陕南膨胀土及其灾害地质研究

STUDIES ON EXPANSIVE SOILS AND ITS HAZARD GEOLOGY OF THE SOUTH OF SHAANXI

肖荣久　等著

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内 容 简 介

膨胀土及其灾害地质的研究是现代工程地质学发展中的一个新领域。本书专门讨论了陕南膨胀土及其灾害地质问题。全书共分十章内容，包括陕南膨胀土分布的地质背景与膨胀土的类型、膨胀土的工程地质特性、物质组成成分、微观结构特征、胀缩机理、判别与分类、膨胀土地基和膨胀土斜坡的灾害地质问题、陕南膨胀土工程地质图及陕南膨胀土的工程地质勘察等。本书是一本比较系统的研究陕南膨胀土及灾害地质的基本理论与工程实践的专著。

本书可供从事各类工程建筑的勘察、设计、施工的工程技术人员、以及大专院校工业与民用建筑专业和工程地质专业的师生参考。

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前 言

膨胀土是一种吸水膨胀、失水收缩，具有较大胀缩变形能力的高塑性粘性土，即使在一定的荷载作用下，它仍然具有胀缩变形能力。

膨胀土在世界分布十分广泛，它在六大洲中的40多个国家都有分布。我国先后发现有膨胀土的省区达20多个，是世界上分布较广、面积较大的国家之一。

膨胀土给人类的工程活动带来危害，已成为全球性的地质灾害，估计每年的经济损失约在50亿美元以上。我国有人估计，每年因膨胀土灾害带来的经济损失约达10亿元左右。

陕西省境内秦岭以南汉江流域的汉中盆地、西乡盆地、安康盆地广泛分布着膨胀土（陕南汉江流域膨胀土分布地理位置图），由于土体的胀缩变形及其滑坡灾害等，导致工程建筑和农田的破坏，给我省和人民造成了巨大的经济损失。如襄渝铁路早阳至安康西的七里沟段，全长约32.8 km通过膨胀土地层，据1978年统计，路基下沉塌陷，翻浆冒泥，边坡剥落、溜塌、滑坡等十分严重，甚至许多防护与加固工程也被摧毁。仅1974年9、10月间，一次久旱后的连绵阴雨，竟使全段已竣工路基工程，有一半以上遭受不同程度的破坏。又如汉中盆地的城固某厂，因连续几年发生膨胀土滑坡，使建筑物变形开裂及倒塌多次，该厂1973年为治理滑坡投资300余万元。勉县某中型工厂，曾因膨胀土滑坡的发生拖延了基建工期，1973年为治理膨胀土滑坡投资达170余万。更有甚者，在陕南汉江流域因膨胀土灾害破坏而无法挽救的工厂，只好停工停产。膨胀土灾害在陕南，不仅给厂矿企业造成经济损失，在农业上也是一大灾害。据陕西省滑坡普查队于1989年7月在西乡县境内的十二个滑坡点（群）调查，农田地面开裂、沉陷、鼓包和被挤压，甚至使稻田漏水，房屋被拉裂破坏，水利设施受损达几十处，给农业生产带来极大威胁。因此，开展膨胀土及其灾害地质研究，不论在理论上或实践方面，对陕南的国民经济及建设都具有十分重要的意义。我院1989年向地矿部地质行业基金委员会申请，以题为“陕南膨胀土及其灾害地质研究”的科研项目，经过1990～1993年的研究，在以下几方面取得了成果：

1 以试验资料为基础，通过X—射线衍射分析、差热分析、透射式电镜鉴定及化学分析等方法，研究了陕南膨胀土的物质成分，即粒度成分、粘土矿物成分、化学成分及物理-化学特征；

