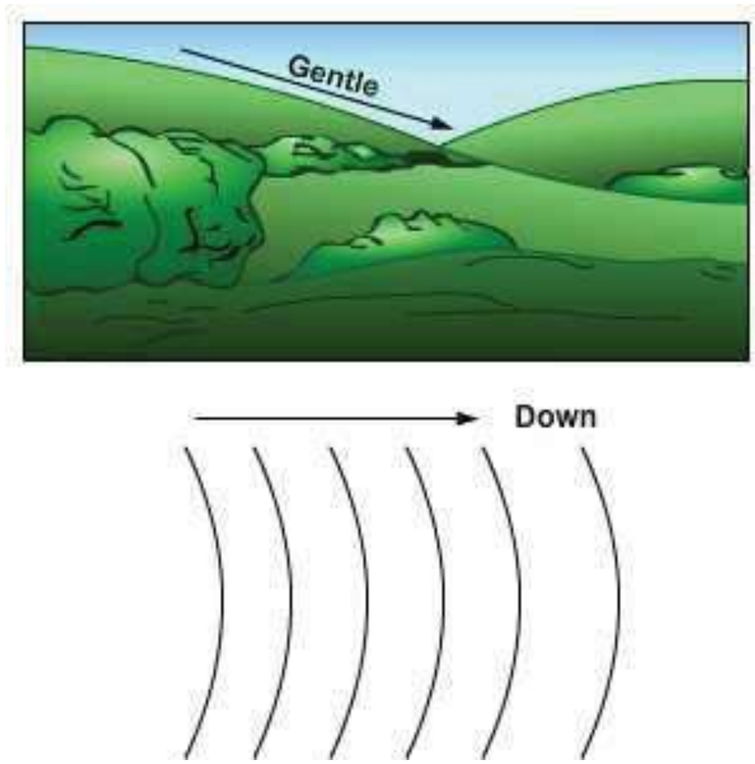


Figure 19-17 - Uniform gentle slope.

Contour lines that are evenly spaced and close together indicate a uniform, steep slope, as shown in *Figure 19-18*.

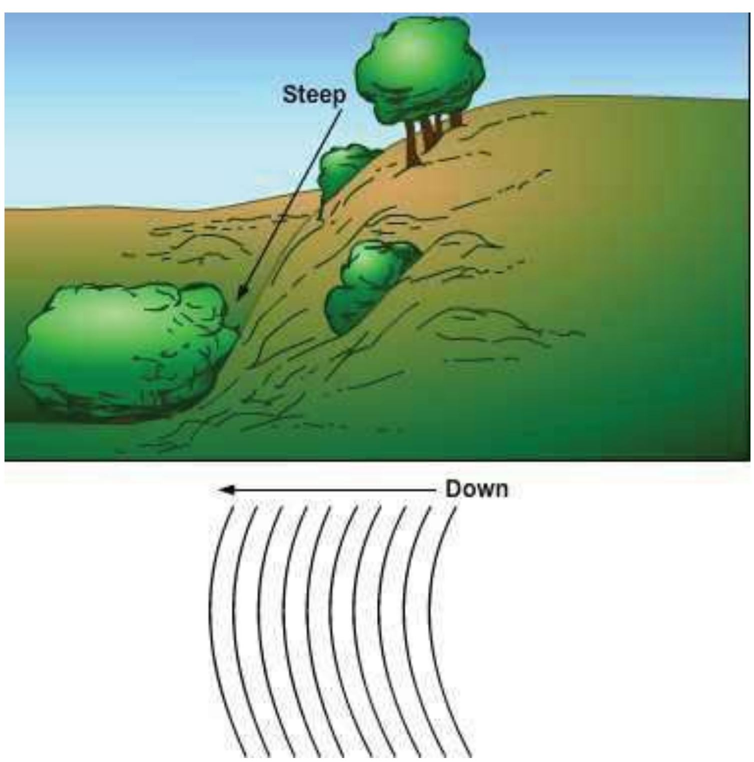


Figure 19-18 - Uniform steep slope.

The closer the contour lines are to each other, the steeper the slope. Contour lines closely spaced at the top and widely spaced at the bottom indicate a concave slope, as shown in *Figure 19-19*.

