

Contents

| | |
|---------------------|----------|
| <i>Preface</i> | xxv |
| Introduction | 1 |

PART I

SOIL: Material Characterization

| | |
|--|-----------|
| 1. Origin and Classification of Soils | 11 |
| 1.1 Soil Origin | 11 |
| 1.2 Why Classify? | 12 |
| 1.3 Criteria for Classifying Soil | 12 |
| 1.4 Classification on the Basis of Grain Size | 13 |
| 1.5 Classification on the Basis of Plasticity | 17 |
| 1.6 Classifying a Soil | 21 |
| 1.7 Symbols and Graphic Representation | 22 |
| 1.8 Classified Soil and its Engineering Properties | 23 |
| <i>Solved Examples</i> | 24 |
| <i>Exercises</i> | 26 |
| 2. The Three Phase System | 27 |
| 2.1 Jargon | 27 |
| 2.2 Weight Relationships | 28 |
| 2.3 Volume Relationships | 28 |
| 2.4 Density and Unit Weight Relationships | 29 |
| 2.5 Inter-relationships | 30 |
| <i>Solved Examples</i> | 31 |
| <i>Exercises</i> | 32 |
| 3. The Effective Stress Principle | 34 |
| 3.1 The Principle | 34 |
| 3.2 Measurable Stresses | 35 |

| | | |
|-----------|---|-----------|
| 3.3 | The Nature of Effective Stress | 36 |
| | <i>Exercises</i> | 38 |
| 4. | Effective Stress Under Hydrostatic Conditions | 39 |
| 4.1 | Distribution of Effective Stress with Depth | 39 |
| 4.2 | Influence on Effective Stress of a Shift in the Water Table | 40 |
| 4.3 | Influence on Effective Stress of a Shift in the Ground Surface | 42 |
| 4.4 | A Preview of the Functional Relations between Engineering Properties and Effective Stress | 43 |
| | <i>Solved Examples</i> | 45 |
| | <i>Exercises</i> | 47 |
| 5. | Permeability | 49 |
| 5.1 | An Engineering Property | 49 |
| 5.2 | Permeability—a Function of Soil Type | 49 |
| 5.3 | Permeability—a Function of Void Ratio | 50 |
| 5.4 | Permeability—a Function of Soil Structure | 51 |
| 5.5 | Permeability—a Function of the Permeant | 51 |
| 5.6 | Permeability—a Function of Effective Stress | 52 |
| | <i>Exercises</i> | 52 |
| 6. | Measuring Permeability | 54 |
| 6.1 | Darcy's Law | 54 |
| 6.2 | Constant Head Permeameter | 57 |
| 6.3 | Falling Head Permeameter | 57 |
| 6.4 | Laboratory Measurement of Permeability | 59 |
| | <i>Solved Examples</i> | 59 |
| | <i>Exercises</i> | 60 |
| 7. | Effective Stress Under Steady State One-dimensional Flow | 61 |
| 7.1 | Seepage Force | 61 |
| 7.2 | Downward Flow | 61 |
| 7.3 | Upward Flow | 63 |
| 7.4 | Quick Condition | 63 |
| | <i>Solved Examples</i> | 64 |
| | <i>Exercises</i> | 66 |
| 8. | Compressibility | 69 |
| 8.1 | An Engineering Property | 69 |
| 8.2 | Compressibility—a Function of Effective Stress | 70 |
| 8.3 | Compressibility—a Function of Soil Type | 72 |
| 8.4 | Compressibility—a Function of Stress History | 72 |
| 8.5 | Normally Consolidated and Overconsolidated Clay | 73 |
| | <i>Solved Examples</i> | 76 |
| | <i>Exercises</i> | 79 |

