

Eighth Edition

Surveying with Construction Applications



*Barry F. Kavanagh
Dianne K. Slattery*

ABBREVIATIONS

GENERAL

AASHTO	American Association of State Highway and Transportation Officials
ACSM	American Congress on Surveying and Mapping
Az	azimuth
Bg	bearing
BM	benchmark (TBM) temporary benchmark
BS	backsight (rod reading in leveling; line sighting in theodolite work)
C _L	correction due to erroneous length of tape
C _P	correction due to nonstandard tension
C _S	correction due to effects of sag
C _T	corrections due to nonstandard temperature
CAD	computer assisted drafting (or design)
CADD	computer assisted drafting and design
cc	cut cross
CIG	Canadian Institute of Geomatics
conc.mon.	concrete monument
c + r	error in line of sight due to combined effects of curvature and refraction
Deg	degree
Dep	departure
DoD	Department of Defense
EDM	electronic distance measurement
EG	existing ground
Elev	elevation
FS	foresight (rod reading in leveling; line sighting in theodolite work)
GIS	geographic information system
GPS	global positioning system
HARN	high accuracy reference network
HI	height of instrument above a datum
hi	height of instrument above the instrument station
HOT	hub on tangent
IB	iron bar
Inst	instrument
IP	iron pipe
IS	intermediate sight, used in leveling and total station activities (also IFS, intermediate foresight)
Lat	latitude
Long	longitude
Lt	left
Mon	monument
NSPS	National Society of Professional Surveyors
Occ	occupied station reference
OG	original ground
o/s	offset
ppm	parts per million
RAP	reference azimuth point
ROW	right of way
RP	reference point
RR	rod reading
Rt	right
TBM	temporary benchmark
TP	turning point
Twp	township
UTM	universal transverse Mercator projection
X-sect	cross section

IMPERIAL UNITS

ac	acre
bbbl	barrel
cu ft	cubic foot
cu in.	cubic inch
cu yd	cubic yard
cwt	hundred weight
fbm	foot board measure
ft	foot or feet
gal	gallon(s)
in.	inch(es)
lb	pound
lf	linear foot (feet)
mi	mile(s)
mph	miles per hour
psi	pounds per square inch
sq ft	square foot (feet)
sq in.	square inch(es)
sq yd	square yard(s)
mf bm	thousand foot board measure
m gal	thousand gallons
yd	yard(s)

METRIC UNITS

C	Celsius
cm	centimeter
ha	hectare
kg	kilogram(s)
km	kilometer(s)
kN	kilonewton(s)
kPa	kilopascal(s)
L	liter(s)
m	meter(s)
m ²	square meter
m ³	cubic meter
mm	millimeter(s)
t	tonne

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EIGHTH EDITION

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Missouri State University

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PREFACE

Many technological advances have occurred in surveying since *Surveying with Construction Applications* was first published. This eighth edition is updated with the latest advances in instrumentation technology, field-data capture, and data-processing techniques. Although surveying is becoming much more efficient and automated, the need for a clear understanding of the principles underlying all forms of survey measurement remains unchanged.

NEW TO THIS EDITION

- General surveying principles and techniques, used in all branches of surveying, are presented in Part I, Chapters 1–11, while contemporary applications for the construction of most civil projects are covered in Chapters 12–19. With this organization, the text is useful not only for the student, but it can also be used as a handy reference for the graduate who may choose a career in civil/survey design or construction. The glossary has been expanded to include new terminology. Every effort has been made to remain on the leading edge of new developments in techniques and instrumentation, while maintaining complete coverage of traditional techniques and instrumentation.
- Chapter 2 is new, reflecting the need of modern high school graduates for the reinforcement of precalculus mathematics. In Chapter 2, students will have the opportunity to review techniques of units, conversions, areas, volumes, trigonometry, and geometry, which are all focused on the types of applications encountered in engineering and construction work.
- Chapter 3 follows with the fundamentals of distance measurement; Chapter 4 includes complete coverage of leveling practices and computations; and Chapter 5 presents an introduction to electronic distance measurement. Chapter 6 introduces the students to both theodolites and total stations, as well as common surveying practices with those instruments. Chapter 7 gives students a broad understanding of total station operations and applications. Chapter 8, “Traverse Surveys and Computations,” introduces the students to the concepts of survey line directions in the form of bearings and azimuths; the analysis of closed surveys precision is accomplished using the techniques of latitudes and departures, which allow for precision determination and error balancing so that survey point coordinates can be determined and enclosed areas determined. Modern total stations (Chapter 7) have been programmed to accomplish all of the aforementioned activities, but it is here in Chapter 8 that students learn about the theories underlying total station applications.
- Chapter 9 covers satellite positioning, the modern technique of determining position. This chapter concentrates on America’s Global Positioning System, but includes descriptions of the other systems now operating fully or partially around the Earth in Russia, China, Europe, Japan, and India. All these systems combined are known as

