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Engineering Journeyman

Volume 1. Survey

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THIS IS THE FIRST of four volumes for the career development course (CDC) 3E551, Engineering Journeyman.

The material in this volume pertains to the engineering technology principles that make up the foundation of this career field. Unit 1 covers the principles for survey theory. Unit 2 covers the skills for establishing survey control. Unit 3 covers techniques in survey application.

Volume two covers geographic information systems operation.

Volume three covers computer-aided drafting and design along with construction management procedures.

Volume four covers contingency operations.

A glossary is included for your use.

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For Guard and Reserve personnel, this volume is valued at 16 hours and 4 points.

NOTE:

In this volume, the subject matter is divided into self-contained units. A unit menu begins each unit, identifying the lesson headings and numbers. After reading the unit menu page and unit introduction, study the section, answer the self-test questions, and compare your answers with those given at the end of the unit. Then complete the unit review exercises.

Unit 1. Survey Theory

SURVEY IS AT THE CORE of our career field's skill set. It is the application of mathematics to gather information and interpret problems in order to develop solutions. This unit begins by explaining the most basic parts of survey theory. This includes definitions of world coordinates systems, how we measure angles and distances, and an overview of the practice of keeping field notes. The last portion of the unit provides you with important skills that make our job easier. It begins with feature code libraries and how they ease data gathering and interpretation. The section then explains 2-peg and collimation tests, which tests the accuracy of the auto-level and total station instruments. Finally, calculating allowable misclosure ends the section; pay close attention to this, as it is critical to understanding the next unit of study.

1–1. Theory

Survey theory is the way of thinking behind the practice. This section briefly explains the systems we use to locate things on the Earth's surface. It also explains what we mean when we say surface. After survey theory, we cover the measurement of angles and distances. This is math heavy so attention to detail is important. Finally, we end by discussing the importance, types, and practice of keeping field notes. Your goal is to get a firm grasp of the foundation of surveying by understanding the concepts in this section of the unit.

001. Survey theory

Survey is applied math. The differences between math and survey theory are the terms used in each. Instead of a Cartesian plane, survey uses *grids* for coordinate systems, *datum* to change three dimensions into two, and *geoids* to correct measured elevations against true elevations. There are also similarities between survey and math. We still use points and lines to locate and measure places and objects.

We can build on the ideas we learned in mathematics to understand survey. Let us break our comparison of the two into three parts: surfaces, points, and lines. These are the three ideas that are the basis for understanding the theory behind surveying.

Surfaces

When talking about surfaces, we will concern ourselves with three ideas: *datum*, *grids*, and *projections*. These three ideas draw a basic picture of where our points, lines, and elevations live.

Datum

The points and lines that we survey are not in three-dimensional space, they are in two dimensions. The Earth, on the other hand, is three-dimensional. In order for all points and lines on the Earth to relate to one another accurately, they need to share a common reference surface. That reference surface is a *datum*. The surface used in Air Force surveying is the *reference ellipsoid*, World Geodetic

System 1984 (WGS 84) (fig. 1–1). A *reference ellipsoid*, another way to say *datum*, is a common reference surface.

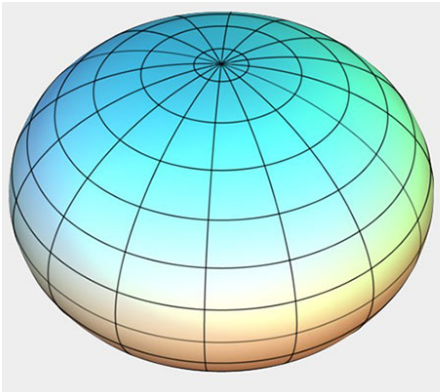

Figure 1–1. Reference ellipsoid.

Grids

The WGS 84 uses a geographic coordinate system. A geographic coordinate system is geocentric, meaning that the measurements on the surface are relative to the center of the *reference ellipsoid*. The coordinates on the surface, measured in latitude with 0 degrees (º) at the equator, and 90º at the north and south poles, and in longitude, 0º at the prime meridian, and 180º at the international date line. The origin of this system, 0º latitude by 0º longitude, is off the west coast of Africa in the Gulf of Guinea (fig. 1–2). The angles measure from the *reference ellipsoid's* center (fig. 1–3).

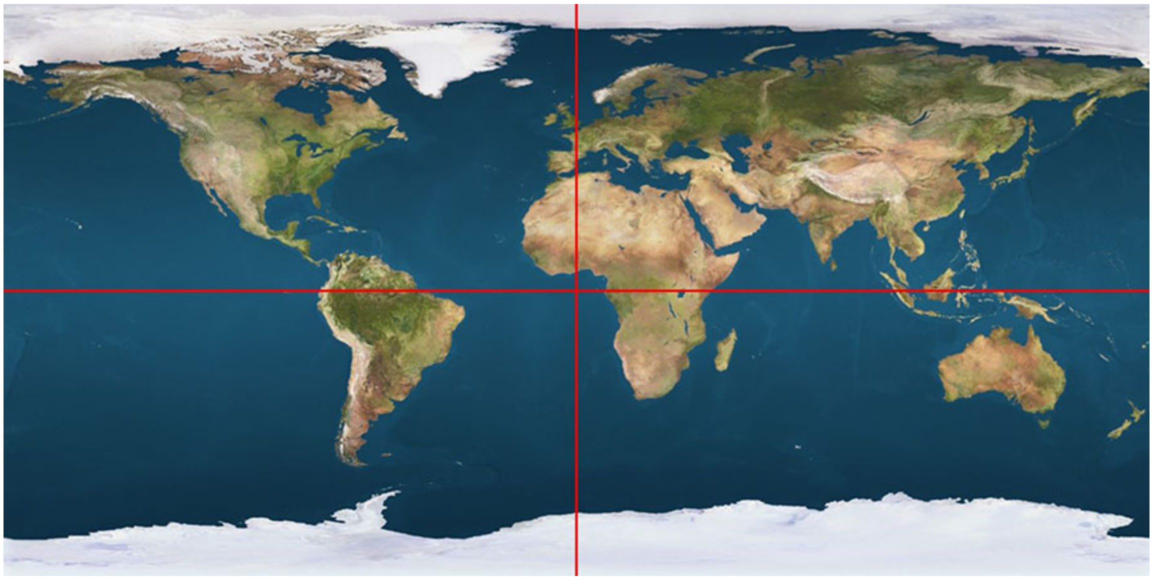

Figure 1–2. Geographic coordinate system origin.

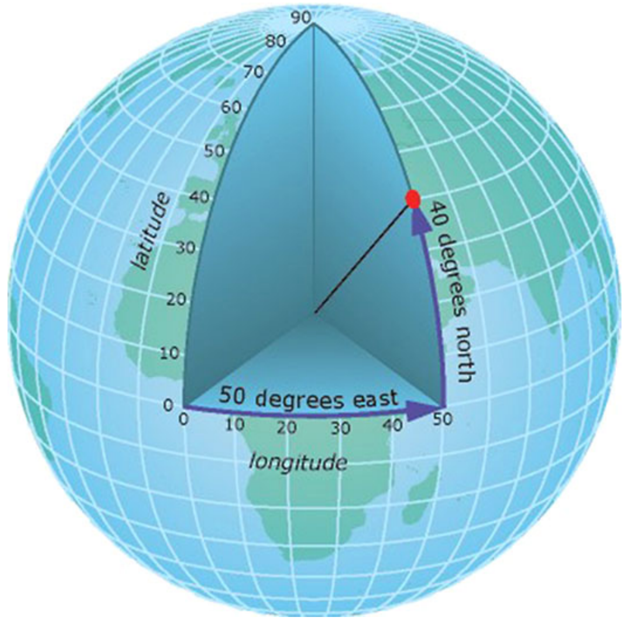

Figure 1–3. Geo-centric angle measurement.

Projections

Lines do not exist on a three-dimensional surface, only curves. Curves are not easy to survey. In order to simplify the process of measuring locations, we *project* the *ellipsoid* onto a two-dimensional surface as straight lines. There are many kinds of *projections;* we use Universal Transverse Mercator (UTM). UTM is a conformal *projection*. Conformal simply means that the way we stretch the *ellipsoid* preserves the angles measured on its surface, as opposed to shape, area, or distance. It is easier, and more accurate, to project smaller areas than larger ones. UTM projects 60 smaller longitudinal zones, starting from 180º W, each 6º wide, numbered 1 to 60. Twenty latitudinal zones are also defined, beginning at 80º S, running north to 84º N, denoted C to X, omitting O (because it's too similar to zero) (fig. 1–4).

Once projected in two dimensions, measure zones in Eastings and Northings. Eastings are the "x" coordinates while Northings are the "y." Eastings (x) begin at 500,000 meters along a line running north to south at the zone's center. Northings (y), in the Northern Hemisphere, begin at 0 meters at the equator and increases as you move north. In the Southern Hemisphere, Northings begin at the equator set at a value of 10,000,000 meters (fig. 1–5). With Easting and Northing, it is customary to either place the UTM zone and hemisphere, or the UTM zone and latitudinal zone.

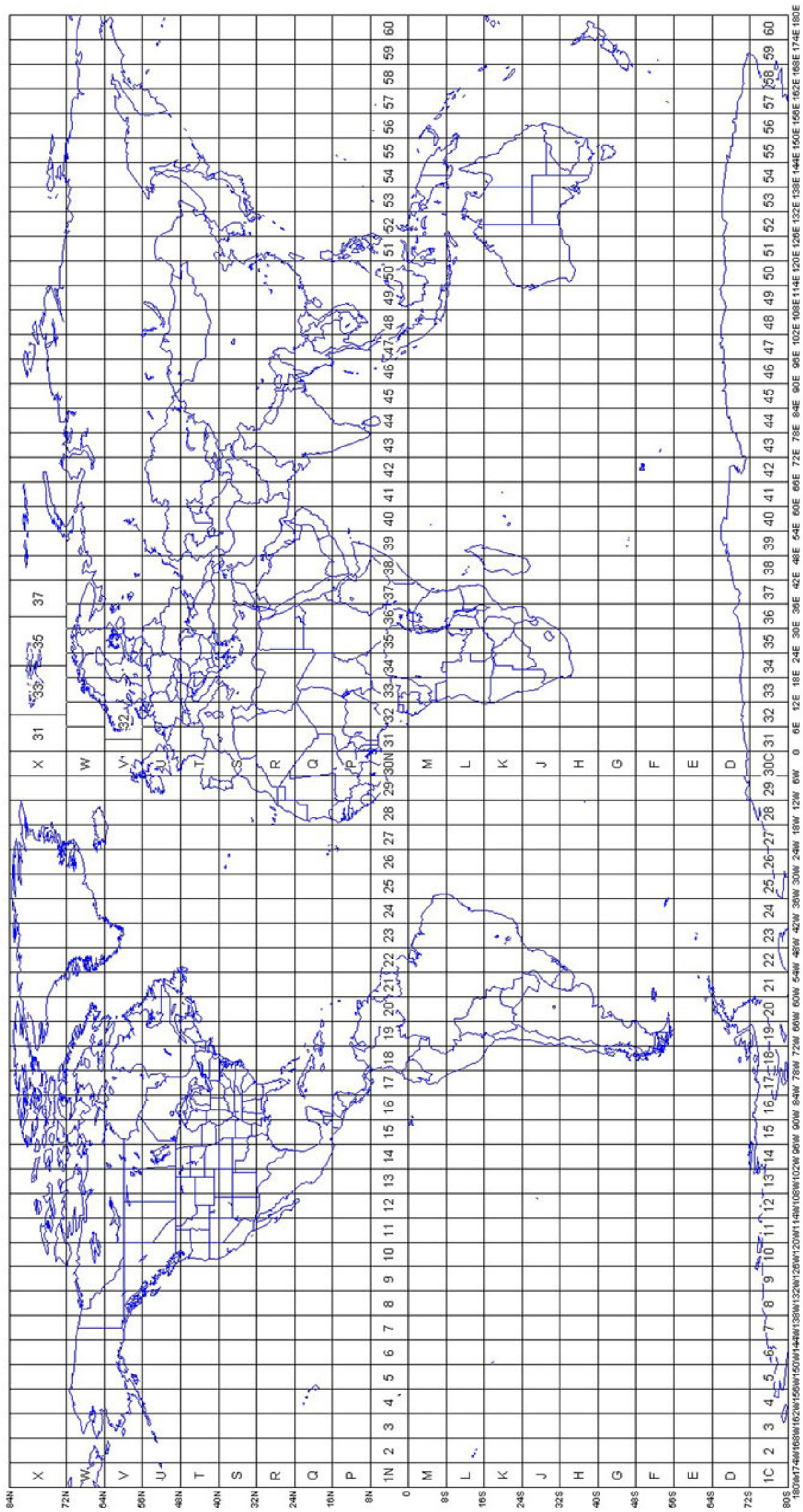

Figure 1–4. UTM grid zones.

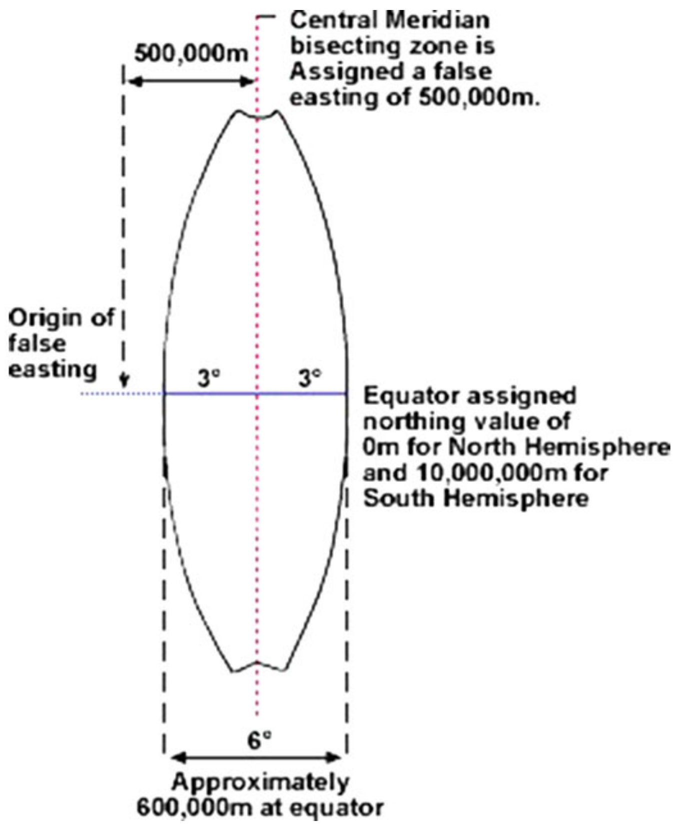

Figure 1–5. Eastings and Northings.

Points

Points are the most fundamental unit in surveying. Points define locations. A point is described by its position, in a coordinate system, up or down from, and left or right of, the origin. A Cartesian example is a point described as (3, 2); this point is three units right of the origin, and two units up. A geographic, or geocentric, example would be the position of Greenwich, England, which is 51.48ºN by 0.0ºW (because the prime meridian runs through the town of Greenwich). Greenwich's location in UTM would be, UTM Zone 30U Easting: 708287.7 meters, Northing: 5707121.99 meters. List Easting before Northing because Easting is the "x" value.

Lines

In linear algebra, you learned to define a line in a few ways. A line of infinite length can be defined by giving just the x or y value. A line x=10, is a line straight up and down; this makes the y value all real numbers. The slope-intercept form y = m * x + b (read as "**m** times **x** plus **b**"), describes a line by its rate of change, m, and where it crosses the y-axis, b. In survey, we have a new way to define a line—distance and direction.

Distance is a relatively simple concept; most people understand that it is a matter of measuring in some way. Direction is more specific to the field of study. In survey, we have two terms that describe direction—azimuth and bearing. Azimuth describes an angle using true, grid, or compass north as the 0º. A line, in this method, calculates other points and lines. Simply measure the direction, in degrees, and measure the distance. Bearing is less common but simple. Bearing is like azimuth except that it breaks the 360º circle into four quadrants of 90º each (fig. 1–6). An azimuth of 300º would be written N60ºW, read "North 60 degrees West."

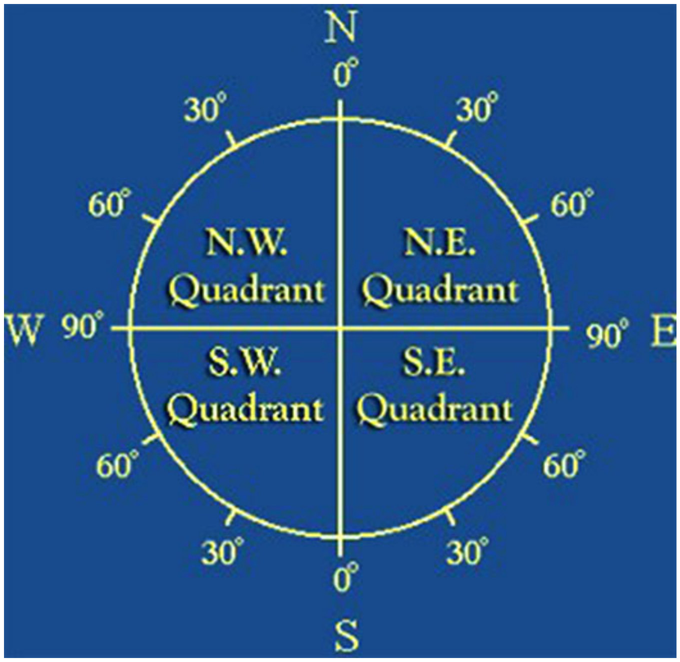

Figure 1–6. Bearing and azimuth.

The interesting and tricky part of survey theory is application. Though these practices are standardized, and the Air Force uses certain *datum* and *projections*, there are many ways and many different tools used to measure a point, angle, and distance.

002. Measuring angles and distances

Before we start talking about establishing control and performing actual surveys, we will review the basics of survey measurement. The two measurements that you will always be concerned with are angles and distances. There are different ways to measure each, and we will discuss a few of them here.

Measure distances

We use some kind of device to measure distance. That device can be a measuring tape, a wheel, a total station and prism rod, a range finder, and so forth. Aside from these more well-known methods, the two that we are going to review are pace count and stadia distance.

Measuring your pace count

Though not very precise, pace count is useful when estimating distances. Your pace count will be the estimated distance you travel when taking one natural step. This does not account for slopes in the terrain, which is another reason why the pace count is only an estimate. The procedure for establishing your pace count is as follows:

1. Measure a distance of 100 meters using a tape measure or other dependable measuring method.
2. Walk, as naturally as you can, the measured 100 meter distance, counting each step.
3. Repeat two additional times.
4. Take the total number of steps and divide by three.
5. Divide that number by 100.
6. The result will be your distance per step in meters.

As an example, let’s say that you walk the 100 meter distance in 32 steps the first time, 30 the second, and 34 the third. The total number of steps is 96. Dividing by three gives us 32 steps per 100 meters, on average. When we divide this number by 100 meters, we get your pace count of .32 meters per step.

Your pace count is a simple tool used when every other measuring method fails. Pace count is also useful during reconnaissance (recon) surveys as a way to get a general idea of the size of the survey site. You now have your first measuring tool—your steps. Your pace is only an estimate, so let us look into something that is more precise.

Measuring stadia distances

Most optical surveying equipment measures distance-using lines above and below the central crosshairs. These are *stadia lines*. The stadia lines, in conjunction with the *stadia interval factor*, are components assisting us to compute the distance from the survey instrument to a graduated rod. The stadia interval factor uses the principle of similar triangles to describe the relationship between the instrument and graduated rod, and between the stadia lines and two points on the rod. Because these two measurements are proportional to the distance, we can compute it.

The stadia interval factor, expressed as a ratio, is most commonly 1:100, 1:200, and 1:333. Though the stadia interval factor will be equipment dependent, written on the instrument or its case, the most common ratio in the United States is 1:100.

The s*tadia intercept* is the distance between the stadia lines. Read the rod at the upper and lower stadia lines—in figure 1–7 they are 6.22 and 4.3, respectively. Take readings when the rod person (RP) "waves" the rod forward and backward and are the highest readings the instrument person views. The difference between the two readings (6.22 minus 4.3 equals 1.92 feet [ft.]) is the stadia intercept, *I*. To obtain the horizontal distance, *d*, solve the formula: d = (Stadia Interval Factor) ● I

Or

100/1 ● 1.92 = 192 ft.

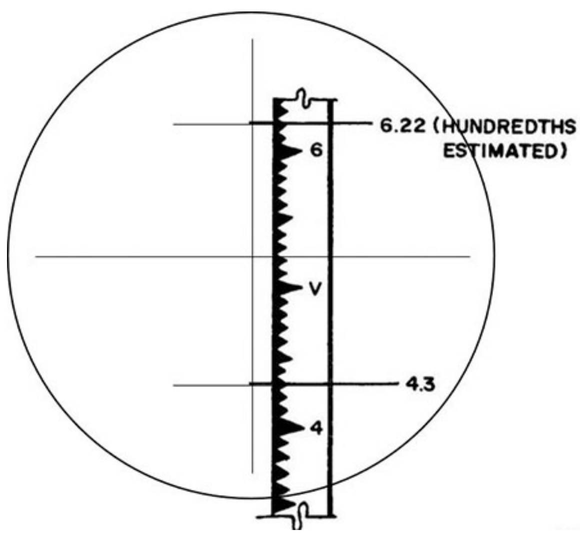

Figure 1–7. Stadia measurement.

Take the center hair reading as a check. If we subtract the reading from the top to the center, and then from the center to the bottom, they should be the same. When they are not the same, take the measurements again.

Measure angles

When discussing angles, the first thing we must establish is a baseline. A baseline is the zero angle from which we can measure all other angles. Establish the baseline using magnetic, true, or assumed north. Measure angles from the baseline in a circle broken into 360 parts, or degrees. Measure degrees clockwise from the baseline.

Because we always use some kind of north as a baseline, we call our measurements azimuths. Azimuths are angle measurements based upon a north line. If our azimuth is 0º, or north, then it follows that our *back azimuth* is 180º, or south. Therefore, any azimuth value plus 180º is a back azimuth. In figure 1–8, the line from point A to point B, or line AB, has an azimuth *a* and a back azimuth *b*.

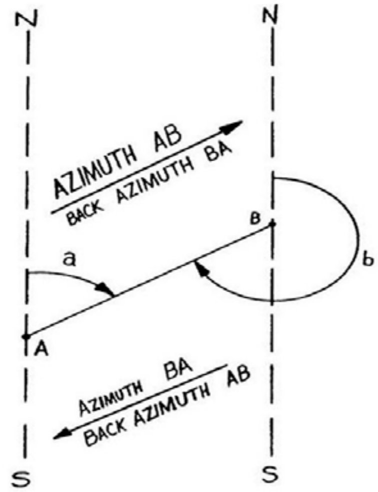

Figure 1–8. Azimuth and back azimuth.

Magnetic north

Magnetic north is the resting direction of a freely suspended compass needle. Magnetic north is the zero value, with angles measured from this point. Although forward and back azimuths for a line should differ by 180°, compass-measured differences may vary several degrees because of local magnetic attraction. *Do <u>not</u> use this method when exact north is critical.*

Grid north

Grid north is parallel to lines of longitude running from true north, the Earth's rotational axis, to true south. Use grid north to establish horizontal control because it is consistent. While the rotational axes of the Earth never change positions, magnetic north moves gradually throughout an area offset from true north. The difference between magnetic north and grid north is *declination*. This may be to the east or west and referred to as east or west declination (fig. 1–9). In order to compute the grid north for any area, we would either add or subtract the declination from the magnetic north value. When the declination is easterly, we add; when it is westerly, we subtract.

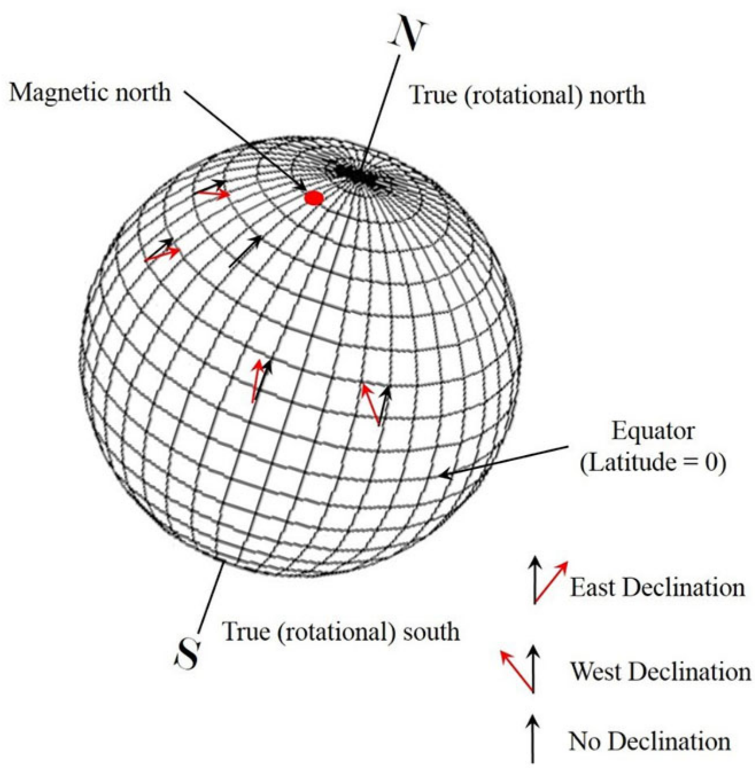

Figure 1–9. Declination.

Assumed north

When we cannot establish a grid north baseline, we can use an assumed azimuth. The surveyor chooses an assumed azimuth. A good example of this is using a road centerline to reference the measurements of a survey. When the data is post-processed, compare it to actual features and positions to estimate the locations of survey measurements. Using assumed azimuths is not very accurate but can be useful for expedient surveys.

Calculating azimuths

Let us say we have established our grid azimuth at 0º, our equipment is set up, and we are ready to measure angles. We have measured all the angles as in figure 1–10. At this point, we know only that the line AD has an azimuth of, or is pointing at, 48º. To calculate the azimuths of the other line segments, we either add or subtract the turned angle based upon which way we turn. Subtract the turned angle from the original azimuth when turning counterclockwise and add when turning clockwise.

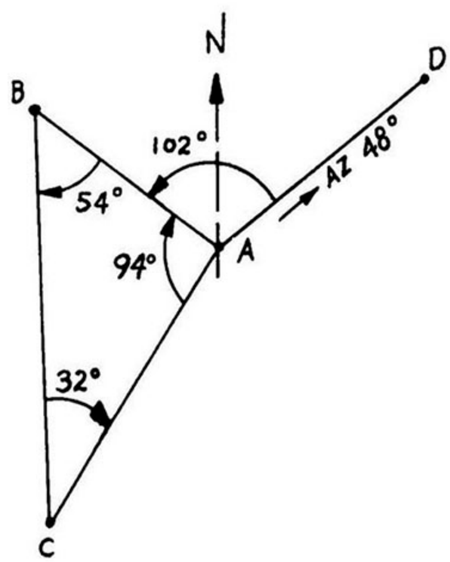

Figure 1–10. Measured azimuths.

We can now calculate the azimuth for the other lines as follows:

Line AB:

1. The measurement direction is *counterclockwise* so we *subtract* 102º from 48º.
    a. 102 - 48 = 54
    b. Because we crossed the 0º azimuth, we subtract 54º from 360º and get 306º.
    c. Line AB has an azimuth of 306º.

Line BA:

1. Line BA is the *back azimuth* of line AB so we subtract 180º from 306º.
    a. 306 - 180 = 126.
    b. Line BA has an azimuth of 126º.

Line BC:

1. The measurement direction is *clockwise* so we *add* 54º to 126º.
    a. 126 + 54 = 180.
    b. Line BC has an azimuth of 180º.

Line CB:

1. Line CB is the *back azimuth* of line BC so we subtract 180º from 180º.
    a. 180 - 180 = 0.
    b. Line CB has an azimuth of 0º.

Line CA:

1. The measurement direction is *clockwise* so we *add* 32º to 0º.
    a. 32 + 0 = 32.
    b. Line CA has an azimuth of 32º.

003. Maintain survey field notes

When effectively written and managed, field notes answer questions about the survey. A surveyor's field notes are a complete record of all measurements, sketches, diagrams, and narrations made during the survey. Field notes clarify information that serves the user. The best survey is of little value when notes are not complete and clear. Field notes are the only record left after the survey team leaves the site. Most importantly, field notes can become legal documents, usable in a court of law.

Field notes

Historically, field notes were hand-printed in field notebooks. This practice has seen a dramatic change with the introduction of electronic data collectors. Unfortunately, electronic equipment sometimes fails and data is lost—a potential problem you need to be prepared for and a good reason to keep manual field notes.

Write field notes neatly and legibly in Gothic-style freehand. Make numerals and decimal points legible so there can be only one interpretation. Keep notes on standard survey forms or standardized field notebooks. Keep in mind that someone unfamiliar with surveying may need to use your field notes; therefore, field notes should be clear and detailed.

Keep survey notes in a field notebook—either permanently bound or loose-leaf. A complete description of the survey includes the following information:

- The name, rank, squadron address, and phone number printed in ink on the inside and outside cover.
- The project title, date, weather conditions, and location of the survey.
- An index of field notes.
- List of party personnel and their duties.
- List of instruments used, including serial numbers, calibration data, and dates used.
- A generalized sketch and description of the project.

The *heading* on EACH page that has measurement notes must include:

- Station name.
- Date.
- Instrument person, recorder.
- Instrument used.
- Pertinent weather conditions.

The *body* contains all pertinent measurement notes. Each page is be checked for errors and omissions indicated by the instrument person's initials on the bottom.

Record field notes in three methods: tabulation, sketches, and descriptions. The table below describes each form.

Recording Field Notes	
Method	**Description**
Tabulations	Record numerical measurements in columns according to a prescribed plan depending upon the instrument, the survey's order of accuracy, and the type of measurement.
Sketches	Help to clarify field notes, and should be used liberally. To scale (or not to scale), approximate scale, or exaggerated for clarity. It is very important to *include a north arrow to orient the sketch*. Add measurements directly to the sketch or key them in somehow.
Descriptions	Tabulations, with or without sketches, can also be supplemented with descriptions. The description may only be one or two words that clarify the recorded measurements. It may also be a lengthy narration used at some future date, possibly years later, to locate a survey monument (MON).

When using total station or a Global Positioning System (GPS), at an absolute minimum, use a field notebook to record the names of the survey team members, methods of conducting the survey, weather, and dates. The key to field notes is attention to detail. It is much easier to refer to notes than to do a survey twice.

Abbreviations and preparations

Use only standard abbreviations, signs, and symbols for field notes. Notes must have only one meaning. If there's *any* doubt as to the meaning or interpretation of a symbol or abbreviation, spell out the words.

Corrections

Erase nothing in your field notes. Line through the incorrect information and write the correct information above the line. Explain the circumstance of the corrections, except for obvious mathematical errors, in the REMARKS column. *Do not* void or reject any position in the field notes, except when bumping the instrument or observing the wrong target, and then place a note in the REMARKS column stating the reason for the correction. Voided or rejected pages must reference to a substitute page.

Electronic field notes

We have been discussing the importance of handwritten field notes, which are critical to surveying. New surveying equipment, like total station and GPS instruments, use electronic data collectors that automatically display and record distance and angle measurements. Newer equipment also has the capability to transfer the stored field data directly into the office computers. Although automatic data collectors make the note keeper's task easier, they do not eliminate the need for sketches and descriptions of the survey site.

With electronic field notes, it is faster to process data. Faster processing is a huge advantage after gathering a large amount of data. The biggest disadvantage is, while you cannot alter handwritten field notes without leaving a mark, electronic notes and data change easily without leaving any evidence.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

001. Survey theory

1. Give a brief definition of a reference ellipsoid.

2. Where is the origin of the WGS 84 reference ellipsoid located?

3. In what way do projections simplify the process of measuring locations?

4. Give a brief description of how to convert an azimuth to a bearing.

002. Measuring angles and distances

1. What does your pace not account for?

2. Explain how to calculate the stadia intercept.

3. Determine the back azimuth of 33º, and show your work.

4. How do we convert the magnetic azimuth when the declination is easterly? When it is westerly?

5. Describe the difference between an azimuth and a turned angle.

003. Maintain survey field notes

1. What should the heading on each page that has measurement notes include?

2. What must voided or rejected pages reference?

1–2. Additional Concepts

The concepts in this section are a part of many survey methods. The feature code libraries make surveying in groups and processing survey data simpler and more efficient. Perform 2-peg and collimation tests regularly to evaluate auto-levels and total stations accuracies. Calculating allowable misclosure is particularly important. It is the first step in gauging the quality of a survey. The allowable misclosure is the limit of error defined by the survey, though it is important to know that the project engineers determine final error limits.

004. Using feature code libraries

Feature code libraries help surveyors quickly display survey data. When the data is post-processed, the codes can tell the software how to draw the features. The feature codes applied to points, lines, and polygons quickly prepare the data for use. Feature code libraries can also tell the survey equipment to ask the surveyor for further information, or add attributes filled in on the site, rather than noted and added to the data during post-processing. Your skill and attention to detail when creating or editing feature code libraries simplify and speed up the survey process.

Feature definition manager

The feature definition manager is in our post-processing software. Under the file menu, select tools, and the manager will be the second tool from the top (fig. 1–11).

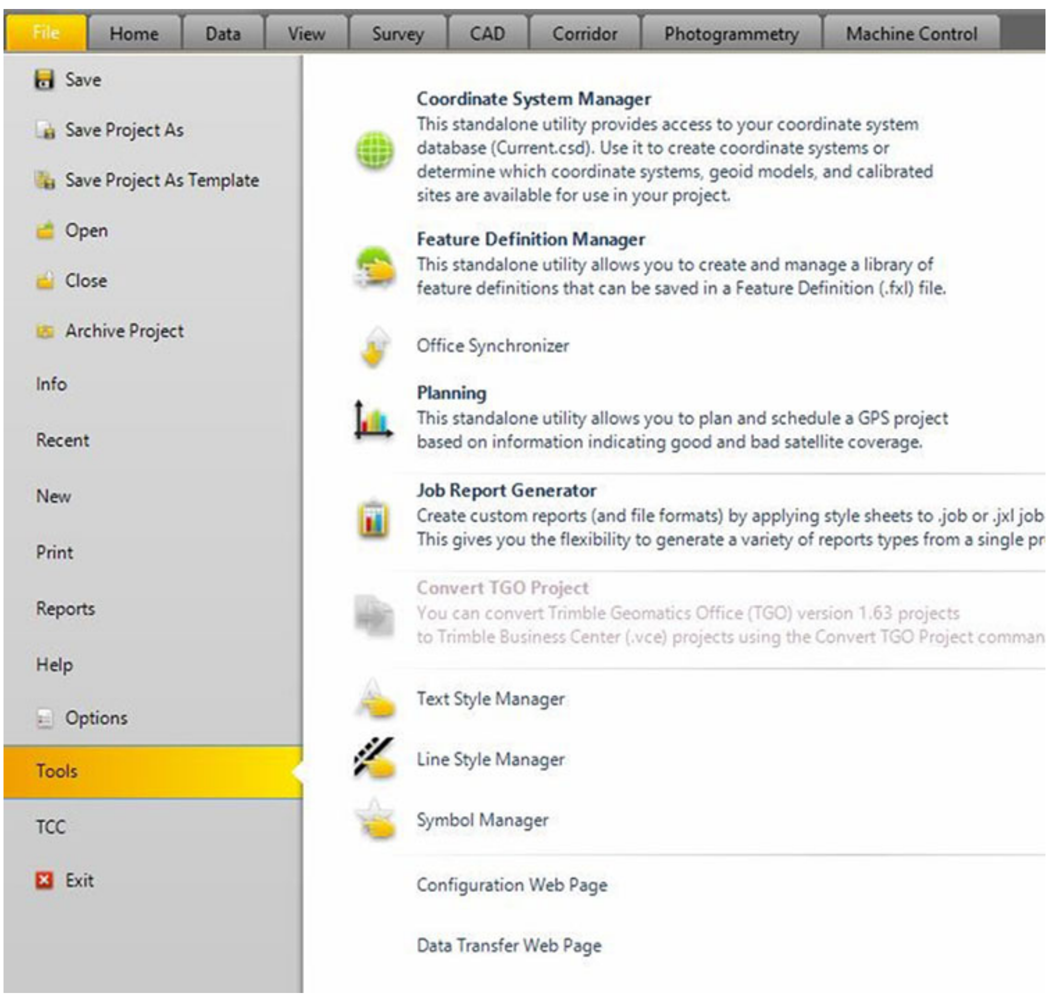

Figure 1–11. Feature definition manager.

Once we select the feature definition manager tool and select new file, we see the window shown in figure 1–12. This window is broken into three parts. The table of contents (TOC) is on the left and shows our categories and groups of feature code definitions. The bottom is the display field, showing what our points will look like during post-processing. Finally, the central area is where we will be doing most of our work.

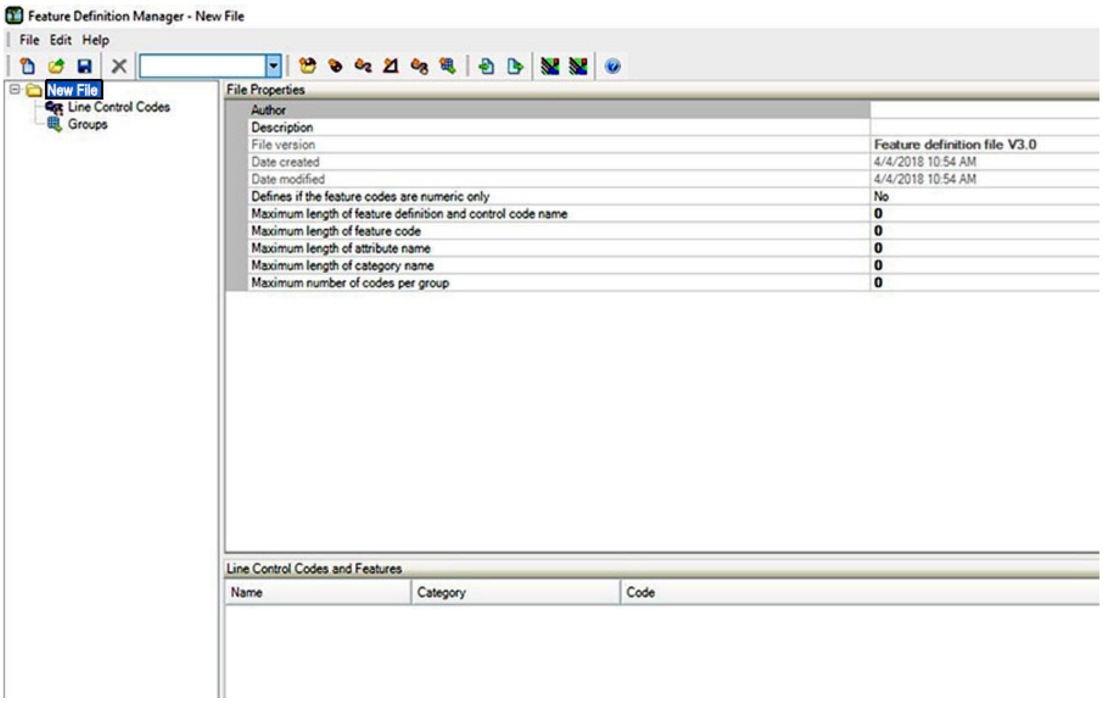

Figure 1–12. New file layout.

Now that we have become familiar with the rudiments of our working environment, let us go over the feature definition types available to us.

Feature definition types

When we right click on the ToC, and hover over the word "New," we see the components we can add to our feature code library (fig. 1–13). Each of these has different settings and different ways they will behave. There are also components that are just for organizing the codes for easy access. The types are category, point, line, polygon, line control, and group.

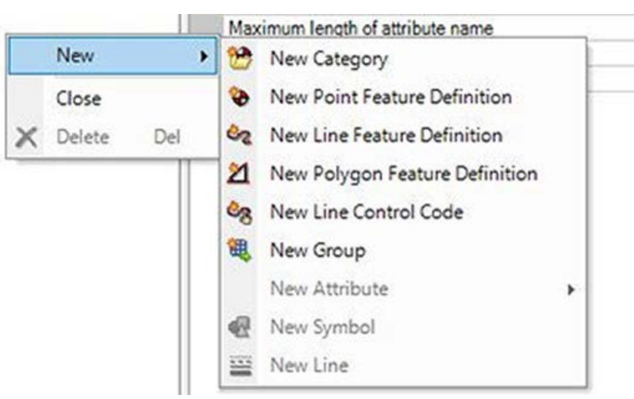

Figure 1–13. New file layout.

Categories

Categories are folders for different groups of codes. They are useful for quickly identifying and exporting point codes that have to do with particular types of surveys or specific feature groups. An example of this could be a parking lot codes category. Parking lots have common features such as drains, curbs, edge of pavement, and so forth. Another example would be a topography category for civil designs. A topography category could include topo points, tree points, fence lines, or even large rock or tree stump points and/or polygons.

Point feature definition

Point features have six settings (fig. 1–14). The first is by name, or what we are surveying, such as a tree, a manhole, and so forth. The second is the code, which is the shorthand for the point name that the control will use, such as “mh” for manhole, or “eop” for edge of pavement. The category option allows you to select, in a dropdown, a pre-defined category in which to place point features. The layer and color fields are both for computer-aided drafting (CAD) program displays. The layer option is to define which layer the point data displays on, and the color defines which color the points will be. Finally, the “Include in Surface” checkbox is last. This option allows you to choose whether the data of this point feature definition will be part of any surface used to develop contours or triangulated irregular networks (TIN).

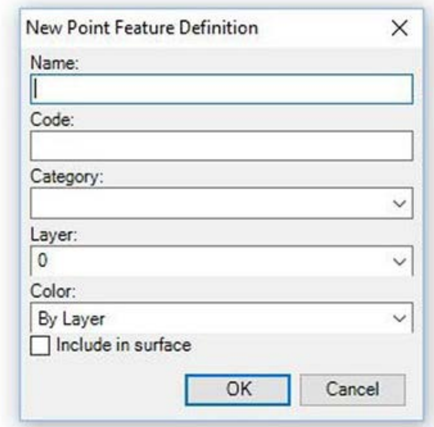

Figure 1–14. New point feature definition window.

Line feature definition

The settings found in the line feature definition window are similar to the point feature definition window. They both have name, code, category, layer, color, and “Include in Surface” settings. The line feature definition has three addition settings, line style, line style scale, and field line style (fig. 1–15). The line style is a dropdown list to choose whether the line is solid or dashed. The line style scale setting allows you to determine the frequency of dashes. An example is a regular dashed line that has a scale of one dash per inch or a scale of five dashes per inch. The last setting, field line style, sets the line display style to dashed or solid and applies to the survey controller display only.

Polygon feature definition

There are three differences between the line feature definition and the polygon feature definition: the fill color, transparency, and the borderline settings (fig. 1–16). The borderline settings are similar to the line style settings but they only apply to the boundary running around a defined polygon. The fill color is obvious and is the same as the line and point color settings. The transparency setting is the biggest difference between polygon feature definitions and other feature definitions. The transparency setting adjusts how clearly you can “see through” the fill color in the polygon, by percentage.

