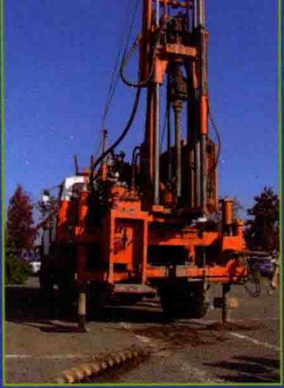
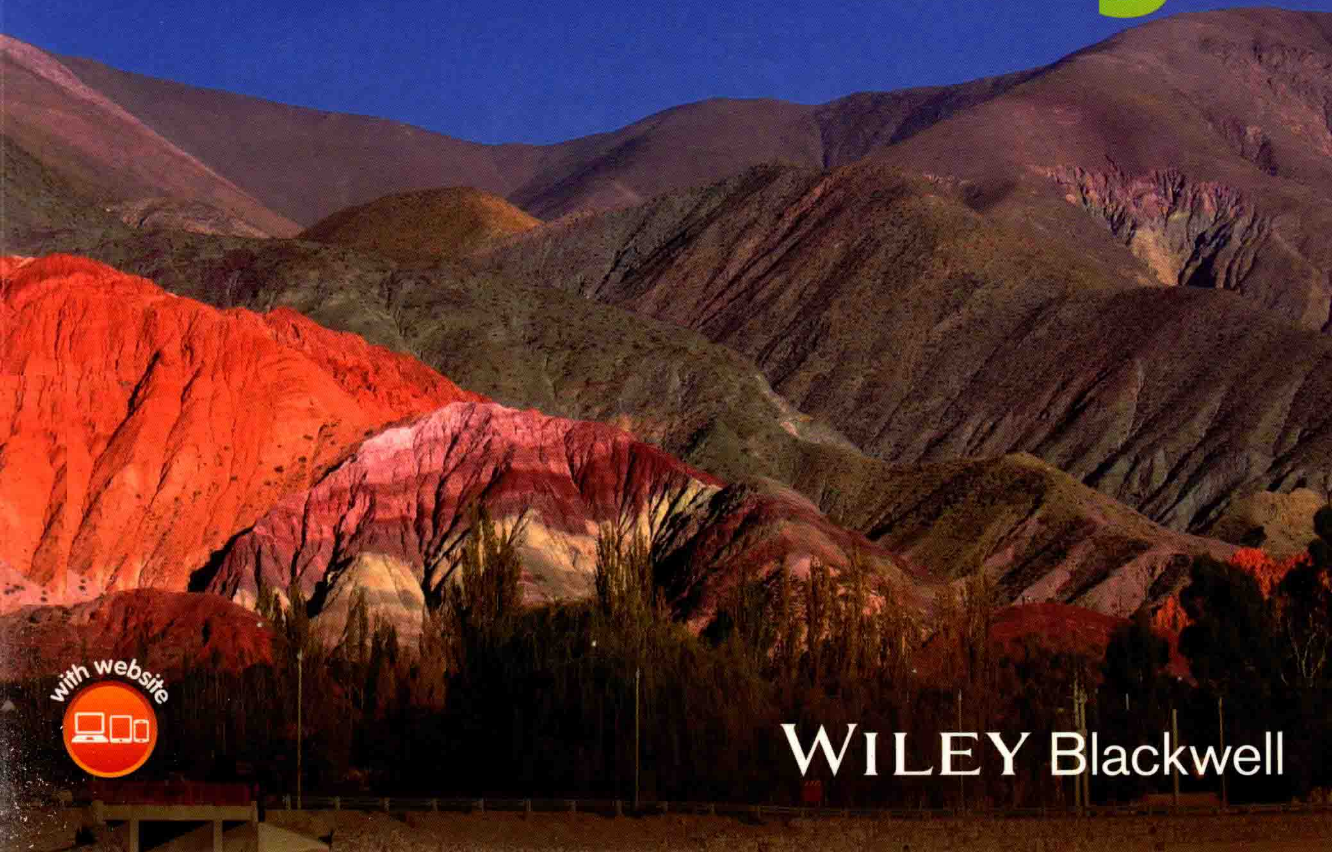



Ming Xiao

Geotechnical Engineering Design



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Geotechnical Engineering Design

Ming Xiao
Associate Professor of Civil Engineering
College of Engineering
The Pennsylvania State University, University Park
USA

with contributions from

Daniel Barreto
Lecturer
School of Engineering & the Built Environment
Edinburgh Napier University
UK

WILEY Blackwell

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Geotechnical Engineering Design

Preface

This book presents the fundamental design principles and approaches in geotechnical engineering, including an introduction to engineering geology, subsurface explorations, shallow and deep foundations, slope stability analyses and remediation, filters and drains, Earth retaining structures, geosynthetics, and basic seismic evaluations of slope stability, lateral earth pressures, and liquefaction. It is intended for use as a textbook in the geotechnical design courses for senior undergraduate and M.S. graduate students. Therefore, the topics covered in this book are presented to meet this level. This book applies the principles of soil mechanics and focuses on the design methodologies in geotechnical engineering. The readers of this book are expected to have undertaken a soil mechanics course and already understood the principles of engineering properties of soils, stresses in soils, seepage in soils, soils shear strength, and consolidation.

