FOUNDATION ENGINEERING HANDBOOK

Second Edition

Edited by

HSAI-YANG FANG Ph.D.

Professor of Civil Engineering and Director, Geotechnical Engineering Division, Fritz Engineering Laboratory, Lehigh University

Copyright © 1991 by Van Nostrand Reinhold Library of Congress Catalog Card Number: 89-70490 ISBN: 0-442-22487-7

All rights reserved. No part of this work covered by the copyright hereon may be reproduced or used in any form or by any means—graphic, electronic, or mechanical, including photocopying, recording, taping, or information storage and retrieval systems—without written permission of the publisher.

Printed in the United States of America

Van Nostrand Reinhold 115 Fifth Avenue New York, New York 10003

Chapman and Hall 2-6 Boundary Row London, SE1 8HN, England

Thomas Nelson Australia 102 Dodds Street South Melbourne 3205 Victoria, Australia

Nelson Canada 1120 Birchmount Road Scarborough, Ontario M1K 5G4, Canada

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Foundation engineering handbook / edited by Hsai-Yang Fang. — 2nd ed.

p. cm. Includes bibliographical references. ISBN 0-442-22487-7

 Foundations—Handbooks, manuals, etc.
 Soil mechanics— Handbooks, manuals, etc.
 Fang, Hsai-Yang.

TA775.F675 1990 624.1'5—dc20

89-70490

CIP

То

G. M. Cornfield H. Bolton Seed Aleksandar S. Vesić Hans F. Winterkorn

for their pioneering work

CONTENTS

Preface xv List of Contributors xvii

1 SUBSURFACE EXPLORATIONS AND SAMPLING John Lowe III and Philip F. Zaccheo

1	.1	Introduction	

- 1.2 Planning an Exploration Program 1
- 1.3 Reconnaissance Investigations 2
- 1.4 Explorations for Preliminary Design 6
- 1.5 Explorations for Detailed Design 8
- 1.6 Geophysical Explorations 8
- 1.7 Soundings and Probings 12
- 1.8 Boring Methods 14
- 1.9 Excavation Methods for Exploration 29
- 1.10 Groundwater Investigations 30
- 1.11 Test Grouting 37
- 1.12 Representative but Disturbed Samples 37
- 1.13 Undisturbed Samples 43
- 1.14 In Situ Soil Testing in Boreholes 51
- 1.15 Rock Coring 53
- 1.16 Miscellaneous Exploratory Techniques 59
- 1.17 Preservation, Shipment, and Storage of Samples 61
- 1.18 Logs of Subsurface Explorations 64
- 1.19 Contracting and Supervising Exploratory Programs 68
- 1.20 Subsurface Explorations Reports 69

2 SAMPLING AND PREPARATION OF MARINE SEDIMENTS Ronald C. Chaney

- 2.1 Introduction 72
- 2.2 Offshore/Nearshore Soil Samples 75
- 2.3 Handling, Wrapping, and Labeling 80
- 2.4 Storage 82
- 2.5 Preparation of Soil Samples 83
- 2.6 Laboratory versus In-Situ Properties 84

3 SOIL TECHNOLOGY AND ENGINEERING PROPERTIES OF SOILS Hans F. Winterkorn and Hsai-Yang Fang

- 3.1 Definition of Soil 88
- 3.2 Description and Identification of Soils 88
- 3.3 Rocks and Their Classification 92
- 3.4 Physical Properties Employed in Engineering Classifications of Soil Materials 99
- 3.5 Soil Classification Systems 102
- 3.6 Soil Types by Deposition or Other Special Features 109

viii	Contents	
3.13	Effect of Temperature on Engineering Troportion of Cons	129
	EARING CAPACITY OF SHALLOW FOUNDATIONS Fah Chen and William O. McCarron Introduction 144	

