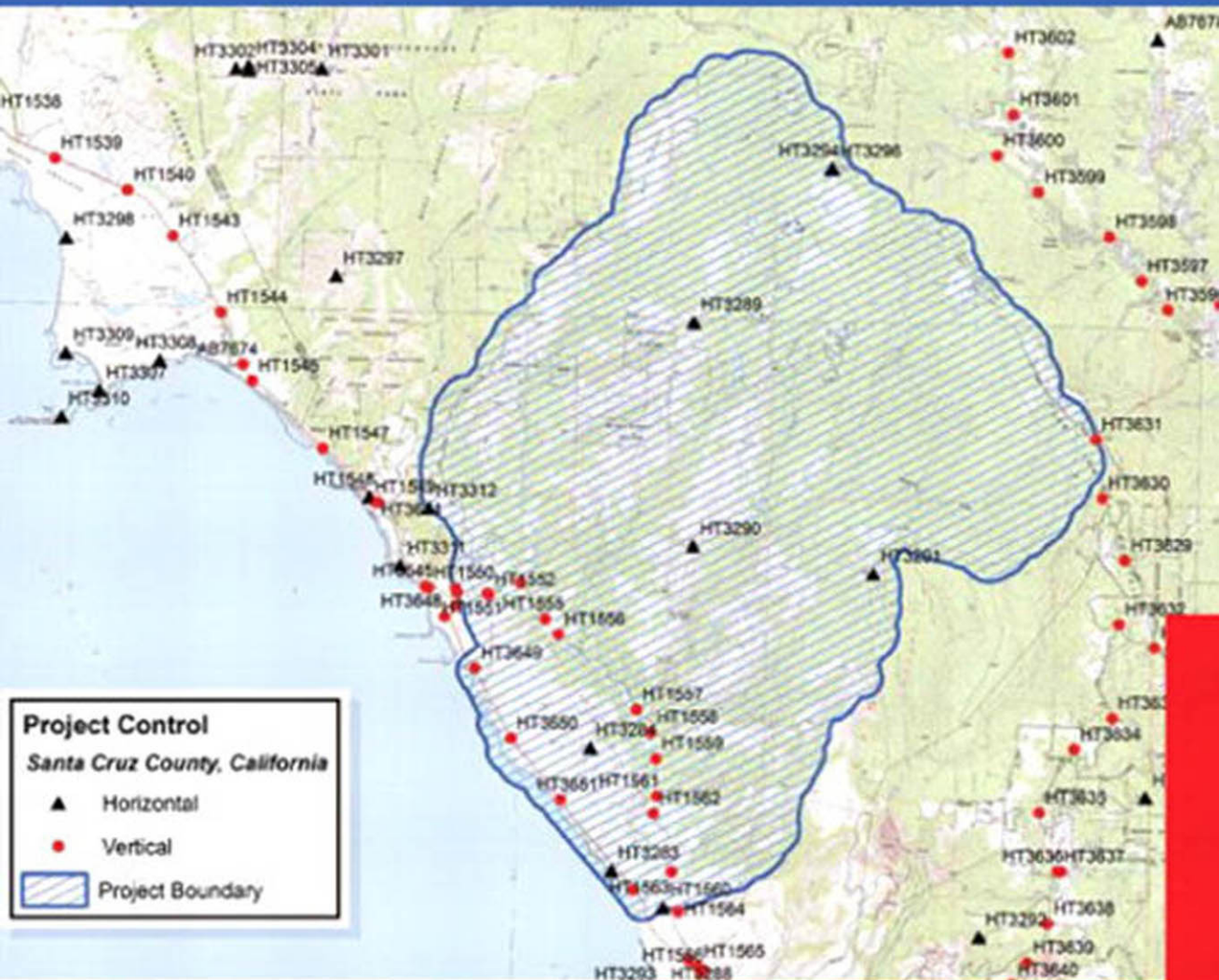


# Surveying

## Principles and Applications

Ninth Edition



**Barry Kavanagh • Tom Mastin**

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NINTH EDITION

**Barry F. Kavanagh**

Seneca College, Emeritus

**Tom B. Mastin**

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# 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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# Contents