2 利用偏光显微镜和扫描电子显微镜，研究了陕南膨胀土的微观结构特征；

3 通过大量的土工试验，测试了陕南膨胀土的物理力学性质及胀缩特性，为工程建设提供了科学的参考试验数据；

4 根据野外普查的地质、地貌、成因类型及岩性特征对陕南膨胀土进行了分类；结合陕南膨胀土的物质成分、微观结构特征，深入地探讨了膨胀土内在胀缩变形的机理；

5 根据陕南膨胀土特有的物质成分、工程地质特性，应用多变量数学分析、模糊理论和灰色系统理论，提出 了陕南膨胀土的判别与分类的方法；

6 根据陕南膨胀土地基上建（构）筑物开裂损坏，研究了建筑物破坏机理和膨胀土的灰土改良，并提出膨胀土地基胀缩变形的预防措施；

7 通过对陕南膨胀土滑坡灾害的大量调查，研究了膨胀土滑坡灾害的发生规律和机理，提出防治斜坡灾害的措施；

8 陕南膨胀土类型、工程地质性质及胀缩特性的研究，结合陕南汉江流域的地质、地貌、膨胀土堆积成因类型，编制了陕南膨胀土工程地质图；

9 根据陕南膨胀土工程地质图的分区，提出陕南膨胀土工程地质勘察的要点。

上述研究成果，对膨胀土灾害的条件、发育规律、发生机理和防治措施等理论方面以及陕南工农业建设规划、设计和施工等实践方面将是有益的文献，因此，该项研究具有重要理论和实际应用意义。

全书共分十章。第一章重点介绍了陕南膨胀土分布的地理位置及水文、气象、区域地质、地貌条件及陕南膨胀土的类型与分布；第二章主要论述了陕南膨胀土的工程地质特性，即基本物理性质、水理性质、胀缩特性及力学性质；第三章论述陕南膨胀土物质成分，即粒度成分、主要粘土矿物成分、化学成分及物理－化学特征等；第四章介绍了陕南膨胀土的微观结构特征；第五章论述了陕南膨胀土的胀缩变形机理，即在不同膨胀土微观结构基础格架上，粘土矿物颗粒晶格扩张、水化膜楔力作用下，导致陕南膨胀土产生出不同膨胀潜势的膨胀土；第六章在介绍国内外膨胀土判别与分类现状基础上，提出应用多变量数学分析函数式判别方法及应用模糊综合评判、灰色系统理论对陕南膨胀土的分类；第七章介绍了陕南膨胀土地基灾害及其破坏机理、加灰改良试验研究以及预防地基胀缩变形危害的措施；第八章论述了陕南膨胀土斜坡灾害，特别是膨胀土滑坡破坏的特性规律和机理以及防治措施；第九章介绍了陕南膨胀土工程地质图的编制原则和工程地质分区；第十章阐述了膨胀土工程地质勘察的阶段、重点内容、场地与地基评价及勘察方法。全书由肖荣久、王桂增、于芳等整理撰写，最后由肖荣久定稿。

参加“陕南膨胀土及其灾害地质研究”项目研究工作的有王桂增、赵强、邓媛华、付积慧、于芳、刘满全、高世祥、祁晓丽、李敏、夏慧民等。在陕南膨胀土及灾害地质调查研究中，曾得到汉中地区、安康地区及西乡县抗震防灾办公室、城建局、建筑设计院、建筑学会及航空航天部零一二基地设计院等的大力支持和帮助；在试验分析研究中曾得到西北水利科学研究所、中科院水土保持研究所、煤炭科学研究院西安分院、陕西应用物理化学研究所、能源部热工研究所及西安建筑科技大学等单位实验室的热情帮助；科研项目申请、实施、管理等得到西安地质学院院、系、科研处、陕西省第一水文地质工程地质队等领导及同志们的热情支持和帮助。在此对上述各单位及同志一并表示深切谢意！此外，胡广韬教授、李生林教授、曲永新研究员、关文章教授级高工、范世凯教授级高工、顾安全教授、韩文峰教授 在百忙中对本成果进行了评审，作者在此向他们表示深切的感谢！

最后，向资助本课题的地质行业科学技术发展基金委员会表示衷心的感谢！

肖荣久

1994 年 12 月

PREFACE

Expansive soil is a kind of high plasticity clay with considerable ability of swell-shrinking deformation swelling when absorbing water and shrinking when losing it's water. Even though acted by load, it still remains this capability.

Expansive soils are widely dispersed in the world. There are more than fourty countries all over six continents where expansive soils are distributed . China, whose provinces where expansive soils are successively discovered have exceeded twenty, is one of the country in the world with wide spread expansive soils.

