

高国瑞 著

近代土质学

(第二版)



科学出版社

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(第二版)

Neoteric Soil Geotechnology

(Second Edition)

高国瑞 著

科学出版社

北 京

内 容 简 介

近代土质学是当前岩土工程和工程地质专业学科的重要组成部分,是把土质学理论和土力学性状有机地结合,并在土结构理论和测试技术上有发展的新的理论体系。用土的成分和结构观点分析土的工程性状是本书的基本内容。本书的重点是以物理化学理论分析土中存在的相互作用,用现代测试技术测定土成分和结构,按空间结构力学原理解释变形和强度机制。本书中插入了大量珍贵的扫描电镜照片。

本书除可供大学本科高年级学生和研究生作教材之用外,还可供建筑、水利、交通、铁路以及其他工业部门从事岩土工程、工程地质、地下工程、土力学地基基础与土工实验的科研、设计、施工、勘察人员参考。

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高国瑞 1927年8月1日生。江苏昆山人。1949年毕业于上海大同大学。曾任南京建筑工程学院教授、成都地质学院客座教授、南京工业大学教授。曾是国际工程地质协会中国国家小组成员、江苏省国际科技中心理事。1956年享受国务院特殊津贴。

1950年参加工作后一直从事岩土工程勘察设计科研及教学工作。1978年率先利用扫描电镜对中国黄土、红土、膨胀土和海洋土进行系统研究，创立了以“土结构理论”为中心的“近代土质学”理论，为发展“近代土质学”奠定了基础。1991年获江苏省科技进步奖二等奖；1995年获国家教委科技进步二等奖。

第二版前言

《近代土质学》第一版是 1990 年出版的，出版后颇受读者的欢迎，特别是 1996 年本书获得国家教委科技进步奖之后，在科技教学界获得普遍好评，尤其是受到科教部门的老师和研究生的普遍欢迎。由于第一版图书早已断货，且不断有要求再版的呼声，故为了满足广大读者的需求，决定再版。

第一版在 20 多年前出版时，由于当时出版印刷技术水平和条件极差，出版物的编辑和印刷质量不能和现在同日而语，特别是扫描电镜照片的质量很难反映土结构三维图像的真实面貌，故在此次再版中，除了增加新的研究内容外，还增加了大量必要的扫描照片。

再版时在每章后面增加必要的英文提要，配合书中新增加的照片、公式和图表，有助于国际同行对本书内容的了解。这些英译文部分是请南京工业大学赵凯博士、武汉理工大学高国猷教授译校的，在此表示感谢。

再版过程中得到南京工业大学交通学院院长陈国兴教授的全力支持，他组织他的博士生阮滨、金丹丹、王炳辉，硕士生叶亚三、尤文浩、刘翔、刘勇、董菲蕃、黄营、童飞、卢小飞对书中图文进行编制整理；同时，也得到了该学院副院长王旭东教授的大力支持，在此对他们一并致以衷心的感谢。

在所有的物质中，土是最常见的。人类与大自然的斗争中，最先遇到的物质之一也是土。人类的衣、食、住、行无一不和土有关系，然而人们对土的认识却远远落后于其他物质。事实上，各个学科对土的认识水平也是不平衡的。当农业科学工作者运用现代科学技术成就研究土的基本性质的时候，为了解决住、行而利用土作为建筑物地基和交通构筑物基础的岩土工程师们却大多还在使用传统的测试方法来确定土的工程性状。显然，这种差距亟待缩小。可是 20 多年过去了，似乎进展不大。

随着现代科学技术的迅速发展，很多高新技术不断向各门学科渗透，促进了这些学科的发展。X 射线衍射技术和扫描电子技术的应用，使工程地质和岩土工程的分析和评价获得新的活力，预示着岩土工程将发生一次极为深刻的飞跃，以摆脱目前进展不快的状况。为了迎接这一技术改革的到来，就应当使从事岩土工程设计、勘察、科研的科技工作者和高等院校的师生们具备这一学科的新的理论和掌握应用这些理论解决实践问题的能力。

