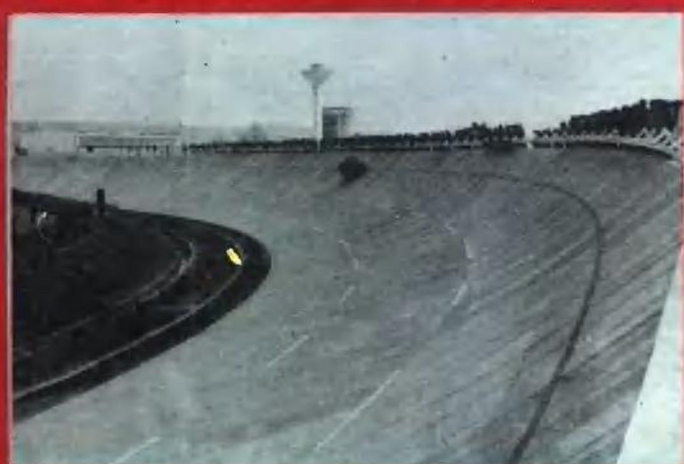
中国膨胀土工程地质研究

李生林 等著

国家自然科学基金资助项目



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内 容 简 介

本书扼要阐述了膨胀土工程地质研究领域的中心课题、研究观点和研究路线，重点介绍了膨胀土微观结构研究的新理论和新技术，系统展示了我国各地典型膨胀土的区域研究成果，结合具体工程论证了运用生石灰改良膨胀土胀缩性的机理与效果，较详细地讨论了运用塑性图判别膨胀土的理论与实践。

本书可供从事各类工程建筑的勘察、设计、和施工的工程技术人员，以及大专院校土木工程和工程地质专业的师生参考。

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Studies on the Engineering Geology of Expansive Soils in China

Li Shenglin
Qin Sujuan
Bo Zunzhao
Shi Bin

The Project Supported by National Natural Science Foundation of China

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前　言

膨胀土是颗粒高分散、成分以粘土矿物为主、对环境的湿热变化敏感的高塑性粘土。它的主要特征是：1.粒度组成中粘粒（<2μm）含量大于30%；2.粘土矿物成分中，伊利石—蒙脱石等强亲水性矿物占主导地位；3.土体湿度增高时，体积膨胀并形成膨胀压力；土体干燥失水时，体积收缩并形成收缩裂缝；4.膨胀、收缩变形可随环境变化往复发生，导致土的强度衰减；5.属液限大于40%的高塑性土；6.属固结性粘土。具有上述2、3、4项特征的粘土类岩石称膨胀岩。

膨胀土分布十分广泛，它在世界六大洲中的40多个国家都有分布，中国是其中分布广、面积大的国家之一。我国先后已有20多个省区发现有膨胀土。

膨胀土常给人类的工程活动带来危害，并造成全球性的地质灾害。美国工程界称膨胀土是"隐藏的灾害"。日本工程界称膨胀土是"难对付的土"，"问题多的土"。有人曾估计，全世界每年因膨胀土造成的经济损失大约为50亿美元以上。

我国膨胀土造成的灾害更是触目惊心。如湖北郧县为避丹江口水库淹没而就地迁城于汉江的二级阶地，六年后新城由于膨胀土地基的危害，在30万m^2的房屋中有90%以上变形开裂，无法使用，造成经济损失达2000多万元。据不完全统计，我国由于膨胀土地基致害的建筑面积达1000万m^2左右。铁路、公路受其危害的情况也很严重，穿越膨胀土的铁路竟有"逢堑必崩，无堤不塌"之说。又如襄渝铁路由于膨胀土灾害，每公里造价提高91.64万元。膨胀土不仅危害工程建筑，而且往往还是形成崩塌、滑坡、泥石流等地质灾害的缘源。

1978年南京大学地质系组建膨胀土科学研究组，对膨胀土灾害的条件、发育规律和防治措施开展了系统的专题研究。由于课题研究的重要理论意义和实际的应用价值，即时得到了国家自然科学基金的有力支持。课题研究成果于1980年获江苏省重大科技成果奖。

本书是我们膨胀土科研组十余年来从事中国膨胀土工程地质研究的全面、系统的总结，书中重点反映了课题研究中下述几项具突破性的成果。

一、土体结构及其地质成因的研究是现代土质学研究的基石。在课题研

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究中，运用土体的概念加强了对膨胀土土体地质成因及其宏观结构方面的研究，克服了前人研究中不重视地质研究的缺陷。在开展大量区域性研究的基础上，掌握了不同地区膨胀土的物质材料来源、形成与演化条件及地质结构特征，为提出有针对性的防治措施奠定了基础。通过对广西贵县及柳州膨胀性红粘土全面研究得出结论，它们并不是碳酸盐岩石的风化残积物，而是复杂地质成因的结果。