## PART I

### SURVEYING PRINCIPLES 1

#### CHAPTER 1 Basics of Surveying 2

- 1.1 Overview 2
- 1.2 Surveying Defined 3
- 1.3 Types of Surveys 4
- 1.4 Classes of Surveys 5
- 1.5 Definitions 5
- 1.6 Surveying Instrumentation 6
- 1.7 Overview of a Modern Surveying Data System—The Science of Geomatics 9
- 1.8 Survey Geographic Reference 12
- 1.9 Survey Grid Reference 14
- 1.10 Survey Legal Reference 14
- 1.11 Survey Vertical Reference 14
- 1.12 Distance Measurement 14
- 1.13 Units of Measurement 14
- 1.14 Location Methods 15
- 1.15 Accuracy and Precision 17
- 1.16 Accuracy Ratio 18
- 1.17 Errors 18
- 1.18 Mistakes 18
- 1.19 Stationing 19
- 1.20 Field Notes 19
- 1.21 Field Management 20
- Questions 21

#### CHAPTER 2 Leveling 22

- 2.1 General Background 22
- 2.2 Theory of Differential Leveling 26

- 2.3 Curvature and Refraction 27
- 2.4 Types of Surveying Levels 28
- 2.5 Leveling Rods 33
- 2.6 Definitions for Differential Leveling 34
- 2.7 Techniques of Leveling 37
- 2.8 Benchmark Leveling (Vertical Control Surveys) 38
- 2.9 Profile and Cross-Section Leveling 41
- 2.10 Reciprocal Leveling 47
- 2.11 Peg Test 48
- 2.12 Three-Wire Leveling 49
- 2.13 Trigonometric Leveling 51
- 2.14 Level Loop Adjustments 52
- 2.15 Suggestions for Rod Work 53
- 2.16 Suggestions for Instrument Work 53
- 2.17 Mistakes in Leveling 54
- Problems 55

#### CHAPTER 3 Distance Measurement 60

- 3.1 Methods of Distance Determination 60
- 3.2 Distance Measuring Techniques 60
- 3.3 Other Indirect Measuring Techniques 61
- 3.4 Gunter's Chain 62
- 3.5 Taping 62
- 3.6 Taping Accessories 65
- 3.7 Taping Techniques 66
- 3.8 Standard Conditions for the Use of Steel Tapes 70



3.9	Taping Corrections: General Background	71
3.10	Systematic Slope Corrections	71
3.11	Erroneous Tape Length Corrections	73
3.12	Temperature Corrections	73
3.13	Tension and Sag Corrections	74
3.14	Random Errors Associated with Systematic Taping Errors	76
3.15	Random Taping Errors	76
3.16	Techniques for Ordinary Taping Precision	77
3.17	Mistakes in Taping	78
3.18	Electronic Distance Measurement	79
3.19	Electronic Angle Measurement	81
3.20	Principles of Electronic Distance Measurement (EDM)	82
3.21	EDM Instrument Characteristics	84
3.22	Prisms	84
3.23	EDM Instrument Accuracies	85
3.24	EDM Instruments Without Reflecting Prisms	86
	• Questions	87
	• Problems	88

## **CHAPTER 4 Angles and Directions 91**

4.1	General Background	91
4.2	Reference Directions for Vertical Angles	91
4.3	Meridians	91
4.4	Horizontal Angles	91
4.5	Azimuths	94
4.6	Bearings	94
4.7	Relationships Between Bearings and Azimuths	94

4.8	Reverse Directions	96
4.9	Azimuth Computations	97
4.10	Bearing Computations	98
4.11	Comments on Bearings and Azimuths	102
4.12	Magnetic Direction	104
	• Problems	109

## **CHAPTER 5 Total Stations and Theodolites 110**

5.1	Introduction	110
5.2	Electronic Theodolites	113
5.3	Total Station	115
5.4	Instrument Setup	117
5.5	Geometry of the Theodolite and the Total Station	118
5.6	Adjustment of the Theodolite and the Total Station	118
5.7	Laying Off Angles	119
5.8	Prolonging a Straight Line	120
5.9	Bucking-In	121
5.10	Intersection of Two Straight Lines	121
5.11	Prolonging a Measured Line by Triangulation over an Obstacle	122
5.12	Prolonging a Line Past an Obstacle	123
5.13	Total Station Field Techniques	125
5.14	Summary of Typical Total Station Characteristics	131
5.15	Field Procedures for Total Stations	132
5.16	Motorized Total Stations	144
5.17	Handheld Total Stations	148
5.18	Summary of Modern Total Station Characteristics	149
5.19	Ground-Based LiDAR Imaging	151

