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# ENGINEERED SLOPES IN CHINA

– Approaches and Case Studies

# 中国典型工程边坡



The Three Gorges Reservoir Volume

三峡库区卷



中国三峡出版社  
China Three Gorges Press

# ENGINEERED SLOPES IN CHINA — Approaches and Case Studies

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### 三峡库区卷

中国长江三峡水利枢纽工程是当今世界最大的水利水电工程。地处山区，成库区域沿长江干流绵延574km。规划动迁移民120多万人，迁建12座县城（城市）、116个集镇。伴随大规模移民工程建设，形成了大量类型各异的工程边坡。包括残坡积土、崩滑堆积体、填土、膨胀土等土质边坡，块状、层状、碎裂结构等岩质边坡。根据不同类型边坡的工程特性，采用了喷锚、格构、挡土墙、抗滑桩及桩板墙、明洞急流槽、锚固抗剪洞、柔性防护网、排水等多种工程防护措施，同时建立了边坡变形专业监测系统。

本图册采用大量典型图片，并结合典型工程实例，系统介绍了三峡库区主要边坡类型与变形破坏模式、边坡防护的主要工程措施，以及边坡防护工程与周边环境相协调的建设成果，展现了三峡移民城镇的新风貌和边坡工程防护的新成就。

The Three Gorges Project is the largest hydropower complex in the world. The reservoir covers a total length of 574 km along the Yangtze River. More than 1.2 million people have been resettled, and 12 counties and 116 towns have been moved. Accompanying the large-scale construction of the relocation project, all kinds of engineered slopes are formed, including the slopes made of residual soil, clinosol, colluvial deposit, earth filling, swelling soil, and the rock slopes with various structures. According to the engineering characteristics of different types of slopes, many kinds of reinforcement measures have been adopted, such as shotcrete, frame beam, retaining wall, slope stabilizing piles and sheet-pile wall, open cut tunnel chute, anchorage shear keys, flexible protecting net and drainage. A system for monitoring the slope deformation has been established at the same time.

This book presents many photos and selected cases on engineered slopes in the reservoir area. It systemically introduces the principal types of slopes and their deformation and failure modes, main engineering measures for slope protection, as well as slope protecting projects and construction achievements. This book also exhibits the new views of immigrant towns on the reinforced slopes.

封面设计  
杨大昕



The Three Gorges Reservoir Volume

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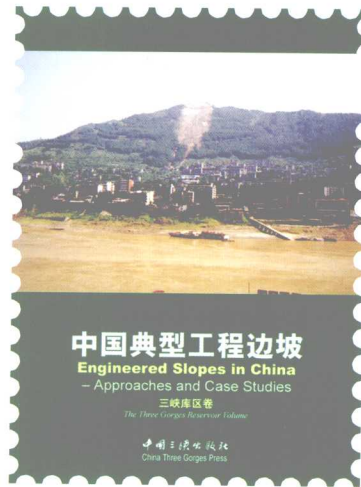
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## 内 容 提 要

中国长江三峡水利枢纽工程是当今世界最大的水利水电工程, 地处山区, 成库区域沿长江干流绵延574km, 规划动迁移民120多万人, 迁建12座县城 (城市), 116个集镇。伴随大规模移民工程建设, 形成了大量类型各异的工程边坡, 包括残坡积土、崩滑堆积体、填土、膨胀土等土质边坡, 块状、层状、碎裂结构等岩质边坡。根据不同类型边坡的工程特性, 采用了喷锚、格构、挡土墙、抗滑桩及桩板墙、明洞急流槽、锚固抗剪洞、柔性防护网、排水等多种工程防护措施, 同时建立了边坡变形专业监测系统。

本图册采用大量典型图片, 并结合典型工程实例, 系统介绍了三峡库区主要边坡类型与变形破坏模式, 边坡防护的主要工程措施, 以及边坡防护工程与周边环境相协调的建设成果, 展现了三峡移民城镇的新风貌和边坡工程防护的新成就。

本书可供土木、水利、交通、地质灾害防治等领域的工程技术人员和高等院校师生参考使用。

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# 序言

我国相当一部分国土处于崇山峻岭，遭受的滑坡和泥石流灾害十分严重。正在进行的大规模重大工程建设中的边坡稳定问题也至关重要。矿山、水利以及交通工程中发生的滑坡灾害带来了巨大的人员伤亡和财产损失。与此同时，三峡、小浪底以及青藏铁路等工程的成功建设也积累了大量的宝贵经验。

