西安交通大學本科“十二五”规划教材

SOIL MECHANICS

土力学

Liao Hong-jian　Su Li-jun　Li Hang-zhou　Xiao Zheng-hua

廖红建　苏立君　李杭州　肖正华 编著

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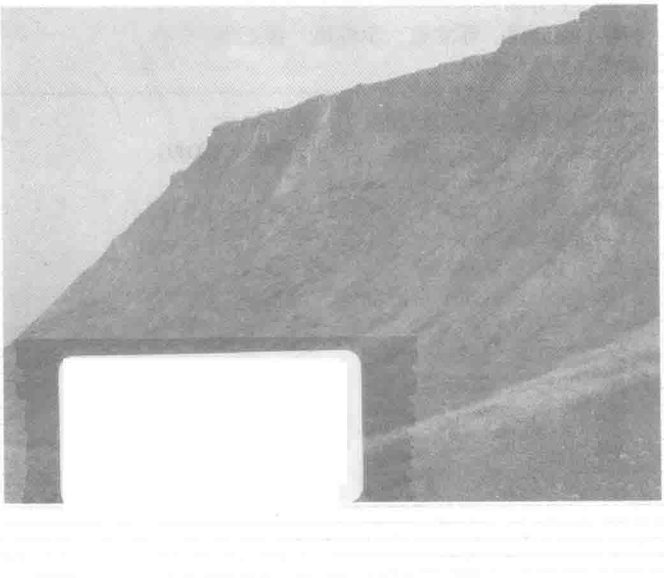

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内容提要

本书是土木工程专业的必修课程《土力学》的英文教材。本教材既注重我国土力学课程的知识结构体系，又吸收国外经典土力学英文原版教材的精髓，采用我国现行的规范和标准进行编写。全书重视土力学基本理论和知识、技能的阐述，力求把知识的传授与能力的培养结合起来，内容丰富，条理清晰，系统性和逻辑性较强，便于学生系统学习和深入理解。

本书内容共分8章，包括土的基本性质和工程分类、土的渗透性和渗流力、地基中的应力分布、土的压缩性和地基沉降计算、土的抗剪强度、地基承载力、边坡稳定性以及土压力和挡土墙。每章后附有习题和参考文献，附录中列出了土力学常用专业名词英汉对照和习题答案，为学生和教师查阅和学习提供了方便。

本书可作为高等院校土木工程专业《土力学》课程的双语教材，其内容与中文教材的知识体系相呼应，也可作为相关专业（水利水电工程、采矿工程、交通运输工程等）的土力学课程的双语教材，以及研究生和工程科技人员的参考书。

图书在版编目(CIP)数据

土力学 = Soil Mechanics:英文/廖红建等编著. —西安:西安交通大学出版社,2015.7

西安交通大学"十二五"规划教材

ISBN 978-7-5605-7754-8

Ⅰ.①土… Ⅱ.①廖… Ⅲ.①土力学-高等学校-教材-英文 Ⅳ.①TU43

中国版本图书馆CIP数据核字(2015)第187420号

书　　名　土力学

编　　著　廖红建　苏立君　李杭州　肖正华

责任编辑　王晓芬

出版发行　西安交通大学出版社

（西安市兴庆南路10号　邮政编码710049）

网　　址　http://www.xjtupress.com

电　　话　(029)82668357　82667874(发行中心)

(029)82668315(总编办)

传　　真　(029)82668280

印　　刷　西安建科印务有限责任公司

开　　本　727mm×960mm　1/16　　印张　15.5　　字数　274千字

版次印次　2015年12月第1版　2015年12月第1次印刷

书　　号　ISBN 978-7-5605-7754-8/TU·164

定　　价　38.00元

读者购书、书店添货、如发现印装质量问题，请与本社发行中心联系、调换。

订购热线:(029)82665248　(029)82665249

投稿热线:(029)82664953

读者信箱:475478288@qq.com

Brief Introduction

This book was compiled as a textbook of soil mechanics for undergraduate students in civil engineering. It substantially considered the structure and contents of soil mechanics in China. Moreover, good materials from foreign textbooks of soil mechanics in English were also included. All of the codes and standards in China included in this book are the newest. The authors paid much attention to explain the basic theory, knowledge and skills in soil mechanics, tying to combine delivery of knowledge and improve the ability of students.