| | |
|---|------------|
| 9. Effective Stress Under Transient Hydrodynamic Conditions | 80 |
| 9.1 An Analogy | 80 |
| 9.2 A Mechanistic Model | 81 |
| 9.3 The Condition of Continuity | 83 |
| 9.4 Terzaghi's One-dimensional Consolidation Theory | 85 |
| 9.5 Effective Stress Distribution in a Compressible Layer during Consolidation | 90 |
| <i>Solved Examples</i> | 92 |
| <i>Exercises</i> | 93 |
| 10. Measuring Compressibility Characteristics and Computing Amount of and Time for Consolidation | 97 |
| 10.1 Consolidation and Settlement | 98 |
| 10.2 Determining Coefficients of Compressibility and Consolidation | 98 |
| 10.3 Limitations in Predicting Consolidation Behaviour | 102 |
| 10.4 Amount of Consolidation | 104 |
| 10.5 Time for Consolidation | 106 |
| <i>Solved Examples</i> | 106 |
| <i>Exercises</i> | 109 |
| 11. Shear Strength and its Measurement | 114 |
| 11.1 An Engineering Property | 114 |
| 11.2 Measurement of Shear Strength | 115 |
| 11.3 The Mohr's Circle | 117 |
| 11.4 Types of Triaxial Compression Tests | 119 |
| 11.5 Shear Stress, Shear Strength and the Triaxial Test | 120 |
| 11.6 Stress-Strain Behaviour of Sands | 121 |
| 11.7 Stress-Strain Behaviour of Clays | 123 |
| 11.8 Concept of Failure | 124 |
| 11.9 Shear Strength—A Function of Effective Stress | 125 |
| 11.9.1 <i>Experimental Results</i> | 125 |
| 11.9.2 <i>Stress Conditions at Failure in Terms of Total Stresses</i> | 128 |
| 11.9.3 <i>Stress Conditions at Failure in Terms of Effective Stresses</i> | 130 |
| 11.9.4 <i>Relationships among Stresses at Failure</i> | 132 |
| 11.10 Cohesion and Friction | 133 |
| 11.11 Pore Water Pressure Parameters | 134 |
| <i>Solved Examples</i> | 135 |
| <i>Exercises</i> | 138 |
| 12. Shear Strength Parameters | 142 |
| 12.1 Shear Strength and Strength Parameters | 142 |
| 12.2 Effective Stress-Strength Parameters—A Function of Soil Type | 146 |
| 12.3 Effective Stress-Strength Parameters—A Function of Stress History and Stress Range | 147 |
| 12.3.1 <i>Behaviour of Overconsolidated Clays</i> | 148 |
| 12.3.2 <i>Behaviour of Sands at High Stresses</i> | 149 |

| | | | |
|------------|--|-----|------------|
| 12.4 | The Relevant Parameters | 150 | |
| 12.4.1 | Effective Stress Analysis | 152 | |
| 12.4.2 | Total Stress Analysis | 153 | |
| 12.5 | In Perspective | 155 | |
| | <i>Solved Examples</i> | 156 | |
| | <i>Exercises</i> | 157 | |
| 13. | Engineering Properties of Natural On-land Deposits | | 160 |
| 13.1 | Variability | 160 | |
| 13.2 | Sensitivity | 161 | |
| 13.3 | Of Coarse Grained Soils | 162 | |
| 13.4 | Of Normally Consolidated Clays | 163 | |
| 13.5 | Of Overconsolidated Clays | 164 | |
| 13.6 | Of Residual Deposits | 164 | |
| 13.7 | Of Organic Deposits | 166 | |
| | <i>Exercises</i> | 167 | |
| 14. | Engineering Properties of Natural Offshore Deposits | | 168 |
| 14.1 | Terrigenous and Pelagic Soils | 169 | |
| 14.2 | Of Under Consolidated Clays | 169 | |
| 14.3 | Of Dense Sands | 170 | |
| 14.4 | Of Calcareous Clays | 171 | |
| 14.5 | Of Calcareous Sands | 171 | |
| 14.6 | Applications | 174 | |
| | <i>Exercises</i> | 174 | |
| 15. | Engineering Properties of Man-made Deposits | | 176 |
| 15.1 | Soil as a Building Material | 176 | |
| 15.2 | Field Controllable Compaction Variables | 177 | |
| 15.3 | Density and Structure—Functions of Compaction Conditions | 179 | |
| 15.4 | Engineering Behaviour—A Function of Density and Structure | 183 | |
| 15.4.1 | Swelling | 184 | |
| 15.4.2 | Shrinkage | 184 | |
| 15.4.3 | Construction Pore Water Pressures | 184 | |
| 15.4.4 | Permeability | 184 | |
| 15.4.5 | Compressibility | 184 | |
| 15.4.6 | Stress-strain | 185 | |
| 15.4.7 | Effective Stress-Strength Parameters | 186 | |
| 15.5 | Designing Soil—An Exercise in Optimization | 187 | |
| 15.6 | Compacting Coarse Grained Soils | 187 | |
| | <i>Exercises</i> | 188 | |
| 16. | On Partially Saturated Soils | | 190 |
| 16.1 | The Three Phase System | 190 | |

- 16.2 Effective Stress Concept 192
- 16.3 An Empirical Approach—The χ -Factor 193
- 16.4 A Mechanistic Picture 194
- 16.5 Observed Reality 195
- 16.6 Dealing with Problems Today 195
- Exercises* 197

