SOIL IMPROVEMENT AND GROUND MODIFICATION METHODS

PETER G. NICHOLSON

BH

SOIL IMPROVEMENT AND GROUND MODIFICATION METHODS

PETER G. NICHOLSON

ELSEVIER

AMSTERDAM • BOSTON • HEIDELBERG • LONDON
NEW YORK • OXFORD • PARIS • SAN DIEGO
SAN FRANCISCO • SYDNEY • TOKYO

Butterworth-Heinemann is an imprint of Elsevier

B H

Butterworth Heinemann:
Butterworth Heinemann is an imprint of Elsevier
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, UK225 Wyman Street, Waltham, MA 02451, USA

Library of Congress Cataloging-in-Publication Data
Application Submitted

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-0-12-408076-8

For information on all Butterworth-Heinemann publications visit our website at store.elsevier.com

This book has been manufactured using Print On Demand technology.

PREFACE

With very few exceptions, everything we construct in our built environment lies in or on the ground. As a consequence, the earth materials involved must be evaluated to ensure that engineering properties will adequately provide for acceptable performance of a project. There are many different properties that must be assessed based on the requirements of the project, and these will vary greatly depending on the overall (and underlying) objectives. One must be careful not to overlook other components that may affect lives and property, including natural and man-made hazards. These may involve natural, constructed and cut slopes, potential flooding and storm surges, earthquakes, and so on.

For most structures, including buildings, bridges, roadways, and engineered earth structures, there are some fundamental "rules" pertaining to the ground that must be followed in order to ensure the "success" of the structure. For example, imposed loads must be supported without ground failure, and within maximum limits of acceptable settlement or deformations. To properly evaluate the capacity of earth materials to adequately support loads, one should have a basic understanding of soil mechanics and be able to perform relatively straightforward design exercises as required for the circumstances. However, this is *as long as the strength parameters are correctly evaluated and ground conditions are well defined.* While load applications can be defined with reasonably good accuracy, it is much more difficult to make an accurate evaluation of earth material properties and their response to imposed loadings. Engineers use a number of methods to estimate the response of earth materials to various loading conditions. While performing full-scale load tests at the field site can produce one of the best evaluations, these types of tests are not often performed due to feasibility and cost restraints. This forces the engineer to rely on interpretations based on experience and a combination of laboratory and in situ test results from field investigations and sampling. Unfortunately, this, in turn, creates a whole additional level of uncertainty arising from questions about everything from testing accuracy, sample disturbance, and sample representation, to natural spatial variability of conditions and material properties in the ground, for example. These are just the basic challenges that face all geotechnical engineers when dealing with designs in or on the ground.

In many cases, the ground conditions and the earth materials are not ideal for proposed or planned development. In these instances, the geotechnical engineer must thoughtfully consider how to address potential problems with plausible solutions. Modification of the earth materials or stabilization of soils can provide a means to achieve the desired goals of assuring adequate engineering properties and/or responses for a variety of applications and conditions. Depending on the initial ground conditions, soil properties, and desired outcomes, the engineer may select from a wide choice of ground improvement and soil stabilization techniques that will help solve challenges of poor site conditions, inadequate soil qualities, mitigation of potential problems, or remedial work.

As development continues throughout the world, many of the most ideal sites have already been built upon, leaving less desirable sites for future use. This is compounded with the desire and need to build larger and safer structures in urban areas, imposing greater loads and/or requiring greater reliability than previously considered. At many locations that may have previously been considered unsuitable for development due to poor soil conditions, ground improvement techniques provide suitable alternatives for new construction. In addition, precious resources of select earth materials may be preserved with better use of existing soils that can be treated to provide acceptable engineering properties and the reuse of waste material or industry by-products.

In many instances, the combination of ground conditions and objectives requires the use of more than one approach or methodology to achieve the desired goals. This may be particularly helpful for large projects where multiple problems exist, where different types of soil strata are encountered, or when surface treatments are needed after a stabilization of deeper materials is completed. For smaller projects, the use of multiple techniques may be cost prohibitive, and a single method, albeit comparatively more expensive in some respect than some others, may be the best solution.

