



Table of Contents

PREFACE

xix

Acknowledgments xxi

1 • INTRODUCTION

1

1.1	Definition of Surveying	1
1.2	Geomatics	3
1.3	History of Surveying	4
1.4	Geodetic and Plane Surveys	9
1.5	Importance of Surveying	10
1.6	Specialized Types of Surveys	11
1.7	Surveying Safety	12
1.8	Land and Geographic Information Systems	14
1.9	Federal Surveying and Mapping Agencies	15
1.10	The Surveying Profession	16
1.11	Professional Surveying Organizations	17
1.12	Surveying on the Internet	18
1.13	Future Challenges in Surveying	18
	Problems	20
	Bibliography	20

2 • UNITS, SIGNIFICANT FIGURES, AND FIELD NOTES

22

PART I UNITS AND SIGNIFICANT FIGURES 22

- 2.1 Introduction 22
- 2.2 Units of Measurement 22
- 2.3 International System of Units (SI) 24
- 2.4 Significant Figures 26
- 2.5 Rounding Off Numbers 28

PART II FIELD NOTES 29

- 2.6 Field Notes 29
- 2.7 General Requirements of Handwritten Field Notes 30
- 2.8 Types of Field Books 31
- 2.9 Kinds of Notes 32
- 2.10 Arrangements of Notes 32
- 2.11 Suggestions for Recording Notes 34
- 2.12 Introduction to Survey Controllers 35
- 2.13 Transfer of Files from Survey Controllers 38
- 2.14 Digital Data File Management 40
- 2.15 Advantages and Disadvantages of Survey Controllers 41
- Problems 42
- Bibliography 43

3 • THEORY OF ERRORS IN OBSERVATIONS

44

- 3.1 Introduction 44
- 3.2 Direct and Indirect Observations 44
- 3.3 Errors in Measurements 45
- 3.4 Mistakes 45
- 3.5 Sources of Errors in Making Observations 46
- 3.6 Types of Errors 46
- 3.7 Precision and Accuracy 47
- 3.8 Eliminating Mistakes and Systematic Errors 48
- 3.9 Probability 48
- 3.10 Most Probable Value 49
- 3.11 Residuals 50
- 3.12 Occurrence of Random Errors 50
- 3.13 General Laws of Probability 54
- 3.14 Measures of Precision 55
- 3.15 Interpretation of Standard Deviation 57
- 3.16 The 50%, 90%, and 95% Errors 57
- 3.17 Error Propagation 59
- 3.18 Applications 64
- 3.19 Conditional Adjustment of Observations 64
- 3.20 Weights of Observations 65

3.21	Least-Squares Adjustment	66
	Problems	67
	Bibliography	69

4 • LEVELING—THEORY, METHODS, AND EQUIPMENT **70**

PART I LEVELING—THEORY AND METHODS 70

4.1	Introduction	70
4.2	Definitions	70
4.3	North American Vertical Datum	72
4.4	Curvature and Refraction	73
4.5	Methods for Determining Differences in Elevation	75

PART II EQUIPMENT FOR DIFFERENTIAL LEVELING 82

4.6	Categories of Levels	82
4.7	Telescopes	83
4.8	Level Vials	85
4.9	Tilting Levels	87
4.10	Automatic Levels	87
4.11	Digital Levels	89
4.12	Tripods	90
4.13	Hand Level	90
4.14	Level Rods	91
4.15	Testing and Adjusting Levels	94
	Problems	98
	Bibliography	100

5 • LEVELING—FIELD PROCEDURES AND COMPUTATIONS **101**

5.1	Introduction	101
5.2	Carrying and Setting Up a Level	101
5.3	Duties of a Rodperson	103
5.4	Differential Leveling	104
5.5	Precision	110
5.6	Adjustments of Simple Level Circuits	112
5.7	Reciprocal Leveling	113
5.8	Three-Wire Leveling	114
5.9	Profile Leveling	114
5.10	Grid, Cross-Section, or Borrow-Pit Leveling	120
5.11	Use of the Hand Level	120
5.12	Sources of Error in Leveling	120
5.13	Mistakes	123
5.14	Reducing Errors and Eliminating Mistakes	124

5.15	Using Software	124
	Problems	125
	Bibliography	128

6 • DISTANCE MEASUREMENT

129

PART I METHODS FOR MEASURING DISTANCES 129

6.1	Introduction	129
6.2	Summary of Methods For Making Linear Measurements	129
6.3	Pacing	130
6.4	Odometer Readings	130
6.5	Optical Rangefinders	130
6.6	Tacheometry	131
6.7	Subtense Bar	131

PART II DISTANCE MEASUREMENTS BY TAPING 131

6.8	Introduction to Taping	131
6.9	Taping Equipment and Accessories	132
6.10	Care of Taping Equipment	133
6.11	Taping on Level Ground	134
6.12	Horizontal Measurements on Sloping Ground	136
6.13	Slope Measurements	137
6.14	Sources of Error in Taping	139

PART III ELECTRONIC DISTANCE MEASUREMENT 143

6.15	Introduction	143
6.16	Propagation of Electromagnetic Energy	144
6.17	Principles of Electronic Distance Measurement	147
6.18	Electro-Optical Instruments	148
6.19	Total Station Instruments	151
6.20	EDM Instruments Without Reflectors	152
6.21	Computing Horizontal Lengths From Slope Distances	152
6.22	Errors in Electronic Distance Measurement	154
6.23	Using Software	161
	Problems	162
	Bibliography	163

7 • ANGLES, AZIMUTHS, AND BEARINGS

164

7.1	Introduction	164
7.2	Units of Angle Measurement	164
7.3	Kinds of Horizontal Angles	165

7.4	Direction of a Line	166
7.5	Azimuths	167
7.6	Bearings	168
7.7	Comparison of Azimuths and Bearings	169
7.8	Computing Azimuths	171
7.9	Computing Bearings	173
7.10	The Compass and the Earth's Magnetic Field	174
7.11	Magnetic Declination	176
7.12	Variations in Magnetic Declination	176
7.13	Software for Determining Magnetic Declination	178
7.14	Local Attraction	179
7.15	Typical Magnetic Declination Problems	180
7.16	Mistakes	182
	Problems	182

8 • TOTAL STATION INSTRUMENTS; ANGLE OBSERVATIONS

185

PART I TOTAL STATION INSTRUMENTS 185

8.1	Introduction	185
8.2	Characteristics of Total Station Instruments	185
8.3	Functions Performed by Total Station Instruments	188
8.4	Parts of a Total Station Instrument	189
8.5	Handling and Setting up a Total Station Instrument	192
8.6	Servo-Driven and Remotely Operated Total Station Instruments	195

PART II ANGLE OBSERVATIONS 196

8.7	Relationship of Angles and Distances	196
8.8	Observing Horizontal Angles with Total Station Instruments	197
8.9	Observing Multiple Horizontal Angles by the Direction Method	200
8.10	Closing the Horizon	201
8.11	Observing Deflection Angles	202
8.12	Observing Azimuths	204
8.13	Observing Vertical Angles	204
8.14	Sights and Marks	206
8.15	Prolonging a Straight Line	208
8.16	Balancing-in	209
8.17	Random Traverse	209
8.18	Total Stations for Determining Elevation Differences	211
8.19	Adjustment of Total Station Instruments and their Accessories	212
8.20	Sources of Error in Total Station Work	216
8.21	Propagation of Random Errors in Angle Observations	222
8.22	Mistakes	223
	Problems	224
	Bibliography	225

9 • TRAVERSING**226**

- 9.1 Introduction 226
- 9.2 Observation of Traverse Angles or Directions 228
- 9.3 Observation of Traverse Lengths 229
- 9.4 Selection of Traverse Stations 230
- 9.5 Referencing Traverse Stations 231
- 9.6 Traverse Field Notes 232
- 9.7 Angle Misclosure 233
- 9.8 Traversing with Total Station Instruments 234
- 9.9 Radial Traversing 235
- 9.10 Sources of Error in Traversing 237
- 9.11 Mistakes in Traversing 237
- Problems 237

10 • TRAVERSE COMPUTATIONS**239**

- 10.1 Introduction 239
- 10.2 Balancing Angles 240
- 10.3 Computation of Preliminary Azimuths or Bearings 242
- 10.4 Departures and Latitudes 243
- 10.5 Departure and Latitude Closure Conditions 245
- 10.6 Traverse Linear Misclosure and Relative Precision 245
- 10.7 Traverse Adjustment 246
- 10.8 Rectangular Coordinates 249
- 10.9 Alternative Methods for Making Traverse Computations 250
- 10.10 Inversing 254
- 10.11 Computing Final Adjusted Traverse Lengths and Directions 255
- 10.12 Coordinate Computations in Boundary Surveys 257
- 10.13 Use of Open Traverses 259
- 10.14 State Plane Coordinate Systems 262
- 10.15 Traverse Computations using Computers 263
- 10.16 Locating Blunders in Traverse Observations 263
- 10.17 Mistakes in Traverse Computations 266
- Problems 266
- Bibliography 269

11 • COORDINATE GEOMETRY IN SURVEYING CALCULATIONS**270**

- 11.1 Introduction 270
- 11.2 Coordinate Forms of Equations for Lines and Circles 271
- 11.3 Perpendicular Distance from a Point to a Line 273

11.4	Intersection of Two Lines, Both Having Known Directions	275
11.5	Intersection of a Line with a Circle	277
11.6	Intersection of Two Circles	280
11.7	Three-Point Resection	282
11.8	Two-Dimensional Conformal Coordinate Transformation	285
11.9	Inaccessible Point Problem	290
11.10	Three-Dimensional Two-Point Resection	292
11.11	Software	295
	Problems	296
	Bibliography	300

12 • AREA

301

12.1	Introduction	301
12.2	Methods of Measuring Area	301
12.3	Area by Division into Simple Figures	302
12.4	Area by Offsets from Straight Lines	303
12.5	Area by Coordinates	305
12.6	Area by Double-Meridian Distance Method	309
12.7	Area of Parcels with Circular Boundaries	312
12.8	Partitioning of Lands	313
12.9	Area by Measurements from Maps	317
12.10	Software	319
12.11	Sources of Error in Determining Areas	320
12.12	Mistakes in Determining Areas	320
	Problems	320

13 • GLOBAL NAVIGATION SATELLITE SYSTEMS—INTRODUCTION AND PRINCIPLES OF OPERATION

323

13.1	Introduction	323
13.2	Overview of GPS	324
13.3	The GPS Signal	326
13.4	Reference Coordinate Systems	329
13.5	Fundamentals of Satellite Positioning	339
13.6	Errors in Observations	341
13.7	Differential Positioning	349
13.8	Kinematic Methods	352
13.9	Relative Positioning	352
13.10	Other Satellite Navigation Systems	355
13.11	The Future	358
	Problems	359
	Bibliography	360

14 • GLOBAL NAVIGATION SATELLITE SYSTEMS—STATIC SURVEYS **361**

- 14.1 Introduction 361
- 14.2 Field Procedures in Static GNSS Surveys 362
- 14.3 Planning Satellite Surveys 365
- 14.4 Performing Static Surveys 377
- 14.5 Data Processing and Analysis 378
- 14.6 Things to Consider 387
- 14.7 A Method for Obtaining Orthometric Height Differences Using GNSS 389
- 14.8 Sources of Errors in Satellite Surveys 390
- 14.9 Mistakes in Satellite Surveys 393
- Problems 394
- Bibliography 395

15 • GLOBAL NAVIGATION SATELLITE SYSTEMS—KINEMATIC SURVEYS **396**

- 15.1 Introduction 396
- 15.2 Planning of Kinematic Surveys 397
- 15.3 Initialization Techniques 399
- 15.4 Equipment Used in Kinematic Surveys 400
- 15.5 Methods Used in Kinematic Surveys 402
- 15.6 Performing Post-Processed Kinematic Surveys 405
- 15.7 Communication in Real-Time Kinematic Surveys 407
- 15.8 Real-Time Networks 408
- 15.9 Performing Real-Time Kinematic Surveys 410
- 15.10 Machine Guidance and Control 412
- 15.11 Errors in Kinematic Surveys 414
- 15.12 Mistakes in Kinematic Surveys 415
- Problems 415
- Bibliography 416

16 • ADJUSTMENTS BY LEAST SQUARES **417**

- 16.1 Introduction 417
- 16.2 Fundamental Condition of Least Squares 419
- 16.3 Least-Squares Adjustment by the Observation Equation Method 420
- 16.4 Matrix Methods in Least-Squares Adjustment 424
- 16.5 Matrix Equations for Precisions of Adjusted Quantities 426
- 16.6 Least-Squares Adjustment of Leveling Circuits 428
- 16.7 Propagation of Errors 432
- 16.8 Least-Squares Adjustment of GNSS Baseline Vectors 433
- 16.9 Least-Squares Adjustment of Conventional Horizontal Plane Surveys 439
- 16.10 The Error Ellipse 448
- 16.11 Adjustment Procedures 453

16.12	Other Measures of Precision for Horizontal Stations	454
16.13	Software	456
16.14	Conclusions	456
	Problems	457
	Bibliography	463

17 • MAPPING SURVEYS

464

17.1	Introduction	464
17.2	Basic Methods for Performing Mapping Surveys	465
17.3	Map Scale	466
17.4	Control for Mapping Surveys	467
17.5	Contours	468
17.6	Characteristics of Contours	471
17.7	Method of Locating Contours	472
17.8	Digital Elevation Models and Automated Contouring Systems	474
17.9	Basic Field Methods for Locating Topographic Details	475
17.10	Planning a Laser-Scanning Survey	485
17.11	Three-Dimensional Conformal Coordinate Transformation	488
17.12	Selection of Field Method	489
17.13	Working with Survey Controllers and Field-to-Finish Software	490
17.14	Hydrographic Surveys	492
17.15	Sources of Error in Mapping Surveys	497
17.16	Mistakes in Mapping Surveys	497
	Problems	497
	Bibliography	499

18 • MAPPING

500

18.1	Introduction	500
18.2	Availability of Maps and Related Information	501
18.3	National Mapping Program	501
18.4	Accuracy Standards for Mapping	502
18.5	Manual and Computer-Aided Drafting Procedures	506
18.6	Map Design	507
18.7	Map Layout	509
18.8	Basic Map Plotting Procedures	510
18.9	Contour Interval	512
18.10	Plotting Contours	513
18.11	Lettering	514
18.12	Cartographic Map Elements	515
18.13	Drafting Materials	517
18.14	Automated Mapping and Computer-Aided Drafting Systems	518
18.15	Migrating Maps between Software Packages	523
18.16	Impacts of Modern Land and Geographic Information Systems on Mapping	524
18.17	The Importance of Metadata	525

