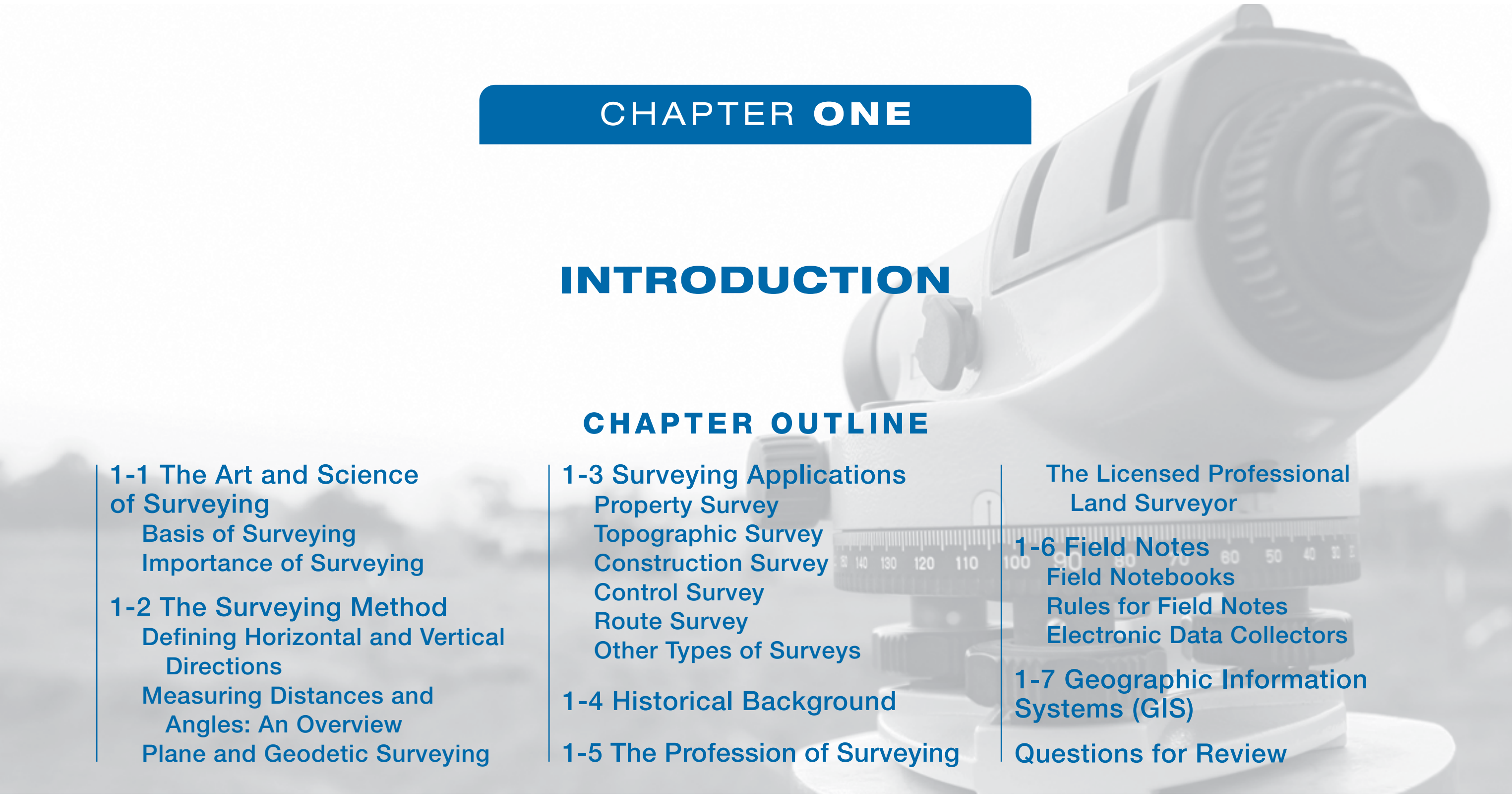


CHAPTER **ONE**

INTRODUCTION

CHAPTER OUTLINE

This textbook is intended to serve as an introduction to the fundamentals of surveying. The purposes of this chapter, and the following two chapters of Part 1, are to present a broad overview of the surveying method, to discuss the importance of surveying as a profession, and to cover some basic concepts regarding measurement, computation, and surveying mathematics. This will give the beginning student a foundation for effective study of the traditional and modern surveying instruments, field and office procedures, and surveying applications that are presented in the following parts of the book.

1-1 THE ART AND SCIENCE OF SURVEYING

Simply stated, surveying involves the measurement of *distances* and *angles.* The distances may be horizontal or vertical in direction. Similarly, the angles may be measured in a horizontal or vertical plane. Usually distances are measured on a slope, but they must eventually be converted to a corresponding horizontal distance. Vertical distances are also called *elevations.* Horizontal angles are used to express the directions of land boundaries and other lines.

There are two fundamental purposes for measuring distances and angles. The first is to *determine the relative positions of existing points* or objects on or near the surface of the earth. The second is to lay out or *mark the desired positions of new points* or objects that are to be placed or constructed on or near the earth's surface. There are many specific applications of surveying that expand upon these two basic purposes; these applications are outlined in Section 1-3.