Expansive soil brings about great demages to human engineering action and has been a global geological hazard bringing on economic losses about five billion dollars every year. It has been estimated in our country that the economic losses caused by expansive soil hazard annually amount to one million or so.

Expansive soils are widely spread in Hanzhong basin, Xixiang basin and Ankang basin of Han River basin to the south of Qinling mountains in Shaanxi province. Landslides cause damages to buildings and farmland, and bring about enormous economic losses to Shaanxi province and it's people. For instance, 32. 8 km. long section of Xiangyu railway between Zhaoyang and Ankang across expansive soil area. According to the Statistics in 1978, a number of geological hazards including roadbed subsidences, boilings and pumpings, collapses and landslides occured, and caused serious damages, even many protected and stabilized projects were destroyed. Merely during the period from Sep. to Oct. in 1974, induced by an unbroken spell of wet weather after a long drought, more than half of the completed roadbeds were damaged in varying degrees. For another example, buildings deformed and collapsed many times in a factory in Chenggu county because of landslides of expansive soil in successive years. In order to control landslides, 3,000,000 yuan or more had been invested in 1973. In another medium—sized factory in Mianxian, time limit of capital construction was prolonged on account of landslides of expansive soil and over 1,700,000 yuan had to be spended in landslides prevention in 1973. Furthermore, factories in Han River basin damged by hazards on expansive soil, if could not be retrieved, would have to be closed. Not only did hazards on expansive soil in the south of Shaanxi province cause economic losses to factories, mines and other enterprises, but also did harm to agriculture. According to the investigation on twelve landslide spots (groups) in Xixian county made by Shaanxi general survey team of

landslides in Jul. 1989, farmland was caused to rift, subsident and blow up, even the rice field was caused to leak water, buildings were destroyed and tens of water conservancy facilities were damaged. All of these seriously imperilled agricultural production. Therefore, studying on expansive soil and it's calamity geology has great significance to national economy and it's construction of southern Shaanxi. In 1989, Xi'an College of Geology applied for a scientific research project named "the study on expansive soil and it's calmity geology in the south og Shaanxi province " to geological fund committee of geology and mineral resource department. Based on the studies from 1990 to 1993, we have obtained following achievements.

1. On the basis of test data, the mass composition of expansive soil in the south of Shaanxi including granular composition, clay mineral composition, chemical composition and it's physical—chemical characteritics have been studied by the application of X—ray diffraction analysis, differential thermal analysis, TEM and chemical analysis.

2. The microstructural features of expansive soil in the south of Shaanxi have been studied by means of polarizing microscope and scanning electron microscope.

3. The physical and swell-shrinking characteristics of expansive soil providing scientific reference test data for project construction have been tested by means of a great deal of soil test.

4. Expansive soil in the south of Shaanxi have been classified according to geology, geomorphology, forming factors and soil characteristics, and the inherent swell — shrinking machenism of expansive soil has been throughly discussed in the light of mass composition and microstructural features of expansive soil.

5. In accordance with peculiar mass composition and engineering geological properties of expansive soil, the differentiation and classification methods of expansive soil have been proposed by means of multi-variable mathematical analysis, fuzzy theory and grey systematic theory.

6. According to the dao e of bulidings on the foundation of expansive soil, the machenism of the damage of buildings and improvement of expansive soil with adding in ash content have been studied, and measures to prevent swell—shrinking deformation of expansive soil foundation have been proposed.

7. Based on a great number of investigation on landslides, the regularity and mechanism of landslides in the area of expansive soil have been studied, and measures to prevent hazards on slope have been put forword.

8. Engineering geological map of expansive soil in the south of Shaanxi has been compiled by means of the study of expansive soil, engineering geological characteristics and it's swell—shrinking property combining with geology, geomorphology and forming factors of expansive soil in southern Shaanxi Han River basin.

9. The emphasises of engineering geological investigation have been proposed in accor-

dance with engineering geological zoning of expansive soil in the south of Shaanxi province.

The afore-mentioned studies are of great value to theoretical studies including condition of hazards on expansive soil, developing regularity, forming mechanism and preventive measures, and to practices including industrial and agricultrial planning, designing and construction. Therefore, the studies are of great significance on theoretical and practical application.

