21世纪全国本科院校土木建筑类创新型应用人才培养规划教材

土力学（中英双语）

主　编　郎煜华
副主编　张国栋　张　华　向先超

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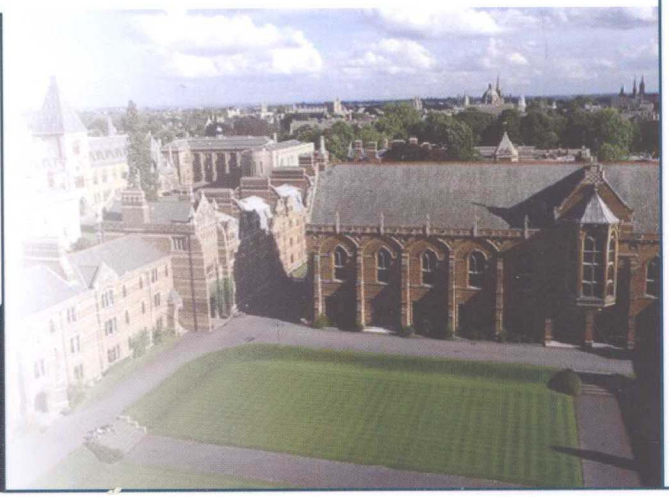

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内 容 简 介

当前，双语教学已经成为衡量高等院校教学水平的基准之一，而开展双语教学最重要的就是要选择合适的教材，其标准有3条：一是学生容易学；二是教师容易教；三是英文要纯正。作者遵循以上标准编写了本书。本书依据国内土力学教学大纲，考虑国内学生和老师的使用特点，参考英国大学本科教材编译而成，且经过两年多班次的本科使用及多次修订而成。

本书共分9章，主要内容包括：土的分类及识别特性，土的渗透性与渗流，土的抗剪强度、应力分析原理，边坡稳定性，侧向土压力，土的承载力，地基沉降和土的压缩性，地基沉降率。每章后均附有习题，书后还附有中英对照土力学词汇表，供学生练习和参考。

本书可作为高等院校土木工程及相关专业土力学双语课程的教材，也可作为相关技术人员的学习参考用书。

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前言

土力学主要研究基础土与土体构造物中的渗透，压缩与强度特性。本书是基于斯密斯土力学原理和一些土力学教材的中文版本编写而成。

本书共分 9 章：第 1 章土的分类及识别特性；第 2 章土的渗透性与渗流；第 3 章土的抗剪强度；第 4 章应力分析原理；第 5 章边坡稳定性；第 6 章侧向土压力；第 7 章土的承载力；第 8 章地基沉降和土的压缩性；第 9 章地基沉降率。每章后均附有习题，书后还附有中英对照土力学词汇表，供学生练习和参考。

很荣幸有机会为土力学中英双语课程的学生编译此书。感谢张国栋博士，张华博士及向先超博士撰写了部分章节。另外特别感谢英国赫瑞特瓦特大学的吴克俭教授的帮助与鼓励！

郎煜华
三峡大学，2011 年

PREFACE

Soil mechanics is focused mainly on seepage, compression and strength in foundation soils and earth structures. The Chinese-English Soil Mechanics is compiled based on the Smith's Elements of Soil Mechanics and some Chinese version of soil mechanics textbook.

There are 9 chapters in this book: 1. Classification and Identification Properties of Soil; 2. Soil Water, Permeability and Flow; 3. Shear Strength of Soils; 4. Elements of Stress Analysis; 5. Stability of Slopes; 6. Lateral Earth Pressure; 7. Bearings Capacity of Soils; 8. Foundation Settlement and Soil Compression; 9. Rate of Foundation Settlement. There are exercises in the end of each chapter, and there is a vocabulary of Chinese-English Soil Mechanics as a appendix.

I am grateful that I had the opportunity to write this textbook for students who choose the Chinese-English Course of Soil Mechanics. As the person in charge, I wish to thank Dr. ZHANG Guo-dong, Dr. ZHANG Hua and Dr. XIANG Xian-chao for their contribution to several chapters. I particularly feel indebted to Professor WU Ke-jian, Heriot-Watt University, for his advice and encouragement.