There are eight chapters in this book, including: basic characteristics and engineering classification of soils, permeability of soil and seepage force, stress distribution in soil, compression and consolidation of soil, shear strength, bearing capacity, stability of slopes and lateral earth pressure and retaining walls. Exercises and references are provided at the end of each chapter, and answers are given in the appendix for the reference of lecturers. The English-Chinese translation of frequently-used words and expressions in soil mechanics were also provided in the appendix, which may facilitate the students to study this book.

This book can be used as a bilingual teaching textbook of soil mechanics for undergraduate students in civil engineering because its contents are consistent with the current textbooks in Chinese. It can also be used as a bilingual teaching textbook of soil mechanics for undergraduate students in hydraulic, mining and transportation engineering. Master students and professionals in related professions can also use it as a reference book.

Preface

1. Importance of this course

Soil mechanics is a basic compulsory course for undergraduate students in civil engineering. Through this course, students should master the basic theory and skills of soil mechanics related to civil engineering. Soil mechanics is closely related to the construction of civil engineering. Many engineering constructions, including dams, embankments, tunnels, canals and waterways, foundations for bridges, roads, buildings, and solid waste disposal systems, etc., depend on the geological conditions of the site and mechanical behavior of the soil.

The geological conditions in China are complicated. There are various types of soil, the properties of which also vary significantly. Further more, some special soils or regional soils (such as soft soil, collapsible loess, expansive soil, red clay and permafrost, etc.) have special behaviors different from general soils. Therefore, it is necessary to study the engineering characteristics of soils in order to take appropriate engineering measures. There are many geotechnical problems caused by natural factors or human activities, which are involved various engineering activities, such as civil engineering, mining engineering, underground engineering, and so on. The design and construction of these engineering constructions are closely related to the geological environment and mechanical behavior of soils. Therefore, it is necessary to understand various characteristics (such as physical, chemical and mechanical etc.) of soils.

2. Characteristics and engineering background of the course

As an important basic application –oriented course as well as a practical science of engineering, soil mechanics is to study the characteristics of ground and engineering behavior of soils. It is used to analyze and solve the engineering problems encountered in the design and construction of the foundation and problems associated with geomaterials. This course is an important part of the civil engineering disciplines.

Soil mechanics is a practical engineering discipline that takes soils as the research objects, which is a branch of engineering mechanics. Weathered rocks might disintegrate, metamorphose, be carried to a new environment by various natural forces and accumulated or deposited there, which formed soils. Based on the knowledge of mechanics and engineering geology, soil mechanics is used to study the stress, strain, strength and stability of soils related to engineering constructions under the action of external factors (such as load, water, temperature etc.), using the principles of mechanics and geotechnical testing techniques. Therefore, soil mechanics is a very practical engineering science.

The utilization of soils can be traced back to ancient time. Our ancestors used soils as construction material to build burial sites, flood protection, and shelters. Neolithic sites found in Banpo village, Xi'an, China indicated that, at that time, people had been able to use soil pedestal and stone foundation for the simple houses with the consideration of foundation stability problems. Later, in the Qin Dynasty the method of compaction was used to build roads, and wood pile in the Sui Dynasty and lime soil foundation in the Tang Dynasty were used to build towers. During the European industrial revolution, with the construction of large buildings, railway and highway and the development of science, the sporadic theory of soil mechanics was established. The first scientific study of soil mechanics was undertaken by French physicist Charles –Augustin de Coulomb, who published an equation for calculating the shear strength of sands and a theory of earth pressure in 1773. Coulomb's work and another theory of earth pressure published by Scottish engineer William Rankine in 1857 are currently still in use to quantify earth pressures. In 1869, Карлович published the world's first book of foundation engineering. According to the theory of elasticity, J. Boussinesq obtained the analytic solution of three - dimensional stress distribution in a foundation under the action of a concentrated load in 1885. In 1900, C. O. Mohr proposed the soil strength theory. In early twentieth Century, people had accumulated a lot of experience and data in engineering practice, and theoretically discussed the strength, deformation and permeability properties of soil. Thus, soil mechanics gradually formed an independent discipline. In the 1920s, L. Prandtl published the bearing capacity theory. In this period, there was a great development in the theory of slope stability. W. Fellenius improved the analysis method for circular sliding of slopes, known as the Fellenius method of slices or the Swedish method of slices. Based on the practice and theoretical investigation by professionals and researchers in civil engineering for more than a century, in 1925, K. Terzaghi summarized and published the first book of soil mechanics in United States. In 1929, he published the book "Engineering geology" together with other writers. Since then, soil mechanics, engineering geology and foundation engineering had gained continuous development each as an independent science, respectively. Since the first session held in 1936 in USA, the International Conference on Soil Mechanics and Geotechnical Engineering had been held for 18 times till 2013. Researchers from around the world exchanged research experience on this subject during the conference. With the development of practice and the advance in science, more and more theories and techniques were used for the research in soil mechanics. Application and improvement of basic characteristics of soil, effective stress principle, consolidation theory, deformation theory, stability soil mass, soil dynamics, soil rheology, etc. in soil mechanics were the main issues in this phase of the study. In 1954, B. B. Соколовский published a book of "Loose media statics". A. W. Skempton, A. W. Bishop and N. Janbu had made contributions to the effective stress principle and the theory of slope stability. Chinese scholars Wenxi Huang, Zongji Chen, Jiahuan Qian and Zhujiang Shen had made contributions to constitutive relations of soil, clay microstructure and soil rheology, geotechnical earthquake engineering and soil rheology, and constitutive relations of soft soil, respectively.