PART II

SITE: Location Characterization

| | |
|--|------------|
| 17. Site Investigation | 201 |
| 17.1 Why Investigate 201 | |
| 17.2 Designing an Investigation 202 | |
| 17.2.1 Design—a Function of the Civil Engineering Project and the Soil Conditions 203 | |
| 17.2.2 Data Collection 204 | |
| 17.2.3 Codal Provisions and Good Practices 205 | |
| 17.3 Investigation Methodologies 205 | |
| 17.3.1 Geophysical and Remote Sensing Methods 206 | |
| 17.3.2 Drilling Bore Holes and Sampling 206 | |
| 17.3.3 Pits, Trenches and Shafts 206 | |
| 17.3.4 In Situ Testing 207 | |
| 17.3.5 Laboratory Testing 207 | |
| 17.4 Drilling Technologies 207 | |
| 17.4.1 Auger Drilling 208 | |
| 17.4.2 Percussion Drilling 212 | |
| 17.4.3 Jet and Wash Drilling 213 | |
| 17.4.4 High Speed Rotary Drilling 213 | |
| 17.4.5 Stabilizing the Bore Hole 213 | |
| 17.5 Samplers and Sampling Techniques 215 | |
| 17.5.1 Open Drive Samplers 216 | |
| 17.5.2 Driving the Sampler into Soil 219 | |
| 17.6 Consequences of Sampling Disturbance 219 | |
| 17.7 In Situ Field Testing 220 | |
| 17.7.1 Penetration Tests 220 | |
| 17.7.2 Ground Water Observations 223 | |
| 17.7.3 Permeability Tests 224 | |
| 17.7.4 Determining Undrained Strength of Clays with a Vane Shear Test 224 | |
| 17.8 Presenting Results of Site Investigation 225 | |
| <i>Solved Examples</i> 227 | |
| <i>Exercises</i> 228 | |

PART III
ANALYTICAL TECHNIQUES

| | |
|---|------------|
| 18. Flow Analysis | 233 |
| 18.1 One Dimensional Steady State Flow 233 | |
| 18.1.1 <i>Flow Through Homogeneous Deposit</i> 233 | |
| 18.1.2 <i>Flow Through Layered Systems</i> 234 | |
| 18.2 Two Dimensional Steady State Flow—Laplace Equation 235 | |
| 18.3 Flow Nets 237 | |
| 18.3.1 <i>Confined Flow</i> 243 | |
| 18.3.2 <i>Unconfined Flow</i> 244 | |
| 18.3.3 <i>Determining Pore Water Pressures Under Two Dimensional Flow</i> 247 | |
| 18.4 Radial Flow 247 | |
| <i>Solved Examples</i> 253 | |
| <i>Exercises</i> 256 | |
| 19. Settlement Analysis | 260 |
| 19.1 Stress Distribution 262 | |
| 19.2 Consolidation Settlement 267 | |
| 19.3 Immediate Settlement 269 | |
| 19.3.1 <i>Elastic Mechanism</i> 270 | |
| 19.3.2 <i>Undrained Case—Applicable to Clays</i> 271 | |
| 19.3.3 <i>Drained Case—Applicable to Sands</i> 271 | |
| 19.4 Corrections to Computed Settlements 271 | |
| 19.4.1 <i>Rigidity of the Footing</i> 272 | |
| 19.4.2 <i>Footing Location at Some Depth below Ground Surface</i> 272 | |
| 19.4.3 <i>Width of Footing in Relation to Thickness of Compressible Layer</i> 272 | |
| 19.4.4 <i>Variability in E and μ</i> 274 | |
| 19.5 Determining Total Settlement in Different Soil Types 275 | |
| 19.5.1 <i>Saturated Clay</i> 275 | |
| 19.5.2 <i>Partially Saturated Clay</i> 275 | |
| 19.5.3 <i>Sands</i> 276 | |
| 19.6 Settlement from Field Tests 276 | |
| 19.6.1 <i>Using Penetration Resistance Tests</i> 276 | |
| 19.6.2 <i>Using a Plate Load Test</i> 277 | |
| 19.7 Settlement of Deep Foundations 278 | |
| <i>Solved Examples</i> 280 | |
| <i>Exercises</i> 286 | |
| 20. Bearing Capacity Analysis | 289 |
| 20.1 Failure by Shear 289 | |
| 20.2 Failure Mechanisms in Shallow and Deep Foundations 290 | |
| 20.3 Failure along an Over-simplified Failure Surface 291 | |

