ESSENTIALS OF SOIL MECHANICS AND FOUNDATIONS

Basic Geotechnics

FIFTH EDITION

DAVID F. McCARTHY

Library of Congress Cataloging-in-Publication Data
McCarthy, David F.
Essentials of soil mechanics and foundations : basic geotechnics /
David F. McCarthy. — 5th ed.
p. cm.
Includes bibliographical references and index.
ISBN 0-13-506932-7
1. Soil mechanics. 2. Foundations. I. Title.
TA710.M29 1998
624.1'5—dc21 97-14326
CIP

Cover photo: © Westlight
Editor: Ed Francis
Production Editor: Linda Hillis Bayma
Production Coordination: WordCrafters Editorial Services, Inc.
Design Coordinator: Julia Zonneveld Van Hook
Cover Designer: Rod Harris
Production Manager: Deidra M. Schwartz
Marketing Manager: Danny Hoyt
Illustrations: Academy Artworks, Inc.

This book was set in Times Roman by BookMasters, Inc. and was printed by Quebecor Printing/Book Press. The cover was printed by Phoenix Color Corp.

© 1998, 1993, 1988, 1982, 1977 by Prentice-Hall, Inc.
Simon & Schuster/A Viacom Company
Upper Saddle River, New Jersey 07458

All rights reserved. No part of this book may be reproduced, in any form or by any means, without permission in writing from the publisher.

ISBN 0-13-506932-7

Printed in the United States of America

10 9 8 7 6 5

Prentice-Hall International (UK) Limited, *London*
Prentice-Hall of Australia Pty. Limited, *Sydney*
Prentice-Hall Canada Inc., *Toronto*
Prentice-Hall Hispanoamericana, S.A., *Mexico*
Prentice-Hall of India Private Limited, *New Delhi*
Prentice-Hall of Japan, Inc., *Tokyo*
Simon & Schuster Asia Pte. Ltd., *Singapore*
Editora Prentice-Hall Do Brasil, Ltda., *Rio de Janeiro*

Contents

Preface xiii

PART I BACKGROUND AND BASICS 1

Chapter 1 The Soil and Rock of Planet Earth: Geologic Overview 3

1.1 Rock: The Source of Soils 4
1.2 Soil Categories: Residual, Transported 8
Residual Soils 8
Transported Soils 9
1.3 Plate Tectonics 23
1.4 Earthquakes 31
1.5 Effect on Design and Construction 54
Problems 55

Chapter 2 Soil Composition: Terminology and Definitions 57

2.1 Soil Composition: Analytical Representation 57
Weight-Volume, Mass-Volume Relationship 58
2.2 Basic Terms Relating to Soil Composition and Condition 60
2.3 Submerged Soil 68
Problems 70

Chapter 3 Soil Types and Soil Structure 72

3.1 Major Soil Types 72
3.2 Particle Shapes and Sizes 74
3.3 Clay and Water 76
3.4 Soil Structure 80
3.5 Some Special Soil Categories 84
Collapsible Soils 85
Liquefaction 86

Expansive Clays 86
Dispersive Clays 88
Laterites 90
Problems 91

Chapter 4 Index Properties and Classification Tests, and Soil Classification Systems 92

4.1 Index Properties 93
4.2 Classification Tests 94
Particle Size Distribution (Mechanical Analysis) 94
In-Place Density, In-Place Unit Weight 99
Relative Density 100
Water Content 103
Consistency of Clays 103
Consistency in the Remolded State and Plasticity 105
Presence of Clay Minerals 107
Testing for Dispersive Clays 108
Other Properties 110
4.3 Classification Systems 110
4.4 ASTM and AASHTO Test Procedure Designations 120
Problems 122

Chapter 5 Site Investigations: Purpose and Methods, Information and Procedures Available 124

5.1 Maps and Aerial Photographs as Sources of Information 125
5.2 Borings and Test Pits 128
Boring Methods 129
Soil Sampling 134
Sample Spacing in Soil Borings 140
Boring Spacing and Depth 141
Rock Core Drilling 143
Test Pits 145
5.3 Soil Resistance Testing in Boreholes 147
Penetration Resistance and the Standard Penetration Test 147
Penetration Resistance and Cone Penetrometers 149
Dilatometer and Pressuremeter Tests 150
5.4 Presentation of Boring Information 154
Boring Logs 154
Recognizing Limitations of Boring Data 157
5.5 In-Place Testing 158
In-Place Shear Tests—Vane Shear 159
Slope Inclination Indicator 160
Pore Pressure and Piezometer 160
5.6 Groundwater, Soil Water, and Soil Gas Sampling 161
5.7 Geophysical Methods 171
Seismic Refraction 171
Electrical Resistivity 176
Correlation between Resistivity and Earth Materials 182
Thickness of Layers 183
Ground-Penetrating Radar 183
Problems 183

PART II ENGINEERING PROPERTIES AND BEHAVIOR OF SOIL DEPOSITS 187

Chapter 6 Movement of Water through Soil: Basic Hydrogeology, Subsurface Flow, Permeability, Capillarity 189