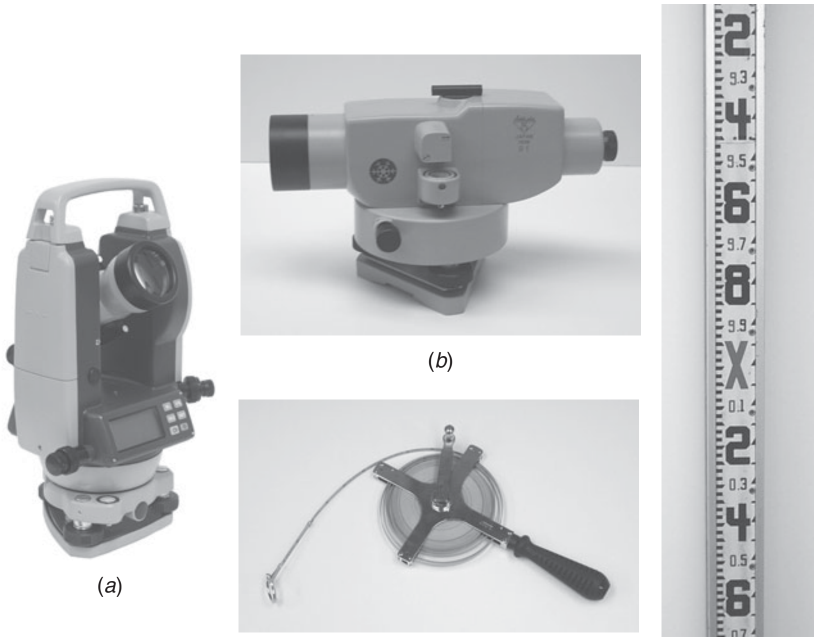
Surveying measurements must be made with *precision* to achieve a maximum of *accuracy* with a minimum expenditure of time and money. (We will discuss the terms *precision* and *accuracy* in more detail in Section 2-4.)

The practice of surveying is an art because it is dependent upon the skill, judgment, and experience of the surveyor. Surveying may also be considered an applied science because field and office procedures rely upon a systematic body of knowledge, related primarily to mathematics and physics. An understanding of the *art and science of surveying* is, of course, necessary for surveying practitioners, as well as for those who must use and interpret surveying data (architects, construction contractors, geologists, and urban planners, as well as civil engineers).

Basis of Surveying

Surveying is based on the use of precise measuring instruments in the field and on systematic computational procedures in the office. The instruments may be traditional or electronic. The computations (primarily of position, direction, area, and volume) involve applications of geometry, trigonometry, and basic algebra.

Electronic handheld calculators and digital computers are used to perform office computations. In the past, surveyors had to perform calculations using trigonometric and logarithmic tables, mechanical calculators, and slide rules. Today, the availability of relatively low-cost electronic calculators, desktop computers, and surveying software (computer programs) relieves the modern-day surveyor from many hours of tedious computations. But it is still very important for the surveyor to understand the underlying mathematical procedures and to be able to perform the step-by-step computations by applying and solving the appropriate formulas.



(a) (b) (c) (d)

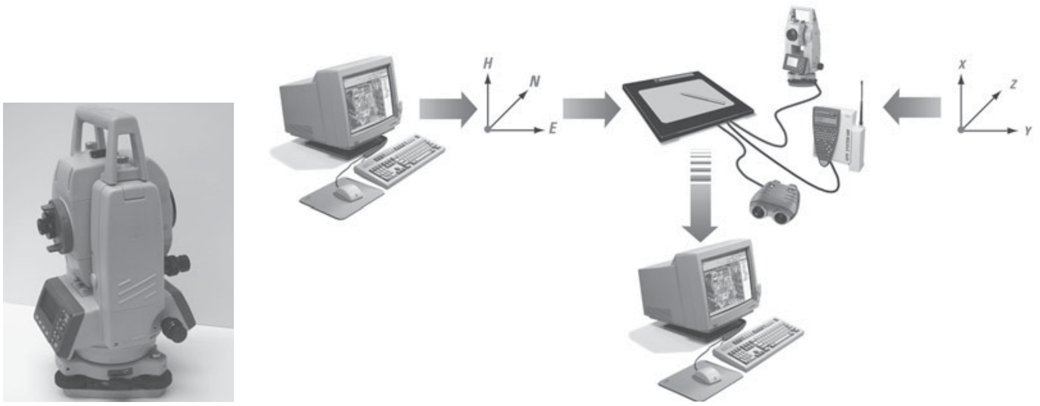
FIGURE 1-1. Traditional surveying instruments: (*a*) Theodolite (*Courtesy of CST/Berger, Illinois*), (*b*) level, (*c*) a level rod, and (*d*) a steel tape.

The traditional measuring instruments used in the field are the *transit* or *theodolite* (to measure angles), the *level* and *level rod* (to measure vertical distances or elevations), and the *steel tape* (to measure horizontal distances). They are illustrated in Figure 1-1. The use of these types of instruments is described in detail in subsequent chapters.

Electronic measuring devices have largely replaced traditional instruments in surveying field work. One of the most advanced of these modern instruments is the *electronic recording tacheometer*, or *total station*, as it is also called (see Figure 1-2*a*). It comprises an electronic distance measuring (EDM) device, an electronic theodolite to measure angles, and an automatic data recorder. Many companies provide a "field-to-finish" system (Figure 1-2*b*), complete with the computer hardware and software needed to analyze and plot the survey data.