18.18	Sources of Error in Mapping	525
18.19	Mistakes in Mapping	525
	Problems	526
	Bibliography	528

19 • CONTROL SURVEYS AND GEODETIC REDUCTIONS

529

19.1	Introduction	529
19.2	The Ellipsoid and Geoid	530
19.3	The Conventional Terrestrial Pole	532
19.4	Geodetic Position and Ellipsoidal Radii of Curvature	534
19.5	Geoid Undulation and Deflection of the Vertical	536
19.6	U.S. Reference Frames	539
19.7	Transforming Coordinates Between Reference Frames	544
19.8	Accuracy Standards and Specifications for Control Surveys	549
19.9	The National Spatial Reference System	552
19.10	Hierarchy of the National Horizontal Control Network	552
19.11	Hierarchy of the National Vertical Control Network	553
19.12	Control Point Descriptions	553
19.13	Field Procedures for Conventional Horizontal Control Surveys	557
19.14	Field Procedures for Vertical-Control Surveys	562
19.15	Reduction of Field Observations to their Geodetic Values	567
19.16	Geodetic Position Computations	579
19.17	The Local Geodetic Coordinate System	582
19.18	Three-Dimensional Coordinate Computations	584
19.19	Software	586
	Problems	586
	Bibliography	589

20 • STATE PLANE COORDINATES AND OTHER MAP PROJECTIONS

591

20.1	Introduction	591
20.2	Projections Used in State Plane Coordinate Systems	592
20.3	Lambert Conformal Conic Projection	595
20.4	Transverse Mercator Projection	596
20.5	State Plane Coordinates in NAD 27 and NAD 83	596
20.6	Computing SPCS 83 Coordinates in the Lambert Conformal Conic System	598
20.7	Computing SPCS 83 Coordinates in the Transverse Mercator System	603
20.8	Reduction of Distances and Angles to State Plane Coordinate Grids	609
20.9	Computing State Plane Coordinates of Traverse Stations	619
20.10	Surveys Extending from One Zone to Another	622
20.11	The Universal Transverse Mercator Projection	623
20.12	Other Map Projections	624
20.13	Ground Versus Grid Problem	628

20.14	Map Projection Software	632
	Problems	634
	Bibliography	636

21 • BOUNDARY SURVEYS

637

21.1	Introduction	637
21.2	Categories of Land Surveys	638
21.3	Historical Perspectives	639
21.4	Property Description by Metes and Bounds	640
21.5	Property Description by Block-and-Lot System	643
21.6	Property Description by Coordinates	645
21.7	Retracement Surveys	645
21.8	Subdivision Surveys	648
21.9	Partitioning Land	650
21.10	Registration of Title	651
21.11	Adverse Possession and Easements	652
21.12	Condominium Surveys	652
21.13	Geographic and Land Information Systems	659
21.14	Sources of Error in Boundary Surveys	659
21.15	Mistakes	659
	Problems	660
	Bibliography	662

22 • SURVEYS OF THE PUBLIC LANDS

663

22.1	Introduction	663
22.2	Instructions for Surveys of the Public Lands	664
22.3	Initial Point	667
22.4	Principal Meridian	668
22.5	Baseline	668
22.6	Standard Parallels (Correction Lines)	670
22.7	Guide Meridians	670
22.8	Township Extent, Meridional (Range) Lines, and Latitudinal (Township) Lines	670
22.9	Designation of Townships	672
22.10	Subdivision of a Quadrangle into Townships	672
22.11	Subdivision of a Township into Sections	673
22.12	Subdivision of Sections	675
22.13	Fractional Sections	675
22.14	Notes	676
22.15	Outline of Subdivision Steps	676
22.16	Marking Corners	678
22.17	Witness Corners	678
22.18	Meander Corners	678
22.19	Lost and Obliterated Corners	679
22.20	Accuracy of Public Land Surveys	681

22.21	Descriptions by Township Section, and Smaller Subdivision	682
22.22	BLM Land Information System	683
22.23	Sources of Error	684
22.24	Mistakes	684
	Problems	684
	Bibliography	686

23 • CONSTRUCTION SURVEYS

687

23.1	Introduction	687
23.2	Specialized Equipment for Construction Surveys	688
23.3	Horizontal and Vertical Control	692
23.4	Staking Out a Pipeline	693
23.5	Staking Pipeline Grades	694
23.6	Computing the Bend Angles in Pipelines	696
23.7	Staking Out a Building	697
23.8	Staking Out Highways	701
23.9	Other Construction Surveys	706
23.10	Construction Surveys Using Total Station Instruments	707
23.11	Construction Surveys Using GNSS Equipment	710
23.12	Machine Guidance and Control	712
23.13	As-built Surveys with Laser Scanning	714
23.14	Sources of Error in Construction Surveys	715
23.15	Mistakes	715
	Problems	715
	Bibliography	717

24 • HORIZONTAL CURVES

718

24.1	Introduction	718
24.2	Degree of Circular Curve	719
24.3	Definitions and Derivation of Circular Curve Formulas	721
24.4	Circular Curve Stationing	723
24.5	General Procedure of Circular Curve Layout by Deflection Angles	724
24.6	Computing Deflection Angles and Chords	726
24.7	Notes for Circular Curve Layout by Deflection Angles and Incremental Chords	728
24.8	Detailed Procedures for Circular Curve Layout by Deflection Angles and Incremental Chords	729
24.9	Setups on Curve	730
24.10	Metric Circular Curves by Deflection Angles and Incremental Chords	731
24.11	Circular Curve Layout by Deflection Angles and Total Chords	733
24.12	Computation of Coordinates on a Circular Curve	733
24.13	Circular Curve Layout by Coordinates	735
24.14	Curve Stakeout Using GNSS Receivers and Robotic Total Stations	740
24.15	Circular Curve Layout by Offsets	741

24.16	Special Circular Curve Problems	744
24.17	Compound and Reverse Curves	745
24.18	Sight Distance on Horizontal Curves	746
24.19	Spirals	747
24.20	Computation of "As-Built" Circular Alignments	751
24.21	Sources of Error in Laying Out Circular Curves	754
24.22	Mistakes	755
	Problems	755
	Bibliography	757

25 • VERTICAL CURVES

758

25.1	Introduction	758
25.2	General Equation of a Vertical Parabolic Curve	759
25.3	Equation of an Equal-Tangent Vertical Parabolic Curve	760
25.4	High or Low Point on a Vertical Curve	762
25.5	Vertical Curve Computations Using the Tangent-Offset Equation	762
25.6	Equal Tangent Property of a Parabola	766
25.7	Curve Computations by Proportion	767
25.8	Staking a Vertical Parabolic Curve	767
25.9	Machine Control in Grading Operations	768
25.10	Computations for an Unequal Tangent Vertical Curve	768
25.11	Designing a Curve to Pass Through a Fixed Point	770
25.12	Sight Distance	772
25.13	Sources of Error in Laying Out Vertical Curves	774
25.14	Mistakes	774
	Problems	774
	Bibliography	776

26 • VOLUMES

777

26.1	Introduction	777
26.2	Methods of Volume Measurement	777
26.3	The Cross-Section Method	778
26.4	Types of Cross Sections	779
26.5	Average-End-Area Formula	780
26.6	Determining End Areas	781
26.7	Computing Slope Intercepts	784
26.8	Prismoidal Formula	786
26.9	Volume Computations	788
26.10	Unit-Area, or Borrow-Pit, Method	790
26.11	Contour-Area Method	791
26.12	Measuring Volumes of Water Discharge	792
26.13	Software	793
26.14	Sources of Error in Determining Volumes	794
26.15	Mistakes	795
	Problems	795
	Bibliography	797

27 • PHOTOGRAMMETRY**798**

27.1	Introduction	798
27.2	Uses of Photogrammetry	799
27.3	Aerial Cameras	800
27.4	Types of Aerial Photographs	802
27.5	Vertical Aerial Photographs	804
27.6	Scale of a Vertical Photograph	805
27.7	Ground Coordinates from a Single Vertical Photograph	808
27.8	Relief Displacement on a Vertical Photograph	810
27.9	Flying Height of a Vertical Photograph	812
27.10	Stereoscopic Parallax	813
27.11	Stereoscopic Viewing	816
27.12	Stereoscopic Measurement of Parallax	817
27.13	Analytical Photogrammetry	819
27.14	Stereoscopic Plotting Instruments	819
27.15	Orthophotos	824
27.16	Ground Control for Photogrammetry	825
27.17	Flight Planning	826
27.18	Airborne Laser-Mapping Systems	828
27.19	Remote Sensing	829
27.20	Software	834
27.21	Sources of Error in Photogrammetry	836
27.22	Mistakes	836
	Problems	836
	Bibliography	839

28 • INTRODUCTION TO GEOGRAPHIC INFORMATION SYSTEMS**840**

28.1	Introduction	840
28.2	Land Information Systems	842
28.3	GIS Data Sources and Classifications	843
28.4	Spatial Data	843
28.5	Nonspatial Data	849
28.6	Data Format Conversions	849
28.7	Creating GIS Databases	852
28.8	Metadata	858
28.9	GIS Analytical Functions	858
28.10	GIS Applications	862
28.11	Data Sources	863
	Problems	865
	Bibliography	867

APPENDIX A • TAPE CORRECTION PROBLEMS **868**

- A.1 Correcting Systematic Errors in Taping 868

APPENDIX B • EXAMPLE NOTEFORMS **871**

APPENDIX C • ASTRONOMICAL OBSERVATIONS **878**

- C.1 Introduction 878
- C.2 Overview of Usual Procedures for Astronomical Azimuth Determination 879
- C.3 Ephemerides 881
- C.4 Definitions 884
- C.5 Time 886
- C.6 Timing Observations 888
- C.7 Computations for Azimuth from Polaris Observations by the Hour Angle Method 889
- C.8 Azimuth from Solar Observations 891
- C.9 Importance of Precise Leveling 893

APPENDIX D • USING THE WORKSHEETS FROM THE COMPANION WEBSITE **894**

- D.1 Introduction 894
- D.2 Using the Files 894
- D.3 Worksheets as an Aid in Learning 898

APPENDIX E • INTRODUCTION TO MATRICES **900**

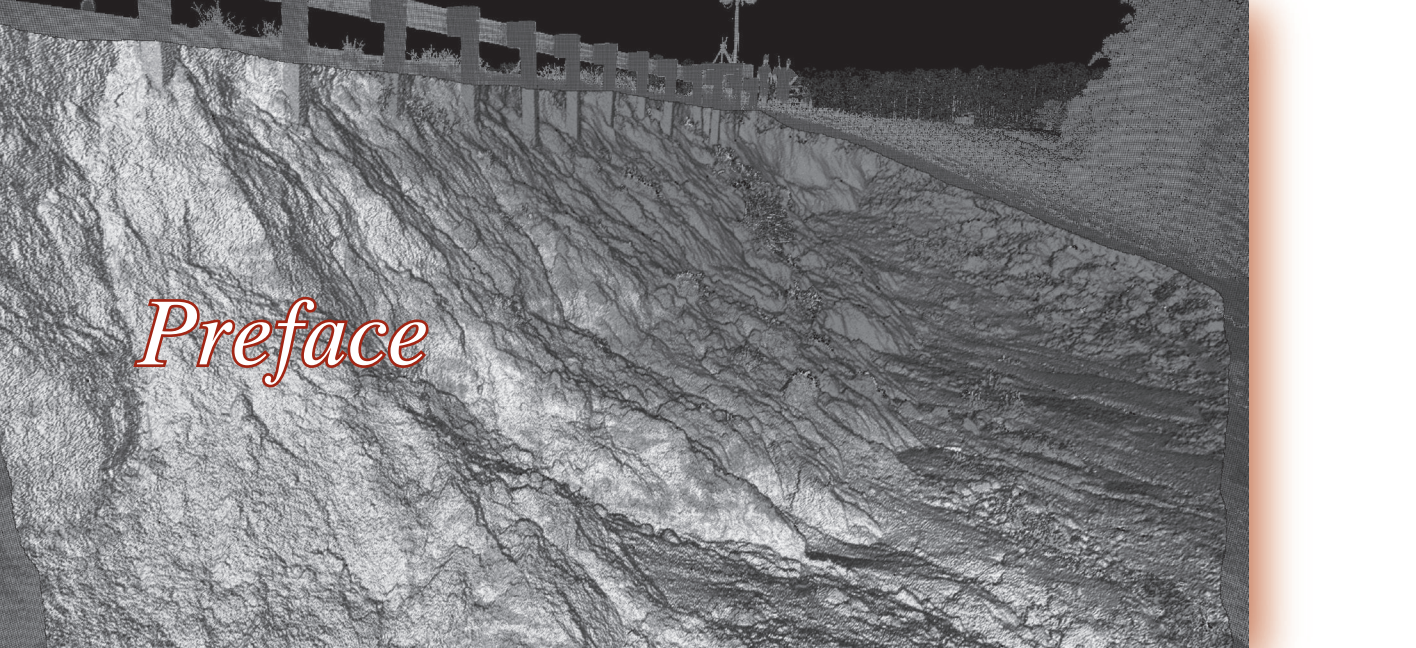
- E.1 Introduction 900
- E.2 Definition of a Matrix 900
- E.3 The Dimensions of a Matrix 901
- E.4 The Transpose of a Matrix 902
- E.5 Matrix Addition 902
- E.6 Matrix Multiplication 902
- E.7 Matrix Inverse 904

**APPENDIX F • U.S. STATE PLANE COORDINATE
SYSTEM DEFINING PARAMETERS 906**

- F.1 Introduction 906
- F.2 Defining Parameters for States Using the Lambert
Conformal Conic Map Projection 906
- F.3 Defining Parameters for States Using the Transverse Mercator
Map Projection 909

APPENDIX G • ANSWERS TO SELECTED PROBLEMS 911

INDEX 917



Preface

Elementary Surveying: An Introduction to Geomatics, 15th Edition, is a readable text that presents the basic concepts and practical material in each of the areas fundamental to modern surveying (geomatics) practice. It is written primarily for students beginning their study of surveying (geomatics) at the college level.

