

CONTENTS

PREFACE	xvii
ACKNOWLEDGMENTS	xxi
SYMBOLS AND NOTATIONS	xxiii
1 INTRODUCTION	1
1.1 Historical Use of Foundations / 1	
1.2 Kinds of Foundations and their Uses / 1	
1.2.1 Spread Footings and Mats / 1	
1.2.2 Deep Foundations / 4	
1.2.3 Hybrid Foundations / 7	
1.3 Concepts in Design / 7	
1.3.1 Visit the Site / 7	
1.3.2 Obtain Information on Geology at Site / 7	
1.3.3 Obtain Information on Magnitude and Nature of Loads on Foundation / 8	
1.3.4 Obtain Information on Properties of Soil at Site / 8	
1.3.5 Consider Long-Term Effects / 9	
1.3.6 Pay Attention to Analysis / 9	
1.3.7 Provide Recommendations for Tests of Deep Foundations / 9	
1.3.8 Observe the Behavior of the Foundation of a Completed Structure / 10	

Problems / 10

2 ENGINEERING GEOLOGY	11
2.1 Introduction / 11	
2.2 Nature of Soil Affected by Geologic Processes / 12	
2.2.1 Nature of Transported Soil / 12	
2.2.2 Weathering and Residual Soil / 14	
2.2.3 Nature of Soil Affected by Volcanic Processes / 14	
2.2.4 Nature of Glaciated Soil / 15	
2.2.5 Karst Geology / 16	
2.3 Available Data on Regions in the United States / 16	
2.4 U.S. Geological Survey and State Agencies / 17	
2.5 Examples of the Application of Engineering Geology / 18	
2.6 Site Visit / 19	
Problems / 19	
3 FUNDAMENTALS OF SOIL MECHANICS	21
3.1 Introduction / 21	
3.2 Data Needed for the Design of Foundations / 21	
3.2.1 Soil and Rock Classification / 22	
3.2.2 Position of the Water Table / 22	
3.2.3 Shear Strength and Density / 23	
3.2.4 Deformability Characteristics / 23	
3.2.5 Prediction of Changes in Conditions and the Environment / 24	
3.3 Nature of Soil / 24	
3.3.1 Grain-Size Distribution / 24	
3.3.2 Types of Soil and Rock / 26	
3.3.3 Mineralogy of Common Geologic Materials / 26	
3.3.4 Water Content and Void Ratio / 30	
3.3.5 Saturation of Soil / 31	
3.3.6 Weight–Volume Relationships / 31	
3.3.7 Atterberg Limits and the Unified Soils Classification System / 34	
3.4 Concept of Effective Stress / 37	
3.4.1 Laboratory Tests for Consolidation of Soils / 39	
3.4.2 Spring and Piston Model of Consolidation / 42	
3.4.3 Determination of Initial Total Stresses / 45	
3.4.4 Calculation of Total and Effective Stresses / 47	

3.4.5	The Role of Effective Stress in Soil Mechanics /	49
3.5	Analysis of Consolidation and Settlement /	49
3.5.1	Time Rates of Settlement /	49
3.5.2	One-Dimensional Consolidation Testing /	57
3.5.3	The Consolidation Curve /	64
3.5.4	Calculation of Total Settlement /	67
3.5.5	Calculation of Settlement Due to Consolidation /	68
3.5.6	Reconstruction of the Field Consolidation Curve /	69
3.5.7	Effects of Sample Disturbance on Consolidation Properties /	73
3.5.8	Correlation of Consolidation Indices with Index Tests /	78
3.5.9	Comments on Accuracy of Settlement Computations /	80
3.6	Shear Strength of Soils /	81
3.6.1	Introduction /	81
3.6.2	Friction Between Two Surfaces in Contact /	81
3.6.3	Direct Shear Testing /	84
3.6.4	Triaxial Shear Testing /	84
3.6.5	Drained Triaxial Tests on Sand /	89
3.6.6	Triaxial Shear Testing of Saturated Clays /	92
3.6.7	The SHANSEP Method /	119
3.6.8	Other Types of Shear Testing for Soils /	122
3.6.9	Selection of the Appropriate Testing Method /	123
	Problems /	124