The composition and engineering geological conditions of the supporting soil for foundations are complex and different from each other. Requirements of engineering geology for the supporting soil are different for different engineering constructions. Therefore, the engineering problems of soils are various. The composition, thickness, physical and mechanical properties, bearing capacity of soils, etc. are the basic conditions for assessing the stability of the soil supporting the foundation. Therefore, failure of the supporting soil is frequently encountered in engineering construction. A famous case history was the instability of the supporting soil for a grain elevator in Transcona, Canada. Another one was the non-uniform settlement of the foundation for the leaning tower of Pisa in Italy.

The Transcona grain elevator completed in September 1913 was 59.44m long, 31m high and 23.47m wide. Within 24 hours after loading the grain elevator at a rate of about 1m of grain height per day, the bin house began to tilt and settle. Fortunately, the structural damage was minimal and the bin house was later restored. No borings were done to identify the soils and to obtain information on their strength.

The tower of Pisa is located in the city of Pisa, Italy. The city is located on the Arno River, northwest to Rome. The Tower is 54m in height and 142000kN in weight. The Pisa Tower was built in several stages from 1173 to 1370. During this period, the construction stopped twice due to the tower inclination. Prior to restoration work performed between 1990 and 2001, the tower leaned at an angle of 5.5 degrees. The tower now leans at about 3.99 degrees. This means that the top of the tower is displaced horizontally 3.9m from where it would be if the structure were perfectly vertical. The tower's tilt started during the construction because that the south side of the soil mass supporting the foundation was too soft to properly support the structure's weight. The plastic deformation of the foundation, creep, falling water tables, etc. accelerated the Tower inclination. Circular excavations were used for unloading at the opposite side and grouting was carried out to reinforce the soil surrounding the foundation. The body of the tower also reinforced to prevent it from collapse.

To guarantee the stability serviceability of a building, the bearing capacity of the supporting soil must meet two basic conditions: strength and deformation. The soil should have sufficient strength to ensure the stability of the ground under loading. On the other hand, the deformation of the ground should not exceed the allowable value of required by the building. Therefore, a good ground for construction generally has higher strength and lower compressibility.

3. Main contents and requirements

The main contents and requirements of each part are as follows:

1) The basic properties and the permeability of soil

Students are required to understand the concept of a three-phase composition of the soil, parameters for physical properties of soil and their relationship, soil permeability, the theory background of Darcy's law and methods for measuring the coefficient of permeability, concepts and calculation of hydrodynamic pressure and critical hydraulic gradient, the main types of seepage failure and its prevention measures, and the engineering classification of soil.

2) Stress distribution in soil

The stress in soils will be re-distributed during the construction, which causes the deformation of the ground. If the induced stress is too large and exceeds the ultimate bearing capacity of soils, it will cause failure of the ground. Therefore, to understand the calculation of stress and deformation is the premise for ensuring the serviceability and safety of buildings. The students are required to master basic concepts of effective stress, pore water pressure, gravity stress and additional stress, the theory of effective stress under both hydrostatic and seepage conditions, the calculation methods for gravity stress, effective stress, foundation pressure and additional stresses.

3) Compression and consolidation of soil

The stress and deformation occur under the loads of buildings, which eventually induced subsidence and non-uniform settlement of the foundation. If the settlement exceeds a certain limit, it will cause deformation, cracking, tilting or even dumping of buildings. Therefore, the calculation of the settlement is an important issue related to safety and stability of a building. Thus students are required to understand the compression characteristics of soils and the consolidation state, the compressive index of soil and its determination method, the layer-wise summation method for calculating the foundation settlement, and the foundation settlement calculation methods for normally consolidated and overconsolidated soils, including calculation methods of one-way seepage consolidation settlement of the foundation. These are the fundamental knowledge for settlement calculation and the foundation design of actual engineering constructions.