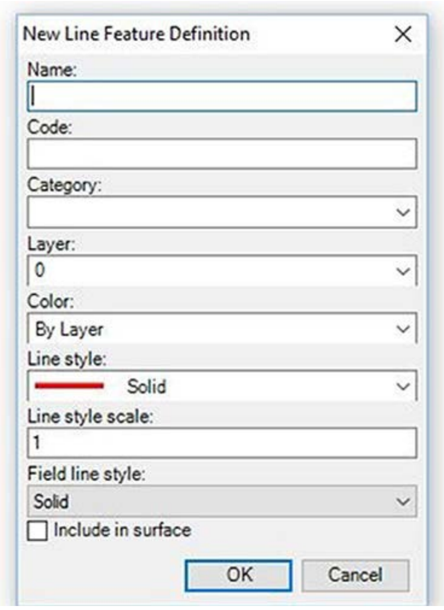

Figure 1–15. New line feature definition window.

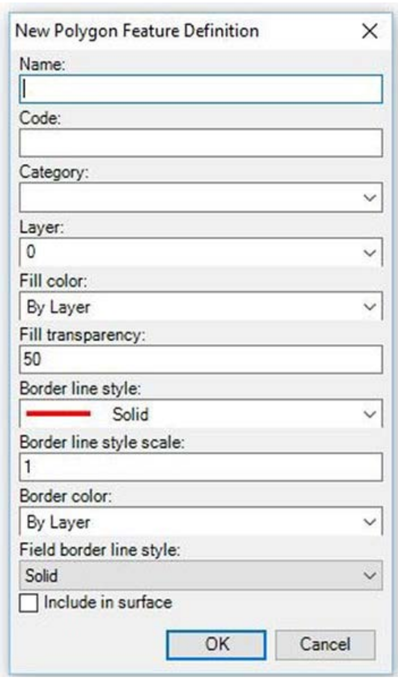

Figure 1–16. New line feature definition window.

Line control codes

Line control codes assign behavior to line features. For example, we can assign a code to a line feature that tells the line to start, and assign a different code to tell that line when to end. When we bring the data back into the post-processing software, it will draw the data using the behaviors assigned by the line control codes.

In the new line control code window, there are four fields: name, code, selected action, and all actions. The name field allows you to type a name for the control code. The code field provides a place to type the code that the surveyor will use to apply the behavior to a sequence of feature codes. The selected action field will explain the behavior of the line control code selected from the all actions list (fig. 1–17).

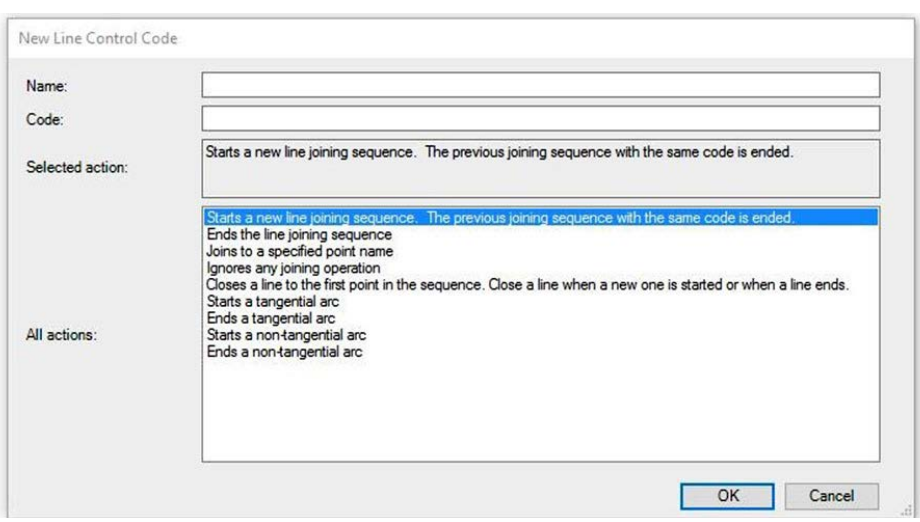

Figure 1–17. New line control code window.

The most useful codes are starts line, ends line, starts non-tangential arc, and ends non-tangential arc.

Starts line and ends line

The starts and ends line codes are simple but have some particular behaviors. The ends line code, for example, will end the line for that sequence of feature code types and prevent a line from drawing between the last and next code with the same feature code. The starts line is different because it will begin a line sequence between the next series of repeating feature codes. The starts line is the same because it ends the previous sequence in order to begin the next.

Starts and ends non-tangential arc

These are non-tangential because they do not require a previous point to define the entry into the curve. The starts non-tangential arc begins a series of at least three points that share the same feature code. The ends non-tangential arc is the final code applied to the final sequence of feature codes. There must be at least one point between the starts and ends non-tangential arc to complete the curve.

Group

Some field devices enable you to group a set of feature definition codes and line control codes so that they correspond with buttons on the device. You can create multiple groups from which surveyors can select the one they need for a particular job.

Feature definition attributes

Before we prepare our library for our survey equipment, we should give our feature codes attributes. Attributes are additional information that describes characteristics about a feature. This information can range from the number assigned to a water valve, to the invert elevation (IE) of a series of drainage pipes. Attribution is a good way to electronically record field notes about particular features. The drawback is we have to know which attribution we need *before* surveying. As part of survey planning, make sure to consider what additional information about the features you need.

To apply an attribute to a feature code, select the feature code from the ToC, then right click in the attribute area, hover over "New Attribute," and select the attribute you need (fig. 1–18).

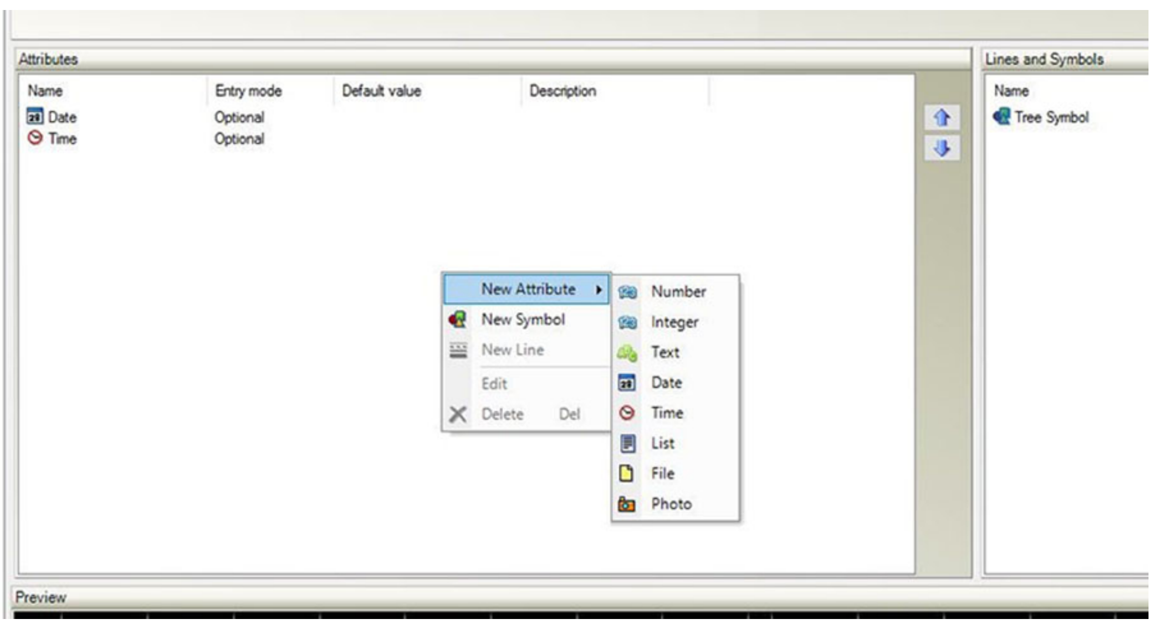

Figure 1–18. New attribute options.

Each of these attributes types differs from the others. Let us briefly examine the options for each type.

Number and integer attributes

Like all the other attribute types, there are sections in the "Number" and "Integer" windows for name, description, and entry mode (fig. 1–19). The name field is the display title the surveyor will see in the equipment controller. The description text box is where you will give a short description to assist the surveyor in understanding the purpose of the attribute. Finally, the entry mode is a dropdown box with three options: "office use only," "optional," and "required." Selecting the "office use only" option prevents attribute field modification except during post-processing. Selecting "optional" disables the requirement to fill the field in order to take the survey measurement. The "required" field applies the opposite; the measurement does not take unless the field is complete.

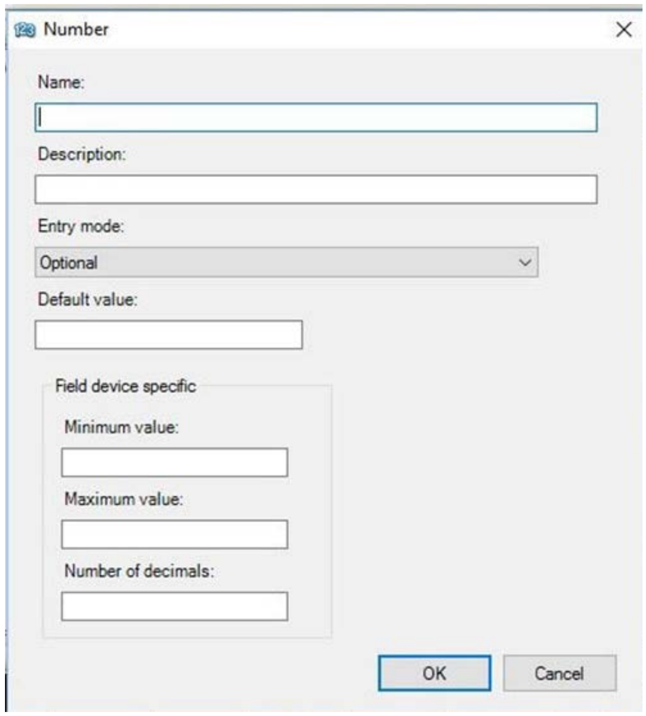

Figure 1–19. Number attribute window.

Specific fields in the number and integer attribute types are default value, minimum value, and maximum value. The default value allows you to set a starting value to the field. Minimum and maximum values set limits on how high or low values can be set. An example of how this is used could be a tree feature. We could define the minimum height of a tree to be 6 ft.—anything less as a bush, or sapling. Leave the maximum height blank when we have no way to know the height of the tallest tree. Our default value could then be set to the average expected height for expedience or set to zero if we have no way of knowing.

The number and integer fields differ in two ways. Integer attribute types do not have decimal values and must be an integer, which means that the second difference is that the integer window will not have a "number of decimals" field.

Text attribute

The text attribute allows you to include text with the feature code. The text value can begin with a default value defined in the field of the same name or left blank. The number of characters this attribute holds can be limited by assigning a value in the "maximum length" field (fig. 1–20). If we continue with our tree example, this attribute defines the type of tree, such as birch, maple, oak, and so forth.

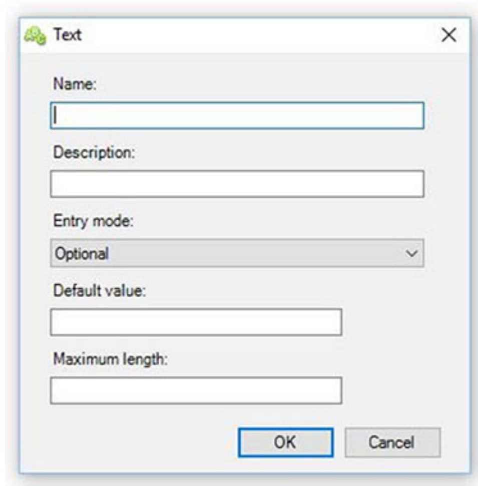

Figure 1–20. Number attribute window.

Date and time attributes

The date attribute has one extra field aside from name, description, and entry mode. The extra field is the format field that allows you to customize the arrangement of the day, month, and year (fig. 1–21). The time attribute is the same with one exception—the format options are limited to hour, minute, and second arrangements. Again, in our tree example, we could use this attribute type to record the planting date of the tree and/or the time we surveyed the tree.

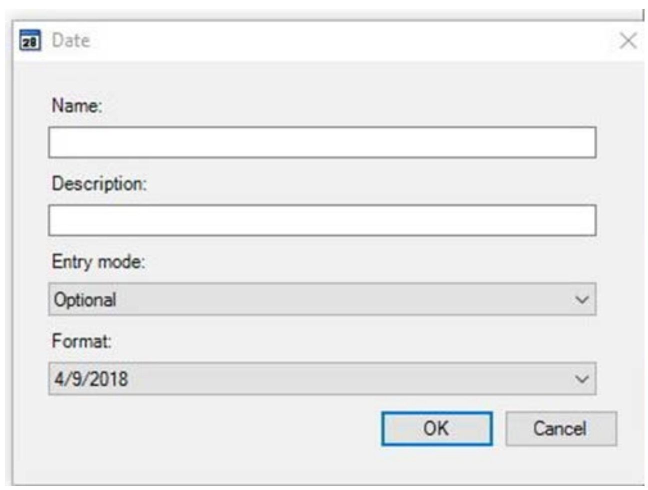

Figure 1–21. Date attribute window.

List attribute

The list attribute adds a dropdown list of specific options to the feature code (fig. 1–22). Using our tree example, again, instead of leaving a text attribute for the surveyor to fill, if we know what types of trees are in the survey area, we can add those to the list attribute. Using the list over text can minimize human error in the field but limit the flexibility of the surveyor.

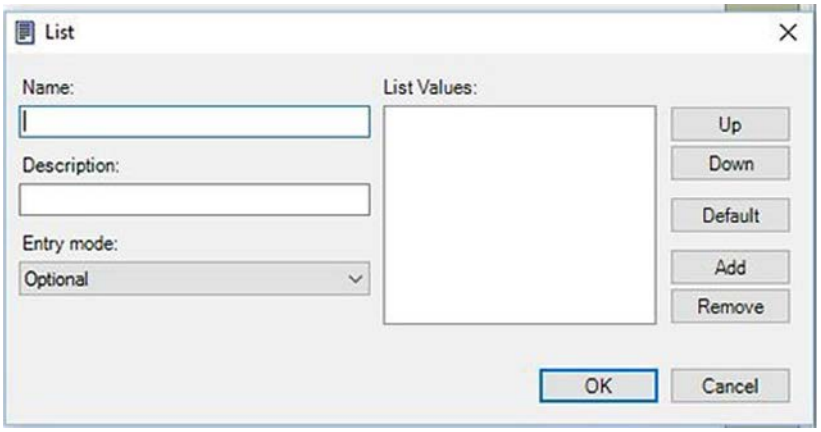

Figure 1–22. List attribute window.

File and photo attributes

The final attributes are "File" and "Photo." Each of these attributes allows the surveyor to attach the name of a file or photo to the survey measurement (fig. 1–23). For example, during a crash survey we work closely with public affairs, they take the pictures, and we survey the objects. In order to ensure that each point and picture reference one another, we can add an attribute to the points with the name of the corresponding photograph.

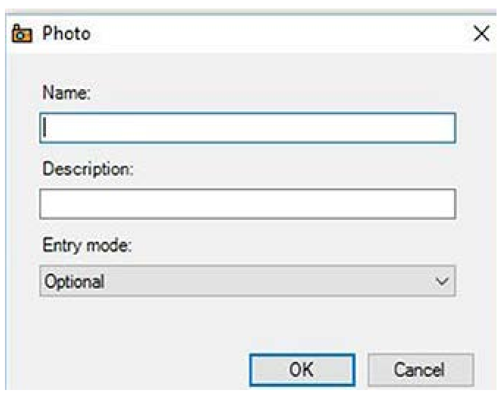

Figure 1–23. Photo attribute window.

Feature code symbols

The last thing we should add to our feature codes are their symbols. When we right click on the attributes or symbols portion of our feature codes, below the "New Attributes" option, is the "New Symbol" option. If we select it, the "New Symbol" window will open (fig. 1–24). Here we can give our symbol a name and description, and define the symbol, color, and the placement size and scaling rules.

The placement and scaling rules can be either input as fixed values or based on an attribute. This can be helpful when, for example, surveying water valves. A helpful attribute could be the direction in azimuth or bearing (requiring a number attribute type) that will place our symbol at the same direction, thereby assisting us in drawing water lines. Scaling, on the other hand, could use the attribute for the radius of tree branches from the trunk, which would draw the symbol at different sizes based on the value. The dimensioning choices (either ground or sheet at the bottom) offer the choice of type of units, either real-world units or relative units on paper, based upon the scale. Finally, the "Edit Preferences" button opens a window where you can change the unit type to meters, survey feet (sft), and so forth.

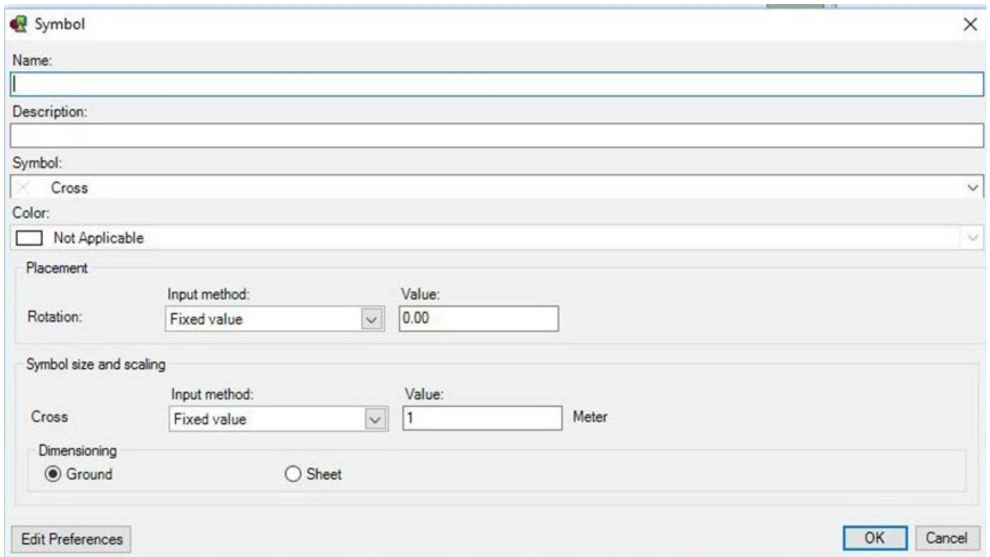

Figure 1–24. New symbol window.

The last thing to note about symbols is in the symbol dropdown field. There is an import option in the dropdown that will open the Symbol Manager. The Symbol Manager allows you to customize which symbols to include in the feature definition library. The ellipsis (…) next to the file path field will open a file navigation window and allow you to select a ".sym" file format. A ".sym", or symbol library, adds symbols to the program and can be obtained, or created, in some CAD software (fig. 1–25).

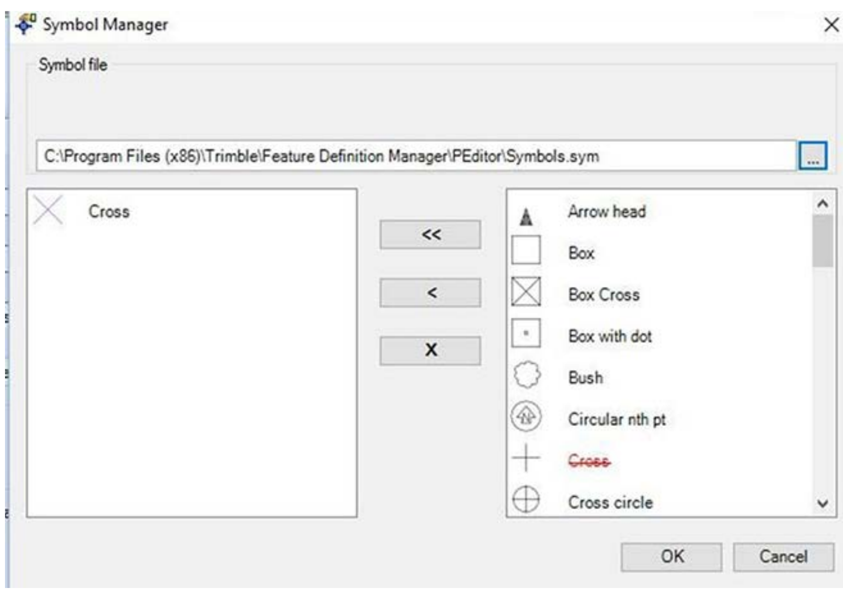

Figure 1–25. Symbol manager window.

Export feature definitions

Export feature code libraries by selecting "Export" from the "File" menu (fig. 1–26). There are four export file types for feature code libraries—simple text, Nikon code list, data dictionary file, and feature/attribute library. The file type you choose will depend upon the type of equipment that you are using. The simple text file type is probably the most useful. Simple text is in a ".csv" file format, meaning that it is a comma-delimited table. Most survey controllers will have an import function that will allow you to use the simple text file type. The second most useful file type is the data dictionary file, used by older controllers. Keep that in mind if you find yourself using older equipment.

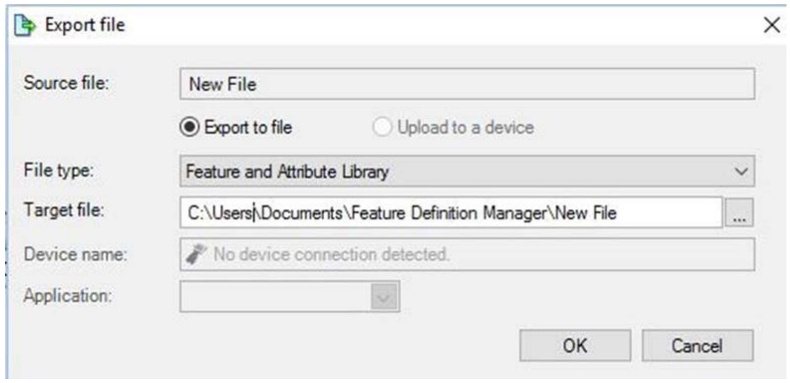

Figure 1–26. Export window.

005. Performing instrument function checks

One of the first things we learned in the military was that we inspect all equipment immediately after issue. Survey equipment is no different from a helmet or rifle and needs regular inspection. The auto-level, in particular, requires regular calibration. In order to know if the auto-level is functioning properly, we perform a *2-peg*, or *collimation check*. The 2-peg test will give you the degree of error in the auto-level. Use the collimation check when you need to recalibrate the horizontal angle (HA) and vertical angle (VA) compensator in a total station.

Auto-level 2-peg test

The basic idea is to take two pairs of measurements, each of the same stakes, then subtract the measurements of each stake from one another, removing the values, and then subtract these differences from one another to find the error.

Equipment

To perform a 2-peg test, we need a graduated rod, two stakes, a hammer to drive them, and of course, the auto-level and tripod. Two people perform this test—an instrument person and an RP.

Procedure

The procedure/process for the 2-peg test will require two positions for instrument setup. During the first, we place the instrument between two stakes placed 100 ft. on opposite sides of the instrument (fig. 1–27). The second setup occurs on the outside of the stakes facing toward them (fig. 1–28). The RP will place the rod on top of the stakes and the instrument person takes readings. The procedure is as follows:

1. After setup, take a reading from the graduated rod on top of the stake at point A.
    a. Our reading is 4.23.
2. Turn, and repeat step one over point B.
    a. Our reading is 4.26.
3. Record the results in a table as follows:

	Stake A	Stake B
Position 1	4.23	4.26
Position 2		

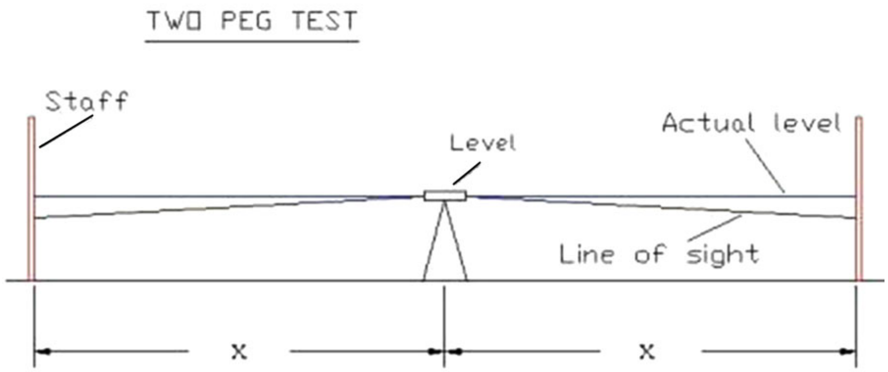

Figure 1–27. 2-peg setup #1.

4. Setup outside the stakes, to one side.
5. Take a reading from the graduated rod on top of the stake at point A.
    a. Our reading is 3.99.
6. Take a reading from the graduated rod on top of the stake at point B.
    a. Our reading is 4.01.

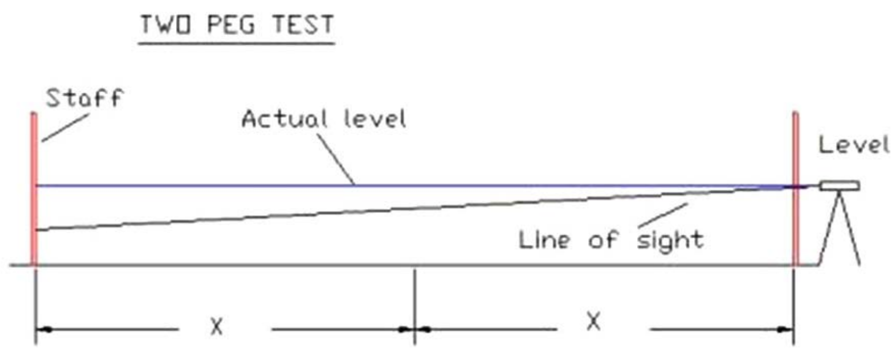

Figure 1–28. 2-peg setup #2.

7. Record the results in a table as follows:

	Stake A	**Stake B**
Position 1	4.23	4.26
Position 2	3.99	4.01

8. Add the readings for both stakes.

    a. Stake A = 4.23 - 3.99 = 0.24 ft.

    b. Stake B = 4.26 - 4.01 = 0.25 ft.

9. Subtract the results to evaluate the collimation (line-of-sight) error.

    a. 0.24 - 0.25 = -.01 ft.

The result is less than .08 ft. (or 1 inch), meaning it is within tolerance. Had the result been .08 ft. or greater, you would have had to consider getting the instrument recalibrated.

Total station collimation check

Check and adjust manual total stations periodically. Adjustments fix angle measurement errors caused by the total station. This involves setting a baseline at a target 100 meters away and turning 180º multiple times to read any error in measurement. Modern electronic total stations have a microprocessor that accomplishes the collimation adjustment for us. In order for the microprocessor to compensate for the error, use the collimation test to adjust the microprocessor periodically. The process to adjust the compensation values is dependent upon the survey controller software, not the instrument itself. Generally, though, the procedure is as follows:

1. Set up the instrument as meticulously as possible. The idea is to reduce the human error to almost zero.
2. Set up a target 100 meters away from the instrument at roughly the same height.
3. In the controller software at the main menu, select Instrument, then Adjust, then HA/VA collimation, then select Next in the bottom right corner.
4. Site in the target you set 100 meters away.
5. Press the measure button until the value on the screen reads “10.”
6. Toward the bottom left of the screen, press the “Change Face” button.
7. Press the measure button until the second value on the screen reads “10,” like the first.
8. The controller will display the result and it will be stored for future use by the microprocessor.

006. Calculate allowable misclosure

The Federal Geodetic Control Subcommittee (FGCS), which nationally standardizes some survey procedures, created an equation to determine the allowable error for a given survey. That equation is:

$$C = m * \sqrt{K}$$

Where C is the allowable closure, in millimeters (mm), m is a predetermined constant, and K is the length of the survey in kilometers. While tape or stadia measure K and C is the final product of the equation, m is a little more complicated. We select m based upon the desired order of accuracy. The orders of accuracy, determined by the FGCS, are as follows:

First Order, Class I	mm = 4
First Order, Class II	mm = 5
Second Order, Class I	mm = 6
Second Order, Class II	mm = 8
Third Order	mm = 12

Let us look at a few examples of how this works. Our misclosure is 0.08 and the length of our survey is 5 kilometers. The order of accuracy we need, as determined by the engineer, is First Order, Class I. The math works this way:

$$C = 4 * \sqrt{5}$$

$$C = 8.944 \text{ mm}$$

This is our allowable closure. Unfortunately, it is not yet a helpful number. We completed our survey using ft. but the allowable closure is in mm. We need to convert 8.944 from mm to ft.:

$$\text{mm} * 0.0032808 = \text{ft.}$$

$$8.944 * 0.0032808 = 0.0293$$

0.08 is more than 0.0293. This means that our survey does not meet the First Order, Class I category requirements. In fact, when we run through each of the categories, our survey is a Third Order survey.

The best way to read this is, "A five kilometer long, First Order, Class I survey must have a misclosure less than 0.0293 ft."

Let us take our same survey but increase the length. Our misclosure is still 0.08 but our length is now 40 kilometers. The accuracy requirement is still First Order, Class I. Let us look through the math now:

$$C = 4 * \sqrt{40}$$

$$C = 25.30 \text{ mm}$$

Then converted from mm to ft. we get:

$$\text{mm} * 0.0032808 = \text{ft.}$$

$$25.30 * 0.0032808 = 0.083$$

Our survey misclosure of 0.08 is less than the allowable misclosure of 0.083. Another way to read this is, "A forty kilometer, First Order, Class I survey must have a misclosure less than 0.083 ft."

By now, you have a clearer idea of the basic skills and concepts you need. You understand the world coordinate systems are broken into smaller, local coordinate grids and that within these grids we measure angles and distance to define grid coordinates. Next, you learned that recording this information, in whatever format, is just as important as the calculations themselves because we share our information with others. Finally, you were given an understanding of feature code libraries to make your surveys more efficient, the 2-peg and collimation test to ensure your surveys are accurate, and the allowable misclosure giving you a standard to evaluate the quality of your work.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

004. Using feature code libraries

1. When we post-process the data, what do the line control codes do?

2. What are attributes and how can they add to a survey?

005. Performing instrument function checks

1. What is the basic idea behind the 2-peg test?

2. Which part of the total station does the collimation test adjust?

006. Calculate allowable misclosure

1. What committee created the equation for calculating allowable error for survey; what is the equation?

2. What are the orders of accuracy determined by the FGCS?

Answers to Self-Test Questions

001

1. Another way to say datum, it is a common reference surface.
2. On the prime meridian off the west coast of Africa in the Gulf of Guinea.
3. By projecting curves onto a two-dimensional surface as straight lines.
4. Determine the quadrant the azimuth is in and subtract by 0 for NE, 90 for SE, 180 for SW, or 270 for NW.

002

1. Slope in the terrain.
2. Subtract the upper stadia line reading from the lower stadia line reading.
3. $180^{\circ} + 33^{\circ} = 213^{\circ}$.
4. Add when easterly, subtract when westerly.
5. An azimuth is a direction in degrees from north while a turned angle is the number of degrees turned from any azimuth.

003

1. Station name, date, instrument person, recorder, instrument used, and pertinent weather conditions.
2. A substitute page.

004

1. They draw the data using the behaviors assigned by the line control codes.
2. Additional information about the feature, they describe the characteristics of a feature.

005

1. Take two pairs of measurements, each of the same stakes, then subtract the measurements of each stake from one another, removing the values, and then subtract these differences from one another to find the error.
2. The microprocessor that compensates for error, or the compensator.

006

1. FGCS; $C=m * \sqrt{K}$.
2. First Order Class I, First Order Class II, Second Order Class I, Second Order Class II, Third Order.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

1. (001) Which reference ellipsoid surface do we use in the Air Force?
   a. Geographic Coordinate System (GCS).
   b. Universal Transverse Mercator (UTM).
   c. North American Datum 1983 (NAD83).
   d. World Geodetic System 1984 (WGS84).

2. (001) To represent the ellipsoid in two dimensions, we use a projection called
   a. Geographic Coordinate System (GCS).
   b. Universal Transverse Mercator (UTM).
   c. North American Datum 1983 (NAD83).
   d. World Geodetic System 1984 (WGS84).

3. (001) What do we call a projection that preserves angles, as opposed to shape, area, or distance?
   a. Reference.
   b. Azimuthal.
   c. Conformal.
   d. Cylindrical.

4. (001) A bearing of "South 60 degrees East" translates to an azimuth of
   a. 60.
   b. 90.
   c. 120.
   d. 180.

5. (002) What ratio is the *most common* stadia interval in the United States?
   a. 1:100.
   b. 1:200.
   c. 1:333.
   d. 1:500.

6. (002) What is parallel to lines of longitude from the Earth's rotational axis?
   a. Zenith.
   b. Bearing.
   c. Grid north.
   d. Magnetic north.

7. (002) When correcting magnetic north to grid north, what do we do with an easterly declination?
   a. Divide by longitude.
   b. Add to magnetic north.
   c. Multiply by grid north.
   d. Subtract from magnetic north.

8. (002) With a starting azimuth of 48º and after turning counterclockwise 102º, what measurement is our new azimuth?
   a. 54º.
   b. –54º.
   c. 160º.
   d. 306º.

9. (003) Because someone unfamiliar with surveying may use your field notes, the field notes must be
   a. clear and detailed.
   b. general and in English.
   c. specific and in active voice.
   d. locked in a box and protected from tampering.

10. (003) Since field notes are legal documents and we do not erase anything, how do we mark corrections?
    a. Line through error, note change above the line.
    b. Scratch out error, note change on separate page.
    c. Line through error, note change on separate page.
    d. Tear out page, start the survey over and begin a new page.

11. (004) Where in our post-processing software can we find the feature definition manager?
    a. Edit menu, under Tools, top of the list.
    b. File menu, under Tools, second on the list.
    c. File menu, under Options, last item on list.
    d. Survey menu, under Features, bottom of the list.

12. (004) What six feature definition types are in the feature code libraries?
    a. Point, line, polygon, group, array, and integer.
    b. Integer, decimal, character, string, array, and photo.
    c. Category, point, line, polygon, line control, and group.
    d. Category, point, line, polygon, polygon control, and group.

13. (004) What feature code library command starts a line at a point?
    a. Begin Line.
    b. Starts Line.
    c. First Point.
    d. Activate Line.

14. (004) What do we call additional information we want to collect and assign to feature codes?
    a. Features.
    b. Attributes.
    c. Descriptions.
    d. Characteristics.

15. (004) What are the four file types for feature code libraries?
    a. Shapefile, database, .job file, and Nikon code list.
    b. Simple text, comma delimited, image, and CAD drawing.
    c. HTML file, XML file, data dictionary file, and simple text.
    d. Simple text, Nikon code list, data dictionary file, and feature/attribute library.

16. (005) At what decimal feet must the 2-peg test results be before the instrument needs calibration?
    a. .08.
    b. .18.
    c. .25.
    d. .125.

17. (005) Where in the controller menus can you find the horizontal angle (HA)/vertical angle (VA) collimation test function?
    a. Main menu, then COGO (coordinate geometry), then Adjust.
    b. Main menu, then Survey, then Measure points.
    c. Main menu, then Instrument, then Adjust.
    d. Main menu, then Instrument, then Tests.

18. (006) What equation is used to convert millimeters (mm) to feet (ft.)?
    a. mm / 3.2808 = ft.
    b. mm * 3.2808 = ft.
    c. mm / 0.0032808 = ft.
    d. mm * 0.0032808 = ft.

Please read the unit menu for unit 2 and continue ➔

Student Notes

Unit 2. Survey Control

CONTROL IS THE WAY we reference our surveys. When we talk about reference, we mean the connection we make between our measurements and the local grid coordinate system. Surveyors accomplish this by performing a very stringent type of survey to establish either temporary or permanent benchmarks (BM). Backsights (BS), or MONs, are the physical markers used to label a control point. This unit covers the procedures and concepts behind establishing control for your surveys. We begin with the manual method using the auto-level and total station instruments and then end with a section explaining Global Navigation Satellite System (GNSS) surveying methods.

2–1. Establish Control—Manual Method

The manual method of establishing control puts most of the accountability for accuracy on the surveyor. Your skills determine the quality of measurements and calculations that make up a manual survey. Manual survey is concerned about two types of control in separate procedures. The horizontal control, or the x and y coordinates, is accomplished using a type of survey called a traverse. A vertical or elevation survey commonly uses the level-loop method to calculate heights and elevations. This section will cover two methods, but these are not the only two. This will provide you with enough knowledge and skill to branch out into other methods as you develop in your career as a surveyor.

007. Establish geodetic control monuments

Surveying relies on physical reference objects placed in the ground. We place marks on the ground and record their coordinate and elevation information. These marks, or MONs, are normally metal but can also be wood, rebar, or any material (fig. 2–1). MONs mark the points in a geodetic control network. Geodetic control networks are groups of MONs, each with known and specific coordinates. These known MONs provide surveyors with a verified location to begin a survey.

The intent of this lesson is to provide basic information on establishing geodetic control. For comprehensive instructions, see United States Army Corps of Engineers (USACE) Engineer Manual (EM) 1110–1–1005, *Control and Topographic Surveying*.

Figure 2–1. Standard brass survey disk.

Features of a monument

Maps record MON locations and nearby objects to aid in finding MONs in a network. A map showing a MON with distances and directions to surrounding objects is a "tie sheet." Photographs further assist in recovering a MON. Coordinates guide surveyors to the vicinity of the MON. MON labels include the name of the organization that set it and other useful identifying information. Once it is labeled, it is a more visible “witness post.”

A surveyor may or may not have many options when placing a MON. For geodetic control, the location must meet practical concerns about line of sight, spacing between nearby MONs, and ease of access. MONs are either permanent or temporary depending on their purpose.

Permanent markers

Permanent MONs are MONs set in relatively stable material or in a structure. They preserve the coordinates and elevation of the location and are placed with the intent to last more than 2 years.

Temporary markers

Temporary markers last 2 years or less. Temporary markers are usually rebar driven into the ground, copper nail and washer driven into a stake, or a P-K nail driven into asphalt. Many military surveyors establish temporary benchmarks (TBM) by placing a survey medallion or unit coin in concrete.

Selecting a site

Selecting an appropriate site for a MON involves many considerations. The site needs to be accessible, secure, and have good line of sight. Setting a mark involves sound judgment in the areas of security, utility, stability, environment, and safety.

Site Selection Considerations	
Type	**Description**
Security	Any mark is susceptible to damage or destruction through accidents or vandalism. Anticipate any construction in the area, and make sure the mark is well away from travel routes or proposed excavation. Avoid the outside of river bends, which are more likely to suffer erosion during high water periods. Be aware of floodplains and the potential for sediment covering marks.
Utility	Be certain that a mark is accessible. A hard-to-find site it is of little use. Look for nearby, permanent objects to use for reference markers. Look for sites that provide good line of sight to or from the construction area.
Stability	All marks are subject to the effects of geologic and soil activity. Vertical control marks are particularly vulnerable because this activity results in vertical movements much more than horizontal motion. Crests of hills are ideal because they do not have slope instability. In addition, frost heave movement is minimal because of separation from the water table. Vegetation also affects stability. Trees, bushes, and grasses can move or hide a mark. Geological events can disturb a mark. Avoid areas near fault lines, old mines and wells, or with large moving boulders. Man-made structures also tend to move. New facilities will settle, and small buildings can shift due to frost or flooding.
Safety	Permanent marks are usually rods driven several feet into the ground. Make sure there are no utility – especially electrical – lines underneath the mark. Safety considerations also affect later surveyors. Make sure that a surveyor is safe while establishing control. Keep clear of overhead power, high vehicle and aircraft traffic areas, pedestrian sidewalks, and high-powered communications equipment.
Satellite visibility	Good line of sight applies to total station and satellite. A site may meet all the desired criteria but be close to a mountain range that increases DOP.

Site Selection Considerations	
Type	**Description**
	Also, be sure that a site is accessible at all times. Access to a mark when satellite coverage is low will offer far less reliability.

Installing a monument

EM 1110–0–1002, *Survey Markers and Monumentation,* describes several ways to install a MON. The site and the environment will drive which type of MON you will use. Labeled A through G, we categorize different soil types and frost levels. For civil engineer (CE) surveyors, the two most common are types C and G.

Type C

Type C MONs (fig. 2–2) use the standard USACE bronze disk. They are best suited for bedrock or permanent concrete structures. Aluminum models are also available that are less expensive and may apply better for local conditions.

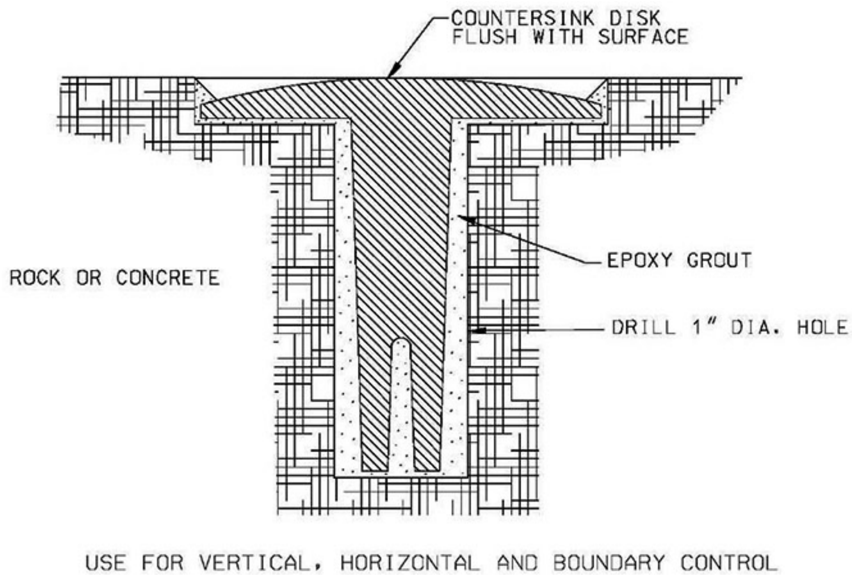

Figure 2–2. Type C monument.

First, stamp the mark designation and year on the disk. Then, make sure the selected spot meets the site selection considerations. Once we choose a location, drill a hole 1-inch wide and 4 inches deep into the concrete or bedrock. Recess the area around the top of the hole to a diameter slightly larger than that of the disk. The top of the disk should be level and flush with the surrounding rock or concrete. Remove all rock dust from the hole.

Second, fill the drilled hole with clean water and then pour in the epoxy or non-shrink grout. Make sure that the area under the disk—its stem and underside—is completely filled with epoxy or grout. Any voids will retain moisture, which could damage the mark during freezing or extreme heat conditions. Also, be sure that the epoxy or grout forms a lip at the edges of the disk. That lip will prevent accidental or intentional prying of the mark.

Type G

Construct the type G mark (fig. 2–3) by excavating a 6-inch-wide, 2-foot-deep hole. In areas where the maximum frost depth is greater than 2 feet, the hole’s depth should be 1 foot below the maximum frost depth. The USACE disk may be driven into a 4-foot by ¾-inch diameter pipe or on a 4-foot by No. 5 reinforcement steel bar (rebar). Drive the pipe or bar assembly into the center of the hole until the disk is slightly above the surface. The use of a pipe or rebar is optional. You may push the disk directly into the fresh concrete. Then, fill the hole with concrete up to the bottom of the disk.

Some metals react badly to one another. Be aware that placing aluminum MONs on steel rebar is not a good idea. Aluminum will corrode when placed in physical contact with some metals, including steel. A plastic insert serves as a barrier to prevent corrosion, and prolongs the life of the MON.