The total station and other modern instruments will be discussed again later on in the text. But the fundamental principles of surveying remain the same, whether the electronic or the more traditional instruments are used. The beginning student must still learn these basic principles before using sophisticated modern instruments. In any event, the steel tape, the transit, and the level are still used for many construction and small-scale surveys. In fact, we shall see later on that the steel tape is more accurate than most electronic devices when it comes to measuring relatively small horizontal distances.

With skillful use of surveying instruments and with proficient application of field and office procedures, almost



(a) (b)

FIGURE 1-2. (*a*) An electronic total-station surveying instrument that can be used to measure and record distances and angles and compute coordinates. (*Courtesy of Leica Geosystems, Inc.*) (*b*) In a field-to-finish system, data may be stored electronically. The data can be "dumped" into the office desktop computer for computations and plotting or printing.

FIGURE 1-3. Practically every line recorded on this photograph was laid out with a transit, a steel tape, and a level—the primary equipment of the surveyor. (*Courtesy of New Jersey Department of Environmental Protection*)

any measurement problem can be solved. Conversely, it is difficult to solve any problem requiring relatively large and accurate measurements without resorting to proper surveying methods and instruments.

Importance of Surveying

Surveying plays an essential role in the planning, design, layout, and construction of our physical environment and infrastructure. The term *infrastructure* is commonly used to represent all the constructed facilities and systems that allow human communities to function and thrive productively.

Surveying is the link between design and construction. Roads, bridges, buildings, water supply, sewerage, drainage systems, and many other essential public-works projects could never be built without surveying technology. Figure 1-3 shows a bird's-eye view of a typical urban environment that depends on accurate surveying for its existence. Nearly every detail seen on that photograph was positioned by surveying methods.

In addition to its customary applications in construction and land-use projects, surveying is playing an increasingly important role in modern industrial technology. Some activities that would be nearly impossible without accurate surveying methods include testing and installing accelerators for nuclear research and development, industrial laser equipment, and other sensitive precision instruments for manufacturing or research. The precise construction of rocket-launching equipment and guiding devices is also dependent on modern surveying.

Without surveying procedures, no self-propelled missile could be built to the accuracy necessary for its operation. Its guiding devices could not be accurately installed; its launching equipment could not be constructed; it could not be placed in position or oriented on the pad; and its flight could not be measured for test or control. Moreover, its launch position and the position of its target would be a matter of conjecture. Surveying is an integral part of every project of importance that requires actual construction.

1-2 THE SURVEYING METHOD

The earth, of course, is spherical in shape. This fact, which we take for granted today, was an issue of great debate only a few hundred years ago. But despite the unquestionable roundness of the earth, most surveying activities are performed under the tacit assumption that measurements are being made with reference to a flat horizontal surface. This requires some further explanation.

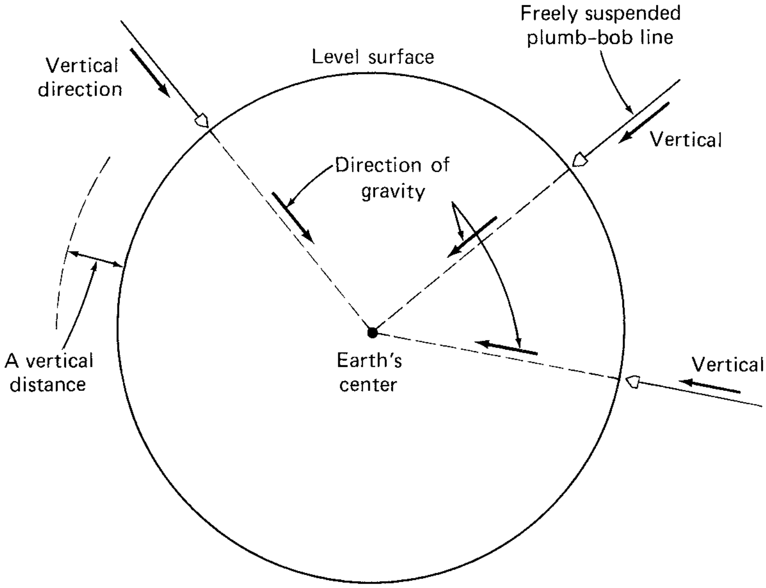


FIGURE 1-4. The vertical direction is defined as the direction of the force of gravity.

Defining Horizontal and Vertical Directions

The earth actually has the approximate shape of an *oblate spheroid*, that is, the solid generated by an ellipse rotated on its minor axis. Its polar axis of rotation is slightly shorter than an axis passing through the equator. But for our purposes, we can consider the earth to be a perfect *sphere* with a constant diameter. In fact, we can ignore, for the time being, surface irregularities like mountains and valleys. And we can consider that the surface of the sphere is represented by the average level of the ocean, or *mean sea level.*

By definition, the curved surface of the sphere is termed a *level surface.* The direction of gravity is perpendicular or normal to this level surface at all points, and *gravity* is used as a reference direction for all surveying measurements. The direction of gravity is easily established in the field by a freely suspended *plumb line*, which is simply a weight, or *plumb bob*, attached to the end of a string. The direction of gravity is different at every position on the earth's surface. As shown in Figure 1-4, the direction of all plumb lines converge at the center of the earth; at no points are the plumb lines actually parallel.