以上这些就是我想再版这部著作的动机和目的。

本书的内容主要取材于 20 世纪 70 年代以来在国内外发表的最新科技成果。

由于本书所涉及的领域很广、技术很新，而本人却是才疏学浅，特别是年老体衰，因此不妥之处一定不少，诚恳希望读者指出来，以便修正。

本书中很多观点和意见：如第3章的“非晶质黏土矿物”在土中的影响，第4章的“净势能”理论的应用，第5章的搬运过程中的“分散和集聚”作用，第6章的结构的“概念、层次、要素和命名方案”以及分类鉴别方法，第8章的“变形和强度机制”，第9章和第10章关于“中国区域性土（黄土、红土、膨胀土、海洋土）的成分、结构和工程性质的关系，以及它们的分布规律、形成与发展”等都是在个人见解基础上提出来的。此外，第7章的某些测试技术，如运用X射线能谱分析和激光显微光波分析测定土粒表面微区成分，从而确定胶结连接性质的方法也都是作者初次提出来的。尽管这些都不尽成熟，但却非常重要，20多年过去了，本书再次抛出这些观点向广大读者请教，希望与大家讨论。

本书中关于我国区域性土（如黄土湿陷发展机制和其他各类区域性土的形成等）的研究成果得到过国家自然科学基金的资助，特此加以说明。

Preface to the Second Edition

The first edition of the *Neoteric Soil Geotechnology* received high praise once it was published in 1990. After winning the Prize of Science and Technology Progress of State Education Commission of China in 1996, it became even more popular in the education circles and industrial community, especially among the post-graduate students and university faculties. We are often asked by the readers for reprint of it as the book is already out of stock in the market for a long time. In view of such requests, we decide to publish this second edition.

The print technology was so poor two decades ago that the SEM photos could not illustrate the real state of the soil structures in three dimensions. Therefore, many SEM photos of high quality are included in this second edition besides the new contents.

In order to communicate with the international peers interested in soil geotechnology, the abstracts in english are given at the end of each chapter as well as the table of contents. Hereby the author would express his appreciation to Professor Guoyou Gao at Wuhan University of Technology, who provides these translations.

Special thanks are due to Professor Guoxing Chen, Dean of the College of Transportation Science & Engineering at Nanjing University of Technology, for his enthusiastic help and invaluable assistance in the reprint of this book. The author would also like to give his gratitude to Bin Ruan, Dandan Jin, Binghui Wang, Yasan Ye, Wenhao You, Xiang Liu, Yong Liu, Feifan Dong, Ying Huang, Fei Tong and Xiaofei Lu for their help in editing the manuscript. Professor Xudong Wang, vice dean of the same college, is also gratefully acknowledged for his support in this reprint process.

It is well known that soil is one of the most common natural substances. It is also one of the matters that the humankind confronts first during fighting against nature for living. Soil is related to our basic necessities and daily activities. However, our knowledge of soil is lack seriously behind that of other substances. Actually, levels of understanding on soil among different subjects are of great differences. Most geotechnicalengineers who take soil as the foundation

of building and work base of Transportation construction, still adopt traditional measuring and testing methods to evaluate the engineering properties of soil. However, agricultural scientific researchers, to whom of interest are the grains and cotton planted in soil, apply modern scientific and technological achievements to study the basic properties of soil. It is obviously essential to shorten these distances. After two decades, unfortunately, it still has a long way to go.

Along with the rapid development of modern sciences and technologies, many high-tech fields constantly penetrate into one another to promote their developments. The application of X-rays diffraction and scanning electron technologies makes the engineering geology and geotechnical engineering obtain fresh energy, which indicates an extremely profound leap in the near future. To welcome the coming technical reform, it is necessary to let the scientific workers who deal with geotechnical engineering design, reconnaissance and scientific research, the teachers and students from colleges and universities grasp the new theories of this new subject and obtain the ability to put such theories into practice.