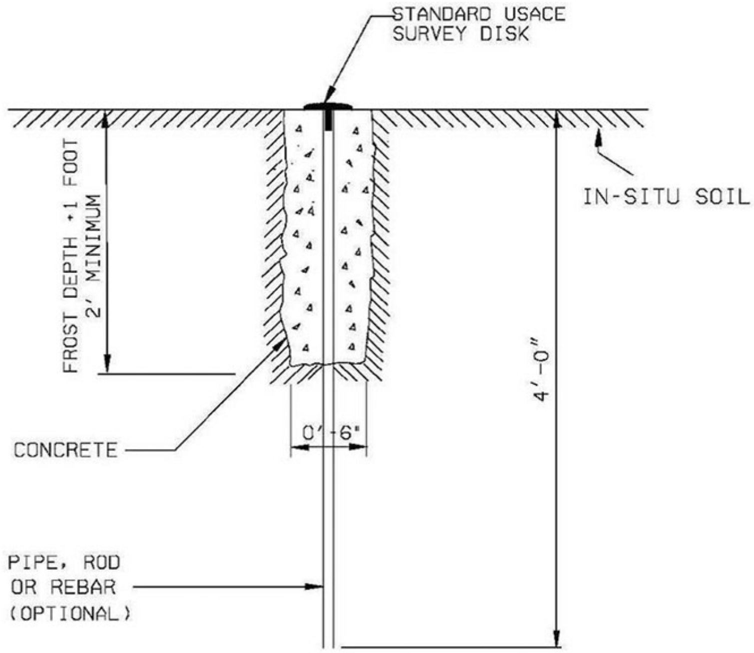

Figure 2–3. Type G monument.

008. Establish horizontal control—manual method

Horizontal control is the process of placing stakes around an area we are surveying and calculating the coordinate values for each stake from a MON or position with known or assumed coordinates. Once horizontal control is established, meaning each stake has coordinate values assigned to it, we can survey any other objects from any of the TBMs we established.

We said we assign coordinates and elevations, but when we say horizontal control, we are only concerned with coordinates. The best way to understand how we accomplish horizontal control is to establish it.

In this lesson, we will run through the procedure for completing a *closed traverse*. A *closed traverse*, as opposed to an *open traverse*, simply means that we will connect our traverse back to our known starting setup position or another known point. The broad parts to the procedure are to establish a baseline, measure distances/angles, calculate the latitude/departure, calculate/apply an adjustment, calculate coordinates, and calculate the traverse precision. After we place our TBMs in the ground around the survey site, we can establish a baseline.

Establish a baseline

A baseline is a reference point from which we can measure angles. The idea is to pick a compass angle that we can say is zero degrees. In survey, we refer to this compass angle as an *azimuth*. The azimuth that we really want is the grid azimuth. To do that, we will use a compass to find the magnetic zero azimuth and magnetic north and add or subtract the declination. We can now configure our instrument to read zero degrees as our azimuth. Zeroing an instrument is equipment dependent, and you may need to refer to the equipment manual. Our site configuration looks like figure 2–4.

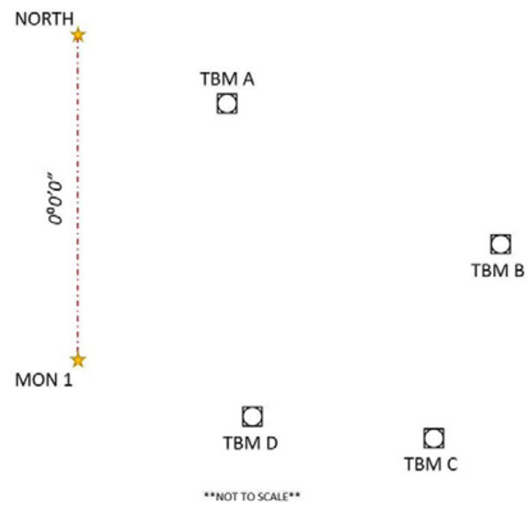

Figure 2–4. Survey site configuration.

Measure distances/angles

We measure distances in many ways, from the least accurate (pace count), to the most accurate (electronic distance measures [EDM]), and anything in between, such as tape measures and stadia. The choice of method for measuring distance depends upon the surveyor and the level of accuracy the survey requires. Angle measurement depends upon the instrument as much as it does the surveyor. The method of angle measurement will be dependent upon the instrument as defined in its user manual.

With our instrument set up over MON1, and a baseline established, we can begin measuring distances and angles. In our example, we will use ft. as the unit of distance, and degrees (^{o}), minutes (’), and seconds (”) for angle units. We will turn our instrument to TBMA and record the azimuth and distance in our field notebook. For TBMA, we have an azimuth (compass direction) of $26^o10'$. Let us convert that angle to decimal degrees, to make the math we have to do later easier. The conversion formula looks like this:

$$X^o + (X'/60) + (X''/3600) = \text{Decimal}^o$$

For our angle, $26^o10'$, we don’t have to worry about X” because we have no seconds, so our formula looks like this:

$$26^o + (10/60) = 26.167^o$$

While we are at it, let us use what we learned about bearings in the previous lessons and record our bearing in our notes. The final entry should look something like figure 2–5.

Traverse Computation Sheet					
Designation:					Date:
Station	Measured Angle	Quadrant	Bearing Angle	Horiz. Distance	
MON1					
		NE	26.167	285.1	
TBMA					

Figure 2–5. TBMA field notes.

At this point in the control survey, we will pick up our instrument and set up over TBMA. After setup, we need a new baseline. Luckily, we already have one. If we turn our instrument and face MON1, we can use the back azimuth of our MON1 azimuth. A back azimuth is the line direction 180º opposite the initial azimuth measurement. For us, that means that 26º10’ turns into 206º10’. Now that we have a baseline, we can turn our instrument and get the azimuth and distance recorded for TBMB, after figuring the decimal degrees and bearing, of course (fig. 2–6).

Traverse Computation Sheet						
Designation:					Computed	Date:
Station	Measured Angle	Quadrant	Bearing Angle	Horiz. Distance	ADJUSTED	
					Length	Direction
MON1						
		NE	26.167	285.1		
TBMA						
		SE	75.417	610.45		
TBMB						

Figure 2–6. TBMA and TBMB field notes.

Now we continue to move from TBM to TBM, recording the azimuth/bearing and distance until we make our final measurement from TBMD back to MON1. This will close our traverse and complete our initial field notes (fig. 2–7).

Traverse Computation Sheet				
Designation:				
Station	Measured Angle	Quadrant	Bearing Angle	Horiz. Distance
MON1				
		NE	26.167	285.1
TBMA				
		SE	75.417	610.45
TBMB				
		SW	15.5	720.48
TBMC				
		NW	1.7	203
TBMD				
		NW	53.1	647.02
MON1				

Figure 2–7. Distance/direction field notes.

The next step is to calculate the difference in position of each of the TBMs from the previous. This means we find out what the difference is in Northing between TBMB and TBMC and what the difference in Easting is between the same.

Latitude and departure

In survey terms, the latitude is the difference in Northing between two BMs, and the departure is the difference in Easting. In order to calculate the latitude and departure we need the bearing angle and the distance between those points, which we have. Let us use the MON1 to TBMA measurements to calculate our first latitude and departure values.

Looking at figure 2–8, we can see that since we used the bearing angle we have created a right triangle.

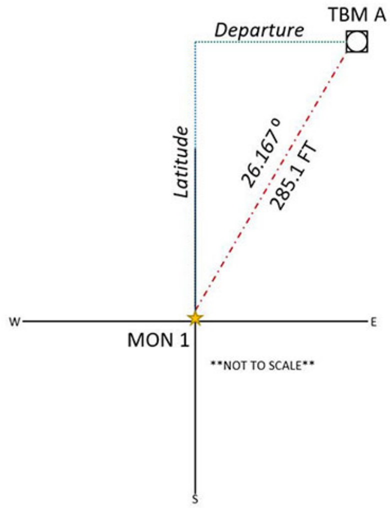

Figure 2–8. Latitude/departure visualization.

Since this is a right triangle, we can use the cosine function to calculate the latitude and the sine function to calculate the departure. For example, the latitude calculation looks like this:

$$\text{Cos } \theta = A/H$$

$$\text{Cos } 26.167 = A/285.1$$

$$A = 255.88$$

In addition, our departure calculation looks like this:

$$\text{Sin } \theta = O/H$$

$$\text{Sin } 26.167 = O/285.1$$

$$O = 125.73$$

Now we can record the latitude and departure in the field notes and repeat for the other BMs. Our field notes should now look similar to figure 2–9. Make a note here; some of these values are negative. The negative value indicates a position to the west or south. Take the latitude value for TBMA to TBMB, which is –153.70. The negative latitude value means that the Northing coordinate will be 153.70 units, in this case ft., south of the current position, in this case from TBMA to TBMB. Negative departure is the same, except it is a movement westward.

Traverse Computation Sheet						
Designation:					Computed By:	
Station	Measured Angle	Quadrant	Bearing Angle	Horiz. Distance	UNADJUSTED	
					Latitude	Departure
MON1						
		NE	26.167	285.1	255.88	125.73
TBMA						
		SE	75.417	610.45	-153.70	590.78
TBMB						
		SW	15.5	720.48	-694.28	-192.54
TBMC						
		NW	1.7	203	202.91	-6.02
TBMD						
		NW	53.1	647.02	388.48	-517.41
MON1						

Figure 2–9. Latitude/departure field notes.

With the latitudes and departures recorded, we can move on to the next step—traverse adjustment.

Traverse adjustment

Our survey is a closed traverse. In a closed traverse, we start and end on the same point. If we start and end on the same point, then the starting and ending coordinates are the same. The same coordinates mean that the total movement from MON1 to MON1 should be zero, because we went away, then we came back. The first thing needed to figure the adjustment for the traverse is how far the latitudes and departures are off. This is the *misclosure*. To find the misclosure, we will add the latitude column together, and then add the departure column together (fig. 2–10).

Traverse Computation Sheet						
Designation:					Computed By:	
Station	Measured Angle	Quadrant	Bearing Angle	Horiz. Distance	UNADJUSTED	
					Latitude	Departure
MON1						
		NE	26.167	285.1	255.88	125.73
TBMA						
		SE	75.417	610.45	-153.70	590.78
TBMB						
		SW	15.5	720.48	-694.28	-192.54
TBMC						
		NW	1.7	203	202.91	-6.02
TBMD						
		NW	53.1	647.02	388.48	-517.41
MON1						
					-0.70	0.54

Figure 2–10. Addition to find the misclosure.

The misclosure is –0.70 for the latitude and 0.54 for the departure. The second bit of information we need is the total length of the traverse. The length is easy enough—just add the horizontal distance column in your field notes to get 2,466.05 ft. Now we have everything we need to compute the adjustment.

The adjustment is the distribution of the misclosure to each latitude or departure. Horizontal distances define the proportion of the total misclosure each latitude or departure will receive. Let us take MON1 to TBMA as an example:

Correction = (Total Misclosure / Traverse Length) * Horizontal Distance

Correction = (–0.70 / 2,466.05) * 285.1

Correction = –0.08

Add our correction of 0.08 to the latitude for MON1 to TBMA we figured earlier. A very easy thing to miss is the positive and negative value. In this example, we have a negative correction so we need to add it to the remove it. Consider the departure for MON1 to TBMA:

Correction = (Total Misclosure / Traverse Length) * Horizontal Distance

Correction = (0.54 / 2,466.05) * 285.1)

Correction = 0.06

Notice that this value is also positive. Note the misclosure value, though, of 0.54. If we are attempting to remove this value from the calculations we have made, then why are we increasing the amount of misclosure? To remove the 0.54, we need to SUBTRACT the same amount from the departures. This means that the correction values for the departure will always be negative. This also means that the latitude values will always be positive because the latitude misclosure is negative. We can verify all of this by adding the correction values in each column, make our field notes look something like figure 2–11.

Traverse Computation Sheet						
Designation:					Computed By:	
Station	Measured Angle	Quadrant	Bearing Angle	Horiz. Distance	UNADJUSTED	
					Latitude	Departure
MON1						
		NE	26.167	285.1	255.88	125.73
TBMA					0.08	-0.06
		SE	75.417	610.45	-153.70	590.78
TBMB					0.17	-0.13
		SW	15.5	720.48	-694.28	-192.54
TBMC					0.20	-0.16
		NW	1.7	203	202.91	-6.02
TBMD					0.06	-0.04
		NW	53.1	647.02	388.48	-517.41
MON1					0.18	-0.14
				TOTALS:		
				2466.05	-0.70	0.54
				CORRECTIONS:		
					0.70	-0.54

Figure 2–11. Misclosure adjustment.

The next thing to do is to create a column in your field notes that has the corrected latitudes and departures. Corrected latitudes and departures are the latitude or departure we calculated earlier added to the adjustment value. With that recorded, we can move on to calculating the actual coordinates for each TBM.

Calculate coordinate values

In order to calculate the coordinate values for each of the TBMs, we need coordinates for MON1. Compute all the other coordinates in series beginning with MON1. Since we only need each of the TBMs to be correct relative to one another, we can put any number we want, but there is no reason we can't use the Northing and Easting from an actual, permanent survey MON. Let us just call MON1s Northing, 10000, and Easting, 10000. Now all we do is add the corrected latitude for TBMA to the Northing for MON1, then for TBMB we add the Northing for TBMA, and so on (fig. 2–12).

ADJUSTED		Northing	Easting
Latitude	Departure		
		10000	10000
255.96	125.66	10255.96	10125.66
-153.53	590.65	10102.44	10716.32
-694.07	-192.70	9408.36	10523.62
202.97	-6.07	9611.33	10517.55
388.67	-517.55	10000.00	10000.00

Figure 2–12. Computing coordinate values.

If we did everything right, then the coordinates for MON1 (10000, 10000) at the top of the notes and the coordinates for MON1 at the bottom of the notes will be the same. From the figure, we can see that they are, so we performed our adjustments correctly and can now check the precision of the traverse as our final step.

Traverse precision

The traverse precision is referring to the known MON, which is MON1. We already know the value difference between the actual coordinates and the ones we measured. The misclosure for the latitude and for the departure calculates the distance from the actual MON to the measured MON (fig. 2–13). To calculate the distance we use the Pythagorean Theorem, like this:

$$a^2 + b^2 = c^2$$

$$(0.54)^2 + (0.70)^2 = c^2$$

$$c = 0.89$$

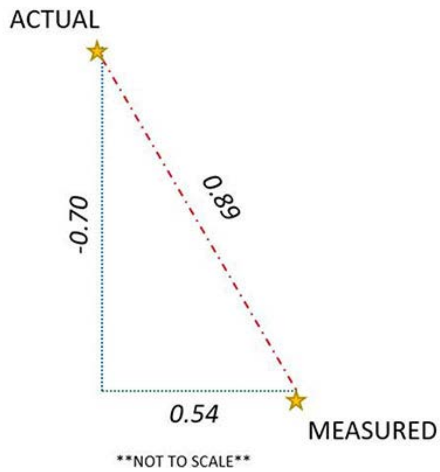

Figure 2–13. Traverse precision visualization (in feet).

Then, we can take the distance between actual and measured, which is 0.89, and divide it by the total traverse length, 2466.05, to get 0.00036090. We then take that value and see how many times it divides one in order to figure the frequency, or precision, of the misclosure. The precision works out to be 1/2771, which reads "1 foot deviation every 2771 feet." The math looks like this:

$$0.89 / 2466.05 = 0.00036090$$

$$1 / 0.00036090 = 2770.8$$

$$\text{Precision} = 1/2771$$

The precision requirement will depend upon the survey's purpose. The purpose will also dictate which equipment and to how many significant figures the survey measures. The precision is a good gauge for the confidence the using agency can have in the quality of the survey.

009. Establish vertical control—manual method

The manual method used to establish vertical control is leveling. Leveling is a survey method that is concerned with elevation values, or height from mean sea level. The basic idea is to take a MON of known elevation and calculate the elevations of a series of *turning points* (TP) until we reach a final point and calculate its elevation. A level loop moves not just from MON to TPs then the final position, but also back along another series of TPs to the initial MON. Level loops are the preferred method of leveling because we can check the quality of the survey. In this lesson, we cover leveling equipment, procedures, math checks, and misclosure. Let us begin with the equipment.

Leveling equipment

We use two pieces of equipment to collect elevation information—the auto-level and a graduated rod (fig. 2–14). The auto-level is a telescope, leveled on a tripod, called “auto” because of an internal pendulum. The internal pendulum maintains a horizontal line of site by compensating when the telescope is up to 10 minutes out of level. In simpler terms, the auto-level’s sight picture is exact level as long as it is roughly level ±10 minutes.

Figure 2–14. Common auto-level.

The graduated rod, usually a Philadelphia rod, is the second piece of equipment. Graduated rods divide into units, meters or ft., and then further divide into fractions of those units, usually tenths. The use of the rod is the most important element here. The best practice is to “wave” the rod toward and away from the instrument. As we wave the rod toward and away from the instrument, the values will read highest. In between the high and low value, as the rod reaches level, it will seem to “rest” on the lowest value; this is the recorded value (fig. 2–15).

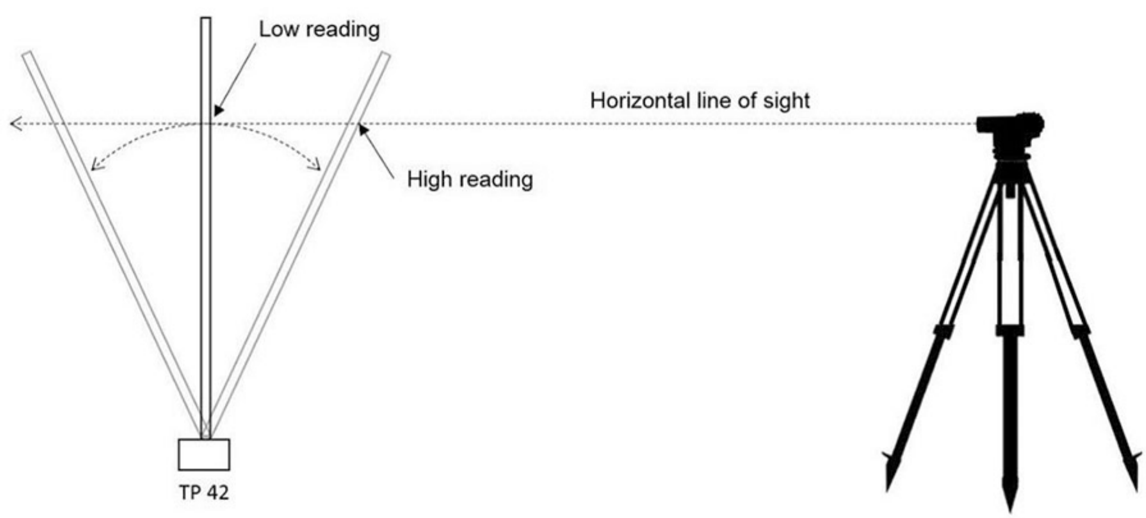

Figure 2–15. Waving the rod.

Level-loop procedure

The level-loop procedure begins with a BM elevation. The elevation can be assumed, chosen by the surveyor, or can be part of data on a geodetic MON.

Step 1 - Initial setup

In our example, we will use a MON with an elevation of 205.23 ft. We make a note of it in our survey field notebook (fig. 2–16).

Station	Backsight (+)	Height of Instrument (HI)	Foresight (-)	Elevation	Distance (feet)	Distance(meters)
BM				205.23		

Figure 2–16. Initial field notes.

We are attempting to get the elevation of a manhole, noted as MH in our field notebook. After placing a series of TP stakes leading up to the manhole, we set up our instrument. The first instrument setup is between the MON and the first TP.

Step 2 - Backsight and height of instrument

Next, we will turn the instrument toward the MON and record the value on the graduated rod. This value is the BS. We then add this value to the initial elevation, which gives us our height of instrument (HI) (fig. 2–17). Our HI works out to 209.65.

Station	Backsight (+)	Height of Instrument (HI)	Foresight (-)	Elevation	Distance (feet)	Distance(meters)
BM	4.42			205.23		
		209.65				

Figure 2–17. BS to HI calculation.

Step 3 - Foresight and turning point elevation

Since we have calculated our telescope's height, which is the elevation plus the distance it is from the ground, we can calculate the elevation at TP1. We turn the instrument to face TP1 and read the rod at that point as 3.61. This tells us that the distance from the telescope's height to the ground at TP1 is 3.61 ft. We refer to this value as the foresight (FS). In order to calculate the elevation at TP1, we take the HI and subtract the FS we just measured giving us an elevation of 206.04 (fig. 2–18).

Station	Backsight (+)	Height of Instrument (HI)	Foresight (-)	Elevation	Distance (feet)	Distance(meters)
BM	4.42			205.23		
		209.65				
TP1			3.61	206.04		

Figure 2–18. HI to elevation calculation.

Step 4 - Repeat

At this point, we need to set up between TP1 and TP2. From our new location, we can take a BS of TP1 and add it to TP1's elevation to get our new position's HI. Then, we turn toward TP2 to collect the FS, subtracting it from the HI to get the elevation at TP2. Remember, add the BS, and subtract the FS. Figure 2–19 shows our calculations for TP1 to TP2.

Station	Backsight (+)	Height of Instrument (HI)	Foresight (-)	Elevation	Distance (feet)	Distance(meters)
BM	4.42			205.23		
		209.65				
TP1	4.56		3.61	206.04		
		210.6				
TP2			2.1	208.5		

Figure 2–19. TP1 to TP2.

Repeat this procedure for each TP until we reach the manhole. After we reach the manhole, we repeat the procedure again using the TPs in reverse order until we return to the MON. Our survey field notebook now looks like figure 2–20.

Station	Backsight (+)	Height of Instrument (HI)	Foresight (-)	Elevation	Distance (feet)	Distance(meters)
BM	4.42			205.23		
		209.65				
TP1	4.56		3.61	206.04		
		210.6				
TP2	2.63		2.1	208.5		
		211.13				
TP3	0.7		1.48	209.65		
		210.35				
MH	3.22		2.42	207.93		
		211.15				
TP3	7.89		3.89	207.26		
		215.15				
TP2	0.54		1.68	213.47		
		214.01				
TP1	4.55		7.85	206.16		
		210.71				
BM			5.56	205.15		

Figure 2–20. Field notebook after data collection.

Math check

Before we do anything else, we should make sure we collected our information correctly. We want to be able to know if we made a mistake when we took our measurements or when we did the addition of the BS or subtraction of the FS. To do this, we are going to compare the difference between our BS/FS numbers and the starting and ending MON elevations. First, we will add the BSs together to get 28.51. Then, we will add our FSs together, getting 28.59. After we subtract we get 0.08. Our starting MON elevation subtracted from our measured MON elevation is also 0.08. This means our math checks out (fig. 2–21).

Math Check			
Sum of BS:	28.51	Sum of FS:	28.59
BS-FS:	0.08	BM-BM:	0.08

Figure 2–21. Math check.

What we have done is compared the changes in elevation we got from the BSs/FSs with the deviation in elevations at the MON. Because our math is correct, the difference between BS/FS and MON elevations is the same. If we had made a mistake adding or subtracting during the survey, the numbers would be different.

The math check, also referred to as a page check, has a secondary function. It provides the misclosure or the error of the survey. The elevation of the initial MON and the measured MON should be the same, but they are not. The 0.08 is the misclosure. Let us look at how to manage misclosure.

Misclosure adjustment

Now that we know the quality of our survey, based upon order of accuracy, we remove the error by distributing it across the survey points. Our first step is to calculate the adjustment per HI value. We do this using:

Adjustment per HI = (Misclosure/N)

(Where N is the number of stations in the survey.)

Our survey has a misclosure of 0.08 and has eight stations. The math looks like this:

Adjustment per HI = (0.08/8)

Adjustment per HI = 0.01

It is not enough to add a –0.01 to each of the HIs. The HI is the sum of the BS and the elevation of the TP. The elevations are the difference between the HI and the FS. This connection means that if we subtract –0.01 from any HI, each HI that follows will lose that same amount. To adjust the survey, we compound the misclosure by multiplying the adjustment by the station number:

Cumulative Adjustment = Misclosure * Station Number

As an example, look at TP2. TP2 is the third HI in the field notes. This means that the adjustment for TP2's HI is 0.03. Another way to look at this is that the HI adjustment for TP2 includes the two adjustments from the BM and from TP1, thus 0.03. For each elevation, we add the adjustment and note it in the field notebook like in figure 2–22.

Station	Backsight (+)	Height of Insturment (HI)	Foresight (-)	Elevation
BM	4.42	0.01		205.23
		209.65		
				206.05
TP1	4.56	0.02	3.61	~~206.04~~
		210.6		
				208.52
TP2	2.63	0.03	2.1	~~208.5~~
		211.13		
				209.68
TP3	0.7	0.04	1.48	~~209.65~~
		210.35		
				207.97
MH	3.22	0.05	2.42	~~207.93~~
		211.15		
				207.31
TP3	7.89	0.06	3.89	~~207.26~~
		215.15		
				213.53
TP2	0.54	0.07	1.68	~~213.47~~
		214.01		
				206.23
TP1	4.55	0.08	7.85	~~206.16~~
		210.71		
				205.23
BM			5.56	~~205.15~~

Figure 2–22. Distributed misclosure adjustment in field notebook.

Notice that the initial elevation at our BM MON and the measured elevation at the end are now the same. This does not remove the error from the survey but is an approximate correction. Now we can take our survey field notes and return to the office where engineers and construction workers can use our data!

010. Establish control—robotic total station

Though understanding manual survey methods is important to understanding survey theory, they are rarely used. These days, a computer inside the instrument performs the majority of the computing. Fortunately, the procedure is similar enough to older methods to make learning relatively quick. Even with the similarities, though, the computer does not think the same as a person and the procedure for establishing control reflects that. This lesson will provide a transition from establishing control using manual methods to using robotic instrumentation using the differences and similarities between the two.

Step 1 - Initial setup

Our survey will begin over a known point and will use an unknown point as the BS to establish a baseline. The biggest thing to be aware of during equipment setup is the place to which we measure the instrument. On the side of the total station is a "+" sign and a "–" sign. The "+" sign is the "true height" of the instrument at the lens. The "–" sign is "bottom of notch" where the instrument's tribrach connector starts. This is important to remember when we enter the instrument height later in the procedure. Now we have three things: a known point, an unknown point to which we set a zero azimuth, and an instrument height. After we set up the instrument, BS prism, create a new job, and perform a quick collimation calibration, we can begin our survey starting with station setup.

Step 2 - Station setup

The first thing we need to do is to perform station setup. This procedure will create a baseline for the first instrument setup. All measurements or functions made from this setup will use this baseline. You can see in figure 2–23 that we have set up our job, "Rounds How To." We have also connected our total station, indicated on the right by the picture of a total station with its height listed next to it. From here, we select the "Measure" icon. Then from the Measure menu, we will select "VX & S Series," or whichever total station type is set up in the controller survey styles, then "Station Setup."

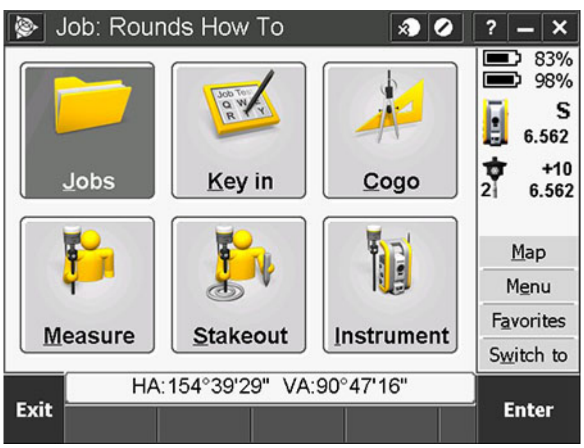

Figure 2–23. General survey main menu.

Corrections

The Corrections screen (fig. 2–24) lists pressure, temperature, parts per million (PPM), and refraction constant. The S-series total stations measure the atmospheric pressure using the instrument's internal sensor. If you are using an earlier model total station, consult the user's manual to see if it requires manual entry. You, the surveyor, enter the temperature manually regardless of instrument model. The instrument, using the pressure and temperature variables, computes the PPM. Finally, the refraction constant is the degree to which the atmosphere affects the EDM in the instrument. The refraction constant for S-series total stations is set either at 0.142 or .2. Unless the temperature is extremely low or the humidity is high, the refraction constant value can remain at 0.142.

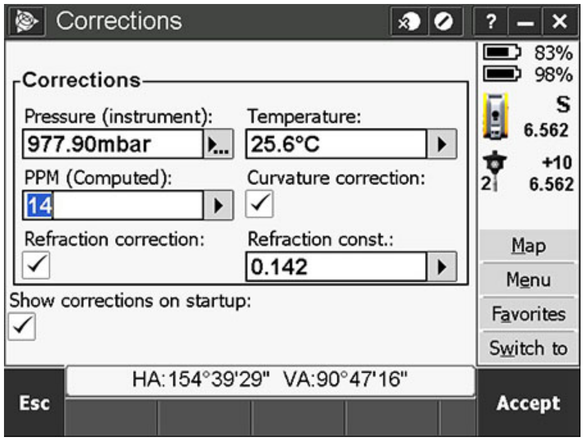

Figure 2–24. Corrections screen.

Instrument point

After finishing any changes to the Corrections screen, we press the "Accept" button in the lower-right corner of the menu. The screen will then change to the instrument point screen (fig. 2–25). Here we set the information about the point the instrument is currently set up on. In our example, we set our point to one, with a code "TBM" for temporary benchmark. The instrument height is set to 5.000 sft. Because we do not have a permanent control point for the area we are surveying, the Northing, Easting, and Elevation are set to assumed, or local, coordinates. In addition, because we are setting up these points to establish control, we have selected the control point checkbox.

Earlier we talked about two places on the instrument that we can measure the HI to, either the true height or bottom of notch. The arrow next to the Height textbox allows you to select from which point the height was measured and which units to use. The point of measurement displays in parentheses next to the Height textbox title.

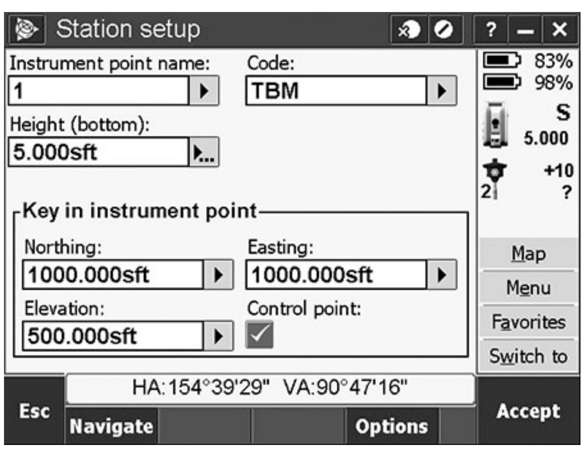

Figure 2–25. Instrument point setup screen.

Backsight point

With the instrument's location defined, we can identify our BS and establish a baseline. Once we click on "Accept" on the Instrument Point screen, the display changes to the backsight point screen (fig. 2–26). In this screen, we define the name of the BS, ours is two, and give it a code, TBM like our instrument point, and give the measured height of the prism we are using. Since our survey uses local coordinates, we need to define a zero azimuth to orient our survey. We key in zero in the Azimuth textbox and select the “Angles and Distance” method of measurement. This describes to the instrument’s computer how to calculate the coordinates for the BS point based upon the given azimuth in the same way the surveyor would when performing a manual survey.

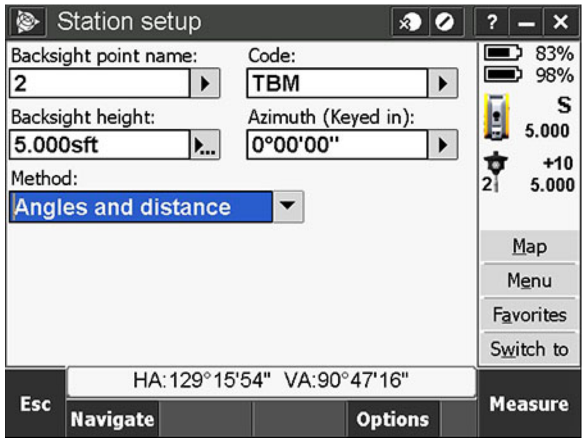

Figure 2–26. Backsight point setup screen.

All that remains is to turn the instrument to the prism setup on our BS and press the “Measure” button in the bottom-right corner.

Station setup results

The survey controller now displays the results of our setup. It gives us the basic information we entered, and the bottom half of the screen displays the calculated angles and slope distance. This provides you, the surveyor, the chance to identify any mistakes you may have made when entering data. This is a common sense check. It also provides you the option of changing the BS height in the event a mistake. In figure 2–27, we can see that the vertical angle is off. It should be 90 degrees even, but we entered the wrong BS height and got different results. When this happens, re-measure the BS and instrument heights and double-check your settings.

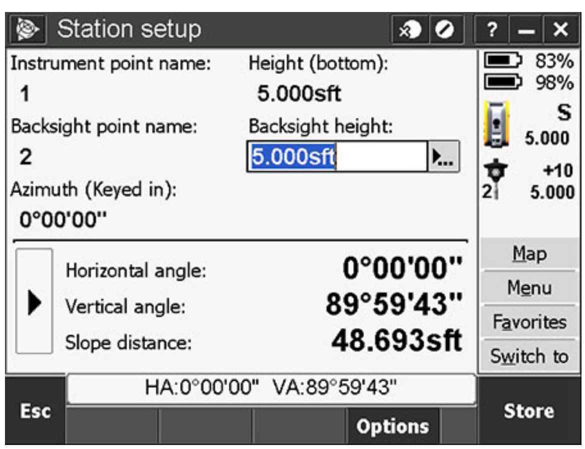

Figure 2–27. Station setup results.

When you are satisfied with the results of the setup, press the “Store” button in the lower right of the screen. This will save the BS as a new point and base further measurements from this setup on the baseline we created.

Step 3 - Measure rounds

Once we store the setup, the survey controller will display the Main Menu again. We select the Measure button, and the controller displays the screen shown in figure 2–28. This is the same Measure menu as before but because the instrument is set up, and ready to measure features, more options are available. Since we are going to establish control, we select the “Measure Rounds” button.

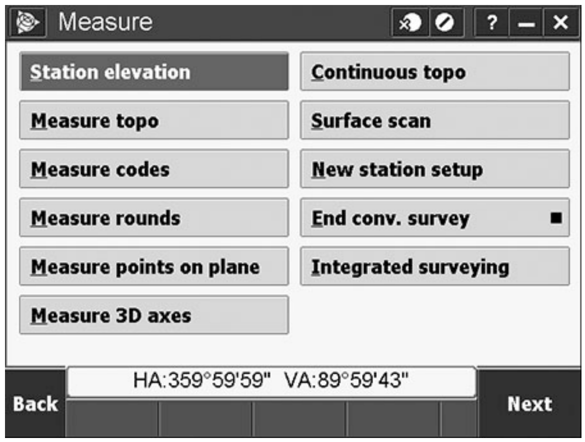

Figure 2–28. Measure screen after station setup.

Rounds - Backsight

Selecting the “Measure Rounds” button displays the “Rounds - Backsight” screen (fig. 2–29). This screen is a review and verification of the BS information. The screen has a few options listed at the bottom—Exclude, Turn, and Options. The Exclude option prevents the instrument from taking new observations during Measure Rounds of the BS. It will use the station setup BS calculation only. This reduces the precision of the survey. The Turn option will turn the instrument, facing it toward the BS prism. This makes it easier to center the crosshairs on the center of the prism.

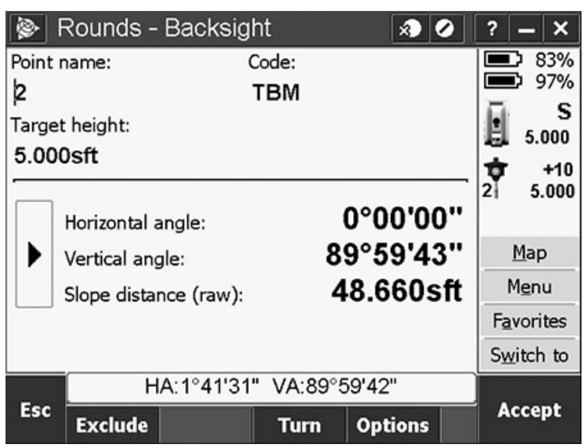

Figure 2–29. Rounds - Backsight screen.

Options

The Options button will display the Options screen (fig. 2–30). Here, we adjust the parameters of the rounds to meet our needs. The first option is Face Order. During measurement, the instrument will measure the FS, Face 1 (F1), then turn the vertical 360 degrees and measure it again, Face 2 (F2). The average of these two measurements will be the stored value. The Face Order defines which face will make measurements first—F1 or F2. For each point, the instrument will measure both faces. The Observation Order sets the point order the measurements are taken in. The Sets per Point option sets the number of times the instrument measures faces. If we have two faces and two sets, the instrument will measure F1, then F2, then F1 again, and F2 again. The Number of Rounds option sets how many times the instrument performs the number of sets on the points. If we set Number of Rounds to two, the instrument will rotate through each of the points, performing the number of sets per point, then repeat, going through each of the points the same way a second time. The Automate Rounds checkbox, if unchecked, waits for the surveyor to measure the point before turning faces or changing points. If the box is checked, the instrument will automatically measure and rotate without the surveyor's input. Turning on Automate Rounds also enables the Monitoring settings. The checkbox marked Skip Obstructed tells the instrument to continue with the round after six seconds if the prism is blocked or unmeasurable. Finally, in the Monitoring section, the "Time between Rounds" textbox allows the surveyor to adjust the amount of time the instrument waits between turning faces. This provides the surveyor time to look through the telescope and verify that the instrument is on target.

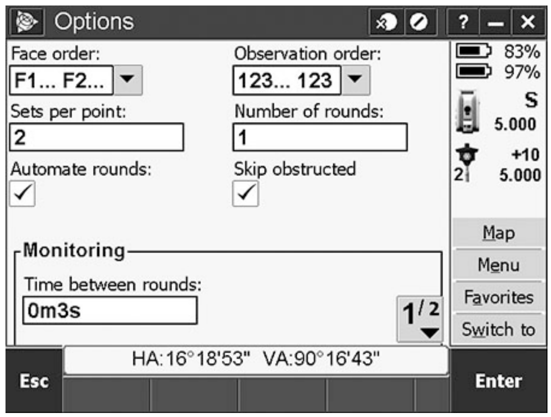

Figure 2–30. Options page one.

On the second page of options are the auto-measure passive targets, averaged observations, and measure distance on F2 options (fig. 2–31). The auto-measure passive targets checkbox sets whether the instrument will measure without surveyor input during measure rounds. If unchecked, the surveyor will manually measure each point after the instrument turns to face it. Averaged observations are the number of measurements the instrument will take and average per face. In our example, the five-observation average from F1 average with the five-observation average of F2. With measure distance on F2 checked, the instrument compares and corrects the distance values between F1 and F2.

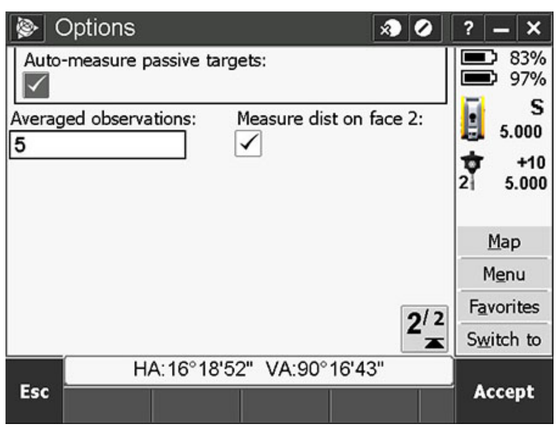

Figure 2–31. Options page two.

Now our options are all set but we have one last thing to do, which is a collimation adjustment. This is important because if the target, when facing, lands off center, then we need to adjust it. The collimation test will reduce or eliminate a lot of this kind of error.

Rounds - foresight

The last thing that we need to do before we can measure rounds is select and measure our FS. In our case, point three is our FS, the third of the control points we are establishing, which we measure from the Foresight screen (fig. 2–32). This screen looks the same as the one for we had during station setup. Once we type in the name, code, method of measurement, and height of our FS, we aim the instrument and press the “Measure” button in the bottom right of the screen.

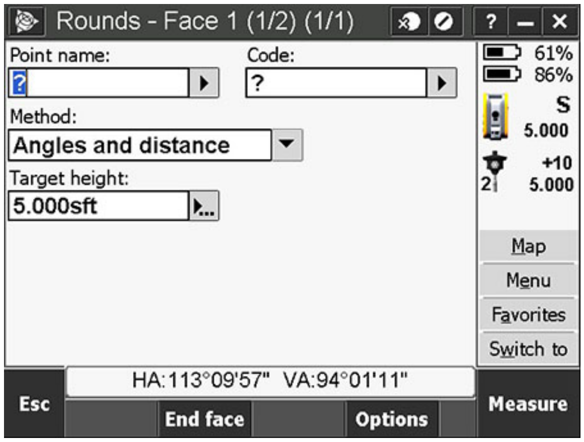

Figure 2–32. Foresight screen.

Rounds - end face

With set up complete, we can now start measuring rounds. To do this, we press the End Face button at the bottom of the screen. Because our settings include Automate Rounds, the instrument will begin measuring each point in the order we specified. After the instrument finishes, it will make a sound indicating that measurement is complete. The controller will then display the results of the rounds (fig. 2–33). This is the Standard Deviations screen. Standard Deviation is how close together each shot was, their shot group. If the group was not close enough, pressing the +Round button at the bottom of the screen will tell the instrument to complete an additional round of measurements and include them in its calculation. The Details button will show specifics on each point’s measurements, while the Options button will bring you to the Options screen. Finally, pressing the Close button saves and exits the function.

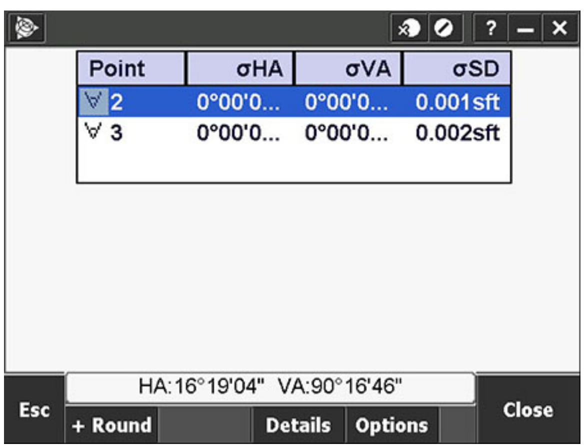

Figure 2–33. Standard deviations screen.

Step 4 - Repeat

The next step is to perform what amounts to a traverse. You must set up on each BM, moving from FS to FS, performing station setup, and measure rounds. Like in a manual traverse, we close on the same point that we started on. Once we have finished moving from station to station, we can perform the traverse calculations.

Step 5 - Traverse coordinate geometry

The coordinate geometry (COGO) button on the main menu is the home of the last function we will use. On the second page of the COGO menu is the Traverse button. After pressing the Traverse button, the screen in figure 2–34 displays. The controller is asking us for a name and starting station for our traverse, so that later we can read the information from the controller. We call ours "airforce" and enter the station we started at, which is 1.