**5.20 Instruments Combining Total Station Capabilities and GPS Receiver Capabilities 154**

- Questions 154

**CHAPTER 6 Traverse Surveys 156**

- 6.1 General Background 156
- 6.2 Open Traverse 157
- 6.3 Closed Traverse 157
- 6.4 Balancing Angles 159
- 6.5 Latitudes and Departures 160
- 6.6 Computation of Latitudes and Departures to Determine the Error of Closure and the Precision of a Traverse 161
- 6.7 Traverse Precision and Accuracy 168
- 6.8 Traverse Adjustments 169
- 6.9 Compass Rule Adjustment 169
- 6.10 Effects of Traverse Adjustments on the Original Data 170
- 6.11 Omitted Measurements 172
- 6.12 Rectangular Coordinates of Traverse Stations 175
- 6.13 Area of a Closed Traverse by the Coordinate Method 178
- 6.14 Review Problem 181
- 6.15 Geometry of Rectangular Coordinates 186
- 6.16 Illustrative Problems in Rectangular Coordinates 187

- Problems 192

**CHAPTER 7 Satellite Positioning Systems 195**

- 7.1 General Background 195
- 7.2 United States' Global Satellite Positioning System (GPS) 195

- 7.3 GPS Codes, Signals, and Frequencies 197
- 7.4 Receivers 197
- 7.5 GPS Position Measurements 198
- 7.6 GPS Carrier Phase Measurement 204
- 7.7 Continuously Operating Reference Station (CORS) 206
- 7.8 Canadian Active Control System 207
- 7.9 Survey Planning 208
- 7.10 GPS Field Procedures 213
- 7.11 GPS Applications 220
- 7.12 Vertical Positioning 222
- 7.13 Conclusion 225
- 7.14 GPS Glossary 225
- 7.15 Recommended Readings 227

- Questions 228

**CHAPTER 8 Topographic and Hydrographic Surveying and Mapping 230**

- 8.1 General Background 230
- 8.2 Maps and Plans 231
- 8.3 Scales and Precision 233
- 8.4 Plan Plotting 234
- 8.5 Introduction to Contours 240
- 8.6 Summary of Contour Characteristics 243
- 8.7 Topographic (Planimetric) Surveys 246
- 8.8 Cross Sections and Profiles 249
- 8.9 Cross Sections, End Areas, and Volumes 252
- 8.10 Prismoidal Formula 257
- 8.11 Construction Volumes 258
- 8.12 Area Computations 259



