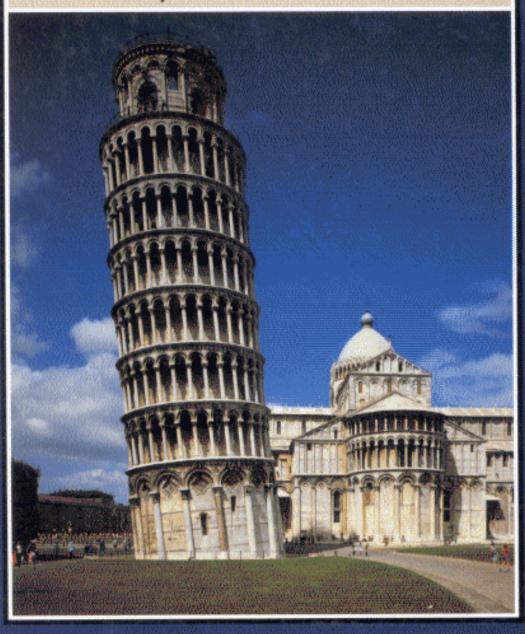
SECOND EDITION

FOUNDATION DESIGN

Principles and Practices



DONALD P. CODUTO

Preface Notatio	on and Units of Measurement	xiii xv
PART	A – General Principles	1
	1. Foundations in Civil Engineering	3
	1.1 The Emergence of Modern Foundation Engineering	4
	1.2 The Foundation Engineer	6
	1.3 Uncertainties	7
•	1.4 Building Codes	9
	1.5 Classification of Foundations	10
	Key to Color Photographs	11
	2. Performance Requirements	14
	2.1 Design Loads	15
	2.2 Strength Requirements	24
	Questions and Practice Problems 2.1–2.4	25
	2.3 Serviceability Requirements	25
	Questions and Practice Problems 2.5–2.8	41
	2.4 Constructibility Requirements	41
	2.5 Economic Requirments	43
	Summary	44
	Comprehensive Questions and Practice Problems 2.9–2.14	45
	3. Soil Mechanics	47
	3.1 Soil Composition	47
	3.2 Soil Classification	55
	Questions and Practice Problems 3.1-3.4	56
	3.3 Groundwater	57
	3.4 Stress	59
	Questions and Practice Problems 3.5-3.6	62

3.5 Compressibility and Settlement	63
Questions and Practice Problems 3.7	80
3.6 Strength	81
Questions and Practice Problems 3.8–3.10	97
Summary	98
Comprehensive Questions and Practice Problems 3.11-3.16	100
4. Site Exploration and Characterization	102
4.1 Site Exploration	103
4.2 Laboratory Testing .	113
Questions and Practice Problems 4.1–4.4	114
4.3 In-Situ Testing	115
Questions and Practice Problems 4.5–4.7	138
4.4 Synthesis of Field and Laboratory Data	138
4.5 Economics	138
Summary	140
Comprehensive Questions and Practice Problems 4.8-4.11	141
PART B - SHALLOW FOUNDATION ANALYSIS AND DESIGN	143
5. Shallow Foundations	145
5.1 Spread Footings	145
5.2 Mats	152
5.3 Bearing Pressure	153
Summary	167
Comprehensive Questions and Practice Problems 5.1-5.9	168
6. Shallow Foundations—Bearing Capacity	170
6.1 Bearing Capacity Failures	171
6.2 Bearing Capacity Analyses in Soil—General Shear Case	173
Questions and Practice Problems 6.1-6.3	186
6.3 Groundwater Effects	187
6.4 Allowable Bearing Capacity	190
6.5 Selection of Soil Strength Parameters	193
Questions and Practice Problems 6.4–6.10	197
6.6 Bearing Capacity Analyses—Local and Punching Shear Cases	198
6.7 Bearing Capacity on Layered Soils	199
6.8 Accuracy of Bearing Capacity Analyses	201
6.9 Bearing Spreadsheet	203
Questions and Practice Problems—Spreadsheet Analyses 6.11–6.13	203
Summary	204
Comprehensive Questions and Practice Problems 6.14–6.17	205
7. Shallow Foundations—Settlement	207
7.1 Design Requirements	208