| | | |
|------------|---|------------|
| 20.4 | Failure along a Circular Failure Surface | 294 |
| 20.5 | The Bearing Capacity Equation | 294 |
| 20.6 | A More Realistic Failure Surface—Terzaghi's Theory | 296 |
| 20.7 | Generalised Bearing Capacity Equation | 297 |
| | 20.7.1 Shape Factors | 299 |
| | 20.7.2 Depth Factors | 300 |
| | 20.7.3 Inclination Factors | 300 |
| | 20.7.4 Ground Slope Factors | 301 |
| | 20.7.5 Base Tilt Factors | 301 |
| | 20.7.6 Footing Subjected to a Moment | 302 |
| 20.8 | Selecting Appropriate Strength Parameters | 302 |
| | 20.8.1 Strength Parameters Relevant for Determining Bearing Capacity of Footings on Sand | 303 |
| | 20.8.2 Strength Parameters Relevant for Determining Bearing Capacity of Footings on Clay | 303 |
| 20.9 | Determining Bearing Capacity from Field Tests | 304 |
| | 20.9.1 Using <i>N</i> -values | 305 |
| | 20.9.2 Using <i>q_c</i> -values | 306 |
| 20.10 | Bearing Capacity of Deep Foundations | 306 |
| 20.11 | Estimating Axial Pile Capacity—Theoretical Approach | 308 |
| | 20.11.1 Determining Unit End Bearing | 308 |
| | 20.11.2 Determining Unit Skin Friction | 310 |
| | 20.11.3 Determining Axial Pile Load Capacity in Different Soil Profiles | 312 |
| | 20.11.4 Determining Axial Pile Load Capacity for Pipe Piles | 312 |
| 20.12 | Estimating Axial Pile Capacity—Pile Load Test Approach | 313 |
| 20.13 | Estimating Axial Pile Capacity—Driving Resistance Approach | 314 |
| | 20.13.1 Engineering News Formula | 314 |
| | 20.13.2 Newer Formulae | 315 |
| | 20.13.3 Wave Equation Analysis | 315 |
| 20.14 | Negative Skin Friction | 316 |
| 20.15 | Pile Group and Group Capacity | 316 |
| | Solved Examples | 318 |
| | Exercises | 323 |
| 21. | Slope Stability Analysis | 326 |
| | 21.1 Stability of Infinite Slopes | 327 |
| | 21.2 Stability of Finite Slopes | 331 |
| | 21.3 Stability Numbers | 333 |
| | 21.4 Method of Slices | 334 |
| | 21.5 The Swedish Method of Slices | 336 |
| | 21.6 The Critical Failure Surface | 337 |
| | 21.7 Non-circular Failure Surfaces | 338 |
| | 21.7.1 Single Straight Line Failure Surface | 338 |
| | 21.7.2 Two or Three Line Failure Surfaces | 339 |

- 21.8 The Two-wedge Method 340
 - Solved Examples* 342
 - Exercises* 345

22. Earth Pressure Analysis 347

- 22.1 Lateral Earth Pressure 347
- 22.2 States of Failure 349
- 22.3 Rankine's Theory 353
- 22.4 Coulomb's Theory 355
- 22.5 Culmann's Method 358
- 22.6 Factors Affecting Lateral Earth Pressure 359
 - 22.6.1 *Soil Displacement* 359
 - 22.6.2 *Soil Strength and Strength Parameters* 359
 - 22.6.3 *Water Table* 360
 - 22.6.4 *Sloping Soil Surface* 360
 - 22.6.5 *Wall Friction* 360
 - 22.6.6 *Wall Inclination* 360
 - 22.6.7 *Surcharge Load* 361
- 22.7 Earth Pressure Under Drained and Undrained Conditions 361
- 22.8 Tension Crack and Height of Unsupported Cut 361
 - Solved Examples* 362
 - Exercises* 367

PART IV
ENGINEERING DESIGN

23. Sub-Structures: Foundations 371

- 23.1 Loads on Foundations 371
- 23.2 Foundation Types 372
 - 23.2.1 *Shallow Foundations* 374
 - 23.2.2 *Deep Foundations* 375
 - 23.2.3 *Choice of Foundations* 376
- 23.3 Design Criteria 378
 - 23.3.1 *Acceptable Settlement* 380
 - 23.3.2 *Acceptable Safety against Bearing Capacity Failure* 381
- 23.4 The Design Process—Geotechnical and Structural Design 382
- 23.5 Design Water Table Level 382
- 23.6 Design Soil Parameters 383
- 23.7 Geotechnical Design of Shallow Foundations 386
 - 23.7.1 *Foundation Location* 386
 - 23.7.2 *Foundation Shape and Range of Widths* 386
 - 23.7.3 *Settlement and Bearing Capacity Analyses* 387
 - 23.7.4 *Results and Recommendations* 387
 - 23.7.5 *Benefits of Basements* 387