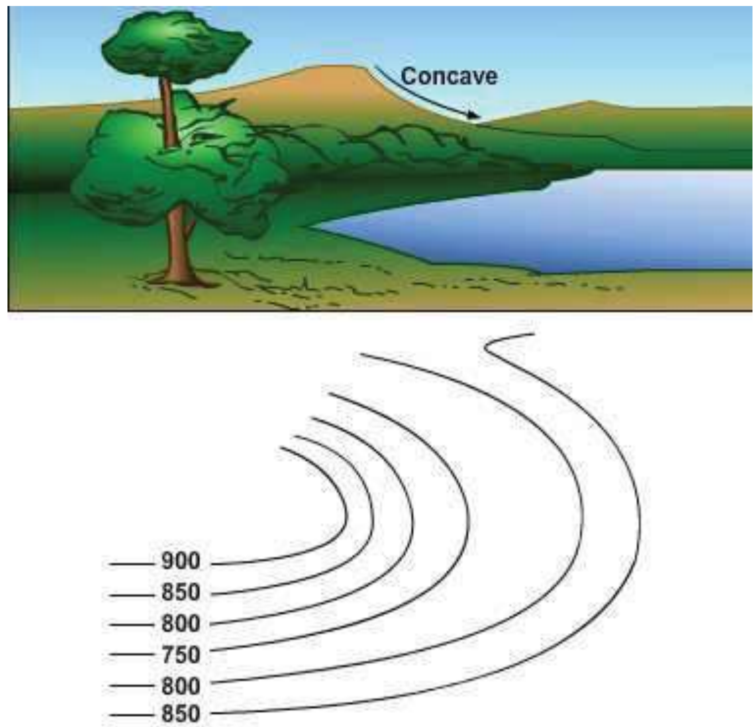


Figure 19-19 - Concave slope.

Contour lines widely spaced at the bottom indicate a convex slope, as shown in *Figure 19-20*.

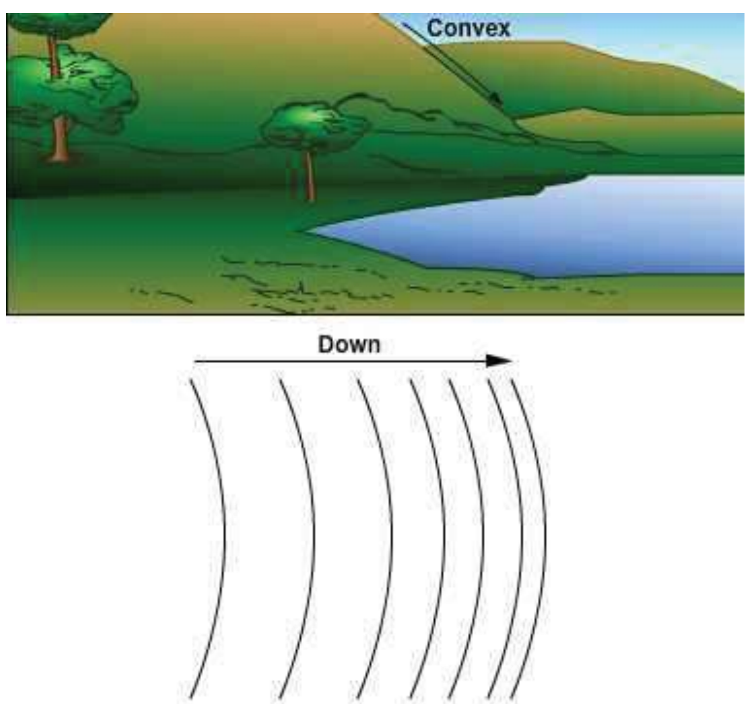


Figure 19-20 - Convex slope.

A panoramic sketch is a pictorial representation of the terrain in elevation and perspective as seen from one point of observation. This type of map shows the horizon, which is always of military importance, with intervening features, such as crests, woods, structures, roads, and fences. *Figures 19-21* through *19-27* show panoramic sketches and maps. Each figure shows a different relief feature and its characteristic contour pattern. Each relief feature illustrated is defined in the following paragraphs.

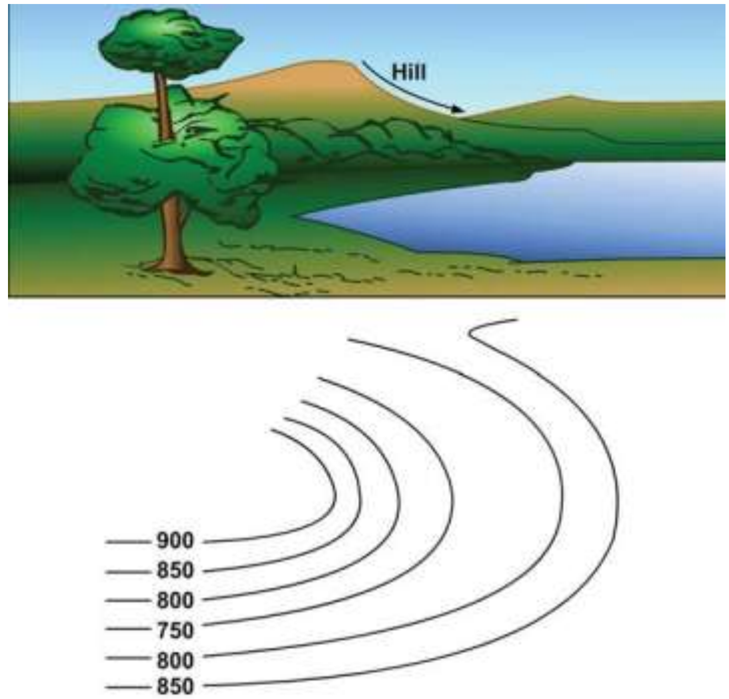


Figure 19-21 - Hill.

A hill is a point or small area of high ground, as shown in *Figure 19-21*. When you are on a hilltop, the ground slopes down in all directions.