The *vertical direction* is taken to be the direction of gravity. Therefore, it is incorrect to define vertical as simply "straight up and down," as many beginning students tend to do. The vertical direction varies from point to point on the earth's surface. The only common factor is the direction of gravity.

By definition, the *horizontal direction* is the direction perpendicular (at an angle of 90°) to the vertical direction of gravity. Because the vertical direction varies from point to point, the horizontal direction also does. A horizontal length or distance, then, is not really a perfectly straight line. It is curved like the surface of the earth. This is illustrated in Figure 1-5.

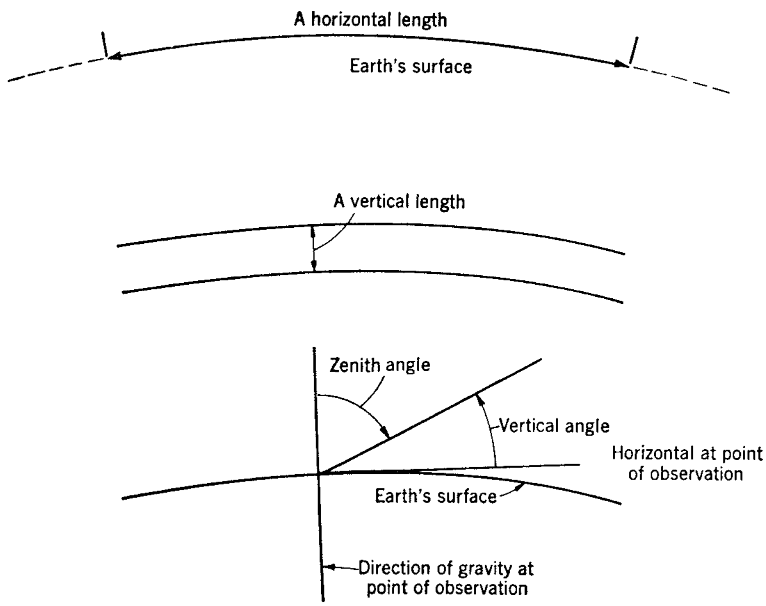


FIGURE 1-5. A true horizontal distance is actually curved, like the surface of the earth.

Measuring Distances and Angles: An Overview

As shown in Figure 1-5, a *horizontal distance* or *length* is measured along a level surface. At every point along that length, the line tangent to the level surface is horizontal. Horizontal distances may be measured by stretching a steel tape between a series of points along a horizontal line. Electronic distance meters, which use infrared light waves and measure very long distances almost instantaneously, are also used. For most surveys, the curvature of the earth can be neglected, as will be discussed in more detail in the next section. Taping and the use of EDM instruments are discussed in Chapter 4.

A *vertical distance* is measured along the direction of gravity and is equivalent to a difference in *height* between two points. When the height is measured with reference to a given level surface such as mean sea level, it is called an *elevation.*

Vertical distances are usually measured with wooden or fiberglass rods held vertically and graduated in centimeters or hundredths of a foot. An instrument called a *level* is used to observe the rod at different points. A level consists of a telescopic line of sight, which can be made horizontal by adjusting an attached sensitive spirit bubble. The instrument can be turned in various directions around a stationary vertical axis. As shown in Figure 1-6, the difference in the readings on the rod at two points is equivalent to the difference in height or elevation between the points.

The relative vertical positions of several points separated by long distances can be determined by a continuous series of level rod observations, as illustrated in Figure 1-7. This procedure is called *leveling.* The line of sight of the level is horizontal at each observation. Because most level rod observations are made with relatively short line-of-sight distances (less than about 300 ft or 90 m), the effect of the earth's curvature is not at all noticeable. This is explained more thoroughly in the following discussion of plane surveying. In any case, proper leveling methods will compensate for the effects of curvature, as well as for possible instrumental errors. Leveling theory and field procedures are discussed in detail in Chapter 5.

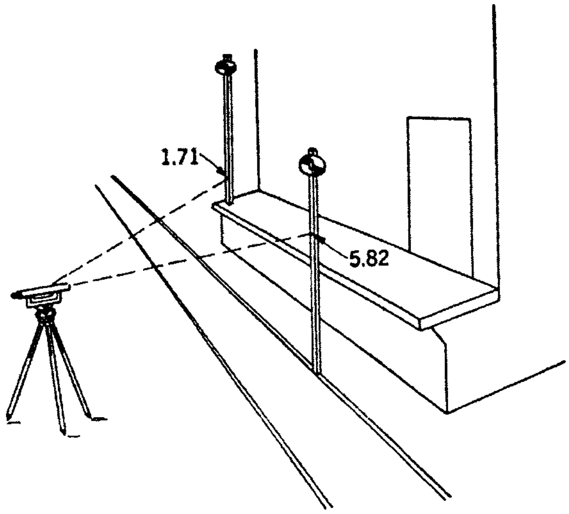


FIGURE 1-6. Measuring a difference in height between a rail and a platform. The difference here is 5.82 − 1.71 = 4.11 ft.