This text presents an overview and discussion of a number of ground improvement methodologies that have been devised over the years. Many of these are fundamental and have existed in some form for a long, long time. Others have developed with advancements in technology, and still others are continually emerging with the ever changing engineering environment. Over the past few decades, there have been significant advancements made in the tools, technology, and materials available to the engineer faced with finding workable, economic solutions to the myriad geotechnical problems that arise. In addition, construction and development have reached new levels in size, loads, and complexity. Safety issues and environmental concerns have also played an important role in reshaping values and approaches that may have evolved since earlier references on the subjects of soil and ground improvement were published. The intent of this work is not necessarily to prepare one with all of the tools needed to plan and/or design a ground improvement program, but to provide insight to the general civil engineer, contractor, or construction manager as to what tools are now available and what approaches have been effective in solving a wide range of geotechnical challenges. With this background and knowledge, one can be better prepared to consider options when faced with difficult or less than optimal soil and site conditions.

Section I provides a short background on why and where ground improvement is needed; a brief description of the various categories of methods as they apply to controlling one or more types of engineering properties and/or performance; an overview of the types of applications available and tried; an outline of typically desired improvements (objectives); an outline of factors that control the choice of improvement method that may be most suitable; and information about technological advancements that allow new tools and materials to be implemented. Included in Chapter 3 is a brief overview of basic soil mechanics fundamentals, such as soil strength, compressibility (settlement), and fluid flow (permeability) topics. In addition, this chapter describes the performance of typical field investigations with commonly collected and reported data. It is from this data (usually contained in boring logs and geotechnical reports) and correlations with soil characteristics that many ground improvement designs are formulated.

Section II provides full coverage of the topic of soil densification. Beginning with Chapter 4 is a description of objectives and improvements attained by densification of soil, including fundamental soil engineering properties and an overview of liquefaction phenomenon, followed by a thorough explanation of the principles of shallow compaction theory, control of compacted soil engineering properties, and finally, a discussion of field applications, contractual specifications, and quality control described in Chapter 5.

Section III on hydraulic modification provides an overview of how the control of water within the ground can be used to improve soil and site conditions. Strength gains, stability in slopes, seepage, drainage, and consolidation are addressed. A wide variety of methods, including conventional drain and pumps for dewatering, are outlined, along with more innovative techniques utilizing geosynthetics (for drainage and filtration) and electrokinetics (for dewatering, forced consolidation, stabilization of wastes, contaminant control and/or removal, and as an aid to grouting).

Section IV is devoted to the broad subjects related to stabilization by the addition of admixtures, grouting, and thermal treatments. Chapter 11 outlines the various available materials commonly mixed with soil to improve engineering properties, including natural soils and waste products. The applicability of mixing these various materials with different soil types is also discussed. In addition, Chapter 11 provides a general overview of the mixing methods, engineering property improvement objectives, and common applications for admixture treatments. Chapter 12 is devoted to describing a variety of grouting techniques, objectives, and various applications. Without the addition of materials to be mixed with existing soil, a discussion of thermal treatments is included in Chapter 13. Both heating and freezing methods are described, although heat treatments are usually cost-prohibitive and are rarely used anymore except for use in some geoenvironmental applications. Freezing technologies, on the other hand, have now advanced to the point of being incorporated as viable solutions for a variety of applications and have been used in a number of notable high-profile projects, as described in Section 13.4.3.

Section V outlines techniques that incorporate the use of structural elements for stabilization of existing ground as well as for new construction. Chapter 14 describes how geosynthetic reinforcement materials are utilized for construction of stabilized earth walls, slopes, and as an aid for construction over weak or soft foundation materials. Chapter 15 provides an overview of in situ reinforcement with structural members in the form of soil nails, anchors, tiebacks, and bolts. These methods are primarily used for slope stabilization, tunneling support, and excavation/subsurface foundation support. Chapter 16 describes the relatively simplistic, but very functional, practical, and often aesthetic applications of soil confinement. Cribs, gabions and mattresses provide multiple functions and have been widely used for retaining walls, slope stabilization, earth structure foundations, and erosion control in channels or other high-energy flow regimes. Cellular confinement with geosynthetic materials and the use of fabricated modular blocks have also added some structural components to traditional geotechnical applications. Then Chapter 17 discusses the use of relatively newer, lightweight technologies and materials, including expanded polystyrene (EPS) foam, industrial wastes, and recycled materials.

Finally, Chapter 18 touches on the ongoing advancements, emerging trends, and new ideas that foster future advancements to soil and ground improvement. With continuing advancements in ground modification technology, application ideas, and materials, there will certainly be new innovations and untested applications to push new limits of our understanding and appreciation for what can be accomplished.

Note regarding ASTM Standards: Throughout this text, references are made to test standards published by the American Standards of Testing and Materials, current at the time of writing. Rather than referencing each test standard in the list of references for each chapter, the Book of Standards is referenced as a whole and a listing of topic related standards is provided at the end of each chapter in which the standards are mentioned.