Above is the motivation that the author decides to publish this book.

This book is mainly composed of the scientific and technological achievements published at home and abroad since the 1970s. The author should be responsible for any careless omissions, which are unavoidable due to the development of soil geotechnology covering extensive fields, and sincerely hope that all of you dear friends point them out to improve this book.

Many concepts and opinions provided in this book are proposed by the author. For example, the effects of the “non-crystalline clay mineral” on soil in Chapter Three, the application of the “net potential energy” theory in Chapter Four, the “decentralization and centralization” during transportation in Chapter Five, the “concept, hierarchy, element and naming scheme” of the structure and “classification & identification methods” in Chapter Six, the “deformation and strength mechanism” in Chapter Eight, and the “relationships between the compositions, structures and engineering properties of regional soils in China (Loess Soil, Lat-eritic Soil, Expansive Soil and Marine Soil) as well as their distribution regularities, formation and development”, etc. in Chapters Nine and Ten are all brought forward based on the author own concepts. Chapter Seven covers some measuring and testing techniques presented by the author for the first time, such as using X-rays energy spectrum and laser micro light wave analysis to determine the micro-area compositions of soil grain surface so as to create the method of ce-

menting bond. All of these concepts are very important but not mature enough, thus the author would like to consult and discuss with you dear readers.

It is worthy to mention that the research on regional soils (such as evolution mechanism of loess collapsibility, the formation and distribution of regional soils in China) in this book is supported by the National Natural Science Fund.

第一版说明

随着科学技术的进步和社会经济的发展,近年来国内外有关土质学理论和测试方法的进展迅速,不断涌现出许多新的成果,为土的性质理论研究注入新鲜内容,为岩土工程技术的发展丰富了理论基础。该书作者高国瑞教授数十年来孜孜不倦,潜心从事土的成分、结构和工程性质的研究,取得了一系列可喜成果,他结合国内外最新科学成就,熔东西方学术精华于一炉,辛勤写作了《近代土质学》这本专著,这是我国岩土工程和工程地质学界应该庆贺的事。

20世纪70年代末,该书作者在国内率先应用扫描电镜研究黄土的微结构,对我国土的微结构的研究发展起到了推动作用。随后,作者又对膨胀土、海相黏土和红土等的微结构进行了研究,总结了自然土结构的特征、结构要素以及有关名词和分类等,为土结构研究做出了突出贡献。作者在研究工作中广泛采用扫描电镜、透射电镜、X射线能谱、X射线衍射和热分析等现代测试技术,获得并积累了大量我国各类土矿物成分和微观结构方面的资料和图像,在国内外学术会议及著名学术刊物上发表了多篇有重要价值的论著,并获得与会国内外学术界同行的好评和重视。

《近代土质学》是作者执教于南京建筑工程学院,受聘于成都地质学院兼职教授和博士生导师以来,得以专心从事教学科研和著述工作后的第一部专著。该书总结了作者多年来从事土的微结构研究的成果,并且从理论上和方法上进行了系统化。作者运用成分和结构的观点,系统地研究土工程特性的形成过程,即分析了土颗粒内外相互作用的物理化学反应;论述了土-水-电解质系统中土与水相互作用的物理化学现象和黏粒表面净势能水理性质的机制,从而从根本上理解土的结构和工程性质关系的由来。所以,该书的确是一本内容新颖、论述精微、广收博采,吸收了东西方学术精髓的优秀著作,在不少方面对我国现有土质学、工程岩土学等教材有所更新和提高,值得推崇和借鉴。

该书特色之一是通过土的成分和微结构分析来阐明土的行为贯穿全书,即土的工程性质诸参数直接受控于土的成分及微观结构特征。作者以空间结构力学的观点,从土结构的变形和结构连结的力学分析这一途径来解释土的强度本质和土的变形机制。该书除利用新的测试技术对微观层次做了深入、广泛的研究外,更着力于亚微观领域的研究,经土粒连结结构类型的界定及其力学模型的建立来说明宏观的物理力学行为,探索确立土的强度、变形机制和土结构连结与力学分析之间的相互关系,这是本部著作在理论上的主要特色。作者对于土在受到工程建