··	miliodador.o.
4.2	Methods of Analysis

- Soil Governing Parameters 145 4.3
- Bearing Capacity by the Upper-Bound Method 145 4.4
- Bearing Capacity by the Lower-Bound Method 150 4.5
- Footing Depth and Shape and Inclined and Eccentric Loads 152 4.6
- 4.7 Footing Shape, Depth, and Inclination Effects 154
- Nonhomogeneous Foundations and Anisotropic Strength 154 4.8
- Influence of Groundwater Table 156 4.9
- 4.10 Comments on Bearing Capacity Solutions 157
- 4.11 Sliding Stability of Gravity Structures 157
- Choice of Safety Factor 158 4.12
- Example Problems 159 4.13
- Numerical Evaluation of Bearing Capacity 161 4.14

5 STRESS DISTRIBUTION AND SETTLEMENT OF SHALLOW FOUNDATIONS Robert D. Holtz

- Introduction 166 5.1
- 5.2 Settlement of Shallow Foundations 167
- Applicability of the Theory of Elasticity to Calculation of Stresses and Displacements in Earth Masses 169 5.3
- Calculation of Initial Distortion Settlements 170 5.4
- 5.5 Distortion Settlement of Granular Soils 177
- 5.6 Calculation of Stress Distributions 185
- 5.7 Consolidation Settlements 192
- 5.8 Secondary Compression Settlements 209
- Tolerable Criteria 212 5.9
- Foundation Treatment Alternates 216 5 10

6 EARTH PRESSURES

G. W. Clough and J. M. Duncan

- At-Rest Lateral Pressures 224
- 6.2 Active and Passive Lateral Earth Pressures 224
- Soil-Structure Interaction for Unmoving Walls 228 6.3
- 6.4 Earth Pressures due to Surface Loads 229
- Earth Pressures due to Compaction 230 6.5
- Relation Between Earth Pressures and Wall Movements 232
- Earth Pressures for Design 234

7 DEWATERING AND GROUNDWATER CONTROL

J. Patrick Powers

- Impact of Groundwater on Construction 236
- Design of Structures Below the Water Table 236 7.2

- 7.3 Methods of Groundwater Control 236
- 7.4 Field Pumping Tests 239
- 7.5 Design of Predrainage Systems 241
- 7.6 Managing Groundwater Control 244
- 7.7 Disputes over Groundwater Control 245
- 7.8 Cost of Groundwater Control 245
- 7.9 Undesirable Side-Effects of Dewatering 246
- 7.10 Permanent Dewatering Systems 246
- 7.11 Ground Freezing 247

8 COMPACTED FILL Jack W. Hilf

- 8.1 Introduction 249
- 8.2 Soil Compaction 249
- 8.3 Compaction Equipment 273
- 8.4 Control of Compaction 294
- 8.5 Miscellaneous Problems in Compaction 309

9 SOIL STABILIZATION AND GROUTING Hans F. Winterkorn and Sibel Pamukcu

- 9.1 Introduction 317
- 9.2 Principle of Soil Stabilization 317
- 9.3 Methods of Soil Stabilization 318
- 9.4 Stabilization of Soils with Granular Skeleton 319
- 9.5 Chemical Stabilization 324
- 9.6 Cement Stabilization 328
- 9.7 Lime Stabilization 337
- 9.8 Ash and Slag Stabilization 344
- 9.9 Bituminous Stabilization 346
- 9.10 Thermal and Electrokinetic Stabilization 349
- 9.11 Construction 351
- 9.12 Grouting Principles 353
- 9.13 Grouting Techniques 354
- 9.14 Planning of the Grouting Project 358
- 9.15 The Grouting Process 363
- 9.16 Control of Grouts and Grouting Operations 368
- 9.17 Examples of Applications of Grouting 369

10 STABILITY OF EARTH SLOPES Hsai-Yang Fang and George K. Mikroudis

- 10.1 Introduction 379
- 10.2 Factors Affecting Slope Stability Analysis 379
- 10.3 Factor of Safety 380
- 10.4 Slope Stability Analysis Procedure: Limit Equilibrium Methods 381
- 10.5 Slope Stability Analysis Procedure: Limit Analysis Methods 395
- 10.6 Methods Considering Seismic Effects 399
- 10.7 Slope Stability in Soils Presenting Special Problems 404
- 10.8 Computer-Aided and Expert Systems for Slope Stability Analysis 406