A stream course that has at least a limited extent of reasonably level ground and is bordered on the sides by higher ground is a valley, as shown in *Figure 19-22*. The valley generally has maneuvering room within it. Contours indicating a valley are U-shaped and tend to parallel a major stream before crossing it. The more gradual the fall of a stream, the farther apart are the parallel contour lines. The curve of the contour crossing always points upstream.

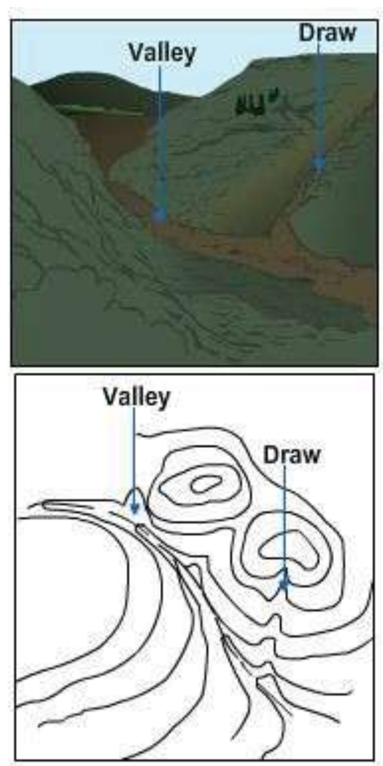


Figure 19-22 - Valley and draw.

A draw is a less-developed stream course where there is essentially no level ground and, therefore, little or no maneuvering room within its sides and towards the head of the draw. Draws occur frequently along the sides of ridges at right angles to the valley between them. Contours indicating a draw are V-shaped with the point of the V toward the head of the draw.

A ridge is a line of high ground that normally has minor variations along its crest, as shown in *Figure 19-23*. The ridge is not simply a line of hills. All points of the ridge crest are appreciably higher than the ground on both sides of the ridge.

*Figure 19-*23 also shows a spur, which is usually a short continuously sloping line of higher ground normally jutting out from the side of a ridge. A spur is often formed by two roughly parallel streams that cut draws down the side of the ridge.

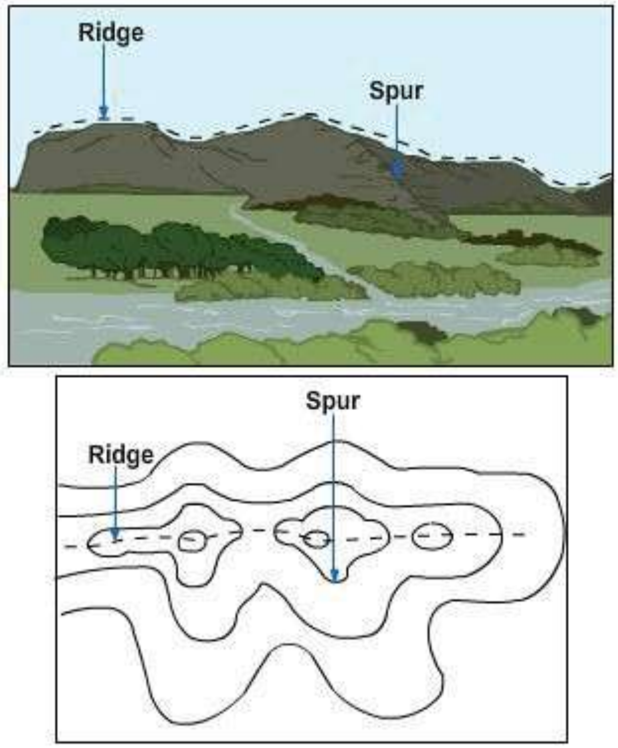


Figure 19-23 - Ridge and spur.

A saddle is a dip or low point along the crest of a ridge, as shown in *Figure 19-24*. A saddle is not necessarily the lower ground between the two hilltops; it may be simply a dip or break along an otherwise level ridge crest.

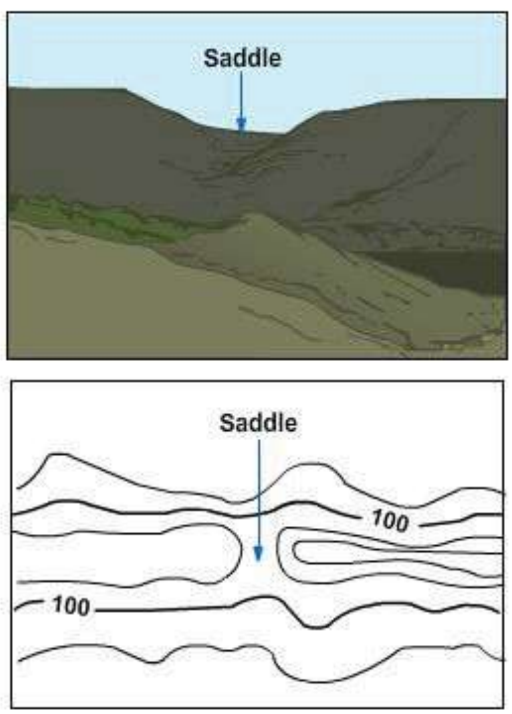


Figure 19-24 - Saddle.

