

FUNDAMENTALS OF SOIL MECHANICS FOR SEDIMENTARY AND RESIDUAL SOILS

Laurence D. Wesley



WILEY

JOHN WILEY & SONS, INC.

CONTENTS

PREFACE	xv
ACKNOWLEDGMENTS	xix
1 SOIL FORMATION, COMPOSITION, AND BASIC CONCEPTS	1
1.1 Weathering Processes, Sedimentary and Residual Soils / 1	
1.2 Clay Minerals / 3	
1.3 Influence of Topography on Weathering Processes / 5	
1.4 Factors Governing the Properties of Sedimentary and Residual Soils / 6	
1.5 Remolded, or Destructured, Soils / 10	
References / 11	
2 BASIC DEFINITIONS AND PHASE RELATIONSHIPS	13
2.1 Components of Soil / 13	
2.2 Phase Relationships / 14	
2.3 Examples in Use of Phase Relationships / 17	
2.4 Measurement of Basic Properties / 22	
2.4.1 Bulk Density / 22	
2.4.2 Water Content / 22	
2.4.3 Solid Density and Specific Gravity / 22	
Exercises / 24	

3	BASIC INDEX TESTS, SOIL CLASSIFICATION AND DESCRIPTION	27
3.1	General / 27	
3.1.1	Gravel and Sand / 27	
3.1.2	Clay / 28	
3.1.3	Silt / 28	
3.2	Particle Size and Its Role in Influencing Properties / 28	
3.2.1	Measurement of Particle Size / 29	
3.3	Plasticity and Atterberg Limits / 31	
3.3.1	Determination of Atterberg Limits / 31	
3.4	Liquidity Index of Clay and Relative Density of Sand / 35	
3.5	Sensitivity, Thixotropy, and Activity of Clays / 36	
3.6	Systematic Classification Systems / 37	
3.6.1	Unified Soil Classification System / 38	
3.6.2	Additional Notes Regarding Classification / 40	
3.6.3	Description of In situ (Undisturbed) Characteristics of Soil / 42	
3.7	Classification of Residual Soils / 44	
3.7.1	Parent Rock / 45	
3.7.2	Usefulness of Existing Systems / 45	
3.7.3	Classification of Weathering Profile / 46	
3.7.4	Importance of Mineralogy and Structure / 47	
	References / 48	
4	STRESS AND PORE PRESSURE STATE IN THE GROUND	49
4.1	Vertical Stress in the Ground / 49	
4.2	Pore Pressures above Water Table and Seasonal Variations / 50	
4.2.1	Case A: Coarse-Grained Soils / 52	
4.2.2	Case B: Low-Permeability Clays / 53	
4.2.3	Case C: Medium- to High-Permeability Clays / 53	
4.3	Hill Slopes, Seepage, and Pore Pressures / 55	
4.4	Significance of the Water Table (or Phreatic Surface) / 56	
4.5	Horizontal Stress in Ground / 57	
4.6	Worked Examples / 60	
4.6.1	Worked Example 1 / 60	
4.6.2	Worked Example 2 / 62	
	References / 64	
	Exercises / 64	

5	STRESSES IN THE GROUND FROM APPLIED LOADS	67
5.1	General / 67	
5.2	Elastic Theory Solutions for Stresses Beneath Loaded Areas / 68	
	References / 74	
	Exercises / 75	
6	PRINCIPLE OF EFFECTIVE STRESS	77
6.1	The Basic Principle / 77	
6.2	Applied Stresses, Drained and Undrained Behavior / 80	
6.3	Pore Pressure Changes Under Undrained Conditions / 81	
6.4	Some Practical Implications of the Principle of Effective Stress / 83	
6.4.1	Stress State on Soil Element Below Submerged Surface (Bed of Lake or Seabed) / 83	
6.4.2	Force Resisting Sliding of Concrete Gravity Dam / 84	
6.4.3	Influence of Rainfall on Slope Stability / 85	
6.4.4	Ground Settlement Caused By Lowering Water Table / 86	
	References / 87	
7	PERMEABILITY AND SEEPAGE	89
7.1	General / 89	
7.2	Pressure, "Head," and Total Head / 90	
7.3	Darcy's Law / 92	
7.3.1	Notes on Darcy's Law / 92	
7.3.2	Note on Seepage Velocity / 92	
7.4	Measurement of Permeability / 93	
7.5	General Expression for Seepage in a Soil Mass / 95	
7.6	Steady-State Flow, Laplace Equation, and Flow Nets / 97	
7.6.1	Flow nets—Conventions Used in Their Construction / 99	
7.6.2	Boundary Conditions for Flow Nets / 100	
7.6.3	Methods for Solution of Flow Nets / 101	
7.6.4	Basic Requirements of Flow Net and Rules for Hand Sketching Flow Nets / 102	
7.6.5	Use of Flow Nets for Practical Purposes / 103	