LANG Yu-hua
China Three Gorges University, 2011

目录 Contents

第1章 土的分类及识别特性

Chapter 1 Classification and Identification Properties of Soil

在土木工程领域里，几乎所有工程都是建造在地面或者地下的。无论是建筑物、道路、隧道还是桥梁，对土木工程师来讲，当地土的性质是非常重要的。岩土工程是指工程领域中与土地相关工程建设的一个分支。土力学是该分支中的一门学科，主要研究土木工程中土的性质。

岩土工程师并不是对土地感兴趣的唯一的专业人士，土壤物理学家、农业工程师、农民和园丁都对与他们相关的土壤问题感兴趣。但是，这些人关注更多的是地表的有机土层，而岩土工程师则主要对表层土之下的工程用土感兴趣，他们关心的是这类土的工程性质和状态。

In the field of civil engineering, nearly all projects are built on to, or into, the ground. Whether the project is a structure, a roadway, a tunnel, or a bridge, the nature of the soil at that location is of great importance to the civil engineer. Geotechnical engineering is the term given to the branch of engineering which is concerned with aspects pertaining to the ground. Soil mechanics is the subject within this branch which looks at the behaviour of soils in civil engineering.

Geotechnical engineers are not the only professionals interested in the ground, soil physicists, agricultural engineers, farmers and gardeners all take an interest in the types of soil with which they are working. These workers, however, concern themselves mostly with the organic topsoil found at the soil surface. In contrast, geotechnical engineers are mainly interested in the engineering soils found beneath the topsoil. It is the engineering properties and behaviour of these soils which are their concern.

1.1 农业用土和工程用土

1.1 Agricultural and engineering soil

如果在原始的未经扰动的土地上进行开挖，常常会遇到下面这些物质(图 1.1)。

1. 表层土

有机土层，通常不超过500mm，

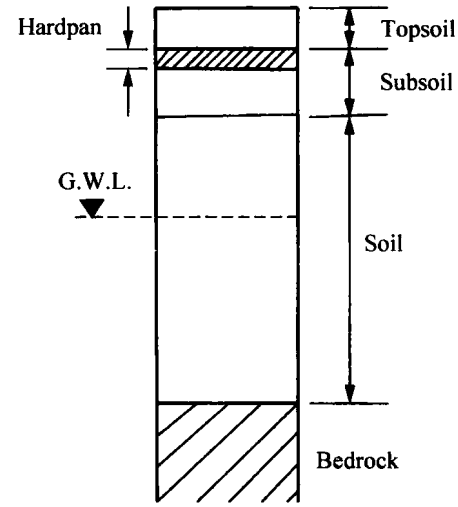
If an excavation is made through previously undisturbed ground the following materials are usually encountered (Fig. 1.1).

1. Topsoil

A layer of organic soil, usually not more than 500

一般含有腐殖质(植物高度腐烂形成的有机质)。

mm thick, in which humus (highly organic partly decomposed vegetable matter) is often found.



Topsoil: 表层土
Hardpan: 硬质层
Subsoil: 次层土
G.W.L.: 地下水位
Soil: 土
Bedrock: 基岩

图 1.1 开挖剖面的物质

Fig. 1.1 Materials encountered during excavation

2. 次层土

地壳受现代风化影响的部分，处于表层土与下面未风化土层之间。

2. Subsoil

The portion of the Earth's crust affected by current weathering, and lying between the topsoil and the unweathered soil below.

3. 硬质层

在潮湿气候条件下，降雨可使腐殖质分解形成腐殖酸。这种酸会使铁和铝的氧化物析出，它们下降到较低的土层中，并作为胶结物，形成硬的像岩石的材料。硬质地层很难挖掘，遇水也不软化，对普通土钻探方法有很强的抵抗。在表层土与次层土的交界处有时会发现硬质层。

3. Hardpan

In humid climates humic acid can be formed by rain water causing decomposition of humus. This acid leaches out iron and alumina oxides down into the lower layers where they act as cementation agents to form a hard, rock-like material. Hardpan is difficult to excavate and, as it does not soften when wet, has a high resistance to normal soil drilling methods. A hardpan layer is sometimes found at the junction of the topsoil and the subsoil.

4. 土

从次层土延伸到基岩的软质地质堆积层。有些土之间有一定的胶结，它们影响着土的物理性质。如果这种胶结形成了像岩石的物质，那么这种物质必须被描述为岩石。一种粗略的判断原则是，如果该物质

4. Soil

The soft geological deposits extending from the subsoil to bedrock. In some soils there is a certain amount of cementation between the grains which affects the physical properties of the soil. If this cementation is such that a rock-hard material has been produced then the material must be described as rock. A rough rule is that if

可以用手或者手工工具进行挖掘，那么它就是土。

5. 地下水

储存于地下的水体。地下水的上表面可以处于地下任何深度，通常称之为地下水位面或者地下水水位。

the material can be excavated by hand or hand tools it is a soil.

