Soil Mechanics Fundamentals and Applications

Second Edition

Isao Ishibashi
Hemanta Hazarika

CRC Press
Taylor & Francis Group

Soil Mechanics Fundamentals and Applications

Second Edition

Isao Ishibashi
Hemanta Hazarika

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Printed on acid-free paper
Version Date: 20150211

International Standard Book Number-13: 978-1-4822-5041-1 (Hardback)

Library of Congress Cataloging-in-Publication Data

Ishibashi, Isao.
Soil mechanics fundamentals and applications. -- Second edition / Isao Ishibashi and Hemanta Hazarika.
pages cm
"A CRC title."
Includes bibliographical references and index.
ISBN 978-1-4822-5041-1 (alk. paper)
1. Soil mechanics. I. Hazarika, Hemanta. II. Title.

TA710.I725 2015
624.1'5136--dc23 2014037716

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

Preface to the First Edition

Soil Mechanics Fundamentals is written with the intention of providing a very basic yet essential concept of soil mechanics to students and engineers who are learning the fundamentals of soil mechanics for the first time. This book is meant mainly for college students who have completed key engineering science courses such as basic calculus, physics, chemistry, statistics, mechanics of solids, and engineering materials and are ready to enter into one of the specialty areas of civil, architectural, and **geotechnical engineering**. This book is intended to provide a thorough, fundamental knowledge of soil mechanics in a simple and yet comprehensive way, based on the students' knowledge of the basic engineering sciences. Special emphasis is placed on giving the reader an understanding of **what soil is, how it behaves, why it behaves that way, and the engineering significance of such behavior**.

There are many books on soil mechanics, geotechnical engineering, and the foundation engineering field. Through our experience in teaching introductory soil mechanics courses to college students for more than 20 years, we have come to realize that most of these textbooks either lack comprehensive explanations of soil behavior or contain massive information without clear and organized contents. We have always felt the need for a better introductory textbook for our students. For us, the ideal first textbook on soil mechanics should be presented with a firm basis of the knowledge of the engineering sciences. First, the varied behavior of soils should be well explained, based on mathematics, physics, and chemistry in a simple and yet comprehensive way. Second, the rather complex phenomena of soil mechanics should be better organized and presented in a systematic way with a smooth flow of information. Last, students who have finished the first course of soil mechanics should be ready to apply the learned concepts to field applications such as foundation engineering with a full comprehension of the fundamentals of soil behavior. In other words, students should not simply memorize equations and numbers, but also understand why and how soil mechanics works. We believe that only then will students and engineers confidently face challenging situations in well-thought-out, logical, and innovative ways.

This book was written in such a way that the preceding ideal introduction of soil mechanics concepts can be approached as closely and as smoothly as possible. For example, plasticity of soils is rather easily understood after learning clay minerals and the interactions of clay and water. Similarly, the quicksand phenomenon in front of sheet pile and heaving at the bottom of excavation come after flow of water and effective stress concepts. Also, Mohr's circle is presented just before the shear strength and lateral earth pressure theory. At the same time, we intentionally avoided including too much information in each subject area. The same holds true for the presentation of equations. There are always exceptions and there are many empirical correlations available in the field of soil mechanics. However, this book includes only the essential ones to emphasize the importance of fundamentals.

To summarize, this book is not meant to cover the full spectrum of the geotechnical engineering discipline, but rather to provide the simplest yet most comprehensive first textbook in soil mechanics for students and engineers in the field of civil engineering as well as architecture to understand what soil is, how it works, and why it works that way.

Isao Ishibashi
Hemanta Hazarika
2010

Preface to the Second Edition

The first edition of this book (***Soil Mechanics Fundamentals***) was published in 2010 with the aim to offer an introductory soil mechanics textbook to college students, who for the first time would be exposed to this fascinating yet complex subject area. The book was written with concise contents, yet with in-depth fundamental principles on the subject. At the same time we tried to keep the cost of the book affordable to the readers. The book has been well received all over the world, as it explains soil's fundamental behavior from basic engineering science knowledge with carefully selected engineering practices and applications. Our original purpose of the book has been accomplished and it has been well distributed around the world, including a Japanese version published by Kyoritsu Publishing Company, Tokyo, Japan. It has been adopted as a textbook in many institutions worldwide and has been read by many practicing engineers.