Although this book is introductory to the practice of surveying, its in-depth approach makes it ideal for self-study and preparation for licensing examinations. This edition includes more than 400 figures and illustrations to help clarify discussions, and numerous example problems are worked out to illustrate computational procedures. Throughout the book, the reader will find quick response (QR) codes. Videos in Chapters 3, 4, 6, 9, and 13–18 present enhanced instruction on the material in the book presented by the author and Dr. Thomas Seybert. There are a total of over nine and one-half hours of new video instruction accompanying this book. Additionally, this edition is supported by Pearson's MasteringEngineering online tutorial homework program, which allows instructors to integrate dynamic homework with automatic grading and personalized feedback.

In keeping with the goal of providing an up-to-date presentation of surveying equipment and procedures, the total stations are stressed as the instruments for making angle and distance observations. In the chapters on GNSS surveys, discussions have been included to bring awareness to the inaccuracies of directions obtained from a GNSS survey along with the effect of centering errors on horizontal positioning. Chapter 17 introduces the reader to unmanned systems and Chapter 18 has a section on the importance of metadata. In Chapter 20, mapping the ground versus grid problem is discussed including subsections on low-distortion projections and single project factor use.

In line with past editions, this book continues to emphasize the theory of errors in surveying work. At the end of each chapter, common errors and mistakes related to the topic covered are listed so that the students will be reminded to exercise caution in all of their work. Practical suggestions resulting from the author's many years of experience are interjected throughout the text. Updated versions of STATS, Wolfpack, and Matrix are available on the companion website. These programs contain options for statistical computations, traverse computations for polygon, link, and radial traverses; area calculations; astronomical azimuth reduction; two-dimensional coordinate transformations; horizontal and vertical curve computations; and least-squares adjustments. Mathcad® worksheets and Excel® spreadsheets are included on the companion website. These programmed computational sheets demonstrate the solution to many of the example problems discussed herein. For those desiring additional knowledge in map projections, the Mercator, Albers equal area, oblique stereographic, and oblique Mercator map projections have been included with these files.

WHAT'S NEW IN THIS EDITION

- Videos providing enhanced instruction for material in Chapters 3, 4, 6, and 13–18.
- Introduction to unmanned aerial systems (UASs) in Chapter 19.
- Examination of the importance of metadata.
- Discussion on the Gravity for Redefinition of the American Vertical Datum (GRAV-D) project.
- Focus on using GNSS static survey methods to obtain accurate orthometric heights in a project.
- Analysis on the effect in the accuracy of baseline lengths in a GNSS survey caused by centering errors of the receiver.
- Computations using root mean square errors to define map accuracy.
- Section 4.3 on the planned vertical datum for the North American continent involving Canada, Mexico, and the United States.
- Discussion on the planned new horizontal and vertical datums.
- Section 20.13 on the ground versus grid problem with map projections including low-distortion projections and use of project factors.
- A lesson on the Landsat satellite imagery.
- Revised problem sets for every chapter.

RESOURCES FOR INSTRUCTORS AND STUDENTS

- **Mastering Engineering.** This online tutorial homework program, www.masteringengineering.com, is available with *Elementary Surveying: An Introduction to Geomatics, 15th Edition*. It provides instructors with customized, easy-to-assign, and automatically graded homework and assessments, plus a powerful gradebook for tracking student and class performance. Tutorial homework problems emulate the instructor's

office-hour environment. These in-depth tutorial homework problems are designed to coach students with feedback specific to their errors and optional hints that break problems down into simpler steps. This digital solution is also available as MasteringEngineering is available with or without Pearson eText, a complete online version of the book.

- **Instructor's Solutions Manual.** This supplement is available to adopters of this textbook in PDF format.
- **Presentation Resource.** All figures and tables from the textbook are available in PowerPoint format.
- **Video.** Videos present instruction on solving specific problems in the book or demonstrate field procedures when using surveying instruments. The videos are designed to be a flexible resource to be used however each instructor and student prefers.

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Abbreviations

Construction Surveys

BB	batter boards
BL	building line
CB	catch basin
CG	centerline of grade
CL	centerline
C	cut
CS	curve to spiral
esmt	easement
F	fill
FG	finish grade
FH	fire hydrant
FL	fence line
FS	finished surface
GC	grade change
GP	grade point
GR	grade rod (ss notes)
L, Lt	left (X-sect notes)
MH	manhole
PC	point of curvature
PI	point of intersection
PL	property line
PP	power pole
PT	point of tangency
pvm	pavement
R, Rt	right (X-sect notes)
R/W	right-of-way
SC	spiral to curve
SD	storm drain
SG	subgrade
spec	specifications
Sq	square
ss	slope stake; side slope
Std	standard
Str Gr	straight grade
X sect	cross-section

Control Surveys; GPS Surveys

BM	benchmark
BS	backsight
CORS	continuously operating reference station
DGPS	differential GPS
EDM	electronic distance measurement
FS	foresight
GPS	global positioning system
HARN	high accuracy reference network
HDOP	horizontal dilution of precision
NGRS	National Geodetic Reference System
OTF	on-the-fly initialization (kinematic GPS)
PDOP	positional dilution of precision
RTDGPS	real-time differential GPS
RTK	real-time kinematic (GPS)
SNR	signal-to-noise ratio
VDOP	vertical dilution of precision

Property Surveys

A	area
CF	curb face
ch "X"	chiseled cross
CI	cast iron
diam	diameter
Dr	drive
ER	end of return
Ex	existing
H & T	hub and tack
HC	house connection sewer
IB	iron bolt; iron bar
IP	iron pipe; iron pin
L & T	lead and tack
MHW	mean high water
MLLW	mean low low water
MLW	mean low water
Mon	monument
P	pipe; pin
PLS	professional land surveyor
Rec	record
St	street
Std Surv Mon	standard survey monument
2" × 2"	two-inch square stake
"X"	crosscut in stone
yd	yard

Public Lands Surveys

AMC	auxiliary meander corner
bdy, bdys	boundary; boundaries
BT	bearing tree
CC	closing corner
ch, chs	chain; chains
cor, cors	corner; corners
corr	correction
decl	declination
dist	distance
frac	fractional (sec, etc.)
GM	guide meridian
lk, lks	link; links (Gunter's chain)
mer	meridian
mkd	marked
Mi Cor	mile corner
MC	meander corner
MS	mineral survey
Prin Mer, PM	principal meridian
R, Rs	range; ranges
R 1 W	range 1 west
SC	standard corner
Sec, Secs	section; sections
SMC	special meander corner
Stan Par, SP	standard parallel
T, Tp, Tps	township; townships
T 2 N	township 2 north
USMM	U.S. mineral monument
WC	witness corner

Miscellaneous

alt	altitude
Chf	chief of party
CI	cast iron
Con Mon	concrete monument
CDT	central daylight time
CS	corrugated steel
CST	central standard time
Delta (Δ)	central angle (of curve)
dep	departure
Dir, D	direct
EDT	eastern daylight time
Elev	elevation
EST	eastern standard time
FB	field book
FL	face left
FR	face right
GHA	Greenwich hour angle
GIS	geographic information system
GPS	global positioning system
HA	hour angle
hi	height of instrument above station
HI	height of instrument above datum
hor	horizontal
IS	intermediate sight
IFS	intermediate foresight
ISS	inertial surveying system
lat	latitude

LHA	local hour angle
LIS	land information system
long	longitude
MDT	mountain daylight time
MST	mountain standard time
N	nadir point
NAD27	North American Datum of 1927
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NGVD29	National Geodetic Vertical Datum of 1929
obs	observer
obsn	observation
orig	original
PDT	Pacific daylight time
PST	Pacific standard time
red	reduction
RP	reference point
rev, R	reversed
sta	station
stk	stake
TBM	temporary benchmark
TIN	triangulated irregular network
TP	turning point
tel	telescope
temp	temperature
UTC	universal coordinated time
Z	zenith

Some Commonly Used Surveying Symbols

	Chiseled monument		Power pole
	Concrete monument		Property line
	Curb inlet		Stake (or hub) with tack
	Fence, chain link		Storm sewer (length, size, type)
	Fence, wood w/posts		Telephone line (buried)
	Gas line		Telephone line (suspended)
	Guy wire		Telephone pole
	Headwall		Traffic signal
	Hydrant on water line		Valves on water line
	Iron pipe		Water line
	Power line		

Conversion Factors

Length

1 millimeter (mm) = 1000 micrometers (μm)
 1 centimeter (cm) = 10 mm
 1 meter (m) = 100 cm
 1 m = 39.37 inches (in) [U.S. Survey Foot]
 1 kilometer (km) = 1000 m
 1 km = 0.62137 miles
 1 in. = 25.4 mm *exactly* [International Foot]
 1 ft = 304.8 mm *exactly* [International Foot]
 1 mile = 5280 ft
 1 nautical mile = 6076.10 ft = 1852 m
 1 rod = 1 pole = 1 perch = 16.5 ft
 1 Gunter's chain (ch) = 66 ft = 4 rods
 1 mile = 80 ch
 1 vara = about 33 inches in Mexico and
 California and 33-1/3 inches in Texas
 1 fathom = 6 ft

Volume

1 m³ = 35.31 ft³
 1 yd³ = 27 ft³ = 0.7646 m³
 1 litre = 0.264 gal [U.S.]
 1 litre = 0.001³
 1 gal [U.S.] = 3.785 litres
 1 ft³ = 7.481 gal [U.S.]
 1 gal [Imperial] = 4.546 litres = 1.201 gal [U.S.]

Area

1 mm² = 0.00155 in.²
 1 m² = 10.76 ft²
 1 km² = 247.1 acres
 1 hectare (ha) = 2.471 acres
 1 acre = 43,560 ft²
 1 acre = 10 ch², i.e., 10 (66 ft $\times$ 66 ft)
 1 acre = 4046.9 m²
 1 ft² = 0.09290 m²
 1 ft² = 144 in.²
 1 in.² = 6.452 cm²
 1 mile² = 640 acres (normal section)

Angles

1 revolution = 360 degrees = 2π radians
 1° (degree) = 60' (minutes)
 1' = 60" (seconds)
 1° = 0.017453292 radians
 1 radian = 57.29577951° = 57°17'44.806"
 1 radian = 206,264.8062"
 1 revolution = 400 grads (also called gons)
 tan 1" = sin 1" = 0.000004848
 π = 3.141592654

Other Conversions

1 gram (g) = 0.035 oz
 1 kilogram (kg) = 1000 g = 2.20 lb
 1 ton = 2000 lb = 2 kips = 907 kg
 1 m/sec = 3.28 ft/sec
 1 km/hr = 0.911 ft/sec = 0.621 mi/hr

GPS SIGNAL FREQUENCIES

<u>Code</u>	<u>Frequency (MHz)</u>
C/A	1.023
P	10.23
L1	1575.42
L2	1227.60
L5	1176.45

ELLIPSOID PARAMETERS

<u>Ellipsoid</u>	<u>Semimajor Axis (a)</u>	<u>Semiminor Axis (b)</u>	<u>Flattening (1/f)</u>
Clarke, 1866	6,378,206.4	6,356,583.8	294.97870
GRS80	6,378,137.000	6,356,752.314	298.257222101
WGS84	6,378,137.000	6,356,752.314	298.257223563

Some Other Important Numbers in Surveying (Geomatics)

Errors and Error Analysis

68.3 = percent of observations that are expected within the limits of one standard deviation

0.6745 = coefficient of standard deviation for 50% error (*probable error*)

1.6449 = coefficient of standard deviation for 90% error

1.9599 = coefficient of standard deviation for 95% error (*two-sigma error*)

Electronic Distance Measurement

299,792,458 m/sec = speed of light or electromagnetic energy in a vacuum

1 Hertz (Hz) = 1 cycle per second

1 kilohertz (kHz) = 1000 Hz

1 megahertz (MHz) = 1000 kHz

1 gigahertz (GHz) = 1000 MHz

1.0003 = approximate index of atmospheric refraction (varies from 1.0001 to 1.0005)

760 mm of mercury = standard atmospheric pressure

Taping

0.00000645 = coefficient of expansion of steel tape, per 1°F

0.0000116 = coefficient of expansion of steel tape, per 1°C

29,000,000 lb/in.² = 2,000,000 kg/cm² = Young's modulus of elasticity for steel

490 lb/ft³ = density of steel for tape weight computations

15°F = change in temperature to produce a 0.01 ft length change in a 100 ft steel tape

68°F = 20°C = standard temperature for taping

Leveling

0.574 = coefficient of combined curvature and refraction (ft/miles²)

0.0675 = coefficient of combined curvature and refraction (m/km²)

20.6 m = 68 ft = approximate radius of a level vial having a 20" sensitivity

Miscellaneous

6,371,000 m = 20,902,000 ft = approximate mean radius of the earth

1.15 miles = approximately 1 minute of latitude = approximately 1 nautical mile

69.1 miles = approximately 1 degree of latitude

101 ft = approximately 1 second of latitude

24 hours = 360° of longitude

15° longitude = width of one time zone, i.e., 360°/24 hr

23°26.5' = approximate maximum declination of the sun at the solstices

23^h56^m04.091^s = length of sidereal day in mean solar time, which is 3m55.909^s of mean solar time short of one solar day

