

# Ninth Edition



**Barry Kavanagh • Tom Mastin**

# **Surveying**

## **Principles and Applications**

NINTH EDITION

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distribution in the U.S.A. or Canada**

## 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 transit work)
C <sub>L</sub>	correction due to erroneous length of tape
C <sub>P</sub>	correction due to nonstandard tension
C <sub>S</sub>	correction due to effects of sag
C <sub>T</sub>	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
Elev	elevation
ETI	electronic tacheometer instrument (more popularly known as Total Station)
FS	foresight (rod reading in leveling; line sighting in transit 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
bbl	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 <sup>2</sup>	square meter
m <sup>3</sup>	cubic meter
mm	millimeter(s)
t	tonne

# Preface

## WHAT'S NEW IN THIS EDITION

Responding to the advice of reviewers and faculty who have adopted this text for use in their programs, we have shortened and streamlined the text from seventeen to fourteen chapters.

- Optical theodolites, total stations, and total station applications have now been brought together in Chapter 5.
- Chapter 7, "Satellite Positioning Systems"; Chapter 9, "Geographic Information Systems"; and Chapter 11, "Remote Sensing," have been substantially revised.
- The treatment of hydrographic surveying has been shortened and included at the end of Chapter 8, "Topographic Surveying."
- Chapter 13, "Engineering Surveying," has been revised to combine all the engineering work into one chapter.
- Chapter 14, "Land Surveys," has been rewritten to reflect coauthor Tom Mastin's knowledge and experience.
- In addition, all chapters were carefully reviewed and updated to ensure that the latest in technological advances were included. New end-of-chapter questions have been added and end-of-chapter problems have been expanded and refreshed. The websites given in selected chapters and in Appendix E have been updated and expanded.

The text is divided into four parts:

- Part I, Surveying Principles, includes chapters on the basics of surveying, leveling, distance measurement (taping and electronic distance measurement), angles and directions, theodolites, total stations, traverse surveys, satellite positioning, topographic surveying and mapping, geographic information systems, and control surveys.
- Part II, Remote Sensing, includes chapters on satellite imagery and airborne imagery.

- Part III, Surveying Applications, includes chapters on engineering surveys and land surveys.
- Part IV, Appendices, includes the following information: random errors, trigonometric definitions and identities, glossary, answers to selected chapter problems, Internet websites, a color photo gallery (located at the end of the book), typical field projects, and early surveying.

Finally, this edition introduces coauthor Tom B. Mastin of the California Polytechnical State University. Tom's background includes many years of experience in academics, land surveying, and engineering surveying, and he is a great addition to the team producing this text.

## INSTRUCTOR SUPPLEMENTS

The following online supplements are available for instructors:

- Online PowerPoints
- Online Instructor's Manual

To access supplementary materials online, instructors need to request an instructor access code. Go to <http://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 and click on the Instructor Resources button on the left side of the catalog product page. Select a supplement, and a login page will appear. Once you have logged in, you can access instructor material for all Prentice Hall textbooks. If you have any difficulties accessing the site or downloading a supplement, please contact Customer Service at <http://247pearsoned.custhelp.com/>.

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- **CHAPTER 8** Topographic Surveying and Mapping
- **CHAPTER 9** Geographic Information Systems
- **CHAPTER 10** Control Surveys

## BASICS OF SURVEYING

### 1.1 OVERVIEW

The concept of surveying has been around ever since some members of the human race stopped hunting and gathering, and began to stay for extended periods in one geographic area, where they could support themselves with various agricultural endeavors. The early practices of land ownership required some mechanism to mark (and re-mark when necessary) the boundaries of individual landowners and thus reduce conflicts over competing land claims. Many early settlements occurred near bodies of water where shorelines shifted over time due to flooding and other natural occurrences, thus requiring continual surveys to re-mark boundaries; see Appendix H for early Egyptian surveying techniques.

*What do surveyors do?* Surveyors take and analyze measurements.

*What do surveyors measure?* Surveyors measure distances, angles, and positions.

*What distances do surveyors measure?* Surveyors measure horizontal distances, slope distances, and vertical distances.

*What angles do surveyors measure?* Surveyors measure angles in the horizontal and vertical planes.

*What positions do surveyors measure?* Surveyors measure the two-dimensional positions of points on or near the surface of the earth referenced to a defined Cartesian grid or to a geographic grid (latitude and longitude), and they measure elevation dimensions referenced to mean sea level (MSL); as

well, they measure three-dimensional positions of points on or near the earth's surface referenced to a defined ellipsoidal model of the earth called the Geodetic Reference System (GRS80).

*Who can perform surveys?* The two largest fields of surveying are land surveying (boundary or property surveying) and engineering surveying. North American surveyors engaged in establishing, or reestablishing, legal boundaries must be licensed by the state or province in which they are working (see Chapter 14). They must pass state/provincial exams and have years of field training before being licensed. On the other hand, engineering surveys are performed by surveyors who have civil engineering (or civil engineering technology) education, together with suitable field experience, and are thus prepared to perform a wide variety of preengineering and construction layout surveys. Some university programs and state/provincial professional organizations have established programs (including *Geomatics*) and objectives designed to produce "professional" surveyors capable of working in both fields. Another, more recent, indication of the changing scene is that some "layout surveys" on large projects, once performed by both engineering and land surveyors, are now being accomplished by construction equipment operators who are guided by in-cab interactive monitors or other *line and grade* signaling devices. See Chapter 13.