致力于减轻地质灾害和边坡工程研究的中国工程师和学者非常荣幸有机会主办2008年第10届国际滑坡与工程边坡会议。经讨论，我们决定出版有关中国滑坡和工程边坡的两套姐妹画册。中国典型滑坡画册由殷跃平博士主编，于2007年12月出版。中国典型工程边坡画册分别包括矿山工程卷、交通工程卷、水利水电工程卷及三峡库区卷。现在，我们非常高兴地看到，在各位同仁的共同努力下，该系列画册的出版已经成为现实。

本系列画册描述了工程建设中的一些重要的滑坡实例。盐池河滑坡和韩城电厂地面变形是由于地下开采引起的两个典型例子。前者掩埋了一个村庄，导致284人死亡；后者对边坡的变形和破坏影响持续了20年之久。由开挖引起的滑坡失事比较普遍。天生桥二级、小湾及漫湾等水电工程的教训值得我们重视。干将坪滑坡是三峡水库蓄水后的一次失事实例，尽管128人成功撤离，但仍导致了24人死亡。还有大量的位于黄土地区、寒冻土地区和沙漠地区的公路与铁路边坡，独具中国特色。

该系列画册还包括了若干成功的重大工程边坡实例。三峡船闸高边坡开挖石方量达 $22 \times 10^6 \text{m}^3$ ，应力释放问题受到普遍关注，争论热烈，现在已经得到了答案。小浪底进、出口边坡位于第三纪砂岩与厚黏土夹层之上。在这个边坡布置了165m高土石坝的全部引水系统，施工期及运行期的成功运用，对这个黄河上的主要工程的安全极为重要。锦屏拱坝高达304m，开挖深度达530m，边坡坡度陡峻，达1:0.5~1:0.3。读者还会惊叹于那些描述三峡工程120万移民新城镇的图片。为了确保这些边坡的安全我们做了大量的工作。

我们真诚地感谢国务院三峡工程建设委员会办公室、中国水电工程顾问集团公司、中国矿业大学（北京）以及中交第一公路勘察设计研究院有限公司提供的经济资助以及在收集资料方面所做的努力；特别感谢那些提供宝贵图片和文档的人员，虽然不能在此一一列出他们的名字；特别感谢谭国焕教授、岳中琦教授、吴宏伟教授和殷建华教授，是他们组织人员进行了翻译；特别感谢苏宝纨女士，她和她的助手们志愿翻译了四卷画册的中文。没有他们的努力，该画册英文内容的出版几乎是不可能的。

陈祖煜  
凤懋润

# Foreword

With its large and mountainous topography, China has suffered from serious landslide and mudflow hazards. The large-scale economic construction has also raised serious slope stability concerns. Catastrophic landslides happened in the engineered slopes created in mining, hydropower and transportation projects, bringing huge losses of human lives and properties. On the other hand, valuable experiences have been obtained from many successful engineering slopes such as those involved in the projects of Three Gorges, Xiaolangdi, and the Qinghai – Tibet Railway, etc.

The Chinese engineers and scholars working on geohazard mitigations and slope engineering are particularly privileged to have the opportunity of hosting the 10th International Symposium on Landslides and Engineered Slopes in 2008. After a warm discussion, we decided to publish the sister-volumes of albums entitled ‘Landslides in China – Selected Case Studies’ and ‘Engineered Slopes in China – Approaches and Case Studies’ respectively as gifts to the Symposium. The landslide volume was edited by Dr. YIN Yueping and published in December, 2007. This ‘early bird’ brought great pressure and encouragement to us who had taken the responsibility of compiling the latter, an even big collection that consists of 4 volumes concerned with slopes of mining, highway and railway, water resources and hydropower, and the Three Gorges Reservoir projects respectively. We are happy to see that this album has now come to reality as a result of the joint efforts made by our colleagues working on different industrial and civil areas.

This album describes some important slope failure cases in engineering. The landslide of Yanchihe and the large ground movement of the Hancheng Power Plant are typical examples of slope failures induced by underground mining. The former buried a village and killed 284 people, and the latter caused more than 20 years sustaining slope movement and damages to the power plant. Landslides triggered by excavations are common and the slope failure cases of Tianshenqiao II, Xiaowan and Manwan projects are certainly worthwhile to be studied. Qianjianping Landslide is one case of slope failure caused by filling of the Three Gorge reservoir. Although 128 people had successfully evacuated, it still resulted in 24 fatalities. Still many engineered slopes on highways and railways in the area of loess, frozen soil and desert are specific in China.