This book is separated into ten chapters. Geographical position of expansive soil, hydrology, climate, reginal geology and geomorphology, and types and distributions of expansive soil are emphatically introduced in Chapter 1. In Chapter 2, the author chiefly discusses engineering geological characteristics of expansive soil in the south of Shaanxi including basic physical characteristics, hydrological characteristics, swell—shrinking property and dynamic property. In Chapter 3, the author discouses mass composition of expansive soil including granular composition, major clay mineral composition, chemical composition and physical—chemical features et al. Microstructural features of expansive soil in the south of Shaanxi are introduced in Chapter 4, and swell—shrinking deformation mechanism of expansive soil is discussed in Chapter 5. The author explains that on the basic skeloton of microstructure of expansive soil, expansion of crystal lattices of clay mineral and the force of water—film cause expansive soil in the south of Shaanxi to produce expansive soil of various swelling potential. In Chapter 6, the author proposes to apply multi—variable mathematical analysis formula, comprehensive Fuzzy model, and grey systematic theory to classify expansive soil on the basis of introducing the differentiation and classification status of expansive soil at home and abroad. Hazards on expansive soil foundation and it's damage machenism, the study of improvement test with adding in ash content, and measures to prevent damages caused by swell—shrinking deformation of expansive soil foundation are introduced in Chapter 7. In Chapter 8, hazards on expansive soil slope, especially the regularity and mechanism of landslides of expansive soil, and preventive measures are discussed. In chapter 9, the auther introduces the principle of compiling engineering geological map of expansive soil in the south of Shaanxi and engineering geological zoning. In the last chapter, the stage, emphatic content, site and foundation evaluation and method of engineering geological investigation of expansive soil are expounded. The whole book is composed by Xiao Rongjiu, Wang Guizheng and Yu Fang, and finalized by Xiao Rongjiu.

Person who paticipates in the study of expansive soil and it's calamty geology are Wang Guizheng, Zhao Chiang, Deng Yuanhua, Fu Jihui, Yu Fang, Liu Manquan, Gao Shixiang, Qi Xiaoli, Lin Min, Xia Huimin et al. The auther wishes to express his most sincere thanks to Earthquake Resistance and Calamty Prevention Office, Urban Construction Bureau, Architecture Designing Institute, Architectual Society and Designing Institute in base 012 of the ministry of aviation in Hang zhong, An kang and Xi xiang for all their support and help in the study of expansive soil and it's calamity geology. Tremendous thanks are owed to the laboratories of Northwest Hydraulic Institute, Water and Soil Consevation Institute of the

Chinese Academy of Sciences, Shaanxi Institute of Applied Physics and Chemistry, Xi'an Academy of Coal Science, Thermal Engineering Institute of Energy Resource Department and Xi'an University of Architectural Science and Technology who enthusiastically offered help during the course of test analysis and study. Finally, the author is very grateful to Xi'an College of Geolgy for their fervent support and assistance in application, implementation and administration of the project. I also wish in particular to thank prof. Hu Guangtao, prof. Li Shenglin, prof. Qu Yongxin, prof. Guan Wenzhang, prof. Fan Shikai, prof. Gu Anquan and prof. Han Wenfeng for their reading and appraising the report in the midst of pressing affairs.

Finally, I'm greatly grateful to Geological Industry Science and Technology Development Foundation Committee for supporting the project.

Xiao Rongjiu

Dec. 1994 Xi'an

目 录

PREFTER

第一章　陕南膨胀土分布的地质背景与膨胀土的类型

一　陕南膨胀土分布的地理位置及水文、气候条件

1　陕南膨胀土分布的地理位置

陕南是指陕西省境内秦岭以南广大区域的简称。膨胀土在陕南汉江流域、嘉陵江流域、丹江、洛河流域的盆地及河谷中均有分布，但以汉江流域的汉中盆地、西乡盆地及安康盆地分布最广泛，是膨胀土集中分布区(图 1-1)。膨胀土分布面积约 1 300 km²，占汉江流域中三个盆地面积的 1/2 以上。