二、研究者已普遍认识到矿物成分对膨胀土胀缩性的控制意义。本书运用X射线衍射、X射线能谱、红外光谱、透射电子显微镜及化学全分析等手段，半定量地分析和鉴定了各地区膨胀土矿物成分的特征。正确地评价了矿物成分对土的胀缩性的影响，强调指出了认为膨胀土的矿物成分必然是以蒙脱石为主的模糊认识。土体胀缩性能的强弱不仅与其矿物成分有关，而且尚受其颗粒的分散程度、结构特征等因素控制。如以伊利石为主、自然高分散、具层流状微结构的广西宁明强膨胀土就是很好的一例。

三、研究土体的微观结构特征及其与土的工程地质性质的关系，是当代土质学最新水平的体现。体现这一水平的关键是微结构研究试样的脱水干燥问题。课题组于1985年组装的真空冷冻升华干燥备样仪解决了这一难题，填补了我国在这方面的空白，并使我国的土体微观结构研究跻身于世界先进行列。此外，本书对粘土微观结构研究的指导原则，粘土微结构名词术语等的论述，均将对我国土的微结构研究起重大的推动作用。

四、在研究我国膨胀土的交换阳离子与其胀缩性的关系方面有重要发现。发现高含交换性 Mg^{2+}离子的土具有较强的膨胀和收缩性质。对此类土可采用一定数量的生石灰掺料削弱其胀缩性。这一措施不仅在理论上是有依据的，而且在实践中也是可行的。河南平顶山公路总段及山东泰安公路管理段等单位运用此法改良膨胀土路基取得了成功。

五、课题虽属基础理论研究，但在研究进程中也尽可能地注意到理论联系生产实际，为工程建设解决实际问题，并在这方面取得了较好的经济与社会效益。如为解放军总后勤部安徽定远汽车试验场高速环道膨胀土路基提出的治理方案，不仅保证了工程的质量，而且也为该项工程节约了数百万元的投资。应该说，在这方面还仅仅是开始。本书所阐明的基础理论和方法将为今后继续作好这方面的工作奠定基础。

最后，课题组提出的利用塑性图判别膨胀土的方法解决了膨胀土（包括膨胀性红粘土）的判别问题。经过全面众多地区大量的实际资料证明，它是一种简单易行、准确可靠的判别方法。准确的判别是预测和防治膨胀土灾害的前题。可喜的是，该方法已纳入土分类国家标准（GBJ145—90），并自

1991年8月在全国正式推广使用。

参加膨胀土课题研究的除秦素娟、薄遵昭、吴兰洲等同志外，尚有我的历届硕士研究生：施斌、曹小强、刘松玉、汪永新、邢光春和陈浩东等同志。他们在导师指导下，紧密围绕研究课题的中心，结合我国不同地区的典型膨胀土或重大工程完成了硕士论文。本书有一些章节就是取材于他们的硕士论文。从这个意义上说，本书又是教学与科学研究的密切相结合的产物。

本书共八章。第一章论述的是中国膨胀土工程地质研究的中心课题、研究路线和方法，是统帅课题研究的大纲。第二章介绍的是膨胀土的一般工程地质特征，简要阐明了膨胀土土体的地质成因、物质组成和组织结构等方面的基本研究内容、观点和方法。第三章展示的是对我国广西宁明、贵县、柳州，湖北郧县、河南平顶山、安徽合肥等主要膨胀土进行区域研究的成果，是课题研究取得上述重要成果的基础。本章较好地体现了作者倡导的"宏观指导微观，微观解释宏观"的研究路线。第四章膨胀土研究中的工程实录，反映的是课题研究为解决几项工程中膨胀土灾害的具体实例。第五章介绍的是膨胀土经人工击实和掺料生石灰后所产生的效应及其机理。书中反映的情况仅仅是我们改良膨胀土工程性质的一个开端，这项工作我们仍在继续探索之中。第六章在综述已有判别分类方法的基础上，重点介绍了运用塑性图判别膨胀土的理论与实践。本章在结合膨胀土的胀缩等级评价中，推荐采用模糊数学及灰色系统理论的评价方法。第七章介绍的是课题研究中的新技术与新方法。重点介绍自制的冷冻真空升华干燥备样仪的工作原理、仪器结构和干燥效果。升华干燥仪不仅是研究膨胀土，也是研究高含水软土微结构的必要条件。另外，本章还简介了微结构图像的定量处理及微结构定向度的研究方法。膨胀土活动带深度的准确定量研究一直是膨胀土区工程、建筑设计者所密切关注的问题。本章结合山东泰（安）莱（芜）路工程介绍了运用土吸力法解决膨胀土活动带深度的经验。为摸清膨胀土的发育规律，搞清它们的胀缩性质和提出有针对性的防治措施，做好工程地质勘察是关键。为此，第八章简介了膨胀土区工程勘察的基本原则和要点，对适宜于采用的勘察方法也有述及。