the Global Navigation Satellite System (GNSS). Chapter 10, “Geomatics,” reflects the advances modern technology has made in the capture of positioning data on Earth-surface features, the processing of measurement technology, and the depiction of the surface features in the form of maps, plans, screen images, aerial photogrammetric images, and digital imaging taken from satellites and aircraft. Chapter 11 covers horizontal and vertical control, both at the national level and at the project level.

- Part II includes specific applications in engineering construction and begins with Chapter 12, an introduction to machine guidance and control. This new technology has recently made great advances in large-scale developments, such as highway and roads construction and airport construction. It involves creating three-dimensional data files for all existing ground surface features and all new-design surface features. Equipment operators (dozers, scrapers, loaders, and backhoes) can view the existing ground elevations, profiles, and cross-sections on in-cab computer monitors. They can also see the proposed elevations, and the like, for the project, and the current location of the cutting edge (blade, bucket, etc.) of their machine. Being able to see all of this from the cab, the operators don’t need further help with line and grade directions.
- The remainder of Part II covers engineering projects: “Highway Curves” (Chapter 13), “Highway Construction Surveys” (Chapter 14), “Municipal Street Construction Surveys” (Chapter 15), “Pipeline and Tunnel Construction Surveys” (Chapter 16), “Culvert and Bridge Construction Surveys” (Chapter 17), and “Building Construction Surveys” (Chapter 18). Chapter 19, “Quantity and Final Surveys,” introduces the student to the types of computations and records keeping that surveyors must do to provide data for the processing of interim and final payments to the contractors.
- To help streamline the text, some of the previous edition’s appendices have been transferred to the Instructor’s Manual (see below).
- Finally, this edition introduces coauthor Dianne K. Slattery, a professor in the Department of Technology and Construction Management at Missouri State University in Springfield, Missouri. Dr. Slattery has wide academic and practical experience in civil engineering and in engineering surveying, and has used previous editions of this text to teach undergraduate courses in Construction Surveying for more than 15 years.

SUPPLEMENTS

The available Instructor’s Manual includes solutions for all end-of-chapter problems; a typical evaluation scheme; subject outlines (two terms or two-semester programs); term assignments, sample instruction class handouts for instrument use, and so on; and mid-term and final tests. Also included is a PowerPoint presentation that can be used as an aid in presenting text material and as a source for overhead transparencies. In addition, former text appendices are now also included in the Instructors Manual, including Steel Tape Corrections, Stadia Techniques and Calculations, Early Surveying, and Surveying and Mapping Web sites.

To access supplementary materials online, instructors need to request an instructor access code. Go to www.pearsonhighered.com/irc to register for an instructor access code. Within 48 hours of registering, you will receive a confirming e-mail including an instructor access code. Once you have received your code, locate your text in the online catalog

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Technology continues to expand; improvements to field equipment, data-processing techniques, and construction practices in general will inevitably continue. Surveyors must keep up with these dynamic events. We hope that students, by using this text, will be completely up to date in this subject area and will be readily able to cope with the technological changes that continue to occur. Comments and suggestions about the text are welcomed and can be e-mailed to us at *barry.kavanagh@cogeco.ca* and *DianneSlattery@Missouristate.edu*.

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SURVEYING PRINCIPLES

Part I, which includes Chapters 1–11, introduces you to traditional and state-of-the-art techniques in data collection, layout, and presentation of field data. Chapter 1 covers surveying fundamentals. Elevation determination is covered in the chapters on leveling (Chapter 4), total stations (Chapter 7), and satellite positioning (Chapter 9). Distance measurements are covered, using both conventional taping techniques (Chapter 3), and electronic distance measurement (EDM) techniques (Chapter 5). Data presentation is covered in Chapters 7 and 10. Angle measurements and geometric analysis of field measurements are covered in Chapters 6–8. Horizontal positioning is covered in Chapters 9 and 10, and control for both data-gathering and layout surveys is covered in Chapter 11.