11 LANDSLIDES Bengt B. Broms and Kai S. Wong

- 11.1 Introduction 410
- 11.2 Causes of Landslides 411
- 11.3 Consequences of Landslides 415

x Contents

- 11.4 Slope Movements Preceding Landslides 415
- 11.5 Classification 417
- 11.6 Investigations for Landslides 425
- 11.7 Analysis of Landslides 427
- 11.8 Instrumentation 432
- 11.9 Methods of Correcting Landslides 435

12 RETAINING STRUCTURES AND EXCAVATIONS Thomas D. Dismuke

- 12.1 Introduction 447
- 12.2 Restrained Retaining Structures 447
- 12.3 Gravity Structures 478
- 12.4 Cantilever Retaining Walls 503
- 12.5 Special Structures 504
- 12.6 Sheet Piling and H-Piles 507

13 PILE FOUNDATIONS

Bengt H. Fellenius

- 13.1 Introduction and Background 511
- 13.2 Aspects for General Consideration 512
- 13.3 The Shaft Resistance 513
- 13.4 Toe Resistance 516
- 13.5 Capacity Determined from In-Situ Field Testing 517
- 13.6 Installation Considerations 517
- 13.7 Residual Compression 517
- 13.8 The Neutral Plane 518
- 13.9 Capacity of a Pile Group 520
- 13.10 Summary of Design Procedure for Capacity and Strength 520
- 13.11 Settlement of Pile Foundations 521
- 13.12 Static Testing of Piles 524
- 13.13 Pile Dynamics 529
- 13.14 Horizontally Loaded Piles 531
- 13.15 Seismic Design of Lateral Pile Behavior 533
- 13.16 Design Example 533

14 DRILLED SHAFT FOUNDATIONS Fred H. Kulhawy

- 14.1 Introduction 53714.2 General Behavior Patterns 537
- 14.3 Axial Compression Capacity 538
- 14.4 Drained Axial Compression Capacity 539
- 14.5 Undrained Axial Compression Capacity 545
- 14.6 Axial Uplift Capacity 548
- 14.7 Belled Shafts 549
- 14.8 Compression and Uplift Displacements 549
- 14.9 Other Site and Loading Conditions 550
- 14.10 Closing Comments on Design 551
- 14.11 Pertinent Standards and Specifications 551

15 FOUNDATION VIBRATIONS George Gazetas

- 15.1 Introduction 553
- 15.2 Machine Foundation Vibrations: Statement of the Problem 553

- 15.3 Soil Moduli and Damping—Field and Laboratory Testing Procedures 555
- 15.4 Harmonic Vibration of Block Foundations: Definition and Use of Impedances (Dynamic "Springs" and "Dashpots") 564
- 15.5 Computing Dynamic Impedances: Tables and Charts for Dynamic "Springs" and "Dashpots" 569

16 EARTHQUAKE EFFECTS ON SOIL-FOUNDATION SYSTEMS

Part I: Prior to 1975

- H. Bolton Seed
- 16.1 Introduction 594
- 16.2 Influence of Soil Conditions on Shaking Intensity and Associated Structural Damage 597
- 16.3 Influence of Soil Conditions on Ground Settlement 614
- 16.4 Influence of Soil Conditions on Liquefaction Potential 614
- 16.5 Influence of Soil Conditions on Landslides 619

Part II: From 1975 to 1989

Ronald C. Chanev and Sibel Pamukcu

- 16.6 Introduction 623
- 16.7 Influence of Soil Conditions on Ground Settlement 624
- 16.8 Influence of Soil Conditions on Liquefaction Potential 628
- 16.9 Influence of Soil Conditions on Landslides 635
- 16.10 Behavior of Clays and Silts During Cyclic Loading 653
- 16.11 Remedy of Earthquake Damage on Soil-Foundation Systems 661

17 FOUNDATION PROBLEMS IN EARTHQUAKE REGIONS Leonardo Zeevaert

- 17.1 Introduction 673
- 17.2 Irrotational Seismic Waves 673
- 17.3 Shear Seismic Waves 675
- 17.4 Case History 677