6.1 Basic Hydrogeology 190
Subsurface Flow, Basic Facts 190
6.2 Permeability (Hydraulic Conductivity) 194
Factors Affecting Flow 197
Darcy's Law for Flow 199
Laminar and Turbulent Flow 201
Effect of Soil Type 201
Empirical Relationships 202
Permeability Tests 203
Laboratory Permeability Tests 204
Field Permeability Tests 207
6.3 Capillarity 208
Water in Capillary Tubes 209
Capillary Rise in Soil 212
Time Rate of Capillary Rise 215
Suspended Capillaries 215
Elimination of Capillary Water in Soil 215
Effects of Surface Tension 216
Problems 216

Chapter 7 Movement of Water through Soil: Practical Effects: Seepage, Drainage, Frost Heave, Contamination 220

7.1 Flow Nets and Seepage 220
Flow of Subsurface Water 220
The Need for Flow Nets and Flow Net Theory 221
Boundaries for the Flow Net 226
Flow Nets for Nonisotropic Soils 230
Uplift Forces 231
Other Seepage Forces 231
Practical Considerations 234
Quicksand 234
7.2 Drainage 234
Conditions Requiring Drainage 236
Dewatering Shallow Excavations 236
Dewatering Intermediate Depths 236
Deep Drainage 241
Consolidation Drainage 241
Summary: Techniques for Subsurface Drainage 241
Drainage after Construction 242
Foundation Drains 242
Blanket Drains 243
Interceptor Drains 243
Flow through a Structure 245
Filter Design 245

Drainage, Filtration, and Separation with Geosynthetics (Synthetic Fabrics) 247
Land Drainage 253
Effects of Drainage 257
Soil Percolation Rate 257
7.3 Frost Heave in Soils 258
Permafrost 263
7.4 Soil and Groundwater Contamination 265
Soil Gas 271
Use of Geosynthetics to Prevent Ground Contamination 276
Problems 278

Chapter 8 Combined Stresses in Soil Masses: Stress at a Point and Mohr's Circle 281
8.1 Stress at a Point: Analytical Development 281
8.2 Mohr's Circle 285
Problems 292

Chapter 9 Subsurface Stresses 295
9.1 Stresses Caused by the Soil Mass 295
Vertical Stresses 295
Effect of Groundwater Table 296
Horizontal (Lateral) Stresses 297
9.2 Stress within the Soil Mass Resulting from Vertical Surface Loading 300
Uniform Homogeneous Soils 300
Boussinesq Stress Distribution 300
Westergaard Stress Distribution 301
Computational Aids 302
Application for Foundation Loading 303
Sixty-Degree Approximation 306
Layered Soils Having Different Properties 307
Effect of Foundation Installation Below Finished Grade 309
Effect of Changing the Surface Grade 310
Problems 312

Chapter 10 Settlement: Soil Compression, Volume Distortion, Consolidation 316
10.1 Basic Considerations 316
10.2 Settlement of Foundations on Sand 320
Schmertmann Method 320
Approximations for Estimating Settlement of Foundation on Sand 325
10.3 Settlement of Foundations on Clay Soils 327
Volume Distortion Settlement for Clays 327
Primary Compression Settlement for Clays 331
Secondary Compression of Clay Soil 343
10.4 Settlement Resulting from Earth Fill 345
10.5 Consolidation 346
10.6 Surcharging 352
Acceleration of the Soil Improvement Process 353
Horizontal Drainage 354

Chapter 11 Shear Strength Theory 363

11.1 Laboratory Tests 363
Direct Shear Test 364
Triaxial Compression Test 367
Unconfined Compression Test 369
Vane Shear Test 370
11.2 Shear Test Results Plotted on Mohr's Circle Coordinates 371
Strength or Failure Envelope 371
11.3 Shearing Strength 374
Shearing Strength of Cohesionless Soil 374
Approximating Values of φ from Boring Data 380
Shearing Strength of Clay Soils 380
Shear Strength of Clay Related to Triaxial Testing 386
Approximating Values of Cohesion from Boring Data 392
Shear Strength of Mixed Soils 393
Position of Failure Plane Related to Angle φ 393
11.4 Stress Paths 394
Stress Path for Tests in Consolidated-Drained Conditions 396
Stress Path for Tests in Consolidated-Undrained Conditions 397
Applications 399
Problems 400

PART III APPLICATION OF SOIL MECHANICS THEORIES 405

Chapter 12 Foundations: Introductory Concepts 407

12.1 General Types of Foundations—Foundation Categories 407
Spread Footings 408
Mat (or Raft) Foundations 409
Pile and Pier Foundations 409
Caissons 410
Floating Foundations 410
12.2 Pile Foundation Types and Installation Procedures 411
Pile Drivers for Driven Piles 411
Pile Types and Materials 416
Representative Pile Load Capacities and Available Lengths 421
Methods to Aid Pile Installation 421
Other Installation Considerations 423
12.3 Relating Soil Conditions and Foundation Types 424
Problems 427