Although most distance measurements are now done with EDM techniques, many applications still exist for steel taping on the short-distance measurements often found in construction layouts. Techniques for taping corrections can be found in Chapter 3 and in the online Instructors Manual (see the Preface for access to the Instructors Manual).

SURVEYING FUNDAMENTALS

1.1 SURVEYING DEFINED

Surveying is the art and science of taking field measurements on or near the surface of the Earth. Survey field measurements include horizontal and slope distances, vertical distances, and horizontal and vertical angles. In addition to measuring distances and angles, surveyors can measure position as given by the northing, easting, and elevation of a survey station by using satellite-positioning and remote-sensing techniques. In addition to taking measurements in the field, the surveyor can derive related distances and directions through geometric and trigonometric analysis.

Once a survey station has been located by angle and distance, or by positioning techniques, the surveyor then attaches to that survey station (in handwritten or electronic field notes) a suitable identifier or attribute that describes the nature of the survey station. In Chapter 10, you will see that attribute data for a survey station can be expanded from a simple descriptive label to include a wide variety of related information that can be tagged specifically to that survey station.

Since the 1980s, the term **geomatics** has come into popular usage to describe the computerization and digitization of data collection, data processing, data analysis, and data output. Geomatics not only includes traditional surveying as its cornerstone but also reflects the now-broadened scope of measurement science and information technology. Figure 10.1 shows a digital surveying data model. This illustration gives you a sense of the diversity of the integrated scientific activities now covered by the term *geomatics*.

The vast majority of engineering and construction projects are so limited in geographic size that the surface of the Earth is considered to be a plane for all X (easterly) and Y (northerly) dimensions. Z dimension (height) is referred to a datum, usually mean sea level. Surveys that ignore the curvature of the Earth for horizontal dimensions are called **plane surveys**. Surveys that cover a large geographic area—for example, state or provincial boundary surveys—must have corrections made to the field measurements so that these measurements reflect the curved (ellipsoidal) shape of the Earth. These surveys are called **geodetic surveys**. The Z dimensions (**orthometric heights**) in geodetic surveys are also referenced to a datum—usually mean sea level.

In the past, geodetic surveys were very precise surveys of great magnitude, for example, national boundaries and control networks. Modern surveys (data gathering, control, and layout) utilizing satellite-positioning systems are geodetic surveys based on the ellipsoidal shape of the Earth and referenced to the geodetic reference system (GRS80) ellipsoid. Such survey measurements must be translated mathematically from

ellipsoidal coordinates and ellipsoidal heights to plane grid coordinates and to orthometric heights (referenced to mean sea level) before being used in leveling and other local surveying projects.

Engineering or construction surveys that span long distances (e.g., highways, railroads) are treated as plane surveys, with corrections for the Earth's curvature being applied at regular intervals (e.g., at 1-mi intervals or at township boundaries). **Engineering surveying** is defined as those activities involved in the planning and execution of surveys for the location, design, construction, maintenance, and operation of civil and other engineered projects.* Such activities include the following:

1. Preparation of surveying and related mapping specifications.
2. Execution of photogrammetric and field surveys for the collection of required data, including topographic and hydrographic data.
3. Calculation, reduction, and plotting (manual and computer-aided) of survey data for use in engineering design.
4. Design and provision of horizontal and vertical control survey networks.
5. Provision of line and grade and other layout work for construction and mining activities.
6. Execution and certification of quality control measurements during construction.
7. Monitoring of ground and structural stability, including alignment observations, settlement levels, and related reports and certifications.
8. Measurement of material and other quantities for inventory, economic assessment, and cost accounting purposes.
9. Execution of as-built surveys and preparation of related maps, plans, and profiles upon completion of the project.
10. Analysis of errors and tolerances associated with the measurement, field layout, and mapping or other plots of survey measurements required in support of engineered projects.

Engineering surveying does not include surveys for the retracement of existing land ownership boundaries or the creation of new boundaries. These activities are reserved for licensed property surveyors—also known as professional land surveyors or cadastral surveyors.