8.13 Area by Graphical Analysis 260

8.14 Hydrographic Surveys 263

• Problems 277

## CHAPTER 9 Geographic Information Systems 280

9.1 Background 280

9.2 Scope of GIS 282

9.3 Day-to-Day GIS 283

9.4 What Surveyors Need to Know 284

9.5 Construction of Data 291

9.6 Basic Analysis of Data 296

9.7 Components of GIS 296

9.8 Types of Data 300

9.9 Glossary 303

9.10 Internet Websites 304

9.11 Publications 305

• Questions 305

## CHAPTER 10 Control Surveys 307

10.1 General Background 307

10.2 Plane Coordinate Grids 315

10.3 Lambert Projection 320

10.4 Transverse Mercator Grid System 320

10.5 Universal Transverse Mercator (UTM) Grid System 322

10.6 Use of Grid Coordinates 328

10.7 Illustrative Examples 335

10.8 Horizontal Control Techniques 339

10.9 Project Control 342

10.10 Control Survey Markers 349

10.11 Direction of a Line by Gyrotheodolite 352

• Questions 353

• Problems 353

## PART II

### REMOTE SENSING 355

#### CHAPTER 11 Satellite Imagery 356

11.1 General Background 356

11.2 Techniques of Remote Sensing 357

11.3 Electromagnetic Spectrum 357

11.4 Selection of Radiation Sensors 359

11.5 An Introduction to Image Analysis 360

11.6 Classification 366

11.7 Feature Extraction 366

11.8 Ground-Truth or Accuracy Assessment 366

11.9 U.S. National Land-Cover Data (NLCD) 2006 367

11.10 Remote-Sensing Satellites 368

11.11 Imaging Radar Satellites 370

11.12 Satellite Imagery Versus Airborne Imagery 371

11.13 Remote Sensing Internet Websites and Further Reading 372

11.14 Further Reading 373

• Questions 374

#### CHAPTER 12 Airborne Imagery 375

12.1 General Background 375

12.2 Aerial Camera Systems 375

12.3 Photographic Scale 377

12.4 Flying Heights and Altitude 379

12.5 Relief (Radial) Displacement 380

12.6 Flight Lines and Photograph Overlap 381

12.7 Ground Control for Mapping 383

12.8 Mosaics 386

- 12.9 Stereoscopic Viewing and Parallax 387
- 12.10 Photogrammetric Stereoscopic Plotting Techniques 392
- 12.11 Airborne Digital Imagery 395
- 12.12 LiDAR Mapping 395
- 12.13 Aerial Surveying and Photogrammetric Mapping 396
- 12.14 Aerial Photography Interpretation 399
- 12.15 Applications of Air Photo Interpretation for the Engineer and the Surveyor 399
- 12.16 Airborne Imaging Websites 400
- 12.17 Further Reading 400
- Questions 400
- Problems 401

## PART III

### SURVEYING APPLICATIONS 403

#### CHAPTER 13 Engineering Surveys 404

- 13.1 Route Surveys and Highway Curves 404
- 13.2 Circular Curves: General Background 404
- 13.3 Circular Curve Geometry 405
- 13.4 Circular Curve Deflections 409
- 13.5 Chord Calculations 410
- 13.6 Metric Considerations 411
- 13.7 Field Procedure 412
- 13.8 Moving Up on the Curve 413
- 13.9 Offset Curves 414
- 13.10 Vertical Curves: General Background 419
- 13.11 Geometric Properties of the Parabola 421

- 13.12 Computation of the High or Low Point on a Vertical Curve 422
- 13.13 Procedure for Computing a Vertical Curve 422
- 13.14 Municipal Services Construction Practices 424
- 13.15 Highway Construction 437
- 13.16 Sewer Construction 445
- 13.17 Pipeline Construction 452
- 13.18 Culvert Construction 453
- 13.19 Building Construction 453
- 13.20 Other Construction Surveys 454
- 13.21 Construction Survey Specifications 457
- Questions 458
- Problems 458

#### CHAPTER 14 Land Surveys 461

- 14.1 General Background 461
- 14.2 Public Land Surveys 463
- 14.3 Property Conveyance 478
- 14.4 Surveys of Simultaneous Conveyances 482
- 14.5 Surveys of Sequential Conveyances 483
- 14.6 Title or Mortgage Surveys 486
- 14.7 Cadastral Surveying 487
- 14.8 Land Surveying Websites 487
- Problems 488

## PART IV

### APPENDICES 489

#### APPENDIX A Random Errors 490

#### APPENDIX B Trigonometric Definitions and Identities 502

**APPENDIX C Glossary 505**

**APPENDIX D Answers to Selected  
Chapter Problems 514**

**APPENDIX E Internet Websites 526**

**APPENDIX F Examples of Current  
Geomatics Technology 528**

**APPENDIX G Typical Field  
Projects 529**

**APPENDIX H Early Surveying 545**

**Index 563**

# Field Note Index

Page #	Figure #	Description
41	2-15	Leveling field notes and arithmetic check
43	2-18	Profile field notes
45	2-21	Cross-section notes (municipal format)
46	2-22	Cross-section notes (highway format)
50	2-28	Survey notes for three-wire leveling
114	5-5	Field notes for repeated angles
137	5-27	Field notes for total station graphics descriptors
158	6-3	Field notes for open traverse
214	7-13	Station visibility diagram
215	7-14	GPS field log
248	8-12	Topographic field notes for single baseline; split baseline
278	Table 8-7	Topography field notes (Problem 8.4)
345	10-23	Field notes for control point directions and distances
346	10-24	Prepared polar coordinate layout notes
430	13-23	House survey (plat)
431	13-24	Property markers used to establish centerline
477	14-11	Split-line field notes for township subdivision
487	14-14	Typical title or mortgage survey
529	G-1	Field book layout
530	G-2	Sample taping field notes for building dimensions—Project 1
532	G-3	Sample field notes for Project 3 (traverse distance)
534	G-4	Sample field notes for Project 4 (differential leveling)
535	G-5	Sample field notes for Project 5 (traverse angles)
537	G-6	Sample field notes for Project 6 (topography tie-ins)
538	G-7	Sample field notes for Project 6 (topography cross sections)
562	H-16	Field notes for directions