vii

7.2 Overview of Settlement Analysis Methods	208
7.3 Induced Stresses Beneath Shallow Foundations	210
Questions and Practice Problems 7.1–7.4	217
7.4 Settlement Analyses Based on Laboratory Tests	217
Questions and Practice Problems 7.5–7.8	229
7.5 Settlement Spreadsheet	229
Questions and Practice Problems—Spreadsheet Analyses 7.9–7.13	230
7.6 Settlement Analyses Based on In-Situ Tests	231
Questions and Practice Problems 7.14–7.16	241
7.7 Schmertmann Spreadsheet	242
Questions and Practice Problems—Spreadsheet Analyses 7.17–7.21	242
7.8 Settlement of Foundations of Stratified Soils	243
7.9 Differential Settlement	244
Questions and Practice Problems 7.22–7.23	250
7.10 Rate of Settlement	250
7.11 Accuracy of Settlement Predictions	251
Summary	257
Comprehensive Questions and Practice Problems 7.24–7.27	258
8. Spread Footings—Geotechnical Design	259
8.1 Design for Concentric Downward Loads	259
Questions and Practice Problems 8.1–8.9	271
8.2 Design for Eccentric or Moment Loads	273
8.3 Design for Shear Loads	276
Questions and Practice Problems 8.10–8.12	278
8.4 Design for Wind or Seismic Loads	279
8.5 Lightly-Loaded Footings	281
Questions and Practice Problems 8.13–8.14	285
8.6 Footings On or Near Slopes	285
8.7 Footings on Frozen Soils	288
8.8 Footings on Soils Prone to Scour	293
8.9 Footings on Rock	296
Questions and Practice Problems 8.15–8.20	296
Summary	298
Comprehensive Questions and Practice Problems 8.21–8.24	299
9. Spread Footings—Structural Design	301
9.1 Selection of Materials	303
9.2 Basis for Design Methods	303
9.3 Design Loads	305
9.4 Minimum Cover Requirements and Standard Dimensions	306
9.5 Square Footings	307
Questions and Practice Problems 9.1–9.8	324
9.6 Continuous Footings	326
Questions and Practice Problems 9.9–9.10	330

9.7 Rectangular Footings	331
9.8 Combined Footings	333
9.9 Lightly-Loaded Footings	333
9.10 Connections with the Superstructure	335
Questions and Practice Problems 9.11–9.15	349
Summary	350
Comprehensive Questions and Practice Problems 9.16–9.17	351
10. Mats	352
10.1 Rigid Methods	354
10.2 Nonrigid Methods	356
10.3 Determining the Coefficient of Subgrade Reaction	362
10.4 Structural Design	365
10.5 Settlement	366
10.6 Bearing Capacity	367
Summary	367
Comprehensive Questions and Practice Problems 10.1–10.5	368
PART C – Deep Foundation Analysis and Design	371
11. Deep Foundations	373
11.1 Types of Deep Foundations and Definitions	374
11.2 Load Transfer	376
11.3 Piles	378
Questions and Practice Problems 11.1–11.8	400
11.4 Drilled Shafts	402
Questions and Practice Problems 11.9-11.11	418
11.5 Caissons	418
11.6 Mandrel-Driven Thin-Shells Filled with Concrete	421
11.7 Auger-Cast Piles	423
11.8 Pressure-Injected Footings	425
11.9 Pile-Supported and Pile-Enhanced Mats	429
11.10 Anchors	429
Questions and Practice Problems 11.12–11.14	432
Summary	432
Comprehensive Questions and Practice Problems 11.15–11.17	434
12. Deep Foundations—Structural Integrity	435
12.1 Design Philosophy	436
12.2 Loads and Stresses	438
12.3 Piles	441
Questions and Practice Problems 12.1–12.5	453
12.4 Drilled Shafts	454
Questions and Practice Problems 12.6–12.7	461