The book was completed after I have taught geotechnical engineering for 9 years as faculty of civil engineering. Although excellent textbooks on the principles of geotechnical engineering and textbooks on foundation engineering are available to students, instructors and students have few options in selecting textbooks that cover geotechnical design aspects other than foundation engineering, particularly in senior undergraduate and M.S. graduate courses. This prompted me to embark on writing this textbook. While writing this book, I remained mindful of how a student can best and most easily grasp the content. Each chapter opens with an introduction on why the topic is important in the engineering practice, and graphical illustrations are appropriately included to offer visual images of the engineering applications. Ample graphical illustrations on field applications and design approaches are provided throughout the book. In Chapters 3–9 where designs are presented, a sample problem and its solution are included at the end of each topic. The homework problems at the end of each chapter are designed to test the student's basic understanding of the concepts and design approaches and to challenge the student to solve real-world design issues.

A unique aspect of this book is the inclusion of Eurocode 7: Geotechnical design, the European Standard for the design of geotechnical structures. The design approaches of many topics in this book use both allowable stress design (in the United States) and limit state design (in Europe), and two sets of solutions for many sample problems are provided to explain both the design methodologies. Both the America Society for Testing and Materials (ASTM) standards and the British standards are referred to in Chapter 1 (Introduction to Engineering Geology) and Chapter 2 (Geotechnical Subsurface Exploration). The inclusion of Eurocode allows the international audience to preliminarily understand the commonalities and differences in geotechnical engineering designs on a global scale, particularly in Europe and North America.

Considering the targeted level of readers and the typical duration of a course in which this textbook would be used, some topics are not presented in great depth. For example, Chapter 3 (Shallow Foundation Design) and Chapter 4 (Introduction to Deep Foundation Design) present only the fundamentals of foundation design; the topic of drilled shafts is not presented. Chapter 8

(Introduction to Geosynthetics Design) presents only the basics of geosynthetics and three common field applications using geosynthetics: mechanically stabilized earth walls, reinforced soil slopes, and filtration and drainage. Chapter 9 (Introduction to Geotechnical Earthquake Design) presents the basic seismology and earthquake characteristics and three basic seismic evaluations: slope stability, lateral earth pressures, and liquefaction. Special topic courses on these individual topics may require other available textbooks.

I am indebted to many people who helped and supported the long process of writing this book. Jennifer Welter, Madeleine Metcalfe, and Harriet Konishi of John Wiley and Sons had been patient, supportive, and instrumental in the development of this book. Benjamin T. Adams, my undergraduate, master's, and doctoral student and friend, provided valuable thoughts and help. Many professors, practitioners, and agencies generously provided photos and graphs for this book; the acknowledgements of them are included in the figure captions. I particularly appreciate my wife, Shasha, for her continuous support and sacrifice in the pursuit of this book and in life.

Ming Xiao
The Pennsylvania State University
University Park
USA

About the Authors

Ming Xiao

Dr. Ming Xiao is an Associate Professor in the Department of Civil and Environmental Engineering at the Pennsylvania State University, USA. He received a B.S. degree in Civil Engineering from Shandong University (China), an M.S. degree in Geotechnical Engineering from Zhejiang University (China), and both M.S. degree in Computer Science and Ph.D. degree in Geotechnical Engineering from Kansas State University. Before joining the Pennsylvania State University, Dr. Xiao was an Assistant and then Associate Professor in the Department of Civil and Geomatics Engineering at the California State University, Fresno, from 2005 to 2013. Dr. Xiao's research involves seepage and erosion, performances of earthen structures (such as dams, levees, and geosynthetically reinforced bridge supports) under in-service conditions and extreme events, and innovative alternative materials, biogeochemically treated soils, recycled materials, and their engineering applications. Dr. Xiao has received a number of research grants as principal or co-principal investigator from the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the Federal Highway Administration (FHWA), the California Department of Resources Recycling and Recovery, the California Department of Transportation, the Pennsylvania Department of Transportation, and other companies. He has written two books and published over 50 peer-reviewed journal and conference papers. He is a registered Professional Engineer of Civil Engineering in the states of California and Ohio. He is a member of the American Society of Civil Engineers (ASCE), the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), the Consortium of Universities for Research in Earthquake Engineering (CUREE), Tau Beta Pi National Engineering Honor Society (USA), and Chi Epsilon National Civil Engineering Honor Society (USA). He is the Chair of the Geotechnics of Soil Erosion technical committee and a member of the Embankments, Dams, and Slopes technical committee of the ASCE Geo-Institute. He is an Editorial Board Member of the ASTM Journal of Testing and Evaluation, and he has served as an international advisory board member and session chair for a number of international conferences.