This album contains a number of large-scale successful engineered slopes. The navigation lock of the Three Gorges project involves an excavation of  $22 \times 10^6 \text{ m}^3$  rocks and the issue of stress release had been a serious concern, to which the answer is available now. The intake and outlet slopes of the Xiaolangdi Project were built in Tertiary inter-bedded sandstones with thick clay seams. As these slopes accommodate all water diversion facilities of this 165 m high embankment dam, the successful performance during construction and operation has been a great contribution to this key project in the Yellow River. The left abutment of the 304 m high Jinping arch dam necessitates a 530 m deep excavation with a sloping of 0.5–0.3 (H) on 1 (V). Readers will also be impressed by the pictures that describe the new cities for the 1.2 million resettlement people of the Three Gorges Project. Tremendous efforts have been made to ensure safe performance of these slopes.

We would like to extend our sincere thanks to Office of Three Gorges Construction Council under the State Council, China Hydropower Engineering Consulting Group Corporation, China University of Mining & Technology, Beijing and CCCC First Highway Consultants Co., Ltd for their financial support and efforts in collecting all the necessary information. Special thanks also go to those who offered their valuable photos and documents. To mention them one by one appears to be impossible, but their contributions will be remembered. We are particularly indebted to Professors George Tham, Zhongqi Yue, Charles Ng, and Jianhua Yin from Hong Kong, who organized the English translation work. We are especially grateful to Mrs. So Po Yuen, Cynthia, who edited the English language voluntarily for all the 4 volumes based on her technical assistant’s work. Without their effort, the English texts of this book would not have been made possible.

CHEN Zuyu  
FENG Maorun

# 目录

## Contents

●	序言	Forword
1	前言	Preface
6	<b>1. 三峡库区城镇建设地质背景</b>	
7	Geologic Background to Town Construction in the Three Gorges Reservoir Areas	
6	1.1 地理环境	
7	Geographical Environment	
8	1.2 地质环境	
10	Geological Environment	
14	<b>2. 三峡库区主要边坡类型与变形破坏模式</b>	
15	Slope Types and Deformation Failure Modes in Three Gorges Reservoir Areas	
14	2.1 库区高边坡的区域特征	
15	Regional Characteristics of High Slopes in Three Gorges Reservoir Areas	
20	2.2 库区主要边坡类型及其变形破坏模式	
21	Main Slope Types and Their Deformation Failure Modes in the Three Gorges Reservoir Areas	
36	<b>3. 三峡库区边坡防护主要方式</b>	
37	Slope Protection Methods in Three Gorges Reservoir Areas	
36	3.1 喷锚支护	
37	Shotcrete - Anchor Bar Supporting	
39	3.2 格构护坡	
39	Frame Beam Protection for Slopes	
43	3.3 挡土墙	
44	Retaining Wall	
45	3.4 抗滑桩及桩板墙	
46	Slope Stablizing Piles and Sheet-Pile Walls	
50	3.5 明洞急流槽	
51	Open Cut Tunnel Chute	
52	3.6 锚固抗剪洞	
52	Anchorage Shear Key	
53	3.7 柔性防护	
53	Flexible Protection	
54	3.8 边坡排水	
54	Slope Drainage	
56	3.9 监测预警	
57	Monitoring and Early-warning	