5,729.578 ft = radius of 1° curve, arc definition

5,729.651 ft = radius of 1° curve, chord definition

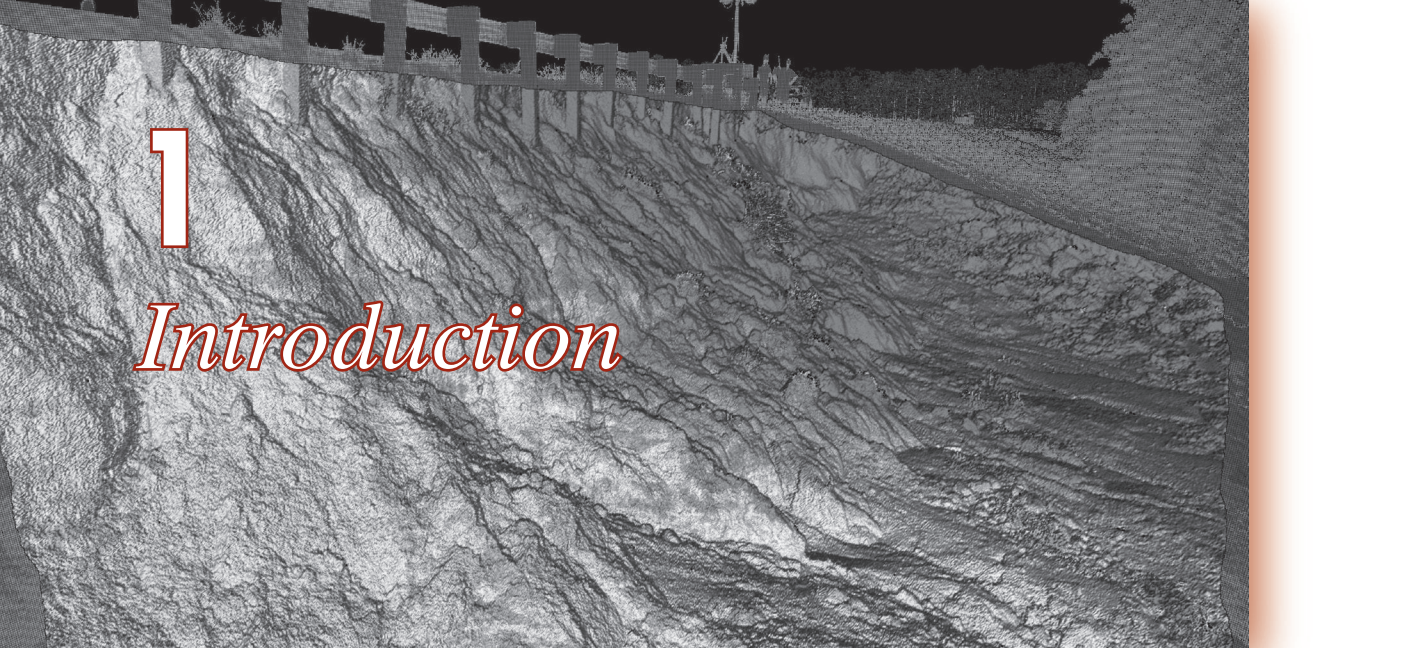
100 ft = 1 station, English system

1000 m = 1 station, metric system

6 miles = length and width of a normal township

36 = number of sections in a normal township

10,000 km = distance from equator to pole and original basis for the length of the meter



1

Introduction

■ 1.1 DEFINITION OF SURVEYING

Surveying, which is also interchangeably called *geomatics* (see Section 1.2), has traditionally been defined as the science, art, and technology of determining the relative positions of points above, on, or beneath the Earth's surface, or of establishing such points. In a more general sense, however, surveying (geomatics) can be regarded as that discipline that encompasses all methods for measuring and collecting information about the physical earth and our environment, processing that information, and disseminating a variety of resulting products to a wide range of clients. Surveying has been important since the beginning of civilization. Its earliest applications were in measuring and marking boundaries of property ownership. Throughout the years its importance has steadily increased with the growing demand for a variety of maps and other spatially related types of information, and the expanding need for establishing accurate line and grade to guide construction operations.

Today the importance of measuring and monitoring our environment is becoming increasingly critical as our population expands, land values appreciate, our natural resources dwindle, and human activities continue to stress the quality of our land, water, and air. Using modern ground, aerial, and satellite technologies, and computers for data processing, contemporary surveyors are now able to measure and monitor the Earth and its natural resources on literally a global basis. Never before has so much information been available for assessing current conditions, making sound planning decisions, and formulating policy in a host of land-use, resource development, and environmental preservation applications.

Recognizing the increasing breadth and importance of the practice of surveying, the *International Federation of Surveyors* (see Section 1.11) adopted the following definition:

“A surveyor is a professional person with the academic qualifications and technical expertise to conduct one, or more, of the following activities;

- to determine, measure and represent the land, three-dimensional objects, point-fields, and trajectories;
- to assemble and interpret land and geographically related information;
- to use that information for the planning and efficient administration of the land, the sea and any structures thereon; and
- to conduct research into the above practices and to develop them.

Detailed Functions

The surveyor’s professional tasks may involve one or more of the following activities, which may occur either on, above, or below the surface of the land or the sea and may be carried out in association with other professionals.

1. The determination of the size and shape of the Earth and the measurements of all data needed to define the size, position, shape and contour of any part of the Earth and monitoring any change therein.
2. The positioning of objects in space and time as well as the positioning and monitoring of physical features, structures and engineering works on, above or below the surface of the Earth.
3. The development, testing and calibration of sensors, instruments and systems for the above-mentioned purposes and for other surveying purposes.
4. The acquisition and use of spatial information from close range, aerial and satellite imagery and the automation of these processes.
5. The determination of the position of the boundaries of public or private land, including national and international boundaries, and the registration of those lands with the appropriate authorities.
6. The design, establishment, and administration of geographic information systems (GIS), and the collection, storage, analysis, management, display and dissemination of data.
7. The analysis, interpretation, and integration of spatial objects and phenomena in GIS, including the visualization and communication of such data in maps, models and mobile digital devices.
8. The study of the natural and social environment, the measurement of land and marine resources and the use of such data in the planning of development in urban, rural, and regional areas.
9. The planning, development and redevelopment of property, whether urban or rural and whether land or buildings.
10. The assessment of value and the management of property, whether urban or rural and whether land or buildings.
11. The planning, measurement and management of construction works, including the estimation of costs.

In application of the foregoing activities surveyors take into account the relevant legal, economic, environmental, and social aspects affecting each project.”

The breadth and diversity of the practice of surveying (geomatics), as well as its importance in modern civilization, are readily apparent from this definition.

■ 1.2 GEOMATICS

As noted in Section 1.1, geomatics is a relatively new term that is now commonly being applied to encompass the areas of practice formerly identified as surveying. The principal reason cited for making the name change is that the manner and scope of practice in surveying have changed dramatically in recent years. This has occurred in part because of recent technological developments that have provided surveyors with new tools for measuring and/or collecting information, for computing, and for displaying and disseminating information. It has also been driven by increasing concerns about the environment locally, regionally, and globally, which have greatly exacerbated efforts in monitoring, managing, and regulating the use of our land, water, air, and other natural resources. These circumstances, and others, have brought about a vast increase in demands for new spatially related information.

Historically surveyors made their measurements using ground-based methods using the transit and tape¹ as their primary instruments. Computations, analyses, and the reports, plats, and maps they delivered to their clients were prepared (in hard copy form) through tedious manual processes. Today's surveyor has an arsenal of tools for measuring and collecting environmental information that includes electronic instruments for automatically measuring distances and angles, satellite surveying systems for quickly obtaining precise positions of widely spaced points, modern aerial digital imaging and laser-scanning systems for quickly mapping and collecting other forms of data about the Earth, and, as shown in Figure 1.1, unmanned systems to carry sensors such as digital cameras and sonar. In addition, computer systems are available that can process the measured data and automatically produce plats, maps, and other products at speeds unheard of a few years ago. Furthermore, these products can be prepared in electronic formats and be transmitted to and from remote locations via telecommunication systems.

Concurrent with the development of these new data collection and processing technologies, *geographic information systems* (GISs) have matured. These



Figure 1.1
Unmanned
aerial system.
(Courtesy of Leica
Geosystems, Inc.)

¹These instruments are described in Appendix A and Chapter 6, respectively.

computer-based systems enable virtually any type of spatially related information about the environment to be integrated, analyzed, displayed, and disseminated.² The key to successfully operating geographic information systems is spatially related data of high quality; the collection and processing of this data places great new demands upon the surveying community.

As a result of these new developments noted above, and others, many feel that the name surveying no longer adequately reflects the expanded and changing role of their profession. Hence the new term geomatics has emerged. In this text, the terms surveying and geomatics are both used, although the former is used more frequently. Nevertheless students should understand that the two terms are synonymous as discussed above. Additionally due to the many diverse fields in what was traditionally called surveying, the entire field is now part of what is known as the *geospatial industries*.

■ 1.3 HISTORY OF SURVEYING

The oldest historical records in existence today that bear directly on the subject of surveying state that this science began in Egypt. Herodotus recorded that Sesostris (about 1400 B.C.) divided the land of Egypt into plots for the purpose of taxation. Annual floods of the Nile River swept away portions of these plots, and surveyors were appointed to replace the boundaries. These early surveyors were called *rope-stretchers*, since their measurements were made with ropes having markers at unit distances.

As a consequence of this work, early Greek thinkers developed the science of geometry. Their advance, however, was chiefly along the lines of pure science. Heron stands out prominently for applying science to surveying in about 120 B.C. He was the author of several important treatises of interest to surveyors, including *The Dioptra*, which related the methods of surveying a field, drawing a plan, and making related calculations. It also described one of the first pieces of surveying equipment recorded, the *dioptra* [Figure 1.2(a)]. For many years Heron's work was the most authoritative among Greek and Egyptian surveyors.

Significant development in the art of surveying came from the practical-minded Romans, whose best-known writing on surveying was by Frontinus. Although the original manuscript disappeared, copied portions of his work have been preserved. This noted Roman engineer and surveyor, who lived in the first century, was a pioneer in the field, and his essay remained the standard for many years. The engineering ability of the Romans was demonstrated by their extensive construction work throughout the empire. Surveying necessary for this construction resulted in the organization of a surveyors' guild. Ingenious instruments were developed and used. Among these were the *groma* [Figure 1.2(b)], used for sighting; the *libella*, an A-frame with a plumb bob, for leveling; and the *chorobates*, a horizontal straightedge about 20 ft long with supporting legs and a groove on top for water to serve as a level.

²Geographic information systems are briefly introduced in Section 1.9, and then described in greater detail in Chapter 28.

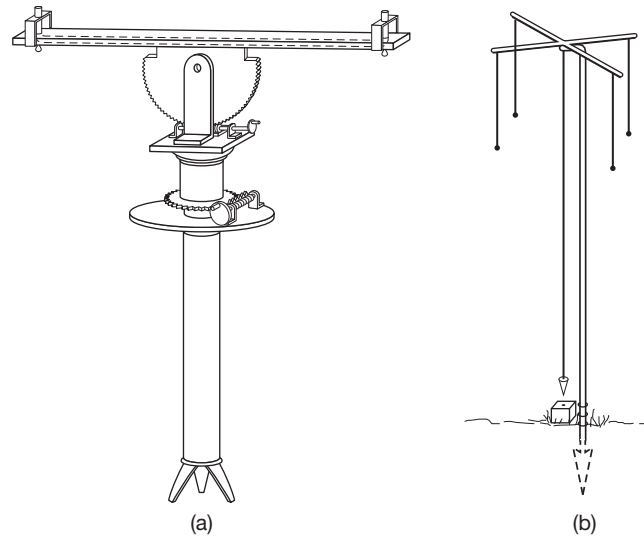


Figure 1.2
Historical surveying instruments: (a) the diometer and (b) the groma.

One of the oldest Latin manuscripts in existence is the *Codex Acerianus*, written in about the 6th century. It contains an account of surveying as practiced by the Romans and includes several pages from Frontinus's treatise. The manuscript was found in the 10th century by Gerbert and served as the basis for his text on geometry, which was largely devoted to surveying.

During the Middle Ages, the Arabs kept Greek and Roman science alive. Little progress was made in the art of surveying, and the only writings pertaining to it were called "practical geometry."

In the 13th century, Von Piso wrote *Practica Geometria*, which contained instructions on surveying. He also authored *Liber Quadratorum*, dealing chiefly with the *quadrans*, a square brass frame having a 90° angle and other graduated scales. A movable pointer was used for sighting. Other instruments of the period were the *astrolabe*, a metal circle with a pointer hinged at its center and held by a ring at the top, and the *cross staff*, a wooden rod about 4 ft long with an adjustable crossarm at right angles to it. The known lengths of the arms of the cross staff permitted distances to be measured by proportion and angles.

Early civilizations assumed the Earth to be a flat surface, but by noting the Earth's circular shadow on the moon during lunar eclipses and watching ships gradually disappear as they sailed toward the horizon, it was slowly deduced that the planet actually curved in all directions.

Determining the true size and shape of the Earth has intrigued humans for centuries. History records that a Greek named Eratosthenes was among the first to compute its dimensions. His procedure, which occurred about 200 B.C., is illustrated in Figure 1.3. Eratosthenes had concluded that the Egyptian cities of Alexandria and Syene were located approximately on the same meridian, and he had also observed that at noon on the summer solstice, the Sun was directly overhead at Syene. (This was apparent because at that time of that day, the image of the Sun could be seen reflecting from the bottom of a deep vertical well

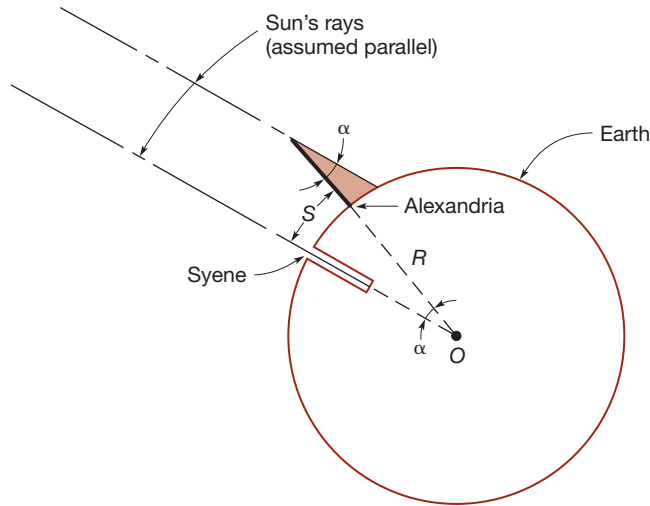


Figure 1.3
Geometry of the
procedure used
by Eratosthenes
to determine
the Earth's
circumference.

there.) He reasoned that at that moment, the Sun, Syene, and Alexandria were in a common meridian plane, and if he could measure the arc length between the two cities, and the angle it subtended at the Earth's center, he could compute the Earth's circumference. He determined the angle by measuring the length of the shadow cast at Alexandria from a vertical staff of known length. The arc length was found from multiplying the number of caravan days between Syene and Alexandria by the average daily distance traveled. From these measurements, Eratosthenes calculated the Earth's circumference to be about 25,000 mi. Subsequent precise geodetic measurements using better instruments, but techniques similar geometrically to Eratosthenes', have shown his value, though slightly too large, to be amazingly close to the currently accepted one. (Actually, as explained in Chapter 19, the Earth approximates an oblate spheroid having an equatorial radius about 13.5 mi longer than the polar radius.)