A depression is a low point or sinkhole surrounded on all sides by higher ground, as shown in *Figure 19-25*.

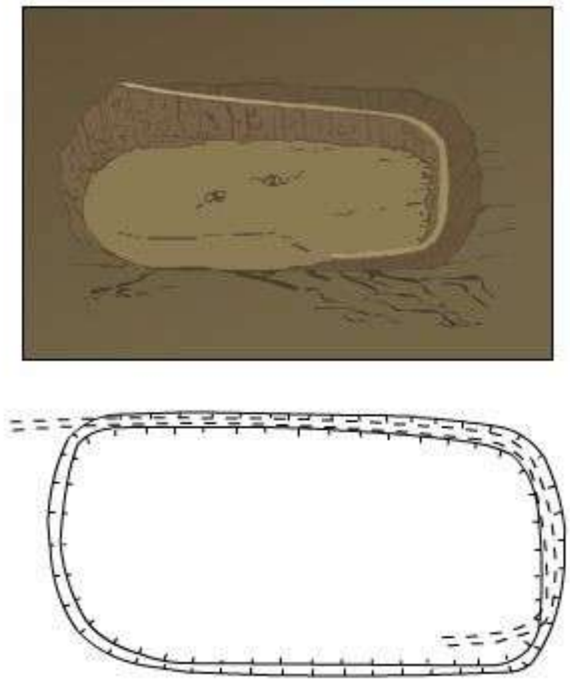


Figure 19-25 - Depression.

Cuts and fills are man-made features that result when the bed of a road or railroad is graded or leveled off by cutting through high areas and filling in low areas along the right-of-way, as shown in *Figure 19-26*.

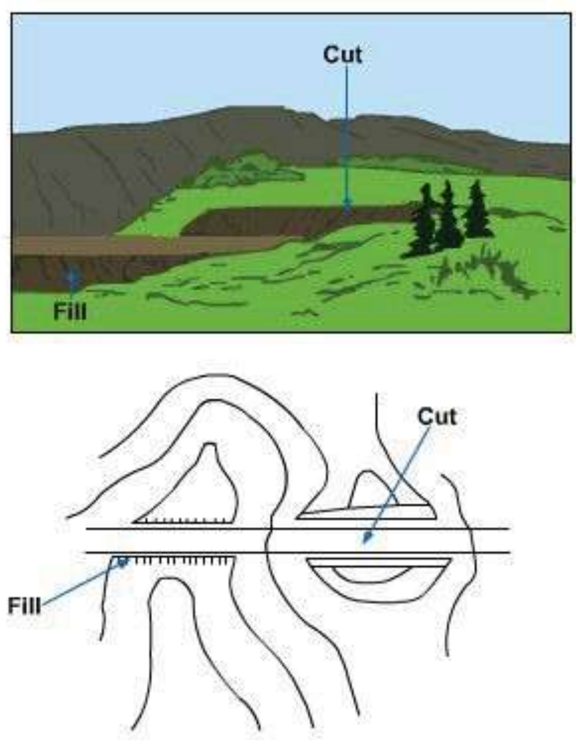


Figure 19-26 - Contour cut and fill.

A vertical or near vertical slope is a cliff. As described previously, when the slope of an inclined surface increases, the contour lines become closer together. In the case of a cliff, the contour lines can actually join, as shown in *Figure 19-27*. Notice the tick marks shown in this figure. These tick marks always point downgrade.

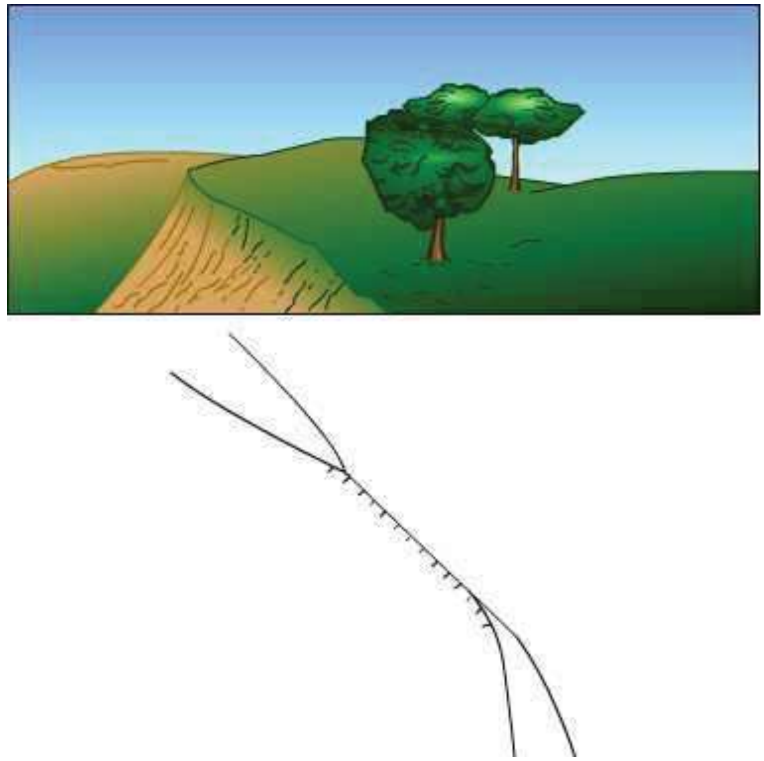


Figure 19-27 - Cliff.