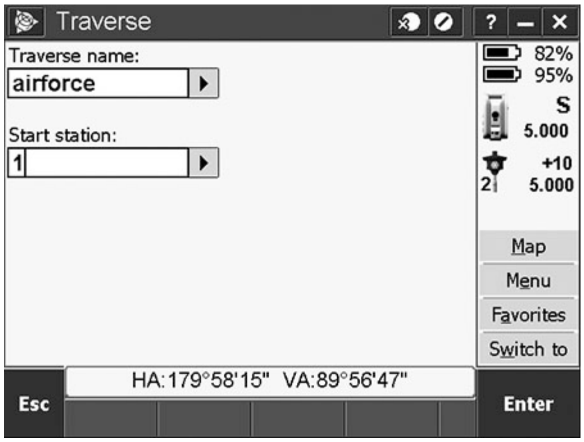

Figure 2–34. Traverse name screen.

The next screen will ask us to orient our survey using the BS of our start station and the FS of our end station. In ours, we started on point one and backsighted to point two. Then, we foresighted from point one to point three (fig. 2–35).

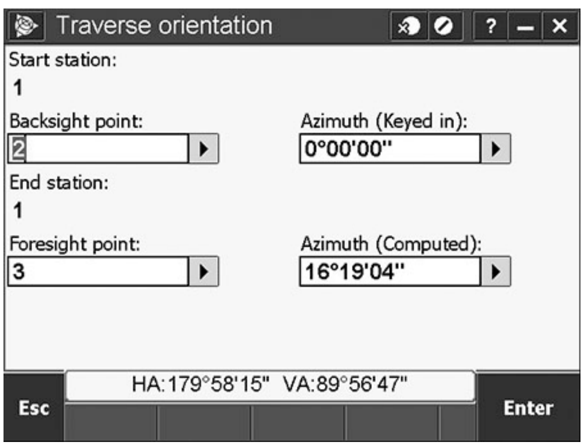

Figure 2–35. Traverse orientation screen.

Once we press Enter, the controller will display a setup screen for our traverse. Here we will use the Add button, in the bottom right, to include the BM points. It is best practice to add each point in the order it was surveyed beginning with the initial instrument point, then the first FS, the next FS, and so on. Our list now resembles figure 2–36.

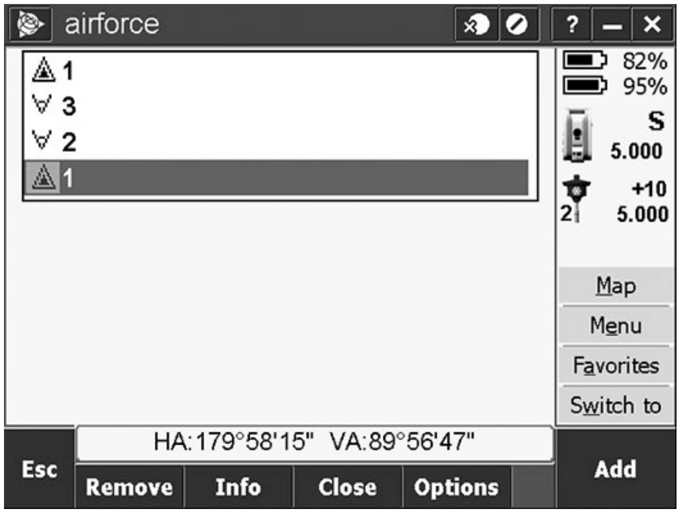

Figure 2–36. Add points screen.

Do you recall the math we did, after collecting the distance and angles during manual survey? What we have just done is given the controller the information, in the correct order, to perform the same calculations. When we select the Close button at the bottom of the screen, the controller will make the same calculations we did during manual survey (fig. 2–37). This will include the accuracies and precisions.

Figure 2–37. Close results screen.

Note how low the Precision ratio is. That is below fourth order accuracy. If you remember, earlier we measured our BS and it had a 12-second error on the vertical. If we had caught that when we set up the baseline, our precisions would be much better. Fortunately, like our traverse computations, the control will adjust these numbers. To do this, press the “Adj. Ang.” button in the bottom-right corner of the screen. This will apply the adjustments and now we have much better numbers (fig. 2–38).

Figure 2–38. Adjusted close results.

When we talked about order of accuracy during manual survey, we also went over Allowable Closure. Robotic survey order of accuracy is the same; the allowable closure is dependent upon the needs of the engineer or survey requestor. The following table displays the orders of accuracy referring to the precision ratio in the traverse results screens:

Order and Class	Ratio
First Order	1:100,000
Second Order, Class I	1:50,000
Second Order, Class II	1:20,000
Third Order, Class I	1:10,000
Third Order, Class II	1:5,000

A ratio lower than 1:5,000 is often referred to as fourth order. The importance of meticulous and careful work cannot be overemphasized. The more detail oriented you can be when performing any survey the better.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

007. Establish geodetic control monuments

1. What are the differences between permanent and temporary markers?

2. What are the two most common types of soil categories for MONs?

008. Establish horizontal control—manual method

1. What is the formula for converting degrees, minutes, and seconds into decimal degrees?

2. What two values do we need to calculate the latitudes and departures?

009. Establish vertical control—manual method

1. Why is it important the RP wave the rod?

2. How do you perform a math check? What do good results look like?

3. How do we distribute the misclosure throughout the survey?

010. Establish control—robotic total station

1. If we set the number of rounds to two and the number of sets to two, how many total sets does the instrument perform?

2. What function does the “+Round” button tell the instrument to perform?

3. What does the “Close” function in the Traverse function do?

4. What are the orders of accuracy and their ratios?

2–2. Establish Control—Global Navigation Satellite System Method

The GNSS uses a network of satellites in orbit around the Earth to measure locations on the surface. The satellites transmit their location and the schedule of future locations in their orbit 24 hours a day. A receiving unit on the ground can then use the time the signal was sent and the time it was received to calculate the distance to the satellite and, therefore, the distance from the satellite to the position on the ground. The schedule allows the receiver to compare observations made during an interval of time to improve the accuracy of the location that it measures. This section will explain the basic operation and set up of the receiver and its software. Your understanding of how to customize the settings to fit specific situations and requirements is the most important thing you can take away from this section.

011. Planning a Global Positioning System survey mission

Unlike the MONs used in optical surveying, the satellites that provide horizontal and vertical control for GPS equipment are always on the move. Knowing where and how to look up the schedule of satellite coverage, commonly referred to as an almanac, and how that coverage affects the quality of control is important. There are many tools used to analyze the almanac, but one of the most dependable is the GNSS planning tool—online.

Global Navigation Satellite System planning tool—online

The GNSS planning tool—online provides a wealth of information about satellites used in GPS survey. This information ranges from the dilution of precision (DOP) and visibility, to which satellite constellations you use, and even the effect the ionosphere has on the satellite signals!

The Website www.trimble.com/gnssplanningonline/ provides a Web-based application that looks like figure 2–39; this is the Settings screen.

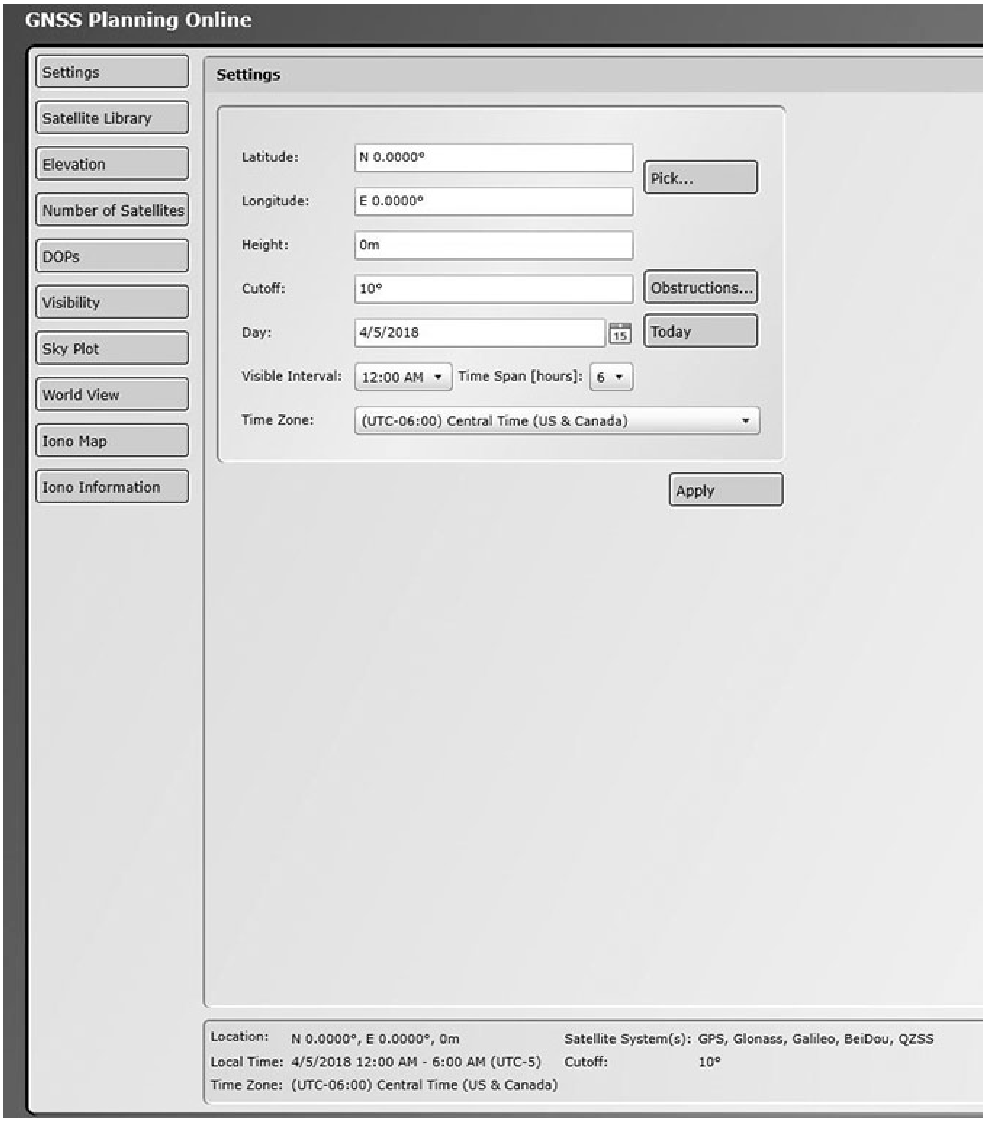

Figure 2–39. GNSS planning tool––online.

The tool has a simple interface broken into three parts. The first is the menu list on the left. Each button corresponds to a different screen. The second is the information area at the bottom of the screen. The information area retains the Settings and other information you have applied to this session. The third, and final, area is the interactive area that takes up the rest of the screen. In the interactive area, you can make adjustments or display information based upon the settings you have applied to the session. Let us go through and set up a planning session.

Set up Global Positioning System plan information

The first two screens in the menu, “Settings” and “Satellite Library,” set up the information that the rest of the Web application will display. In the “Settings” screen, we will set up our time, equipment, and location information. In the “Satellite Library” screen we will adjust which constellations, and which satellites within those constellations, we will use.

Settings screen

The Settings screen has a parameter we can adjust called Day. The two ways we modify this value is by selecting the “Today” radio button, or by entering a custom address. Ours will be set to 5/27/2018. Next, let us adjust the “Visible Interval” parameter. The visible interval dropdown list has every hour of the day, and a time span dropdown list with values of 6, 12, and 24 hours. We will set our interval at the 6 hours following 1 o’clock in the afternoon, or from 1300 to 1900. Then is the time zone, which is self-explanatory. There are two other boxes above the date and time for the instrument height, ours is 2 meters, and the elevation mask or cutoff, which we will leave at 10º. Finally, we need to define the latitude and longitude of our survey area. We define it either by inputting the coordinates or by selecting the “Pick” button. The “Pick” button will open a map of the world that we can use to search for and manually select our survey location. Our location will be Simpson Park, in St. Louis, Missouri. Our settings should now look like figure 2–40.

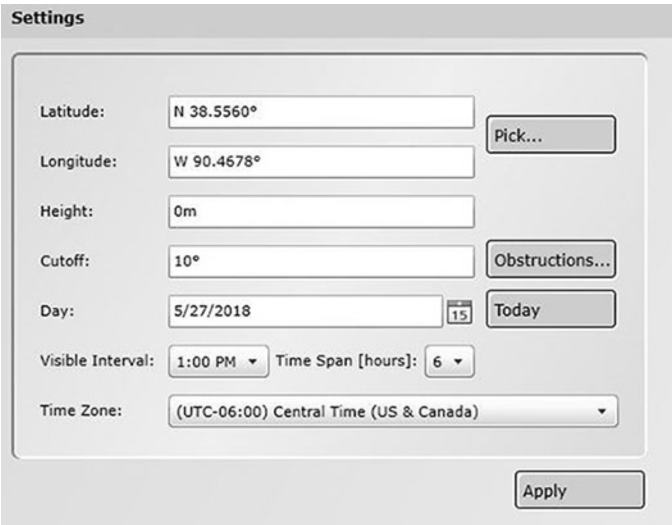

Figure 2–40. Modified settings.

Now that we have the time, equipment, and location settings applied, let us select the “Satellite Library” button in the menu and make further adjustments.

Satellite Library screen

The “Satellite Library” screen has two purposes—to adjust constellations’ information and list the information for each satellite within those constellations. Along the top of the screen are the five available satellite constellations, GPS, Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS) (Russian for Global Navigation Satellite System), Galileo, BeiDou, and QZSS. The only one we will select is GPS because it is the constellation built by the United States and the only secure GPS for us to use. There are 32 satellites in the GPS constellation; we will leave all of them on (fig. 2–41).

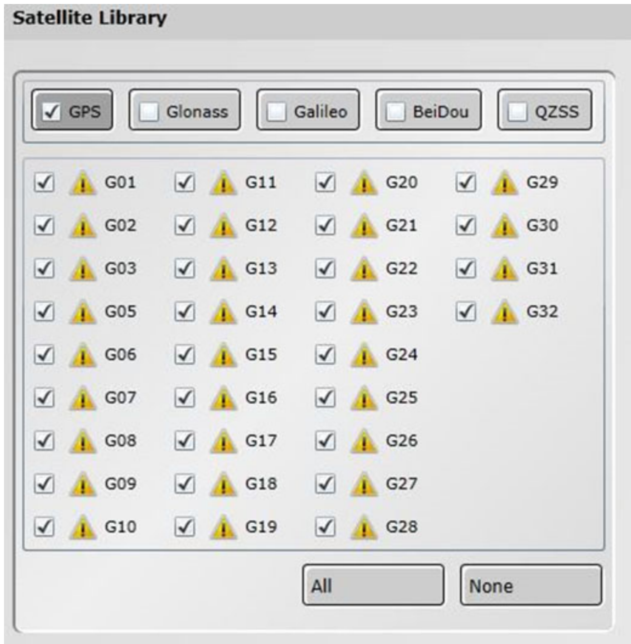

Figure 2–41. Modified settings.

Review satellite data

At the bottom of the screen is the information area. In the information area we can see, no matter which screen we are viewing, the settings we applied in the first two screens. After we verify that the settings are what we need them to be, we can start reviewing data. The remaining menus will allow us to review information about the selected constellation during the time we specified. We can start with the "Elevation" screen.

Elevation screen

This screen displays a line graph of satellite elevation. Each line represents a satellite selected in the library. The lines' arcs are based upon the angle of their elevation from the survey area (fig. 2–42). This is a good way to ensure that your surveys have a good spread of satellites across the sky. The more satellites there are at the same period, at different elevations, the better the survey quality.

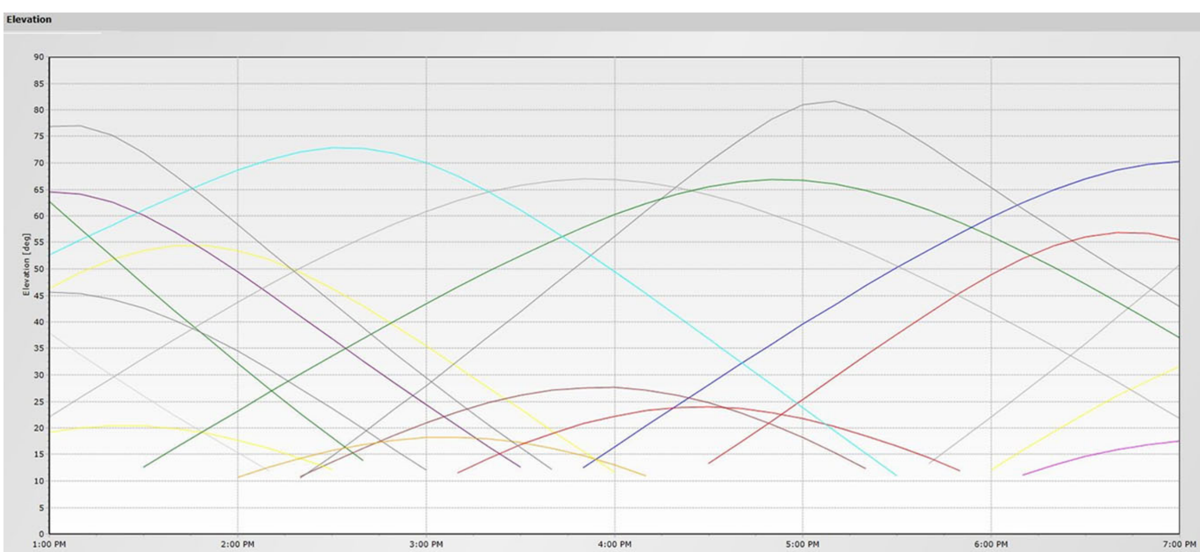

Figure 2–42. Elevation line graph.

Number of Satellites screen

Here, the total number of satellites in the sky, within the specified elevation mask, display in 10-minute increments. This screen is a straightforward bar graph with the total number of satellites on the left by the time on the bottom (fig. 2–43). This screen is also very useful in identifying times when you may not have enough satellites for your preferred survey style or times of higher reliability.

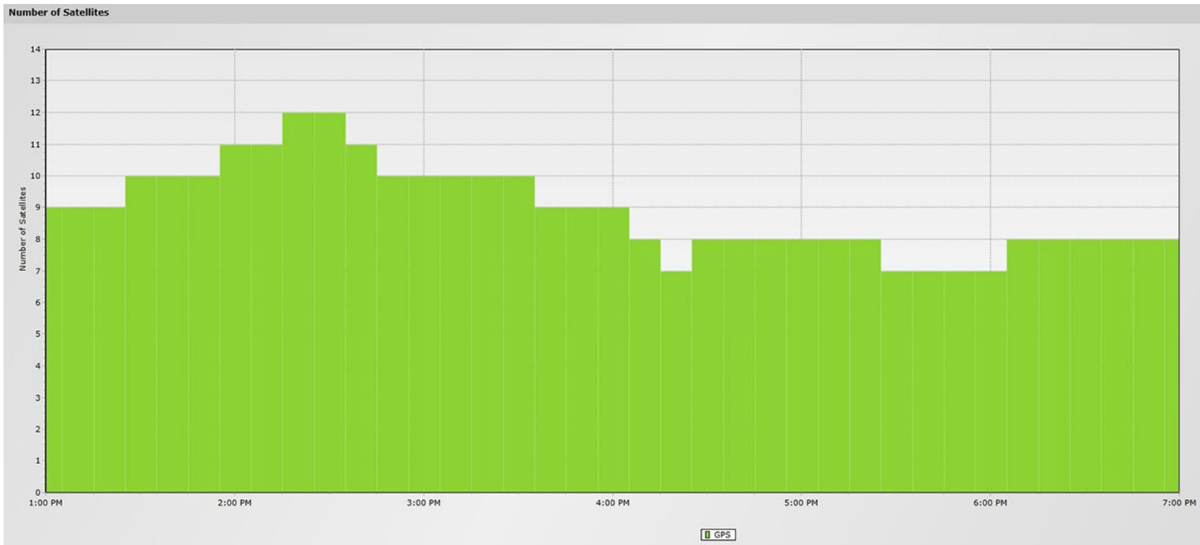

Figure 2–43. Number of Satellites bar graph.

Dilution of Precisions screen

The optimum arrangement of satellites would be an even spacing across the whole of the sky within the elevation mask. We call the quality of the arrangement DOP. A good arrangement has a low value. A DOP of 1.0 is better than a DOP of 3.0. There are also different kinds of DOPs—geometrical DOP (GDOP), position DOP (PDOP), time DOP (TDOP), and vertical and horizontal DOP (VDOP and HDOP). The most important of these are VDOP and HDOP. VDOP and HDOP are indicators of the quality of the measurements taken during that time. For the best-case scenario, we want to take our measurements during times of low DOP. In figure 2–44, 5:50 PM would have lower quality measurements than any other time during our interval.

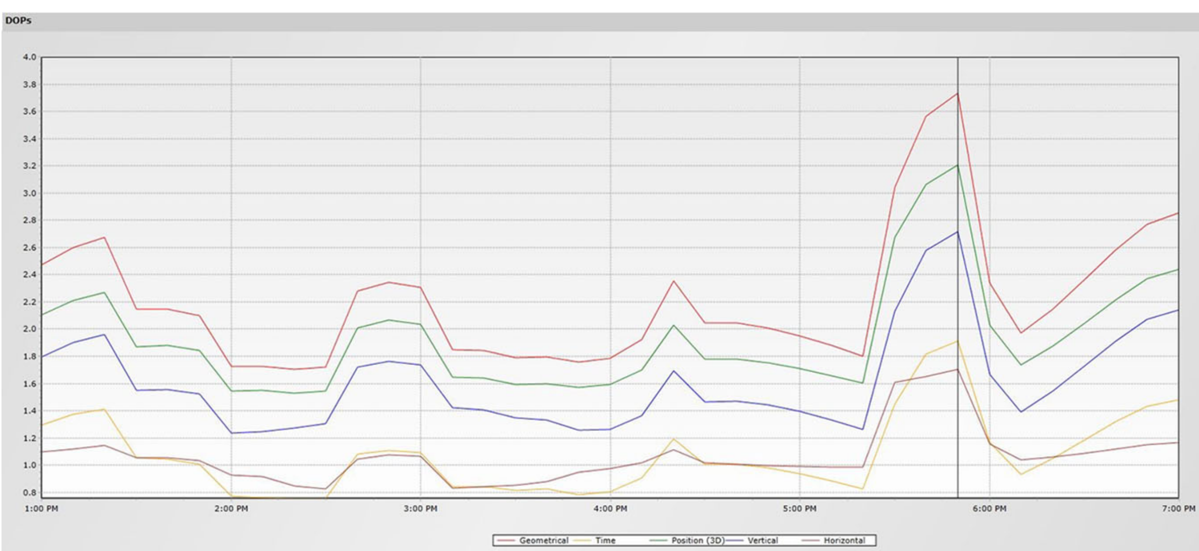

Figure 2–44. DOPs screen.

Visibility screen

The “Visibility” screen is similar to the “Number of Satellites” screen. They are both bar graphs and both show the number of satellites available at differing times of day. The difference between them is that while the “Number of Satellites” screen shows only the total number, the “Visibility” screen shows *which* satellites are available and for how long (fig. 2–45).

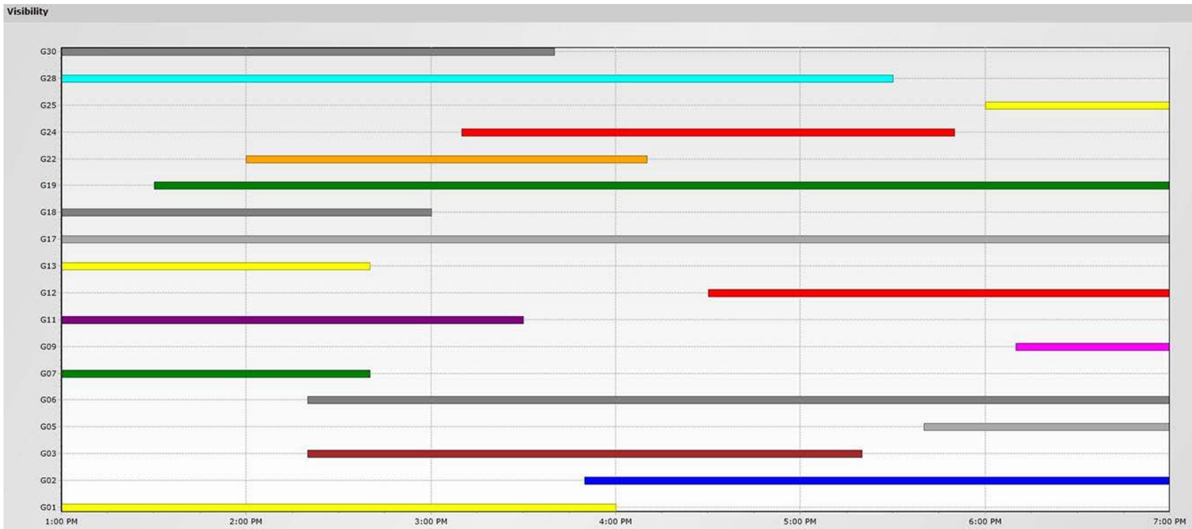

Figure 2–45. Visibility screen.

Skyplot and World View

The next screen is “Skyplot.” Skyplot shows the paths of each satellite during the time we specified in the “Settings” screen. As we adjust the time slider, we can see the changing positions of the satellites throughout our interval. Read this screen by direction, in degrees, marked on the outside of the circle. Read the elevation angle by a series of circles the outermost valued at 0º, increasing by 30º increments until the elevation angle reaches 90º where the crosshairs meet (fig. 2–46).

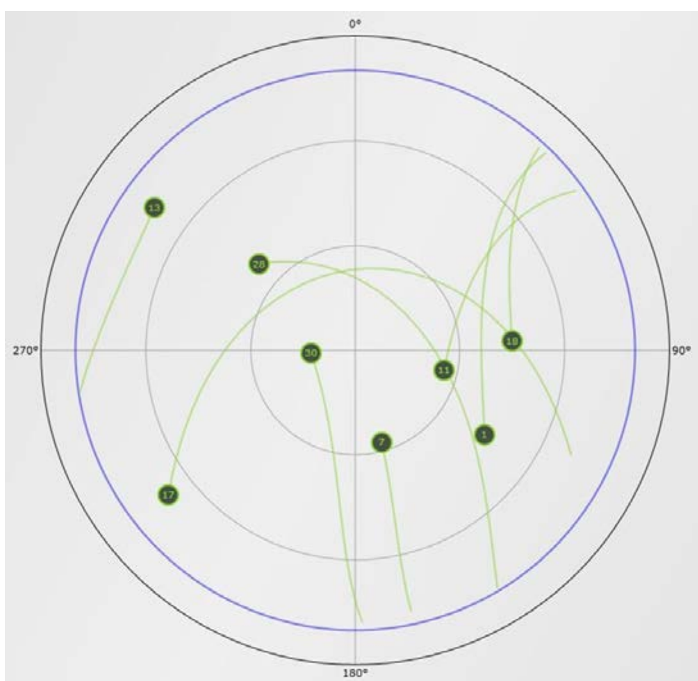

Figure 2–46. Skyplot.

The “World View” screen shows the same kind of information, but in a different way. “World View” shows the positions of the satellites over the surface of the Earth instead of relative to their elevation angles (fig. 2–47).

Figure 2–47. World View screen.

Ionospheric map and ionospheric information

The satellites in the GNSS networks transmit information to our receivers in the form of radio waves. These radio waves pass through most, if not all, of the layers in the Earth’s atmosphere. One of those layers, the ionosphere, can affect the velocity of the satellite’s radio transmissions. This is important because the receiver will use the timestamp in the transmission of when it was sent, compare that to the time received, and calculate the length of that line. The directions and number of satellite lines calculated are what the receiver uses to calculate position and elevation. If the ionosphere slows those transmissions, then the calculations can be off by tens of meters.

The effect of the ionosphere is its total electron content (TEC). TEC is the concentration of electrons in the ionosphere and is a good measure of the degree of effect the ionosphere will have on radio transmissions. The GPS satellite constellation uses a forecast of the TEC to adjust for the effect of the TEC. Deviations from the forecast will have the biggest impact on the quality of your surveys.

The “Iono Map” screen will display the TEC by color across the globe. The colors range from blue, low TEC, to red, very high TEC, but are available only after the survey. Both the “Iono Map” and the “Iono Information” screens are useful for quality control after a survey is completed (fig. 2–48).

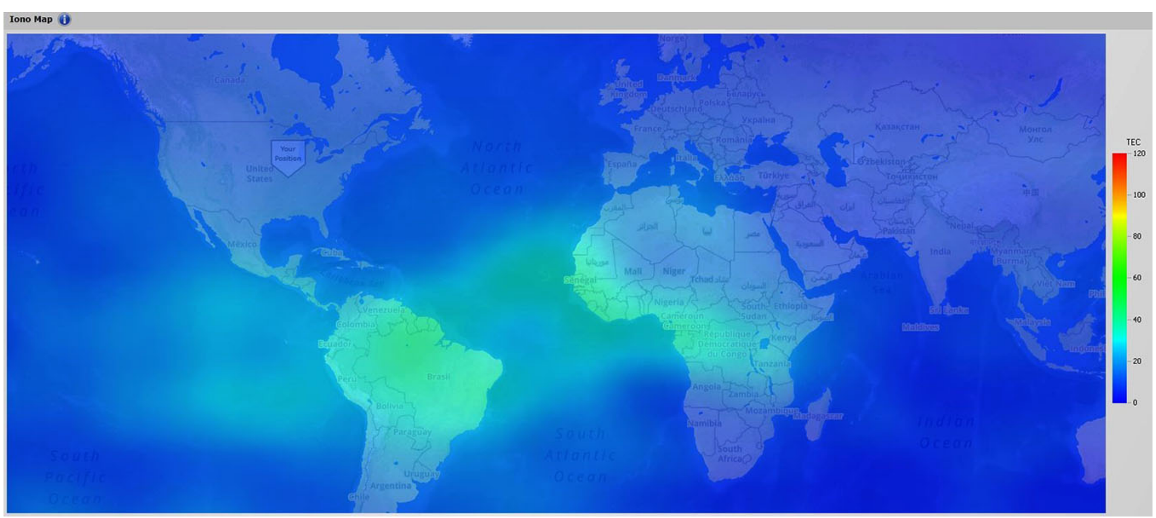

Figure 2–48. Iono map.

Global Positioning System quality

Using each of these graphs and graphics is key to the most important part of GPS surveying and quality. The primary factor that surveyors can really control in GPS survey is *when* they perform surveys. Using these tools will allow you to decide on the best time to get the most dependable survey data. If there is one thing that all engineering Airmen strive for, it's excellence. Excellence in survey means attention to detail.

012. Establish control—Global Navigation Satellite System—static

If you have not noticed already, the farther we move away from manual surveying methods, the less the survey quality depends upon the surveyor. This is true, more so for the last method we use to establish control, the GNSS. Using GNSS to survey reduces the surveyor's involvement with equipment and calculation to the bare minimum. Using planning software or similar online resources, we can find the best time to survey based upon the available satellites over an area. Proper equipment setup and software settings are the other way we get involved in the process. From there, the equipment does the rest; this includes post-processing of GNSS data, which a computer does for us. The benefits are faster, simpler, and more dependable surveys.

There are two types of static surveys—static and fast static (sometimes referred to as rapid static). The difference between the two is very small. Both are single units, set up to receive satellite observation data, and are set up the same way. The difference between the two is the amount of time the unit spends receiving observations of a given point.

The only part of the data-collection process that you have control over is when to survey and how the software is set up. Let us go over how to prepare the software in the controller and then go into further detail on what is happening between the satellites and the equipment.

Static survey style setup

When you first open the survey controller software, you will see a menu. In this menu is a button labeled "General Survey"; below this is the "Settings" button. Selecting Settings will open the menu shown in figure 2–49.

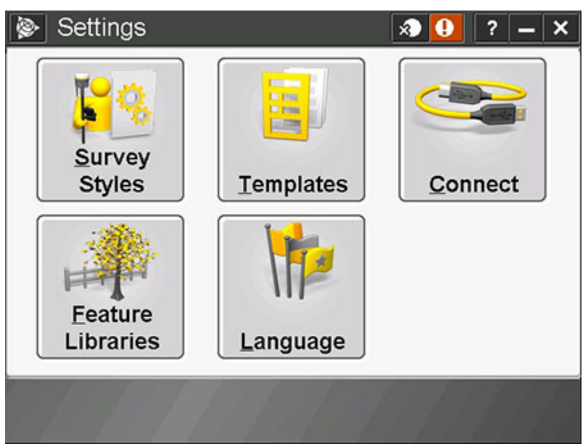

Figure 2–49. Settings menu.

From here, select "Survey Styles," and the "Survey Styles" list will open (fig. 2–50). This is a list of the survey styles currently configured in the controller. Each style explains to the controller, which then explains to the instrument, in what way to perform a kind of survey.

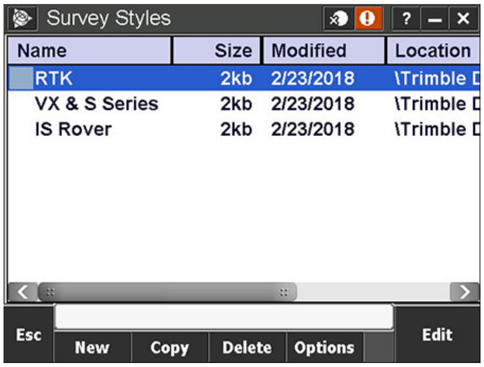

Figure 2–50. Survey styles list.

There is not yet a survey style listed for static surveying. To make one, we first select the “New” button at the bottom of the screen. This will open the “Style Details” screen (fig. 2–51). The controller asks for two settings—the style name and the style type. The style name should be something that explains, in a few words, the purpose or use of the style. Our style name is “Static” to match the kind of survey it defines. Next, we select the “GNSS” style type, which is the method of surveying we intend to use. When we are finished, we select “Accept” in the bottom right.

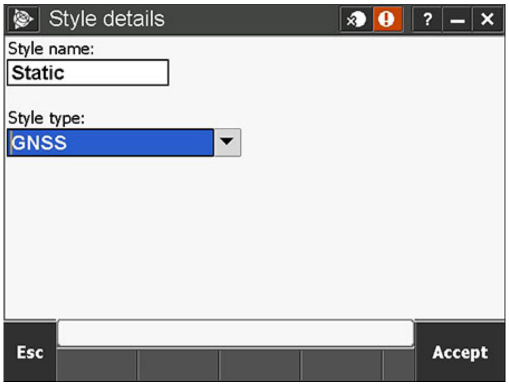

Figure 2–51. Style details.

Pressing “Accept” displays a list of default functions the GNSS survey type performs (fig. 2–52). Each item in the list has a group of settings assigned to it. The two we are concerned with are “Rover Options” and “Base Options.” Select “Rover Options” from the list and select the Edit button in the lower right.

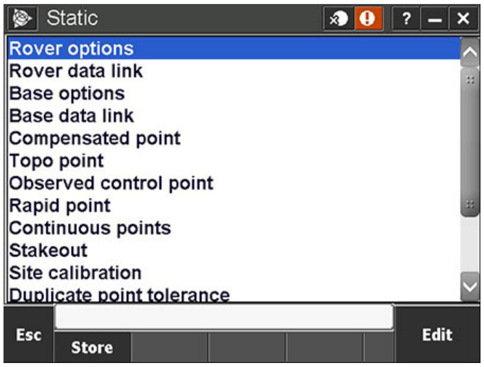

Figure 2–52. Style details.

There are three pages of settings defining what the controller and receiver do when used as a rover. Each setting has an effect on survey performance.

Rover options - page 1

The first page has the survey type, logging device, logging interval, elevation mask, and PDOP mask settings (fig. 2–53). The survey type refers to the kind of GNSS survey we want the rover to perform when using this survey style. The options for a GNSS style are FastStatic, post-processed kinematic (PPK), and real-time kinematic (RTK). Since ours is a Static survey, we select FastStatic. Remember, the difference between a Static and Fast Static survey is the time of observation. Next is the "Logging Device" option. This option is either Controller or Receiver and tells the equipment where to save the satellite data. The "Logging Interval" option allows you to set the amount of time between saves. This should be either 1, 2, 3, 5, 10, 15, or 30 seconds for post-processing. The "Elevation Mask" is the angle, from the horizon, below which the receiver ignores satellites. The reason for this is that the atmosphere is denser closer to the horizon and introduces more error to satellite signals. Finally, the "PDOP Mask" lets you adjust the value where the instrument stops logging and waits for better PDOP. The default is six; however, below four is optimal and higher than seven we consider extremely poor.

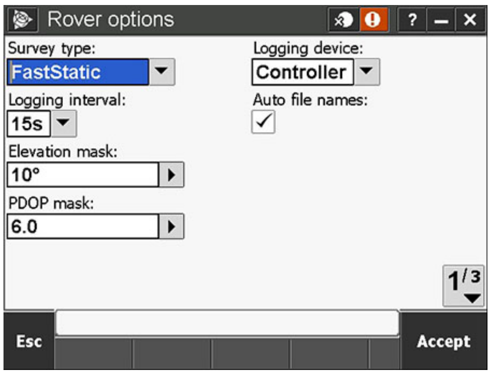

Figure 2–53. First page of rover options.

Rover options - page 2

The second page of options focuses on the receiver antenna. The settings are antenna type, the height measurement location, the antenna height, and its serial number. The antenna type will depend on your receiver equipment. Most currently used equipment has internal antennas; older equipment will have a receiver connected to the antenna by a cable. The antenna we select in figure 2–54, because it is newer, is set to R10 Internal. The antenna height is set to 2 meters because our rover attaches to a fixed-height pole. Since we know the height of the pole, we set the measured to option to "Bottom of quick release" which tells the controller to add the height of the receiver antenna from there. We use the serial number option to match particular antenna to a particular controller. The only equipment we use is the R10 antenna, so we will leave this field blank so that we can use any antenna with this controller.

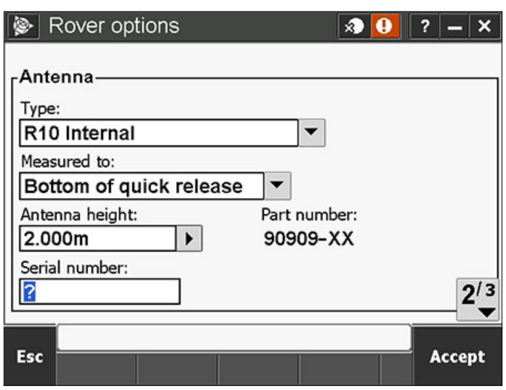

Figure 2–54. Second page of rover options.

Rover options - page 3

The final page of rover options is, with the exception of one option, concerned with signal tracking. The two changeable options in the “GNSS Signal Tracking” box are “GPS L2C,” and “GLONASS.” The L2C checkbox turns on and off L2C signal observation logging. L2C is a satellite signal frequency used for newer civil applications. Since our equipment is the R10, which is newer, it has the capability to receive these signals. For observations that are more accurate, we will check the L2C box. The “GLONASS” checkbox tells the receiver whether to log observations from the GLONASS satellite network. As of 2017, federal agencies, including the Department of Defense (DOD), were ordered to discontinue GLONASS use. This is why we unchecked it in figure 2–55. The last item is the “Tilt” checkbox. Within newer GPS receivers, a device compensates for minor tilt of the pole, hence the name “Tilt.”

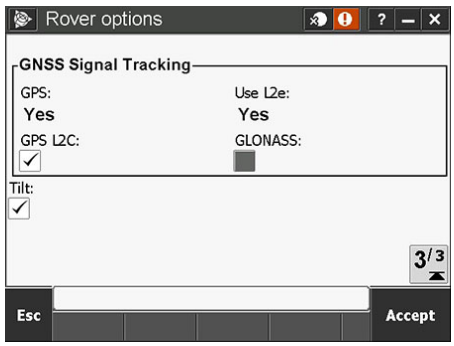

Figure 2–55. Third page of rover options.

Our controller is now set up to use the survey equipment as a static rover. We can press the “Accept” button, which brings us back to the list of options for our survey style. The “Base Options” are the last settings we will make to the survey style. Select “Base Options” and press “Edit.”

Base options

The “Base Options” pages are the same as the “Rover Options” pages, with one exception. The “Logging Device” option needs to be set to log to the receiver, and we cover why in the next section. Once you ensure the settings are what you need, press “Accept.” Then, in the survey style options menu, press “Store” at the bottom of the screen.

Static survey procedure

Once our style is set up and stored, we can take our equipment into the field and begin a survey. The first thing we need is a known point. In the office, we keyed in the coordinates and elevation for our known point. We can then go to the site and set up our base receiver on the known point. After connecting the control, in the “General Survey” menu, select “Measure” and we can see our “Static” survey style in the list (fig. 2–56).

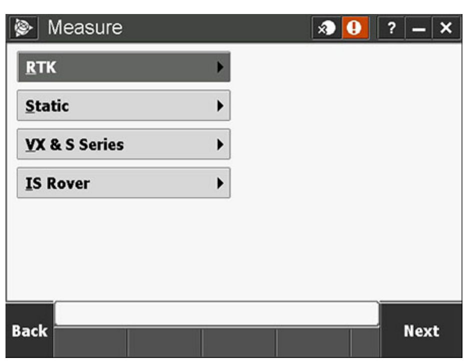

Figure 2–56. Measure menu.

Selecting our "Static" style will open another list of options, including "Start Base Receiver," "Measure Points," "Measure Codes," and "End GNSS Base Survey." We can begin with "Start Base Receiver."

Start base receiver

Every survey begins with a known point, and GNSS surveys are no different. We collect the coordinates for our known point from whatever we use to record them; this will differ from installation to installation. Once we select our known control point, we key the point coordinates into the job file on the controller. Ensure that the coordinate units match the job file settings. After we set up the control point data in the control and assemble the equipment over the known point, we can start the base receiver. To start the base receiver we select "Start base receiver" in the "Static" survey menu. The controller will then ask you for information on the point (fig. 2–57). Since we keyed in our point already, when we enter the point name, the code will auto populate. All that remains is to enter the antenna height, ours is two meters, and from where we measured the height. When we are satisfied with our settings, we select Enter in the bottom-right corner to begin logging observations to the base receiver. It is worth noting that when we set up the "Base Options" when we created the survey style, we set the logging device to receiver. This is important because once the base is started, we can disconnect the controller and use it to operate the rover.

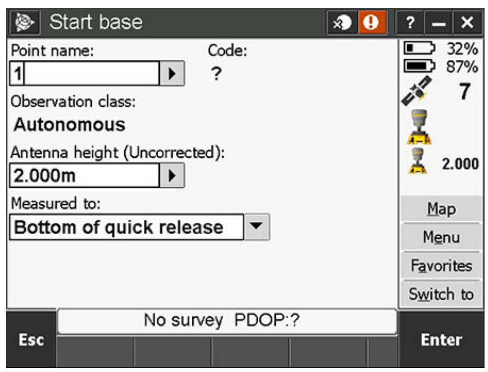

Figure 2–57. Start base receiver point select.

Static rover

With the base receiver running, we can begin establishing temporary control points around the site. To do this, we take the controller we disconnected from the base receiver and connect it to a rover receiver. Once connected we go back into the "Static" survey menu and select "Measure points" which opens the "Measure points" screen (fig. 2–58). Before we talk about the "Measure points" screen, we should make sure our options are set the way we need them.