| | | | |
|------------|--|-----|------------|
| 23.8 | Geotechnical Design of Deep Foundations | 388 | |
| 23.8.1 | Identifying a Strong Bearing Layer for Locating the Pile Tip | 388 | |
| 23.8.2 | Selection of Pile Type | 388 | |
| 23.8.3 | Range of Pile Lengths and Diameters | 389 | |
| 23.8.4 | Axial Capacity Analysis | 389 | |
| 23.8.5 | Settlement Analysis | 389 | |
| 23.8.6 | Results and Recommendations | 389 | |
| | <i>Solved Examples</i> | 390 | |
| | <i>Exercises</i> | 392 | |
| 24. | Earth Structures: Dams and Embankments | | 395 |
| 24.1 | Types of Earth Structures | 395 | |
| 24.2 | Types of Earth Dams | 396 | |
| 24.3 | Components of Earth Dams | 398 | |
| 24.3.1 | The Core – its Thickness and Inclination | 399 | |
| 24.3.2 | The Shell | 400 | |
| 24.3.3 | The Cut-off Barrier | 400 | |
| 24.3.4 | Transition Filters | 400 | |
| 24.3.5 | Internal Drains | 401 | |
| 24.3.6 | Protective Layers for Erosion Control | 401 | |
| 24.3.7 | Toe Drainage | 402 | |
| 24.4 | Design Criteria | 402 | |
| 24.5 | Design Process | 405 | |
| 24.6 | Choice of Parameters | 406 | |
| 24.7 | Construction and Quality Control | 407 | |
| 24.8 | Performance Monitoring Using Instruments | 408 | |
| 24.9 | Stage Construction | 409 | |
| 24.10 | Road, Rail and Other Embankments | 410 | |
| | <i>Solved Examples</i> | 411 | |
| | <i>Exercises</i> | 415 | |
| 25. | Earth Retaining Structures | | 416 |
| 25.1 | Types of Earth Retaining Structures | 416 | |
| 25.2 | Design of Retaining Walls | 418 | |
| 25.2.1 | The Design Criteria | 418 | |
| 25.2.2 | The Design Process | 420 | |
| 25.2.3 | Backfill Material | 420 | |
| 25.2.4 | Drainage | 420 | |
| 25.2.5 | Tentative Dimensions | 420 | |
| 25.2.6 | Earth Pressures | 421 | |
| 25.2.7 | Sliding Resistance | 421 | |
| 25.2.8 | Overturning | 421 | |
| 25.2.9 | Pressure Distribution Along Base | 422 | |
| 25.3 | Earth Pressures Behind Different Retaining Structures | | |
| | —Influence of Soil Displacement | 422 | |
| 25.3.1 | Retaining Walls, Cantilever Sheet Piles and Anchored Bulkheads | 422 | |

- 25.3.2 *Braced Walls* 423
- 25.3.3 *Boxed Sections* 424
- 25.3.4 *Driven Piles* 425
- 25.3.5 *Tunnels* 425
- 25.3.6 *Laterally Loaded Piles* 425
- Solved Examples* 426
- Exercises* 430

PART V GEOTECHNICAL CONSTRUCTION

- 26. Earthwork and Earthmoving Equipment** **435**
- 26.1 *Man Versus Machine* 435
 - 26.2 *Excavatability, Bulk-up and Shrinkage* 436
 - 26.3 *Productivity* 437
 - 26.4 *Planning of Earthwork* 438
 - 26.5 *Earthmoving Equipment* 439
 - 26.5.1 *Multi-task Equipment* 440
 - 26.5.2 *Excavators* 441
 - 26.5.3 *Loaders* 443
 - 26.5.4 *Haulers* 444
 - 26.5.5 *Graders* 445
 - 26.5.6 *Roto-tillers, Milling Machines and Soil Mixers* 445
 - 26.5.7 *Sprinkler* 445
 - 26.6 *Compaction Equipment* 446
 - 26.6.1 *Static Steel Drum Rollers* 446
 - 26.6.2 *Vibratory Rollers* 447
 - 26.6.3 *Sheepsfoot Rollers* 448
 - 26.6.4 *Pneumatic Tyre Rollers* 448
 - 26.6.5 *Small Compactors* 449
 - 26.7 *Selection of Equipment* 449
 - Solved Examples* 450
 - Exercises* 452
- 27. Foundation Construction** **454**
- 27.1 *Shallow Foundations* 454
 - 27.2 *Deep Foundations* 454
 - 27.3 *Piling Equipment* 457
 - 27.3.1 *Driving Equipment* 457
 - 27.3.2 *Drilling Equipment* 459
 - 27.4 *Driven Steel Piles* 459
 - 27.5 *Driven Precast Concrete Piles* 460
 - 27.6 *Driven Cast-In-Situ Concrete Piles* 461

- 27.7 Bored Cast-In-Situ Concrete Piles 463
- 27.8 Under-Reamed or Belled Piles 465
- 27.9 Auger Cast-In-Situ Concrete Piles 465
- 27.10 Choosing the Most Appropriate Pile 466
- 27.11 Mini or Micropiles 469
- 27.12 Barrettes 469
- 27.13 Caissons and Wells 469
 - Solved Examples* 469
 - Exercises* 470

