## CONTENTS

### Part I Surveying Principles 15

#### 1 Surveying Fundamentals 16

1.1 Surveying Defined 16  
1.2 Surveying: General Background 17  
1.3 Control Surveys 18  
1.4 Preliminary Surveys 18  
1.5 Surveying Instruments 19  
1.6 Construction Surveys 20  
1.7 Distance Measurement 20  
1.8 Angle Measurement 23  
1.9 Position Measurement 23  
1.10 Units of Measurement 24  
1.11 Stationing 25  
1.12 Types of Construction Projects 26  
1.13 Random and Systematic Errors 27  
1.14 Accuracy and Precision 27  
1.15 Mistakes 29  
1.16 Field Notes 29  

Review Questions 30

#### 2 Surveying Mathematics 32

2.1 Unit Conversions 32  
2.2 Lines and Angles 36  
2.3 Polygons 36  
2.4 Circles 48  
2.5 Rectangular Coordinates 50  

Problems 52

### 3 Tape Measurements 57

3.1 Background 57  
3.2 Gunter's Chain 58  
3.3 Tapes 59  
3.4 Steel Tapes 60  
3.5 Taping Accessories and Their Use 62  
3.6 Taping Techniques 66  
3.7 Taping Corrections 70  
3.8 Systematic Taping Errors and Corrections 70  
3.9 Random Taping Errors 74  
3.10 Techniques for "Ordinary" Taping Precision 75  
3.11 Mistakes in Taping 76  
3.12 Field Notes for Taping 76  
Problems 78

### 4 Leveling 81

4.1 General Background 81  
4.2 Theory of Differential Leveling 81  
4.3 Types of Surveying Levels 83  
4.4 Leveling Rods 87  
4.5 Definitions for Differential Leveling 90  
4.6 Techniques of Leveling 91  
4.7 Benchmark Leveling (Vertical Control Surveys) 94  
4.8 Profile and Cross-Section Leveling 95  
4.9 Reciprocal Leveling 102  
4.10 Peg Test 103
4.11 Three-Wire Leveling 106
4.12 Trigonometric Leveling 108
4.13 Level Loop Adjustments 109
4.14 Suggestions for Rod Work 110
4.15 Suggestions for Instrument Work 111
4.16 Mistakes in Leveling 112

5 Electronic Distance Measurement 120
5.1 General Background 120
5.2 Electronic Angle Measurement 121
5.3 Principles of Electronic Distance Measurement 121
5.4 EDM Instrument Characteristics 124
5.5 Prisms 125
5.6 EDM Instrument Accuracies 126
5.7 EDM Without Reflecting Prisms 127

6 Introduction to Total Stations and Theodolites 130
6.1 General Background 130
6.2 Reference Directions for Vertical Angles 130
6.3 Meridians 130
6.4 Horizontal Angles 130
6.5 Theodolites 133
6.6 Electronic Theodolites 134
6.7 Total Station 137
6.8 Theodolite/Total Station Setup 137
6.9 Geometry of the Theodolite and Total Station 139
6.10 Adjustment of the Theodolite and Total Station 139
6.11 Laying Off Angles 143

6.12 Prolonging a Straight Line (Double Centering) 145
6.13 Bucking-in (Interlining) 146
6.14 Intersection of Two Straight Lines 147
6.15 Prolonging a Measured Line over an Obstacle by Triangulation 148
6.16 Prolonging a Line Past an Obstacle 149

Review Questions 150

7 Total Stations 151
7.1 General Background 151
7.2 Total Station Capabilities 151
7.3 Total Station Field Techniques 157
7.4 Field Procedures for Total Stations in Topographic Surveys 164
7.5 Field-Generated Graphics 170
7.6 Construction Layout Using Total Stations 172
7.7 Motorized Total Stations 175
7.8 Summary of Modern Total Station Characteristics and Capabilities 182
7.9 Instruments Combining Total Station Capabilities and GPS Receiver Capabilities 183
7.10 Portable/Handheld Total Stations 184

Review Questions 186

8 Traverse Surveys and Computations 187
8.1 General Background 187
8.2 Balancing Field Angles 189
8.3 Meridians 190
8.4 Bearings 192
8.5 Azimuths 195
8.6 Latitudes and Departures 199
8.7 Traverse Precision and Accuracy 205
8.8 Compass Rule Adjustment 206
8.9 Effects of Traverse Adjustments on Measured Angles and Distances 208
8.10 Omitted Measurement Computations 209
8.11 Rectangular Coordinates of Traverse Stations 210
8.12 Area of a Closed Traverse by the Coordinate Method 214

Problems 216

9 Satellite Positioning 220

9.1 General Background 220
9.2 The U.S. Global Positioning System 224
9.3 Receivers 225
9.4 Satellite Constellations 227
9.5 GPS Satellite Signals 229
9.6 GPS Position Measurements 230
9.7 Errors 238
9.8 Continuously Operating Reference Station 239
9.9 Canadian Active Control System 241
9.10 Survey Planning 242
9.11 GPS Field Procedures 246
9.12 GPS Applications 252
9.13 Vertical Positioning 258
9.14 Conclusion 262
9.15 GPS Glossary 262
9.16 Recommended Readings 263

Review Questions 265

10 An Introduction to Geomatics 266

10.1 Geomatics Defined 266
10.2 Introduction to Electronic Surveying 266
10.3 Branches of Geomatics 268
10.4 Data Collection Branch: Preelectronic Techniques 269