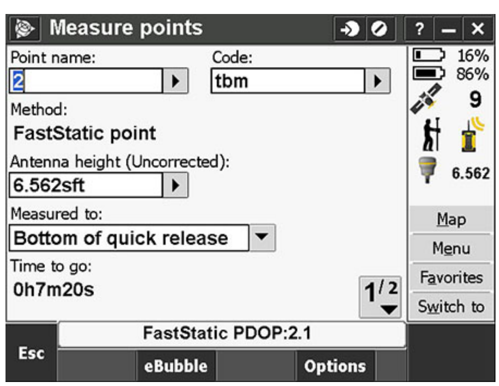

Figure 2–58. Measure points screen - page 1.

Selecting “Options” at the bottom of the screen opens the “Options” settings (fig. 2–59). The settings on the first page are “Auto store point” and “L1/L2 FastStatic times.” The auto store options set as unchecked because we want to decide when to stop and store the point information. If we check the box then when the controller reaches the time limit for the observation, the point is automatically stored. The observations times are part of the “L1/L2 FastStatic times” settings. These settings are broken into three parts based on four satellite vehicles (SV), five SVs, and six or more SVs, respectively. Notice that by default the fewer SVs the longer the instrument is set to collect data on the point. It is possible to make these times more or less stringent, but for most purposes, such as ours in this text, the default times are fine.

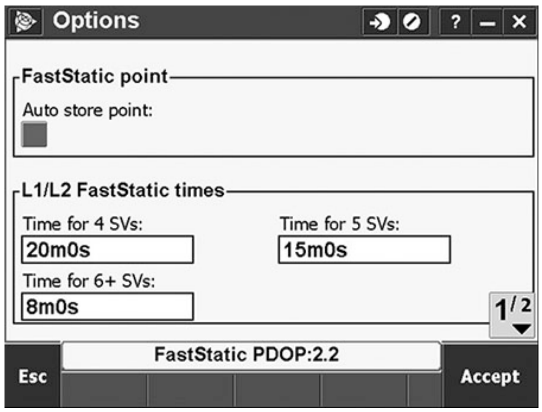

Figure 2–59. Measure points options - page 1.

The second page of options has one setting that allows us to turn on and off the attribute prompts before beginning measurements. If turned off, the controller will automatically fill in the point name, code, and antenna height (if defined in the job already) and begin measuring the point. Once satisfied with the options, we select “Accept” in the bottom-right corner to return to the “Measure points” screen.

After leveling the rod, usually with a bubble level, we can select “Measure” and the instrument will begin recording satellite observations and calculating its location. The “Time to go” timer at the bottom of the first page indicates how much time is left before the instrument receives enough information to satisfactorily calculate the point location. On the second page, we can review the total amount of time the instrument has received observations from four, five, and six SVs, respectively (fig. 2–60). These times correlate with “Options” we set for minimum observation times. Once the instrument has enough satellite information, it continues to compute observations until we select the store button because we turned off the “Auto-store” option in the “Options” menu.

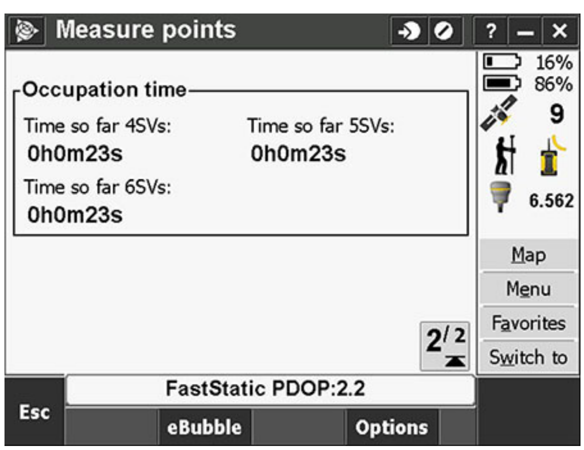

Figure 2–60. Measure points screen - page 2.

We repeat this process for the number of TBMs we need on the site. Our survey example has five total points—point two being the known control MON the base uses and four TBMs we created with the rover. The next step is to export and post-process our data.

Post-processing static survey data

Post-processing refers to correcting our survey data. In manual surveying, we calculated the misclosure and then distributed it throughout the survey. In this way, we compensated for the error in the survey. GNSS survey requires the same process but a computer program, instead of the surveyor, performs the correction. Before we can process the data, we need to get the files pertaining to satellite observations and calculations that the instrument recorded.

Receiver and controller file retrieval

First, we connect our controller to the base station receiver. Then, from the “General survey” screen, we select “Instrument” then “Receiver” files (fig. 2–61).

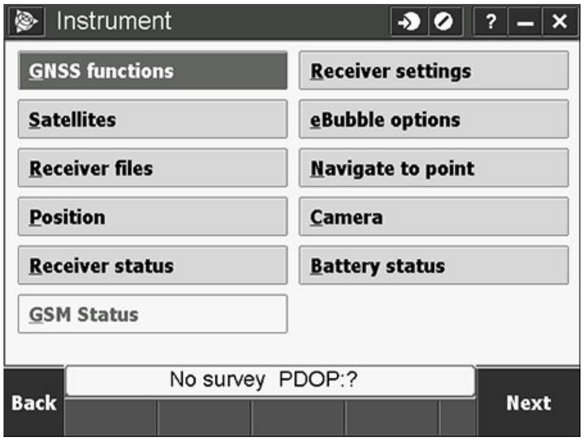

Figure 2–61. Instrument menu.

The “Import from receiver” list will display, populated with all the files available on the receiver (fig. 2–62). Remember, the receiver has the base station observations recorded because we set our base logging device option, in the survey style, to log to the receiver. The receiver names files using the last four digits of its serial number followed by the numeric calendar day (0 to 365), then the .T02 file created that day (0 to 9). Ours is 01131410.T02, that is, 0113 as the serial number, 141 as the number of days since 1 January 2018, and 0 because it was the only .T02 file created with that receiver on that day. Once we select the correct file from the list, we can select “Import.”

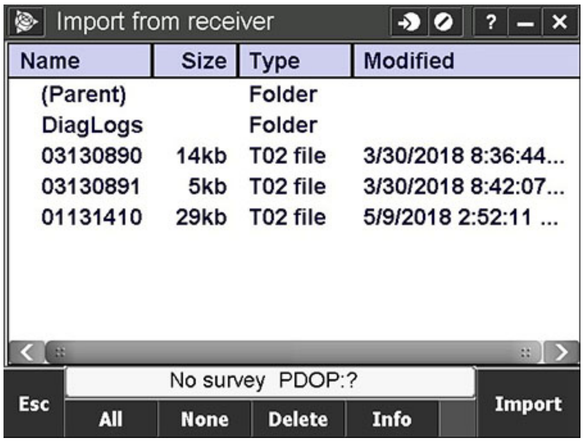

Figure 2–62. Import from receiver.

Since we can select more than one file to import at a time, the controller will show us which files we chose and how many (fig. 2–63). This gives us an opportunity to correct any mistake we make when selecting files. We have selected only one so we can select “Start” and wait for the files from the receiver to the controller.

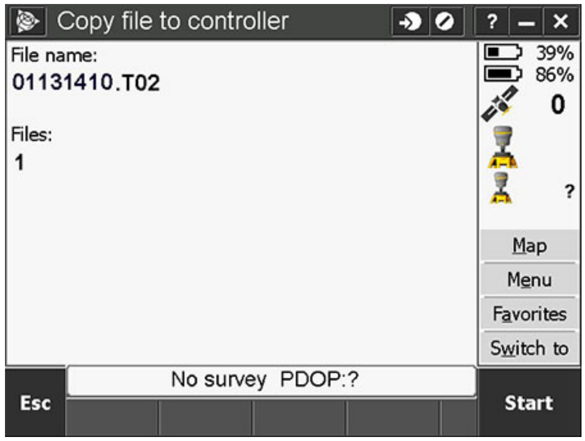

Figure 2–63. Copy file to controller.

Now the controller has the files we need to post-process our data. After connecting the controller to an approved computer, we can navigate to the file location. The location is, by default, /Trimble Data/ (user name) / (job name), replacing the user name and job name with those we used. Our file path is /Trimble Data/USAF/STATIC HOW TO. There are two files we need to copy from the controller. The first is our receiver file that we just imported (.T02). The other file, labeled 42161410.t02 (instead of .T02), is the controller data file with the points the rover collected (fig. 2–64).

01131410.T02	5/21/2018 3:10 PM	T02 File	48 KB
42161410.t02	5/21/2018 2:57 PM	T02 File	23 KB

Figure 2–64. .T02 and .t02 files.

With both of these files copied to the desktop, we need to process the base station coordinates through the Online Positioning User Service (OPUS).

Online Positioning User Service processing

The OPUS compares observations from a data file with the observations taken at continuously operating reference stations (CORS) during the same period. The CORS are permanently established GNSS antennae that receive satellite observations 24 hours a day, 7 days a week. We use CORS to compare and correct coordinate information taken by surveyors. The idea is that the base station file becomes a part of the CORS network mathematically, and is corrected based upon the satellite positions and CORS positions. Each object in the system creates a baseline to the surveyed base station and adjusts based upon the collective average (fig. 2–65).

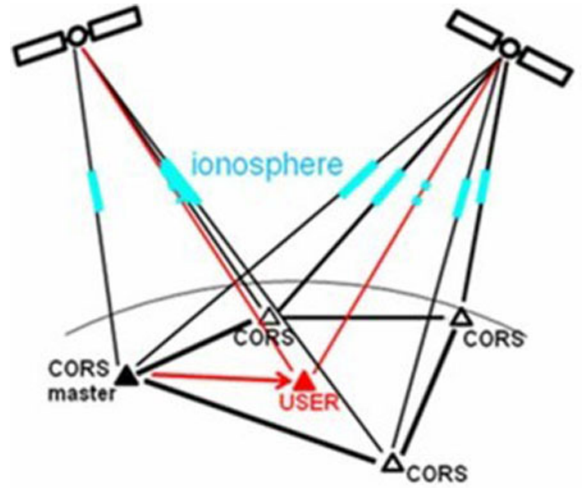

Figure 2–65. GNSS visualization.

OPUS uses a Web interface, https://www.ngs.noaa.gov/OPUS/, as a way to automate receiving, processing, and responding to requests for processing. It takes a limited number of formats. We use a program, called “Convert to RINEX” or just RINEX, to convert the .T02 file to .18o format that OPUS can use. We convert files by opening the program, selecting “File” then “Open,” to point the program at the file. Then we select “File” then “Convert” to finish converting the file (fig. 2–66).

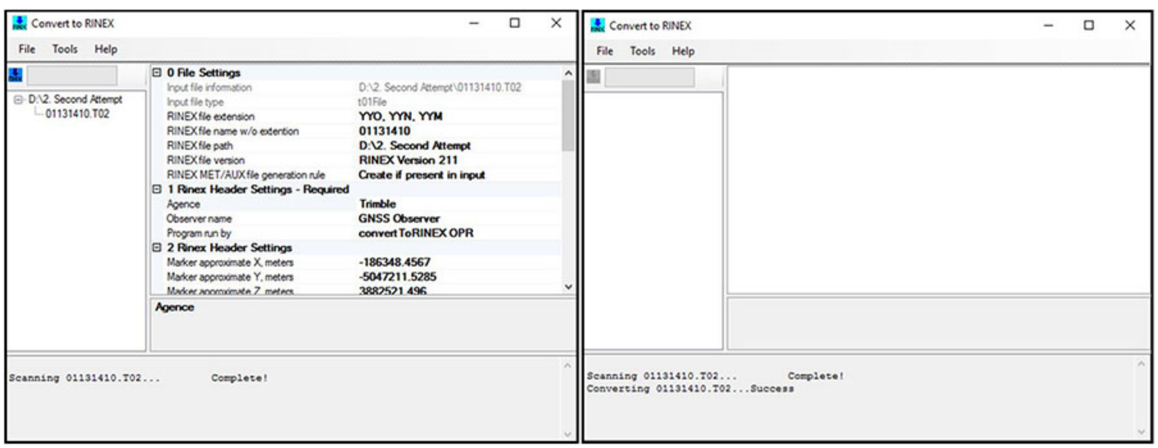

Figure 2–66. Converting files using RINEX.

Once complete, the program places three files in the same directory as the original .T02 file. Each will have the same name but have a different suffix, .18I, .18n, and .18o, respectively. The one we upload to OPUS is the .18o file. Our file is 01131410.18o.

We now go to the OPUS Web interface and click “browse” to select the .18o file. Then, we select the antenna we used for the base station, the base station’s height, and an e-mail address (fig. 2–67). OPUS sends the results to the e-mail address specified. Finally, we need to select whether to use “Rapid-Static” or “Static” for our processing format. Our survey was approximately 36 minutes, making “Rapid-Static” the appropriate option. If we establish a new MON and set up our base station over the point for the required 24 hours, we use the “Static” option. OPUS will then confirm reception of the file. Then we wait for the response.

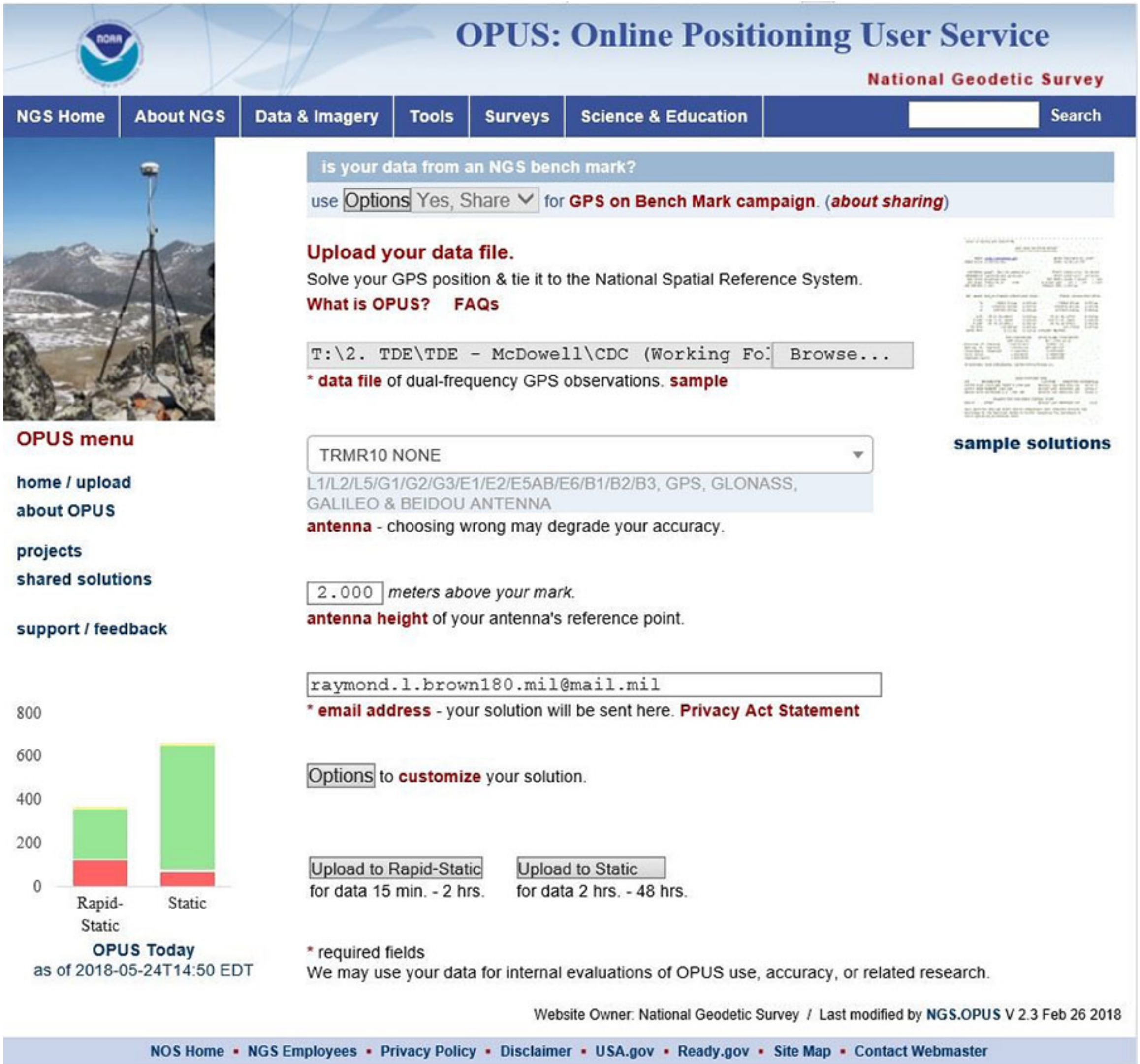

Figure 2–67. OPUS Web interface.

Once we get the OPUS results back, we are looking for two pieces of information—the Northing and Easting (fig. 2–68). These coordinates are the corrected coordinates for the base station point. When we process the data, the software we use will prompt us for the values and bases the corrections upon these coordinate values.

```
      LAT:   37 44 10.30441     0.005(m)      37 44 10.32835     0.005(m)
    E LON:  267 53  7.98461     0.010(m)     267 53  7.94717     0.010(m)
    W LON:   92  6 52.01539     0.010(m)      92  6 52.05283     0.010(m)
   EL HGT:         312.722(m)   0.015(m)           311.569(m)   0.015(m)
ORTHO HGT:         343.368(m)   0.018(m) [NAVD88 (Computed using GEOID12B)]

                      UTM COORDINATES    STATE PLANE COORDINATES
                       UTM (Zone 15)        SPC (2402 MO C)
Northing (Y) [meters]    4176915.101         211223.465
Easting (X)  [meters]     578027.512         533982.665
```

Figure 2–68. OPUS results.

Baseline processing

The last part of static surveying is baseline processing. So far, we have surveyed our known control point and all our desired TBMs. Then we took our base station point information and sent it to OPUS, correcting the coordinates to control quality. Processing baselines uses the corrected base station point to adjust the coordinates of the TBMs. First, open a new project in the survey software (fig. 2–69).

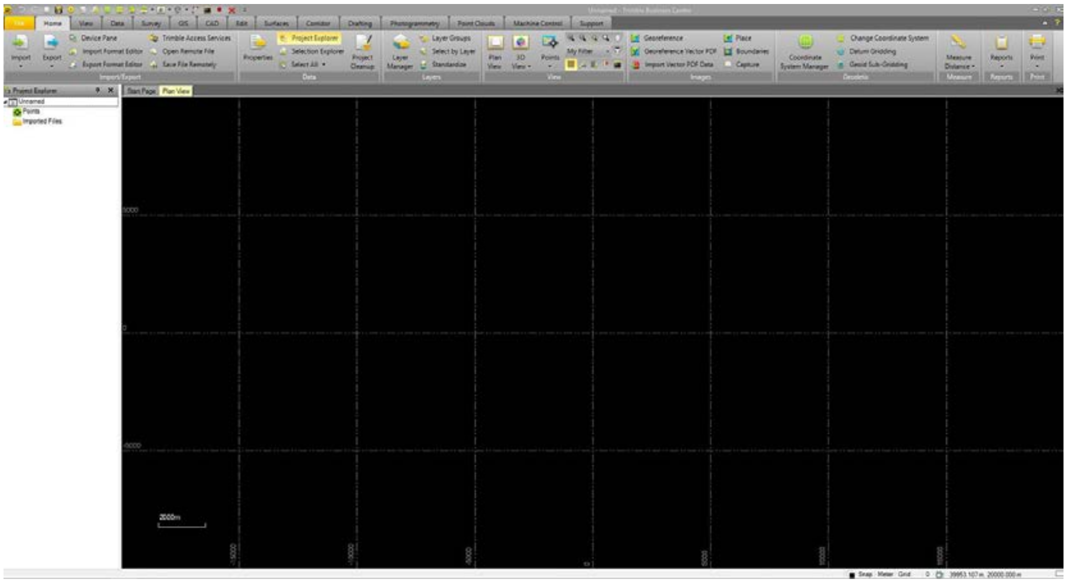

Figure 2–69. New survey project.

Next, we need to bring the data into the software. There are two ways to do this. The first way is to select the “Import” tool in the top-right corner of the screen. This will open the “Import” pane (fig. 2–70).

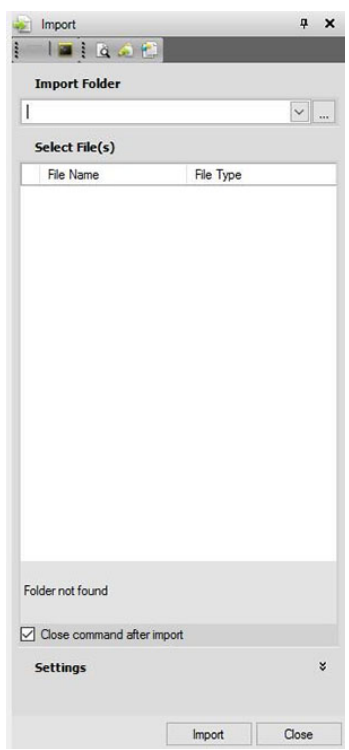

Figure 2–70. Import pane.

From here, we can select the ellipsis, next to the “Import Folder” text box, and browse to our .T02 and .t02 file folder, then select the file and select “Import” at the bottom of the pane. The second way to bring in our data is to drag and drop both the .T02 and .t02 files into the coordinate field, the black area, of the screen.

After we have imported both files, the “Receiver Raw Data Check In” window opens (fig. 2–71). In this window, we can review our points and ensure that they are all there. It also tells us from which files each of the points came from. Two tabs at the bottom allow us to check the antenna and receivers used for this survey. Once we are satisfied with the information, we select OK.

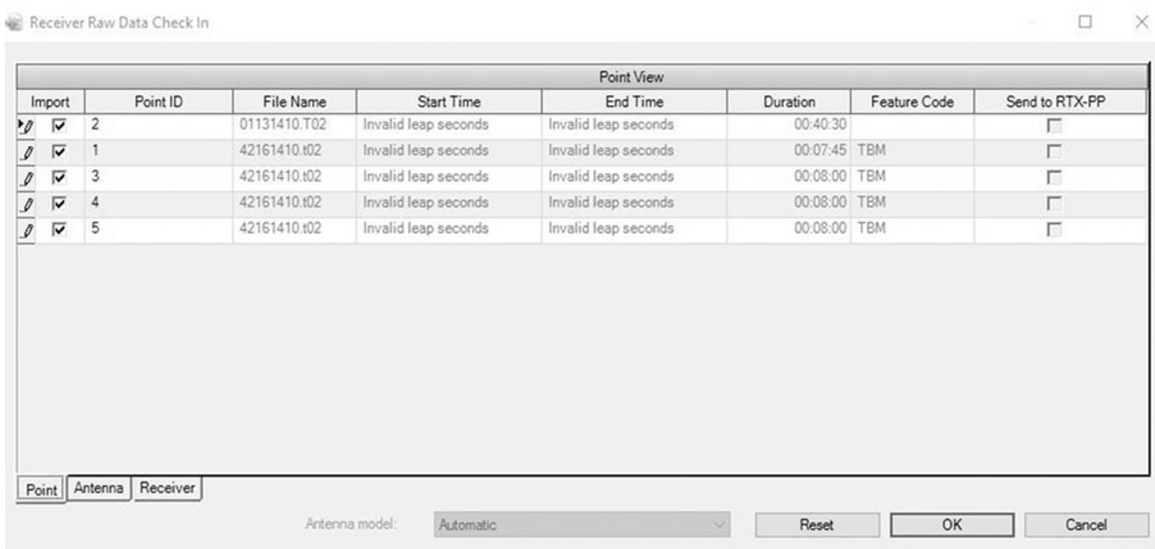

Figure 2–71. Receiver Raw Data Check In.

Since we did not select a projection for our project, the software opens a prompt asking for the best-known grid coordinates for the base station point (fig. 2–72). In our case, we will assign the corrected OPUS Northing and Easting to the point “2.” This will adjust the coordinate value from the receiver .T02 file to the coordinates we entered from the OPUS correction. Then we can select “OK.”

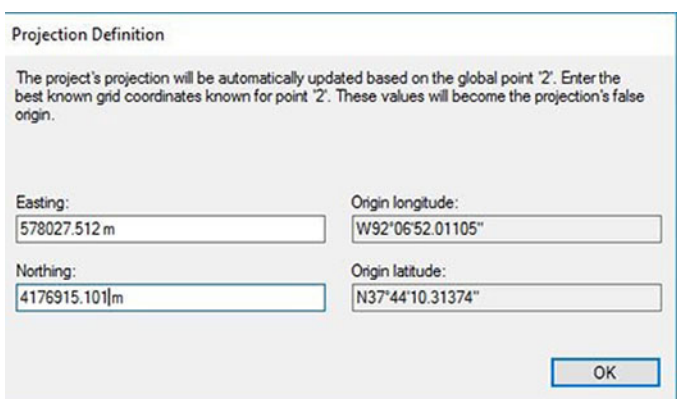

Figure 2–72. Projection Definition window.

If we make a mistake when entering information, or we want to change the quality settings of the point, we can expand the points list in the “Project Explorer” pane on the left. Each of the points can be further expanded to list their different properties. If we right-click on one of the points and select “Properties,” the “Properties” pane will open (fig. 2–73). This pane lists coordinate data for the selected point. Here we can adjust the coordinate values for the point by selecting the numbers in the text boxes. We can also change the point quality by selecting the boxes to the far right of the coordinates. In our example, we need to select the “Control Quality” option for point “2” because it is our control point. We can also double check that we entered the coordinates correctly.

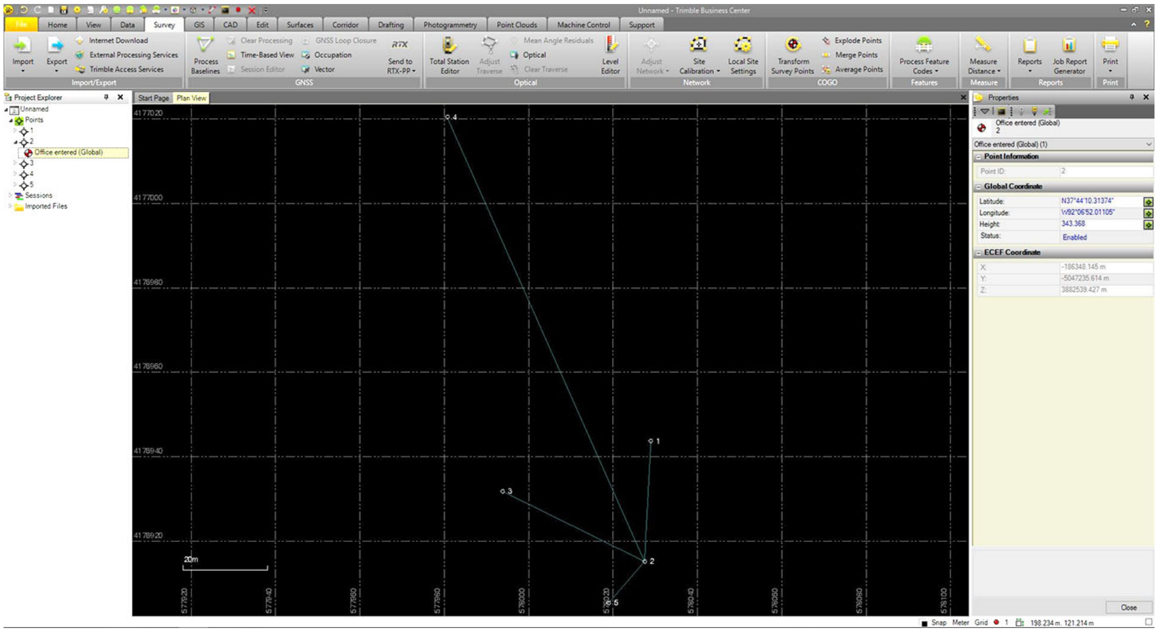

Figure 2–73. Properties pane.

Now that our settings and coordinates are set, we can process the baselines. We start by going to the “Survey” tab at the top of the screen, and then we select “Process Baselines” in the ribbon. This opens the “Process Baselines” window (fig. 2–74). This window shows us each baseline, from base station to point, the precisions, root mean square (RMS), and the length of the baseline. The baselines list by observation from the base station point to the rover point. The listed precisions for both horizontal and vertical are in meters. The most confusing value listed is the RMS. The RMS is a statistical evaluation of the point’s error. It is a way to average the value of a set of numbers; in this case, we are averaging satellite observations. The lower the RMS, the better.

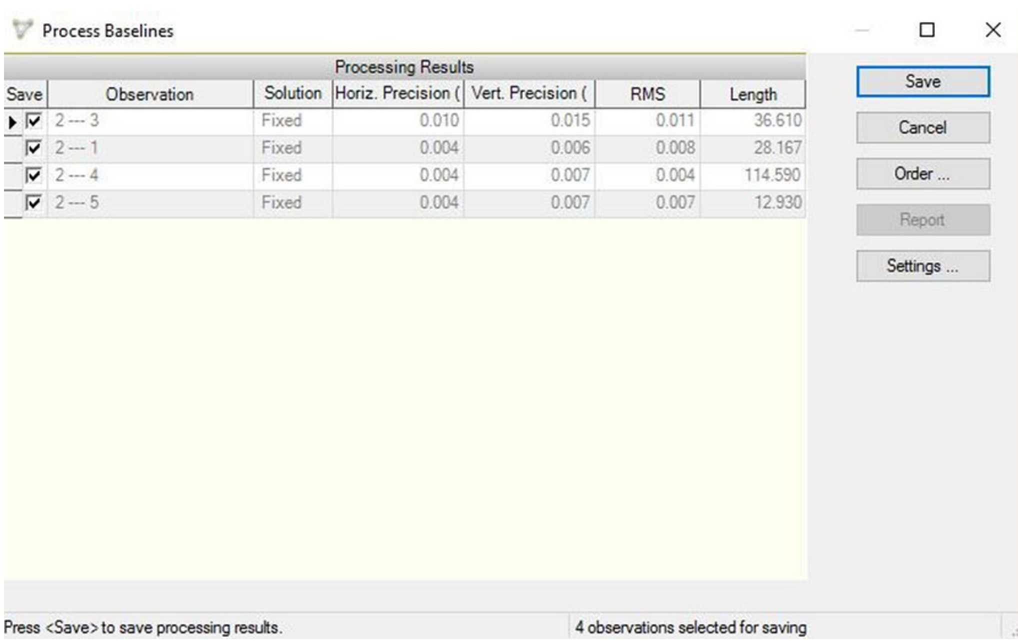

Figure 2–74. Process Baselines window.

Selecting the “Save” button will correct the point data based upon the processed baseline values. The software performs a survey adjustment in the same way we did in manual survey, though much more thoroughly than we can. We can now use the rover point coordinates as control because we have “moved” the point quality from the known base point to the rover points, again, in the same way that we did when performing a manual traverse or level-loop survey.

You now understand the process for completing a Static survey. This includes setting up the survey style, setting up the base receiver, and collecting observation data with the rover. Each of these, in the same order, is a step for troubleshooting. Check first that the survey style settings are the same for both the base receiver and the rover. Then ensure that the coordinate settings for base are correct and that the job units are set appropriately (either feet or meters). Then check that the observation times on the rover are sufficient for the level of quality needed.

013. Establish control—Global Navigation Satellite System—post-processed kinematic

The PPK survey method is similar to the Static method. They both require a base station setup over a known point. We post-process both Static and PPK surveys, the same way, after the survey is complete. The biggest difference is time. The observation times for static points with the rover depended upon the number of satellites that were available to the rover and ranged from 6 to 15 minutes. For a PPK survey, the limiting factor is the period of observation. The longer a PPK rover observes a point, the more precise it becomes. The surveyor decides the period of observation based on the accuracy needed and time available to achieve it. We can go through the PPK procedure and compare it to the Static method as a way to understand the difference.

Post-processed kinematic survey style setup

After navigating to the survey styles menu, we create the “PPK” survey style. To begin with, we adjust the base options. In the base options menu, we change the survey type to “PP kinematic.” Then we set the antenna type (our example uses the R10) and leave the antenna height blank so that we can set it when we start surveying (fig. 2–75).

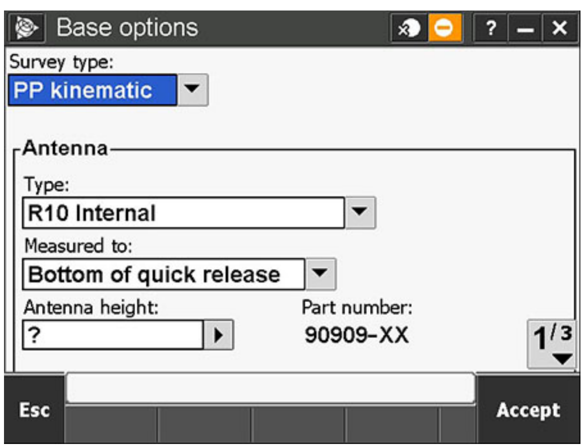

Figure 2–75. PPK base options menu - page 1.

On the next page of base options, we set the logging device, logging interval, and the elevation mask (fig. 2–76). The receiver will be our logging device, so that we can disconnect the controller and use it for the rover. The logging interval is set to 1 second by default, which is good enough for our example. We will leave the elevation mask at 10 degrees just like in the Static survey example. We normally adjust the elevation mask depending upon obstructions like hills or mountains. So far, everything is the same as the Static method.

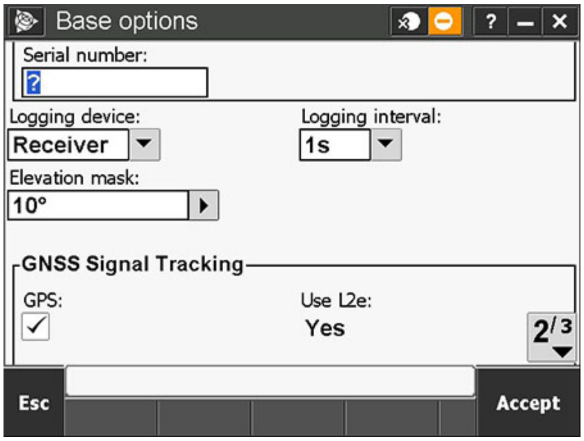

Figure 2–76. PPK base options menu - page 2.

The last part of the second page and the rest of the third page deal with satellite constellations (fig. 2–77). The GPS, GPS L2C, and L5 items are part of the same constellation, the U.S. constellation, but are different radio channels. Our example will use the GPS and GPS L2C channels for simplicity and flexibility. If we used a rover antenna that could not track L2C or L5 satellites then the survey would be no good. Both the base and the rover need to be able to track, at a minimum, four of the same satellites. The remaining items on the third page are satellite constellations that belong to other nations. GLONASS belongs to Russia, Galileo belongs to the European Union, QZSS is Japanese, and BeiDou is Chinese. As a reminder, the DOD mandated that we are not to use GLONASS. Once we have set our base options, we can move on to our rover options.

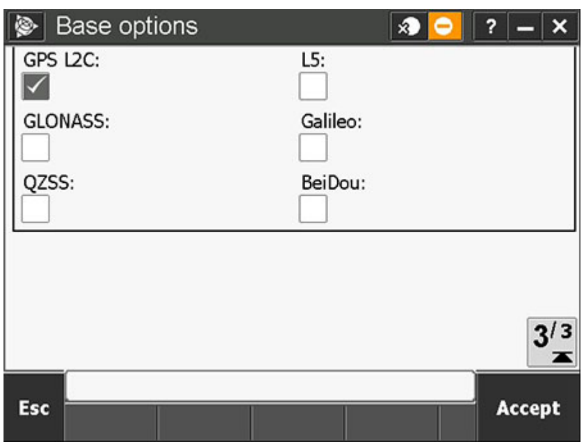

Figure 2–77. PPK base options menu - page 3.

On the first page, the only difference between the rover options for PPK and the options for Static is the survey type (fig. 2–78).

On the second page, we have a few things to address (fig. 2–79). The first is the logging device, which we set to controller. The second is the logging interval. The logging interval for the rover must be the same as the logging interval for the base station. If they are not the same, then when we try to post-process the data, the software will give us an error. The last thing is the PDOP mask; this is the same setting as in the Static options. Generally, a PDOP mask of six is acceptable.

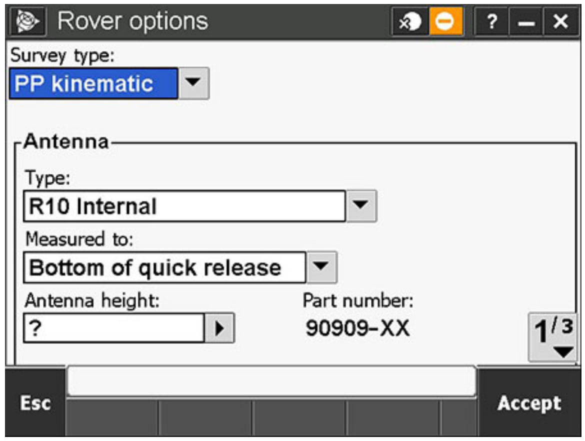

Figure 2–78. PPK rover options menu - page 1.

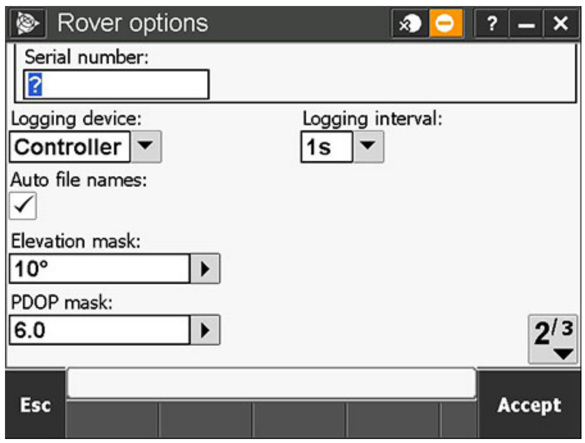

Figure 2–79. PPK rover options menu - page 2.

Finally, on the third page, we turn off the GLONASS check box. We can also turn on or off the Tilt option depending on our equipment (fig. 2–80). Some newer GPS receivers can compensate for a minor tilt of the rod.

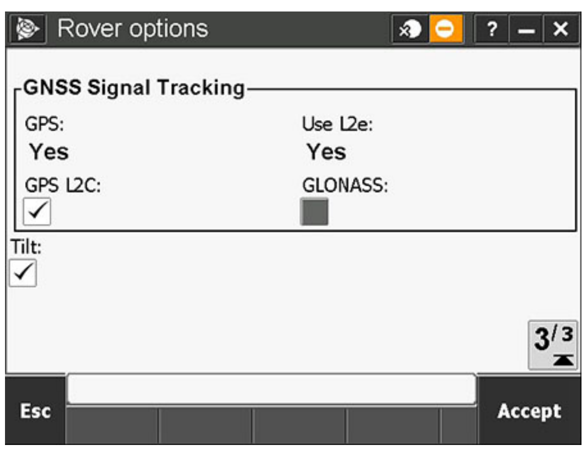

Figure 2–80. PPK rover options menu - page 3.

Measuring points

To begin measuring points, we first set up our base station over a known point. To do this, we will key in the known point coordinates into the control, set up the base station, and start the base receiver. PPK base station setup mirrors Static base station setup. Next, we can disconnect our controller from the base and connect it to our rover. Under the survey menu, in the PPK style, we select “Measure points.” This function allows us to take observations. It is almost the same as the Static “Measure points” function. The differences lie at the bottom of the menu. Here we see “Time so far” and “Epochs remaining (fig. 2–81).” The “Time so far” simply ticks off the minutes and seconds since the measurement period began. The “Epochs remaining” is dependent upon our options.

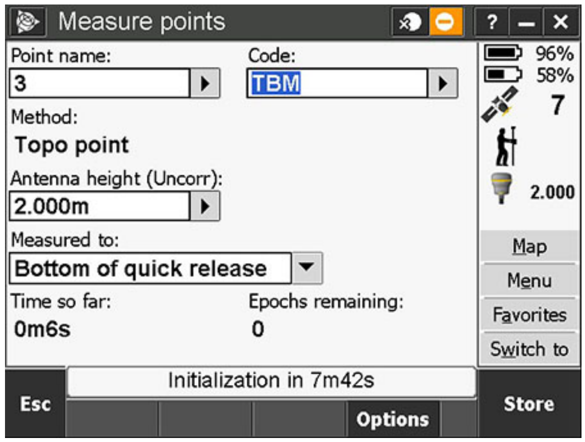

Figure 2–81. Measure points - PPK.

In the “Measure points” options screen, we can adjust the number of epochs that the rover will collect before allowing us to store the data. An epoch is compound observations based upon the occupation time. Our options are set at two measurements over two seconds (fig. 2–82). This means that two, 1-second observations are being collected before the controller will allow storage of a point. Generally, for PPK surveys, we use 30-second occupation times to ensure sub-centimeter accuracy. For example, if we change the number of measurements to 15 and maintain a 30-second observation period, this tells the controller to record the measurements every 2 seconds.

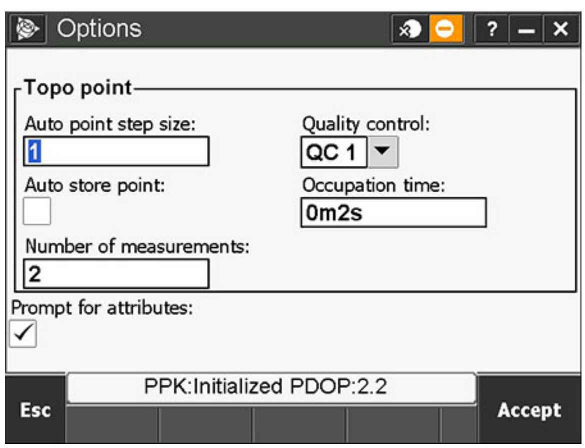

Figure 2–82. Measure points options screen.

Initialization

The last thing we will discuss about the PPK method is initialization. Initialization occurs when we turn on the rover receiving satellite. This can take from 5–15 minutes. Initialization is a term describing the rover information to calculate its position. The rover is doing four things—downloading a copy of the satellite almanac, collecting the current time information, logging ephemeris data, and calculating its location.

Satellite almanac

The almanac is a digital encyclopedia of satellite positions. The satellites send receivers their planned routes and schedules in the form of this almanac. The receiver uses this information to get estimated positions of the satellites in a constellation.

Current time

Satellites calculate time differently than we do. They measure time from their own relative starting point of 1 January 1980. The satellite clocks are not perfect though and require adjustment. Control stations around the world provide adjustments to the satellite clocks in the form of leap seconds. Leap seconds, combined with the almanac, provide receivers with clearer satellite positions. Simply put, leap seconds give the receiver a more detailed schedule.

Ephemeris data

The ephemeris is the precise positions of individual satellites. The rover will compare this with the almanac and time combination to "adjust" the position of the receiver. Think of the satellites as surveyors on MONs with total stations. They are measuring the receiver's location. The last step in a manual survey is to adjust the data by comparing it with the mathematic model of the survey. Satellites do the same but with more complicated mathematics.

Global Positioning System receiver's current location

If the first point we measure is a known point, keyed in to the controller, then we reduce initialization time. The reduced initialization time is because the receiver has a general idea of its location and only has to correct itself. This means that it compares the coordinates it has with the adjustments received from the satellites.

014. Establish control—Global Navigation Satellite System—real-time kinematic

The most preferred method of GPS surveying is RTK. RTK performs the same way as PPK with a few differences. First, there is no post-processing. The base station uses a radio to transmit corrections to the rover while data is collected. These transmissions lead to the second difference, which is that RTK requires seconds to initialize instead of minutes. To establish a control MON using RTK, we need to observe a point for at least 30 seconds. The 30-second observation time almost guarantees that the data is sub-centimeter quality.