2.5.1 Map Scales and Contour Intervals

A topographic map is called either large scale, intermediate scale, or small scale by the use of the following criteria:

- Large scale: 1inch = 100 feet or less
- Intermediate scale: any scale from 1 inch = 100 feet to 1 inch = 1,000 feet
- Small scale:1 inch = 1,000 feet or more

The designated contour interval varies with the purpose and scale of the map and the character of the terrain. *Table 19-3* shows the recommended contour intervals used to prepare a topographic map.

Table 19-3 - Recommended Contour.

Types of Topographic Map	Nature or Terrain	Recommended Contour Interval in Feet
Large Scale	Flat	0.5 or 1
	Rolling	1 or 2
	Hilly	2 or 5
Intermediate Scale	Flat	1,2 or 5
	Rolling	2 or 5
	Hilly	5 or 10
Small Scale	Flat	2,5 or 10
	Rolling	10 or 20
	Hilly	20 or 50
	Mountainous	50, 100 or 200

2.6.1 Contour Map Construction

If EAs can perform ordinary engineering drafting chores, they will not have any difficulty in constructing a topographic map. To some degree, topographers must draw contour lines by estimation. Their knowledge of contour line characteristics and the configuration of the terrain that the contour lines represent is a great help. Topographers must use their skill and judgment to draw the contour lines so that the lines are the best representation of the actual configuration of the ground surface.

Basically, the construction of a contour map consists of three operations:

1. Plot horizontal control that will serve as the framework of the map.
2. Plot details, including the map location of ground points of known ground elevation. These ground points or contour points will be used as guides for the proper location of the contour lines.
3. Construct contour lines at given contour intervals.

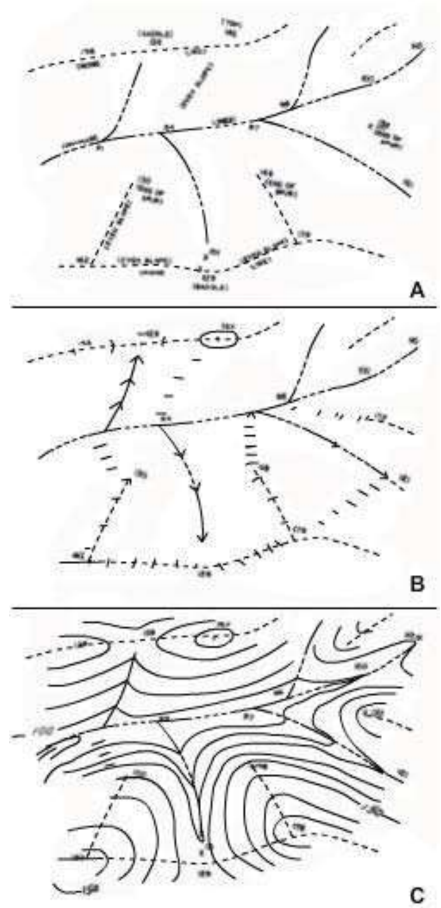


Figure 19-28 - Plotting detail and contouring.

Take special care in the field to locate ridge and valley lines because these lines are usually drawn first on the map before plotting the actual contour points, as shown in *Figure 19-28*, *View A*. Since contours ordinarily change direction sharply where they cross these lines and the slopes of ridges and valleys are fairly uniform, these lines aid in drawing the correct contour lines. After plotting the ridge and valley lines, space contour crossings (by interpolation) along them before making any attempt to interpolate or to draw the complete contour lines, as shown in *Figure 19-28*, *View B.*

Draw contour lines freehand with a contour pen to yield uniform widths. Leave breaks in the lines to provide spaces for the elevations. Write the elevation numbers so they may be read from one or two sides of the map. Some authorities prefer that elevations also be written in a way that the highest elevation numbers are arranged from the lowest to the highest uphill. Show spot elevations at important points, such as road intersections.

Figure 19-28, View C shows the completed contour map. For more refined work, the EA must trace the map using a contour pen on tracing paper or other appropriate medium, to allow reproduction of more copies.

The true shape of features to scale can be better represented on a large-scale map. On small-scale maps, however, symbols are used to represent buildings and other features. Center the symbol on the true position, but draw it larger than the scale of the map.

Detail of this type is portrayed on the map by means of standardized topographic symbols, such as shown in *Figure 19-29*.

When plotting contours, remember that streams and ridge lines have a primary influence on the direction of the contour lines. Remember also that the slope of the terrain controls the spacing of the contour lines. Contour lines crossing a stream follow the general direction of the stream on both sides, then cross the stream in a fairly sharp V that points upstream. Finally, remember that contour lines curve around the nose of ridges in the form of a U pointing downhill and cross ridge lines at approximate right angles.