In the 18th and 19th centuries, the art of surveying advanced more rapidly. The need for maps and locations of national boundaries caused England and France to make extensive surveys requiring accurate triangulation; thus, geodetic surveying began. The U.S. Coast Survey (now the National Geodetic Survey of the U.S. Department of Commerce) was established by an act of Congress in 1807. Initially its charge was to perform hydrographic surveys and prepare nautical charts. Later its activities were expanded to include establishment of reference monuments of precisely known positions throughout the country.

Increased land values and the importance of precise boundaries, along with the demand for public improvements in the canal, railroad, and turnpike eras, brought surveying into a prominent position. More recently, the large volume of general construction, numerous land subdivisions that require precise records, and demands posed by the fields of exploration and ecology have entailed an augmented surveying program. Surveying is still the sign of progress in the development, use, and preservation of the Earth's resources.

In addition to meeting a host of growing civilian needs, surveying has always played an important role in our nation's defense activities. World Wars I and II, the Korean and Vietnam conflicts, and the more recent conflicts in the Middle East, Europe, and Afghanistan have created staggering demands for precise measurements and accurate maps. These military operations also provided the stimulus for improving instruments and methods to meet these needs. Surveying also contributed to, and benefited from, the space program where new equipment and systems were needed to provide precise control for missile alignment, and for mapping and charting portions of the Moon and nearby planets.

Developments in surveying and mapping equipment have now evolved to the point where the traditional instruments that were used until about the 1960s or 1970s—the transit, theodolite, dumpy level, and steel tape—have now been almost completely replaced by an array of new “high-tech” instruments. These include electronic *total station instruments*, which can be used to automatically measure and record horizontal and vertical distances, and horizontal and vertical angles; and *Global Navigation Satellite Systems* (GNSS) such as the *Global Positioning System* (GPS) that can provide precise location information for virtually any type of survey. Laser-scanning instruments combine automatic distance and angle measurements to compute dense grids of coordinated points. Also new aerial cameras and remote sensing instruments have been developed, which provide images in digital form, and these images can be processed to obtain spatial information and maps using new *digital photogrammetric restitution instruments* (also called *softcopy plotters*). Figures 1.4, 1.5, 1.6, and 1.7, respectively, show a total station instrument, 3D mobile mapping system, laser-scanning instrument, and modern softcopy plotter. The 3D mobile mapping system in Figure 1.5 is an integrated system consisting of scanners, GNSS receiver, inertial measurement unit, and a high-quality hemispherical digital camera that can map all items within 100 m of the vehicle as the vehicle travels at highway speeds. The system can capture 1.3 million



Figure 1.4
LEICA TPS 1100
total station
instrument.
(Courtesy Leica
Geosystems, Inc.)

Figure 1.5

A mobile mapping system. (Courtesy Topcon Positioning Systems.)



Figure 1.6

A ground-based laser scanner. (Courtesy of Christopher Gibbons, Leica Geosystems, Inc.)



data points per second providing the end user with high-quality, georeferenced coordinates on all items visible in the images.

One area where laser scanning is finding great acceptance is in *Building Information Management* (BIM). In BIM, scanners are being used to capture the three-dimensional features of both the exterior and interior of existing buildings. The three-dimensional point cloud is then used by engineers, architects, and building contractors in developing plans for reconstruction projects or checking buildings for compliance with codes. Archeologists are also finding uses for laser scanning. By scanning ancient artifacts, not only is the artifact being preserved for future preservation projects, scans have also identified possible clues to how items were constructed and have even identified possible locations of buildings whose locations were previously unknown.



Figure 1.7
Intergraph Image
Station Z softcopy
plotter. (From
*Elements of
Photogrammetry:
With Applications
in GIS*, by Wolf
and Dewitt,
2000, Courtesy
Intergraph, Inc.,
and the McGraw-
Hill Companies.)

■ 1.4 GEODETIC AND PLANE SURVEYS

Two general classifications of surveys are *geodetic* and *plane*. They differ principally in the assumptions on which the computations are based, although field measurements for geodetic surveys are usually performed to a higher order of accuracy than those for plane surveys.

In geodetic surveying, the curved surface of the Earth is considered by performing the computations on an *ellipsoid* (curved surface approximating the size and shape of the Earth—see Chapter 19). It is now becoming common to do geodetic computations in a three-dimensional, *Earth-centered, Earth-fixed* (ECEF) Cartesian coordinate system. The calculations involve solving equations derived from solid geometry and calculus. Geodetic methods are employed to determine relative positions of widely spaced monuments and to compute lengths and directions of the long lines between them. These monuments serve as the basis for referencing other subordinate surveys of lesser extents.

In early geodetic surveys, painstaking efforts were employed to accurately observe angles and distances. The angles were measured using precise ground-based theodolites, and the distances were measured using special tapes made from metal having a low coefficient of thermal expansion. From these basic measurements, the relative positions of the monuments were computed. Later, electronic instruments were used for observing the angles and distances. Although these latter types of instruments are still sometimes used on geodetic surveys, satellite positioning has now almost completely replaced other instruments for these types of surveys. Satellite positioning can provide the needed positions with much greater accuracy, speed, and economy. GNSS receivers enable ground stations to be located precisely by observing distances to satellites operating in known positions along their orbits. GNSS surveys are being used in all forms of surveying including geodetic, hydrographic, construction, and boundary surveying. When combined

with a real-time network (RTN), GNSS surveys are capable of providing accuracy within 0.1 ft over a 50-km region with as little as 3 minutes of data. The principles of operation of the global positioning system are given in Chapter 13, field and office procedures used in static GNSS surveys are discussed in Chapter 14, and the methods used in kinematic GNSS surveys including RTNs are discussed in Chapter 15.

In plane surveying, except for leveling, the reference base for fieldwork and computations is assumed to be a flat horizontal surface. The direction of a plumb line (and thus gravity) is considered parallel throughout the survey region, and all observed angles are presumed to be plane angles. For areas of limited size, the surface of our vast ellipsoid is actually nearly flat. On a line 5-mi line, the ellipsoid arc and chord lengths differ by only about 0.02 ft. A plane surface tangent to the ellipsoid departs only about 0.7 ft at 1 mi from the point of tangency. In a triangle having an area of 75 square miles, the difference between the sum of the three ellipsoidal angles and three plane angles is only about 1 sec. Therefore, it is evident that except in surveys covering extensive areas, the Earth's surface can be approximated as a plane, thus simplifying computations and techniques. In general, algebra, plane and analytical geometry, and plane trigonometry are used in plane-surveying calculations. Even for very large areas, map projections, such as those described in Chapter 20, allow plane-surveying computations to be used. This book concentrates primarily on methods of plane surveying, an approach that satisfies the requirements of most projects.

■ 1.5 IMPORTANCE OF SURVEYING

Surveying is one of the world's oldest and most important arts because, as noted previously, from the earliest times it has been necessary to mark boundaries and divide land. Surveying has now become indispensable to our modern way of life. The results of today's surveys are used to (1) map the Earth above and below sea level; (2) prepare navigational charts for use in the air, on land, and at sea; (3) establish property boundaries of private and public lands; (4) develop data banks of land-use and natural resource information that aid in managing our environment; (5) determine facts on the size, shape, gravity, and magnetic fields of the Earth and (6) prepare charts of our moon and planets.

Surveying continues to play an extremely important role in many branches of engineering. For example, surveys are required to plan, construct, and maintain highways, railroads, rapid-transit systems, buildings, bridges, missile ranges, launching sites, tracking stations, tunnels, canals, irrigation ditches, dams, drainage works, urban land subdivisions, water supply and sewage systems, pipelines, and mine shafts. Surveying methods are commonly employed in laying out industrial assembly lines and jigs.³ These methods are also used for guiding the fabrication of large equipment, such as airplanes and ships, where separate pieces that have been assembled at different locations must ultimately be connected as a unit. Surveying is important in many related tasks in agronomy, archeology, astronomy, forestry, geography, geology, geophysics, landscape architecture, meteorology, paleontology, and seismology, but particularly in military and civil engineering.

³These instruments are described in Appendix A and Chapter 6, respectively.

All engineers must know the limits of accuracy possible in construction, plant design and layout, and manufacturing processes, even though someone else may do the actual surveying. In particular, surveyors and civil engineers who are called on to design and plan surveys must have a thorough understanding of the methods and instruments used, including their capabilities and limitations. This knowledge is best obtained by making observations with the kinds of equipment used in practice to get a true concept of the theory of errors and the small but recognizable differences that occur in observed quantities.

In addition to stressing the need for reasonable limits of accuracy, surveying emphasizes the value of significant figures. Surveyors and engineers must know when to work to hundredths of a foot instead of to tenths or thousandths, or perhaps the nearest foot, and what precision in field data is necessary to justify carrying out computations to the desired number of decimal places. With experience, they learn how available equipment and personnel govern procedures and results.

Engineers who design buildings, bridges, equipment, and so on are fortunate if their estimates of loads to be carried are correct within 5%. Then a factor of safety of 2 or more is often applied. But except for some topographic work, only exceedingly small errors can be tolerated in surveying, and there is no factor of safety. Traditionally, therefore, both manual and computational precision are stressed in surveying.

■ 1.6 SPECIALIZED TYPES OF SURVEYS

Many types of surveys are so specialized that a person proficient in a particular discipline may have little contact with the other areas. Persons seeking careers in surveying and mapping, however, should be knowledgeable in every phase, since all are closely related in modern practice. Some important classifications are described briefly here.

Control surveys establish a network of horizontal and vertical monuments that serve as a reference framework for initiating other surveys. Many control surveys performed today are done using techniques discussed in Chapters 14 and 15 with GNSS instruments.

Topographic surveys determine locations of natural and artificial features and elevations used in map making.

Land, boundary, and cadastral surveys establish property lines and property corner markers. The term cadastral is now generally applied to surveys of the public lands systems. There are three major categories: *original surveys* to establish new section corners in unsurveyed areas that still exist in Alaska and several western states; *retracement surveys* to recover previously established boundary lines; and *subdivision surveys* to establish monuments and delineate new parcels of ownership. *Condominium surveys*, which provide a legal record of ownership, are a type of boundary survey.

Hydrographic surveys define shorelines and depths of lakes, streams, oceans, reservoirs, and other bodies of water. *Sea surveying* is associated with port and off-shore industries and the marine environment, including measurements and marine investigations made by shipborne personnel.

Alignment surveys are made to plan, design, and construct highways, railroads, pipelines, and other linear projects. They normally begin at one control point and progress to another in the most direct manner permitted by field conditions.

Construction surveys provide line, grade, control elevations, horizontal positions, dimensions, and configurations for construction operations. They also secure essential data for computing construction pay quantities.

As-built surveys document the precise final locations and layouts of engineering works, and record any design changes that may have been incorporated into the construction. These are particularly important when underground facilities are constructed, so their locations can be accurately known for maintenance purposes, and so that unexpected damage to them can be avoided during later installation of other underground utilities.

Mine surveys are performed above and below ground to guide tunneling and other operations associated with mining. This classification also includes geophysical surveys for mineral and energy resource exploration.

Solar surveys map property boundaries, solar easements, obstructions according to sun angles, and meet other requirements of zoning boards and title insurance companies.

Optical tooling (also referred to as *industrial surveying* or *optical alignment*) is a method of making extremely accurate measurements for manufacturing processes where small tolerances are required.

Except for control surveys, most other types described are usually performed using plane-surveying procedures, but geodetic methods may be employed on the others if a survey covers an extensive area or requires extreme accuracy.

Ground, aerial, and satellite surveys are broad classifications sometimes used. Ground surveys utilize measurements made with ground-based equipment such as automatic levels and total station instruments. Aerial surveys are accomplished using either *photogrammetry* or *remote sensing*. Photogrammetry uses cameras that are carried usually in airplanes to obtain images, whereas remote sensing employs cameras and other types of sensors that can be transported in either aircraft or satellites. Procedures for analyzing and reducing the image data are described in Chapter 27. Aerial methods have been used in all the specialized types of surveys listed, except for optical tooling, and in this area *terrestrial* (ground-based) photographs are often used. Satellite surveys include the determination of ground locations from measurements made to satellites using GNSS receivers, or the use of satellite images for mapping and monitoring large regions of the Earth.

■ 1.7 SURVEYING SAFETY

Surveyors (geomatics engineers) generally are involved in both field and office work. The fieldwork consists in making observations with various types of instruments to either (a) determine the relative locations of points or (b) to set out stakes in accordance with planned locations to guide building and construction operations. The office work involves (1) conducting research and analysis in preparing for surveys, (2) computing and processing the data obtained from field measurements, and (3) preparing maps, plats, charts, reports, and other documents

according to client specifications. Sometimes the fieldwork must be performed in hostile or dangerous environments, and thus it is very important to be aware of the need to practice safety precautions.

Among the most dangerous of circumstances within which surveyors must sometimes work are job sites that are either on or near highways or railroads, or that cross such facilities. Job sites in construction zones where heavy machinery is operating are also hazardous, and the dangers are often exacerbated by poor hearing conditions from the excessive noise, and poor visibility caused by obstructions and dust, both of which are created by the construction activity. In these situations, whenever possible, the surveys should be removed from the danger areas through careful planning and/or the use of *offset* lines. If the work must be done in these hazardous areas, then certain safety precautions should be followed. Safety vests of fluorescent yellow color should always be worn in these situations, and flagging materials of the same color can be attached to the surveying equipment to make it more visible. Depending on the circumstances, signs can be placed in advance of work areas to warn drivers of the presence of a survey party ahead, cones and/or barricades can be placed to deflect traffic around surveying activities, and flaggers can be assigned to warn drivers or to slow or even stop them, if necessary. The *Occupational Safety and Health Administration* (OSHA), of the U.S. Department of Labor,⁴ has developed safety standards and guidelines that apply to the various conditions and situations that can be encountered.

Besides the hazards described above, depending on the location of the survey and the time of year, other dangers can also be encountered in conducting field surveys. These include problems related to weather such as frostbite and overexposure to the Sun's rays, which can cause skin cancers, sunburns, and heat stroke. To help prevent these problems, plenty of fluids should be drunk, large-brimmed hats and sunscreen can be worn, and on extremely hot days surveying should commence at dawn and terminate at midday or early afternoon. Outside work should not be done on extremely cold days, but if it is necessary, warm clothing should be worn and skin areas should not be exposed. Other hazards that can be encountered during field surveys include wild animals, poisonous snakes, bees, spiders, wood ticks, deer ticks (which can carry Lyme disease), poison ivy, and poison oak. Surveyors should be knowledgeable about the types of hazards that can be expected in any local area, and always be alert and on the lookout for them. To help prevent injury from these sources, protective boots and clothing should be worn and insect sprays used. Certain tools can also be dangerous, such as chain saws, axes, and machetes that are sometimes necessary for clearing lines of sight. These must always be handled with care. Also, care must be exercised in handling certain surveying instruments, like long-range poles and level rods, especially when working around overhead wires, to prevent accidental electrocutions.