(1) 汉中盆地膨胀土分布地理位置

大体为近东西向山间盆地。盆地地势北高南低，东西长约 102 km，南北最宽地段处于褒河-胥水河间，宽约 25～30 km，向东收缩，闭合于洋县龙亭，西端因有梁山突起楔入，将其分为勉县、南郑两个分叉，勉县向西闭合于武侯镇，南郑向西闭合于新集。面积为 1 700 km²。地理坐标：东经 106°40′～107°40′，北纬 32°55′～33°15′。行政区划横跨汉中专区的勉县、南郑、汉中、洋县、城固等五县。

(2) 西乡盆地膨胀土分布地理位置

该盆地位于汉江南侧的牧马河中段，西北与汉中盆地东南边缘的低山丘陵相邻，南邻米仓山北麓，呈北东走向的山间盆地。盆地地势西南高，东北低，长约 21 km，宽 9 km，面积 152 km²。地理坐标：东经 107°40′～10.°52′，北纬 32°50′～33°05′。行政区划属汉中专区，横跨西乡县。

(3) 安康盆地膨胀土分布地理位置

西起马池，东至安康，由马池、汉阴、安康三个小盆地组成的狭长状的山间盆地，盆地呈西北-南东向展布，长约 72 km，宽 3～10 km，面积为 396 km²。地理坐标：东经 108°16′～109°06′，北纬 32°40′～32°55′。行政区划属安康专区的石泉、汉阴、安康三县。

2　陕南膨胀土分布区的水文条件

陕南汉江流域水系发育。汉江及其支流牧马河、月河，分别横贯于汉中盆地、西乡盆地、安康盆地(见图 1-1)。

(1) 汉中盆地水文条件

汉江由西向东穿流于盆地并成为盆地的主干河流。据汉中地区水文站资料，7～8 月为洪水期，历年最大流量 13 200 m³/s；4～6 月为平水期，历年最小流量 8.8 m³/s；汉江支流褒河、濂水河、冷水河、文川河、胥水河、溢水河、沙河、漾家河、党水河等，使盆地水系发育，并且使其