2.7.0 Interpolating Contour Lines

In the examples of interpolation previously given, a single contour line was interpolated between two points of known elevation a known horizontal distance apart, by mathematical computation. In actual practice, usually more than one line must be interpolated between a pair of points, and large numbers of lines must be interpolated between many pairs of points. Mathematical computation for the location of each line would be time-consuming and would be used only in a situation where contour lines had to be located with an unusually high degree of accuracy.

For most ordinary contour-line drawings, one of several rapid methods of interpolation is used. In each case it is assumed that the slope between the two points of known elevation is uniform.

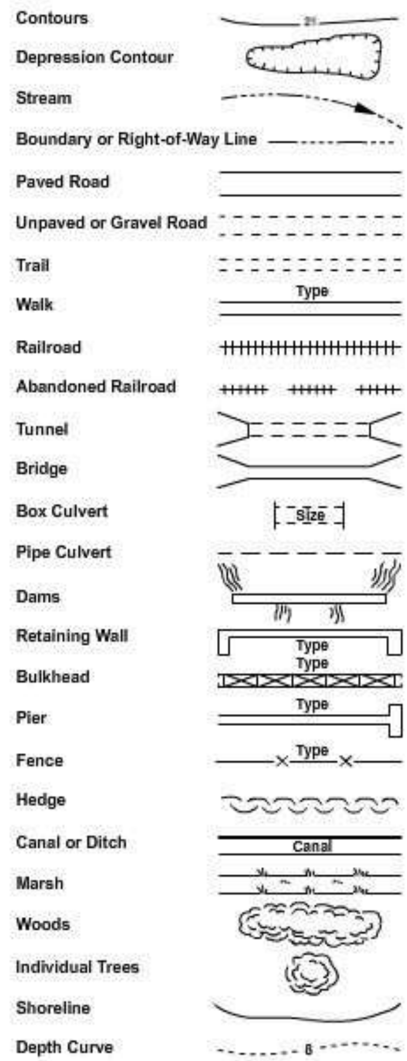


Figure 19-29 - Commonly used map symbols.

Figure 19-30 shows the use of an engineer's scale to interpolate the contours at 2-foot intervals between *A* and *B*. The difference in elevation between *A* and *B* is between 11 and 12 feet. Select the scale on the engineer's scale that has 12 graduations for a distance and comes close to matching the distance between *A* and *B* on the map. In *Figure 19-30* this is the 20 scale. Let the 0 mark on the 20 scale represent 530.0 feet. Then the 0.2 mark on the scale will represent 530.2 feet, the elevation of *A.* Place this mark on *A,* as shown. If the 0 mark on the scale represents 530.0 feet, then the 11.7 mark represents

530.0 + 11.7, or 541.7 feet,

the elevation of *B.* Place the scale at a convenient angle to the line from *A* to *B,* as shown, and draw a line from the 11.7 mark to *B.* You can now project the desired contour line locations from the scale to the line from *A* to *B* by drawing lines from the appropriate scale graduations (2, 4, 6, and so on) parallel to the line from the 11.7 mark to *B.*

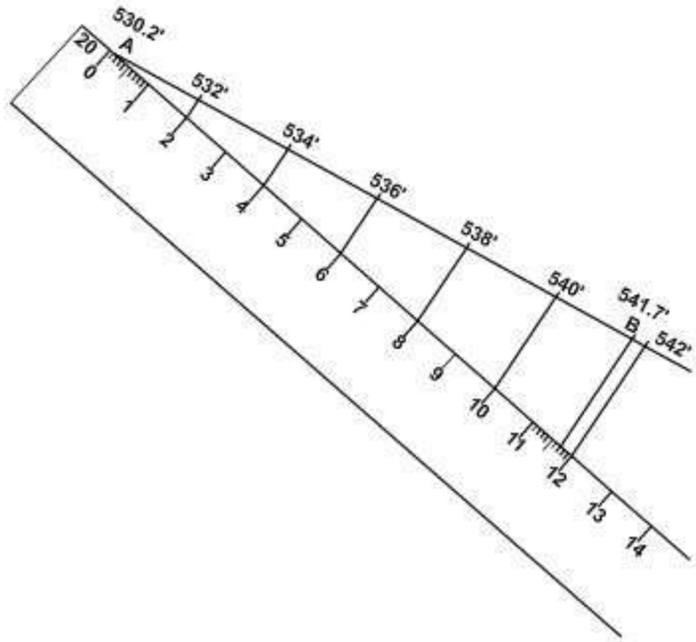


Figure 19-30 - Interpolating contour lines with a scale.

Figure 19-31 shows a graphic method of interpolating contour lines. On a transparent sheet, draw a succession of equidistant parallel lines. Number the lines as shown in the left margin. The 10th line is number 1, the 20th, number 2, and so on. Then the interval between each pair of adjacent lines represents 0.1 feet.