18 OFFSHORE STRUCTURE FOUNDATIONS Ronald C. Chaney and Kenneth R. Demars

- 18.1 Introduction 679
- 18.2 Loading on Foundations 684
- 18.3 Pile Structures in Marine Environment 684
- 18.4 Gravity Platforms 702
- 18.5 Anchor Uplift Capacity 712
- 18.6 Pipelines 716
- 18.7 Jack-Up Platforms 723
- 18.8 Hydraulic Filled Islands 727

19 FOUNDATIONS IN COLD REGIONS Arvind Phukan

- 19.1 Introduction 735
- 19.2 Frozen Soils: Phases and Temperature Profile 735
- 19.3 Design Approach 737
- 19.4 Design Considerations 738
- 19.5 Shallow Foundations 742
- 19.6 Pile Foundations 745

20 GEOTECHNICS OF HAZARDOUS WASTE CONTROL SYSTEMS Jeffrey C. Evans

20.1	Introduction	750

- 20.2 Soil-Waste Interactions 750
- 20.3 Permeability and Compatibility Testing 752
- 20.4 Hazardous Waste Control Systems 760
- 20.5 Covers and Liners 762
- 20.6 Vertical Barrier Systems and Cutoff Walls 765
- 20.7 General Guidance 775

21 REINFORCED EARTH

F. Schlosser and M. Bastick

- 21.1 Introduction 778
- 21.2 Principle and Advantages of Reinforced Earth 778
- 21.3 History and Development 779
- 21.4 Behavior of Reinforced Earth 780
- 21.5 Design Methods 786
- 21.6 Material Specifications 790
- 21.7 Effects of Water and Dynamic Loading 791
- 21.8 Applications 792

22 GEOSYNTHETICS IN GEOTECHNICAL ENGINEERING Robert M. Koerner

- 22.1 Introduction 796
- 22.2 Geotextiles 796
- 22.3 Geogrids 800
- 22.4 Geonets 802
- 22.5 Geomembranes 804
- 22.6 Geocomposites 810

23 DEEP COMPACTION OF GRANULAR SOILS Bengt B. Broms

- 23.1 Introduction 814
- 23.2 Vibration Methods 815
- 23.3 Displacement Methods 821
- 23.4 Loading Methods 827
- 23.5 Control Methods 828
- 23.6 Cost Comparisons 829

24 STABILIZATION OF SOIL WITH LIME COLUMNS Bengt B. Broms

- 24.1 Introduction 833
- 24.2 Principle of the Lime Column Method 837
- 24.3 Applications of the Lime Column Method 847
- 24.4 Laboratory and Field Investigations 850
- 24.5 Control Methods 852
- 24.6 Schedule for Design and Construction 853

25 DURABILITY AND PROTECTION OF FOUNDATIONS Thomas D. Dismuke

- 25.1 Introduction 856
- 25.2 Facility Function and Failure Criteria 857

- 25.3 Properties of Construction Materials, Soil, and Water 857
- 25.4 Site Data 861
- 25.5 Behavior of Materials in Soil and Water 863
- 25.6 Evaluation of Site Data 864
- 25.7 Protection of Foundations 865

26 GROUND ANCHORS AND SOIL NAILS IN RETAINING STRUCTURES llan Juran and Victor Elias

- 26.1 Introduction 868
- 26.2 Principles, Historical Development, and Fields of Application 868
- 26.3 Technology, Construction Process, and Structural Elements 871
- 26.4 Soil-Inclusion Interaction: Pull-Out Capacity Estimates 877
- 26.5 Application Criteria: Advantages and Limitations 883
- 26.6 Feasibility Evaluation 884
- 26.7 Short- and Long-Term Performance of Anchors and Nails 884
- 26.8 Durability Considerations 889
- 26.9 Design of Anchored Walls and Nailed Soil-Retaining Structures 890
- 26.10 Technological Development and Research Needs 902

APPENDIX 907

INDEX 911