为了便于国际交流，在全书中文之后附有诸章节的英文摘要。

本书诸章节的主要执笔者是——李生林：前言、1.1、1.2、1.4、2、3.1、3.3、3.4、3.5、4.1、4.3、5.1、5.2、5.3、6.1、6.2、7.1、8；秦素娟：1.1、1.3、3.1、3.2、3.3、4.1、4.2、4.3、7.1；薄遵昭：1.2、1.4、3.1、3.2、3.3、7.1；吴兰洲：3.1、3.2、3.3、7.1；施斌：1.5、3.4、4.3、5.1、5.2、6.3、7.1、7.2、7.3和全书的英文翻译；曹小强：4.1；刘

松玉：4.2、5.3、6.4；汪永新：3.5；陈浩东：4.3、7.4。

全书由李生林定稿。施斌为全书图片的整饰和出版准备做了大量的工作。

在膨胀土的野外调查研究中，曾得到广西综合建筑设计院勘察队的领导，广州部队后勤部张世煊高级工程师，湖北综合勘察院侯石涛高级工程师，河南水文地质三队的领导及任润虎工程师，安徽省高等级公路工程指挥部领导等诸同志的大力协助。在膨胀土室内试验研究中曾得到中国科学院南京古生物研究所扫描电子显微镜室，河海大学水文研究所遥感室李士鸿工程师及南京地质矿产研究所水汀同志的热心帮助。南京大学地球科学系中心试验室黄耀生高级工程师对设计组装冷冻真空升华干燥仪曾给予热情的支持。作者在此对上述同志一并表示深切的谢意。

对本书的希望和批评请寄：210008，南京市汉口路11号，南京大学工程勘察研究所，作者对此将不胜感谢！

李生林

1992年7月

Preface

Expansive soil is a natural, highly dispersive and plastic one, which contains mainly clay minerals and is very sensitive to either a dry or wet environment. Its main features are: 1. It has a clay content($< 2\mu$) of more than 30% of all fractions; 2. It contains clay minerals such as illite, montmorillonite, kaolinite and their mixed-layer minerals with a strong water affinity; 3. When its moisture content increases(or decreases), its volume will expand(or shrink), forming swelling pressure(or shrinking fissures); 4. As the moisture content of its environment changes, its swelling and shrinkage will occur alternately, thus reducing its strength; 5. It has a liquid limit of more than 40%; and 6. It is an overconsolidated clay. The rock with the features of 2, 3 and 4 is called the expansive rock.

Expansive soil is widely distributed in the world and found in more than 40 countries and regions. China is one of the countries with a large distribution of expansive soils, which have successively been discovered in its more than 20 provinces and regions. It is mainly lacustrine, residual, slopewash, alluvial and diluvial in origin.

Because of its wide distribution and serious harm, expansive soil has been thought of as a geological hazard not to be ignored in the world. In the U.S.A., it is called the "hidden hazard." According to reports, the economic losses caused by expansive soils amount to $ 2.3 billion per year, far more than the total losses caused by floods, earthquakes and windstorms put together. In Japan expansive soil is called the "difficult soil" and the "problem soil," for it often brings about foundation deformation, frost soil and the mud pumping of many roadbeds, the heaving of tunnel archs and landslides of embankments, etc. Such expansive soil hazards are found in many countries. It is estimated that the economic losses caused by it exceeds $ 5 billion annually in the world.