## 62 4. 边坡防护与环境协调

64 Harmony between Slope Protection and Environment

62 4.1 边坡治理与移民新城风貌

64 Slope Treatment and Scene of New Resettlement Towns

67 4.2 边坡防护与城市景观相协调

67 Harmony between Slope Protection and Townscape

68 4.3 边坡防护与文化特色相融合

68 Integration of Slope Protection and Culture

70 4.4 边坡防护与绿化美化相映衬

70 Slope Protection Hand in Hand with Beautification and Greening

72 4.5 边坡防护与开发利用相结合

72 Integration of Slope Use and Protection

## 74 5. 典型边坡治理工程

75 Typical Slope Treatment Projects in Three Gorges Reservoir Area

74 5.1 重庆市奉节县“夔门之都”道路改造与边坡治理工程

75 The Road Reconstruction and Slope Treatment Project for the “Capital of Kuimen” in Fengjie County, Chongqing city

79 5.2 猴子石滑坡治理工程

80 The Treatment Project for the Houzishi Landslide

84 5.3 武隆县城柏杨坪边坡主要采用格构+锚杆进行治理

84 Slope Treatment for Baiyangping Slope in Wulong County --- Frame Beam + Anchor Bar

86 5.4 巫山县新城集仙中路高57m加筋土挡墙

87 The New City is Built in a Valley with Multiple Gullies that Make Flat Plains Highly Demanding



# 前言

长江三峡水利枢纽工程是当今世界上在建的最大水利水电工程。自1994年开工建设以来，工程建设和移民搬迁安置进展顺利。2003年6月成功实现了蓄水至135m水位、五级船闸通航、首批机组并网发电等初期目标。2006年10月，水库蓄水位进一步提高到156m。按照设计，至2009年将全部建成，水库正常蓄水位达到175m，总库容 $3.93 \times 10^{10} \text{m}^3$ ，其中防洪库容 $2.216 \times 10^{10} \text{m}^3$ ，水电站装机总容量 $1.82 \times 10^4 \text{MW}$ ，平均年发电量 $8.84 \times 10^{10} \text{kW} \cdot \text{h}$ ，万吨级船队可通达水库上游重庆港。三峡工程具有防洪、发电、航运等巨大综合效益。

长江三峡工程坝址位于湖北省宜昌市三斗坪。成库区

域为狭长河谷型水库，库区范围沿长江干流段长574km，支流库段主要有香溪、大宁河、小江、乌江等50余条较大一级支流，总岸线长度约5300km。水库水面面积约 $1000 \text{km}^2$ ，其中淹没陆域面积约 $600 \text{km}^2$ 。

三峡库区移民工程涉及湖北省、重庆市的20个县（区）及其所辖277个乡镇，包括湖北省宜昌市夷陵区、秭归县、兴山县、巴东县，重庆市巫山县、巫溪县、奉节县、云阳县、万州区、忠县、开县、石柱县、丰都县、涪陵区、武隆县、长寿区、渝北区、巴南区、江津区、重庆主城区等。其中受淹没影响需要全迁或部分迁建的县城（城市）有秭归、兴山、巴东、巫山、奉节、云阳、万



库区新城（巴东）

A new city by the reservoir (Badong County)



新建的码头 (巴东)  
A new harbor (Badong County)

州、忠县、开县、丰都、涪陵、长寿12座县城（城市）。动迁移民120多万人，搬迁工矿企业1629家，复建公路820km，桥梁198座。

长江三峡工程库区地处山区，地形起伏大，地质条件复杂，环境容量有限。在进行大规模移民工程中，随着一座座移民新城镇的建设，不可避免形成了大量的工程边坡。其中分布于城镇人口密集区和重要工程设施影响区、需要采取防护工程措施的边坡共有2874处，坡面面积 $8.38 \times 10^6 \text{m}^2$ 。中国政府高度重视三峡库区的边坡防护工

作，安排了专项资金，制定了实施规划，采取了有效的防护工程措施，以保证边坡的稳定，防止发生灾害事件。

三峡库区移民工程经过十多年的建设，已经初见成效。12座移民县城（城市）、116个集镇都已经基本完建。三峡库区新风貌已经展示在世人的面前，库区基础设施日益完善，经济发展步入良性循环的轨道，社会事业不断进步，移民群众安居乐业。在移民搬迁安置、生态建设、环境保护、地质灾害治理等方面积累了丰富的经验，是大型水利移民工程的成功范例。



库区新城 (巫山)  
A new city by the reservoir (Wushan County)

## PREFACE

The Yangtze River Three Gorges Project is the largest hydropower-complex project under construction in the world. Since commencement of the project in 1994, construction and resident relocation have made smooth progress. First phase goals including impounding water level to 135 m, ship lock navigation, combining the first batch of units to the grid had been achieved by June 2003. The reservoir water level had been raised to 156 m by October 2006. According to the design schedule, the Three- Gorges Project will be completed in 2009. After completion, its normal pool level will be 175 m, the total capacity of the reservoir will be  $3.93 \times 10^{10} \text{ m}^3$ , the flood control storage will be  $2.216 \times 10^{10} \text{ m}^3$ , the installed capacity of

hydropower station will be 18,200 MW, the average annual energy output will be  $8.84 \times 10^{10} \text{ kW}\cdot\text{h}$ , and 10,000 DWT commercial ship fleets will reach the Chongqing Harbor upstream of the reservoir.