筑荷重后发生的力学强度和变形的变化机制，从土的内部结构特点和变化的角度进行了深入的探讨，解决了长期以来土结构研究不能很好地与土特性结合起来研究的欠缺，这是一个重大进步。

该书特色之二是紧密地与我国实际情况相结合，体现了中国特色。该书将成分、微结构分析和土力学行为的理论与我国的各类主要区域性土相结合，论述了这些区域性土（黄土、软土、胀缩土和红土）的微结构特征、形成过程、演变和分布规律以及这些土的某些特殊工程性质的形成机制，这无疑对我国广阔国土上蓬勃发展的工程建设有重要的实践意义。因此，该书是任何国内外著作所不能代替的。

该书特色之三是对土结构的论述最为全面细致，在同类书中堪称独到。作者应用现代测试技术从微观上阐明土结构的本质，运用物质系统论的观点论述了土结构不同层次的意义，分析了结构的基本单元、结构连结和孔隙与排列三个结构要素的作用，提出了结构单元的模式和命名原则。书中土的微结构的名词和术语的内涵、结构层次和要素以及分类体系都是作者从大量微结构研究中获得的实际资料中概括出来的。尽管作者所建议的土结构分类与力学模型未必是最完善的，探索的途径也不一定就是唯一的，但是相信必定能吸引更多的人把智慧的眼光投向这一亟待开拓的研究领域，加速完成从经验到理性的过渡。

该书的出版将对土力学的发展提供新的内容和新的研究领域；对工程地质和岩土工程人才的培养和教学质量的提高、对土质学理论的发展，起到积极推动作用。希望该书也能对我国的工程勘察工作起到一定的指导作用，成为广大读者的良师益友。当然，这并不是说这本书是完善无缺的，欢迎读者提出修改、讨论或补充意见，使这本带有开创性的著作在大家帮助下得到完善。

最后，对下列专家为该书所作的高度评价表示感谢：

中国地质大学著名工程地质学教授张咸恭

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成都地质学院前院长、著名工程地质学教授张倬元

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南京建筑工程学院副院长、岩土工程副教授宰金珉

1989年12月

Preface to the First Edition

Along with the improvement of science and technologies and with the development of social economy, theories on soil geotechnology and related measuring and testing methods have advanced quickly at home and abroad in recent years. Many remarkable achievements have come forth constantly, which open new horizons to the theoretical research on soil behavior and also to the fundamental theory for geotechnical engineering. Professor Guorui Gao, the author of this book, has devoted all his career to the research on the compositions, structures and behavior of soil over the past ten years, making series of outstanding contributions. This monograph accomplished by all his effort represents the state of the art in the regarding research fields, which is no doubt to deserve congratulations in the areas of geotechnical engineering and engineering geology in our country.

The author took the lead in applying Scanning Electron Microscope to the research on the microstructure of Loess Soil in late 1970s, improving the understanding on the soil microstructure in our country. Since then, he extended to the microstructure researches on various soil types such as Expensive Soil, Marine Soil and Lateritic Soil etc., presenting the structure features, structural elements, related terms and classification system of natural soil. The modern measuring and testing techniques such as Scanning Electron Microscope, Transmission Electron Microscope, X-ray Energy Spectrum, X-ray Diffraction and Differential Thermal Analysis etc. are implemented extensively in his research. Lots of valuable documents and pictures concerning the mineral compositions and microstructure of various soil types are accumulated, as a consequence. Most of them are issued by the international academic conferences and famous publications, which obtain high praise from the international counterparts.