Many other hazards, in addition to those cited above, can be encountered when surveying in the field. Thus, it is essential that surveyors always

⁴The mission of OSHA is to save lives, prevent injuries, and protect the health of America's workers. Its staff establishes protective standards, enforces those standards, and reaches out to employers and employees through technical assistance and consultation programs. For more information about OSHA and its safety standards, consult its website <http://www.osha.gov>.

exercise caution in their work, and know and follow accepted safety standards. In addition, a first-aid kit should always accompany a survey party in the field, and it should include all of the necessary antiseptics, ointments, bandage materials, and other equipment needed to render first aid for minor accidents. The survey party should also be equipped with cell phones for more serious situations, and telephone numbers to call in emergencies should be written down and readily accessible.

■ 1.8 LAND AND GEOGRAPHIC INFORMATION SYSTEMS

Land Information Systems (LISs) and *Geographic Information Systems* (GISs) are areas of activity that have rapidly assumed positions of major prominence in surveying. These computer-based systems enable storing, integrating, manipulating, analyzing, and displaying virtually any type of spatially related information about our environment. LISs and GISs are being used at all levels of government, and by businesses, private industry, and public utilities to assist in the management and decision-making process. Specific applications have occurred in many diverse areas and include natural resource management, facilities siting and management, land records modernization, demographic and market analysis, emergency response and fleet operations, infrastructure management, and regional, national, and global environmental monitoring. Data stored within LISs and GISs may be both natural and cultural, and be derived from new surveys, or from existing sources such as maps, charts, aerial and satellite photos, tabulated data and statistics, and other documents. However, in most situations, the needed information either does not exist, or it is unsatisfactory because of age, scale, or other reasons. Thus, new measurements, maps, photos, or other data must be obtained.

Specific types of information (also called *themes* or *layers* of information) needed for land and geographic information systems may include political boundaries, individual property ownership, population distribution, locations of natural resources, transportation networks, utilities, zoning, hydrography, soil types, land use, vegetation types, wetlands, and many, many more. An essential ingredient of all information entered into LIS and GIS databases is that it is spatially related, that is, located in a common geographic reference framework. Only then are the different layers of information physically relatable so they can be analyzed using computers to support decision making. This geographic positional requirement will place a heavy demand upon surveyors (geomatics engineers) in the future, who will play key roles in designing, implementing, and managing these systems. Surveyors from virtually all of the specialized areas described in Section 1.6 will be involved in developing the needed databases. Their work will include establishing the required basic control framework; conducting boundary surveys and preparing legal descriptions of property ownership; performing topographic and hydrographic surveys by ground, aerial, and satellite methods; compiling and digitizing maps; and assembling a variety of other digital data files.

The last chapter of this book, Chapter 28, is devoted to the topic of land and geographic information systems. This subject seems appropriately covered at the

end, after each of the other types of surveys needed to support these systems has been discussed.

■ 1.9 FEDERAL SURVEYING AND MAPPING AGENCIES

Several agencies of the U.S. government perform extensive surveying and mapping. Three of the major ones are:

1. The *National Geodetic Survey* (NGS), formerly the Coast and Geodetic Survey, was originally organized to map the coast. Its activities have included control surveys to establish a network of reference monuments throughout the United States that serve as points for originating local surveys, preparation of nautical and aeronautical charts, photogrammetric surveys, tide and current studies, collection of magnetic data, gravimetric surveys, and worldwide control survey operations. The NGS plays a major role in coordinating and assisting in activities related to upgrading the national network of reference control monuments, and to the development, storage, and dissemination of data used in modern LISs and GISs.
2. The *U.S. Geological Survey* (USGS), established in 1879, has as its mission the mapping of our nation and the survey of its resources. It provides a wide variety of maps, from topographic maps showing the geographic relief and natural and cultural features, to thematic maps that display the geology and water resources of the United States, to special maps of the Moon and planets. The National Mapping Division of the USGS has the responsibility of producing topographic maps. It currently has nearly 70,000 different topographic maps available, and it distributes approximately 10 million copies annually. In recent years, the USGS has been engaged in a comprehensive program to develop a national digital cartographic database, which consists of map data in computer-readable formats.
3. The *Bureau of Land Management* (BLM), originally established in 1812 as the General Land Office, is responsible for managing the public lands. These lands, which total approximately 264 million acres and comprise about one eighth of the land in the United States, exist mostly in the western states and Alaska. The BLM is responsible for surveying the land and managing its natural resources, which include minerals, timber, fish and wildlife, historical sites, and other natural heritage areas. Surveys of most public lands in the conterminous United States have been completed, but much work remains in Alaska.

In addition to these three federal agencies, units of the U.S. Army Corps of Engineers have made extensive surveys for emergency and military purposes. Some of these surveys provide data for engineering projects, such as those connected with flood control. Surveys of wide extent have also been conducted for special purposes by nearly 40 other federal agencies, including the Forest Service, National Park Service, International Boundary Commission, Bureau of Reclamation, Tennessee Valley Authority, Mississippi River Commission, U.S. Lake Survey, and Department of Transportation.

All states have a surveying and mapping section for purposes of generating topographic information upon which highways are planned and designed. Likewise, many counties and cities also have surveying programs, as have various utilities.

■ 1.10 THE SURVEYING PROFESSION

The personal qualifications of surveyors are as important as their technical ability in dealing with the public. They must be patient and tactful with clients and their sometimes-hostile neighbors. Few people are aware of the painstaking research of old records required before fieldwork is started. Diligent, time-consuming effort may be needed to locate corners on nearby tracts for checking purposes as well as to find corners for the property in question.

Land or boundary surveying is classified as a learned profession because the modern practitioner needs a wide background of technical training and experience, and must exercise a considerable amount of independent judgment. Registered (licensed) professional surveyors must have a thorough knowledge of mathematics (particularly geometry, trigonometry, and calculus); competence with computers; a solid understanding of surveying theory, instruments, and methods in the areas of geodesy, photogrammetry, remote sensing, and cartography; some competence in economics (including office management), geography, geology, astronomy, and dendrology; and a familiarity with laws pertaining to land and boundaries. They should be knowledgeable in both field operations and office computations. Above all, they are governed by a professional code of ethics and are expected to charge professional-level fees for their work.

Permission to trespass on private property or to cut obstructing tree branches and shrubbery must be obtained through a proper approach. Such privileges are not conveyed by a surveying license or by employment in a state highway department or other agency (but a court order can be secured if a landowner objects to necessary surveys).

All 50 states, Guam, and Puerto Rico have registration laws for professional surveyors and engineers (as do the provinces of Canada). In general, a surveyor's license is required to make property surveys, but not for construction, topographic, or route work, unless boundary corners are set.

To qualify for registration as either a professional land surveyor (PLS) or a professional engineer (PE), it is necessary to have an appropriate college degree, although some states allow relevant experience in lieu of formal education. In addition, candidates must acquire two or more years of mentored practical experience and must also pass comprehensive written examinations. In most states, common national examinations covering fundamentals and principles and practice of surveying are now used. However, usually two hours of the principles and practice exam are devoted to local legal customs and aspects. As a result, transfer of registration from one state to another has become easier.

Many states also require continuing education units (CEUs) for registration renewal. Typical state laws require that a licensed land surveyor sign all plats, assume responsibility for any liability claims, and take an *active part* in the fieldwork.

■ 1.11 PROFESSIONAL SURVEYING ORGANIZATIONS

There are many professional organizations in the United States and worldwide that serve the interests of surveying and mapping. Generally the objectives of these organizations are the advancement of knowledge in the field, encouragement of communication among surveyors, and upgrading of standards and ethics in surveying practice. *The National Society of Professional Surveyors* (NSPS) represents boundary and construction surveyors in the United States. The *American Association for Geodetic Surveying* (AAGS) represents geodetic surveying professionals and the *Geographic and Land Information Society* (GLIS) represent those involved in GISs. AAGS and GLIS publish the biannual journal *Surveying and Land Information Science* (SaLIS).

As noted in the preceding section, all states require persons who perform boundary surveys to be licensed. Most states also have professional surveyor societies or organizations with full membership open only to licensed surveyors. These state societies are generally affiliated with NSPS and concentrate on matters of state and local concern.

The *American Society for Photogrammetry and Remote Sensing* (ASPRS) is an organization also devoted to the advancement of the fields of measurement and mapping, although its major interests are directed toward the use of aerial and satellite imagery for achieving these goals. Its monthly journal *Photogrammetric Engineering and Remote Sensing* regularly features surveying and mapping articles.

The *Geomatics Division* of the *American Society of Civil Engineers* (ASCE) is also dedicated to professional matters related to surveying and publishes quarterly the *Journal of Surveying Engineering*.

The *Surveying and Geomatics Educators Society* (SAGES) holds pedagogical conferences on the instruction of surveying/geomatics in higher educational institutions. These conferences occur biennially at host institutions throughout the North American continent.

Another organization in the United States, the *Urban and Regional Information Systems Association* (URISA), also supports the profession of surveying and mapping. This organization uses information technology to solve problems in planning, public works, the environment, emergency services, and utilities. Its *URISA Journal* is published quarterly.

The *Canadian Institute of Geomatics* (CIG), formerly the *Canadian Institute of Surveying and Mapping* (CISM), is the foremost professional organization in Canada concerned with surveying. This organization disseminates information to its members through its *Geomatica*.

The *International Federation of Surveyors* (FIG), founded in 1878, fosters the exchange of ideas and information among surveyors worldwide. The acronym FIG stems from its French name, *Fédération Internationale des Géomètres*. FIG membership consists of professional surveying organizations from many countries throughout the world. FIG is organized into nine technical commissions, each concerned with a specialized area of surveying. The organization sponsors international conferences, usually at four-year intervals, and its commissions also hold periodic symposia where delegates gather for the presentation of papers on subjects of international interest.

■ 1.12 SURVEYING ON THE INTERNET

The explosion of available information on the Internet has had a significant impact on the field of surveying (geomatics). The Internet enables the instantaneous electronic transfer of documents to any location where the necessary computer equipment is available. It brings resources directly into the office or home, where previously it was necessary to travel to obtain the information or wait for its transfer by mail. Some equipment manufacturers provide cloud access in their instruments to support the transfer of information from and to the field crews. Software, educational materials, technical documents, standards, and much more useful information are available on the Internet. As an example of how surveyors can take advantage of the Internet, data from a *Continuously Operating Reference Station* (CORS) can be downloaded from the NGS website for use in GNSS surveys (see Section 14.3.5).

Many agencies and institutions maintain websites that provide data free of charge on the Internet. Additionally, some educational institutions now place credit and noncredit courses on the Internet so that distance education can be more easily achieved. With a web browser, it is possible to research almost any topic from a convenient location, and names, addresses, and phone numbers of goods or services providers in a specific area can be identified. As an example, if it was desired to find companies offering mapping services in a certain region, a web search engine could be used to locate web pages that mention this service. Such a search may result in over a million pages if a very general term such as “mapping services” is used to search, but using more specific terms can narrow the search.

Unfortunately the addresses of particular pages and entire sites, given by their *Uniform Resource Locators* (URLs), tend to change with time. However, at the risk of publishing URLs that may no longer be correct, a short list of important websites related to surveying is presented in Table 1.1.

■ 1.13 FUTURE CHALLENGES IN SURVEYING

Surveying is currently in the midst of a revolution in the way data are measured, recorded, processed, stored, retrieved, and shared. This is in large part because of developments in computers and computer-related technologies. Concurrent with technological advancements, society continues to demand more data, with increasingly higher standards of accuracy, than ever before. Consequently, in a few years the demands on surveying engineers (geomatics engineers) will likely be very different from what they are now.

In the future, the National Spatial Reference System, a network of horizontal and vertical control points, must be maintained and supplemented to meet requirements of increasingly higher-order surveys. New topographic maps with larger scales as well as digital map products are necessary for better planning. Existing maps of our rapidly expanding urban areas need revision and updating to reflect changes, and more and better map products are needed of the older parts of our cities to support urban renewal programs and infrastructure maintenance and modernization. Large quantities of data will be needed to plan and design

TABLE 1.1 UNIFORM RESOURCE LOCATOR ADDRESSES FOR SOME SURVEYING RELATED SITES

Universal Resource Locator	Owner of Site
http://www.ngs.noaa.gov	National Geodetic Survey
http://www.usgs.gov	U.S. Geological Survey
http://www.blm.gov	Bureau of Land Management
http://www.navcen.uscg.mil	U.S. Coast Guard Navigation Center
http://www.usno.navy.mil	U.S. Naval Observatory
http://www.nsp.s.us.com/	National Society of Professional Surveyors
http://www.aag.smo.org	American Association for Geodetic Surveying
http://www.g-lis.org	Geographic and Land Information Society
http://www.asprs.org	American Society for Photogrammetry and Remote Sensing
http://www.asce.org	American Society of Civil Engineers
http://www.geoscholar.com/Sages/	Surveying and Geomatics Educators Society
http://www.salis-journal.org	Surveying and Land Information Science Journal
http://www.pearsonhighered.com/ghilani	Companion website for this book

new rapid-transit systems to connect our major cities, and surveyors will face new challenges in meeting the precise standards required in staking alignments and grades for these systems.

In the future, assessment of environmental impacts of proposed construction projects will call for more and better maps and other data. GISs and LISs that contain a variety of land-related data such as ownership, location, acreage, soil types, land uses, and natural resources must be designed, developed, and maintained. Cadastral surveys of the yet unsurveyed public lands are essential. Monuments set years ago by the original surveyors have to be recovered and remonumented for preservation of property boundaries. Appropriate surveys with very demanding accuracies will be necessary to position drilling rigs as mineral and oil explorations press further offshore. Other future challenges include making precise deformation surveys for monitoring existing structures such as dams, bridges, and skyscrapers to detect imperceptible movements that could be precursors to catastrophes caused by their failure. Timely measurements and maps of the effects of natural disasters such as earthquakes, floods, and hurricanes will be needed so that effective relief and assistance efforts can be planned and implemented. In the space program, the desire for maps of neighboring planets will continue. And we must increase our activities in measuring and monitoring natural and human-caused global changes (glacial growth and retreat, volcanic activity, large-scale deforestation, and so on) that can potentially affect our land, water, atmosphere, energy supply, and even our climate.