	12.5 Caps	461
	12.6 Grade Beams	461
	Summary	462
	Comprehensive Questions and Practice Problems 12.8-12.17	464
13.	Deep Foundations—Axial Load Capacity Based on Static Load Tests	465
	13.1 Load Transfer	466
	Questions and Practice Problems 13.1–13.3	476
	13.2 Conventional Load Tests	476
	13.3 Interpretation of Test Results	480
	Questions and Practice Problems 13.4–13.6	482
	13.4 Mobilization of Soil Resistance	483
	13.5 Instrumented Load Tests	485
	13.6 Osterberg Load Tests	488
	13.7 When and Where to Use Full-Scale Load Tests	490
	Summary	491
	Comprehensive Questions and Practice Problems 13.7–13.9	492
14.	Deep Foundations—Axial Load Capacity	
	Based on Analytic Methods	494
	14.1 Changes in Soil During Construction	495
	Questions and Practice Problems 14.1–14.3	499
	14.2 Toe Bearing	500
	14.3 Side Friction	513
	14.4 Upward Load Capacity	527
	Questions and Practice Problems 14.4–14.11	530
	14.5 Analyses Based on CPT Results	532
	Questions and Practice Problems 14.12	537
	14.6 Group Effects	537
	14.7 Settlement	543
	Questions and Practice Problems 14.13–14.19	553
	Summary	554
	Comprehensive Questions and Practice Problems 14.20–14.27	555
15.	Deep Foundations—Axial Load Capacity	
	Based on Dynamic Methods	559
	15.1 Pile-Driving Formulas	559
	15.2 Wave Equation Analyses	563
	15.3 High-Strain Dynamic Testing	569
	15.4 Low-Strain Dynamic Testing	577
	15.5 Conclusions	577
	Summary	578
	Comprehensive Questions and Practice Problems 15 1-15 9	579

K .	Contents

16.	· · · · · · · · · · · · · · · · · · ·	581
		582
	•	584
16. Deep Foundations—Lateral Load Capacity 16.1 Batter Piles 16.2 Response to Lateral Loads 16.3 Methods of Evaluating Lateral Load Capacity Questions and Practice Problems 16.1–16.5 16.4 p-y Method 16.5 Evans and Duncan's Method Questions and Practice Problems 16.6–16.9 16.6 Group Effects 16.7 Improving Lateral Capacity Summary Comprehensive Questions and Practice Problems 16.10–16.14 17. Deep Foundations—Design 17.1 Design Service Loads and Allowable Definitions 17.2 Subsurface Characterization 17.3 Foundation Type 17.4 Lateral Load Capacity 17.5 Axial Load Capacity 17.5 Axial Load Capacity 17.6 Driveability 17.7 Structural Design 17.8 Special Design Considerations 17.9 Verification and Redesign During Construction 17.10 Integrity Testing Summary Comprehensive Questions and Practice Problems 17.1–17.7 PART D - Special Topics 18. Foundations on Weak and Compressible Soils 18.1 Deep Foundations 18.2 Shallow Foundations 18.3 Floating Foundations 18.4 Soil Improvement Summary Comprehensive Questions and Practice Problems 18.1–18.5 19. Foundations on Expansive Soils 19.1 The Nature, Origin, and Occurrence of Expansive Soils 19.2 Identifying, Testing, and Evaluating Expansive Soils 19.3 Estimating Potential Heave 19.4 Typical Structural Distress Patterns 19.5 Preventive Design and Construction Measures 19.6 Other Sources of Heave Summary	589	
		596
		597
		600
		611
	-	613
		616
	· · · · · · · · · · · · · · · · · · ·	616
	Comprehensive Questions and Practice Problems 16.10–16.14	618
17.		619
		620
		620
	17.3 Foundation Type	620
	17.4 Lateral Load Capacity	622
	17.5 Axial Load Capacity	624
	17.6 Driveability	626
	17.7 Structural Design	626
	17.8 Special Design Considerations	627
	17.9 Verification and Redesign During Construction	630
	17.10 Integrity Testing	631
	Summary	634
	Comprehensive Questions and Practice Problems 17.1–17.7	635
PART D - S	PECIAL TOPICS	637
18.	Foundations on Weak and Compressible Soils	639
	18.1 Deep Foundations	640
	18.2 Shallow Foundations	644
	18.3 Floating Foundations	646
	18.4 Soil Improvement	647
	Summary	652
	Comprehensive Questions and Practice Problems 18.1–18.5	653
19	. Foundations on Expansive Soils	655
		656
	· · · · · · · · · · · · · · · · · · ·	669
		679
		684
		685
		695
		698
	Comprehensive Questions and Practice Problems 19.1–19.9	699