A *horizontal angle* is measured in a plane that is horizontal at the point of measurement, as illustrated in Figure 1-8. When a horizontal angle is measured between points that do not lie directly in the plane, like points *A* and *B* in Figure 1-8, it is measured between the perpendiculars extended to the plane from those points. (Actually, angles are measured between lines, not points. We will discuss this more thoroughly in the part of the book on angular measurement.)

A *vertical angle* is measured in a plane that is vertical at the point of observation or measurement. Either the horizontal direction (horizon) or vertical direction (zenith) may be used as a reference line for measuring a vertical angle. In Figure 1-8, V_1 is the vertical angle between the horizon and the instrument line of sight to point *A*, and V_2 is the vertical angle between the horizon and the line of sight to point *B.* Both vertical and horizontal angles are discussed in more detail in Chapter 6.

Horizontal and vertical angles are measured with an instrument called a *transit* or *theodolite.* This type of instrument consists essentially of an optical line of sight, which is perpendicular to and is supported on a horizontal axis.

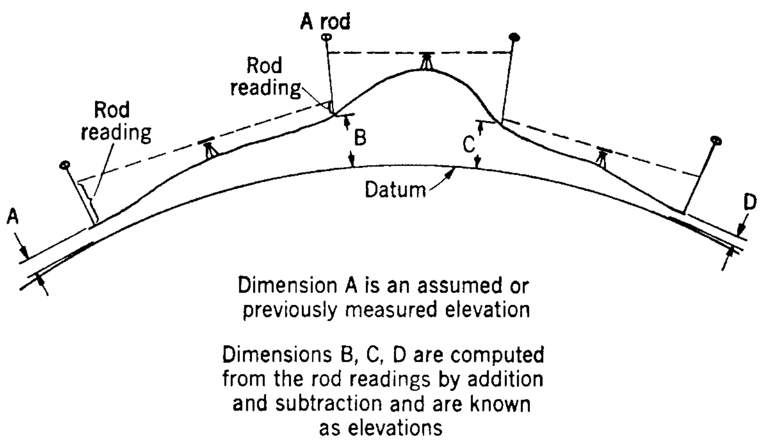


FIGURE 1-7. The relative vertical positions of two or more points are determined by leveling.

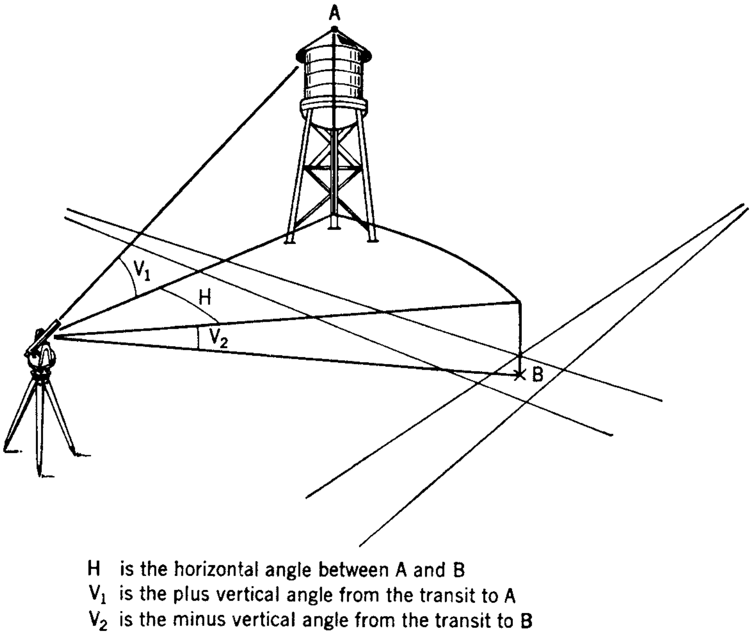


FIGURE 1-8. Measurement of horizontal and vertical angles.

Theodolites are generally finer in quality and performance (and are more expensive) than transits.

As shown in Figure 1-9, the horizontal axis of the instrument is perpendicular to a vertical axis, about which it can rotate. Spirit levels are used to make the vertical axis coincide with the direction of gravity. Modern instruments use an electronic leveling system. In older instruments, graduated metal circles with verniers or glass circles with micrometers are used to read the angles. In modern theodolites, the circles are scanned electronically, and the value of the angle is displayed digitally.

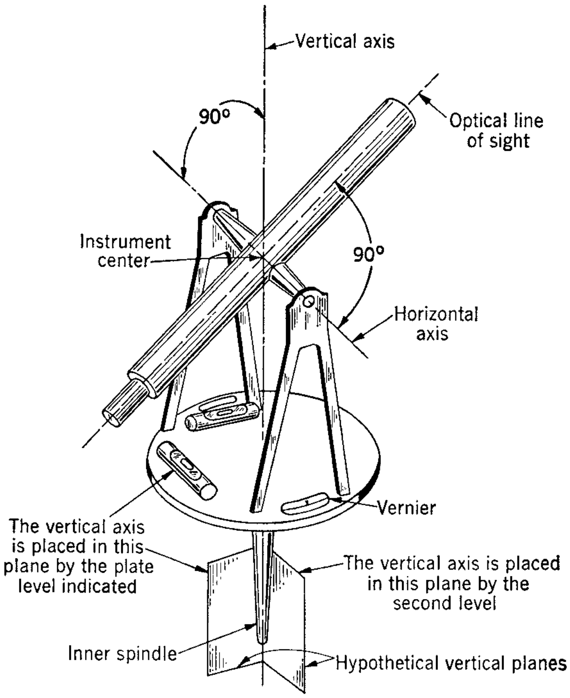


FIGURE 1-9. Transit essentials. Schematic diagram of an *alidade,* which is the upper part of a transit.