The hazards of expansive soil in China are also very serious. For example, to build the Danjiangkou Reservoir, the city of Yun in Hubei province was moved to the second terrace of the Han River. The new city of Yun was built in 1976. After six years, because of lack of knowledge of expansive soil, 90% of its houses, totalling a floor space of 0.3 million m^2, became deformed and cracked, and a floor space of more than 5,000m^2 of houses could not be used, with immediat economic losses adding up to more than ¥ 20 million. According to incomplete estimation, the houses destroyed by expansive soil amount to a floor space of 10 million m^2 per year in China. The hazards of expansive soil often occur along the railways and highways. It is said the "there is no cut that will not cause slides" and "there is no embankment that will not collpase" in regions of expansive soils. For example, when the Zhangyu Railway was built, the cost per kilometer increased to ¥ 916.4 thousand due to expansive soil, which not only undermines engineering construction but causes collapses, landslides, and debris flows in regions of expansive soils.

In 1978, the Department of Earth Sciences of Nanjing University set up a task group of expansive soil. Since then, a number of special topics, such as the forming conditions, the pattern of development and the controlling measures of expansive soil hazards, have been studied. And not long after its formation, the task group received financial assistance from the National Natural Sciences Foundation due to the theoretical and applicable value of its work.

The book is a comprehensive and systematic summary based on the results of the research conducted by the task group in the past decade, and stresses and introduces the following research achievements, i.e., achievements which have made breakthroughs:

A. The study of soil mass structures and the geologic origin of soils is the foundation of modern soil engineering geology. With this in mind, the task group strengthened the study of the geologic origins and macro–structures of expansive soil masses and made up for what the geologic circles had long ignored in their research. Based on a great deal of regional studies, it clarified the material sources, the forming and evolving conditions and the geological structural characteristics of expansive soils in different areas, and this would be the basis of putting forward to corresponding controlling project for expansive soil hazards. The systematic studies of expansive laterite in Guixian and Liuzhou showed that expansive laterite is very complex in origin; it is not eluvial one coming from weathered carbonate rock.

B. The researchers have realized the significance of mineral composition for controlling the swelling and shrinkage of expansive soil. Therefore, this book introduces the application of X–ray diffraction, infrared spectrum analyses, TEM, and chemical analyses in the semiguantative analyses and examination of expansive soil's mineral composition, thus assessing correctly its effect of mineral composition on the swelling and shrinkage of soil and putting right the wrong concept that morillonite is certainly the main element of strongly expansive soils. The swelling and shrinkage of soil are not only related to its mineral composition, but also controlled by the dispersion of grains, the structure of soil mass, etc. For example, strongly expansive soil in Ninming, Guangxi, is the naturally dispersed soil, and its main clayey mineral is lillite, not montmorillonite.

C. Research on the relations between the microstructures and engineering geological properties of soils incarnates the latest research level in contemporay engineering geology. The key to reaching this level is how to dewater and desiccate specimens. In 1985, the task group assembled a freeze–vaccum–sublimation desiccator(FVSD), with which this problem of preparing specimens was solved, and which filled the gap in China so as to enable China to enter the world's advanced ranks in the study of soil microstructures. In addition, some chapters and sections of the book, concerned with the guiding principles of the study of soil microstructures and their terminology, will have an important effect on the study of soil microstructures across China.

D. The book presents an important discovery while studying the relations between the exchange cation and swelling–shrinkage of expansive soil. The authors discovered that the swelling–shrinkage of expansive soil which contains exchange cation Mg^{2+} is quite high in content, and that of the expansive soil admixed with a certain amount of lime reduces. This discovery has not only been supported by theory, but also applied successfully in practice. For example, this method has been successfully applied in improving the expansive soil roadbed in Pingdingshan and Tai'an. The result has been very good.

E. While the study was theoretical, it gave great attention to application. By using its results many engineering problems have been solved and some economic and social benefits made. For example, the project for treating the expansive soil roadbed of the high speed circle of Ding Yuan Automobile Testing Field, a projecr proposed by the task group, not only saved the investment of more than ¥ 1 million, but also guaranteed its engineering quality. Work on application was only a beginning, and the basic theories and methods provided in the book have laid the foundation for the next stage of work.

F. The task goup proposes that the plasticity chart be used as a tool for distinguishing expansive soils. A great deal of experimental data obtained across the country have proved that the plasticity chart is a simple, accurate and feasible method for distinguishing expansive soils. Distinguishing expansive soils correctly is a prerequisite to predicting and controlling expansive soil hazards. It is joyful to the authors that the method has been included in the Standards of Soil Classification (GBJ 145–90), a code which has been in force since August 1991.

In addition to my colleagues Qin Sujun, Bo Zunzhao, and Wu langzhou, Shi Bin, Chou Xiaoqian, Liu Songyi, Wang Yongxin, Xieng Guancheng and Cheng Haodong, all of them my graduate students, participated in the work of the task group. Under my guidance, they focused on the group's work in their master theses. Some chapters and sections of the book are taken from their theses, therefore, the book is also the product of combining teaching with scientific research.