1.2 SURVEYING: GENERAL BACKGROUND

Surveys are usually performed for one of two reasons. First, surveys are made to collect data, which can then be plotted to scale on a plan or map (these surveys are called **preliminary surveys** or **preengineering surveys**); second, field surveys are made to lay out dimensions taken from a design plan and thus define precisely, in the field, the location of the proposed construction works. The layouts of proposed property lines and corners as required in land division are called **layout surveys**; the layouts of proposed construction

*Adapted from the definition of *engineering surveying* as given by the American Society of Civil Engineers (ASCE) in their *Journal of Surveying Engineering* in 1987.

features are called **construction surveys**. Preliminary and construction surveys for the same area must have this one characteristic in common: Measurements for both surveys must be referenced to a common base for X, Y, and Z dimensions. The establishment of a base for horizontal and vertical measurements is known as **control survey**.

1.3 CONTROL SURVEYS

Control surveys establish reference points and reference lines for preliminary and construction surveys. Vertical reference points, called benchmarks, are established using leveling surveys (Chapter 4) or satellite-positioning surveys (Chapter 9). Horizontal control surveys (Chapter 11) use any of a variety of measuring and positioning techniques capable of providing appropriately precise results; such surveys can be tied into (1) state or provincial coordinate grids, (2) property lines, (3) roadway centerlines, and (4) arbitrarily placed baselines or grids. When using positioning satellites to establish or reestablish ground positions, the always-available satellite systems themselves can be considered as a control net—thus greatly reducing the need for numerous on-the-ground reference stations. At present, the only fully deployed satellite-positioning systems are the United States' Global Positioning System (GPS) and the Russian Global Navigation Satellite System (GLONASS). Other countries plan to have positioning systems deployed within the next 5 to 10 years—for example, Europe's Galileo System, China's Compass System, Japan's system, and an Indian positioning system.

1.4 PRELIMINARY SURVEYS

Preliminary surveys (also known as preengineering surveys, location surveys, or data-gathering surveys) are used to collect measurements that locate the position of natural features, such as trees, rivers, hills, valleys, and the like, and the position of built features, such as roads, structures, pipelines, and so forth. Measured tie-ins can be accomplished by any of the following techniques.

1.4.1 Rectangular Tie-Ins

The rectangular tie-in (also known as the right-angle offset tie) was once one of the most widely used field location techniques for preelectronic surveys. This technique, when used to locate point P in Figure 1.1(a) to baseline AB, requires distance AC (or BC), where C is on AB at 90° to point P, and it also requires measurement CP.

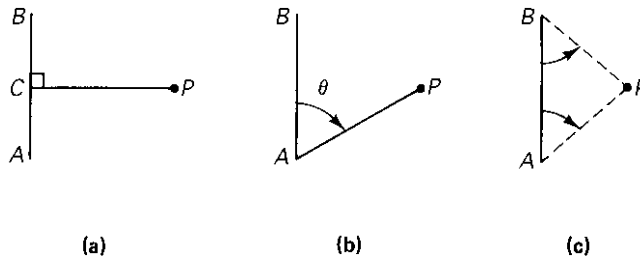


FIGURE 1.1 Location ties.

1.4.2 Polar Tie-Ins

Polar tie-ins (also known as the angle/distance technique) are now the most (refer also to Section 1.4.4) widely used location technique (Chapters 6 and 7). Here, point P is located from point A on baseline AB by measuring angle θ and distance AP [Figure 1.1(b)].

1.4.3 Intersection Tie-Ins

This technique is useful in specialized location surveys. Point P in Figure 1.1(c) is located to baseline AB either by measuring angles from A and B to P or by swinging out arc lengths AP and BP until they intersect. The angle intersection technique is useful for near-shore marine survey locations using theodolites or total stations set up on shore control points. The distance arc intersection technique is an effective method for replacing “lost” survey points from preestablished reference ties.

1.4.4 Positioning Tie-Ins

The second most widely used technique for locating topographic features utilizes direct positioning techniques common to total station surveys and ground-scanning techniques (Chapter 7), satellite-positioning techniques (Chapter 9), and remote-sensing techniques (Chapter 10).