4 INVESTIGATION OF SUBSURFACE CONDITIONS 134

4.1	Introduction /	134
4.2	Methods of Advancing Borings /	136
4.2.1	Wash-Boring Technique /	136
4.2.2	Continuous-Flight Auger with Hollow Core /	137
4.3	Methods of Sampling /	139
4.3.1	Introduction /	139
4.3.2	Sampling with Thin-Walled Tubes /	139
4.3.3	Sampling with Thick-Walled Tubes /	142
4.3.4	Sampling Rock /	142
4.4	In Situ Testing of Soil /	144

4.4.1	Cone Penetrometer and Piezometer-Cone Penetrometer /	144
4.4.2	Vane Shear Device /	146
4.4.3	Pressuremeter /	148
4.5	Boring Report /	152
4.6	Subsurface Investigations for Offshore Structures /	153
	Problems /	155

5 PRINCIPAL TYPES OF FOUNDATIONS 158

5.1	Shallow Foundations /	158
5.2	Deep Foundations /	160
5.2.1	Introduction /	160
5.2.2	Driven Piles with Impact Hammer /	160
5.2.3	Drilled Shafts /	162
5.2.4	Augercast Piles /	168
5.2.5	GeoJet Piles /	170
5.2.6	Micropiles /	172
5.3	Caissons /	172
5.4	Hybrid Foundation /	173
	Problems /	175

6 DESIGNING STABLE FOUNDATIONS 176

6.1	Introduction /	176
6.2	Total and Differential Settlement /	177
6.3	Allowable Settlement of Structures /	178
6.3.1	Tolerance of Buildings to Settlement /	178
6.3.2	Exceptional Case of Settlement /	178
6.3.3	Problems in Proving Settlement /	180
6.4	Soil Investigations Appropriate to Design /	180
6.4.1	Planning /	180
6.4.2	Favorable Profiles /	181
6.4.3	Soils with Special Characteristics /	181
6.4.4	Calcareous Soil /	182
6.5	Use of Valid Analytical Methods /	186
6.5.1	Oil Tank in Norway /	187
6.5.2	Transcona Elevator in Canada /	187
6.5.3	Bearing Piles in China /	188
6.6	Foundations at Unstable Slopes /	189
6.6.1	Pendleton Levee /	189
6.6.2	Fort Peck Dam /	190

6.7	Effects of Installation on the Quality of Deep Foundations / 190	
6.7.1	Introduction / 190	
6.8	Effects of Installation of Deep Foundations on Nearby Structures / 192	
6.8.1	Driving Piles / 192	
6.9	Effects of Excavations on Nearby Structures / 193	
6.10	Deleterious Effects of the Environment on Foundations / 194	
6.11	Scour of Soil at Foundations / 194	
	Problems / 194	
7	THEORIES OF BEARING CAPACITY AND SETTLEMENT	196
7.1	Introduction / 196	
7.2	Terzaghi's Equations for Bearing Capacity / 198	
7.3	Revised Equations for Bearing Capacity / 199	
7.4	Extended Formulas for Bearing Capacity by J. Brinch Hansen / 200	
7.4.1	Eccentricity / 203	
7.4.2	Load Inclination Factors / 204	
7.4.3	Base and Ground Inclination / 205	
7.4.4	Shape Factors / 205	
7.4.5	Depth Effect / 206	
7.4.6	Depth Factors / 206	
7.4.7	General Formulas / 208	
7.4.8	Passive Earth Pressure / 208	
7.4.9	Soil Parameters / 209	
7.4.10	Example Computations / 209	
7.5	Equations for Computing Consolidation Settlement of Shallow Foundations on Saturated Clays / 213	
7.5.1	Introduction / 213	
7.5.2	Prediction of Total Settlement Due to Loading of Clay Below the Water Table / 214	
7.5.3	Prediction of Time Rate of Settlement Due to Loading of Clay Below the Water Table / 219	
	Problems / 222	
8	PRINCIPLES FOR THE DESIGN OF FOUNDATIONS	223
8.1	Introduction / 223	
8.2	Standards of Professional Conduct / 223	
8.2.1	Fundamental Principles / 223	