Plane and Geodetic Surveying

We mentioned in the preceding section that most surveying measurements are carried out as if the surface of the earth were perfectly flat. In effect, this means that we make our measurements as if the lines of force due to gravity were everywhere parallel to each other, and as if underneath the irregular ground surface there existed a flat, horizontal reference plane. This is illustrated in Figure 1-10.

The method of surveying based upon this assumption is called *plane surveying.* In plane surveying, we neglect the curvature of the earth, and we use the principles of plane geometry and plane trigonometry to compute the results of our surveys.

The use of plane surveying methods simplifies the work of the surveyor. And for surveys of limited extent, very little accuracy is lost. Within a distance of about 12 mi, or 20 km, the effect of the earth's curvature on our measurements is so small that we can hardly measure it. In other words, a horizontal distance measured between two points along a truly level (or curved) line is, for practical purposes, the same distance measured along the straight *chord* connecting the two points. In fact, over a distance of about 12 mi, the difference between the length of arc and the chord length is only about 0.25 in.

This textbook is designed primarily as an introduction to plane surveying, which, for the reason described previously, is suitable for surveys extending over distances less than about 12 mi. But as it turns out, the vast majority of ordinary private surveys are performed well within these limits. Certain public surveys, however, are conducted by federal or state agencies and cover large areas or distances.

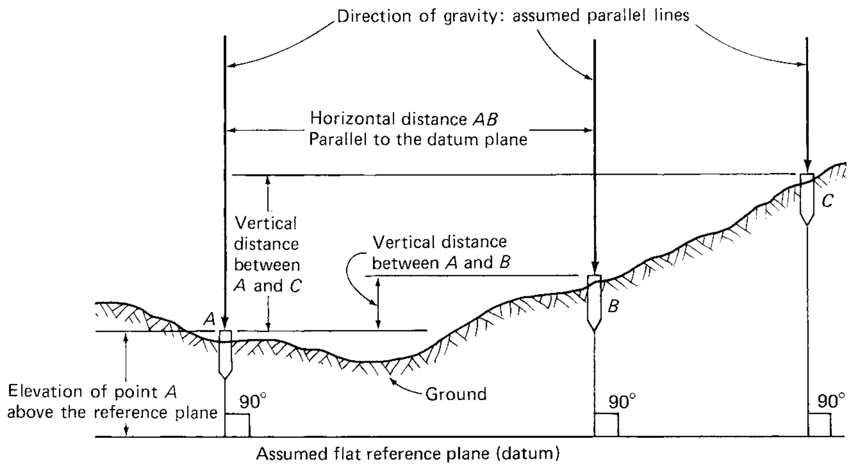


FIGURE 1-10. In plane surveying, the curvature of the earth is neglected and vertical distances are measured with reference to a flat plane.

Such large-scale surveys must account for the true shape of the earth so that the required degree of accuracy is not lost in the results.

A survey that takes the earth's curvature into account is called a *geodetic* survey. These types of surveys are usually conducted by federal agencies such as the U.S. Geological Survey and the U.S. National Geodetic Survey. Various river basin commissions and large cities also perform geodetic surveys. Such surveys generally use very precise instruments and field methods and make use of advanced mathematics and spherical trigonometric formulas to adjust for curvature. In some cases, the instruments and field methods used in a geodetic survey do not differ from those used in a plane survey, but spherical trigonometry must always be used to reduce the geodetic survey data.

The geometry and trigonometry of figures on a curved surface differ considerably from the geometry and trigonometry of plane or flat figures. For example, in a plane triangle, the interior angles always add up to 180°. But this is not the case with a triangle on a curved surface. The triangle shown on the sphere in Figure 1-11, for instance, must contain more than 180°. The sides of that triangle change direction by 90° at each corner, *A* and *B*, on the equator. With angle *C* added to *A* and *B*, the sum is clearly more than 180°. Spherical trigonometry, then, takes into account the properties of geometric shapes on curved surfaces.

Geodetic surveying methods are generally used to map large areas and to establish large-scale networks of points on the earth for horizontal and vertical control. The relative positions of these points are measured with a high degree of precision *and* accuracy, both in longitude and in latitude,* as well as in elevation. They are used as points of reference for many other local surveys that require a lower degree of accuracy.

**Longitude* is the angular distance of a point on the earth's surface, measured east or west of the prime meridian at Greenwich, England. *Latitude* is the angular distance of a point on the earth's surface, measured north or south of the equator.