Figure 19-31 shows how to use this sheet to interpolate contour lines at a 1-foot interval between point *A* and point *B*. Place the sheet on the map so that the line representing 1.7 feet (elevation of *A* is 500.0 + 1.7, or 501.7 feet) is on *A,* and the line representing 6.2 feet (elevation of *B* is 500.0 + 1.7, or 506.2 feet) is on *B.* You can see how you can then locate the 1-foot contours between *A* and *B.*

For a steeper slope, the contour lines would be closer together. If the contour lines are too close, it is advisable to give the numbers on the graphic sheet different values, as indicated by the numerals in the right-hand margin. The space between each pair of lines represents 0.2 foot. Points *A´* and B, have the same elevations as points *A* and *B,* but

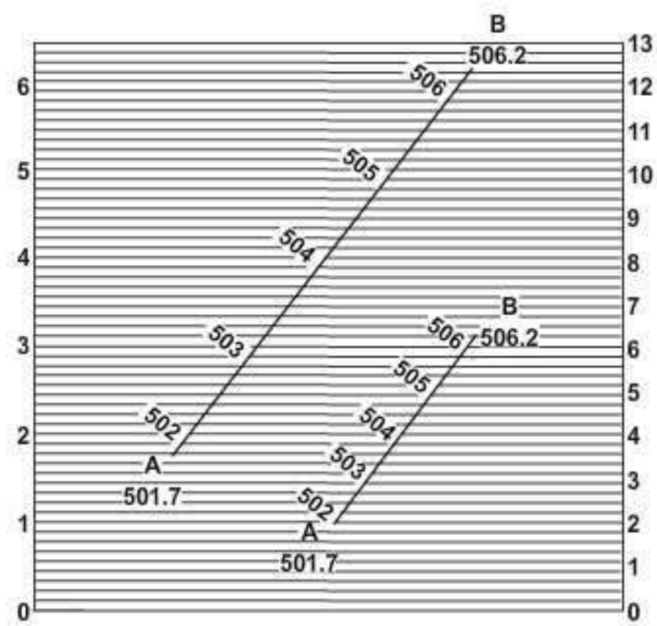


Figure 19-31 - Graphic method of interpolating contour lines.

the fact that the horizontal distance between them is much shorter shows that the slope between them is much steeper. You can see how the 1-foot contours between *A´* and *B*, can be located using the line values shown in the right margin.

A third method of rapid interpolation involves the use of a rubber band marked with the correct, equal decimal intervals. The band is stretched to bring the correct graduations on the points.

2.8.1 General Requirements for Topographic Maps

The scale and contour interval of a map are specified according to the purpose for which the map will be used. A map used for rough design planning of a rural dirt road would be on a smaller scale and have a larger contour interval than one to be used by builders to erect a structure on a small tract in a built-up area. The following guidelines suggest the nature of typical map specifications.

A map should present legibly, clearly, and concisely a summation of all information needed for the use intended, such as planning, design, construction, or record.

Topographic maps for preliminary site planning should have a scale of 1 inch = 200 feet and a contour interval of 5 feet. These maps should show all topographic features and structures with particular attention given to boundary lines, highways, railroads, power lines, cemeteries, large buildings or groups of buildings, shorelines, docking facilities, large rock strata, marshlands, and wooded areas. Secondary roads, small isolated buildings, small streams, and similar minor features are generally less important.

Topographic maps for detailed design for construction drawings should show all physical features, both natural and artificial, including underground structures. Scales commonly used are 1 inch= 20 feet, 1 inch= 40 feet, and 1 inch = 50 feet. The contour interval is 1 foot or 2 feet, depending on the character and extent of the project and the nature of the terrain. Besides contour lines, show any spot elevations required to indicate surface relief.

Additional detail features that are usually required include the following:

1. Plane coordinates for grid systems, grid lines, and identification of the particular system or systems.
2. Directional orientation, usually indicated by the north arrow.
3. Survey control with ties to the grid system, if there is one. This means that the principal instrument stations from which details were located should be indicated in a suitable manner.
4. All property, boundary, or right-of-way lines with identification.
5. Roads and parking areas, including center-line location and elevation, curbs, gutters, and width and type of pavement.
6. Airport runways, taxiways, and apron pavements, including center-line locations with profile elevations and width and type of pavement.
7. Sidewalks and other walkways with widths and elevations.
8. Railroads, including center-line location, top-of-rail elevations, and any turnouts or crossovers.
9. Utilities and drainage facilities, such as gas, power, telephone, water, sanitary sewer and storm sewer lines, including locations of all valve boxes, meter boxes, handholes, manholes, and the invert elevations of sewers and appurtenances.

10. Locations, dimensions, and finished floor (usually first floor) elevations of all structures.

Test your Knowledge (Select the Correct Response)

8. What is the definition of relief as it applies to surveying?

   A. Difference in elevation of the earth's surface
   B. Variation in the natural and man-made features of the earth's surface
   C. Variation of natural features of the earth's surface
   D. Man-made variations of the earth's surface

9. What term is used for the type of line on a map representing the same elevation for all points on the line?

   A. Contour
   B. Elevation
   C. hachure
   D. Grid

10. What term is used for the difference between the values of adjacent contour lines?

   A. Index contour
   B. Contour interval
   C. Intermediate contour
   D. Elevation interval

11. The grid coordinate system works best on what type of features?

   A. Slopes
   B. Relatively level ground
   C. Valleys
   D. Shorelines and cliffs

12. What type of area is represented on a topographic map by contour lines that are evenly spaced and wide apart?

   A. Valley
   B. Gentle, uniform slope
   C. Steep, uniform slope
   D. Ridge

13. In what manner does a panoramic sketch shows the terrain?

   A. In contour lines
   B. In elevation
   C. In perspective
   D. Both B and C

14. What type of lines are drawn before the actual contour lines are plotted on a topographic map?

    A. Spur and ridge
    B. Vertical control and spur
    C. Spur and valley
    D. Ridge and valley

15. Which of the following devices is useful for interpolating contour lines rapidly?

    A. Engineer's scale
    B. Tracing cloth
    C. Graduated rubber band
    D. All of the above

Summary

This chapter discussed the characteristic of topography including relief, natural features, and artificial features. This chapter also introduced you to the methods and procedures used to perform topographic surveying and to prepare topographic maps.