## 1.2 SURVEYING DEFINED

Surveying is the art and science of measuring distances, angles, and positions, on or near the surface of the earth. It is an art in that only a surveyor who possesses a thorough understanding of surveying techniques will be able to determine the most efficient methods needed to obtain optimal results over a wide variety of surveying problems. Surveying is scientific to the degree that rigorous mathematical techniques are used to analyze and adjust the field survey data. The accuracy, and

thus reliability, of the survey depends not only on the field expertise of the surveyor, but also on the surveyor's understanding of the scientific principles underlying and affecting all forms of survey measurement.

Figure 1-1 is an aerial photo of undeveloped property. Figure 1-2 is an aerial photo of the same property after development. All the straight and curved lines that have been added to the post-development photo, showing modifications and/or additions to roads, buildings, highways,



**FIGURE 1-1** Aerial photograph of undeveloped property





**FIGURE 1-2** Aerial photograph of same property after development

residential areas, commercial areas, property boundaries, and so on, are all the direct or indirect result of surveying.

### 1.3 TYPES OF SURVEYS

*Plane surveying* is that type of surveying in which the surface of the earth is considered to be a plane for all  $X$  and  $Y$  dimensions. All  $Z$  dimensions (height) are referenced to the mean surface of the earth (MSL) or to the surface of the earth's

reference ellipsoid (GRS80). Most engineering and property surveys are classed as plane surveys, although some route surveys that cover long distances (e.g., highways and railroads) will have corrections applied at regular intervals (e.g., 1 mile) to correct for the earth's curvature.

*Geodetic surveying* is that type of surveying in which the surface of the earth is considered to be an ellipsoid of revolution for  $X$  and  $Y$  dimensions. As in plane surveying, the  $Z$  dimensions (height) can be referenced to the surface of the earth's reference

ellipsoid (GRS80) or can be converted to refer to the mean surface of the earth (MSL). Traditional geodetic surveys were very precise surveys of great magnitude (e.g., national boundaries and control networks). Modern surveys such as data gathering, control, and layout which utilize satellite positioning [e.g., the global positioning system (GPS)] are also based on the earth's reference ellipsoid (GRS80) and, as such, could be classed as being geodetic surveys. Such geodetic measurements must be mathematically converted to local coordinate grids and to MSL elevations to be of use in leveling and other local surveying projects.

## 1.4 CLASSES OF SURVEYS

**Control surveys** are used to reference both preliminary and layout surveys. Horizontal control can be arbitrarily placed, but it is usually tied directly to property lines, roadway centerlines, or coordinated control stations. Vertical control is often a series of benchmarks, permanent points whose elevations above a datum (e.g., MSL) have been carefully determined. It is accepted practice to take more care in control surveys with respect to precision and accuracy; great care is also taken to ensure that the control used for a preliminary survey can be readily reestablished at a later date, whether it be needed for further preliminary work or for a related layout survey.

**Preliminary surveys** (data gathering) gather geospatial data (distances, positions, and angles) to locate physical features (e.g., water boundaries, trees, roads, structures, or property markers) so that the data can be plotted to scale on a map or plan. Preliminary surveys also include the determination of differences in elevation (vertical distances) so that elevations and contours may also be plotted. [Also see digital terrain models (DTMs) in Chapter 8.]

**Layout surveys** involve marking on the ground (using wood stakes, iron bars, aluminum and concrete monuments, nails, spikes, etc.) the features shown on a design plan. The layout can be for boundary lines, as in land division surveying,

or it can be for a wide variety of engineering works (e.g., roads, pipelines, structures, bridges); the latter group is known as construction surveying. In addition to marking the proposed horizontal location ( $X$  and  $Y$  coordinates) of the designed feature, data will also be given for the proposed (design) elevations which are referenced to MSL.

## 1.5 DEFINITIONS

1. *Topographic surveys*: preliminary surveys used to locate and map the natural and man-made surface features of an area. The features are located relative to one another by tying them all into the same control lines or control grid. See Chapter 8.
2. *Hydrographic surveys*: preliminary surveys that are used to tie in underwater features to surface control points. Usually shorelines, marine features, and water depths are shown on the hydrographic map or electronic chart. See Chapter 8.
3. *Route surveys*: preliminary, layout, and control surveys that range over a narrow but long strip of land. Typical projects that require route surveys are highways, railroads, electricity transmission lines, and channels. See Chapter 13.
4. *Property surveys*: preliminary, layout, and control surveys that are involved in determining boundary locations or in laying out new property boundaries (also known as *cadastral* or *land surveys*). See Chapter 14.
5. *Final ("as-built") surveys*: similar to preliminary surveys. Final surveys tie in features that have just been constructed to provide a final record of the construction and to check that the construction has proceeded according to the design plans.
6. *Aerial surveys*: preliminary and final surveys using both traditional aerial photography and aerial imagery. Aerial imagery includes the use of digital cameras, multispectral scanners, LiDAR, and radar. See Chapter 12.
7. *Construction surveys*: layout surveys for engineering works. See Chapter 13.