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# SURVEYING PRINCIPLES

- **CHAPTER 1** Basics of Surveying
- **CHAPTER 2** Leveling
- **CHAPTER 3** Distance Measurement
- **CHAPTER 4** Angles and Directions
- **CHAPTER 5** Total Stations and Theodolites
- **CHAPTER 6** Traverse Surveys
- **CHAPTER 7** Satellite Positioning Systems
- **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.

## 1.6 SURVEYING INSTRUMENTATION

The instruments most commonly used in field surveying are (1) *satellite positioning receiver*; (2) *total station*; (3) *level and rod*; (4) *theodolite*; and (5) *steel tape*.

1. *Global Navigation Satellite System* (GNSS) is a term used world-wide to describe the various satellite positioning systems now in use, or in various stages of implementation and planning. *Global positioning system* (GPS) is the term used to describe the U.S. NAVSTAR positioning system, which was the original fully-operational GNSS. *GLONASS* describes the Russian satellite positioning system, which is also now fully operational; *Galileo* describes the European Union satellite positioning system, which is soon to be implemented; and *Beidou*, or *Compass*, describes the Republic of China's regional satellite system now being rapidly expanded to a global positioning system.

A satellite positioning receiver (see Figure 1-3) captures signals transmitted by four or more positioning satellites in order to determine position coordinates (e.g., northing, easting, and elevation) of a survey station. Satellite positioning is discussed in Chapter 7. Some satellite positioning receivers are already programmed to capture signals from three systems: GPS, GLONASS, and the soon-to-be-implemented Galileo.

2. In the 1980s, the *total station* first appeared. 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 distances. The central processor also monitors instrument status and executes software programs that enable the surveyor to perform a wide variety of surveying applications. Total stations measure horizontal and vertical angles as well as horizontal and vertical distances. All data can be captured into attached (cable or wireless) *electronic field books* or into onboard storage as the



**FIGURE 1-3** Zepher™ geodetic GPS antenna, with a 5700 GPS receiver and radio communications equipment. Zepher antennas are said to have accuracy potentials similar to those of choke ring antennas—at lower costs

(Courtesy of Trimble)

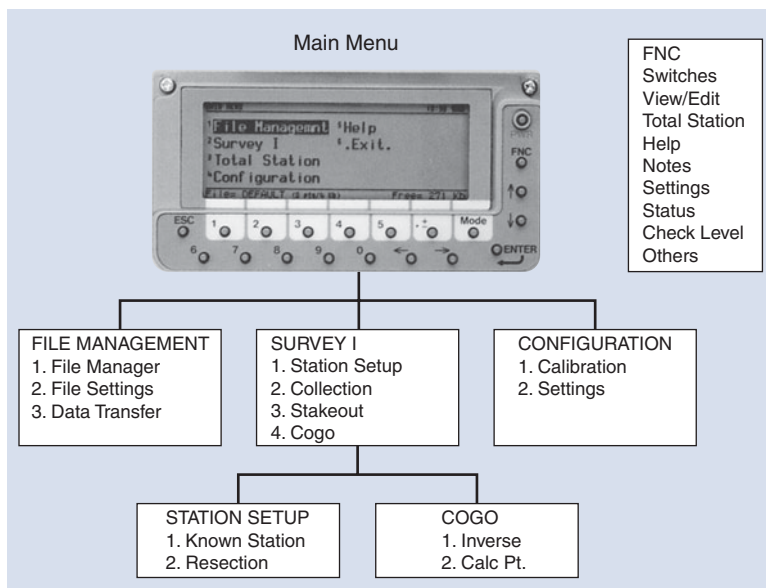
data are received. See Figure 1-4. Total stations are described in detail in Chapter 5.

3. Theodolites (sometimes 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. The theodolite has evolved through three distinct phases.

1. An open-faced, vernier-equipped (for angle determination) theodolite is commonly called a *transit*; a plumb bob is used to center the transit over the station mark. See Figure H-8.