You learned that a topographic map is simply a drawing that shows natural and artificial features of an area and that topographic survey is a survey conducted to obtain the data needed to prepare a topographic map.

Review Questions (Select the Correct Response)

1. In a topographic survey of an area, what kind of control is established by crossties from one side of the area to another?

   A. Primary
   B. Secondary
   C. Horizontal
   D. Vertical

2. Vertical control is normally established by what type of leveling?

   A. Direct
   B. Trigonometric
   C. Barometric
   D. Indirect

3. When time is more critical than a high degree of accuracy, what method of locating details is recommended?

   A. Transit and tape
   B. Transit and stadia
   C. Transit and trigonometric leveling
   D. EDM and level

4. **(True or False)** The stadia method provides horizontal distances of a higher precision than those obtained by taping, EDM, or differential leveling.

   A. True
   B. False

5. The stadia *interval* is defined as the ________.

   A. reading on the rod between the stadia hairs.
   B. distance to the stadia rod.
   C. reading between the upper stadia hair and the middle cross hair.
   D. reading between the lower stadia hair and the middle cross hair.

6. Stadia distance is equal to the ________.

   A. rod reading.
   B. rod reading divided by the stadia constant.
   C. stadia interval.
   D. stadia interval times the stadia constant.

7. Stadia horizontal distances are normally recorded to what degree of accuracy?

   A. To 0.01 foot with a target
   B. To 0.1 foot over 300 feet
   C. To the nearest foot
   D. As close as possible

8. How do you compensate for refraction?

   A. By ignoring the instrument constant
   B. By taking all readings at two different times of the day
   C. By shading the instrument
   D. By using the refraction compensation formula

9. Which of the following methods are used for relief maps?

   A. 3-D models
   B. Hachure lines
   C. Shading representing shadows
   D. All of the above

10. Contour lines are used to show what type of information on a topographic map?

   A. Quickest route
   B. Boundaries
   C. Rivers and streams
   D. Relief

11. In a topographic survey, what term is used for the system in which the actual contour points on the ground are located and plotted?

   A. Cross profiles
   B. Control points
   C. Grid control
   D. Tracing contours

12. When drawing contour lines by using control points, what must you do to locate contour lines?

   A. Scale
   B. Interpolate
   C. Average
   D. Randomize

13. In what direction does the curve of a contour line cross a stream?

   A. Upstream
   B. Westward
   C. Downstream
   D. Eastward

14. What do contour lines represent in relation to the earth's surface?

   A. Horizontal planes
   B. Vertical planes
   C. Grid lines
   D. Different points of elevation

15. Which of the following scales represents a large-scale topographic map?

A. 1 inch = 50 feet
B. 1 inch = 120 feet
C. 1 inch = 500 feet
D. 1 inch = 1,000 feet

16. Which of the following operations is NOT one of the basic operations for construction of a topographic map?

A. Plotting horizontal control
B. Plotting details and ground points
C. Determining slope distances
D. Drawing contour lines

17. For clarity on small-scale maps, how should buildings and other features be shown?

A. To scale
B. Larger than scale and true to shape
C. Larger than scale and by symbols
D. By location in the notes

18. Topographic maps used for the design of construction drawings normally use what contour interval, in feet?

A. 1 or 2
B. 1, 2, or 5
C. 10
D. 20

Trade Terms Introduced in this Chapter

Angle of depression	When the line of sight is depressed below the horizontal.
Angle of elevation	When the line of sight is elevated above the horizontal.
Focal length	Distance between the principal focus and the center of the lens.
Instrument constant	The distance from the center of the instrument to the principal focus.
Interpolating	The process used to estimate an intermediate value from a known set of values.
Principal focus	The point at which light rays that pass through the lens of telescope come together.
Stadia constant	The number calculated by dividing the focal length by the distance between stadia hairs.
Stadia distance	The distance from the principal focus to the stadia rod.
Stadia hairs	The horizontal cross wires or hairs equidistant from the central horizontal cross wire located in telescope of transits or theodolites.
Stadia interval	The distance on the rod between the apparent positions of two stadia hairs.
Stadia reading	The distance on the rod between the apparent positions of two stadia hairs.
Topographic map	A graphic representation of the natural and artificial features of an area.
Topographic survey	A survey conducted to obtain the data needed to prepare a topographic map.
Topography	The characteristics of land surface that include relief, natural features and artificial or man-made features.

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.

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

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