28. Excavation, Underground Construction and Tunnels 472

- 28.1 Underground Construction Methodology 472
- 28.2 Vertical and Horizontal Excavation 473
- 28.3 Management of Ground Water 474
- 28.4 Excavate-Support Sequence 475
 - 28.4.1 *Excavation without Side Support* 475
 - 28.4.2 *Excavation with Side Support* 475
- 28.5 Temporary and Permanent Soil Support 477
- 28.6 Excavation 477
- 28.7 Spoil Removal 479
- 28.8 Drainage of Seeping Water 479
- 28.9 Stabilisation of Nearby Foundations 480
- 28.10 Soil Support Methods 480
 - 28.10.1 *Sheet Piles* 481
 - 28.10.2 *Soldiers with Lagging* 481
 - 28.10.3 *Ribs with Lagging* 481
 - 28.10.4 *Struts, Rakers and Tiebacks* 482
 - 28.10.5 *Diaphragm Walls* 483
 - 28.10.6 *Bored Piles* 484
 - 28.10.7 *Segmental Linings* 484
 - 28.10.8 *Nails and Anchors* 485
- 28.11 Dewatering Methods 486
- 28.12 Cofferdams 490
- 28.13 Caissons and Wells 491
- 28.14 Basements 496
- 28.15 Shafts 498
- 28.16 Tunnels 499
- 28.17 Cut-and-Cover Tunnels 500
- 28.18 Bored Tunnels: Shield Tunnels 501
 - 28.18.1 *Types of Shield Tunneling Machines* 502
 - 28.18.2 *Tunnel Lining and Support in Bored Tunneling* 503
 - 28.18.3 *Surface Settlement* 504
- 28.19 Immersed Tube Tunnels 504
- 28.20 Jacked Tunnels: Box Jacking 505

- 28.21 Small Diameter Tunnels: Microtunnels 505
- 28.22 Horizontal Directional Drilling 507
- 28.23 Impact Molding 508
 - Solved Examples* 508
 - Exercises* 512

PART VI GROUND ENGINEERING

- 29. Ground Improvement and Modification 517**
 - 29.1 New Technologies 517
 - 29.2 What is to be Improved 518
 - 29.3 Improving by Excavating and Replacing 518
 - 29.3.1 *Mixing Additives* 520
 - 29.3.2 *Applications* 521
 - 29.4 In-Situ Ground Improvement 522
 - 29.4.1 *Compaction Piles* 522
 - 29.4.2 *Compaction with Dynamic Loads* 523
 - 29.4.3 *Pre-loading Using Sand Drains* 523
 - 29.4.4 *Grouting* 523
 - 29.4.5 *Replacing Existing Soil with Stronger Soil in Bore Holes* 524
 - 29.4.6 *Deep Mixing* 524
 - 29.4.7 *Inserting Reinforcing Elements* 525
 - 29.4.8 *Freezing Soil* 525
 - 29.4.9 *Applications* 525
 - 29.5 Design Methodology 526
 - Solved Examples* 527
 - Exercises* 528
- 30. In-situ Densification of Soils 530**
 - 30.1 Response of Sands and Clays to Externally Applied Stress 530
 - 30.2 Compaction Piles in Sands 531
 - 30.3 Impact Compaction of Sands 531
 - 30.4 Vibratory Compaction in Sands 532
 - 30.4.1 *Vibroflotation* 532
 - 30.4.2 *Vibropiles or Vibro Compaction Piles* 533
 - 30.5 Explosions in Sands 533
 - 30.6 Comparison of in Situ Densification Methods in Sands 535
 - 30.7 Vibroflotation in Clays—Not an In-Situ Densification Process 535
 - 30.8 Accelerated Pre-consolidation of Clays 536
 - 30.8.1 *Types of Drains* 536
 - 30.8.2 *Vertical and Radial Consolidation* 538
 - 30.8.3 *Methodology* 540