Chapter 13 Foundations: Design Considerations and Methods 430

SHALLOW FOUNDATIONS—DESIGN AND INSTALLATION CRITERIA 431
13.1 Basic Concepts—Long (Strip) Footings 431
13.2 Bearing Capacity Equations 433
Additional Considerations, Bearing Capacity Equation 439
Application for Design—The Extended Bearing Capacity Equation 442
Footings on Slopes 450

13.3 Footing Design Data from Penetration Resistance in Boreholes 452
Standard Penetration Test and Sand 452
The Standard Penetration Test and Cohesive Soil 457
Static Cone Penetrometer and Sand 457
Static Cone Penetrometer and Cohesive Soil 459
The Pressuremeter and Foundation Design 460
13.4 Seismic Bearing Capacity of Spread Footing Foundations 465
13.5 Presumptive Bearing Pressures 469
13.6 Foundation Walls 470
DEEP FOUNDATIONS—CAPACITY AND INSTALLATION CRITERIA 473
13.7 Pile and Pier Foundations 473
Statical Analysis 473
Statical Method—Driven Piles in Sand 474
Statical Method—Driven Piles in Clay 480
Factor of Safety 486
Negative Skin Friction 486
Other Design Considerations 487
Statical Method—Bored Piers and Piles 487
Arrangement for Piles in a Group 490
Group Capacity 491
Pile Group Settlement 494
Pile Load Tests 495
Pile-Driving Formulas 497
13.8 Supervision of Foundation Construction 503
Problems 504

Chapter 14 Earth Moving, Compaction, and Stabilization 511
14.1 Field Procedures—General Considerations, Methods, and Techniques 512
Alternative Methods of Transporting Earth Fill 518
14.2 Field Equipment—Surface Zone Compaction 519
Surface Compaction Equipment 519
14.3 Deep-Ground Improvement Techniques 526
Vibrocompaction 527
Vibroreplacement 530
Dynamic Deep Compaction 531
Compacting by Explosives 533
14.4 Soil Stabilization 534
Use of Natural and Chemical Additives 534
Use of Geosynthetics for Stabilization and Reinforcement 536
14.5 Methods for Establishing Required Soil Density 539
14.6 Field Control and Field Density Tests 545
Sand-Cone Method 547
Balloon Method 547
Nuclear Moisture-Density Method 548
Problems 550

Chapter 15 Stability of Unsupported Slopes 553

15.1 Types of Slope Movements 554
15.2 Isotropic Soils and Uniform Slopes of Infinite Extent 557
Cohesionless Soil 557
Soils Possessing Cohesion 560
15.3 Slopes of Finite Extent—Soils Possessing Cohesion 562
Types of Rotational Slides in Isotropic Soils 562
Stability Analysis—General Concepts 562
Strength Properties for Analysis—Clay and Mixed Soils 565
Basic Methods for Stability Analysis 566
Methods of Slices 568
Noncircular Slip Surfaces 578
Effect of Tension Cracks 582
Sliding Block Analysis 582
15.4 Computational Aids—Slope Stability Charts 584
Taylor Charts 584
Bishop-Morganstern, Barnes Charts 589
Barnes Charts/Tables for Excavated Slopes 598
Spencer Charts 601
Morganstern Charts for Rapid Drawdown 603
15.5 Variation in Shear Stress and Factor of Safety 606
15.6 Improving Stability of Slopes 607
Problems 609

Chapter 16 Lateral Pressures and Retaining Structures 613

16.1 Lateral Earth Pressure and Retaining Walls 615
At-Rest Pressure 615
Effect of Submergence 617
Active and Passive Lateral Pressures—Basic Considerations 618
16.2 Earth Pressures against Retaining Walls 622
Classical Theories 622
16.3 Lateral Pressures Related to Wall Movement 626
Practical Considerations 626
Cohesionless Soil Backfill 628
Goh Analysis 629
Cohesive Soil Backfill 629
Recommended Design Criteria for Gravity Walls 632
Effects of Groundwater Freezing 632
16.4 Retaining Wall Design Requirements 635
Common Types of Walls, Construction Considerations 635
Basic Design Considerations 637
Surface Loads near Wall 645
Terzaghi-Pack Charts for Backfill Pressures 646
Earthquake Forces and Gravity Retaining Walls 648
16.5 Alternate Types of Retaining Structures 651
Gabion Retaining Walls 651
Reinforced Earth 652
16.6 Excavation Bracing 654

Types and Installation of Excavation Bracing 654
Lateral Pressures for Designing Bracing 659
16.7 Anchored Bulkheads 663
16.8 Water-Retaining Structures: Dams 667
Earth Fill Dams 670
Rockfill Dams 674
Concrete and Masonry Dams 675
Problems 682

Appendix A Application of LaPlace Equation to Flow Nets 687

Appendix B Laboratory Procedure to Determine Coefficient of Consolidation 690

Appendix C Mathematical Development of the Bishop Equation for Slope Stability 694

***Glossary* 697**

Bibliography 704

Answers to Selected Problems 718

Index 723