20. Foundations on Collapsible Soils	701
20.1 Origin and Occurrence of Collapsible Soils	701
20.2 Identification, Sampling, and Testing	705
20.3 Wetting Processes	710
20.4 Settlement Computations	712
20.5 Collapse in Deep Compacted Fills	715
20.6 Preventive and Remedial Measures	715
Summary	718
Comprehensive Questions and Practice Problems 20.1–20.10	719
21. Reliability-Based Design	721
21.1 Methods	722
21.2 LRFD for Structural Strength Requirements	726
21.3 LRFD for Geotechnical Strength Requirements	727
21.4 Serviceability Requirements	730
21.5 The Role of Engineering Judgement	731
21.6 Transition of LRFD	731
Summary	732
Comprehensive Questions and Practice Problems 21.1–21.4	733
PART E - EARTH-RETAINING STRUCTURE ANALYSIS AND DESIGN	735
22. Earth-Retaining Structures	737
22.1 Externally Stabilized Systems	738
22.2 Internally Stabilized Systems	745
Summary	748
23. Lateral Earth Pressures	749
23.1 Horizontal Stresses in Soil	749
23.2 Classical Lateral Earth Pressure Theories	757
Questions and Practice Problems 23.1–23.7	766
23.3 Lateral Earth Pressures in Soils with $c \ge 0$ and $\phi \ge 0$	767
23.4 Equivalent Fluid Method	770
23.5 Presumptive Lateral Earth Pressures	773
Questions and Practice Problems 23.8–23.13	774
23.6 Lateral Earth Pressures From Surcharge Loads	777 780
23.7 Groundwater Effects	783
Questions and Practice Problems 23.14–23.16	783 783
23.8 Practical Application	785 785
Summary Comprehensive Questions and Practice Problems 23.17–23.18	786 786
·	78 7
24. Cantilever Retaining Walls	788
24.1 External Stability Ouestions and Practice Problems 24.1–24.3	802
Quesnons and Fractice Froblems 24.1–24.3	002

v		n	
А	ı	,	

24.2 Retwall Spreadsheet	803
Questions and Practice Problems—Spreadsheet Analyses 24.4–24.6	803
24.3 Internal Stability (Structural Design)	804
Questions and Practice Problems 24.7–24.9	816
24.4 Drainage and Waterproofing	817
24.5 Avoidance of Frost Heave Problems	821
Summary	822
Comprehensive Questions and Practice Problems 24.10–24.17	823
25. Sheet Pile Walls	826
25.1 Materials	826
25.2 Construction Methods and Equipment	830
25.3 Cantilever Sheet Pile Walls	830
25.4 Braced or Anchored Sheet Pile Walls	835
Summary	841
Comprehensive Questions and Practice Problems 25.1-25.7	842
appendix A—Unit Conversion Factors	844
Appendix B—Computer Software	848
eferences	849
ndex	875