1.5 SURVEYING INSTRUMENTS

The instruments most commonly used in field surveying are (1) level and rod, (2) steel tapes, (3) theodolite, (4) total station, and (5) satellite-positioning receiver. The level and rod are used to determine differences in elevation and elevations in a wide variety of surveying, mapping, and engineering applications. Levels and rods are discussed in Chapter 4. Steel tapes are relatively precise measuring instruments and are used mostly for short measurements in both preliminary and layout surveys. Steel tapes and their usage are discussed in detail in Chapter 3.

Theodolites (also called transits—short for transiting theodolites) are instruments designed for use in measuring horizontal and vertical angles and for establishing linear and curved alignments in the field. During the last 60 years, the theodolite has evolved through four distinct phases:

1. An open-faced, vernier-equipped (for angle determination) theodolite was commonly called a transit. The metallic horizontal and vertical circles were divided into half-degree (30') or third-degree (20') of arc. The accompanying 30' or 20' vernier scales allowed the surveyor to read the angle to the closest 1' or 30" of arc. A plumb bob was used to center the transit over the station mark. See Figures G.8 and G.9 (see the online Instructors Manual). Vernier transits are discussed in detail in Section G.3 (see the online Instructors Manual).
2. In the 1950s, the vernier transit gave way to the optical theodolite. This instrument came equipped with optical glass scales, permitting direct digital readouts or micrometer-assisted readouts. An optical plummet was used to center the instrument over the station mark. See Figure 6.4.

3. Electronic theodolites first appeared in the 1960s. These instruments used photoelectric sensors capable of sensing vertical and horizontal angles and displaying horizontal and vertical angles in degrees, minutes, and seconds. Optical plummets (and later, laser plummets) are used to center the instrument over the station mark (Figure 1.7). Optical and electronic theodolites are discussed in detail in Chapter 6.
4. The total station appeared in the 1980s. This instrument combines electronic distance measurement (EDM), which was developed in the 1950s, with an electronic theodolite. In addition to electronic distance- and angle-measuring capabilities, this instrument is equipped with a central processor, which enables the computation of horizontal and vertical positions. The central processor also monitors instrument status and helps the surveyor perform a wide variety of surveying applications. All data can be captured into electronic field books or into onboard storage as the data are received. See Figure 1.6. Total stations are described in detail in Chapters 6 and 7.

Satellite-positioning system receivers (Figures 9.2–9.4) capture signals transmitted by four or more positioning satellites to determine position coordinates (e.g., northing, easting, and elevation) of a survey station. Satellite positioning is discussed in Chapter 9.

Positions of ground points and surfaces can also be collected using various remote-sensing techniques (e.g., panchromatic, multispectral, lidar, and radar) utilizing ground stations as well as satellite and airborne platforms (Chapter 10).

1.6 CONSTRUCTION SURVEYS

Construction surveys provide the horizontal location and the height above sea level (also known as the provision of **line and grade**) for all component of a wide variety of construction projects—for example, highways, streets, pipelines, bridges, buildings, and site grading. Construction layout marks the horizontal location (line) as well as the vertical location or elevation (grade) for the proposed work. The builder can measure from the surveyor’s markers to the exact location of each component of the facility to be constructed. Layout markers can be wood stakes, steel bars, nails with washers, spikes, chiseled marks in concrete, and so forth. Modern layout techniques also permit the contractor to position construction equipment for line and grade using machine guidance techniques involving lasers, total stations, and satellite-positioning receivers (Chapter 12, Sections 12.3–12.6). When commencing a construction survey, it is important that the surveyor use the same control survey points as those used for the preliminary survey on which the construction design was based.

1.7 DISTANCE MEASUREMENT

Distances between two points can be **horizontal**, **slope**, or **vertical** and are recorded in feet or in meters (Figure 1.2).

Vertical distances can be measured with a tape, as in construction work. However, they are more usually measured with a surveyor’s level and rod (Figures 1.3 and 1.4) or with a total station (Figure 1.6).