4) Shear strength of soil and bearing capacity

The shear strength is one of the important mechanical properties of the soil, which is closely related to the stability and serviceability of buildings. Determination of bearing capacity is the basic content for the design of a foundation. The students are required to understand the Mohr-Coulomb theory and the limit equilibrium condition of soil, the shear strength indexes and test methods for determining these indexes, shear strength properties of soil, failure characteristics of soils, and the calculation methods for critical edge loads and ultimate loads.

5) Slope stability and earth pressure

Earth pressure and slope stability are the problems frequently encountered in engineering construction, which also must be analyzed for the engineering design and construction. The students are required to understand the basic concepts and calculation methods for earth pressure, Rankine's earth pressure theory and Coulomb's earth pressure theory, the types of retaining structures; factors affecting the slope stability, the slope stability analysis for non-cohesive and cohesive soil, the Swedish method of slices and Bishop's method of circular sliding surface.

Contents

SOIL MECHANICS

CHAPTER 1

Basic characteristics and engineering classification of soils

1.1 Introduction

Soil mechanics may be defined as the study of the engineering behaviors of soils, with reference to the design of civil engineering structures made from or in the earth. Nearly all of the civil engineering structures, such as buildings, bridges, highways, tunnels, earth retaining walls, embankments, basements, and sub-surface waste repositories, towers, canals, and dams, are constructed in or on the surface of the earth. To perform satisfactorily, each structure must have a proper foundation.

The four basic types of geotechnical structure are illustrated in Fig. 1. 1. 1, and most of other cases are variations or combinations of them. Foundations (Fig. 1. 1. 1 (a)) transmit loads to the ground and the basic criterion for design is that the settlements should be relatively small. The variables in design of a foundation are the load F, the size of the base B and the depth D. Foundations may support loads that are relatively small, such as car wheels, or relatively large, such as a power station. Slopes (Fig. 1. 1. 1 (b)) may be formed naturally by erosion or built by excavation or filling. The basic variables are the slope angle i and the depth H, and the design requirement is that the slope should not be failed by landsliding.

Slopes that are too deep and too steep to stand unsupported can be supported by a retaining wall (Fig. 1. 1. 1 (c)). The basic variables are the height of the wall H and its depth of burial D, together with the strength and stiffness of the wall and the forces in any anchors or props. The basic requirements for design are complex and involve overall stability, restriction of ground movements and the bending and shearing resistance of the wall. In any structure where there are different levels of water, such as in a dam (Fig. 1. 1. 1 (d)) or around a pumped well, there will be seepage of water. The seepage causes leakage through a dam and governs the yield of a well and it also governs the variation of pressure in the groundwater.

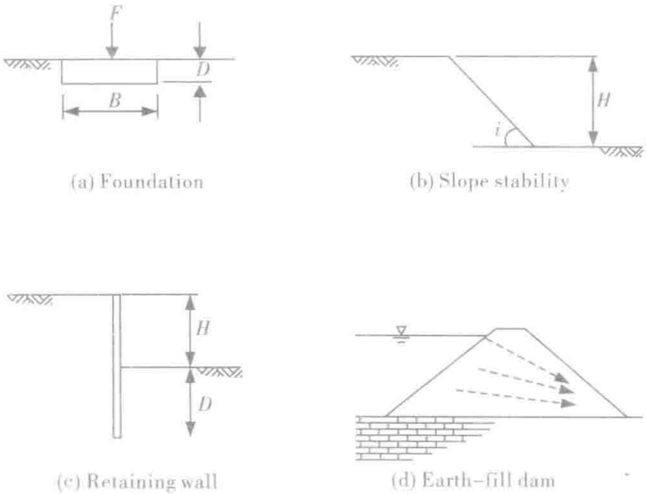

Fig. 1. 1. 1 Geotechnical structures

The structures in Fig. 1. 1. 1 clearly should not fail. There are, however, situation where the material may fail; these include ploughing and flow of mineral ore or grain from storage silo. Solution to problems of this kind can be found using the theories of soil mechanics. Other problems in geotechnical engineering include movement of contaminations from waste repositories and techniques for ground improvement.

1.2 Soil composition and phase relationships

1. 2. 1 Soil composition

Soil is a particulate material, which means that a soil mass consists of an accumulation of individual particles that are bonded together by mechanical or