The dam of the Three Gorges Project is located on Sandouping, Yichang City, Hubei Province. The reservoir is a long narrow valley one 574 km in length along the mainstream of the Yangtze River. There are over 50 main tributaries in the reservoir segment, namely Xiangxi River, Daning River, Xiaojiang River and Wujiang River. The total length of the reservoir bank line is about 5,300 km. The area of the reservoir water surface is about 1,000  $\text{km}^2$  and the area of



云阳滑坡，2001年1月17日

*The Yunyang Landslide happened on January 17th, 2001*

submerged land is 600 km<sup>2</sup> approximately.

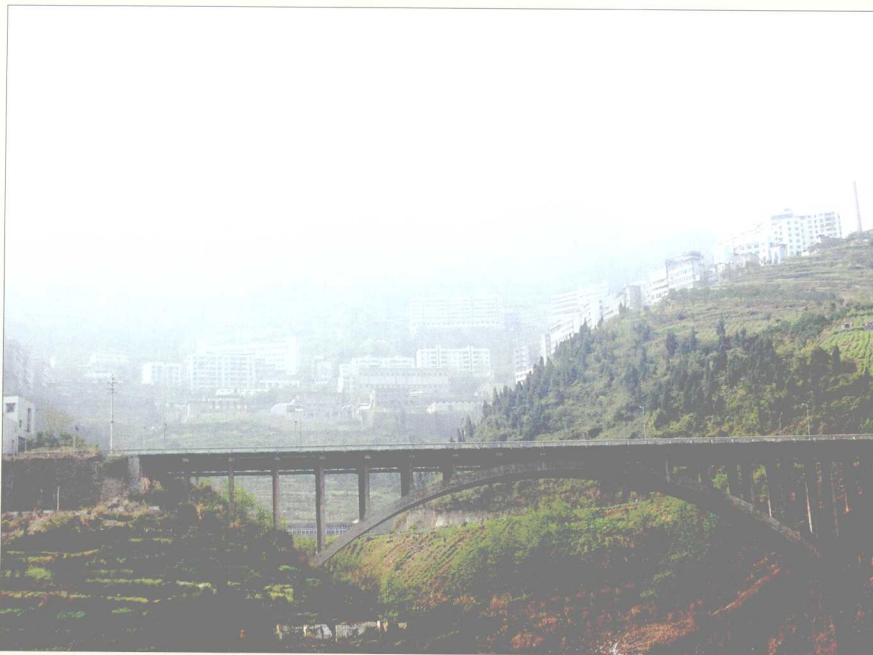
The relocation project of the Three Gorges Reservoir Areas involves 20 counties (districts) of Hubei Province and Chongqing City including 277 villages and towns. They are Yilin District, Zigui County, Xingshan County and Badong County of Yichang City, Wushan County, Wuxi County, Fengjie County, Yunyang County, Wanzhou District, Zhong County, Kai County, Shizhu County, Fengdu County, Fuling District, Wulong County, Changshou District, Yubei District, Banan District, Jiangjin District and downtown of Chongqing City, etc. Among them, twelve counties (cities) need to be partly or completely relocated. They are Zigui County, Xingshan county, Badong County, Wushan County, Fengjie County, Yunyang county, Wanzhou District, Zhong county, Kai County, Fengdu county, Fuling county and Changshou

District. Over 1,200,000 people and 1,629 industrial or mining enterprises need to be moved. Besides, 820 km roads and 198 bridges need to be rebuilt.

The Three Gorges Reservoir Area is located on mountainous terrain, where the landform varies greatly, the geological conditions are complex, and the environmental capacity is limited. Under the large-scale relocation projects, many engineered slopes were inevitably formed along with the construction of new towns. Among them, 2,874 slopes totaling about  $8.38 \times 10^6$  m<sup>2</sup> in surface area are found in densely populated zones and zones affected by engineering establishments. They need to be protected by using engineering measures. The Chinese government puts high priority on slope protection in the Three Gorges Reservoir Areas, and a special fund has been put in place and

implementation plans have been formulated. Effective protection measures have also been carried out to ensure slope stability and the prevention of disasters.