Horizontal and slope distances can be measured with a fiberglass or steel tape (Figure 1.5) or with an electronic distance-measuring device (Figure 1.6). When surveying, the horizontal distance is always required for plan-plotting purposes. A distance measured

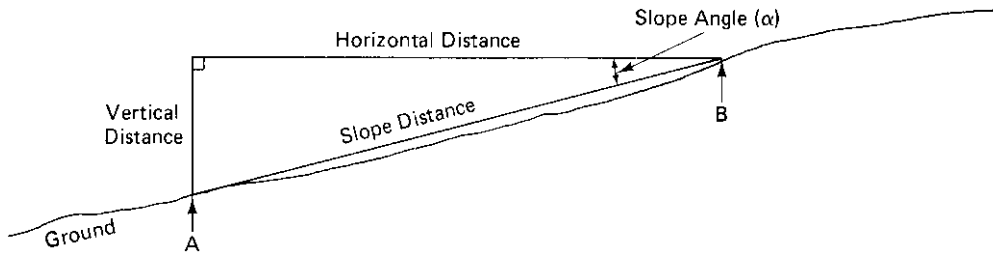


FIGURE 1.2 Distance measurement.

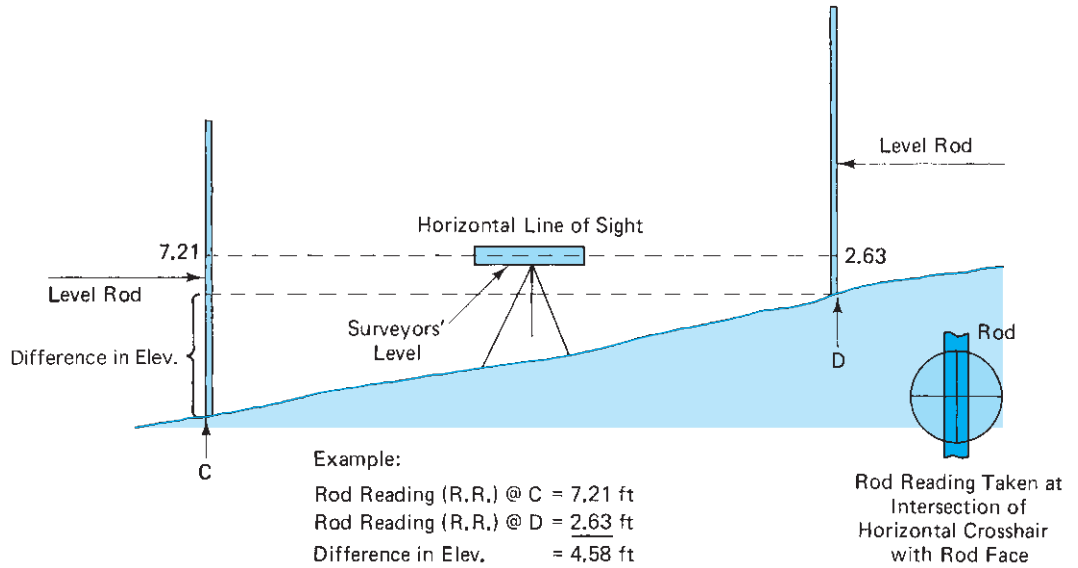


FIGURE 1.3 Leveling technique.

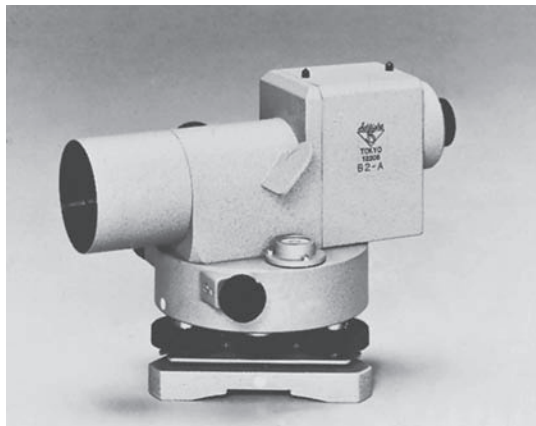
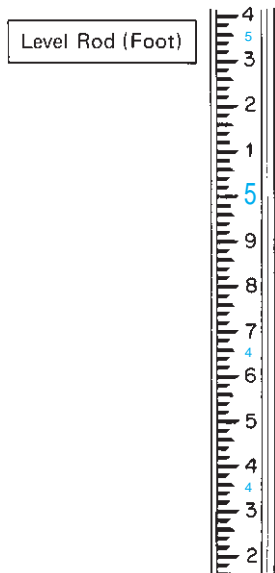


FIGURE 1.4 Level and rod. (Courtesy of SOKKIA Corp.)



FIGURE 1.5 Preparing to measure to a stake tack, using a plumb bob and steel tape.



FIGURE 1.6 Sokkia total station.