| | | |
|---|-----|------------|
| <i>Solved Examples</i> | 541 | |
| <i>Exercises</i> | 543 | |
| 31. Grouting in Soils | | 546 |
| 31.1 Types of Grouts | 546 | |
| 31.2 Desirable Characteristics of Grouts | 546 | |
| 31.3 Grouting Methods | 547 | |
| 31.4 Permeation Grouting | 548 | |
| 31.4.1 Grouting Pressure | 550 | |
| 31.4.2 Grouting Technology | 551 | |
| 31.4.3 Grouting Arrangements | 554 | |
| 31.5 Displacement—Compaction Grouting | 554 | |
| 31.6 Displacement—Soil Fracture Grouting | 556 | |
| 31.7 Jet or Replacement—Displacement Grouting | 557 | |
| 31.7.1 Grouting Technology | 558 | |
| 31.7.2 Grouted Columns | 560 | |
| <i>Solved Examples</i> | 560 | |
| <i>Exercises</i> | 563 | |
| 32. Reinforced Soil | | 565 |
| 32.1 The Mechanism | 565 | |
| 32.2 Reinforcement | 567 | |
| 32.3 Reinforcement—Soil Interaction | 568 | |
| 32.4 Applications | 570 | |
| 32.5 Reinforced Soil Structures with Vertical Faces | 570 | |
| 32.6 Reinforced Soil Embankments | 573 | |
| 32.7 Open Excavation using Soil Nails | 574 | |
| 32.8 Stabilisation of Slopes Using Soil Nails | 575 | |
| 32.9 Reinforcement of Soil Beneath Unpaved Roads | 576 | |
| 32.10 Reinforcement of Soil Beneath Foundations | 576 | |
| <i>Solved Examples</i> | 578 | |
| <i>Exercises</i> | 582 | |
| 33. Geosynthetics | | 585 |
| 33.1 A Man Made Product | 585 | |
| 33.2 Why Geosynthetics? | 585 | |
| 33.3 Types of Geosynthetics | 587 | |
| 33.4 Functions of Geosynthetics | 588 | |
| 33.5 Properties of Geosynthetics | 591 | |
| 33.6 Functional Requirements | 593 | |
| 33.7 Designing with Geosynthetics | 595 | |
| <i>Solved Examples</i> | 598 | |
| <i>Exercises</i> | 600 | |

PART VII
GEOENVIRONMENTAL ENGINEERING

| | |
|---|------------|
| 34. Geoenvironmental Engineering—Genesis | 605 |
| 34.1 Industrialization and Urbanization | <i>605</i> |
| 34.2 Pollution | <i>607</i> |
| 34.3 Control and Remediation | <i>608</i> |
| <i>Solved Examples</i> | <i>610</i> |
| <i>Exercises</i> | <i>611</i> |
| 35. Contamination | 612 |
| 35.1 Subsurface Contamination | <i>612</i> |
| 35.2 Contaminant Transport | <i>613</i> |
| 35.3 Soil—A Geochemical Trap | <i>615</i> |
| 35.4 Effects of Subsurface Contamination | <i>615</i> |
| 35.5 Detection of Polluted Zones | <i>615</i> |
| 35.6 Monitoring Effectiveness of Designed Facilities | <i>616</i> |
| <i>Solved Examples</i> | <i>618</i> |
| <i>Exercises</i> | <i>620</i> |
| 36. Containment of Solid Waste in Landfills | 623 |
| 36.1 Waste Containment | <i>624</i> |
| 36.2 Landfills | <i>625</i> |
| 36.3 Shapes and Sizes of Landfills | <i>626</i> |
| 36.4 Types of Landfills | <i>627</i> |
| 36.5 Impervious Barriers for Liners and Covers | <i>628</i> |
| 36.6 The Liner System | <i>630</i> |
| 36.7 The Cover System | <i>630</i> |
| 36.8 Stability of Landfills | <i>631</i> |
| 36.8.1 <i>Stability Analysis for Sliding of Geomembrane</i> | |
| <i>over Clay in Liner System</i> | <i>632</i> |
| 36.8.2 <i>Stability Analysis for Sliding of Soil over Geomembrane</i> | <i>635</i> |
| 36.9 Landfill Construction & Operation | <i>635</i> |
| 36.10 Closure & Post-closure Care | <i>636</i> |
| 36.11 Sustainable Waste Management | <i>637</i> |
| <i>Solved Examples</i> | <i>637</i> |
| <i>Exercises</i> | <i>640</i> |
| 37. Containment of Slurry Wastes | 643 |
| 37.1 Slurry Transported Wastes | <i>643</i> |
| 37.2 Ponds or Impoundments | <i>643</i> |
| 37.3 Operation | <i>644</i> |
| 37.4 Embankment Construction: Full Height Versus Raising in Stages | <i>646</i> |
| 37.5 Methods of Raising in Stages | <i>646</i> |