5. Groundwater

A reservoir of underground water. The upper surface of this water may occur at any depth and is known as the water table or groundwater level (G.W.L).

1.2 工程定义

地质学家将组成地球地壳的各种材料，无论硬或软沉积，均归类为岩石，而土木工程师则将岩石和土分开考虑。

1.2.1 岩石

岩石由多种矿物组成。矿物是经过特定的化学组合而形成的晶体。岩石中的主要矿物包括石英、长石、方解石和云母。地质学家将所有岩石分为三大基本类别：岩浆岩、沉积岩和变质岩。

1. 岩浆岩

这些岩石由熔融的液体状态变为固体。喷出岩指那些喷出地表的熔融岩浆冷却而形成的岩石。侵入岩指这些熔融岩浆(包括熔化的岩石)侵入地表以下的岩床裂隙中，经过冷凝而形成的岩石。

例如，花岗岩、玄武岩、辉长岩都是岩浆岩。

2. 沉积岩

风化作用使岩石块体变成碎屑，很容易被风、水流和冰川搬运。风化以后，搬运介质被抛下后称为沉积物。这些沉积物通常堆积成层，

1.2 Engineering definitions

Geologists class all items of the Earth's crust as rock, whether hard or soft deposits, While civil engineers consider rock and soil separately.

1.2.1 Rock

Rocks are made from various types of minerals. Minerals are substances of crystalline form made up from a particular chemical combination. The main minerals found in rocks include quartz, feldspar, calcite and mica. Geologists classify all rocks into three basic groups: igneous, sedimentary and metamorphic.

1. Igneous rocks

These rocks have become solid from a melted liquid state. Extrusive igneous rocks are those that arrived on the surface of the Earth as molten lava and cooled. Intrusive igneous rocks are formed from magma (molten rock) that forced itself through cracks into rock beds below the surface and solidified there.

Examples of igneous rocks: granite, basalt, gabbro.

2. Sedimentary rocks

Weathering reduces the rock mass to fragmented particles, which can be more easily transported by wind, water and ice. When dropped by the agents of weathering, they are termed sediments. These sediments

或称为地层，当其同时受到压实和胶结作用后，形成沉积岩。

例如，页岩、砂岩和白垩都是沉积岩。

3. 变质岩

变质岩是岩浆岩和沉积岩经高温高压等变质作用形成的岩石。原有的岩石都经历了化学和物理变化。

变质岩示例：板岩、石英岩、大理岩。

1.2.2 土

经霜冻、温度、重力、风、雨以及化学风化的不断作用形成的岩石颗粒最终形成了土。考虑其成因，通常将土分为3类。

1. 运积土(砾石、砂、粉砂和粘土)

大多数土是由水搬运的。随着小溪或河流的水流速度不断降低，其携带的颗粒中较大、较重的总是先沉积下来。因此，在河流上游多见砾石和砂，而在河流下游或老河段，特别是河流汇入海洋或湖泊处流速降低的地方，则以粉砂和粘土为主。冰川也是另外一种重要的搬运手段，常见的有大型块石、泥砾和冰渍土堆积体。

在世界上的干旱地区，风的不断作用也使砂子堆积形成脊状。这些脊上的砂子基本上在向前滚动，通常形成大小相当均匀的圆形颗粒。浅棕色的风积粉砂又称为黄土，常在薄层中见到，这些颗粒有时被搬运了相当远的距离。

are typically deposited in layers or beds called strata and when compacted and cemented together (lithification) they form sedimentary rocks.

Examples of sedimentary rocks: shale, sandstone, chalk.

3. Metamorphic rocks

Metamorphism through high temperatures and pressures acting on sedimentary or igneous rocks produces metamorphic rocks. The original rock undergoes both chemical and physical alterations.

Examples of metamorphic rocks: slate, quartzite, marble.

1.2.2 Soil

The actions of frost, temperature, gravity, wind, rain and chemical weathering are continually forming rock particles that eventually become soils. There are three types of soil when considering modes of formation.

1. Transported soil (gravels, sands, silts and clays)

Most soils have been transported by water. As a stream or river loses its velocity it tends to deposit some of the particles that it is carrying, dropping the larger, heavier particles first. Hence, on the higher reaches of a river, gravel and sand are found whilst on the lower or older parts, silts and clays predominate, especially where the river enters the sea or a lake and loses its velocity. Ice has been another important transportation agent, and large deposits of boulder clay and moraine are often encountered.