The whole book consists of 8 chapters. Chapter 1 deals with the guiding principles of the study, and its fundamental problems, research guideline and methods. Chapter 2 focuses on the general engineering geological characteristics of expansive soils and gives a brief introduction to the major subjects, viewpoints and methods in the studies of geological origin, material composition and structures of expansive soils. Chater 3 is concerned with regional research results, which form the basis of the study. The expansive soil areas studied include Ninming, Guixian, Liuzhou, Yun County, Pingdingshan, Hefei, etc. Chapter 4 is devoted to several engineering cases on controlling expansive soil hazards. Chapter 5 expounds and discusses the compaction and lime effects of expansive soils and their mechanisms. This work is only a beginning, and further work remains to be done. Chapter 6 deals mainly with the theory and practice of distinguishing expansive soils by means of the plasticity chart. The mathematical methods of "Fuzzy" and the grey system theory are introduced for determining the swelling–shrinkage grades of expansive soils. Chapter 7 presents

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the new techniques and methods used in the study, e.g., the principles, strurture and drying effectiveness of the Freeze–Vacuum–Sublimation Desiccator(FVSD), a device which was assembled by the task group itself. The DIPIX Image Processing System, the D / MAXⅢA Auto Fabric Goniometer and the Filter Paper Method for determining the depth of the active zone of expansive soils are also presented in this chapter. In order to grasp the pattern of development and the swelling–shrinkage properties of expansive soil and provide the corresponding measures for controlling its hazards, it is essential to do well in engineering geological prospecting and investigation. Therefore, Chapter 8 discusses the basic principles, main points and methods of engineering geological prospecting and investigation in the expansive soil areas.

The authors are grateful to their colleagues in Guanxi, Guanzhou, Hubei, Henan, Anhui, etc. for the assistance they lent during their filed work. They also want to extend special acknowledgement to Zhang Shixuan, Hou Shitao, Ren Renhu, Mao Yongqiang, Li Shihong, Shiu Ding and Hung Yaosheng who gave the authors much support and help during their field investigations and conducted a series of sample tests in the labs.

Prof. Li Shenglin

July 1992

目　　录

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中国膨胀土工程地质研究的指导原则

1.1 研究的核心问题

我国膨胀土分布很广，据报道在河北、河南、山东、陕西、湖北、广西、广东、云南等省区均有发现。膨胀土对建筑事业造成的损失颇为严重，已是我国工程地质学、土质学、土力学及基础工程等学界众所关注的一大问题。

本节拟以我们近年来对我国各地膨胀土的地质考察及试验研究为基础，同时参考国内外有关资料，阐明对我国膨胀土科学研究中几个问题的看法。

一、含义、命名和判别方法

关于膨胀土的含义曾在第二次国际膨胀土研究会议上有过讨论，结论是膨胀土是一种对于环境变化，特别是对于湿热变化非常敏感的土，其反映是发生膨胀和收缩，产生膨胀压力。影响土的膨胀性的主要矿物是蒙脱石。

在我国文献中，所谓膨胀土指的是一种具有吸水膨胀，失水收缩的粘性土，其主要矿物成分是蒙脱石–伊利石，或伊利石–蒙脱石。与国际上的含义相比，少掉了产生膨胀压力的内容。应指出的是所有粘性土都具有遇水膨胀、失水收缩的性质。当然，不能将所有的粘性土都说成是膨胀土。可见，关于膨胀土的含义仍是值得进一步讨论的问题。

我们认为，吸水膨胀和失水收缩是粘性土的共性，亦是其区别于非粘性土的主要特性之一。当粘性土的胀缩性增大到一定程度，产生膨胀压力或收缩裂缝，并足以危害单层砖石结构建筑物的稳定与安全时，便可将其作为一种特殊土从中独立出来，称“膨胀土”。这是膨胀土的定性含义。

全国第二次膨胀土专题研究会议制定了专门的判别方法，提出自由膨胀率 $F_s>40\%$ 为膨胀土的判别指标，以 $W_L>40\%$，液性指数 $I_L<0.25$ 为判别参考指标。通过对我国膨胀土塑性指标的研究与统计，我们认为利用塑性图是定量判别膨胀土的简易方法。当土的塑性指标在塑性图（图 1.1）上满足 $W_L>40\%$ 和位于 A 线（$I_P=0.63(W_L-20)$）以上时，便可将其判为膨胀土，并以代号 CHE 表示。

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