(a)



(b)

**FIGURE 1-4** (a) Total station screen showing electronic level bubbles; these highly sensitive bubbles along with laser plummets allow the total stations to be precisely set over a point. (b) Menu schematic for the Nikon DTM 750

(Courtesy of Cansell Survey Equipment Co., Toronto)

2. In the 1950s, the vernier transit gave way to the *optical theodolite*. This instrument came equipped with optical scales, permitting direct digital readouts or micrometer-assisted readouts;
3. In the 1970s, *electronic theodolites* first appeared. These instruments used photoelectric sensors

an optical plummet was used to center the instrument over the station mark. See Figure H-13.



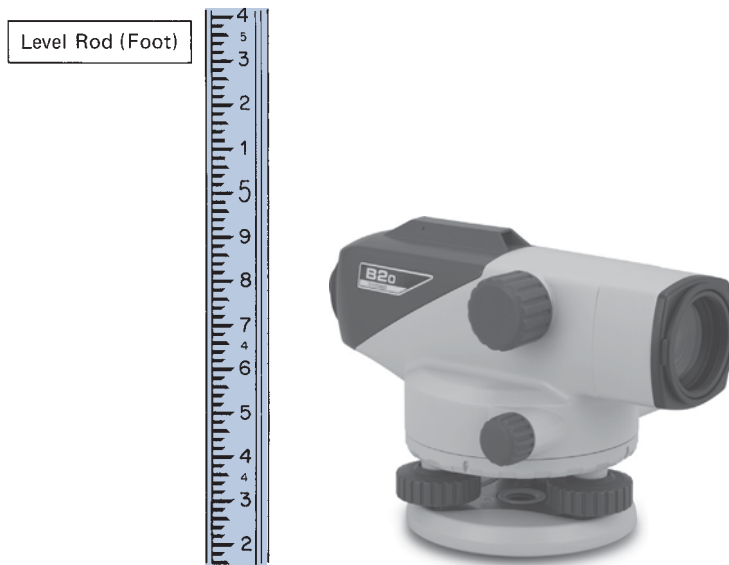
capable of sensing vertical and horizontal angles and then displaying these angles in degrees, minutes, and seconds. Optical plummets and later laser plummets are used to center the

instrument over the station mark. See Figure 1-5. Electronic theodolites are discussed in detail in Chapter 5. Optical and vernier transits are discussed in detail in Section H.2.



**FIGURE 1-5** Early model of an electronic theodolite with interfaced Distomat EDM (mounted on the telescope).

(Courtesy of imagebroker.net/SuperStock)



**FIGURE 1-6** Level and rod

(Courtesy of Sokkia Co. Ltd.)

4. The level and rod are used to determine elevations in a wide variety of surveying, mapping, and engineering applications. See Figure 1-6. Leveling is discussed in Chapter 2.
5. Steel tapes are relatively precise measuring instruments, and are used mostly for short measurements in both preliminary and layout surveys. Steel tapes, and their use, are discussed, in detail, in Chapter 3.

Other instruments are used in remote-sensing techniques to acquire geospatial images; panchromatic, multispectral scanning, radar, and LiDAR imaging can be based on both airborne and satellite platforms. See Chapters 12 and 13.

## 1.7 OVERVIEW OF A MODERN SURVEYING DATA SYSTEM—THE SCIENCE OF GEOMATICS

Advances in computer science have had a tremendous impact on all aspects of modern technology. The effects on the collection and

processing of data in both field surveying and remotely sensed imagery have been significant. Survey data once laboriously collected with tapes, transits, and levels (recorded manually in field books) can now be quickly and efficiently collected using total stations and precise satellite positioning receivers (see Chapter 7). These latter techniques can provide the high-accuracy results usually required in control surveys (see Chapter 10), engineering surveys (see Chapter 13), and land surveys (see Chapter 14). When high accuracy is not a prime requirement, as in some geographic information systems (GISs) surveys and many mapping surveys, data can be efficiently collected from less precise (1 m) satellite positioning receivers and, as well, from satellite and airborne imaging platforms (see Chapters 11 and 12). The broad picture encompassing all aspects of data collection, processing, analysis, and presentation is now referred to as the field of *geomatics*.

*Geomatics* is a term used to describe the science and technology dealing with geospatial data, including *collection, analysis, sorting, management, planning and design, storage, and presentation*. It has applications in all disciplines and