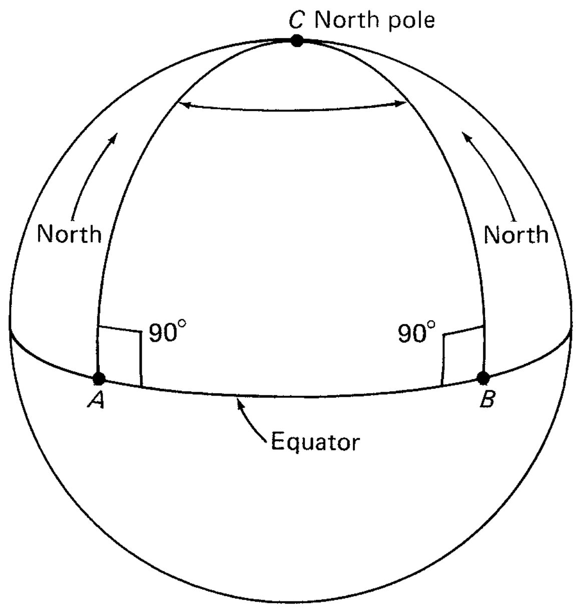


FIGURE 1-11. On a curved surface, the sum of the angles in a triangle is more than 180°.

1-3 SURVEYING APPLICATIONS

As we mentioned at the beginning of this chapter, the two fundamental purposes for surveying are to determine the relative positions of *existing* points and to mark the positions of *new* points on or near the surface of the earth.

Within this framework, many different kinds of surveys are performed. Some specific applications or types of surveys are outlined briefly in this section and are discussed in more detail in Part 3 of the text. Generally, these different types of surveys require different field procedures and varying degrees of precision for carrying out the work.

Property Survey

A *property survey* is performed to establish the positions of boundary lines and property corners. It is also referred to as a *land survey*, *title survey*, or a *boundary survey*. Property surveys are usually performed whenever land ownership is to be transferred or when a large tract of land is to be subdivided into smaller parcels for development. Also, before the design and construction of any public or private land-use project can get under way, it is necessary to accurately establish the legal boundaries of the proposed project site. Constructing a structure on what later is found to be property that belongs to someone else can be a very expensive mistake.

Any survey for establishing or describing land boundaries must be performed under the supervision of a licensed land surveyor. Land surveys in urban areas must be conducted with particular care because of the very high cost of land. In rural areas, less accuracy may be acceptable. Land surveys done to actually mark property corners with permanent monuments are sometimes informally referred to as "stakeout," "outbound," or "bar job" surveys. The results of a property survey may be written into a deed or may be prepared as a drawing called a *plat*, as illustrated in Figure 8-2.

Topographic Survey

A topographic survey is performed to determine the relative positions (horizontal and vertical) of *existing* natural and constructed features on a tract of land. Such features include ground elevations, bodies of water, vegetation, rock outcrops, roads, buildings, and so on.

A topographic survey provides information about the "shape of the land." Hills, valleys, ridges, and the general slope of the ground can be depicted graphically. The data obtained from a topographic survey are plotted and drawn as a suitably scaled map, called a *topographic map*, or *topo map*. Figures 9-1 and 9-2 are examples of topo maps.

The shape of the ground is shown with *contours,* or lines of equal elevation. Because a topo map is always needed before the engineering and architectural design of any building or other project can begin, a topo survey may also be referred to as a *preliminary survey.* Of course, an accurate property survey must always precede the topo survey to establish the boundaries of the project site.

Construction Survey

A construction survey, also called a *layout* or *location survey*, is performed to mark the position of *new points* on the ground. These new points represent the location of building corners, road centerlines, and other facilities that are to be built. These positions are shown on a *site plan*, which is essentially a combination of the property survey and topo survey, along with the newly designed facilities. This may also be called a *plot plan.*

A site plan shows the location dimensions that are to be measured with reference to boundaries or other control points. Vertical heights are given by elevations. Sometimes horizontal positions may be given by coordinates. Wooden stakes are used by the surveyor to mark the positions of the buildings, roads, and other structures. An example of a drawing that includes location dimensions is shown in Figure 1-12.

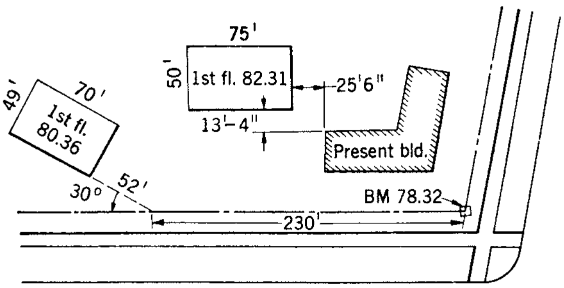


FIGURE 1-12. Typical location dimensions found on engineering or architectural plans, for use during a stakeout survey.

The wooden stakes serve as reference points for the construction contractor who actually builds the project. They may be centerline stakes, offset stakes, or grade stakes. Carpenters, masons, and other skilled trades transfer measurements directly from the survey points. The procedure of placing the markers is called *staking out.* Another term used, especially for pipelines and roads, is *giving line and grade.*

Control Survey

There are two kinds of control surveys: horizontal and vertical. In a horizontal control survey, several points are placed in the ground by the surveyor, using wooden stakes or more permanent markers such as iron bars and concrete monuments. These points, called *stations*, are arranged throughout the site or area under study so that they can be easily seen and surveyed.

The relative horizontal positions of these points are established, usually with a very high degree of precision and accuracy; this is done using *traverse* or global navigation satellite systems (GNSS) survey methods.

In a vertical control survey, the elevations of relatively permanent reference points are determined by *precise leveling* methods. Marked or *monumented* points of known elevation are called elevation *benchmarks* (BMs).