In arid parts of the world wind is continually forming sand deposits in the form of ridges. The sand particles in these ridges have been more or less rolled along and are invariably rounded and fairly uniform in size. Light brown, wind-blown deposits of silt-size particles, known as loess, are often encountered in thin layers, the particles having sometimes travelled considerable distances.

2. 残积土(表土、红土)

这些土在原地经历化学风化而形成，通常位于平缓的岩石表面，元素之间的化学作用产生了残积土，它难以被搬运走。当岩石破碎的速度超过其被搬运的速度时，也可能会产生残积土。如果母岩是岩浆岩或者变质岩，则残积土颗粒大小在粉粒和砾砂之间。

红土是在温暖潮湿的热带条件下，经化学风化而形成的。当雨水将可溶物质溶解后，剩下了不可溶的铁和铝的氢氧化物时，便显示出它们特有的红棕色。

3. 有机土

这类土中含有大量动植物腐烂分解后的物质。它们通常呈黑色，散发着一种特有的气味。有机粉土和粘土的堆积物通常是河相或湖相沉积物。泥炭是一种特殊形式的有机土，是一种深棕色多孔材料，几乎全部由植物轻度或完全腐烂分解而形成。它的存在有 3 种形式。

(1) 纤维状：非塑性的稳定结构，在腐烂过程中结构只有微小的改变。

(2) 似纤维状：这种类型的泥炭有纤维状外貌但比纤维泥炭更软，塑性更强。这种变化多是因为腐烂过程中长期淹没在含较少空气的水下而造成的。

(3) 无定形：这种类型的泥炭在腐烂过程中，原始纤维状植物结构遭到了破坏，因此它实质上已经变成了有机粘土。

泥炭在世界各地广泛分布，给土木工程施工带来极大的麻烦。

2. Residual soil (topsoil, laterite)

These soils are formed in situ by chemical weathering and may be found on level rock surfaces where the action of the elements has produced a soil with little tendency to move. Residual soils can also occur whenever the rate of break up of the rock exceeds the rate of removal. If the parent rock is igneous or metamorphic the resulting soil sizes range from silt to gravel.

Laterite are formed by chemical weathering under warm, humid tropical conditions when the rain water leaches out the soluble rock material leaving behind the insoluble hydroxides of iron and aluminium, giving them their characteristic redbrown colour.

3. Organic soil

These soils contain large amounts of decomposed animal and vegetable matter. They are usually dark in colour and give off a distinctive odour. Deposits of organic silts and clays have usually been created from river or lake sediments. Peat is a special form of organic soil and is a dark brown spongy material which almost entirely consists of lightly to fully decomposed vegetable matter. It exists in one of three forms:

(1) Fibrous: Non plastic with a firm structure only slightly altered by decay.

(2) Pseudo-fibrous: Peat in this form still has a fibrous appearance but is much softer and more plastic than fibrous peat. The change is due more to prolonged submergence in airless water than to decomposition.

(3) Amorphous: With this type of peat decomposition has destroyed the original fibrous vegetable structure so that it has virtually become an organic clay.

Peat deposits occur extensively throughout the world and can be extremely troublesome when encountered in civil engineering work.

1.2.3 颗粒土和粘性土

岩土工程师将土分为颗粒土和粘性土。颗粒土(通常称为无粘性土)由松散颗粒组成，颗粒间没有强大的连接力，如砂、砾石等。粘性土(粘土、粉土)由紧紧粘聚在一起的粘土矿物组成，粘土颗粒呈片状和板状，并吸附了大量的水分在其表面上。层状颗粒相对滑动的能力使得粘性土具有了可塑性。

1.2.3 Granular and cohesive soils

Geotechnical engineers classify soils as either granular or cohesive. Granular soils (sometimes referred to as cohesionless soils) are formed from loose particles without strong inter-particle forces, e.g. sands and gravels. Cohesive soils (e.g. clays, clayey silts) are made from particles bound together with clay minerals. The particles are flaky and sheet-like and retain a significant amount of adsorbed water on their surfaces. The ability of the sheet-like particles to slide relative to one another gives a cohesive soil the property known as plasticity.