| | | |
|--|-----|------------|
| 37.6 Design Aspects | 648 | |
| 37.6.1 Conditions for Analysis of Stability of Slopes | 648 | |
| 37.6.2 Use of Waste as Construction Material | 648 | |
| 37.6.3 Control of Phreatic Line through Internal Drains | 648 | |
| 37.7 Environmental Impact and Control | 649 | |
| Solved Examples | 651 | |
| Exercises | 653 | |
| 38. Vertical Barriers for Containment | | 656 |
| 38.1 Contaminated Sites | 656 | |
| 38.2 Expectations from Vertical Barriers | 657 | |
| 38.3 Suitable Types of Walls | 657 | |
| 38.4 Soil-Bentonite Slurry Trench Walls | 659 | |
| 38.4.1 Construction | 659 | |
| 38.4.2 Material Aspects | 659 | |
| 38.4.3 Design Aspects | 661 | |
| 38.5 Cement-Bentonite Slurry Trench Walls | 661 | |
| Solved Examples | 662 | |
| Exercises | 664 | |
| 39. Geotechnical Reuse of Waste Material | | 665 |
| 39.1 Waste Reduction | 665 | |
| 39.2 Use of Waste in Geotechnical Construction | 665 | |
| 39.3 Waste Characteristics for Soil Replacement | 666 | |
| 39.4 Transportation Considerations | 667 | |
| 39.5 Engineering Properties of Waste | 667 | |
| 39.5.1 Grain Size Distribution | 667 | |
| 39.5.2 Plasticity | 667 | |
| 39.5.3 Specific Gravity of Solids | 667 | |
| 39.5.4 Compaction Characteristics | 667 | |
| 39.5.5 Shear Strength Parameters | 668 | |
| 39.5.6 Permeability | 668 | |
| 39.5.7 Compressibility | 668 | |
| 39.6 Waste Material in Embankments and Fills | 668 | |
| Solved Examples | 670 | |
| Exercises | 671 | |
| PART VIII | | |
| SOIL DYNAMICS | | |
| 40. Soil Behaviour Under Dynamic Loads and Applications | | 675 |
| 40.1 Differences vis-a-vis Behaviour Under Static Loads | 675 | |
| 40.1.1 Dynamic Loads Differ from Static Loads | 675 | |

| | | |
|------------|---|------------|
| 40.1.2 | <i>Acceptable Levels of Strain under Static and Dynamic Loading</i> | 679 |
| 40.1.3 | <i>Additional Soil Properties Relevant for Dynamic Loading</i> | 679 |
| 40.1.4 | <i>Determination of Additional Soil Properties</i> | 680 |
| 40.2 | What is Soil Dynamics | 681 |
| 40.3 | Applications | 683 |
| 40.3.1 | <i>Machine Foundations</i> | 683 |
| 40.3.2 | <i>Geotechnical Earthquake Engineering</i> | 684 |
| 40.3.3 | <i>Construction Vibrations</i> | 684 |
| 40.3.4 | <i>Nondestructive Characterization of Subsurface</i> | 685 |
| 40.3.5 | <i>Offshore Structures</i> | 685 |
| 40.3.6 | <i>Traffic and Rail Induced Vibrations</i> | 686 |
| 40.3.7 | <i>Other Problems</i> | 686 |
| | <i>Solved Examples</i> | 687 |
| | <i>Exercises</i> | 687 |
| 41. | Machine Foundations | 689 |
| 41.1 | Types of Machines | 690 |
| 41.2 | Types of Machine Foundations | 690 |
| 41.3 | Design Criteria for Machine Foundations | 692 |
| 41.4 | Methods of Analysis | 693 |
| 41.4.1 | <i>Elastic Half Space Method</i> | 696 |
| 41.4.2 | <i>Linear Elastic Weightless Spring Method</i> | 697 |
| 41.5 | Evaluation of Soil Parameters | 697 |
| 41.6 | Design Procedure for a Block Foundation (Reciprocating Machine-Cyclic Loading) | 699 |
| 41.7 | Design Procedure for a Block Foundation (Hammer—Impact Loading) | 700 |
| | <i>Solved Examples</i> | 700 |
| | <i>Exercises</i> | 705 |
| 42. | Earthquake Geotechnics | 706 |
| 42.1 | Earthquakes | 706 |
| 42.1.1 | <i>Types of Earthquakes</i> | 706 |
| 42.1.2 | <i>Seismic Waves</i> | 708 |
| 42.1.3 | <i>Location of Earthquakes</i> | 709 |
| 42.1.4 | <i>Strength of an Earthquake</i> | 709 |
| 42.1.5 | <i>Strong Ground Motion</i> | 710 |
| 42.1.6 | <i>Factors Influencing Ground Motion</i> | 711 |
| 42.1.7 | <i>Seismic Hazards</i> | 712 |
| 42.2 | Liquefaction | 712 |
| 42.2.1 | <i>What is Liquefaction?</i> | 712 |
| 42.2.2 | <i>Effect of Liquefaction on Built Environment</i> | 713 |
| 42.2.3 | <i>Evaluation of Liquefaction Susceptibility</i> | 715 |
| 42.2.4 | <i>Liquefaction Hazard Mitigation</i> | 717 |

| | |
|-------------------------------|------------|
| 42.3 Seismic Slope Stability | 718 |
| 42.3.1 Pseudo-static Analysis | 720 |
| 42.3.2 Sliding Block Methods | 721 |
| Solved Examples | 722 |
| Exercises | 724 |
| Further Reading | 726 |
| Index | 728 |