Real-time kinematic survey style setup

We said earlier that RTK is the preferred method of survey, but it is not the preferred method of establishing control. However, in the Air Force, time becomes a major consideration. The job of the surveyor is to determine what is "good enough" to accomplish the mission within the given amount of time. Let us approach RTK in the same way we did PPK, by going through the survey style and examining four RTK options—base, rover, rover radio configuration, and base radio configuration. Let's begin with the base options.

Base options

The first part of the survey style we set up is the base options. The first page of base options has options for the survey type, broadcast format, and antenna parameters (fig. 2–83). Our survey type is set as RTK, obviously. The broadcast format is CMRx. CMRx stands for compact measurement record. This is a broadcast format unique to the current supplier of Air Force survey equipment. A broadcast format is the way that the radio configures the transmission for the rover and how the rover uses these signals to correct for its position. It is important that the base and rover options have the same broadcast format. The antenna parameters refer to the satellite antenna of the base and not the radio antenna. The documentation that comes with your survey equipment will give you the information to fill in these parameters.

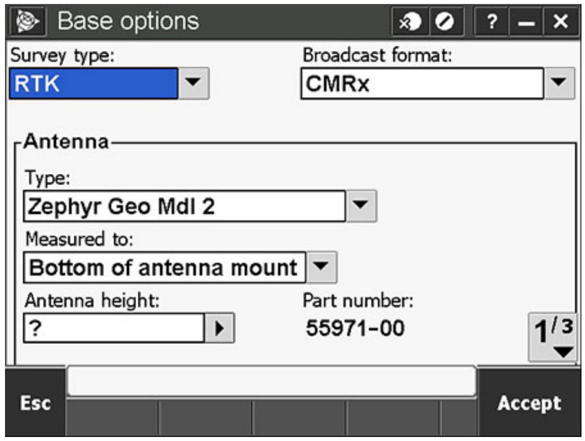

Figure 2–83. RTK base options menu - page 1.

The second page of base options covers the station index and the elevation mask (fig. 2–84). We have already discussed the elevation mask in both the Static and PPK lessons. The station index is of more importance here. The station index is the number that you give it to identify it amongst other base stations. When you begin to measure points on the rover, the controller will ask you to choose the base station from a list; the index will be the number indicating this base station on the list.

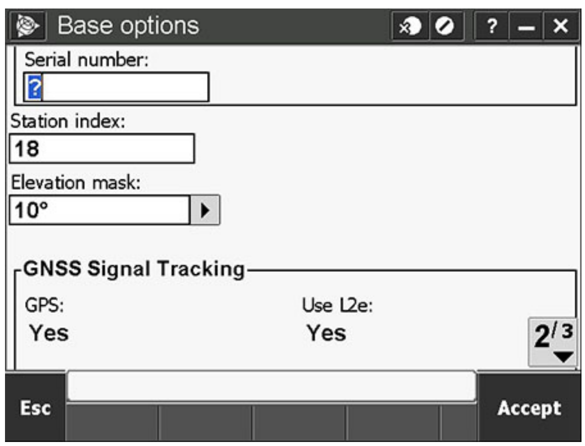

Figure 2–84. RTK base options menu - page 2.

The third page, like in the PPK base options, provides you with the option to ignore certain satellite constellations.

Rover options

The first page of rover options looks identical to the base options. The options are for survey type, broadcast format, and antenna parameters. The only options here that need to be the same as the base options are the survey type and broadcast format. The antenna options may be different to allow different types of equipment to work together. This gives us, the surveyors, more flexibility in which tools we use.

The second page has options that are specific to the rover (fig. 2–85). The first is the "Use station index" option. This allows you to tailor which index numbers that the rover will list and which it will ignore. If we set it to only look for a station index of 18, and if stations 20 and 21 are transmitting, then the rover will not list them when it comes time to select a base station. The prompt station index checkbox tells the controller to ask you before selecting a base station.

Satellite differential refers to the locale correction networks. In America, we use the Wide Area Augmentation System (WAAS) and in Europe, they use the European Global Navigation Overlay

Service (EGNOS). Both WAAS and EGNOS provide a safety net for RTK surveys. For example, if you survey using RTK and lose signal with your base station, and you set the satellite differential to "WAAS," then the WAAS network will provide corrections to the rover until connection to your base station is reestablished.

The remaining options are already familiar to us. They are the elevation mask and the PDOP mask.

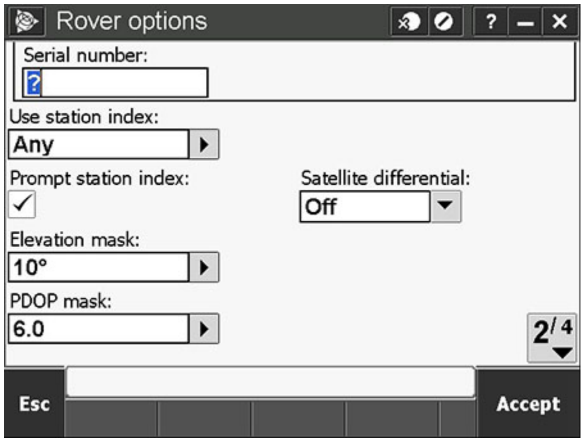

Figure 2–85. RTK rover options menu - page 2.

The third page of rover options, like the third page of base options, is where we can turn on and off specific constellation signal tracking.

On the fourth page, the auto tolerance checkbox is outlined in "Roving precision." The checkbox turns on the receiver's automatic calculation of horizontal and vertical precision tolerances. If unchecked, the controller prompts you to provide horizontal and vertical baseline tolerances. Most often, this box is left checked.

The "xFill" checkbox turns on and off continuity when signal to the base is lost. Most satellites have a specific band, L-band, for providing interim corrections to rovers that have lost connection with their base. This is similar to the satellite differential option but does not require the local correction networks of WAAS and EGNOS.

We are already familiar with the last option, which is tilt (fig. 2–86).

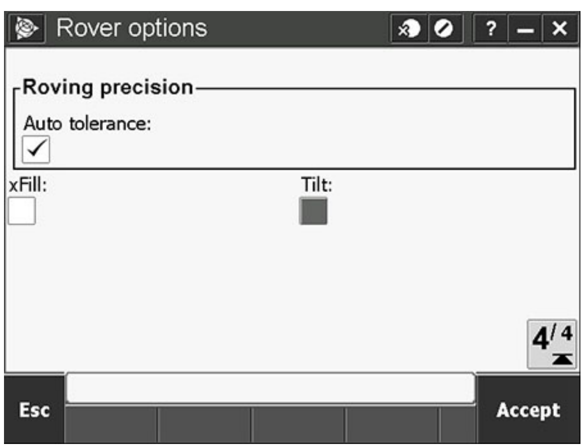

Figure 2–86. RTK rover options menu - page 4.

Rover radio configuration

During an RTK survey, the rover and the base will exchange signals. The rover and base will analyze the characteristics of the signal to determine corrections for the point data. The most common way the rover and base exchange transmissions is through radio waves. We have already seen an indication of radio use when we talked about broadcast format. The rover radio will receive and transmit data to and from the base. Since we are using an R10, we set the radio to "Receiver internal" (fig. 2–87). This will use the R10 receiver's on-board radio to transmit and receive. Some older rover and base receivers will have an external radio, and the data link options must be of that type.

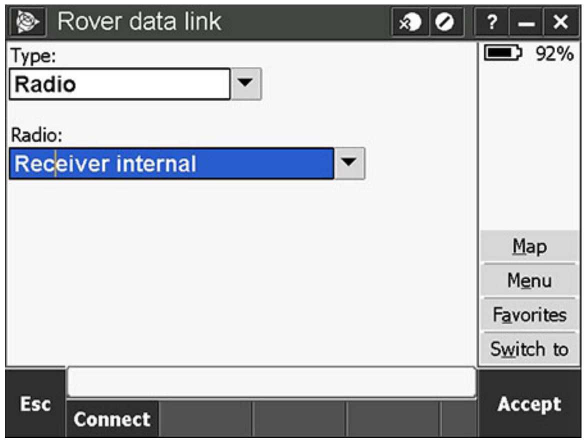

Figure 2–87. Rover data link menu.

We now have our data link type and our radio selected. The next thing is to configure the radio in the receiver itself. All the options so far have been controller options. When we select the "Connect" button at the bottom of the data link screen, the controller will connect to the receiver and display its radio options (fig. 2–88). Here, we need to set the "Radio operating mode" to either rover or base (rover in this case). Then, pick a radio frequency that our rover and base will share. The radio frequencies need to be the same for both the rover and base station. This rule applies for the "Base radio mode" as well. The radio mode describes to the rover and base how to format the radio transmissions.

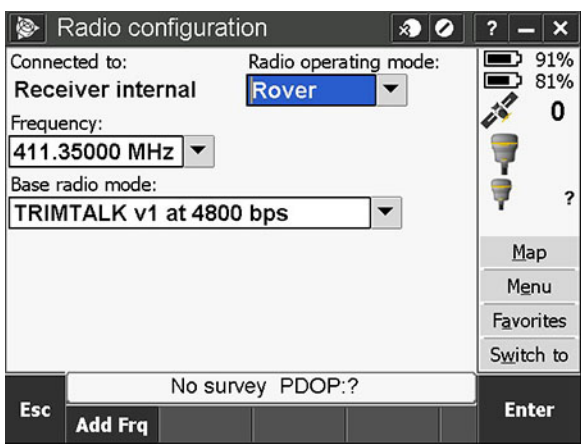

Figure 2–88. Receiver rover radio configuration.

Base radio configuration

Let us move on to the base station radio. Under "Base data link," we can connect to the base station's receiver in the same way we connected to the rover receiver (fig. 2–89). The only difference in options is that the base has one called "Repeaters supported." This is how we set and configure the number of repeaters that the base should be prepared for when it begins to survey. A repeater is a radio antenna that takes a radio signal and repeats it. For example, the area we are surveying is too large for the internal radio transmitters in the rover and base to stay in communication. We can set up a receiver in an area at the edge of the base station's transmission range. The repeater will take the base and rover signals and repeat them, extending the transmission area.

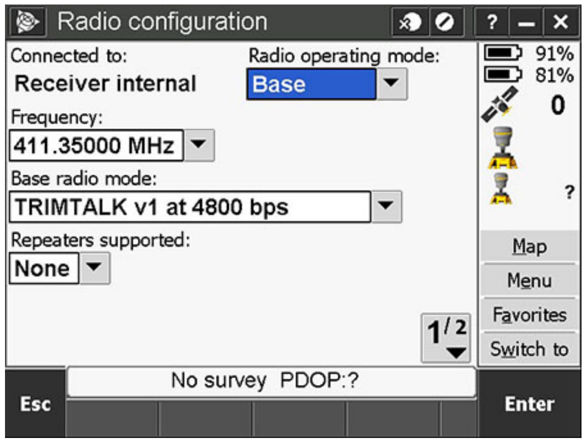

Figure 2–89. Receiver base radio configuration.

With the survey style configured properly, we begin our survey. We set up our base over a known point; connect the controller; and select survey, RTK, then "Start base receiver." We can then disconnect our controller and connect it to the rover to begin measuring points. Once configured, RTK surveys are the simplest to perform.

Cell phone utilization kit

There may be times when using a radio, or access to a radio frequency, may actually limit your ability to conduct a survey. Custom-designed cellular modems or cell phone kits can transmit and receive RTK data. Connect cellular modems directly to your receiver to extend the limits of your surveys. These cell phone kits are small, lightweight, have low power consumption, and are cheap when compared with the cost of radios.

Use cell phone kits in these instances:

- With difficult-to-reach locations.
- Within large project areas.
- Anywhere a radio will be a problem.
- At permanent bases (usually overseas locations).
- When your GPS radio equipment is not consistently used.
- In congested work areas with radio frequencies.

Like any electronic system, there are advantages and disadvantages to using cell phone kits as well. The table below lists both to help you decide what is best for your surveying projects.

Advantages and Disadvantages of Using Cell Phone Kits	
Advantages	**Disadvantages**
• Small. • Lightweight (compared to your typical radio receiver). • Low power consumption. • Economically priced (compared to the cost of radios).	• Difficult to locate a low-cost local carrier for your GPS needs. • Predominantly used overseas. • Capabilities vary by manufacturer.

You now have a good foundation in the methods to start a survey of good quality. This also means you understand how to establish a MON network over an area. From this network, any surveyor can take measurements of construction, topography, and so forth. The manual method you learned will not be a common practice but further reinforces your understanding of survey theory. It gave you a way to approach the practice of survey. The GNSS methods will be the most common. Utilizing GNSS depends upon the level of planning. The online tools in this unit help you find the best times of the day to survey for the area that you are in to ensure the highest quality. Once you have surveyed a control point, you learned the procedure used to establish the physical marker for use by yourself and other surveyors.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

011. Planning a Global Positioning System survey mission

1. What is the Web address for the online planning tool?

2. How many satellites are there in the GPS satellite constellation?

3. When is the number of satellites screen useful?

4. Describe a good DOP arrangement.

5. How does the ionosphere affect satellite transmissions?

6. What is the main thing that GPS surveyors can control?

012. Establish control—Global Navigation Satellite System—static

1. Where is the Survey Styles option located in the survey controller software?

2. What are the two options groups we are most concerned with when setting up a Static style?

3. As of 2017, what was the DOD ordered to stop using?

4. Where are the L1/L2 FastStatic times located?

5. Where is the “Receiver Files” option located in the survey software?

6. How many files do we need from the controller to process Static survey data?

7. What is the Web address for the OPUS?

8. What file format do we need to convert the base receiver file to before we can get its corrections?

9. Where do we enter the corrected base coordinates after importing the base receiver file into the post-processing software?

013. Establish control—Global Navigation Satellite System—post-processed kinematic

1. What are the four non-US satellite constellations and who are their owners?

2. During initialization, what four things is the rover doing?

014. Establish control—Global Navigation Satellite System—real-time kinematic

1. What four options are we concerned with when creating a RTK survey style?

2. What are the advantages of using cell phone kits?

Answers to Self-Test Questions

007

1. Permanent markers last more than 2 years while temporary markers last less than 2 years. Permanent markers are MONs of metal encased in concrete while temporary markers can be anything from a wood stake to a piece of rebar.
2. Types C and G.

008

1. $X^{o} + (X'/60) + (X''/3600) = \text{Decimal}^{o}$.
2. The angle and the distance.

009

1. The lowest reading during the wave is the level reading.
2. Sum the values in the BS column and then Sum FS column values. If the math is good, both column sums will be the same.
3. By multiplying the adjustment by the station number.

010

1. Four.
2. Complete an additional round of measurements and include them in the calculation.
3. Performs the same calculations we did during manual survey.
4. First Order: 1:100,000; Second Order Class I: 1:50,000; Second Order Class II: 1:20,000; Third Order Class I: 1:10,000; Third Order Class II: 1:5,000.

011

1. www.trimble.com/gnssplanningonline/
2. 32.
3. When identifying times when you may not have enough satellites for your preferred survey style or times of higher reliability.
4. Even spacing across the whole of the sky within the elevation mask.
5. Slows the transmissions down.
6. When they perform their surveys.

012

1. Listed in “Settings,” located below “General Survey.”
2. Rover Options and Base Options.
3. GLONASS.
4. Measure points options on the first page.
5. In “General Survey” listed under “Instrument.”
6. Two, the .T02 file from the base receiver, and the .t02 file from the rover controller.
7. www.ngs.noaa.gov/OPUS/.
8. .18o.
9. The Projection Definition window.

013

1. GLONASS, Russia; Galileo, European Union; QZSS, Japan; BeiDou, China.
2. Downloading a copy of the satellite almanac, collecting the current time information, logging ephemeris data, and calculating its location.

014

1. Rover, base, rover radio configuration, and base radio configuration.
2. Cell phone kits are small, lightweight, require low power, and are economically priced.

Complete the unit review exercises before going to the next unit.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

19. (007) Which US Army Corps of Engineers (USACE) engineering manual (EM) has comprehensive instructions on monument installation?
    a. 10–401.
    b. 100–5–0001.
    c. 1110–1–1005.
    d. 1110–A–1005.

20. (007) How many years are *temporary* monument markers expected to last?
    a. One.
    b. Two.
    c. Three.
    d. Four.

21. (007) Regarding installing survey monuments, what are the two *most common* soil types?
    a. A and D.
    b. B and G.
    c. C and G.
    d. D and E.

22. (007) For which materials are bronze disk monuments best suited?
    a. Steel and wood.
    b. Sands and gravels.
    c. Concrete and asphalt.
    d. Bedrock or concrete permanent structures.

23. (008) Convert 30º10’20” into decimal degrees to three decimals.
    a. 30.175º.
    b. 30.151º.
    c. 29.175º.
    d. 29.115º.

24. (008) When adjusting a traverse, which columns do we total to get the misclosure?
    a. Angle and distance.
    b. Latitude and departure.
    c. Latitude and longitude.
    d. Northings and eastings.

25. (008) How do we decide the proportion of misclosure a latitude or departure receives?
    a. Quadrant.
    b. Station number.
    c. Portion of interior angles.
    d. Proportion of horizontal distance.

26. (008) What determines the precision requirements of a survey?
    a. Purpose.
    b. Features.
    c. Equipment.
    d. Graduated rod.

27. (009) We prefer level-loop surveys because we can check the
    a. cleanliness.
    b. coordinates.
    c. quality of the survey.
    d. accuracy of the equipment.

28. (009) What value minus the height of instrument (HI) equals the elevation?
    a. Foresight.
    b. Backsight.
    c. Station number.
    d. Distance (in meters).

29. (010) After robotic total station setup, which screen provides you, as the surveyor, the chance to identify any mistakes when entering data?
    a. Controller Results.
    b. Total Station Results.
    c. Survey Setup Results.
    d. Station Setup Results.

30. (010) Which checkbox, in the measure rounds options, tells the instrument to measure without surveyor input?
    a. Target Auto-measure.
    b. Passive Target Detection.
    c. Automatic Target Measure.
    d. Auto-measure Passive Targets.

31. (010) Where in the survey controller menus can you find the traverse computation function?
    a. Second page of the coordinate geometry (COGO) menu.
    b. Second page of the Survey menu.
    c. First page of the Instrument menu.
    d. Last page of measure rounds options.

32. (011) What is the Web address for Global Navigation Satellite System (GNSS) Planning Online?
    a. www.tyndall.com/surveys.
    b. www.thimbal.com/satellites.
    c. www.trimble.com/surveyplanning/.
    d. www.trimble.com/gnssplanningonline/.

33. (011) Which Global Navigation Satellite System (GNSS) Planning Online screen allows you to set the location of your survey?
    a. Settings.
    b. Satellites.
    c. Satellite Library.
    d. Latitude/Longitude.

34. (011) Which Global Navigation Satellite System (GNSS) Planning Online screen lists and provides satellite information in different constellations and allows you to include or ignore specific satellites?
    a. Settings.
    b. Satellites.
    c. Satellite Library.
    d. Latitude/Longitude.

35. (011) In the *best-case* scenario or ideal survey times, which value is *better* if it is lower?
   a. Antenna height.
   b. Satellite elevation.
   c. Number of satellites.
   d. Dilution of precisions (DOP).

36. (011) When is ionospheric information available for consideration for quality control?
   a. After survey.
   b. Before survey.
   c. During survey.
   d. During inclement weather.

37. (012) Where are the Survey Styles functions in the survey controller software?
   a. Below Survey in Options.
   b. Below General Survey in Settings.
   c. Above Instrument in General Survey.
   d. To the left of Instrument in the Survey menu.

38. (012) We have two survey receivers but only one controller. The logging device setting for the rover is
   a. Receiver.
   b. Controller.
   c. Secure digital (SD) card.
   d. Universal serial bus (USB) port.

39. (012) As of 2017, federal agencies, including the Department of Defense (DOD), were ordered to discontinue the use of which satellite constellation?
   a. Galileo.
   b. BeiDou.
   c. Navigation Satellite Timing and Ranging (NAVSTAR).
   d. *Globalnaya navigatsionnaya sputnikovaya sistema* (GLONASS).

40. (012) After setting up the base receiver, we can disconnect the controller; which base option allows us to do this?
   a. Tilt.
   b. Logging device.
   c. Elevation mask.
   d. Global Positioning System (GPS) L2C.

41. (012) When retrieving files from the receiver, which General Survey menu do we select *first*?
   a. Survey.
   b. Instrument.
   c. Coordinate Geometry (COGO).
   d. Global Navigation Satellite System (GNSS) functions.

42. (012) Which two files do we need to post-process the survey data for a Static survey?
   a. Receiver’s .TT2 and controller’s .tt2.
   b. Receiver’s .dat and the controller’s .dat.
   c. Receiver’s .T02 and the controller’s .t02.
   d. Receiver’s .T02 and the controller’s .job.

43. (012) What is the Web address for the Online Positioning User Service (OPUS) processing service?
    a. www.gps.ncaa.org/OPUS/.
    b. www.ngs.noaa.gov/OPUS/.
    c. www.ngs.ncap.gov/STATIC/.
    d. www.ngs.noaa.gov/SURVEY.

44. (012) Which file format does the Online Positioning User Service (OPUS) Web service require to process survey data?
    a. .18o.
    b. .shp.
    c. .dwg.
    d. .T02.

45. (012) As displayed on the Online Positioning User Service (OPUS) Website, Rapid-Static surveys are *less* than but Static surveys are *more* than how many hours?
    a. 12.
    b. 16.
    c. 24.
    d. 48.

46. (012) The response e-mail from the Online Positioning User Service (OPUS) has a lot of information; what information are we looking for to adjust our survey data?
    a. Elevation Height.
    b. Orthogonal Height.
    c. State Plane Coordinates.
    d. Northing (Y) and Easting (X).

47. (012) When adding the .T02 file to the post processing software, where do you add the corrected Online Positioning User Service (OPUS) coordinates?
    a. Task Pane.
    b. Project Definition.
    c. Import/Export Manager.
    d. Project Properties Window.

48. (012) Under which tab do we find the Process Baselines tool?
    a. Survey.
    b. Drafting.
    c. Corridor.
    d. Surfaces.

49. (013) How many seconds do we set our post-processed kinematic (PPK) observation times to in order to ensure sub-centimeter accuracy?
    a. 15.
    b. 30.
    c. 45.
    d. 60.

50. (014) When setting up real-time kinematic (RTK) survey styles, how do we access the radio settings?
    a. From the data link menu, select Menu on the far right.
    b. Select Connect at the bottom of the radio settings menu.
    c. Select Radio as the data link type and they settings display.
    d. Select Accept after setting the data link options and the radio settings display.

Please read the unit menu for unit 3 and continue ➔

Student Notes

Unit 3. Survey Application

FEATURE DATA COLLECTION and stakeout are the two primary surveys you perform for the Air Force. Feature data is location, elevation, and descriptive data, recorded in a field notebook, that define objects. These include trees, lampposts, rivers, roads, and so forth. We collect this information by measurement for analysis. This is normally as part of planning a construction project or modification to the landscape. Stakeout occurs after the analysis. We stakeout features and points to communicate to the construction workers what we need done at a certain place. The most complex stakeout is that of a road. Engineers shape roads out of the existing terrain in a way that allows vehicle and foot traffic easy travel. Sometimes this involves dramatically reshaping the landscape. The stakeout will explain to the equipment operators how much material we need added or taken away.

3–1. Collecting Features

Along with features, we also collect topography data. Topography is the shape of the ground. We analyze topographic information for its drainage properties. Water control is a primary concern to engineers. Since the shape of the ground directs the flow of water, our surveys explain to the engineer how the water moves in a given area. Aside from water, aircraft crashes and other incidents are a primary concern. Mishap surveys involve the meticulous collection of feature data. Mishap investigators use this data to understand the causes, effects, and nature of how the mishap occurred.

015. Conducting topographic surveys

Topography is the arrangement of natural and artificial physical features of an area. This includes buildings, roads, trees, rivers and so on. Most features are easy to survey. Trees for example are a single point; rivers are points in a line, same with a road. The two most complicated parts of topography to survey are the elevations, or contours, and curves. The quality of surveyed curves and contours depends upon the surveyor. These parts of topographic survey are more of an art than a science, and each depends upon one major factor—the survey's purpose. The purpose can be as general as mapping an area giving major features and rough contours, or as specific as providing contours at 2-ft. intervals for water drainage management. As a surveyor, you need to be meticulous and flexible to fit your skills to the needs of the user.

Reconnaissance survey

The first thing we need to do before we get our survey equipment out is to look at the survey site. We have already discussed what a general recon survey looks like, but topography requires specifics. There are two categories of items to look for once on the site—features and ground shots. Features include all of the roads, buildings, trees, rivers, and so forth. Ground shots refer to places to take measurements of the ground. An example of this is a ditch. A ditch requires at least three points to survey—the top, the bottom, and the opposite top. The key here is to take a measurement at any point of elevation change. How dramatic the elevation change needs to be before we take a measurement is referred to as *resolution*. There are two types of resolution—curve and grid.

Curve resolution

Figure 3–1 illustrates the difference between lower and higher resolution. The left part of the image shows a curve, say a ditch, with only the top, bottom, and opposite top shots measured. The right part shows the same ditch with two more points added. The shape of the ditch is much clearer because the number of points that define it is higher; therefore, the resolution is higher. This concept is applicable to anything with a somewhat round shape, like the curve of a road or parking lot curbing. It also applies to another important concept in topographic survey—*grids*.

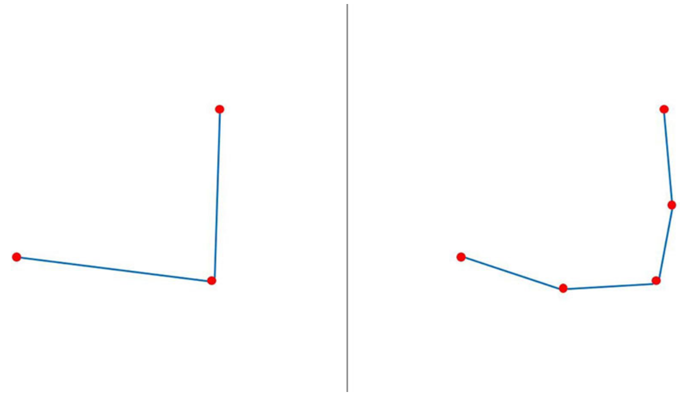

Figure 3–1. Curve resolution.

Grid resolution

When the terrain in an area is relatively flat, it is best to collect topography using a grid pattern. The resolution of a grid pattern depends upon how close the ground shots are together. The closer the shots are together, the higher the resolution. This brings the contours closer to reality (fig. 3–2). In areas where the elevation does not change a lot, the grids can be further apart than if the frequency of elevation changes was higher. The more often the elevation changes in an area, the higher the resolution should be. However, this depends upon the purpose of the survey; water control surveys in a field would need high-resolution grids regardless of how frequent the elevation changes occur.

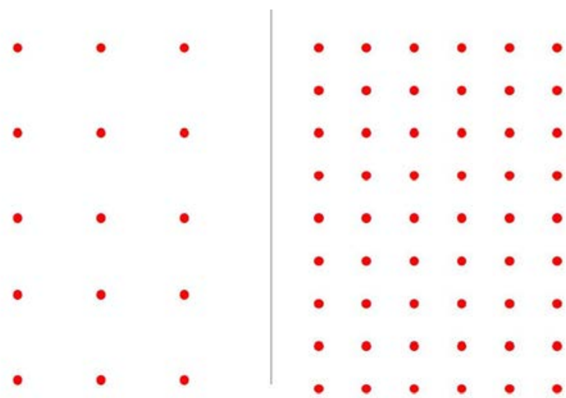

Figure 3–2. Grid resolution.

Feature codes

Depending upon the size of the survey site, you may need to assemble a team of surveyors. The more people that are involved in a topographic survey, the more important uniformity is. After completing the recon survey, have a meeting with the team members to establish a set of feature codes. This will make displaying the features and generating the contours easier when processing the data. Be meticulous during the recon survey to ensure that the team addresses each feature in the code set. Aside from feature codes, this is a good time to discuss the required resolution. Every person on the survey team will need to collect data to the same standard.

Download, convert and/or adjust topographic data

After you establish control, measure the features and ground shots. At the end the survey, you will take the data back to the office for processing. This will involve adjusting/correcting the control, which we covered earlier, and creating a surface and contours. A surface is the way the computer interprets the points you collected. The software will group the points by threes and generate triangles to approximate the surface of the ground. These triangles make preplanning the resolution of the topography grid important.

Import and check survey data

We create surfaces from .dwg, .xml, and .job files, among others. This is important because we can create a group of points in CAD and collect points in the field, create two surfaces, and compare them. In our example, we are going to evaluate the existing ground only from a .job file. We will import our file the same way we discussed importing files for GNSS correction and adjustment. Once imported, we have something similar to figure 3–3 displayed.

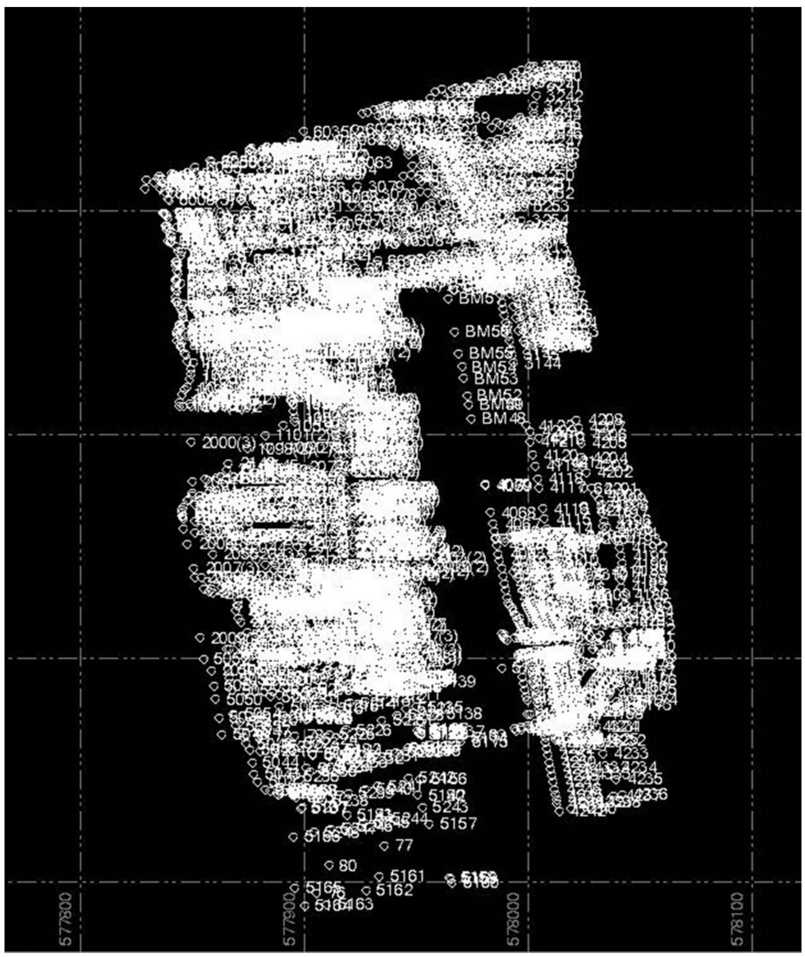

Figure 3–3. Point example.

The first thing you will notice is how confusing this looks. The reason the data is so dense and complex is because of the high resolution of points. Higher resolution topographic surveys will have larger amounts of information. Luckily, we have a piece of software that can make sense of all this information for us. The next step is to create the surface.

Create contours/surface

Under the “Surfaces” tab at the top of the display, in the “Contours” section of the ribbon, there is a tool called “Create Contours (fig. 3–4).”

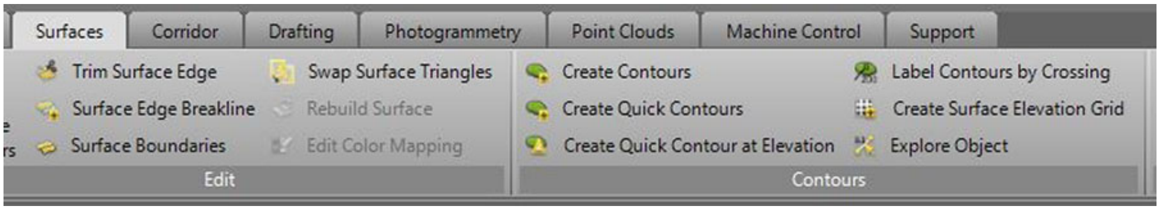

Figure 3–4. Surfaces ribbon.

This will open the “Create Contours” dialog box (fig. 3–5). This menu is our starting point for the creation of contours. It lays out the options and settings for our contours. In addition, some information about the surface is at the bottom of the menu. Notice that we have question marks in our surface information section. This is because we do not have a surface yet.

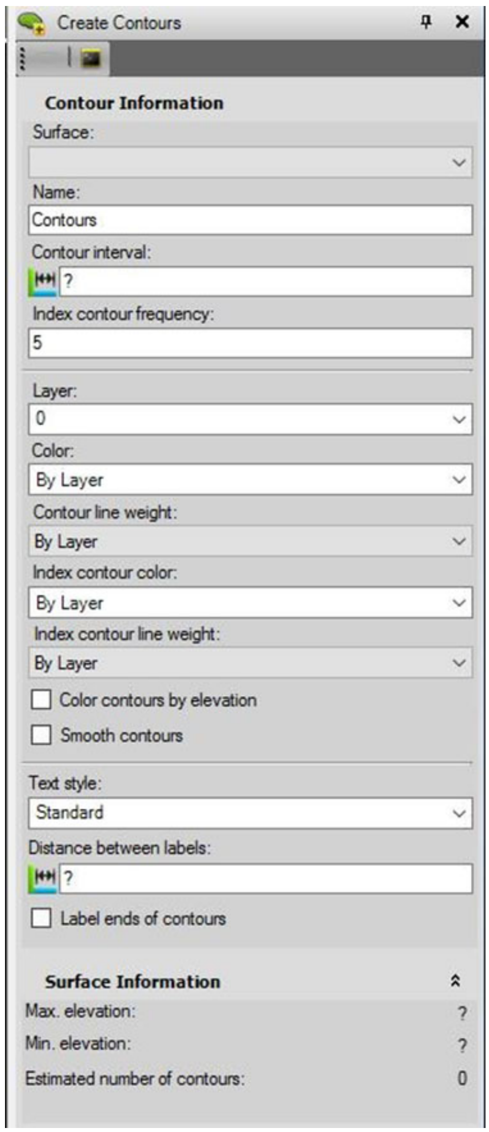

Figure 3–5. Create contours menu.

Create a surface

To create a surface from the "Create Contour" menu, select dropdown list under "Surface." Then select the "New Surface" option. The "Create Surface" menu opens (fig. 3–6). Here we name our surface, classify it by type, and select its members. The points that define a surface are its members.

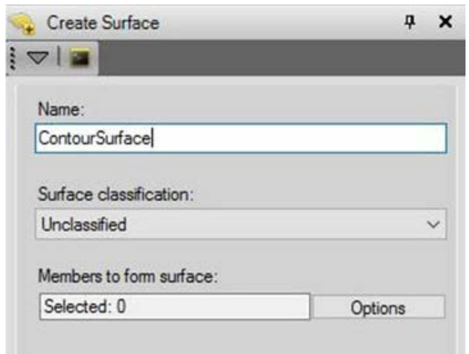

Figure 3–6. Create surface menu.

Once we have given our surface a name and classification, we give it members. At first, there are no members selected, indicated by the "Selected: 0" written under "Members to form Surface." To select members, we select the "Options" button. This will open the "Select Points" menu (fig. 3–7).

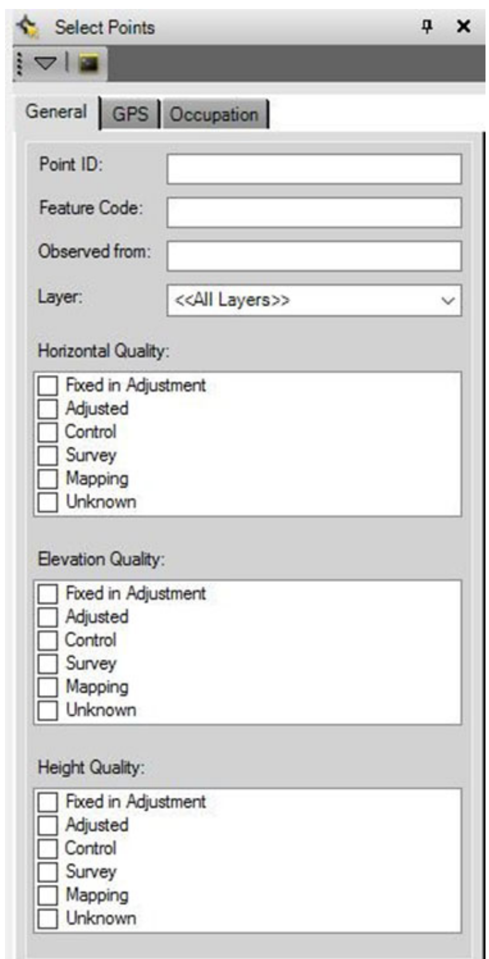

Figure 3–7. Select points menu.

From here, we can select points based upon PointID ranges, feature codes, and from which control point they were observed. For example, if we wanted only the first 25 points of the survey, we enter "1–25" in the PointID textbox. We can also filter the selection by which layer the points are on. The horizontal, elevation, and height quality ranges can also be set. If we want only the points whose measurement was at least survey quality, we select the survey and control checkboxes in the elevation quality section. If none of the options in the menu are selected, the program will default to select all the points after we select OK. Which is what we are doing in the example here.

Selecting OK will bring us back to the "Create Surface" menu (fig. 3–8). Now the "Members to form surface" box has the number of points selected numbered. Selecting OK will generate the surface.

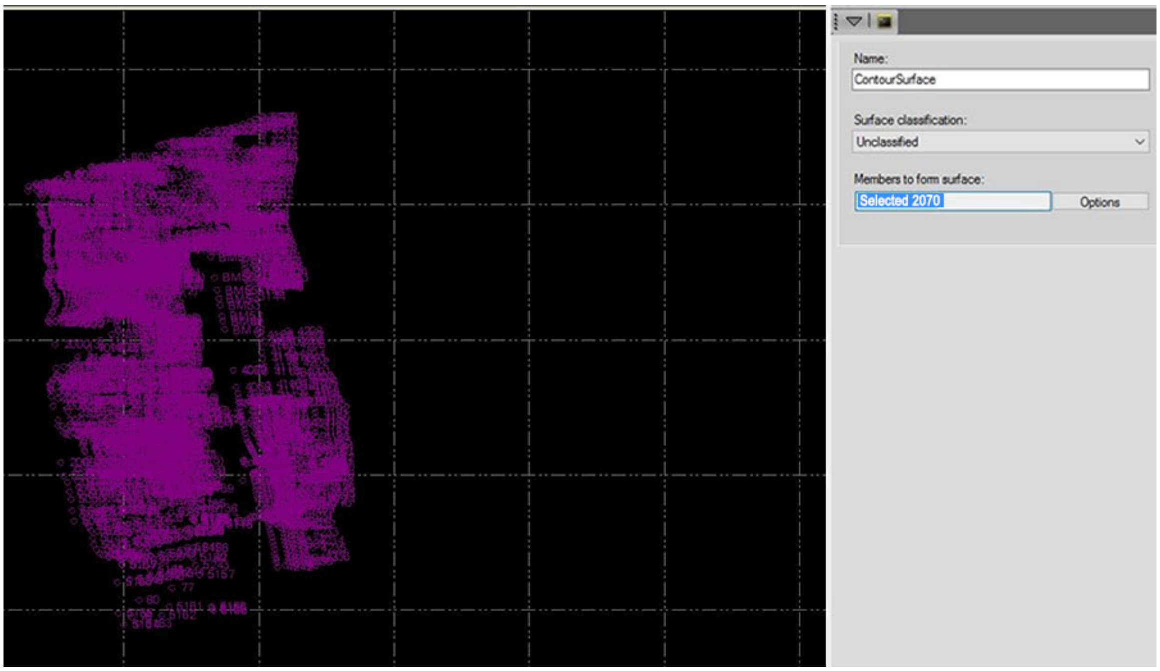

Figure 3–8. Create surface menu with points.

Contour settings

With the surface created, we adjust the remainder of the "Create Contour" settings (fig. 3–9). The "Surface" dropdown contains the name of the surface we just created. The "Name" textbox is where we name our contour group, which is what displays in the project explorer. The "Contour interval" lets us choose the frequency of contour lines. Ours is set to display a contour line every 0.5 meters of elevation change. We can then use the horizontal distance between the lines to approximate the slope of the ground. The "Index contour frequency" field adjusts how often the program generates a contour line with an elevation label. Ours is set to every five contour lines; therefore, every 2 meters, a contour line generates with its elevation labeled.

The options from "Layer" to "Index contour line weight" indicate to the program what color and what weight the contour lines to draw the contour lines. The "Color contours by elevation" checkbox generates each line, based upon elevation, in a different color. The "Smooth contours" checkbox will round off any jagged edges and replace them with smooth curves.

The "Text style" defines how to draw the text on the contour labels. The next section covers this in more detail. The "Distance between labels" option adjusts the minimum distance between elevation labels. Ours is set to three meaning that each block of text, describing an elevation, generates no closer than 3 meters to another. Finally, the "Label ends of contours" option does exactly that—it places an elevation label at the termination point of the contour lines.

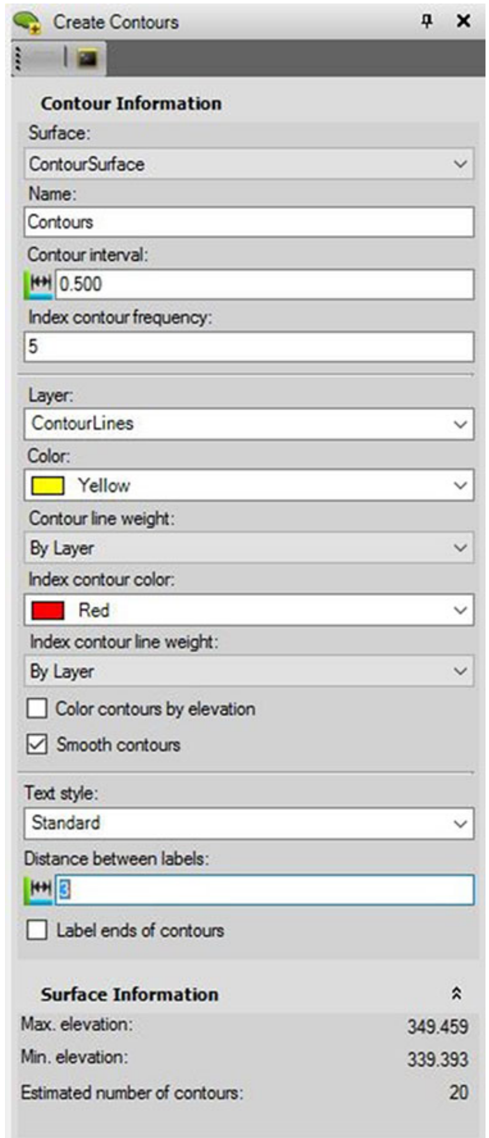

Figure 3–9. Create contour menu settings.

Editing text styles

There will be times when the readability of the elevation labels is poor. To adjust the height, font, and so forth, we need to edit the text style or create a new one. We do this by opening the “Text style manager” under the “CAD” tab, in the “Text” section of the ribbon (fig. 3–10).