On the other hand, we have received much input from the readers of the first edition. ***One of these suggestions was to expand the contents to include an introductory foundation engineering section***. We accepted this suggestion in order to make the book a complete introductory geotechnical engineering book. Syllabuses of many institutions cover the introductory foundation engineering concept after the basic soil mechanics sections. This is our motivation for the second edition, ***Soil Mechanics Fundamentals and Applications***, and thus we kept the original first 12 chapters of soil mechanics without any major changes. Chapter 13 of the previous edition was modified by adding the shallow foundation design section at the end, and it became **Chapter 14 (Bearing Capacity and Shallow Foundations)** in this new edition. Three new chapters on foundation-engineering-related topics have been added: **Chapter 13 (Site Exploration), Chapter 15 (Deep Foundations)**, and **Chapter 16 (Slope Stability)**.

Accordingly, the organization of the new edition of the book (which includes the original 12 chapters) is as follows. Chapters and their contents are carefully placed in an order so that the understanding level of the subject matter increases gradually as we move from one chapter to another. Following the sequence presented in this book is therefore recommended.

After the introductory **Chapter 1** about soil mechanics, **Chapter 2** (Physical Properties of Soils) deals with the origin and the description of soils. The major terms used in soil mechanics are defined by using the three-phase diagram. Soil shapes and gradations are also discussed in this chapter. **Chapter 3** (Clays and Their Behavior) presents unique characteristics of clays from their mineral origins, sizes, shapes, electrical properties, behavior in water, and interaction among particles. Based on this knowledge, their plastic behavior, swelling, and shrinkage properties, sensitivity, and quick clays are discussed.

Based on the information covered in Chapter 2 and Chapter 3, soil classifications by the Unified Soil Classification System (also ASTM) and by the American Association of State Highway and Transportation Officials (AASHTO) are presented in **Chapter 4**.

Chapter 5 handles laboratory and field compaction techniques, including description of relative density and the CBR (California Bearing Ratio) method.

Chapter 6 presents the flow of water through soils. Definitions of various hydraulic heads and the coefficient of permeability are presented, as well as the two-dimensional flow net technique, introduced from a simple one-dimensional water flow mechanism without using the Laplace equation. Finally, a systematic method to compute boundary water pressures is demonstrated.

In **Chapter 7**, the concept of effective stress and its applications to various important soil mechanics problems, including capillary rise, quicksand, and heave at the bottom of an excavation, are discussed. The concept is later used in consolidation theory (Chapter 9) and shear strength (Chapter 11).

Chapter 8 is a preparation chapter for Chapter 9 (Settlements). Stress increments in a soil mass due to various types of footing load on the ground are presented. Most of these solutions are based on Boussinesq's elastic solution, and they are needed as the major source of consolidation settlements in Chapter 9.

In **Chapter 9**, Terzaghi's one-dimensional consolidation theory and its application are presented. To simplify the discussions, the consolidation problems are categorized into two parts: "how soon" (rate) problems and "how much" (amount of final settlement) problems, so that readers can clearly avoid confusion while handling the thickness (H or 2H) of the clay layer.

Chapter 10 deals with Mohr's circle, which is utilized in chapters relating to shear strength and lateral earth pressure. In particular, a clear definition of the shear stress sign convention is made so that the concept of the pole of Mohr's circle (the origin of the planes) can be utilized effectively without any room for mistakes.

Chapter 11 is related to the shear strength of soils. Failure criteria are introduced, and laboratory as well as field shear strength determination techniques are presented. Clear definitions are presented on consolidated, unconsolidated, drained, and undrained shear strength parameters, and usages of these different shear strength parameters are critically evaluated.

In **Chapter 12**, at-rest earth pressure and the classic Rankine and Coulomb active and passive pressure theories are presented. These classic theories are critically reviewed in terms of their assumptions and limitations, and appropriate applications of the theories into practice are discussed.

Chapters 13 through 16 cover introductory foundation engineering. **Chapter 13** is related to site exploration, which is needed prior to foundation design at given sites. It includes a site exploration program, geophysical methods, borehole drilling and sampling, and in-situ testing methods such as the standard penetration test, cone penetration test, and other field test procedures.

Chapter 14 first presents the bearing capacity theory and, as an application, the shallow foundation design procedure is described. **Chapter 15** handles deep foundation design procedures. Various analytical and field pile foundation design procedures are presented. Negative skin friction, pullout resistance, group piles, and the consolidation settlement are also discussed.

Finally, in **Chapter 16**, slope stability problems are presented. The mechanism of slope failure, analytical methods for calculating the factor of safety, and slope stabilization principles are discussed.