- 7.7 Critical Hydraulic Gradient (and “Quicksand”) / 104
 - 7.7.1 Quicksand / 106
 - 7.7.2 Worked Example / 106
- 7.8 Unconfined Flow Nets and Approximations in Conventional Formulation / 108
- 7.9 Use of Filters in Designed Structures / 109
- 7.10 Vertical Flow Through Single Layers and Multilayers / 111
- 7.11 Note on Groundwater Studies and Groundwater Mechanics / 113
- 7.12 Flow into Excavations, Drains, and Wells / 115
- References / 117
- Exercises / 117

8 COMPRESSIBILITY, CONSOLIDATION, AND SETTLEMENT 12

- 8.1 General Concepts / 121
- 8.2 Estimation of Settlement Using Elasticity Theory / 122
 - 8.2.1 Drained and Undrained Behavior / 123
 - 8.2.2 Limitations of Elasticity Theory / 124
- 8.3 Estimation of Settlement Assuming 1-D Behavior / 124
- 8.4 Immediate (“Elastic”) Settlement and Long-Term (Consolidation) Settlement / 126
 - 8.4.1 Immediate and Consolidation Settlement in Sands / 126
 - 8.4.2 Immediate and Consolidation Settlement in Clays / 126
- 8.5 Consolidation Behavior of Clays (and Silts) / 129
 - 8.5.1 Oedometer Test / 129
 - 8.5.2 Consolidation Characteristics—Magnitude / 130
 - 8.5.3 Consolidation Behavior—Time Rate / 142
- 8.6 Estimation of Settlement from Oedometer Test Results / 154
 - 8.6.1 Settlement of a Building Foundation / 154
 - 8.6.2 Settlement of Fill on Soft Clay / 160
- 8.7 Approximations and Uncertainties in Settlement Estimates Based on Oedometer Tests / 165
 - 8.7.1 Interpretation of Void Ratio—Stress Curves and Sample Disturbance / 165
 - 8.7.2 Assumptions Regarding Pore Pressure State / 167
 - 8.7.3 Lateral Deformation / 168
 - 8.7.4 Submergence of Fill Loads / 168

- 8.7.5 Use of Terzaghi Theory of Consolidation for Nonlinear Soils / 168
- 8.7.6 Influence of Inadequate Data on Actual Soil Conditions / 169
- 8.8 Allowable Settlement / 170
 - 8.8.1 Total (or Absolute) Settlement / 170
 - 8.8.2 Relative Movement between Structure and Surrounding Ground / 170
 - 8.8.3 Differential Settlement of Buildings / 170
- 8.9 Radial Flow and Sand (or “Wick”) Drains / 172
 - 8.9.1 Theory for Design of Sand and Wick Drains / 173
- 8.10 Settlement of Foundations on Sand / 174
 - 8.10.1 Schmertman Method Using Static Cone Penetrometer Results / 175
 - 8.10.2 Burland and Burbidge Method / 176
 - 8.10.3 Worked Example / 178
- References / 181
- Exercises / 182

9 SHEAR STRENGTH OF SOILS

185

- 9.1 Basic Concepts and Principles / 185
 - 9.1.1 General Expression for Shear Strength / 186
 - 9.1.2 Undrained Shear Strength (s_u) / 187
 - 9.1.3 Relationship between Strength in Terms of Effective Stress and Undrained Strength / 187
- 9.2 Measurement of Shear Strength / 190
 - 9.2.1 Direct Shear Test (or Shear Box Test) / 190
 - 9.2.2 Triaxial Test / 191
 - 9.2.3 Mohr’s Circle of Stress / 193
 - 9.2.4 Use of Mohr’s Circle for Plotting Triaxial Test Results / 195
 - 9.2.5 Soil Behavior in Consolidated Undrained and Drained Tests / 197
 - 9.2.6 Area Correction in Triaxial Tests / 199
 - 9.2.7 Failure Criteria in Terms of Principal Stresses / 200
 - 9.2.8 Determination of Angle of Failure Plane / 201
 - 9.2.9 Worked Example / 201
- 9.3 Practical Use of Undrained Strength and Effective Strength Parameters / 203
- 9.4 Shear Strength and Deformation Behavior of Sand / 204