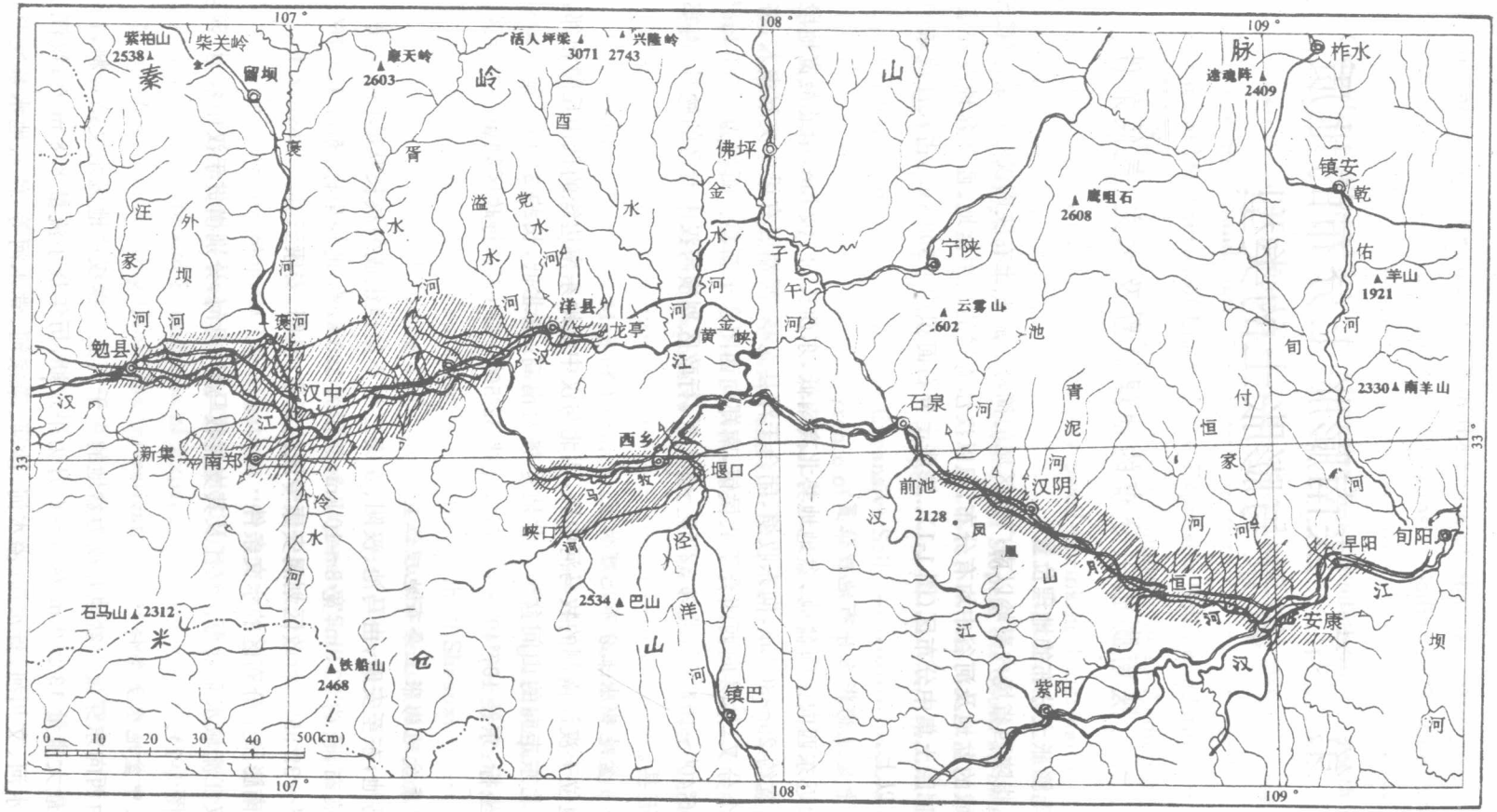


图 1-1　陕南汉江流域膨胀土分布地理位置图

丰富的地表迳流常年补给盆地中的地下水。

(2) 西乡盆地水文条件

牧马河由西南向东北方向流入汉江，成为盆地的主干河流，其盆地内的流程长约 24 km。牧马河平均流量 56.8 m^3/s，最大流量 3 030 m^3/s，最小流量 5.10 m^3/s。主要支流有泾洋河、杨河、沙河等。地表迳流水量丰富，常年补给盆地中的地下水。

(3) 安康盆地水文条件

月河由北西向南东方向流入汉江，盆地内水系发育，大量的支流汇于盆地。汉江平均流量为 626 m^3/s，最大流量为 20 400 m^3/s，最小流量为 44 m^3/s。月河平均流量为 29.7 m^3/s，最大流量 3 070 m^3/s，最小流量 0.45 m^3/s。丰富的地表迳流成为盆地地下水的重要补给源之一。

3 陕南膨胀土分布区的气候条件

陕南汉江流域中三个盆地均属凉亚热带气候，温热潮湿，雨量充沛。四季气候特点是冬春干旱，夏季多暴雨，秋季阴雨连绵。

(1)汉中盆地气候条件

根据汉中气象站的观测资料，干旱时间较长，年平均日照时间为 1 769.9 h。历年平均气温 14.3 ℃，极端最高气温 38.0 ℃，极端最低气温 −10.1 ℃，历年平均蒸发量 1 088.6 mm。降雨时间较短但集中，月连续降雨日可达 18～28 d，日最大降雨量达 117.8 mm，盆地内个别地区可达 160 mm，历年平均降水量 871.8 mm，年均相对湿度 79 %，湿度系数 0.85。汉中地区月均蒸发力与降水量如表 1-1 所示。

表 1-1 汉中地区蒸发力与降水量表

月　份	1	2	3	4	5	6	7	8	9	10	11	12
蒸发力 (mm)	14.2	20.6	43.6	60.3	94.1	114.8	121.5	118.1	57.4	39.0	17.6	11.9
降水量 (mm)	7.5	10.7	32.2	68.1	86.6	110.2	158.0	141.7	146.9	80.3	38.0	9.3