These and other opportunities offer professionally rewarding indoor or outdoor (or both) careers for numerous people with suitable training in the various branches of surveying.

PROBLEMS

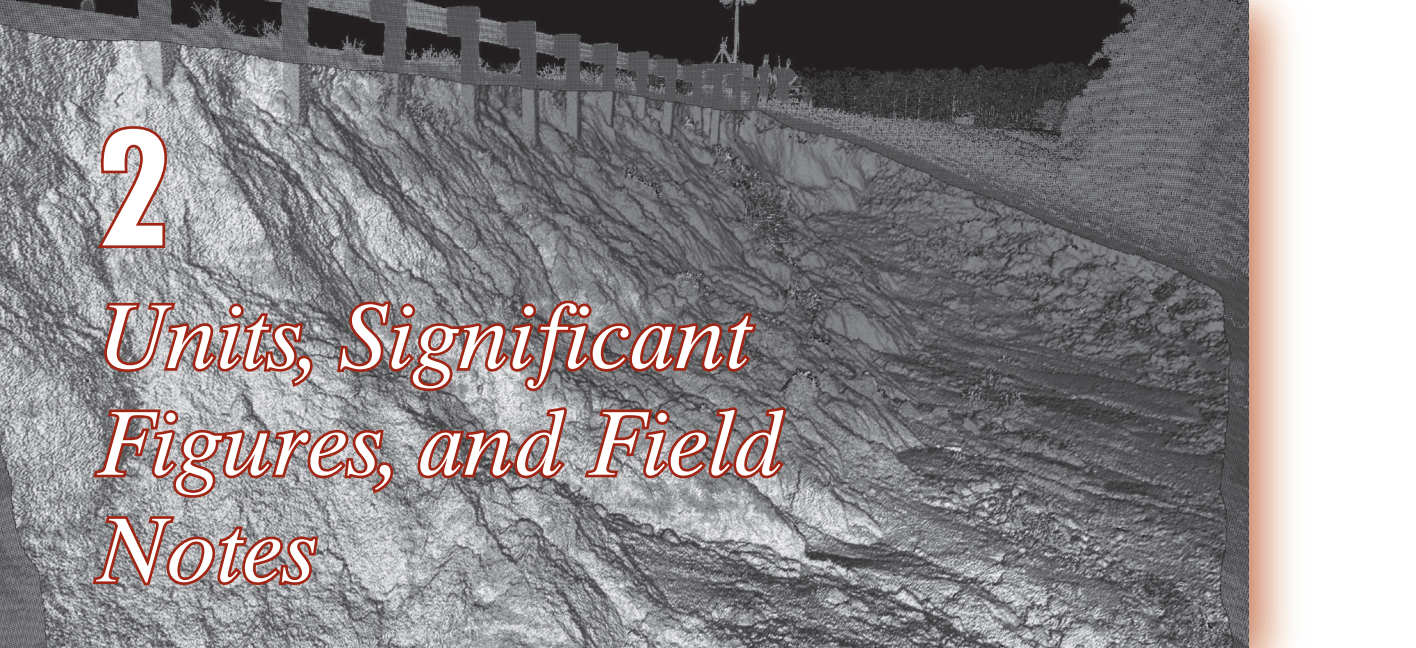
NOTE: Answers for some of these problems, and some in later chapters, can be obtained by consulting the bibliographies, later chapters, websites, or professional surveyors.

- 1.1 List 10 uses for surveying in areas other than land surveying.
- 1.2 Explain the difference between geodetic and plane surveys.
- 1.3 Describe some surveying applications in:
 - (a) Archeology
 - (b) Gas exploration
 - (c) Agriculture
- 1.4 List some applications of surveying in geology, forestry, and archeology.
- 1.5 Why is it important to make accurate surveys of underground utilities?
- 1.6 Discuss the uses for topographic surveys.
- 1.7 What are hydrographic surveys, and why are they important?
- 1.8 Print a view of your location using Google Earth.[®]
- 1.9 Briefly explain the procedure used by Eratosthenes in determining the Earth's circumference.
- 1.10 Describe the steps a land surveyor would need to do when performing a boundary survey.
- 1.11 What is the name of the state-level professional surveying organization in your state or region?
- 1.12 What organizations in your state furnish maps and reference data to surveyors and engineers?
- 1.13 List the legal requirements for registration as a land surveyor in your state.
- 1.14 Briefly describe an Earth-Centered, Earth-Fixed coordinate system.
- 1.15 List the professional societies representing the geospatial industry in the
 - (a) United States
 - (b) Canada
 - (c) International
- 1.16 Explain how aerial photographs and satellite images can be valuable in surveying.
- 1.17 Search the Internet and define a Very Long Baseline Interferometry (VLBI) station. Discuss why these stations are important to the geospatial industry.
- 1.18 Describe how a GIS can be used in flood emergency planning.
- 1.19 Visit one of the surveying websites listed in Table 1.1, and write a brief summary of its contents. Briefly explain the value of the available information to surveyors.
- 1.20 Read one of the articles cited in the bibliography for this chapter, or another of your choosing, that describes an application where satellite surveying methods were used. Write a brief summary of the article.
- 1.21 Same as Problem 1.20, except the article should be on safety as related to surveying.

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2

Units, Significant Figures, and Field Notes

PART I • UNITS AND SIGNIFICANT FIGURES

■ 2.1 INTRODUCTION

Five types of observations illustrated in Figure 2.1 form the basis of traditional plane surveying: (1) horizontal angles, (2) horizontal distances, (3) vertical (or zenith) angles, (4) vertical distances, and (5) slope distances. In the figure, OAB and ECD are horizontal planes, and $OACE$ and $ABDC$ are vertical planes. Then as illustrated, horizontal angles, such as angle AOB , and horizontal distances, OA and OB , are measured in horizontal planes; vertical angles, such as AOC , are measured in vertical planes; zenith angles, such as EOC , are also measured in vertical planes; vertical lines, such as AC and BD , are measured vertically (in the direction of gravity); and slope distances, such as OC , are determined along inclined planes. By using combinations of these basic observations, it is possible to compute relative positions between any points. Equipment and procedures for making each of these basic kinds of observations are described in later chapters of this book.

■ 2.2 UNITS OF MEASUREMENT

Magnitudes of measurements (or of values derived from observations) must be given in terms of specific units. In surveying, the most commonly employed units are for *length*, *area*, *volume*, and *angle*. Two different systems are in use for specifying units of observed quantities, the *English* and *metric* systems. Because of its widespread adoption, the metric system is called the *International System of Units*, and abbreviated *SI*.

The basic unit employed for length measurements in the English system is the foot, whereas the meter is used in the metric system. In the past, two different

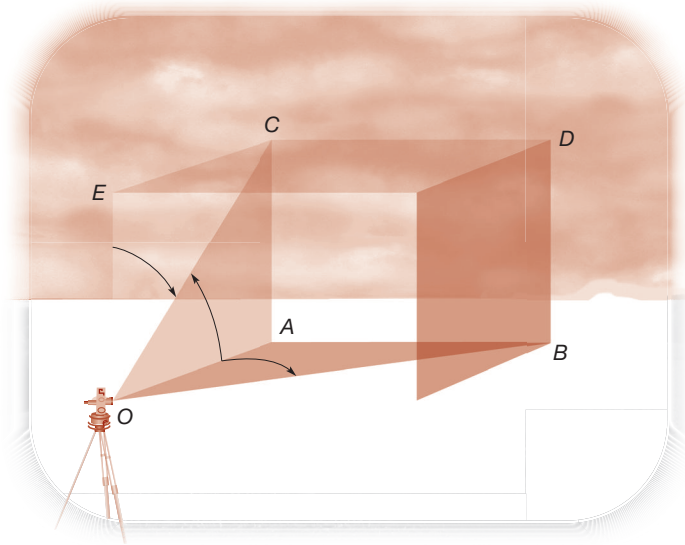


Figure 2.1
Kinds of
measurements in
surveying.

definitions have been used to relate the foot and meter. Although they differ slightly, their distinction must be made clear in surveying. In 1893, the United States officially adopted a standard in which 39.37 in. was exactly equivalent to 1 m. Under this standard, the foot was approximately equal to 0.3048006 m. In 1959, a new standard was officially adopted in which the inch was equal to exactly 2.54 cm. Under this standard, 1 ft equals exactly 0.3048 m. This current unit, known as the international foot, differs from the previous one by about 1 part in 500,000, or approximately 1 foot per 100 miles. This small difference is thus important for very precise surveys conducted over long distances, and for conversions of high elevations or large coordinate values such as those used in State Plane Coordinate Systems as discussed in Chapter 20. Because of the vast number of surveys performed prior to 1959, it would have been extremely difficult and confusing to change all related documents and maps that already existed. Thus the old standard, now called the *U.S. survey foot (sft)*, is still used. Individual states have the option of officially adopting either standard. The National Geodetic Survey uses the meter in its distance measurements; thus, it is unnecessary to specify the foot unit. However, those making conversions from metric units must know the adopted standard for their state and use the appropriate conversion factor.

Because the English system has long been the officially adopted standard for measurements in the United States, except for geodetic surveys, the linear units of feet and *decimals* of a foot are most commonly used by surveyors. In construction, feet and inches are often used. Because surveyors perform all types of surveys including geodetic, and they also provide measurements for developing construction plans and guiding building operations, they must understand all the various systems of units and be capable of making conversions between them. Caution must always be exercised to ensure that observations are recorded in their proper units, and conversions are correctly made.

A summary of the length units used in past and present surveys in the United States includes the following:

- 1 foot = 12 inches
- 1 yard = 3 feet
- 1 inch = 2.54 centimeters (basis of international foot)
- 1 meter = 39.37 inches (basis of U.S. survey foot)
- 1 rod = 1 pole = 1 perch = 16.5 feet
- 1 vara = approximately 33 inches (old Spanish unit often encountered in the southwestern United States)
- 1 Gunter's chain (ch) = 66 feet = 100 links (lk) = 4 rods
- 1 mile = 5280 feet = 80 Gunter's chains
- 1 nautical mile = 1852 m $\approx$ 6076.10 sft $\approx$ 6076.12 ift (nominal length of a minute for any great circle on the Earth)
- 1 fathom = 6 feet.

In the English system, areas are given in *square feet* or *square yards*. The most common unit for large areas is the *acre*. Ten square chains (Gunter's) equal 1 acre. Thus an acre contains 43,560 ft², which is the product of 10 and 66². The *arpent* (equal to approximately 0.85 acre, but varying somewhat in different states) was used in land grants of the French crown. When employed as a linear term, it refers to the length of a side of 1 square arpent.

Volumes in the English system can be given in *cubic feet* or *cubic yards*. For very large volumes, for example, the quantity of water in a reservoir, the *acre-foot* unit is used. It is equivalent to the area of an acre having a depth of 1 ft, and thus is 43,560 ft³.

The unit of angle used in surveying is the *degree*, defined as 1/360 of a circle. One degree (1°) equals 60 min, and 1 min equals 60 sec. Divisions of seconds are given in tenths, hundredths, and thousandths. Other methods are also used to subdivide a circle, for example, 400 *grad* (with 100 *centesimal min/grad* and 100 *centesimal sec/min*). Another term, *gons*, is now used interchangeably with grads. The military services use *mils* to subdivide a circle into 6400 units.

A *radian* is the angle subtended by an arc of a circle having a length equal to the radius of the circle. Therefore, 2π rad = 360°, 1 rad $\approx$ 57°17'44.8" $\approx$ 57.2958°, and 0.01745 rad $\approx$ 1°.

■ 2.3 INTERNATIONAL SYSTEM OF UNITS (SI)

As noted previously, the meter is the basic unit for length in the metric or SI system. Subdivisions of the meter (m) are the *millimeter* (mm), *centimeter* (cm), and *decimeter* (dm), equal to 0.001, 0.01, and 0.1 m, respectively. A kilometer (km) equals 1000 m, which is approximately five eighths of a mile.

Areas in the metric system are specified using the *square meter* (m²). Large areas, for example, tracts of land, are given in *hectares* (ha), where 1 ha is equivalent to a square having sides of 100 m. Thus, there are 10,000 m², or about 2.471 acres/ha. The *cubic meter* (m³) is used for volumes in the SI system. Degrees, minutes, and seconds, or the radian, are accepted SI units for angles.

The metric system was originally developed in the 1790s in France. Although other definitions were suggested at that time, the French Academy of Sciences chose to define the meter as $1/10,000,000$ of the length of the Earth's meridian through Paris from the equator to the pole. The actual length that was adopted for the meter was based on observations that had been made up to that time to determine the Earth's size and shape. Although later measurements revealed that the initially adopted value was approximately 0.2 mm short of its intended definition related to the meridional quadrant, still the originally adopted length became the standard.

Shortly after the metric system was introduced to the world, Thomas Jefferson who was the then secretary of state, recommended that the United States adopt it, but the proposal lost by one vote in the Congress! When the metric system was finally legalized for use (but not officially adopted) in the United States in 1866, a meter was defined as the interval under certain physical conditions between lines on an international prototype bar made of 90% platinum and 10% iridium, and accepted as equal to exactly 39.37 inches. A copy of this bar was held in Washington, D.C. and compared periodically with the international standard held in Paris. In 1960, at the General Conference on Weights and Measures (CGPM), the United States and 35 other nations agreed to redefine the meter as the length of 1,650,763.73 waves of the orange-red light produced by burning the element krypton (Kr-86). That definition permitted industries to make more accurate measurements and to check their own instruments without recourse to the standard meter-bar in Washington. The wavelength of this light is a true constant, whereas there is a risk of instability in the metal meter-bar. The CGPM met again in 1983 and established the current definition of the meter as the length of the path traveled by light in a vacuum during a time interval of $1/299,792,458$ sec. Obviously with this definition, the speed of light in a vacuum becomes exactly 299,792,458 m/sec. The advantage of this latest standard is that the meter is more accurately defined, since it is in terms of time, the most accurate of our basic measurements.