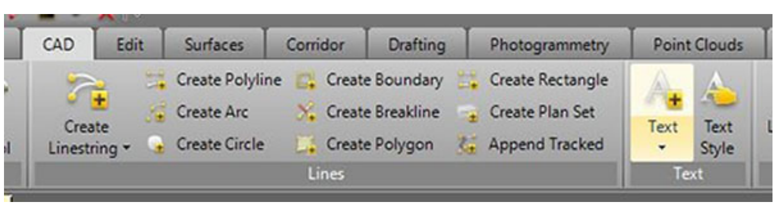

Figure 3–10. Location of text style manager.

Opening the “Text style manager” displays a window with a list of styles on the left and the settings of the selected style on the right (fig. 3–11). Selecting the “New” button on the bottom of the left-side list creates a new text style with the default settings. The settings are similar to the one found in any word processing or CAD program.

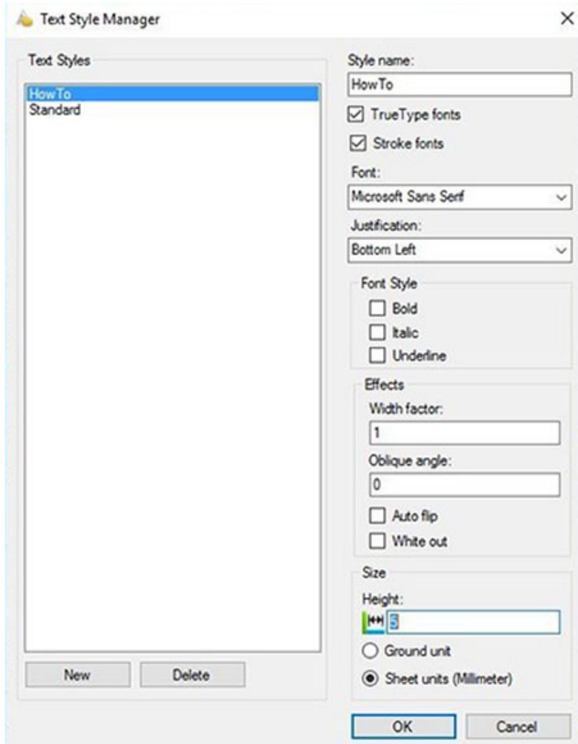

Figure 3–11. Text style manager window.

Exporting contours

The process for exporting contour data is generally the same as for any other. First, we go to the left side of the display into the project explorer and expand the surfaces group. The list shows our contour surface file. When we expand it, our contour file will be listed (fig. 3–12).

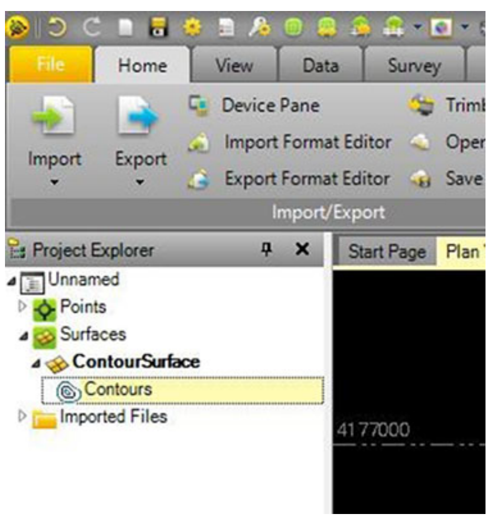

Figure 3–12. Project explorer contour grouping.

Having selected our contour file in the project explorer, we use the “Export” tool under the “Home” tab. This will open the “Export file format editor” (fig. 3–13). First, we select what kind of program we are exporting the data to using the tabs on the top of the menu. Then, we select the specific file format for that program type. In our example, we want a CAD file, specifically a .dwg file. Check to ensure that the "Data" field is populated—ours says "Selected: 180." This means the program selected 180 features to export into the selected format. Then we name the file, and using the ellipsis next to the "File Name" box, select where the file will be stored.

The "Settings" block is broken into two parts. The first part shows the "DWG version." This is useful if we are using an older version of CAD and need an earlier file format so that the file is compatible with the software. "Explode block" will take the file and break it up into discrete elements. Our contours, for example, will be broken into lines and text objects. We set this setting to "off" because we want our contours to remain unified. The "Export point as point block" is the opposite of the explode setting. This will export the objects, in our case lines, as a unified single object. Finally, the "Export unit" sets the units of measure for the exported file.

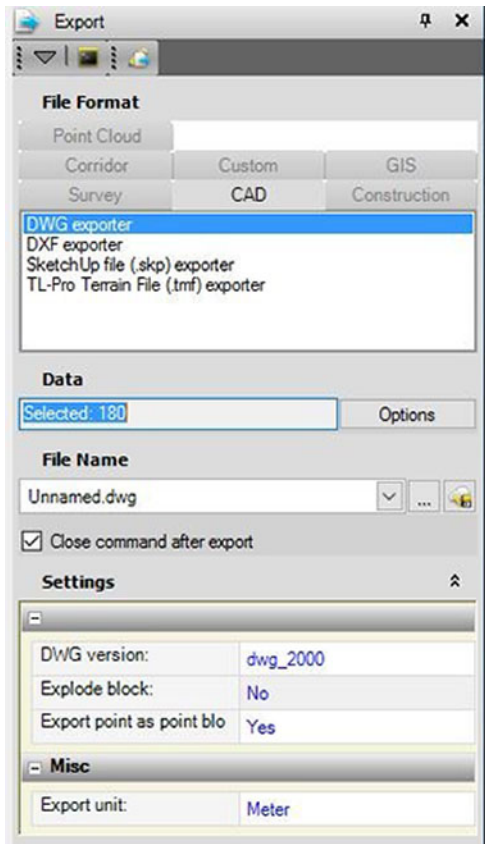

Figure 3–13. Export format editor.

016. Conducting mishap surveys

According to Air Force Instruction (AFI) 34–501, *Mortuary Affairs Program*, the CE squadron will provide survey support to plot remains, personal effects, and aircraft wreckage during search and recovery operations following any mishap in support of accident investigation boards (AIB).

While the procedures for actually surveying a mishap site are similar to a topographic survey, there are many differences. The biggest difference is the presence of damaged or destroyed aircraft other debris, and, potentially, the remains of our brothers and sisters in arms. Immediately following an accident, several organizations quickly respond, gathering data for the mishap investigation. Being prepared and knowing what to expect will help you focus on the task and not get lost in the confusion (fig. 3–14).

Figure 3–14. C5 Galaxy crash at Dover Air Force Base, Delaware.

Planning and preparation

The noncommissioned officer in charge (NCOIC) of execution support is responsible for ensuring that all equipment and materials are available. These items should be ready at all times. Conduct inventory and training every 6 months at an absolute minimum.

The following checklists are not exhaustive or authoritative. They are guides for preparation. Some items seem outdated, but they are useful because mishaps rarely happen in convenient locations. Plan; anticipate dead batteries, lack of access to power or Internet, and uncooperative computer software.

Aircraft Crash Toolbox Inventory			
ITEM	**ISSUE**	**QUANTITY**	**CHECK**
200+ ft. fiberglass tape	each	1	
Compass (bearing)	each	1	
Calculator (trig/scientific)	each	1	
Hub tacks	box	1	
Nails	box	1	
PK nails	box	1	
Hammer, small	each	1	
String	roll	1	
Mechanical pencils 5/7mm	each	2	
Pen, ballpoint	each	6	
Pencil, #2	each	6	
Felt-tip markers, fine point	pack	1	
Felt-tip markers, thick	each	4	
Permanent marker	pack	1	
Eraser	each	2	
Highlighter	pack	1	
Notepad (weatherproof)	each	2	

Aircraft Crash Toolbox Inventory			
ITEM	ISSUE	QUANTITY	CHECK
Clipboard	each	2	
Surveyor's field book	each	1	
Flagging	roll	3	
Flashlight	each	1	
Scotch tape	each	2	
Extra batteries (AA, AAA, 9V, D)	package	12	
Post-its, large (yellow sticky)	pad	2	
Plumb bob	each	1	

Equipment/Materials Inventory			
ITEM	ISSUE	QUANTITY	CHECK
Total station instrument (w/manual)	each	1	
Total station tripod	each	1	
Total station batteries & charger	each	all	
Prism pole	each	2	
Prism	each	2	
Graduated rod	each	1	
Range pole	each	2	
Tripod, range pole	each	2	
Folding chair	each	2	
Small sledge hammer	each	2	
Sledge hammer	each	1	
Pick/chisel/railroad pin	each	1	
Cooler	each	1	
Metal stake flags	bundle	20	
2 inch x 2 inch x 1 ft. hubs	dozen (12)	5	
Global Positioning System (base and rover)	set	1	
Defense advanced Global Positioning System receiver (DAGR)	each	2	
Laptop computer w/accessories and software	each	2	
Compact disc (CD)/digital versatile disc rewritable (DVD-RW)	box	1	

When planning the survey, consider the location of the mishap. If it is on, or near, your installation, then you will still have access to plotters, desktop computers, and sleeping quarters. If the site is distant, you may consider bringing clothes and sleeping, hygiene, and cold weather gear. You may also have to arrange eating and sleeping facilities.

Survey party

The survey party consists of five Airmen from engineering if unit manning allows. This party consists of a survey party chief (SPC), instrument operator (IO), instrument operator recorder (IOR), rod person (RP), and rod person recorder (RPR). The SPC is normally the NCOIC of the execution support section or equivalent 7-level SSgt or above (preferably with previous AIB/mishap experience). If staffing is low, members of the survey party may have to assume more than one responsibility. For example, the SPC can also be the RP and RPR, which is beneficial because he or she will have the experience necessary to determine what data to gather with minimum guidance. The SPC will lead all surveying and mapping operations and be on site at all times.

Initial response

While emergency services are responding to the mishap site, emergency management (EM) will set up a staging area. The chief of execution support, or the SPC, reports to the staging area and meets the on-scene commander (OSC), the base civil engineer (BCE), and/or chief of readiness for a situation brief. The SPC receives initial coordinates of the mishap, names of interim AIB members, convoy times to the site, estimated time-of-arrival for the official AIB, and any other pertinent information.

On-site arrival

A controlled area is set up around the perimeter, and site entrances are limited to entry control points (ECP). The SPC will receive a detailed briefing from the OSC regarding site access. Before approaching the mishap site, it's most important the SPC communicates with emergency managers and hazardous material (HAZMAT) personnel, since aircraft can carry several types of dangerous/hazardous materials. Be aware of the presence of any materials or items in the following list:

- Nuclear accelerators (in the engines).
- Depleted uranium and/or other radioactive components.
- Missiles/rockets.
- Bombs/explosives.
- Ejection seat explosives.
- Canopy jettison explosives.
- Fuel/hydraulic fluids.
- Hydrazine.
- Human remains.

Most of these are contained before the survey starts, but it is possible that fuel, other fluids, and explosives could still be present. If you find explosive equipment during the survey, *stop* and evacuate the area. *Do not* use the radio or any other electro-explosive hazard equipment to communicate discovery of explosives. Immediately send someone to notify explosive ordnance disposal (EOD) or the OSC. Remember to ask the OSC if the area is safe for the survey team to move about freely before entering the site. If so, the SPC is free to begin a recon survey.

Reconnaissance survey

A thorough recon of the area is important before surveying. The recon survey is a visual inspection of the mishap site for hazards and obstacles. The recon survey gives you an idea of the size of the survey area. The SPC should be able to use the recon survey to establish an approximate timeline. The SPC should conduct the recon, preferably with the OSC or interim AIB present. This is an opportunity for the SPC to clarify priorities and concerns.

Aircraft mishap survey procedures

Aircraft mishap surveys are stressful and unpredictable. Flexibility and communication are keys to success. The more familiar you are with the following principles, the better you will perform during a mishap survey.

Establishing control/instrument setup

Like all surveys, establishing control comes first. To establish temporary MONs, either traverses from a known MON, or use a GPS base station and get second party confirmation of the data. If the mishap is on base, control will be easy to establish. When off base, establishing horizontal control may not be as easy. If you do not have a known starting point, consult with local authorities in the area of concern. If all else fails, use the north stake method:

1. Set a stake for the instrument.
2. Set another stake 20 to 30 ft. away exactly at North using a magnetic compass.
3. Zero the instrument.
4. Start surveying.

The north stake will be the zero angle for your survey. Make sure to set baseline hub stakes in a safe location away from emergency and recovery vehicles, their driving lanes, and areas of high foot traffic. It is also important to mark their location to keep the MONs from being disturbed. Once control is established, the bulk of the survey can begin.

Survey

Gaining experience and consulting with the OSC will help you determine which items to survey. Keep in mind that the primary purpose of the survey is for the mishap investigation. The forensics teams use mishap site data to determine impact angles, velocity, and potential causes of the mishap. The primary items are any human remains, points of impact, burn areas, and major aircraft parts. Initial recon needs to be thorough enough to establish priorities for the investigation team. If human remains, explosives, and classified material are discovered and removed before the survey team begins, ensure their locations have been properly marked. There are five things to remember when executing a mishap survey—topography, the way items will be marked, field note consistency, survey equipment, and imagery for the report.

Topography

A big part of a mishap survey is getting the shape of the landscape by collecting topography. Depending on the nature of the mishap, very detailed topographic data may be necessary. Some mishap sites, or areas near or around a site, could require 2-, 1-, or even ½-ft. survey intervals.

Marking items

Every item will be marked and photographed. Coordinate with photographers, usually from public affairs, and investigators for using a system of marking flags. Each point must have a reference number corresponding to the flag number as part of its name. Without these reference numbers, it will be difficult to match photographs, notes, and survey points to each other later in the process. A good practice is assigning component categories point numbers in series of thousands. For example, aircraft parts could be a one thousand series; impact points a two thousand series, human remains a three thousand series, and so on.

Recording field notes

Field notes easily become messy without a solid plan to keep them organized. Plan ahead of time for how different areas and parts of the site will be marked. A good practice is to establish naming conventions for each data-point type rather than consecutive numbers. Using this method, each point will have a unique easily identifiable name. The following table provides some naming convention examples.

Aircraft Crash Site Sample Naming Conventions	
Item	**Abbreviation**
Aircraft	acft
Weapon	wpn
Impact point	mpct
Human remains	hum

Aircraft Crash Site Sample Naming Conventions	
Item	**Abbreviation**
Wing	wng
Fuselage	fus
Right	rt
Left	lt
Forward	fore
Rear	aft

Using the thousand series and field note naming convention methods, the fifth recorded impact point of the rear right wing is 2005_mpct_rt_aft_wng. It is *critical* that any naming convention be the same for all survey party members!

Surveying equipment

Aircraft mishaps never happen at opportune times or in ideal places. While it seems simple to reach for GPS survey equipment, remember the limitations. If there are mountains, trees, buildings, poor satellite coverage, radio restrictions, or other factors, GPS surveying will not be the best option. Use the information from the recon survey to determine the best equipment to use. The best solution may be to use one as primary, and supplement with another.

Imagery

The AIB will need imagery for the final report. It will allow them to communicate a visual of the site to DOD personnel in the investigation process. Obtaining imagery for off-base and remote locations will be challenging. Check with local government agencies to see if they have data readily available. In addition, check with your major command (MAJCOM) functional manager and with the Air Force Civil Engineer Center (AFCEC) reach back center. In an emergency, either of these agencies will go to great lengths to help you get what you need.

Final report

A typical final report should be a presentation bound on 8 ½ x 11 inch paper. The length depends on the type of information the investigation team requires. At a *minimum*, the report should consist of the items described in the following table:

Final Report Contents	
Item	**Description**
Cover sheet	Self-explanatory. Information usually provided by the investigation team.
ToC	Outline of section headings and sub-headings.
Introduction	Purpose, objective, and survey party list.
Local vicinity site map	Showing the relationship of the mishap site to nearest installation.
Overview plan mishap site	The immediate mishap area with surrounding area, facilities, trees, and so forth.
Plotted trajectory plan view	An overhead view showing impact zones, burn areas, cut trees, scrapes, major parts, and the centerline of the trajectory of the main fuselage and any other main trajectories. If available, plot eyewitness locations, wind direction at time of mishap, and flight path. WGS 84 grid on all maps will be helpful to the AIB.
Profile	Show elevations of existing ground in relation to impact area depths, scrape depths, angle of descent, and so forth.

Final Report Contents	
Item	**Description**
Grid overlay	If required, overlay should cover all parts of mishap site. The overlay is necessary when all aircraft parts are to be transported to another location, such as a hangar, in order to be set up to exactly re-create the existing crash site and allow for a more detailed investigation under better conditions. The grid overlay should have WGS 84 coordinates.
Soil sample location map	Show locations of all samples taken, contours of area, and any other pertinent information such as natural drainage.
Parts listing	A list of all parts including the description of the part with station number. It is a good idea to include an "A" with all station numbers depicting parts, a "P" for personal effects, and an "X" for human remains.
Glossary of terms (optional)	If there are many surveying terms mentioned, explain them.
Recommended miscellaneous items	Larger scale maps will be necessary for the AIB. Ensure an accurate scale and north arrow is included on all plotted maps. Maintain a financial disclosure statement to track all expenses incurred. AF policy prohibits the wing from budgeting for disaster recovery. Specific information as to what items are reimbursable is contained in the Stafford Act. This information should be available in the installation legal affairs office. Lessons learned include encountered areas of difficulty and any recommendations for improvement for the next aircraft mishap survey.

Nobody plans to have a mishap. In many instances, because of the breadth of our career field, engineering personnel are often the most experienced people on a mishap site. Members in leadership positions often look to engineering for advice.

Practice and prepare early. It is better to have a skill and not need it, than to need a skill and not have it.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

015. Conducting topographic surveys

1. What are the two types of resolution in topographic surveys?

2. In the post-processing software, where is the "Create Contours" tool located?

3. When selecting points in the Select Points menu, what happens if we leave all the options blank?

4. What does the Contour interval setting do?

5. What does the Index contour frequency setting do?

6. What does the smooth contours checkbox do?

7. Where is the text style manager located?

8. Where is the export tool located?

016. Conducting mishap surveys

1. How often should mishap survey training and equipment inventory occur?

2. Why is it important that the SPC speak with HAZMAT personnel upon site arrival?

3. Upon discovery of explosives, what is one way of communicating you should not use?

4. What three purposes do forensics teams use mishap site data?

5. What are two agencies you can check with to get site imagery?

3–2. Feature Stakeout

The majority of the time, we stakeout three types of objects—buildings, utilities, and roads. These stakeout operations bridge the gap between the engineer's plan and the equipment operator's skills. Each object type has specific characteristics that allow it to function. For example, we lay sewer pipe with a certain slope to allow gravity to move the waste. The utility stakeout survey communicates this requirement to the laborers installing the pipe so that it functions as intended. Laying out tents is different. When we deploy, tent layout is time-sensitive. This time constraint means that setting up the equipment and slowly placing stakes is not practical. Luckily, we can use a trick of geometry to place 10, 20, 50, or 100 tents.

017. Stakeout buildings and utilities

We can talk about basic stakeout in two parts—utility stakeout and building stakeout. Engineers place utilities in different ways depending upon their type. Water lines have one slope, while storm sewer pipes have another. Functioning a certain way means installing a certain way. We construct buildings, on the other hand, with foundations angled to drain water a certain way. Again, that bridge between the engineer and the labor is the stakeout survey. To communicate the installation requirements from the engineer to installers at the site, we place stakes using a stakeout survey.

Utility stakeout

Services placed underground fall in the *utility* category. Utilities include water, sewer, fuel, communications, and electrical. We bury utilities below the finished surface, whether that is a road, airfield, or an open field. We, as surveyors, must know how to indicate to equipment operators how deep to dig.

Except for sewer, all utility stake out procedures are the same. Sewer differs because fluid is gravity-fed and sewer lines need a certain slope. When staking out other utilities, use the same principles of IEs, station, and offset stakes.

Considerations

When you stake out a utility, thoroughly review the plan and profile drawings. These drawings will provide important information about project. Specifically, look for horizontal location distances, angles, and junctions. Utility lines connect to existing lines, hydrants, junctions, manholes, valves, and so forth. Find the detail drawings for each utility and any connection point. Detail drawings will have IEs and necessary slope for sewer lines (fig. 3–15). IEs refer to the depth of the bottom inside of a horizontally laid pipe.

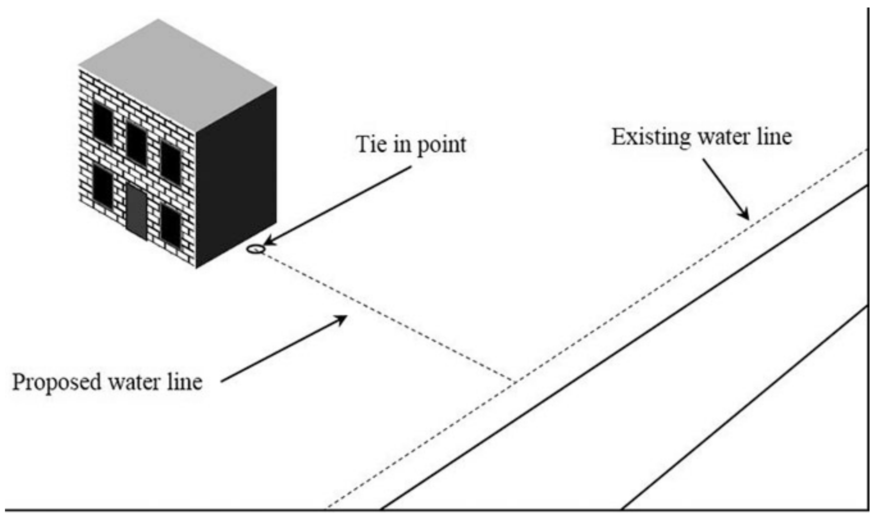

Figure 3–15. Locating existing utilities.

Sewer slope

At various intervals, lift stations lift the waste to move through the next sloped pipe. Installed pipes have uniform alignment and uniform slope. Uniformity prevents dips and turns, which tend to build up of blockages. Drainage pipes do not need to be uniform in size. As waste travels further from the source, more pipes may tie in to the main. This increases flow and the need for larger pipes. A larger pipe will have more fluid and require less slope. The following table shows the slope for different pipe diameters.

Size (inches)	Minimum Slope (inches per foot)	Minimum Slope (decimal per foot)
2 ½ or less	¼	0.020
3 to 6	$^1/_8$	0.010
8 or larger	$^1/_{16}$	0.005

Drainage pipe gradient

Pipe gradient, also called grade, is a technical term referring to slope. It is the difference in elevation (DE), or fall, over a given length between connection points, expressed as a percentage. Fall can be between junctions or a given length of pipe. To find the gradient, divide the fall by the distance.

Gradient = Fall / Distance

<table>
<tr><th colspan="3">Finding the Gradient</th></tr>
<tr><th colspan="3">Example and Solution</th></tr>
<tr><td colspan="3">1. A 235 ft. section of drainage pipe (distance between two stations) has a fall of 4.10 ft.</td></tr>
<tr><td colspan="2">The pipe gradient is calculated as follows:

Gradient = Fall / Distance</td><td>Gradient = 4.10 / 235
Gradient = 0.0174 or 1.74%</td></tr>
<tr><td colspan="3">2. Sometimes, you already know the IE of one station as well as the gradient of the pipe.
To determine the IE of the next station, multiply the gradient by the distance and add the initial inverse elevation.

IE #2 = (Gradient x Distance) + IE #1.

Station 7 + 25 has an IE of 5.75 and the pipe gradient will be at 2.25%.</td></tr>
<tr><td>Determine the IE at station 9 + 25.</td><td>IE #2</td><td>= (2.25% x 200) + 5.75 ft.
= 4.5 ft. + 5.75 ft.
= 10.25 ft.</td></tr>
</table>

Placing offset grade stakes

For this operation, you will need both an auto-level and total station.

Set up the total station on the point where the new utility will connect to the existing one. Turn the instrument to face the connection point at a building or next access point. This process is the same whether connecting to a building or going from junction to junction.

Turn the total station 90° in the direction of the offset and mark a new point. Be sure to place the offset stakes on the opposite side of the ditch from the excavated fill. The second point should be no more than 15 ft. from the start. This allows a safe distance between the work site and the stakes so equipment will not disturb them.

Set up the total station on the new point and BS the point where the new utility connects to the existing one. Turn 90° in the direction of the junction. This ensures the offset stakes are parallel to the trench. Set stakes at designated intervals. Base intervals on the length of pipe sections (one stake at each end of the pipe section). A 100 ft. stretch of pipe with 10 ft. sections will have 10 grade stakes (fig. 3–16).

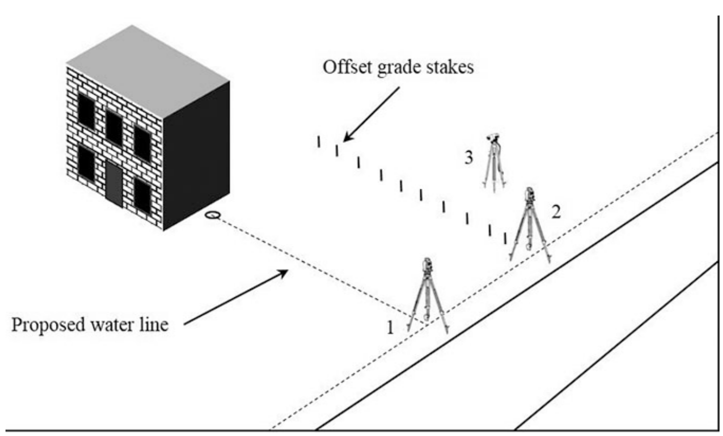

Figure 3–16. Setting offset grade stakes.

Completing the utility computation sheet

Create a computation sheet using two pages in a survey notebook with the same column headings as in figure 3–17. Drive a hub stake in the ground a safe distance from the work site and within direct line of sight—call it TBM A. If available, a nearby manhole cover will suffice. Determine TBM A's elevation through either construction drawings, GPS, or elevation transfer from a known point. Add the elevation of TBM A to the backsight rod reading to determine the HI. Record each station's FS reading. Subtract the rod reading from the HI to get the station elevation. After taking the final station FS reading, take a FS reading of TBMA to close the loop.

DESIGNATION UTILITY LAYOUT DATE Oct 21, 2015

A1C Johnston Ø TSgt MJ Zee

A1C Young Ø 1lt D Gartland

STA	BS	HI	FS	ELEV	INVERT ELEV		CUT	ADJ CUT	ADJ GDE ROD		OFFSET DIST	REMARKS
TBM "A"	4.65			130.28								TOP OF MH "A"
		134.93										
0+00			5.2	129.7	122.64		7.1	7.5	12.7		15'	GND SHOT FRONT STAKE
+10			5.1	129.7	122.74		7.0	7.0	12.1		15'	GND SHOT FRONT STAKE
+20			5.2	129.7	122.84		6.9	7.0	12.2		15'	GND SHOT FRONT STAKE
+30			5.4	129.5	122.94		6.6	7.0	12.4		15'	GND SHOT FRONT STAKE
+40			5.1	129.8	123.04		6.8	7.0	12.1		15'	GND SHOT FRONT STAKE
+50			5.3	129.6	123.14		6.5	6.5	11.8		15'	GND SHOT FRONT STAKE
+60			5.2	129.7	123.24		6.5	6.5	11.7		15'	GND SHOT FRONT STAKE
+70			5.2	129.7	123.34		6.4	6.5	11.7		15'	GND SHOT FRONT STAKE
+80			5.3	129.6	123.44		6.2	6.5	11.8		15'	GND SHOT FRONT STAKE
+90			5.3	129.6	123.54		6.1	6.5	11.8		15'	GND SHOT FRONT STAKE
1+00			5.4	129.5	123.64		5.9	6.0	11.4		15'	GND SHOT FRONT STAKE
+10			5.6	129.3	123.74		5.6	6.0	11.6		15'	GND SHOT FRONT STAKE
+20			5.3	129.6	123.84		5.8	6.0	11.3		15'	GND SHOT FRONT STAKE
+30			5.7	129.2	123.94		5.3	5.5	11.2		15'	GND SHOT FRONT STAKE
1+36			5.1	129.8	124.00		5.8	6.0	11.1		15'	GND SHOT FRONT STAKE
TBM "A"			4.64									TOP OF MH "A"
	Existing IE @ STA 1+36 = 124.00											
	Pipe diameter = 6" Min slope = 0.010 feet / foot											
	Difference in elevation = 0.010' X 136' = 1.36'											
	Invert Elevation = 124 - 1.36 = 122.6											
	Gradient = 1.36'/136 = 1%											

Figure 3–17. Utility computation sheet.

In figure 3–17, the existing IE at station 1+36 is 124.00 ft. We know that the line is a 6-inch pipe, which means it has a minimum slope of 0.01 ft. per ft., or a 1% slope. Over 136 ft., this creates a 1.36-ft. DE. We calculate the IE at each station by taking the previous elevation and subtracting 1%.

Once you have the IEs for each station, determine the cut by subtracting the IE from the station elevation. It is not practical to excavate a trench to the nearest tenth of a foot, round each cut up to the nearest half foot to find the adjusted cut (ADJ CUT). We write the ADJ CUT on the stakes at each station.

Assuming your instrument stays in the same position while equipment operators dig the trench, the adjusted ground rod (ADJ GDE ROD) numbers are also helpful. To find these numbers, add the original FS to the ADJ CUT. As the equipment operators are working, you can use these numbers to verify the depth and gradient of the trench. If you move your instrument, you will need to re-measure the BS, determine the new HI, measure the FS elevation for each station, and rework the ADJ GDE ROD.

With the values for each cut stake, have the rod person stand at each stake, and face the graduated rod toward the instrument. The rod person lifts the rod straight up, holding the base against the grade stake stopping when the IO sees the adjusted FS number. Mark the bottom of the rod on the stake. See figure 3–18 for marking stakes. Be sure to note the station number on the back of the stake, facing away from the ditch.

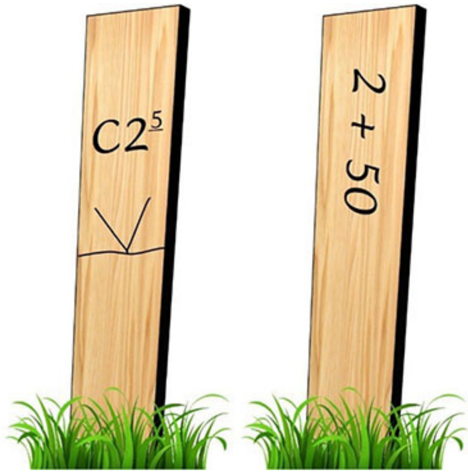

Figure 3–18. Mark cut stakes front and rear.

Batter boards

Utility batter boards are for fine-tuning IEs. While grade stakes measure to the nearest tenth of a foot, batter boards measure to the nearest hundredth. The process to set up batter boards is similar to grade stake setup except there is no offset. Utility batter boards follow the actual pipe trench (fig. 3–19).

First, set support stakes at the same interval as the offset stakes. Be sure they are a safe distance from the ditch and will not interfere with equipment. Set up an auto-level and establish HI. Take FS at each batter board location. Make sure the rod is in the ditch at the IE. Process another computation sheet for the batter boards.

Next, fasten the batter board to the support stakes at the adjusted FS height. Place a nail or other marker on the batter board at the centerline of the pipe. As the construction team installs each pipe, it uses a grade pole to verify final elevation.

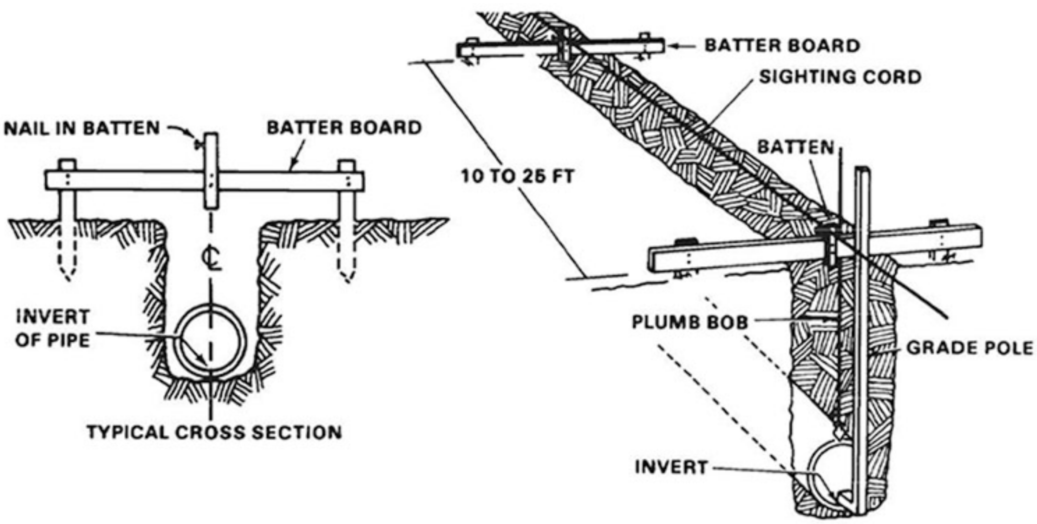

Figure 3–19. Sewer alignment.

Building stakeout

Building stakeout refers to marking a structure's control points, usually corners, by setting up batter boards. These batter boards are temporary devices used to mark the outline and grade of the structure, either inside or outside the building. Although it is possible to use GPS survey equipment to lay out buildings, optical survey is often the most dependable method.

Establish a baseline

The first step of any survey is to establish a baseline, and batter boards are no different. A baseline is the most important part of any survey. The baseline establishes a reference for all other angles on the project (fig. 3–20).

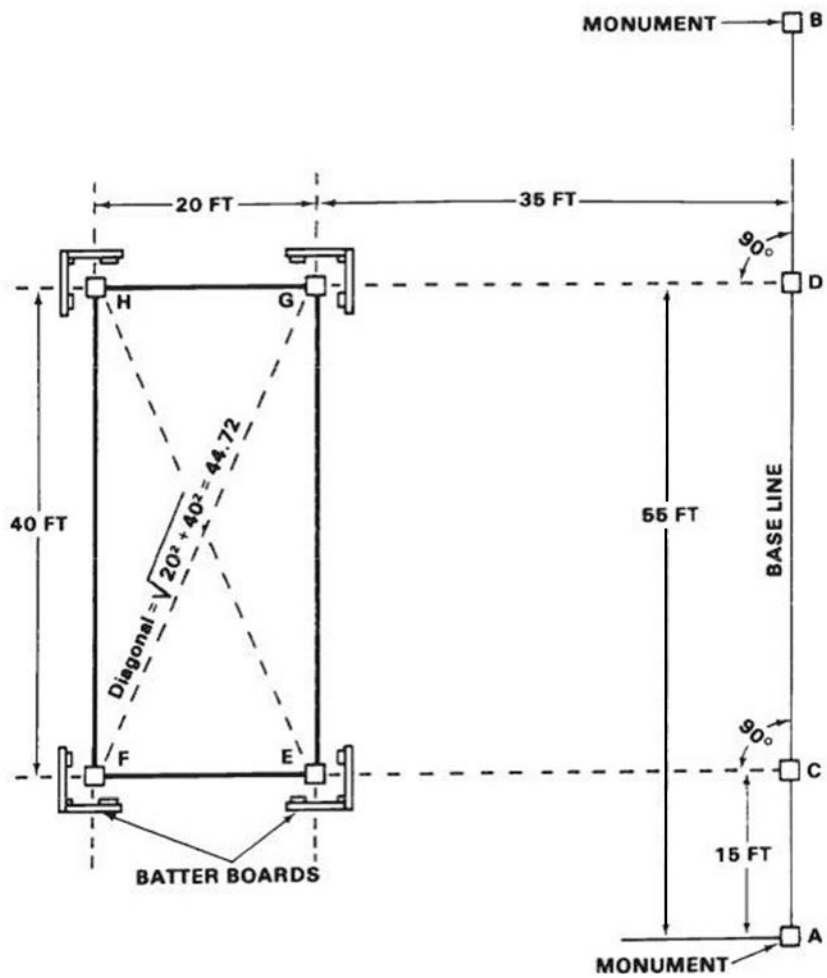

Figure 3–20. Set batter boards referenced to baseline.

The following table lists the essential steps to establish a baseline and lay out the corners of a simple building and batter boards using a total station.

Establish a Baseline	
Step	**Action**
1	Establish point *A* and point *B* as a baseline. The baseline should be no less than 35 ft. from and perpendicular to the building site. 35 ft. allows equipment to move without disturbing your baseline.
2	Determine the elevation of points *A* and *B* either by transferring elevation from a known BM or via GPS.
3	Set up your instrument on point *A* and site point *B* to establish baseline *AB.* Locate *AC* and *AD* along *AB* by tape measure according to building dimensions.
4	Move your instrument to point *C* and site point *B,* backsighting point *A* to ensure alignment. Turn 90° from *B* and locate corner stakes *E* and *F* by tape measure according to building dimensions.

Establish a Baseline	
Step	**Action**
5	Move your instrument to point *D* and site point *B,* backsighting point *A* to ensure alignment. Turn 90° from *B* and locate corner stakes *G* and *H* by measurements according to building dimensions.
6	Check diagonals using $c^2 = a^2 + b^2$, where c^2 is the diagonal with the two sides (*a* and *b)*. If the diagonals are equal then the layout is square.
7	Install 3 support stakes per corner 3 to 4 ft. from the building line.
8	Establish line and grade for the batter boards.

For complex building shapes (fig. 3–21), plan ahead by dividing the building's shape into simple rectangles. Follow the same steps for each rectangle as for a simple building. When each point is located through the process, drive in a hub stake and mark its center.

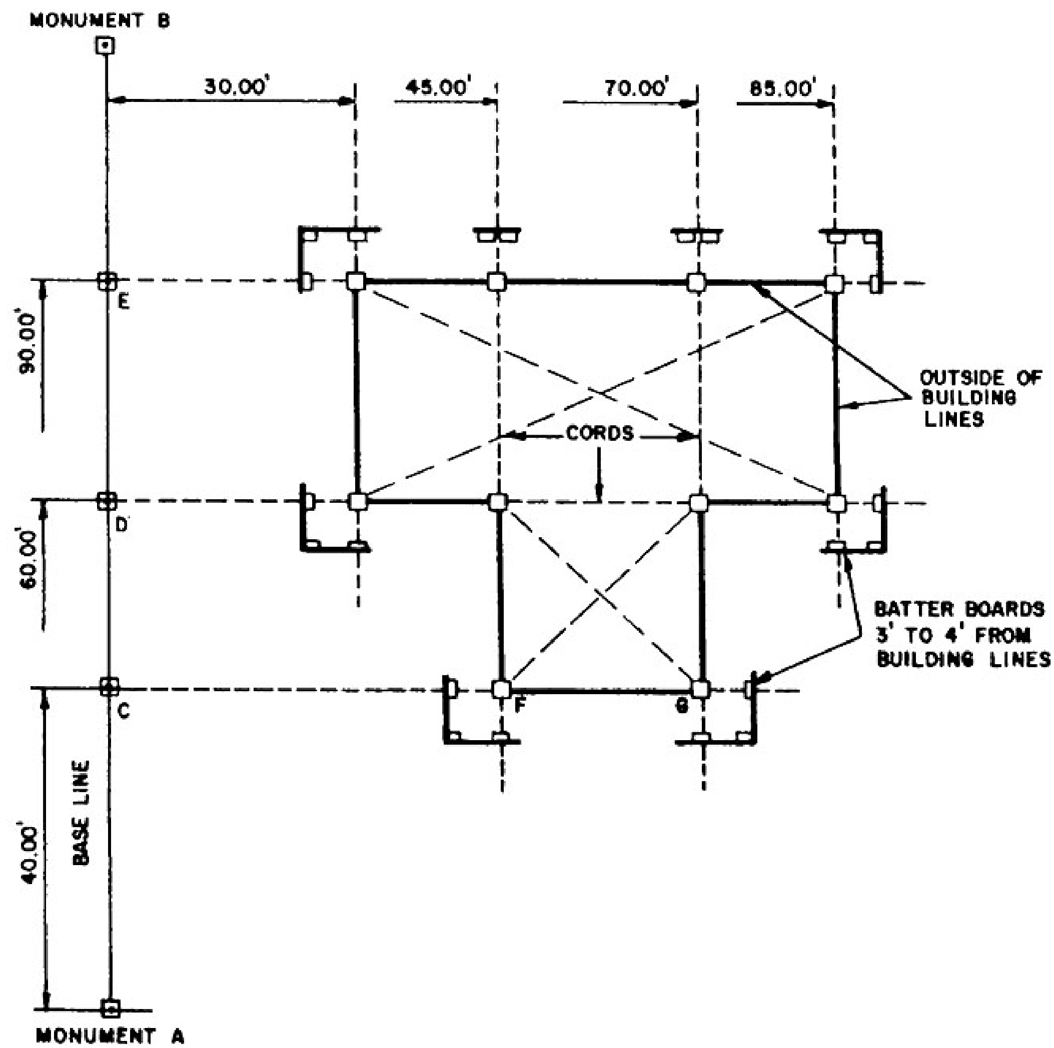

Figure 3–21. Building layout.

Installing batter boards

Once you have located the corners of the building, it is time to set the batter boards. The site plans will have the finish elevation of the foundation. You should be able to measure the elevation of each corner of the building based on the elevations of point A and B on the baseline. An auto-level is the simplest instrument to locate the building lines and to mark them on the top edge of the crosspieces.

Batter boards consist of three 2 x 4 stakes driven into the ground with a crosspiece of 1 x 4 or 1 x 6 lumber nailed to each stake (fig. 3–22). The 2 x 4 stakes need to be tall enough to accept the crosspieces at the same height as the finish grade.

Using the auto-level, determine the difference between the existing elevation of each corner and the finished grade. The DE will be the height of the top of the crosspieces; the top of the crosspiece lumber represents the finished grade. If the existing elevation is higher than the finish grade, install the batter boards outside the building footprint but at the existing grade. Write the amount to cut, measured from the top of the crosspiece and facing the inside of the building.

All batter boards for one structure are set to the same grade or level line. In order to represent the finished grade, attach a string to the crosspieces. Align a nail with the corner hub stake using a plumb bob at each crosspiece. Attach the strings to the nails to represent the outline of the building.

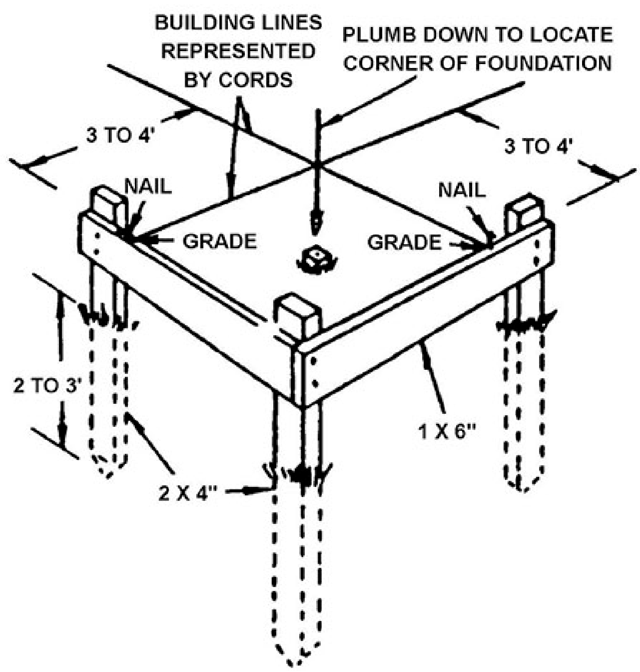

Figure 3–22. Batter boards.