- 9.5 Residual Strength of Clays / 206
 - 9.5.1 Measurement of Residual Strength / 208
- 9.6 Stress Path Concept / 209
- 9.7 Pore Pressure Parameters *A* and *B* / 211
- 9.8 Shear Strength and Deformation Behavior of Clay / 212
 - 9.8.1 Behavior of Fully Remolded Clay / 212
 - 9.8.2 Behavior of Undisturbed Sedimentary Clays / 214
 - 9.8.3 Behavior of Residual Soils / 221
 - 9.8.4 Failure Criterion and Determination of c' and ϕ' from Consolidated Undrained Tests / 224
- 9.9 Typical Values of Effective Strength Parameters for Clays and Silts and Correlations with Other Properties / 225
- 9.10 Undrained Strength of Undisturbed and Remolded Soils / 228
 - 9.10.1 Sedimentary Clays / 228
 - 9.10.2 Remolded Soils / 230
 - 9.10.3 Residual Soils / 231
- 9.11 Measurement of Undrained Shear Strength / 232
 - 9.11.1 Unconfined Compression test / 232
 - 9.11.2 Vane Test / 232
- References / 232
- Exercises / 233

10 SITE INVESTIGATIONS, FIELD TESTING, AND PARAMETER CORRELATIONS

- 10.1 Overview / 235
- 10.2 Drilling / 235
 - 10.2.1 Hand Auguring / 236
 - 10.2.2 Machine Drilling / 236
 - 10.2.3 Continuous Coring with Single-Tube Core Barrel (Also Known as Open Barrel) / 238
 - 10.2.4 Rotary Drilling Using Core Barrels / 238
 - 10.2.5 Wash Drilling / 239
 - 10.2.6 Percussion Boring / 239
- 10.3 Undisturbed Sampling Using Sample Tubes / 239
- 10.4 Block Sampling / 241
- 10.5 Investigation Pits (or Test Pits) / 242
- 10.6 In Situ Testing / 242
 - 10.6.1 Limitations of Drilling and Undisturbed Sampling / 242
 - 10.6.2 Standard Penetration Test (Dynamic Test) / 243
 - 10.6.3 Dutch Static Cone Penetration Test CPT / 246
 - 10.6.4 Shear Vane Test / 249

- 10.7 Correlations between In Situ Test Results and Soil Properties / 250
 - 10.7.1 SPT N Values and CPT Values / 250
 - 10.7.2 Undrained Shear Strength of Clay / 251
 - 10.7.3 Relative Density of Sand / 252
 - 10.7.4 Stiffness Modulus of Sand / 253
- References / 254

11 STABILITY CONCEPTS AND FAILURE MECHANISMS 257

- 11.1 Basic Concepts / 257
- 11.2 Stability of Slopes / 259
- 11.3 Bearing Capacity / 261
- 11.4 Retaining Walls / 262
- 11.5 Further Observations / 264
 - 11.5.1 Safety Factors, Load Factors, and Strength Reduction Factors / 264
 - 11.5.2 Questions of Deformation Versus Stability / 264
- References / 265