Daniel Barreto

Dr. Daniel Barreto is a Lecturer in Geotechnical Engineering in the School of Engineering and the Built Environment at Edinburgh Napier University, UK. He received a B.Eng. degree in Civil Engineering from Universidad de los Andes (Colombia), an M.Sc. degree in Soil Mechanics and Engineering Seismology from Imperial College London (UK), and completed his Ph.D. in Soil Mechanics also at Imperial College London. Before the start of his postgraduate studies, Dr. Barreto worked as Graduate Civil (Geotechnical) Engineer in Colombia and contributed to multiple projects related to the design of various geotechnical structures. Dr. Barreto's research involves advanced laboratory testing on soil and use of the discrete element method (DEM) for geotechnical applications. His particular research interests include soil anisotropy, mechanical behavior of soft rocks and dissolving soils, among others. Dr. Barreto has received a number of research grants as principal or co-principal investigator from institutions such as the Royal Academy of Engineering and the British Council. He has published over 25 peer-reviewed journal and conference papers. He is a member of the British Geotechnical Association (BGA), the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE), and the International Society of Rock Mechanics (ISRM). Dr Barreto is also a Teaching Fellow at Edinburgh Napier University, a title that highlights excellence in teaching practice, and is a Fellow of the Higher Education Academy (FHEA).

About the Companion Website

This book's companion website www.wiley.com/go/Xiao provides you with a solutions manual, resources and downloads to further your understanding of geotechnical engineering design:

- Solutions to the end-of-chapter exercises, including the full workings
- A suite of editable spreadsheets which map onto the worked examples in the book, showing how they are solved.
- Colour versions of the book's many photographs and figures
- PowerPoint slides for tutors

Contents

Chapter 1
Introduction to Engineering Geology

1.1 Introduction

Engineering geology involves description of the structure and attributes of rocks that are associated with engineering works, mapping, and characterization of all geologic features and materials (rocks, soils, and water bodies) that are proximate to a project and the identification and evaluation of potential natural hazards such as landslides and earthquakes that may affect the success of an engineering project. It is different from geology, which concerns the present and past morphologies and structure of the Earth, its environments, and the fossil records of its inhabitants (Goodman 1993).

1.2 Structure of the Earth and geologic time

The Earth is divided into three main layers: crust, mantle, and core (Figure 1.1). The crust is the outer solid layer of the Earth and comprises the continents and ocean basins. The crust varies in thickness from 35 to 70 km in the continents and from 5 to 10 km in the ocean basins. It is composed mainly of aluminosilicates. The mantle, a highly viscous layer about 2900 km thick, is located beneath the outer crust. It includes the upper mantle (about 35–60 km thick) and the lower mantle (about 35–2890 km thick) (Jordan 1979). The mantle is composed mainly of ferro-magnesium silicates. Large convective cells in the mantle circulate heat and may drive the plate tectonic processes. Beneath the mantle and at the center of the Earth are the liquid outer core and the solid inner core. The outer core is an extremely low viscosity liquid layer, about 2300 km thick, and composed of iron and nickel, with an approximate temperature of 4400 °C. The inner core is solid, about 1200 km in radius, and is entirely composed of iron, with an approximate temperature of 5505 °C (Engdahl et al. 1974). The Earth's magnetic field is believed to be controlled by the liquid outer core.

Geologic time is a chronological measurement of the rock layers in the history of the Earth. Evidence from radiometric dating indicates that the Earth is about 4.57 billion years old. The geologic time scale is shown in Figure 1.2. The rocks are grouped by age into *eons*, *eras*, *periods*, and *epochs*. Among the various periods, the Quaternary period (from 1.6 million years ago to the present) deserves special attention as the top few tens of meters of the Earth's surface, which geotechnical engineers often work with, developed during this period (Mitchell and Soga 2005).

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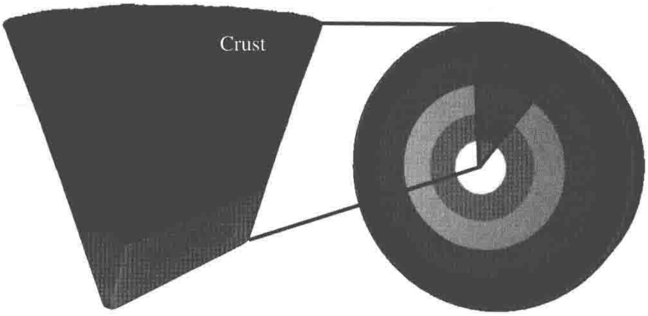

Fig. 1.1 Structure of the Earth.