10.5 Design and Plotting 276
10.6 Contours 284
10.7 Aerial Photography 292
10.8 Airborne and Satellite Imagery 298
10.9 Remote-Sensing Satellites 309
10.10 Geographic Information System 311
10.11 Database Management 316
10.12 Metadata 317
10.13 Spatial Entities or Features 318
10.14 Typical Data Representation 318
10.15 Spatial Data Models 320
10.16 GIS Data Structures 322
10.17 Topology 325
10.18 Remote Sensing Internet Resources 327

Review Questions 328

Problems 328

11 Horizontal Control Surveys 332

11.1 General Background 332
11.2 Plane Coordinate Grids 341
11.3 Lambert Projection Grid 347
11.4 Transverse Mercator Grid 347
11.5 UTM Grid 350
11.6 Horizontal Control Techniques 353
11.7 Project Control 355

Review Questions 364

Problems 364

Part II Construction Applications 365

II.1 Introduction 365
II.2 General Background 365
II.3 Grade 366
12 Machine Guidance and Control 367
12.1 General Background 367
12.2 Motorized Total Station Guidance and Control 370
12.3 Satellite Positioning Guidance and Control 372
12.4 Three-Dimensional Data Files 374
12.5 Summary of the 3D Design Process 376
12.6 Web Site References for Data Collection, DTM, and Civil Design 378
Review Questions 378

13 Highway Curves 379
13.1 Route Surveys 379
13.2 Circular Curves: General Background 379
13.3 Circular Curve Geometry 380
13.4 Circular Curve Deflections 387
13.5 Chord Calculations 389
13.6 Metric Considerations 390
13.7 Field Procedure (Steel Tape and Theodolite) 390
13.8 Moving up on the Curve 391
13.9 Offset Curves 392
13.10 Compound Circular Curves 400
13.11 Reverse Curves 401
13.12 Vertical Curves: General Background 402
13.13 Geometric Properties of the Parabola 404
13.14 Computation of the High or the Low Point on a Vertical Curve 405
13.15 Computing a Vertical Curve 405
13.16 Spiral Curves: General Background 408
13.17 Spiral Curve Computations 410
13.18 Spiral Layout Procedure Summary 415
13.19 Approximate Solution for Spiral Problems 418

13.20 Superelevation: General Background 420
13.21 Superelevation Design 420
Review Questions 422
Problems 422

14 Highway Construction Surveys 425
14.1 Preliminary (Preengineering) Surveys 425
14.2 Highway Design 429
14.3 Highway Construction Layout 431
14.4 Clearing, Grubbing, and Stripping Topsoil 435
14.5 Placement of Slope Stakes 436
14.6 Layout for line and Grade 440
14.7 Grade Transfer 442
14.8 Ditch Construction 445
Review Questions 446

15 Municipal Street Construction Surveys 447
15.1 General Background 447
15.2 Classification of Roads and Streets 448
15.3 Road Allowances 449
15.4 Road Cross Sections 449
15.5 Plan and Profile 449
15.6 Establishing Centerline 452
15.7 Establishing Offset Lines and Construction Control 454
15.8 Construction Grades for a Curbed Street 457
15.9 Street Intersections 461
15.10 Sidewalk Construction 463
15.11 Site Grading 464
Problems 466
16 Pipeline and Tunnel Construction
Surveys 471
16.1 Pipeline Construction 471
16.2 Sewer Construction 473
16.3 Layout for Line and Grade 475
16.4 Catch-Basin Construction Layout 484
16.5 Tunnel Construction Layout 485
Problems 490

17 Culvert and Bridge Construction
Surveys 495
17.1 Culvert Construction 495
17.2 Culvert Reconstruction 495
17.3 Bridge Construction: General 498
17.4 Contract Drawings 502
17.5 Layout Computations 507
17.6 Offset Distance Computations 507
17.7 Dimension Verification 508
17.8 Vertical Control 510
17.9 Cross Sections for Footing Excavations 511
Review Questions 512

18 Building Construction Surveys 513
18.1 Building Construction: General 513
18.2 Single-Story Construction 513
18.3 Multistory Construction 524
Review Questions 530

19 Quantity and Final Surveys 531
19.1 Construction Quantity Measurements:
     General Background 531
19.2 Area Computations 532
19.3 Area by Graphical Analysis 539
19.4 Construction Volumes 545
19.5 Cross Sections, End Areas, and Volumes 547
19.6 Prismoidal Formula 552
19.7 Volume Computations by Geometric Formulas 553
19.8 Final (As-Built) Surveys 553
Problems 555

Appendix A Coordinate Geometry Review 558
A.1 Geometry of Rectangular Coordinates 558
A.2 Illustrative Problems in Rectangular Coordinates 561

Appendix B Answers to Selected Problems 567

Appendix C Glossary 578

Appendix D Typical Field Projects 588
D.1 Field Notes 588
D.2 Project 1: Building Measurements 589
D.3 Project 2: Experiment to Determine “Normal Tension” 590
D.4 Project 3: Field Traverse Measurements with a Steel Tape 592
D.5 Project 4: Differential Leveling 593
D.6 Project 5: Traverse Angle Measurements and Closure Computations 595
D.7 Project 6: Topographic Survey 596
D.8 Project 7: Building Layout 603
D.9 Project 8: Horizontal Curve 604
D.10 Project 9: Pipeline Layout 605

Appendix E Illustrations of Machine Control and of Various Data-Capture Techniques 607

Index 609