8.2.2	Fundamental Canons /	224
8.3	Design Team /	224
8.4	Codes and Standards /	225
8.5	Details of the Project /	225
8.6	Factor of Safety /	226
8.6.1	Selection of a Global Factor of Safety /	228
8.6.2	Selection of Partial Factors of Safety /	229
8.7	Design Process /	230
8.8	Specifications and Inspection of the Project /	231
8.9	Observation of the Completed Structure /	232
Problems /	233	
Appendix 8.1 /	234	
9	GEOTECHNICAL DESIGN OF SHALLOW FOUNDATIONS	235
9.1	Introduction /	235
9.2	Problems with Subsidence /	235
9.3	Designs to Accommodate Construction /	237
9.3.1	Dewatering During Construction /	237
9.3.2	Dealing with Nearby Structures /	237
9.4	Shallow Foundations on Sand /	238
9.4.1	Introduction /	238
9.4.2	Immediate Settlement of Shallow Foundations on Sand /	239
9.4.3	Bearing Capacity of Footings on Sand /	244
9.4.4	Design of Rafts on Sand /	247
9.5	Shallow Foundations on Clay /	247
9.5.1	Settlement from Consolidation /	247
9.5.2	Immediate Settlement of Shallow Foundations on Clay /	251
9.5.3	Design of Shallow Foundations on Clay /	253
9.5.4	Design of Rafts /	255
9.6	Shallow Foundations Subjected to Vibratory Loading /	255
9.7	Designs in Special Circumstances /	257
9.7.1	Freezing Weather /	257
9.7.2	Design of Shallow Foundations on Collapsible Soil /	260
9.7.3	Design of Shallow Foundations on Expansive Clay /	260
9.7.4	Design of Shallow Foundations on Layered Soil /	262

9.7.5	Analysis of a Response of a Strip Footing by Finite Element Method / 263	
Problems / 265		
10	GEOTECHNICAL DESIGN OF DRIVEN PILES UNDER AXIAL LOADS	270
10.1	Comment on the Nature of the Problem / 270	
10.2	Methods of Computation / 273	
10.2.1	Behavior of Axially Loaded Piles / 273	
10.2.2	Geotechnical Capacity of Axially Loaded Piles / 275	
10.3	Basic Equation for Computing the Ultimate Geotechnical Capacity of a Single Pile / 277	
10.3.1	API Methods / 277	
10.3.2	Revised Lambda Method / 284	
10.3.3	U.S. Army Corps Method / 286	
10.3.4	FHWA Method / 291	
10.4	Analyzing the Load–Settlement Relationship of an Axially Loaded Pile / 297	
10.4.1	Methods of Analysis / 297	
10.4.2	Interpretation of Load-Settlement Curves / 303	
10.5	Investigation of Results Based on the Proposed Computation Method / 306	
10.6	Example Problems / 307	
10.6.1	Skin Friction / 308	
10.7	Analysis of Pile Driving / 312	
10.7.1	Introduction / 312	
10.7.2	Dynamic Formulas / 313	
10.7.3	Reasons for the Problems with Dynamic Formulas / 314	
10.7.4	Dynamic Analysis by the Wave Equation / 315	
10.7.5	Effects of Pile Driving / 317	
10.7.6	Effects of Time After Pile Driving with No Load / 320	
Problems / 321		
11	GEOTECHNICAL DESIGN OF DRILLED SHAFTS UNDER AXIAL LOADING	323
11.1	Introduction / 323	
11.2	Presentation of the FHWA Design Procedure / 323	

11.2.1	Introduction /	323
11.3	Strength and Serviceability Requirements /	324
11.3.1	General Requirements /	324
11.3.2	Stability Analysis /	324
11.3.3	Strength Requirements /	324
11.4	Design Criteria /	325
11.4.1	Applicability and Deviations /	325
11.4.2	Loading Conditions /	325
11.4.3	Allowable Stresses /	325
11.5	General Computations for Axial Capacity of Individual Drilled Shafts /	325
11.6	Design Equations for Axial Capacity in Compression and in Uplift /	326
11.6.1	Description of Soil and Rock for Axial Capacity Computations /	326
11.6.2	Design for Axial Capacity in Cohesive Soils /	326
11.6.3	Design for Axial Capacity in Cohesionless Soils /	334
11.6.4	Design for Axial Capacity in Cohesive Intermediate Geomaterials and Jointed Rock /	345
11.6.5	Design for Axial Capacity in Cohesionless Intermediate Geomaterials /	362
11.6.6	Design for Axial Capacity in Massive Rock /	365
11.6.7	Addition of Side Resistance and End Bearing in Rock /	374
11.6.8	Commentary on Design for Axial Capacity in Karst /	375
11.6.9	Comparison of Results from Theory and Experiment /	376
	Problems /	377
12	FUNDAMENTAL CONCEPTS REGARDING DEEP FOUNDATIONS UNDER LATERAL LOADING	379
12.1	Introduction /	379
12.1.1	Description of the Problem /	379
12.1.2	Occurrence of Piles Under Lateral Loading /	379
12.1.3	Historical Comment /	381
12.2	Derivation of the Differential Equation /	382
12.2.1	Solution of the Reduced Form of the Differential Equation /	386