Eon	Era	Period		Epoch	Time (million of years)	Some important events
Phanerozoic	Cenozoic	Quaternary		Holocene	0.01	Last glacial period
				Pleistocene	1.6	
		Tertiary	Neogene	Pliocene	5.3	
				Miocene	23.7	
			Paleogene	Oligocene	36.6	
				Eocene	57.8	
				Paleocene	68.4	Mountains form in Europe
	Mesozoic	Cretaceous			144	Mountains form in western North America
		Jurassic			208	
		Triassic			245	Dinosaurs appear
	Paleozoic	Permian			286	
		Pennsylvanian			320	
		Mississippian			360	First land vertebrates
		Devonian			408	
		Silurian			438	
		Ordovician			505	Ice age at end of period.
		Cambrian			570	Major diversification of life
Proterozoic					2500	
Archean					3800	Simple single-cell life
Hadean					4570	Formation of Earth

Fig. 1.2 Geologic time scale.

1.3 Formation and classification of rocks

The main rock-forming minerals are silicates, and the reminders are carbonates, oxides, hydroxides, and sulfates. There are three major categories of rocks: igneous rocks, sedimentary rocks, and metamorphic rocks.

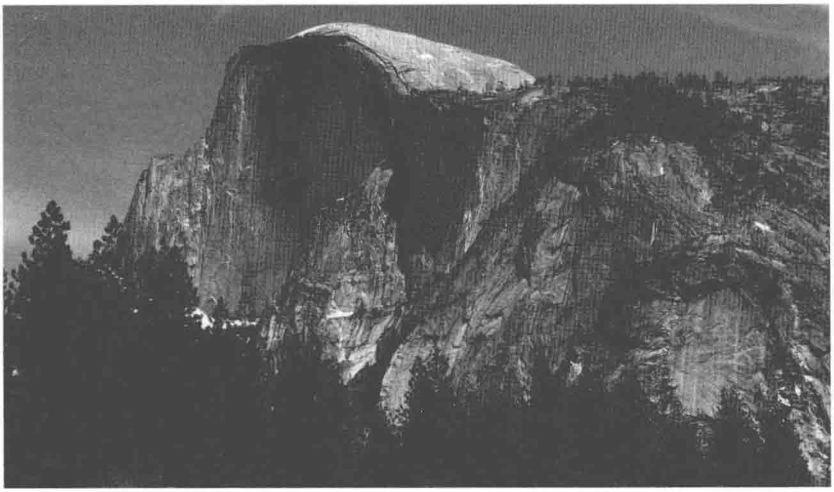

Fig. 1.3 Igneous rock in the Yosemite National Park, California, USA.

1.3.1 Igneous rocks

Igneous rocks are formed due to igneous activities, i.e., the generation and movement of silicate magma. There are two kinds of igneous rocks: *extrusive or volcanic rocks* that are formed by cooling of lava from volcanic eruption, and *intrusive or plutonic rocks* that are formed by the slow cooling of magma beneath the surface. Cooling below the Earth's surface is slow and results in large crystals, whereas cooling on the surface is rapid and results in small crystal size. Therefore, the extrusive rocks are usually fine-grained, and the intrusive rocks are coarse-grained. The intrusive rocks are found in many great mountain ranges that were brought to the surface due to erosion of the overlying material and relative tectonic plate movements. The main intrusive rock type is the light-colored granite. The main extrusive rock type is the dark-colored basalt. Coarse-grained intrusive rocks generally have lower strength and abrasion resistance as compared to fine-grained extrusive rocks (West 1995). Figure 1.3 shows Half Dome in the Yosemite National Park, California; Half Dome is an igneous rock.

1.3.2 Sedimentary rocks

Sedimentary rocks are formed by the accumulated and hardened deposits of soil particles and weathered rocks transported by wind, streams, or glaciers. The accumulated deposits are hardened due to overburden pressure and cemented by minerals such as iron oxide (FeO_2) and calcium carbonate ($CaCO_3$). Among sedimentary rocks, the most widespread are shale, sandstone, limestone, siltstone, mudstone, claystone, and conglomerates. They all display the characteristic stratification resulting from the gradual accumulation of layers of compacted and cemented deposits. The three main rocks that comprise 99% of sedimentary rocks are shale (46%), sandstone (32%), and limestone (22%) (West 1995). Sedimentary rocks are extremely diverse in their texture and mineral composition due to their diverse origin, transportation, and formation environment. Shale, claystone, and mudstone usually have low strength and low abrasion resistance