The network of stations and benchmarks provides a framework for horizontal and vertical control, upon which less accurate surveys can be based. For example, boundary surveys or construction surveys can be *tied* into nearby control survey stations and benchmarks. This minimizes the accumulation of errors and the cost of making all the measurements precise.

Existing topographic features and proposed points or structures are connected to the control network by surveying measurements of comparatively low precision. A steel tape and a builder's level may be used in some cases. An example of a control survey network is shown in Figure 1-13. When local surveys are tied into a control survey, a permanent reference is established that can be retraced if the construction stakes or property corners are obliterated for any reason.

Large-scale or geodetic control surveys must account for the curvature of the earth in establishing relative horizontal and vertical positions. Geodetic control surveys include astronomic observations to determine latitude and longitude and the direction of astronomical north. Modern

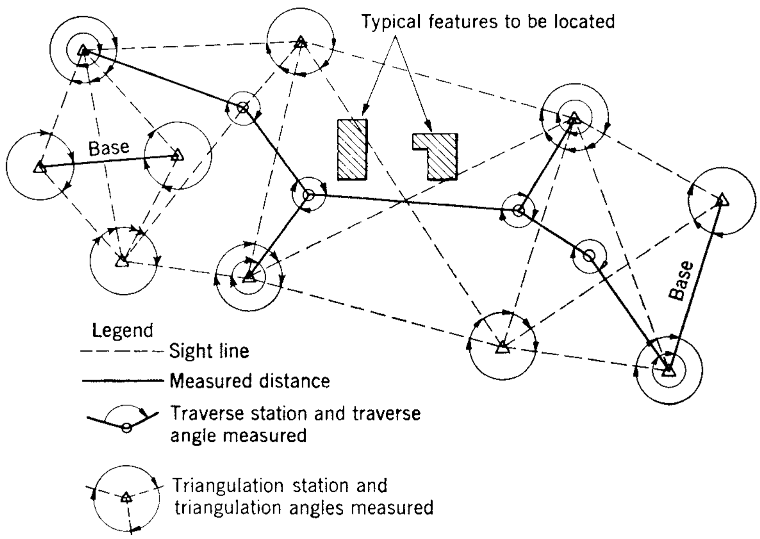


FIGURE 1-13. A horizontal control survey network showing traverse and triangulation stations (points) and courses (lines).

geodetic control surveys can be performed using signals from satellites, which are received by instruments called *global navigation satellite systems* (GNSS).

Route Survey

A route survey is performed to establish horizontal and vertical control, to obtain topographic data, and to lay out the positions of highways, railroads, streets, pipelines, or any other "linear" project. In other words, the primary aspect of a route survey is that the project area is very narrow compared with its length, which can extend up to several kilometers or miles. An example of the results of a route survey—the plan and profile of a proposed road—is shown in Figure 1-14. Plane geometry is used to compute the horizontal and vertical *alignment* of the road.

Other Types of Surveys

A *hydrographic survey* is a preliminary survey applied to a natural body of water. It serves to gather data for mapping the shoreline and for charting the water depths of a river, lake, or harbor. In effect, an underwater topo map is prepared from a hydrographic survey. Navigation and water resources planning projects depend upon data obtained from hydrographic surveys.

A *reconnaissance survey* is a preliminary survey conducted to get very rough data regarding a tract of land. Distances may be approximated by pacing, and spot elevations may be obtained with the use of only a hand level. Examination of aerial photographs may also serve as part of a reconnaissance survey. *Photogrammetric surveying* uses relatively accurate methods to convert aerial photographs into useful topographic maps. A control survey on the ground is still necessary when utilizing photogrammetry to produce accurately scaled maps.

A *cadastral survey* is a boundary survey applied specifically to the relatively large-scale rectangular U.S. Public Lands Survey system. It also refers to the surveying and identification of property in political subdivisions.

Other types of specialized surveys include *mine surveys*, *bridge surveys*, *tunnel surveys*, and *city surveys*. Surveying applications also range from monitoring very small movements of the earth over long periods of time (such as earthquakes and other geological studies) to tracking the orbits of satellites and space vehicles.

Surveying, an activity with roots in antiquity, is now a modern and continually evolving technical discipline and profession.

1-4 HISTORICAL BACKGROUND

Surveying probably has its origins in ancient Egypt, as far back as 5000 years ago. Some type of systematic measurements must have been made, for example, to accurately and squarely lay out the Great Pyramid with respect to the true meridian (the north-south direction line). And the annual floods of the Nile River, which obliterated land boundary markers used for taxation purposes, made it necessary for ancient surveyors to relocate and replace the lost boundaries.

Those early surveyors used ropes that were knotted at uniform intervals to measure distance; the surveyors were, appropriately enough, called *rope stretchers*. The interval between the knots, called a *cubit*, was taken to be the length of the human forearm. The cubit, which, of course, could vary depending on whose forearm was used to establish it, was the basic unit of length used at that time.

It is likely that the subject of geometry (which means "earth measurements") developed primarily because of the need to conduct surveys of the land. Since ancient times, historical records show the development of surveying as an applied science, one that evolved as measuring instruments, as well as computational methods, gradually improved. It is of value for the beginning student of surveying to have at least a general perspective of this historical development. Students may wish to go to *www.surveyhistory.org* for images and explanations of ancient surveying tools.