During the 1960s and 1970s, significant efforts were made toward promoting adoption of SI as the legal system for weights and measures in the United States. However, costs and frustrations associated with making the change generated substantial resistance, and the efforts were temporarily stalled. Recognizing the importance to the United States of using the metric system in order to compete in the rapidly developing global economy, in 1988 the Congress enacted the *Omnibus Trade and Competitiveness Act*. It designated the metric system as the *preferred* system of weights and measures for U.S. trade and commerce. The Act, together with a subsequent *Executive Order* issued in 1991, required all federal agencies to develop definite metric conversion plans and to use SI standards in their procurements, grants, and other business-related activities to the extent economically feasible. As an example of one agency's response, the Federal Highway Administration adopted a plan calling for (1) use of metric units in all publications and correspondence after September 30, 1992 and (2) use of metric units on all plans and contracts for federal highways after September 30, 1996. Although the Act and Executive Order did not mandate states, counties, cities, or industries to convert to metric, strong incentives were provided, for example, if SI directives

were not complied with, certain federal matching funds could be withheld. In light of these developments, it appeared that the metric system would soon become the official system for use in the United States. However, again much resistance was encountered, not only from individuals but also from agencies of some state, county, town, and city governments, as well as from certain businesses. As a result, the SI still has not been adopted officially in the United States.

Besides the obvious advantage of being better able to compete in the global economy, another significant advantage that would be realized in adopting the SI standard would be the elimination of the confusion that exists in making conversions between the English System and the SI. The 1999 crash of the Mars Orbiter underscores costs and frustrations associated with this confusion. This \$125 million satellite was supposed to monitor the Martian atmosphere, but instead it crashed into the planet because its contractor used English units while NASA's Jet Propulsion Laboratory was giving it data in the metric system. For these reasons and others, such as the decimal simplicity of the metric system, surveyors who are presently burdened with unit conversions and awkward computations involving yard, foot, and inch units should welcome official adoption of the SI. However, since this adoption has not yet occurred, this book uses both English and SI units in discussion and example problems.

■ 2.4 SIGNIFICANT FIGURES

In recording observations, an indication of the accuracy attained is the number of digits (significant figures) recorded. By definition, the number of significant figures in any observed value includes the positive (certain) digits plus one (*only one*) digit that is estimated or rounded off, and therefore questionable. For example, a distance measured with a tape whose smallest graduation is 0.01 ft, and recorded as 73.52 ft, is said to have four significant figures; in this case the first three digits are certain, and the last is rounded off and therefore questionable but still significant.

To be consistent with the theory of errors discussed in Chapter 3, it is essential that data be recorded with the correct number of significant figures. If a significant figure is dropped in recording a value, the time spent in acquiring certain precision has been wasted. On the other hand, if data are recorded with more figures than those that are significant, false precision will be implied. The number of significant figures is often confused with the number of decimal places. Decimal places may have to be used to maintain the correct number of significant figures, but in themselves they do not indicate significant figures. Some examples follow:

Two significant figures: 24, 2.4, 0.24, 0.0024, 0.020

Three significant figures: 364, 36.4, 0.000364, 0.0240

Four significant figures: 7621, 76.21, 0.0007621, 24.00.

Zeros at the end of an integer value may cause difficulty because they may or may not be significant. In a value expressed as 2400, for example, it is not known how many figures are significant; there may be two, three, or four, and therefore definite rules must be followed to eliminate the ambiguity. The preferred method of eliminating this uncertainty is to express the value in terms of powers of 10. The

significant figures in the measurement are then written in scientific notation as a number between 1 and 10 with the correct number of zeros and power of 10. As an example, 2400 becomes 2.400×10^3 if both zeros are significant, 2.40×10^3 if one is significant, and 2.4×10^3 if there are only two significant figures. Alternatively, a bar may be placed over the last significant figure, as $240\bar{0}$, $24\bar{0}0$, and $2\bar{4}00$ for 4, 3, and 2 significant figures, respectively.

When observed values are used in the mathematical processes of addition, subtraction, multiplication, and division, it is imperative that the number of significant figures given in answers be consistent with the number of significant figures in the data used. The following three steps will achieve this for addition or subtraction: (1) identify the column containing the rightmost significant digit in each number being added or subtracted, (2) perform the addition or subtraction, and (3) round the answer so that its rightmost significant digit occurs in the leftmost column identified in step (1). Two examples illustrate the procedure.

(a)	(b)
46.7418	378.
+ 1.03	<u>−2.1</u>
<u>+375.0</u>	375.9
422.7718	(answer 376.)
(answer 422.8)	

In (a), the digits 8, 3, and 0 are the rightmost significant ones in the numbers 46.7418, 1.03, and 375.0, respectively. Of these, the 0 in 375.0 is leftmost with respect to the decimal. Thus, the answer 422.7718 obtained on adding the numbers is rounded to 422.8, with its rightmost significant digit occurring in the same column as the 0 in 375.0. In (b), the digits 8 and 1 are rightmost, and of these the 8 is leftmost. Thus, the answer 375.9 is rounded to 376.

In multiplication, the number of significant figures in the answer is equal to the least number of significant figures in any of the factors. For example, $362.56 \times 2.13 = 772.2528$ when multiplied but the answer is correctly given as 772. Its three significant figures are governed by the three significant digits in 2.13. Likewise, in division the quotient should be rounded off to contain only as many significant figures as the least number of significant figures in either the divisor or the dividend. These rules for significant figures in computations stem from error propagation theory, which is discussed further in Section 3.17.

The companion website for this book, <http://www.pearsonhighered.com/ghilani>, contains instructional videos. The video *Significant Figures* discusses the rules applied to significant figures and rounding, which is covered in the following section.

In surveying, four specific types of problems relating to significant figures are encountered and must be understood.

1. Field measurements are given to some specific number of significant figures, thus dictating the number of significant figures in answers derived when the measurements are used in computations. In an intermediate calculation, it is



a common practice to carry at least one more digit than required, and then round off the final answer to the correct number of significant figures.

2. There may be an implied number of significant figures. For instance, the length of a football field might be specified as 100 yd. But in laying out the field, such a distance would probably be measured to the nearest hundredth of a foot, not the nearest half-yard.
3. Each factor may not cause an equal variation. For example, if a steel tape 100.00 ft long is to be corrected for a change in temperature of 15°F, one of these numbers has five significant figures while the other has only two. However, a 15° variation in temperature changes the tape length by only 0.01 ft. Therefore, an adjusted tape length to five significant figures is warranted for this type of data. Another example is the computation of a slope distance from horizontal and vertical distances, as in Figure 2.2. The vertical distance V is given to two significant figures, and the horizontal distance H is measured to five significant figures. From these data, the slope distance S can be computed to five significant figures. For small angles of slope, a considerable change in the vertical distance produces a relatively small change in the difference between slope and horizontal distances.
4. Observations are recorded in one system of units but may have to be converted to another. A good rule to follow in making these conversions is to retain in the answer a number of significant figures equal to those in the observed value. As an example, to convert 178 ft 6-3/8 in. to meters, the number of significant figures in the measured value would first be determined by expressing it in its smallest units. In this case, 1/8th in. is the smallest unit and there are $(178 \times 12 \times 8) + (6 \times 8) + 3 = 17,139$ of these units in the value. Thus, the measurement contains five significant figures, and the answer is $17,139 \div (8 \times 39.37 \text{ in./m}) = 54.416 \text{ m}$, properly expressed with five significant figures. (Note that 39.37 used in the conversion is an exact constant and does not limit the number of significant figures.)

■ 2.5 ROUNDING OFF NUMBERS

Rounding off a number is the process of dropping one or more digits so the answer contains only those digits that are significant. In rounding off numbers to any required degree of precision in this text, the following procedures will be observed:

1. When the digit to be dropped is lower than 5, the number is written without the digit. Thus, 78.374 becomes 78.37. Also 78.3749 rounded to four figures becomes 78.37.
2. When the digit to be dropped is exactly 5, the nearest even number is used for the preceding digit. Thus, 78.375 becomes 78.38 and 78.385 is also rounded to 78.38.

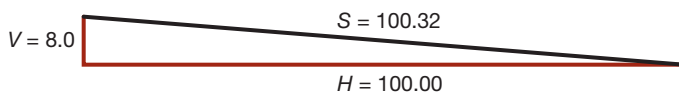


Figure 2.2
Slope correction.

3. When the digit to be dropped is greater than 5, the number is written with the preceding digit increased by 1. Thus, 78.386 becomes 78.39.

Procedures 1 and 3 are standard practice. When rounding the value 78.375 in procedure 2, however, some people always take the next higher hundredth, whereas others invariably use the next lower hundredth. However, using the nearest even digit establishes a uniform procedure and produces better-balanced results in a series of computations. It is an improper procedure to perform two-stage rounding where, for example, in rounding 78.3749 to four digits it would be first rounded to five figures, yielding 78.375, and then rounded again to 78.38. The correct answer in rounding 78.3749 to four figures is 78.37.

It is important to recognize that rounding should only occur with the final answer. Intermediate computations should be done without rounding to avoid problems that can be caused by rounding too early. Example (a) of Section 2.4 is repeated below to illustrate this point. The sum of 46.7418, 1.03, and 375.0 is rounded to 422.8 as shown in the “correct” column. If the individual values are rounded prior to the addition as shown in the “incorrect” column, the incorrect result of 422.7 is obtained.

Correct	Incorrect
46.7418	46.7
+ 1.03	+ 1.0
+ 375.0	+ 375.0
422.7718	 422.7
(answer 422.8)	(answer 422.7)

PART II • FIELD NOTES

■ 2.6 FIELD NOTES

Field notes are the records of work done in the field. They typically contain measurements, sketches, descriptions, and many other items of miscellaneous information. In the past, field notes were prepared exclusively by hand lettering in field books or special note pads as the work progressed and data were gathered. However, survey controllers, also known as data collectors and electronic field books, have been introduced that can interface with many different modern surveying instruments. As the work progresses, they create computer files containing a record of observed data. All surveying controllers provide a mapping feature (see Chapter 17). Some controllers and total stations also provide a camera so that an image of the area where data is being collected can be captured. When these features are absent manually prepared sketches and descriptions often supplement the numerical data they capture. Regardless of the manner or form in which the notes are taken, they are extremely important.

Whether prepared manually, created by a survey controller, or a combination of these forms, surveying field notes are the only permanent records of work

done in the field. If the data are incomplete, incorrect, lost, or destroyed, much or all of the time and money invested in making the measurements and records have been wasted. Hence, the job of data recording is frequently the most important and difficult one in a surveying party. Field books and computer files containing information gathered over a period of weeks are worth many thousands of dollars because of the costs of maintaining personnel and equipment in the field.

Recorded field data are used in the office to perform computations, make drawings, or both. The office personnel using the data are usually not the same people who took the notes in the field. Accordingly, it is essential that without verbal explanations notes be intelligible to anyone.

Property surveys are subject to court review under some conditions, so field notes become an important factor in litigation. Also, because they may be used as references in land transactions for generations, it is necessary to index and preserve them properly. The salable “goodwill” of a surveyor’s business depends largely on the office library of field books. Cash receipts may be kept in an unlocked desk drawer, but field books are stored in a fireproof safe!

■ 2.7 GENERAL REQUIREMENTS OF HANDWRITTEN FIELD NOTES

The following points are considered in appraising a set of field notes:

Accuracy. This is the most important quality in all surveying operations.

Integrity. A single omitted measurement or detail can nullify use of the notes for computing or plotting. If the project was far from the office, it is time consuming and expensive to return for a missing measurement. Notes should be checked carefully for completeness before leaving the survey site and never “fudged” to improve closures.

Legibility. Notes can be used only if they are legible. A professional-looking set of notes is likely to be professional in quality.

Arrangement. Note forms appropriate to a particular survey contribute to accuracy, integrity, and legibility.

Clarity. Advance planning and proper field procedures are necessary to ensure clarity of sketches and tabulations, and to minimize the possibility of mistakes and omissions. Avoid crowding notes; paper is relatively cheap. Costly mistakes in computing and drafting are the end results of ambiguous notes.

Appendix B contains examples of handwritten field notes for a variety of surveying operations. Their plate number identifies each. Other example note forms are given at selected locations within the chapters that follow. These notes have been prepared keeping the above points in mind.

In addition to the items stressed in the foregoing, certain other guidelines must be followed to produce acceptable handwritten field notes. The notes should be lettered with a sharp pencil of at least 3H hardness so that an indentation is made in the paper. Books so prepared will withstand damp weather in the field (or even a soaking) and still be legible, whereas graphite from a soft pencil, or ink from a pen or ballpoint, leaves an undecipherable smudge under such circumstances.

Erasures of recorded data are not permitted in field books. If a number has been entered incorrectly, a single line is run through it without destroying the number's legibility, and the proper value is noted above it (see Figure 5.5). If a partial or entire page is to be deleted, a single diagonal line in red is drawn through opposite corners, and **VOID** is lettered prominently on the page, giving the reasons.

Field notes are presumed to be “original” unless marked otherwise. Original notes are those taken at the same time the observations are being made. If the original notes are copied, they must be so marked (see Figure 5.11). Copied notes may not be accepted in court because they are open to question concerning possible mistakes, such as interchanging numbers, and omissions. The value of a distance or an angle placed in the field book from memory 10 min after the observation is definitely unreliable. Students are tempted to scribble notes on scrap sheets of paper for later transfer in a neater form to the field book. This practice may result in the loss of some or all of the original data and defeats one purpose of a surveying course—to provide experience in taking notes under actual field conditions. In a real job situation, a surveyor is not likely to spend any time at night transcribing scribbled notes. Certainly, an employer will not pay for this evidence of incompetence.

■ 2.8 TYPES OF FIELD BOOKS

Since field books contain valuable data, suffer hard wear, and must be permanent in nature, only the best should be used for practical work. Various kinds of field books as shown in Figure 2.3 are available, but bound and loose-leaf types are most common. The bound book, a standard for many years, has a sewed binding, a hard cover of leatherette, polyethylene, or covered hardboard, and contains 80 leaves. Its use ensures maximum testimony acceptability for property survey records in courtrooms. Bound duplicating books enable copies of the original notes to be made through carbon paper in the field. The alternate duplicate pages are perforated to enable their easy removal for advance shipment to the office.

Loose-leaf books have come into wide use because of many advantages, which include (1) assurance of a flat working surface; (2) simplicity of filing



Figure 2.3
Field books.
(Courtesy Topcon
America Corp.)