12 BEARING CAPACITY AND FOUNDATION DESIGN 267

- 12.1 Bearing Capacity / 267
 - 12.1.1 Bearing Capacity in Terms of Effective Stress / 270
 - 12.1.2 Bearing Capacity in Terms of Total Stress (Undrained Behavior) / 270
 - 12.1.3 Eccentric and Inclined Loads / 270
- 12.2 Shallow Foundations on Clay / 272
 - 12.2.1 Use of Undrained Shear Strength / 272
 - 12.2.2 Application of Factor of Safety / 272
 - 12.2.3 Bearing Capacity Versus Settlement Tolerance in Design of Foundations / 273
 - 12.2.4 Worked Examples / 274
- 12.3 Shallow Foundations on Sand / 276
 - 12.3.1 Use of Bearing Capacity Theory / 276
 - 12.3.2 Empirical Methods for Foundations on Sand / 277
- 12.4 Pile Foundations / 278
 - 12.4.1 Basic Concepts and Pile Types / 278
 - 12.4.2 Pile-Bearing Capacity—Basic Formula and Methods of Estimation / 281
 - 12.4.3 Bearing Capacity of Piles in Clay / 282
 - 12.4.4 Bearing Capacity of Piles in Sand / 285
 - 12.4.5 Pile Group Behavior / 286
 - 12.4.6 Lateral Load Capacity of Piles / 289

References / 303

Exercises / 304

13 EARTH PRESSURE AND RETAINING WALLS

307

13.1 Coulomb Wedge Analysis / 307

13.2 At-Rest Pressure, Active Pressure, Passive Pressure, and Associated Deformations / 312

13.3 Rankine Earth Pressures / 312

13.4 Influence of Wall Friction / 316

13.5 Earth Pressure Coefficients / 316

13.6 Total Stress Analysis / 317

13.7 Maximum Height of Unsupported Vertical Banks or Cuts / 317

13.8 Construction Factors Influencing Earth Pressures on Retaining Walls / 319

13.9 Propped (Strutted) Trenches / 321

13.10 Retaining-Wall Design Example / 322

13.11 Sheet Pile (and Similar) Retaining Walls / 329

13.11.1 FreeStanding and Propped Cantilever Walls / 329

13.12 Reinforced-Earth Walls / 337

13.12.1 Concept and General Behavior / 337

13.12.2 Reinforcement Types / 338

13.12.3 Basic Design Procedures / 339

13.12.4 Other Matters / 349

References / 351

Exercises / 351

14 STABILITY OF SLOPES

355

14.1 Introduction / 355

14.2 Analysis Using Circular Arc Failure Surfaces / 357

14.2.1 Circular Arc Analysis Using Total Stresses / 359

14.2.2 Circular Arc Analysis in Terms of Effective Stresses / 360

14.2.3 Example Calculation Using Bishop Method / 362

14.2.4 Bishop's Method for Submerged Slopes / 363

14.3 Stability Analysis of Infinite Slopes / 366

14.4 Short- and Long-Term Stability of Built Slopes / 368

14.4.1 Excavated Slopes / 369

14.4.2 Embankments on Soft Clays / 371

14.5 Stability Analysis for Earth Dams / 377

- 14.5.1 Estimation of Pore-Water Pressures During or at End of Construction / 377
- 14.5.2 Full-Reservoir Steady-State Seepage Condition / 379
- 14.5.3 Rapid Drawdown Pore Pressures / 380
- 14.6 Influence of Climate and Weather on Stability of Slopes / 381
- 14.7 Stability Analysis Using Noncircular Failure Surfaces / 385
- References / 387
- Exercises / 387

15 SOIL COMPACTION 391

- 15.1 Earthworks and Soil Compaction / 391
- 15.2 Compaction Behavior of Soils / 391
- 15.3 Control of Compaction / 397
 - 15.3.1 Traditional Method of Compaction Control / 397
 - 15.3.2 Alternative Compaction Control Based on Undrained Shear Strength and Air Voids / 397
- 15.4 Difficulties in Compacting Clays / 401
 - 15.4.1 Soils Considerably Wetter Than Optimum Water Content / 401
 - 15.4.2 Soils That Soften During Compaction / 401
- 15.5 Compaction of Granular and Non-Plastic Materials / 402
- References / 404

16 SPECIAL SOIL TYPES 405

- 16.1 General Comments / 405
- 16.2 Partially Saturated Soils / 406
 - 16.2.1 Occurrence / 406
 - 16.2.2 Measurements of Degree of Saturation / 407
 - 16.2.3 Mechanics of Partially Saturated Soils / 408
- 16.3 Expansive or Swelling Clays / 415
 - 16.3.1 Basic Concepts of Expansive Behavior / 415
 - 16.3.2 Estimation of Swelling Pressure and Swell Magnitude / 416
 - 16.3.3 Estimation of Swell Magnitude / 420
- 16.4 Collapsing Soils / 421
- References / 424