1.3 粘土

一般认为岩石碎屑可以通过机械方式减小到0.002mm的极限尺寸大小，因此，含有大于上述尺寸的土颗粒与其母岩的矿物含量相似。

要生成小于0.002mm的颗粒，通常需要在细分之前进行某种形式的化学作用。这些粒子的化学成分虽然与母岩类似，但其晶体结构却不一样，通常称之为粘土颗粒。但岩粉除外，它的颗粒小于0.002mm，主要是由于岩石相互碰撞摩擦的冰川作用形成的。

1.3.1 粘土矿物的分类

构成粘土的矿物基本上都是岩石碎屑化学风化的结果，都是铝、铁的氢氧化物或者硅酸盐，它们通常构成只有几个分子厚度的片状结构。这类薄片由两种基本单元构成，硅的四面体单元和由铝、铁或镁的氢氧化物形成的八面体单元。粘粒

1.3 Clays

It is generally believed that rock fragments can be reduced by mechanical means to a limiting size of about 0.002 mm so that a soil containing particles above this size has a mineral content similar to the parent rock from which it was created.

For the production of particles smaller than 0.002 mm some form of chemical action is generally necessary before breakdown can be achieved. Such particles, although having a chemical content similar to the parent rock, have a different crystalline structure and are known as clay particles. An exception is rock flour, rock grains smaller than 0.002 mm, produced by the glacial action of rocks grinding against each other.

1.3.1 Classes of clay minerals

The minerals constituting a clay are invariably the result of the chemical weathering of rock particles and are hydrates of aluminium, iron or magnesium silicate generally combined in such a manner as to create sheet-like structures only a few molecules thick. These sheets are built from two basic units, the tetrahedral unit of silica and the octahedral unit of the hydroxide of

的尺寸通常都小于 0.002mm，对于不同类型的矿物其内部结构形成的方式也不同。

3 组主要粘土矿物如下。

1. 高岭石组

这种矿物在残余粘土堆积物中占绝大部分，它是由大量的单个四面体硅氧晶片和八面体铝氢氧晶片间隔堆叠而成。高岭石结构稳定，亲水性差。因水含量变化而引起的膨胀和收缩较小。

2. 伊利石组

由一系列单八面体铝晶片层夹在两层四面体硅晶片层中间构成。在八面体层中，一些铝离子被铁、镁离子取代，而在四面体层中，也有部分硅离子被铝离子取代。同高岭石相比，伊利石的亲水性较强，吸水膨胀、脱水收缩的性质较明显。

3. 蒙脱石组

这种矿物的结构类似伊利石，但在四面体层中，有部分硅离子被铁、铝或镁离子取代。蒙脱石亲水性强，具有显著的吸水膨胀、脱水收缩的性质。膨润土就是其中的一个代表，它通常是由火山灰风化而形成的。因其在遇水后具有强大的膨胀性，在水库或者隧道裂缝的灌浆处理中被广泛作为注浆剂使用。它也可以用来作为钻孔泥浆。

1.3.2 粘土堆积物的结构

1. 宏观结构

肉眼可见的粘土堆积物的特征

aluminium, iron or magnesium. The main dimension of a clay particle is usually less than 0.002 mm and the different types of minerals have been created from the manner in which these structures were stacked together.

The three main groups of clay minerals are as follows.

1. Kaolinite group

This mineral is the most dominant part of residual clay deposits and is made up from large stacks of alternating single tetrahedral sheets of silicate and octahedral sheets of aluminium. Kaolinites are very stable with a strong structure and absorb little water. They have low swelling and shrinkage responses to water content variation.

2. Illite group

Consists of a series of single octahedral sheets of aluminium sandwiched between two tetrahedral sheets of silicon. In the octahedral sheets some of the aluminium is replaced by iron and magnesium and in the tetrahedral sheets there is a partial replacement of silicon by aluminium. Illites tend to absorb more water than kaolinites and have higher swelling and shrinkage characteristics.

3. Montmorillonite group

This mineral has a similar structure to the illite group but, in the tetrahedral sheets, some of the silicon is replaced by iron, magnesium and aluminium. Montmorillonites exhibit extremely high water absorption, swelling and shrinkage characteristics. Bentonite is a member of this mineral group and is usually formed from weathered volcanic ash. Because of its large expansive properties when it is mixed with water it is much in demand as a general grout in the plugging of leaks in reservoirs and tunnels. It is also used as a drilling mud for soil borings.

1.3.2 Structure of a clay deposit

1. Macrostructure

The visible features of a clay deposit collectively