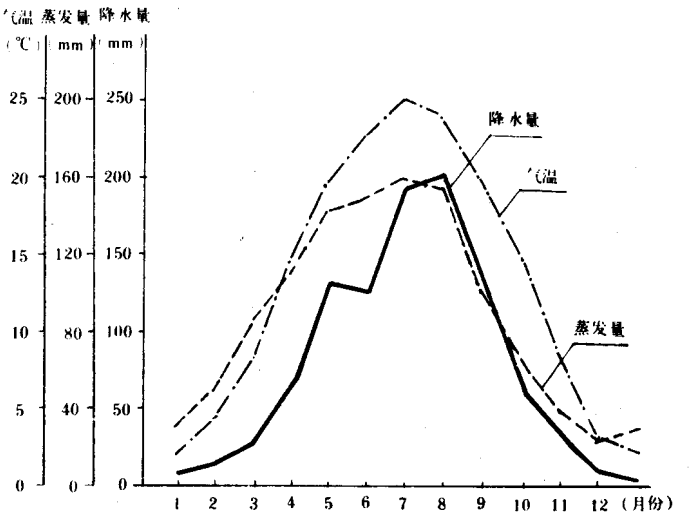
(2) 西乡盆地气候条件

据西乡县气象站观测资料，年平均气温 14.2 ℃，极端最高温度为 38.1 ℃，极端最低温度为 −8.2 ℃。冬春易旱，历年平均蒸发量达 1 094.3 mm，年平均日照时间为 1 698 h。历年平均降水量为 893 mm，秋季阴雨连绵，5～9 月份降水占年降水量的 80 %，年均相对湿度 80.3 %(图 1-2)。

(3) 安康盆地气候条件

根据安康地区气象站资料，历年年均气温为 15.7 ℃，极端最高气温为 41.7 ℃，极端最低气温为 −9.5 ℃。历年平均蒸发量为 1 482.5 mm，年均日照时间为 1 811.4 h，历年平均降水量为 799.3 mm，降水集中在 6～9 月，约占年降水量的 60 %，年均相对湿度 73 %，潮湿系数为 0.56，属于湿度不足带。安康地区月均蒸发力与降水量，如表 1-2 所示。

陕南汉江流域属于凉亚热带气候，具有冬春干旱，秋季阴雨连绵的特点，这就为陕南膨胀土提供了充分干缩，连续集中遇水膨胀的条件。因此，陕南汉江流域气候条件，成为膨胀土以年为单位，具有随气候变化而往复胀缩变形的重要的基础因素。



月　份	1	2	3	4	5	6	7	8	9	10	11	12
蒸发量(mm)	91.9	50.2	87.9	114.0	145.0	149.4	160.1	150.9	87.7	67.6	39.1	6.7
降水量（mm）	5.0	8.5	26.3	65.8	128.0	125.6	18.3	199.2	176.2	59.3	34.3	7.8
气　温（℃）	2.4	4.5	9.0	14.8	19.6	29.1	24.9	24.5	19.8	14.9	9.1	3.3

图 1-2　西乡气象要素曲线图

表 1-2　安康地区蒸发力与降水量表

月　份	1	2	3	4	5	6	7	8	9	10	11	12
蒸发力（mm）	18.5	27.0	51.0	67.3	98.3	122.8	132.6	131.9	67.2	43.9	20.6	16.3
Ⅱ降水量（mm）	4.4	11.1	33.2	80.8	88.5	78.6	120.7	118.7	133.7	70.2	32.8	7.0

二　陕南膨胀土分布的区域地质地貌条件

1　地质构造及地层岩性

(1) 汉中盆地基础地质构造及地层岩性

汉中盆地地处秦岭纬向褶皱带与大巴山元古台拗褶皱带之间，为一近东西向新生代构造断陷盆地。盆地北界为略阳-洋县-宁陕活动断裂带，东界为龙头山-洋县活动断裂带，其西界及南界无明确的断裂构造限定，大体靠近勉县及南郑。

由钻探及物探资料揭示，盆地的岩浆岩、变质岩、沉积岩基底，受多条东西向、北东向、北西向断裂分割、错动，形成诸多相间分布的小型地堑和地垒，使基底凹凸悬殊急剧多变。在文川河以西，大体形成四个断陷中心，它们是忍水-安坎断陷(南郑)，基底海拔－400 m，是最深的一个断陷；高潮-王家坪断陷(勉县)，基底海拔－100～－150 m；汉中-铺镇断陷(汉中)及沙河营断陷(城固)，基底海拔－100 m。

据汉中盆地的最新地层古生物研究资料，在其西段的勉县地区，包括有第四系和第三系；