12.3 Response of Soil to Lateral Loading / 393
12.4 Effect of the Nature of Loading on the Response of Soil / 396
12.5 Method of Analysis for Introductory Solutions for a Single Pile / 397
12.6 Example Solution Using Nondimensional Charts for Analysis of a Single Pile / 401
Problems / 411

13 ANALYSIS OF INDIVIDUAL DEEP FOUNDATIONS UNDER AXIAL LOADING USING t - z MODEL 413

13.1 Short-Term Settlement and Uplift / 413
13.1.1 Settlement and Uplift Movements / 413
13.1.2 Basic Equations / 414
13.1.3 Finite Difference Equations / 417
13.1.4 Load-Transfer Curves / 417
13.1.5 Load-Transfer Curves for Side Resistance in Cohesive Soil / 418
13.1.6 Load-Transfer Curves for End Bearing in Cohesive Soil / 419
13.1.7 Load-Transfer Curves for Side Resistance in Cohesionless Soil / 421
13.1.8 Load-Transfer Curves for End Bearing in Cohesionless Soil / 425
13.1.9 Load-Transfer Curves for Cohesionless Intermediated Geomaterials / 426
13.1.10 Example Problem / 430
13.1.11 Experimental Techniques for Obtaining Load-Transfer Versus Movement Curves / 436
13.2 Design for Vertical Ground Movements Due to Downdrag or Expansive Uplift / 437
13.2.1 Downward Movement Due to Downdrag / 438
13.2.2 Upward Movement Due to Expansive Uplift / 439
Problems / 440

14 ANALYSIS AND DESIGN BY COMPUTER OR PILES SUBJECTED TO LATERAL LOADING 441

14.1 Nature of the Comprehensive Problem / 441
14.2 Differential Equation for a Comprehensive Solution / 442
14.3 Recommendations for p - y Curves for Soil and Rock / 443
14.3.1 Introduction / 443

14.3.2	Recommendations for <i>p-y</i> Curves for Clays /	447
14.3.3	Recommendations for <i>p-y</i> Curves for Sands /	464
14.3.4	Modifications to <i>p-y</i> Curves for Sloping Ground /	473
14.3.5	Modifications for Raked (Battered Piles) /	477
14.3.6	Recommendations for <i>p-y</i> Curves for Rock /	478
14.4	Solution of the Differential Equation by Computer /	484
14.4.1	Introduction /	484
14.4.2	Formulation of the Equation by Finite Differences /	486
14.4.3	Equations for Boundary Conditions for Useful Solutions /	487
14.5	Implementation of Computer Code /	489
14.5.1	Selection of the Length of the Increment /	490
14.5.2	Safe Penetration of Pile with No Axial Load /	491
14.5.3	Buckling of a Pipe Extending Above the Groundline /	492
14.5.4	Steel Pile Supporting a Retaining Wall /	492
14.5.5	Drilled Shaft Supporting an Overhead Structure /	496
	Problems /	499
15	ANALYSIS OF PILE GROUPS	503
15.1	Introduction /	503
15.2	Distribution of Load to Piles in a Group: The Two-Dimensional Problem /	503
15.2.1	Model of the Problem /	504
15.2.2	Detailed Step-by-Step Solution Procedure /	510
15.3	Modification of <i>p-y</i> Curves for Battered Piles /	510
15.4	Example Solution Showing Distribution of a Load to Piles in a Two-Dimensional Group /	511
15.4.1	Solution by Hand Computations /	511
15.5	Efficiency of Piles in Groups Under Lateral Loading /	517
15.5.1	Modifying Lateral Resistance of Closely Spaced Piles /	517
15.5.2	Customary Methods of Adjusting Lateral Resistance for Close Spacing /	518
15.5.3	Adjusting for Close Spacing under Lateral Loading by Modified <i>p-y</i> Curves /	521
15.6	Efficiency of Piles in Groups Under Axial Loading /	527
15.6.1	Introduction /	527

15.6.2	Efficiency of Piles in a Group in Cohesionless Soils /	529
15.6.3	Efficiency of Piles in a Group in Cohesive Soils /	531
15.6.4	Concluding Comments /	534
Problems	/	535
APPENDIX		537
REFERENCES		539
INDEX		559