018. Stakeout roads

Once the project engineer has determined the route of a road and computed the horizontal and vertical curves, the final step is to perform a layout survey. This survey will mark the road's route for construction crews. While marking the route, we place and mark slope and grade stakes. These stakes provide for construction of drainage, maintenance of the route, and aid in the computations of earthwork.

Calculating grade and slope stake data

Grade and slope stakes indicate the exact grade elevations to the construction force. Make sure to consult the construction plans to determine the exact elevation of the subgrade, finished grade, and the distance from the centerline to the edges of the shoulder. Set grade stakes after the centerline (or other horizontal control line), and mark with hubs or stakes. Slope stakes are set after the grade stakes.

Preliminary subgrade stakes

Set preliminary subgrade stakes on the centerline and other grade lines. If the roadway is going through a new area, the pavement and equipment crews will need to dig down in order to place the sub-base and base course materials, which support the pavement. First, determine the amount of cut or fill required at the centerline station from the profile plans. *The amount of cut or fill is equal to the grade rod minus the ground rod.* The *grade rod* is equal to the height of instrument minus the subgrade elevation at the station. The *ground rod* is the FS reading at the station. If the result of this computation is a positive value, it indicates the amount of cut required. If it is negative, it indicates the amount of fill.

Look at the example in figure 3–23. Given a HI of 388.3 ft., minus the subgrade elevation of 372.5 ft. means there is a 15.8-ft. DE from the HI to the subgrade elevation. 15.8 ft. is the *grade rod* reading. The *ground rod* reading at the station is 6.3 ft. Grade rod, minus the ground rod is 15.8 ft. – 6.3 ft. = 9.5 ft. of cut at that station. If the grade rod is smaller than ground rod, then you will need fill at that station. Figure 3–24 shows the instrument set up and measurements for three different scenarios.

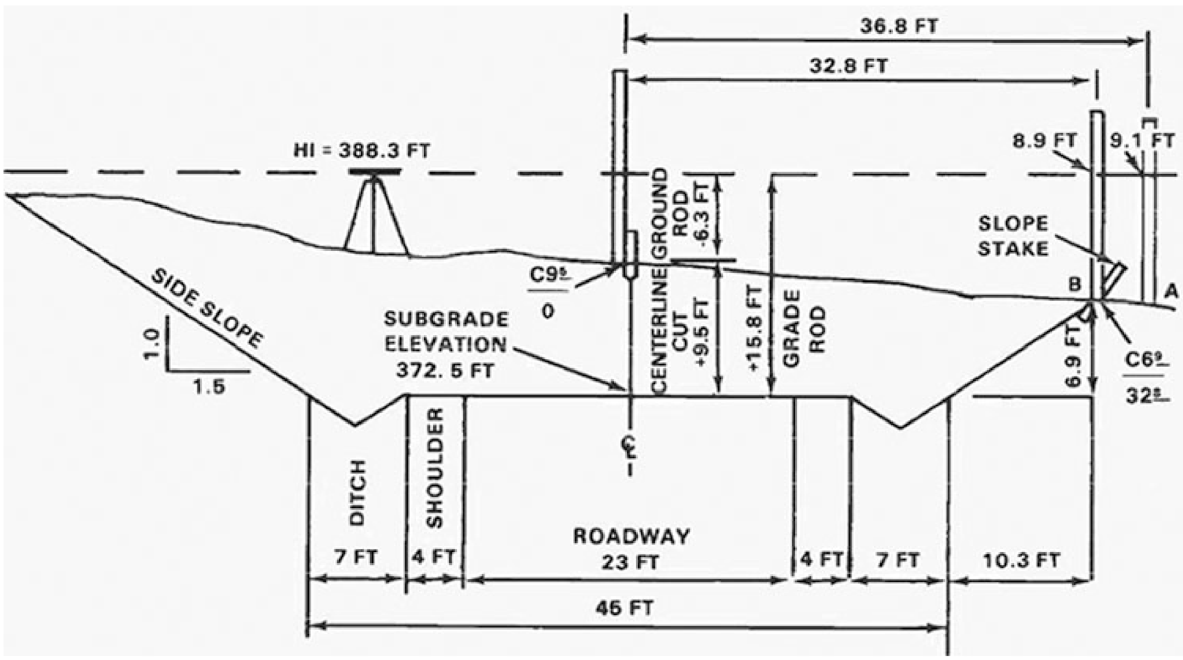

Figure 3–23. Grade rod and ground rod.

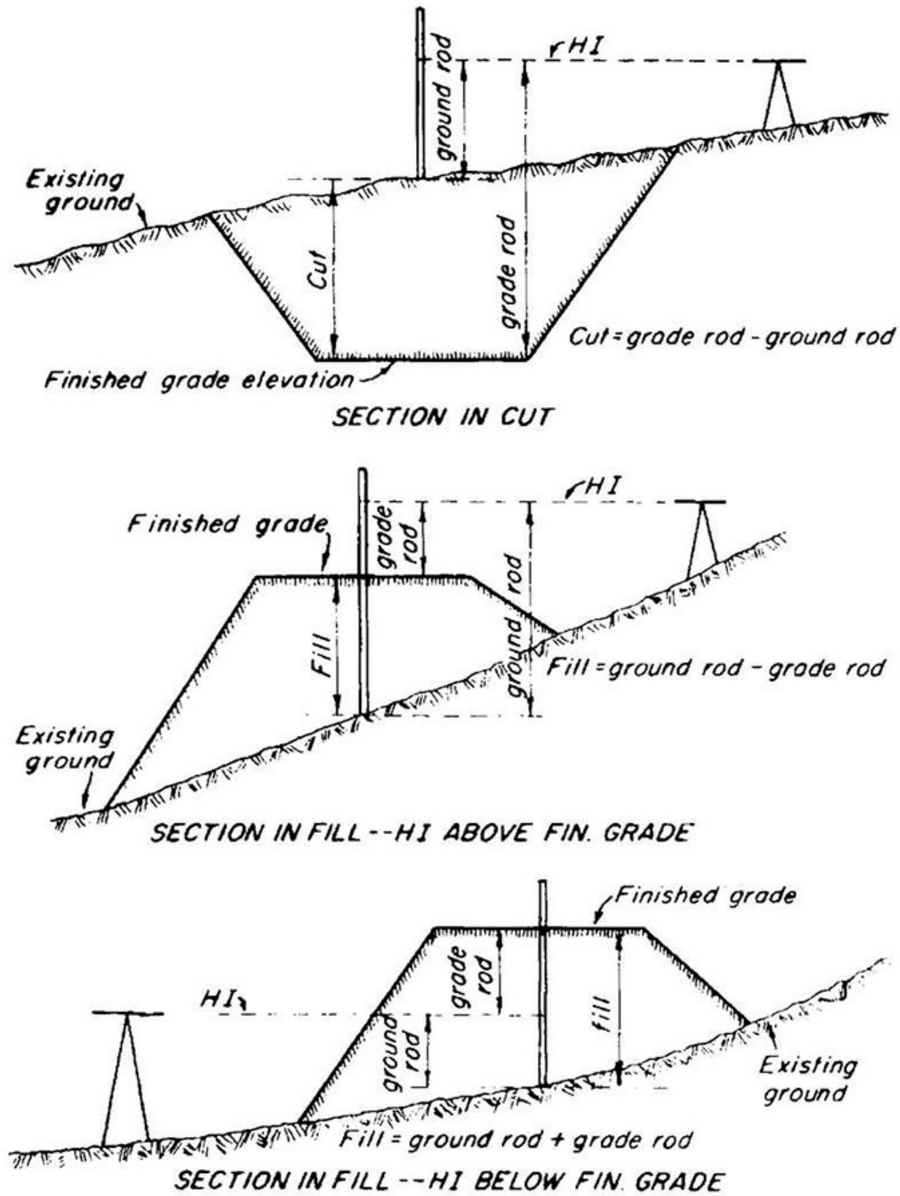

Figure 3–24. Computing cut or fill from grade rod and ground rod.

Marking grade stakes

To make things simpler for the earth-moving equipment operators during rough grading, mark the grade stakes to the nearest half or whole foot (fig. 3–25). There are four different examples of how the grade stake can be marked. The first stake on the left is the front of the stake at station 7+50 on the centerline. Example “a” shows the back of the stake with the amount of cut above the line and the distance from the centerline below it—this one is zero (0) ft. At the base of the stake is a horizontal like with a downward-facing arrow. This provides a quick indication that a cut is required at the station to bring it to grade. Example “b” shows the same information “a” does rounded up to the nearest whole foot. Example “c” indicates a need of 3.5 of fill and that the stake is 14 ft. from the centerline. Example “d” is on the centerline and does not need cut or fill. The site supervisor, not the surveyor, will decide how many grade stakes you will place.

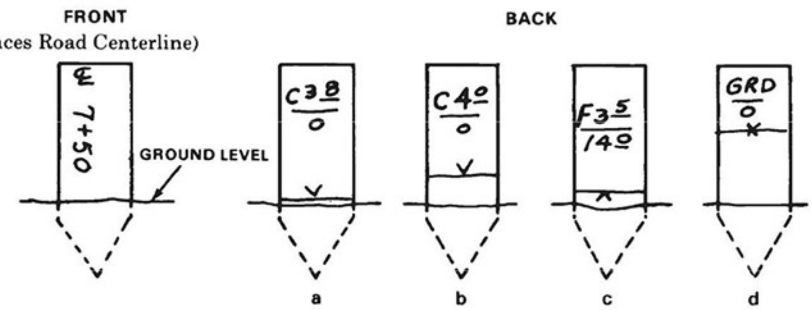

Figure 3–25. Marking grade stakes.

Final grade stakes

Once the heavy equipment operators finish rough grading, it is time to set the final grade stakes, called *blue tops*. When setting blue top stakes, it is very important that the top of the stake be at the finish elevation. The process for determining the elevation is the same as determining the cut or fill for the grade stakes—grade rod minus ground rod (fig. 3–25). Drive the blue top stake into the ground while measuring it against the rod to be certain of the correct height. Equipment operators will bring in material as fill and then grade it until they can see the blue exposed. At a minimum, these need to go at each station, but confirm with the site supervisor to ensure adequate coverage.

Setting grade stakes

You may use the procedures in the table below for setting grade stakes.

Setting Grade Stakes	
Step	**Action**
1	Turn level shots on the centerline hubs (or on the ground next to the stakes) from the BMs.
2	Reduce the field notes and obtain the hub (or ground) elevations to determine the cut or fill at each station.
3	Determine the finished grade elevation at each station from the construction plans.
4	Compute the difference between the finished grade and the hub (or ground) elevations to determine the cut or fill at each station.
5	Go back down the line of stakes and mark the cut or fill on each stake.

NOTE: Record elevations, cuts, and fills in the level notes or construction sheet.

Another procedure you can use to set grade stakes combines steps so that you complete each calculation while at each station and immediately mark the cut or fill on the stake. Take level shots from the BMs. Review the procedure at each station in the following table:

Setting Grade Stakes (Combined Steps)	
Step	**Action**
1	Determine the ground elevation of the station from the level notes to obtain the HI.
2	Obtain the finished grade for the station from the plans.
3	Compute the difference between the HI and the finished grade. This is called the *grade rod*.
4	Read a rod held on the hub top or ground point for the desired cut or fill. This is called the *ground rod.*
6	Mark the cut or fill on the stake.

Follow the steps listed below to mark the finished grade.

Marking the Finished Grade	
Step	**Action**
1	Consult the construction plans and centerline profiles to determine the exact elevations and the distance from the centerline to the edge of the shoulder.
2	Measure the distance from the centerline, at each centerline station, and drive a grade stake at the edge of the shoulder. To prevent construction activities from disturbing the stakes, offset them a few ft.
3	Using a level and a rod, set the top of the stake even with the grade elevation.
4	Measure down from the HI a distance that is equal to the grade rod by subtracting the desired grade elevation from the HI.
5	Set the rod target at this grade-rod reading, and hold the rod on the top of the stake.
6	Drive the stake into the ground until the horizontal hair of the level bisects the target.
7	Mark the top of the stakes with blue keel.

Staking horizontal curves

The procedures below use a curve, computed earlier in the design process. Stake the curve from one of three positions: the point of curvature (PC), point of tangency (PT), intermediate setup, or any combination of the three (fig. 3–26).

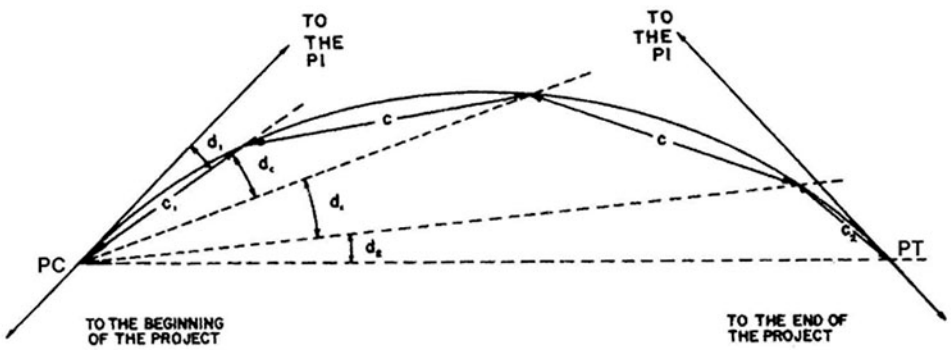

Figure 3–26. Stakeout of a horizontal curve.

Staking from the point of curvature

Staking out a horizontal curve from the PC is a four-step process. These steps do not include the office work of loading the design curve into the survey controller.

1. Set up the total station at the PC. BS the previous point of intersection (PI) or the previous centerline station marker—whichever is appropriate. Point the telescope to the PI and provide the rod person minor corrections until he or she finds the correct location. Mark the location. Repeat this process to mark the PT.
2. Turn back to the PI and verify the sight alignment by backsighting the previous PI or the previous centerline station marker.
3. Turn each deflection angle, calculated in the office, repeating the same process of communicating with the rod person. Stake each chord and subchord length.
4. Move the total station to the PT. This now becomes the PC to repeat the process as necessary.

Staking from an intermediate set up

There are times when curve stakeout from the PC is not possible. In these cases, stake out as many chord lengths as possible, if any, from the PC. Move the instrument forward and set-up over the last visible station along the curve. Specify in the survey controller which station the instrument and BS points occupy. BS the previous station marker, plunge the scope, and then turn the next deflection angle. Repeat this process as necessary until the PC is visible.

Setting slope stakes

After you stake out the roadbed centerline, set the slope stakes where the proposed grade intersects the original grade (i.e., where the cut or fill becomes zero). Drive the slope stakes opposite each station, one on each side of the centerline. Drive them also between stations when there are frequent, uneven changes in grade.

To determine when to drive a slope stake, you must know the following three things.

- Width (W) of the roadbed, including any shoulders and ditches.
- Slope ratio (the horizontal distance per each vertical foot of rise or fall).
- Vertical DE between the finished grade of the road and the ground elevation at the slope stake.

The table below describes the procedure for setting slope stakes for different components.

Setting Slope Stakes	
Type	**Procedure**
On fill sections	In figure 3–27, part A, *d* is the distance from the centerline to the slope stake, $\frac{W}{2}$ is the distance from the centerline to the top of the slope, *h* is the DE between the finished grade and the ground at the slope stake, and *s* is the slope ratio. The ratio *s* multiplied by *h* gives the horizontal distance (*hs*) that the slope covers. The slope stake distance, from the centerline *d*, is the sum of $\frac{W}{2}$ plus *hs*. The example below provides the equation and sum: Assume that $\frac{W}{2}$ is 20 ft., *h* is 10 ft., and the bank has a 4:1 slope. $hs = s \bullet h = 4 \bullet 10 = 40\ feet$ and $d = \frac{W}{2} + hs = 20 + 40 = 60\ feet$
On fill sections with crossfall	In practice, there may be other factors you will have to take into account, such as transverse slope (crossfall), ditches, and so forth. In figure 3–27 part B, there is crossfall (h_c), across $\frac{W}{2}$ so that the horizontal extent of the bank ($h_b s$) is slope (*s*) times the height of the bank (h_b), instead of *hs* as in figure 3–27 part A. In other words, $h_b s$ is slightly shorter than a comparable *hs*, because the crossfall makes the right triangle smaller; thereby, reducing the length of $h_b s$ (h_b is shorter then *h*). Typically obtained from the plans, crossfalls are usually constant.
On cut sections	Figure 3–27 part C, shows a cut section, in which $\frac{W}{2}$ varies with crossfall, side slope, ditch depth, and back slope. Assume that the distance from the centerline to the beginning of the side slope is 20 ft., that the crossfall totals 1 ft., that the ditch depth is 1.5 ft., and that both the side slope

Setting Slope Stakes	
Type	**Procedure**
	and back slope ratios are 2:1. The distance $\frac{W}{2}$ then consists of three horizontal segments as follows: The distance from the centerline to the top of the slope is 20 ft. The distance to the ditch flow line is slope (*s = 2*) times the depth (1.5 ft.), or 3 ft. The distance to the point on the back slope level with the finished centerline is slope (*s = 2*) times the depth (crossfall plus ditch, or 1+1.5 = 2.5 ft.), or 5 ft. $\frac{W}{2} = (20 + 3 + 5) = 28\ feet$

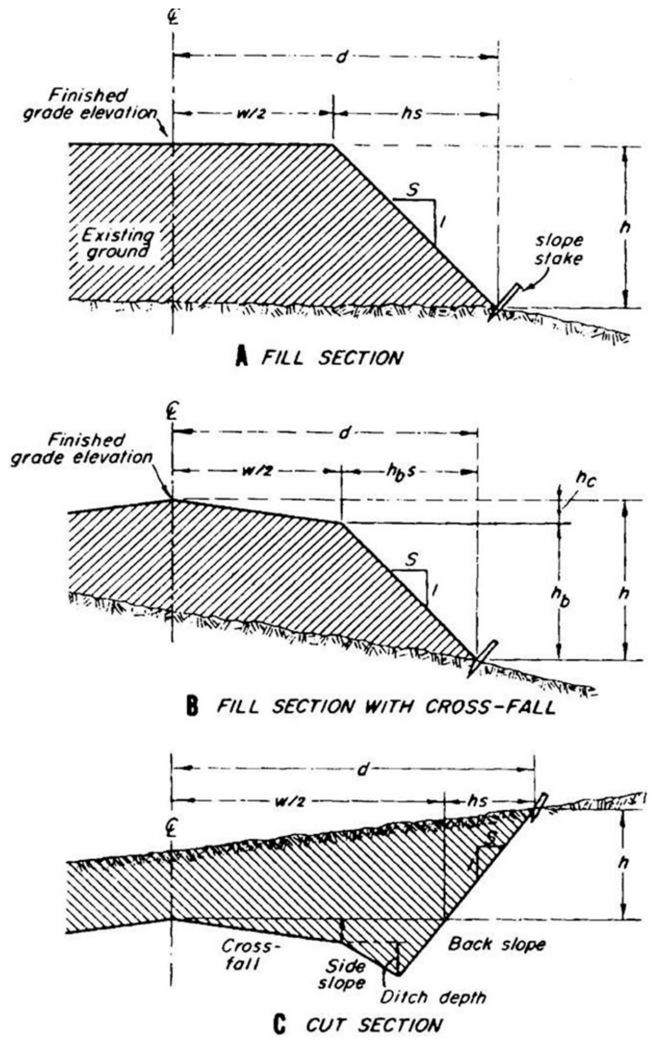

Figure 3–27. Slope stake placement.

Slope stakes are set with an auto-level, leveling rod, and a fiberglass tape. The procedure is a trial-and-error process. The rod person is frequently 200 to 300 ft. from the instrument person. If equipment is running nearby, or if the wind is blowing, the instrument person cannot vocally instruct the rod person where to take the trial shots. The instrument person is not always in a good position to see the ground slope at the rod person's station, so the rod person must know as much as the instrument person about the theory and practice of setting slope stakes. Let us apply this procedure to the problem illustrated in figure 3–28:

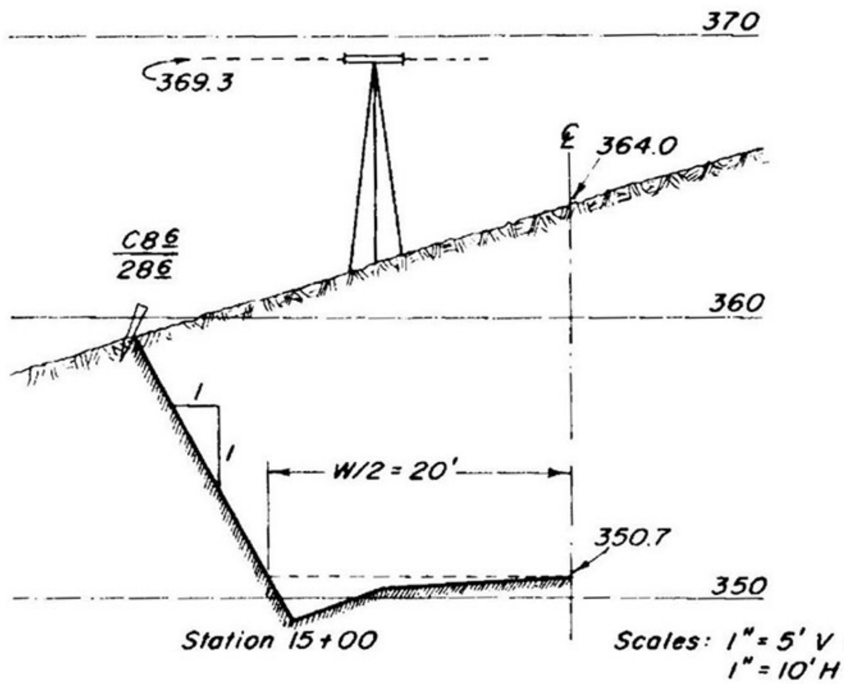

Figure 3–28. Slope stake computations.

Slope stake computation information for station 15+00, figure 3–28.

- The $\frac{W}{2}$ (from the typical section) is 20 ft.
- The back slope ratio 1:1; therefore, $s = 1$.
- The finished centerline grade elevation (from the plans) is 350.7.
- The existing ground elevation at the centerline (from the previously run profile) is 364.0.

Review the steps taken by the instrument person and the rod person in the table below:

Example: Steps Taken by Instrument Person and Rod Person	
Step	**Action**
1	The rod person holds at the centerline for a check, and the rod reads 5.3 through the instrument. 364.0 + 5.3 = 369.3 for the *HI.*
2	The instrument person calculated from the given grades 364.0 – 350.7 = cut 13.3.
3	The instrument person informs the rod person, “cut 13.3.”
4	The rod person computes *d* = 20 + (1 x 13.3) = 33.3 and moves to the left based on pace count.
5	Approaching 30 ft. left, the rod person estimates that the ground has fallen and places the rod for a new ground reading.
6	The instrument person reads 10 on the rod and computes the new cut as 369.3 – (350.7 + 10) = 8.6.
7	The instrument person informs the rod person cut 8.6.
8	The rod person computes *d* = 20 + (1 x 8.6) = 28.6 and informs the instrument person.
9	The rod person sees that the actual cut of 8.6 agrees with the estimated cut of 8.6 and calls to the instrument person, “cut 8.6 at 28.6.”

Example: Steps Taken by Instrument Person and Rod Person	
Step	**Action**
10	The instrument person checks *d* = 20 + (1 x 8.6) = 28.6 signals the rod person “OK”, and enters $\frac{C\,8.6}{28.6}$ in the field notebook.
11	The rod person marks 15+00 on the front of the stake and $\frac{C\,8.6}{28.6}$ on the back and drives it in the ground at 28.6 ft. left.

Culvert location

The best way to maintain a road is to keep water away from it. Sometimes this requires moving the water underneath the road by means of a culvert. To establish the layout of a culvert, locate the intersection of the roadway centerline and a line defining the direction of the culvert. Culvert designs conform to natural drainage lines. Place stakes to mark the inlet and outlet points and mark any cut or fill, if needed. Follow the construction plans for the site carefully, and set the alignment and grade stakes on the centerlines beyond the work area. This way, if any line stake is disturbed or destroyed during the work it replacing them is easily. Figure 3–29 shows a typical layout for a culvert site.

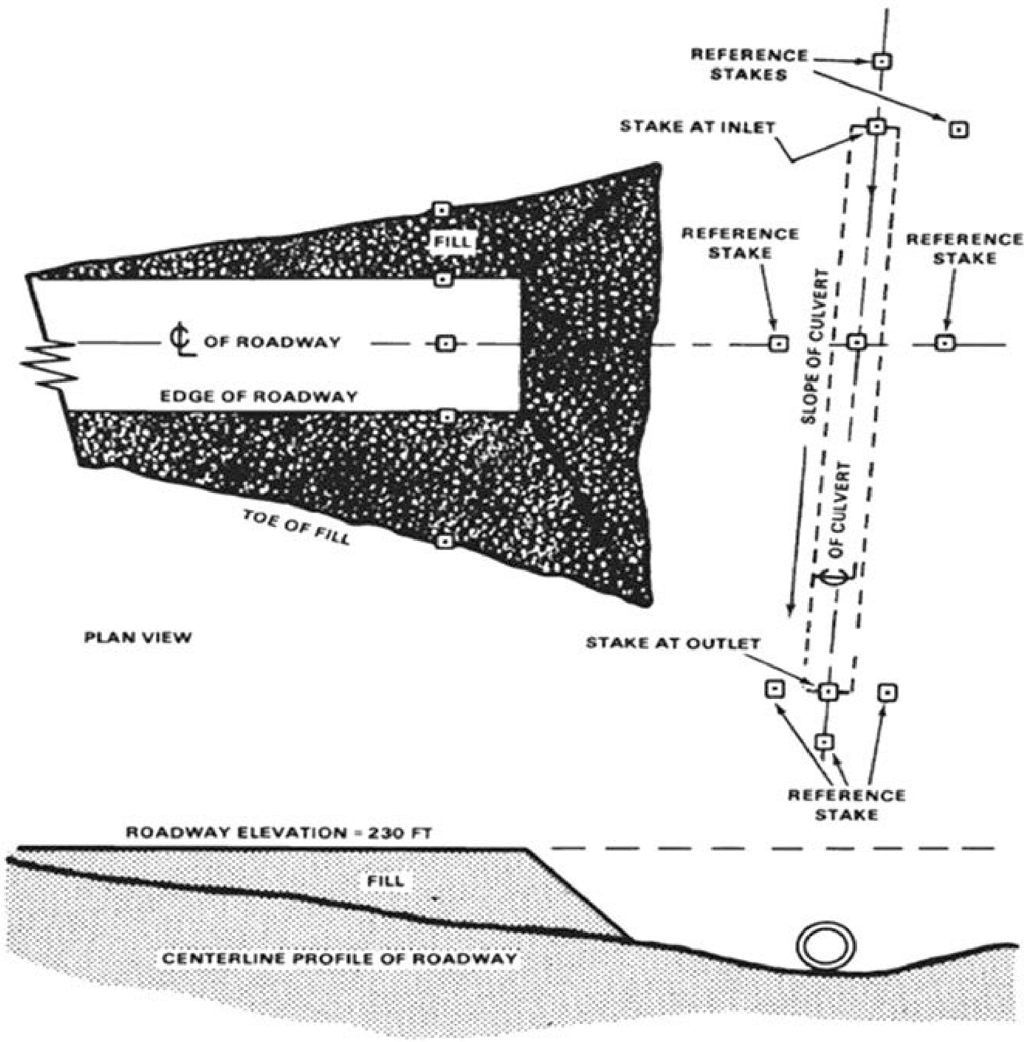

Figure 3–29. Culvert location.

019. Performing expedient stakeout

Most often, the best tool is the simplest. In terms of right triangles, one of the simplest is the 3-4-5 triangle. A 3-4-5 triangle has opposite, adjacent, and hypotenuse lengths that are in a 3:4:5 ratio (fig. 3–30). The 3-4-5 triangle is useful because we can create a right triangle without considering angles. This means that we can use the 3-4-5 as not only a measuring device, but also a square. We usually use this kind of square to rapidly layout tent stakes.

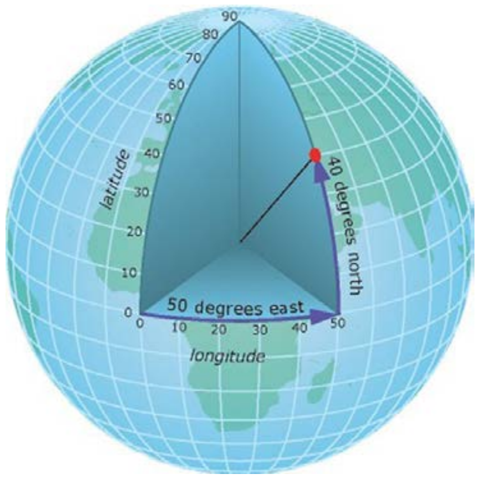

Figure 3–30. 3–4–5 triangle layout.

Another feature of a 3-4-5 triangle is its proportions. Let us say we needed to measure an area that was 10 ft. on a side. If we set the hypotenuse (which is the 5 in the 3-4-5 triangle) to 10, then the opposite and adjacent sides will be 6 and 8, making our 3-4-5 into a 6-8-10. Use the 6-8-10 to align the area using the 10 side. These proportions work whether the multiple is 2, like in our example, or 10, like in the figure.

To create a 3-4-5 triangle we can use three tape measures with a person at each corner. The idea is that each person checks the lengths on the tape measures at their corners and pulls them tight. Then it is a simple matter of flipping the triangle and measuring.

Procedure

The best way to understand how to use a 3-4-5 triangle is to see one in action. The most likely time that you will need to use the triangle is when you are staking tents for site layout. Our example will be a layout of a block of tents. Each tent is 20 feet (') wide by 32.5' long. Tents in a row are spaced 12' apart. A block consists of two rows of tents with a 30' utility lane in between. The block's dimensions total 95' by 116'.

The first thing we need to do is establish a baseline. Our baseline can be the edge of a road, the side of a building, a tree line, or some arbitrary line we made up on the spot. The important thing is to find some way to align what your layout, and measure one side. In our example, let us use the edge of a road, and use a multiple of 10 because our tent blocks are large. We placed our block 30' from the edge of the road. This is how we can place our first stake shown as the yellow dot in figure 3–31.

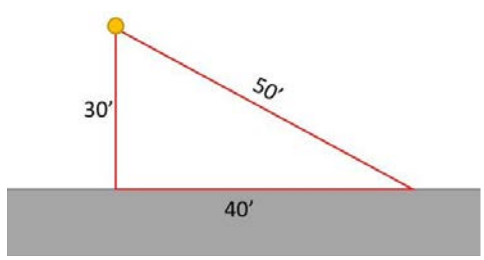

Figure 3–31. First baseline stake.

Next, we should mark the edge of the road at the corner where the 40’ and 50’ sides meet. Then, we can flip the triangle upside-down, and flip it left to right (fig. 3–32).

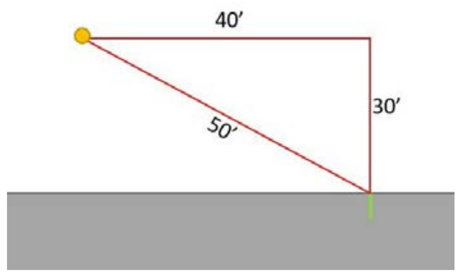

Figure 3–32. First baseline stake.

Now that we have a new baseline, we can stake more tent corners. On the measuring tape, on the 40’ side of the triangle, place stakes 20’ from the yellow corner stake, then another 12’ from the 20’ stake. We now have a stake formation that looks something like figure 3–33. The 20’ side will be the short side of our first SSS tent, and the 12’ stake marks the space between the first two tents.

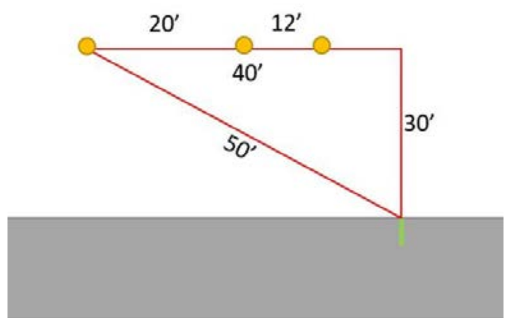

Figure 3–33. First tent stakes.

We begin to flip the triangle end over end and measuring the stakes for the first side of the block (fig. 3–34). From this point forward rotating and flipping the triangle becomes more of an art than a science. Like most things, the best way to understand this is practice. Begin with a plan covering the arrangement of the stakes. Finally, it is best to have a single person in charge of the 3-4-5 triangle team; it reduces confusion and makes the process more efficient.

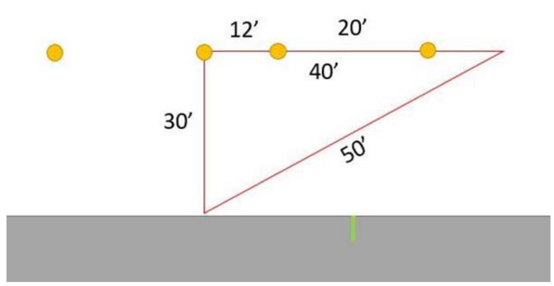

Figure 3–34. Flip over and stake.

We are the bridge between the engineer’s brain and the equipment operators starting construction. This is a massive responsibility, but now you understand the skills needed to fill that need. You can now collect the feature data on an area using topographic survey methods. Take that data, communicate with the engineer, and stake it out. In a deployed environment, you can also rapidly give our comrades a place to work, eat, and sleep.

Self-Test Questions

After you complete these questions, you may check your answers at the end of the unit.

017. Stakeout buildings and utilities

1. What is the minimum slope of a 3- to 6-inch sewer pipe?

2. What is the equation to calculate pipe gradient?

3. Where should we be sure to place the offset stakes?

4. How do we determine the cut after getting the IEs?

5. Where do we mark the station number on the cut stakes?

6. For what do we use utility batter boards?

7. When installing them, what do batter boards consist of?

018. Stakeout road

1. What do we call the difference between the HI and the subgrade elevation?

2. How do we determine the amount to cut at a station after we gave the grade rod elevation?

3. What do we do if the grade rod is smaller than the ground rod at a station?

019. Performing expedient stakeout

1. What characteristic allows us to change the size of a 3-4-5 triangle to a 30-40-50 triangle?

2. What is the first thing we need to establish to begin using the 3-4-5 triangle?

Answers to Self-Test Questions

015

1. Curve and grid.
2. Under the “Surfaces” tab, under the “Contours” section.
3. The program will default to selecting all the points.
4. Sets how frequent contour lines are drawn.
5. Adjusts how often the program generates a contour line with an elevation label.
6. Rounds off any jagged edges and replaces them with smooth curves.
7. Under the “CAD” tab, in the “Text” section.
8. Under the “Home” tab.

016

1. Every 6 months.
2. Aircraft can carry several types of dangerous materials, which may be present at the site.
3. Radio.
4. Forensics teams determine impact angles, velocities, and potential causes of the mishap.
5. MAJCOM and AFCEC.

017

1. 1 inch per 8 ft., or .01 ft. per ft.
2. Gradient = fall / distance
3. Opposite side of the ditch from the excavated fill.
4. Subtract the IEs from the station elevations.
5. On the back of the stake, facing away from the ditch.
6. Fine-tuning IEs.
7. Three 2 x 4 stakes driven into the ground with a crosspiece of 1 x 4 or 1 x 6 lumber nailed to each stake.

018

1. Grade rod value.
2. Subtract the grade rod from the ground rod.
3. Instead of cut, we fill.

019

1. Proportionality.
2. A baseline.

Complete the unit review exercises.

Unit Review Exercises

Note to Student: Consider all choices carefully, select the *best* answer to each question, and *circle* the corresponding letter.

51. (015) The higher the number of points that define a line feature, the higher the
    a. height.
    b. precision.
    c. elevation.
    d. resolution.

52. (015) Contours generated from a grid pattern are closer to reality if they have a
    a. lower elevation.
    b. higher elevation.
    c. lower resolution.
    d. higher resolution.

53. (015) When creating a surface, into which shape does the software group the points?
    a. Circle.
    b. Triangle.
    c. Hexagon.
    d. Rectangle.

54. (015) We find the Create Contours tool in the survey software in the
    a. Corridor section of the Drafting tab.
    b. Edit section of the Point Clouds tab.
    c. Contours section of the Surfaces tab.
    d. Support section of the Photogrammetry tab.

55. (015) Which contour option, while using survey software, allows you to adjust the frequency of contour lines?
    a. Contour interval.
    b. Index contour frequency.
    c. Index contour line weight.
    d. Color contours by elevation.

56. (015) Which contour option, while using survey software, allows you to adjust how often a labeled contour line is generated?
    a. Contour interval.
    b. Index contour frequency.
    c. Index contour line weight.
    d. Color contours by elevation.

57. (015) Where is the Text Style Manager tool located in the survey software?
    a. “CAD” tab, Text section.
    b. “Edit” tab, Drafting section.
    c. “Surfaces” tab, Edit section.
    d. “Drafting” tab, Lines section.

58. (016) How often, in months, do we conduct inventory on mishap survey kits?
    a. 3.
    b. 6.
    c. 12.
    d. 24.

59. (016) When looking for imagery of a mishap location, what is a good backup source for imagery?
    a. National Geodetic Survey (NGS).
    b. National Geography Agency (NGA).
    c. Air Force Civil Engineer Center (AFCEC) reach back center.
    d. Air Force Infrastructure Management Systems Center (AFIMSC).

60. (017) What characteristic of sewer pipe installation *prevents* blockage build up?
    a. Material.
    b. Uniformity.
    c. Invert elevations.
    d. Pipe wall thickness.

61. (017) When installing offset grade stakes, what factor do we base their placement interval on?
    a. Length of install.
    b. Soil composition.
    c. Length of pipe sections.
    d. Diameter of pipe sections.

62. (017) We use the sum of the foresight (FS) and adjusted cut (ADJ CUT) to verify the
    a. depth and gradient of trench.
    b. equipment operators abilities.
    c. length and elevation of trench.
    d. load bearing capacity of the trench.

63. (017) When marking cut stakes, where do we mark the cut line on the stake?
    a. Mark on the rod equal to the adjusted foresight (FS).
    b. Bottom of the rod when the instrument operator sees the FS.
    c. Bottom of the rod when the instrument operator sees the backsight (BS).
    d. Bottom of the rod when the instrument operator sees the adjusted FS.

64. (017) What path do the utility batter boards follow?
    a. Pipe trench.
    b. Parallel to the pipe trench.
    c. Perpendicular to the pipe trench.
    d. Pipe trench plus the offset distance.

65. (017) Which equation do we use to check if our batter boards are square?
    a. $A = l * w$.
    b. $a^2 + b^2 = c^2$.
    c. $b^2 - 4ac$.
    d. tan = sin / cos.

66. (018) What indicates the *exact* grade elevations to the construction force?
    a. Hubs and stakes.
    b. Cut and fill stakes.
    c. Grade and ground rods.
    d. Grade and slope stakes.

67. (018) The amount of cut or fill is equal to
    a. cut stake minus fill stake.
    b. grade rod minus ground rod.
    c. hub elevation minus grade elevation.
    d. elevation minus height of instrument.

68. (018) To what is the ground rod value equal?
    a. Foresight (FS).
    b. Backsight (BS).
    c. Grade rod plus BS.
    d. Grade rod minus BS.

69. (018) To make it easier for the equipment operators, grade stakes are marked to the nearest
    a. meter.
    b. tenth of a foot.
    c. half or whole foot.
    d. quarter or half foot.

70. (018) To what elevation value are the tops of blue top stakes equal?
    a. Finish elevation.
    b. Offset elevation.
    c. Ground elevation.
    d. Instrument elevation.

71. (018) From which three positions are road curves staked?
    a. Bottom of curve (BC), top of curve (TC), point of intersection (PI), or combination of these.
    b. Point of curvature (PC), point of tangency (PT), intermediate setup, or combination of these.
    c. Beginning of curve (BC), end of curve (EC), point of tangency (PT), or combination of these.
    d. Point of intersection (PI), point of curvature (PC), point of tangency (PT), or combination of these.

72. (018) When staking from an intermediate setup, we first backsight the previous station, then plunge the scope. What is the third and final step?
    a. Calculate the bearing.
    b. Turn the back azimuth.
    c. Turn the next deflection angle.
    d. Move the instrument setup to the next station.

73. (018) What equipment do we need to install/set slope stakes?
    a. Compass, protractor, and tape measure.
    b. Auto-level, prism rod, and tape measure.
    c. Auto-level, leveling rod, and fiberglass tape.
    d. Total station, prism rod, and engineer's scale.

74. (019) What is a *beneficial* characteristic of the 3–4–5 triangle layout?
    a. No need for a baseline.
    b. More precise than a total station.
    c. Grade of the terrain is not important.
    d. Proportions can be scaled up or down.

75. (019) To ensure the 3–4–5 triangle process is *efficient*, you should have a single
    a. layout team.
    b. tape measure.
    c. group of tents.
    d. person in charge.

Glossary of Abbreviations and Acronyms

°	degree
’	foot; minute
”	second
ADJ CUT	adjusted cut
ADJ GDE ROD	adjusted ground rod
AFCEC	Air Force Civil Engineer Center
AFI	Air Force instruction
AIB	accident investigation board
BCE	base civil engineer
BM	benchmark
BS	backsight
CAD	computer-aided drafting
CD	compact disc
CE	civil engineer
CMRx	compact measurement record
COGO	coordinate geometry
CORS	continuously operating reference station
DAGR	defense advanced Global Positioning System receiver
DE	difference in elevation
DOD	Department of Defense
DOP	dilution of precision
DVD-RW	digital versatile disc rewritable
ECP	entry control point
EDM	electronic distance measure
EGNOS	European Global Navigation Overlay Service
EM	emergency management; engineer manual
EOD	explosive ordnance disposal
F1	face 1

F2	face 2
FGCS	Federal Geodetic Control Subcommittee
FS	foresight
ft.	foot/feet
GDOP	geometrical dilution of precision
GLONASS	Globalnaya Navigatsionnaya Sputnikovaya Sistema; Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HA	horizontal angle
HAZMAT	hazardous material
HDOP	horizontal dilution of precision
HI	height of instrument
IE	invert elevation
IO	instrument operator
IOR	instrument operator recorder
MAJCOM	major command
mm	millimeter
MON	monument
NCOIC	noncommissioned officer in charge
OPUS	Online Positioning User Service
OSC	on-scene commander
PC	point of curvature
PDOP	position dilution of precision
PI	point of intersection
PPK	post-processed kinematic
PPM	parts per million
PT	point of tangency
rebar	reinforcement steel bar
recon	reconnaissance
RMS	root mean square

RP	rod person
RPR	rod person recorder
RTK	real-time kinematic
sft	survey feet
SPC	survey party chief
SV	satellite vehicle
TBM	temporary benchmark
TDOP	time dilution of precision
TEC	total electron content
TIN	triangulated irregular network
TOC	table of contents
TP	turning point
USACE	United States Army Corps of Engineers
UTM	Universal Transverse Mercator
VA	vertical angle
VDOP	vertical dilution of precision
W	width
WAAS	Wide Area Augmentation System
WGS 84	World Geodetic System 1984
x	Easting
y	Northing

Student Notes

Student Notes

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