In most of the chapters, many **exercise problems** were carefully selected for readers to practice the use of the learned concepts. Spreadsheet techniques are often employed in these exercise problems. At the end of each chapter, many **problems** are selected, and they can be utilized by students to further exercise their skills in problem solving, or they can be presented as homework assignments by instructors. Numerical values of solutions for the problem sections are shown at the end of the book for the convenience of self-study readers.

Throughout the book, **key words** are highlighted with **bold letters** and they also appear in the subject index at the end of the book; thus, readers can easily search the locations of these key words in the main section of the book. ***Some sentences are highlighted with bold and italic letters***, emphasizing the importance of the concepts. **References** appear in ***bold and italic letters*** in the text and are listed at the end of each chapter and in the **author index** at the end of the book.

This book basically uses **SI units** except the ones cited from original references. ***For the measured weight unit, the gf (gram force) unit is used since it is commonly the observed number on weighing balance. Thus, the value in gf units should be multiplied by 0.00981 to obtain Newton force if needed.*** The key **unit conventions** are also summarized and a unit conversion table appears on the back of the front cover page.

Throughout the first as well as the second edition preparation processes, we have received varying input, constructive review comments, and assistance from many colleagues and friends from all over the world. We really appreciate the individuals who supported and guided us. The following is a partial list of these individuals (in alphabetical order of family names without titles): M. Sherif Aggour (United States), Fauziah Ahmad (Malaysia), G. L. Sivakumar Babu (India), A. Boominathan (India), Bodhinanda Chandra (India), Hiroshan Hettiarachchi (United States), Tatsuhisa Hida (Japan), Yoshiaki Kikuchi (Japan), Taizo Kobayashi (Japan), Kunchithapatha Madhavan (United States), Mohamed Mekkawy (United States), Achmad Muhiddin (Indonesia), Mete Omer (United States), Kiyoshi Omine (Japan), Chuzo Tsuchiya (Japan), Yoichi Watabe (Japan), Noriyuki Yasufuku (Japan), Yoshiaki Yoshimi (Japan), and Askar Zhussupbekov (Kazakhstan).

Isao Ishibashi
Hemanta Hazarika
2015

The Authors

Dr. Isao Ishibashi, P.E., is a professor in the Department of Civil and Environmental Engineering, Old Dominion University, Norfolk, Virginia. He was born in Japan, where he obtained bachelor's and master's degrees from Nagoya University, Nagoya, Japan. After earning his PhD from the University of Washington, Seattle, he taught and was on the research faculty at the University of Washington and Cornell University before moving to Old Dominion University in 1986. Professor Ishibashi has been involved in research in many areas, such as soil liquefaction, dynamic soil properties, and static and dynamic earth pressures, as well as seismic water pressure, granular mechanics, slope stability, used-tire application to embankment, and many others in geotechnical and earthquake engineering areas. He is the author or coauthor of more than 100 published technical papers in journals and proceedings in these areas. He is a member of ASCE, ISSMFE, ASTM, EERI, and JGS.

Dr. Hemanta Hazarika is a professor in the Department of Civil Engineering, Kyushu University, Fukuoka, Japan. Born in India, Professor Hazarika obtained his bachelor of technology degree in civil engineering from the Indian Institute of Technology (IIT), Madras, India, and his PhD in geotechnical engineering from Nagoya University, Nagoya, Japan. Before moving to his present position, he worked a few years as a practicing engineer in industry as well as several years in teaching and research in academia and at a public sector research institute in Japan. Professor Hazarika's present research activities include earthquake- and tsunami-induced geotechnical hazards, soil-structure interaction, seismic stability of soil structure, ground improvement geosystems, applications of recycled waste and lightweight geomaterials, and stability of cut slopes, landslides, and their protection. Professor Hazarika has more than 130 technical publications in reputed international journals, proceedings of international conferences, and symposia, including contributed chapters in several books. He is also credited as editor of two books in his research fields. He served and is serving presently as a member of various technical committees of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) and the Japanese Geotechnical Society (JGS). He was also secretary of the Technical Committee No. 4 (presently TC203 Earthquake Geotechnical Engineering and Associated Problems) of ISSMGE. Presently, he is the secretary of the Asian Technical Committee No. 3 (Geotechnology for Natural Hazards) and co-secretary of Asian Technical Committee No. 1 (Mitigation and Adaptation to Climate Change-Induced Geodisasters) of ISSMGE. He is a member of many professional societies in both Japan and abroad, such as ASCE, ISSMGE, IACMAG, IGS, JSCE, and JGS.

Contents