This is my gift to the practice, students, and anyone interested in an array of amazing ways we can consciously work with our environment while advancing engineering and achieving new successes.

Peter G. Nicholson
March 2014

ACKNOWLEDGMENTS

I would like to acknowledge all in the industry who have contributed photos, images, and other information that have helped immensely in the preparation of this text. This includes: Colby Barnett and Haley Clanton—GeoStabilization International; Stuart Bowes—Broons; Horst Brandes—University of Hawaii; Mary Burk—ACH Foam Technologies; Christina Burns—Atlas Copco (Dynapac); Larry Cole, Carmeuse Lime and Stone; Jim Collin—The CollinGroup; Michele Curry—The Reinforced Earth Co.; David Dennison—Bomag; Lisa Edwards—American Wick Drain; Peter Faust—Malcom Drilling; Anne Fleming—Tensar International Corp.; Craig Foster—Maccaferri, Inc.; Blair Gohl—Explosive Compaction Inc.; Jeff Kalani—Yogi Kwong Engineers; Joshua Kolz and Logan Bessette—HB Wick Drains; Frederic Masse—Menard USA; Prof. Paul Mayne—Georgia Tech; Kevin McCann—Landpac Technologies; Kelly McGonagle—Layne Christensen; Clayton Mimura—Geolabs Hawaii; Rick Monroe—DGSI Slope Indicator; Matt Nolan—Hogentogler (SmartDrain); Daniel Mageau—SoilFreeze; Silas Nichols—FHWA; Lisa Render—Atlas EPS (Elevation Geofoam); Marisa Schleter—Hayward Baker; Paul Schmall—Moretrench; Julie Shuster—Wacker Neuson; Don Smith—Pump Hire, Ltd.; Patricia Stelter—Presto Geosystems; Mike Tobin—AFM Corporation; Dana Trierweiler—Infrastructure Alternatives; Billy Troxler—Troxler Laboratories; Robin Vodenlic—GSE Environmental; Kord Wissmann—Geopier Foundations; and Chris Woods—Densification, Inc. Please accept my apology if I omitted anyone.

I would also especially like to thank Shailesh Namekar of Yogi Kwong Engineers for assisting with some of the figures and tables, and Kristie Kehoe for helping me out with emergency detailed editing when I needed it.

Last, I would like to acknowledge the support of my wife Gigi and daughter Emily, for their patience and understanding while "Daddy" worked so many long hours.

Peter G. Nicholson
April 2014

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State and Highway Transportation Officials
ADSC	International Association of Foundation Drilling
ASTM	American Standards of Testing and Materials
BPT	Becker penetration test
CBR	California bearing ratio
CDW	continuous diaphragm wall
CFA	continuous flight auger
CIP	cast-in-place
CIR	compaction impact response
CIS	continuous impact settlement
CKD	cement kiln dust
CPT	cone penetration test
CPTU	cone penetration test (with pore pressures)
CSV	soil stabilization with vertical columns
CVM	compaction meter value
DCP	dynamic cone penetrometer
DDC	deep dynamic compaction
DMT (flat plate)	dilatometer test
DOT	Department of Transportation
EERC	Earthquake Engineering Research Center
FHWA	Federal Highway Administration
FWD	falling weight deflectometer
GCL	geosynthetic clay liner
GCS	geosynthetically confined soil
GEER	Geotechnical Extreme Events Reconnaissance
GGBFS	ground granulated blast furnace slag
GPS	Global Positioning System
GRS	geosynthetically reinforced soil
HEIC	high energy impact compaction
IC	intelligent compaction
LKD	lime kiln dust
LRFD	load and resistant factor design
MIT	Massachusetts Institute of Technology
MSE	mechanically stabilized earth
MSW	municipal solid waste
NCHRP	National Cooperative Highway Research Program
NDM	National Deep Mixing Cooperative Research Program
OMC	optimum moisture content
PMT	pressuremeter test
PVD	prefabricated vertical drains
QA	quality assurance
QC	quality control
RAP	Rammed Aggregate Pier

RC	relative compaction
RDC	rolling dynamic compaction
RIC	rapid impact compaction
SASW	spectral analysis of surface waves
SCPTU	seismic cone penetration test (with pore pressures)
SPT	standard penetration test
TRB	Transportation Research Board
USCS	Unified Soil Classification System
USDA	U.S. Department of Agriculture
VST	vane shear test
ZAV	zero air voids

CONTENTS

SECTION I

Introduction to Ground Improvement and Soil Stabilization