The Neoteric Soil Geotechnology is the first monograph during the author's research and teaching career since he started to teach in Nanjing Architectural and civil Engineering Institute and was invited as a guest professor in Chengdu College of Geology. This book summarizes the author's achievements on soil microstructures research during the past ten years, and organizes them theoretical-

ly and practically. From the soil compositions and fabric point of view, the author has systematically studied the formation of soil engineering properties. The physical and chemical processes of the internal and external interactions of soil grains are revealed. Then, both the interaction of soil and water in the soil-water-electrolyte system and the mechanism of net potential energy of grain surface are discussed accordingly to explain the origin of the structures and properties of soil. Above all, "This book is such an excellent literature with novel contents, exquisite dissertation, extensive collection and academic essentials of the orient and occident, which modifies and enhances the existing teaching materials on soil geotechnology and engineering geology etc. in many aspects, and is definitely worthy of your canonization and reference."

This book is firstly characterized by the methodology that the author illustrates the soil behavior through the compositions and microstructures analysis, which runs through the whole book. The engineering properties are directly controlled by the soil compositions and microstructure features. From the spatial structure mechanics point of view, the soil strength and deformation mechanisms are assumed as the deformation of the basic structure units and the structural bonding intensity. Besides using modern measuring and testing techniques to further study microcosmic layers, attention is also paid to the research on the mesoscopic structure, which intends to illustrate macroscopical physic-mechanic behaviors through defining soil grain bonding types and building their mechanical models. Since then, the interrelations between the strength and deformation mechanisms, structural bonding and mechanical analysis are concluded, which is the main character in theory of this book. The author discussed in depth the changeable mechanisms of the strength and deformation of soil induced by engineering activities. This consists the significant improvement of this book as it overcomes the difficulty to couple the soil structure with its mechanical behavior for so long time.

This book is secondly characterized by its representation of the real situations in our country, considering its special Chinese characteristics. This book applies the theories of soil compositions, microstructure and mechanical behavior to study the main regional soils (e. g., Loess, Soft Soil, Expensive Soil and Lateritic Soil) in our country. The microstructure features, formation process, evolution and distribution regularities of these regional soils are thereby discussed as well as the formation mechanisms of their special engineering properties. This is

of great practical significance for the rapid development of infrastructure constructions on our vast land. Anyway, it is irreplaceable among the literatures.

This book is thirdly characterized by its most comprehensive, exquisite and exclusive discussion on soil structure among the counterparts. The author applied modern measuring and testing techniques to explore the essence of soil structure through microcosmic analysis. From the viewpoint of material systematology, the author discussed different hierarchies of soil structure, analyzing the structural basic units, structural bonding and pore as well as the arrangement function of the three structure elements. The modeling and nomenclature principles of the structure units are thus presented, accordingly. The names and terms, structural hierarchy and elements as well as classification system of the soil structure described in this book are all summarized from the extensive review on the microstructure research of various soil types. Neither the soil structure classification nor its mechanical model proposed by the author are perfect, but of course these will attract more researchers' attention to this field, and hence accelerate the transition from practical experiences to theories.

It can be concluded that the publication of this book will open new horizons and research topics for the development of soil mechanics. It will exert positive influence on cultivating young talents of engineering geology and geotechnical engineering, and developing the fundamental theory of soil science. It is hoped that this book could bring certain instructions for engineering reconnaissance in our country, and become a mentor of plentiful readers. Of course, this does not mean that this book is good enough. The author would welcome the readers sincerely to give their any thoughts on the modification, discussion and supplementation for this book. We believe that within your help, this innovative literature would become even better.

Finally, the Press would like to express the deep appreciation to the following experts for their great opinions on this book:

Zhang Xiangong, a famous professor of engineering geology in China University of Geoscience.

Zhang Zonghu, a commissary of the Ministry of Geoscience of Chinese Academy of Sciences and a famous engineering geologist.

Zhang Zhuoyuan, the former president of Chengdu Geology College and a famous professor of engineering geology.

Tang Nianci, a famous professor of geotechnical engineering in Southeast

University.

Zai Jinmin, a vice president of Nanjing Architectural and Civil Engineering Institute and an associate professor of geotechnical engineering.

December of 1989

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第二版前言

第一版说明

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