The relocation project of the Three Gorges Reservoir Areas has been in progress for over ten years and has achieved initial results. 12 relocation counties (cities) and 116 towns requiring relocation have basically been completed. The project has amassed abundant knowledge and experience in resident relocation, ecology construction, environmental protection and management of geologic hazards, and is a paradigm of successful large-scale hydraulic relocation projects.



修建于边坡上的移民新镇  
A new cities resettlers built in the slopes



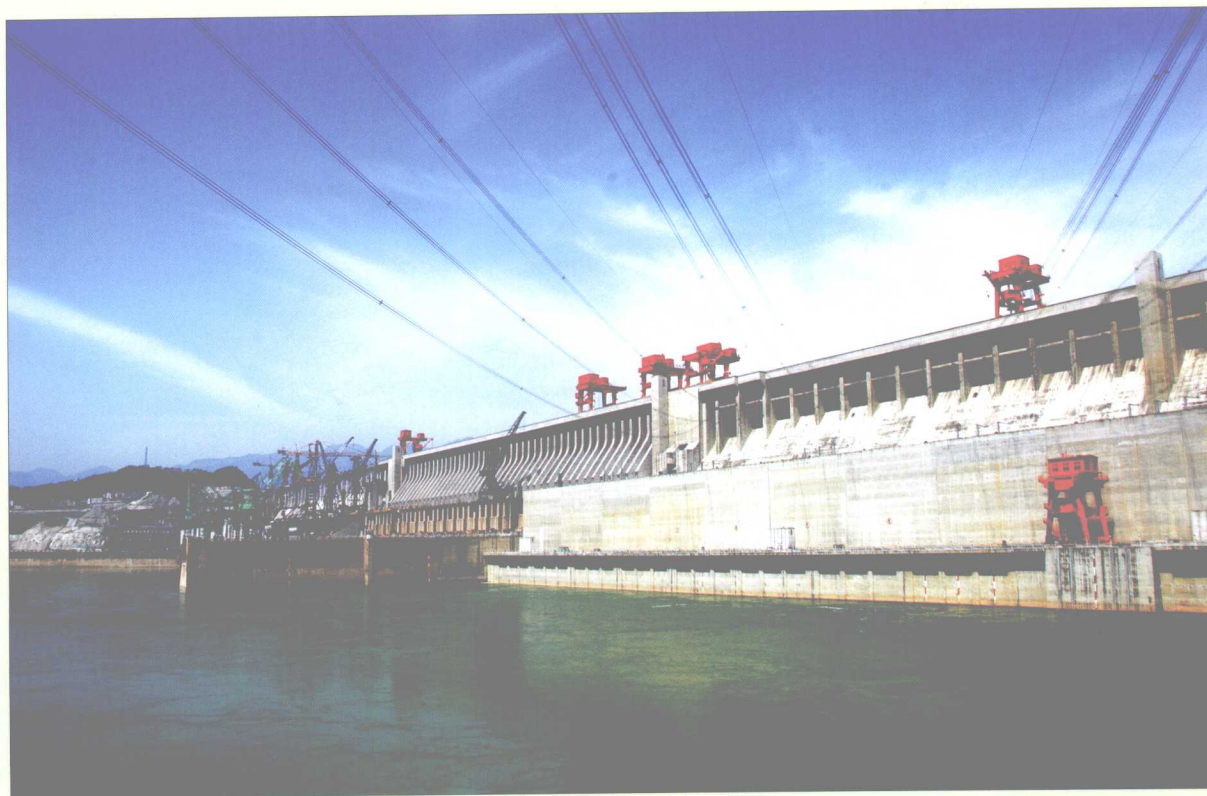
三峡水库  
The Three Gorges Reservoir



三峡水库移民安置区边坡分布示意图  
 Scattered distribution diagram of slopes in resident relocation areas of Three Gorges reservoir areas

本图集简略反映三峡库区移民城镇建设过程中，对工程边坡防护的基本认识、采取的主要防护措施和促进环境保护的成功经验。

This book briefly describes the basic knowledge in slope protection engineering gained, the main protection measures adopted, and the successful environmental protection achieved during the construction of resettlement towns in the Three Gorges Reservoir areas.



三峡大坝  
 The Three Gorges dam

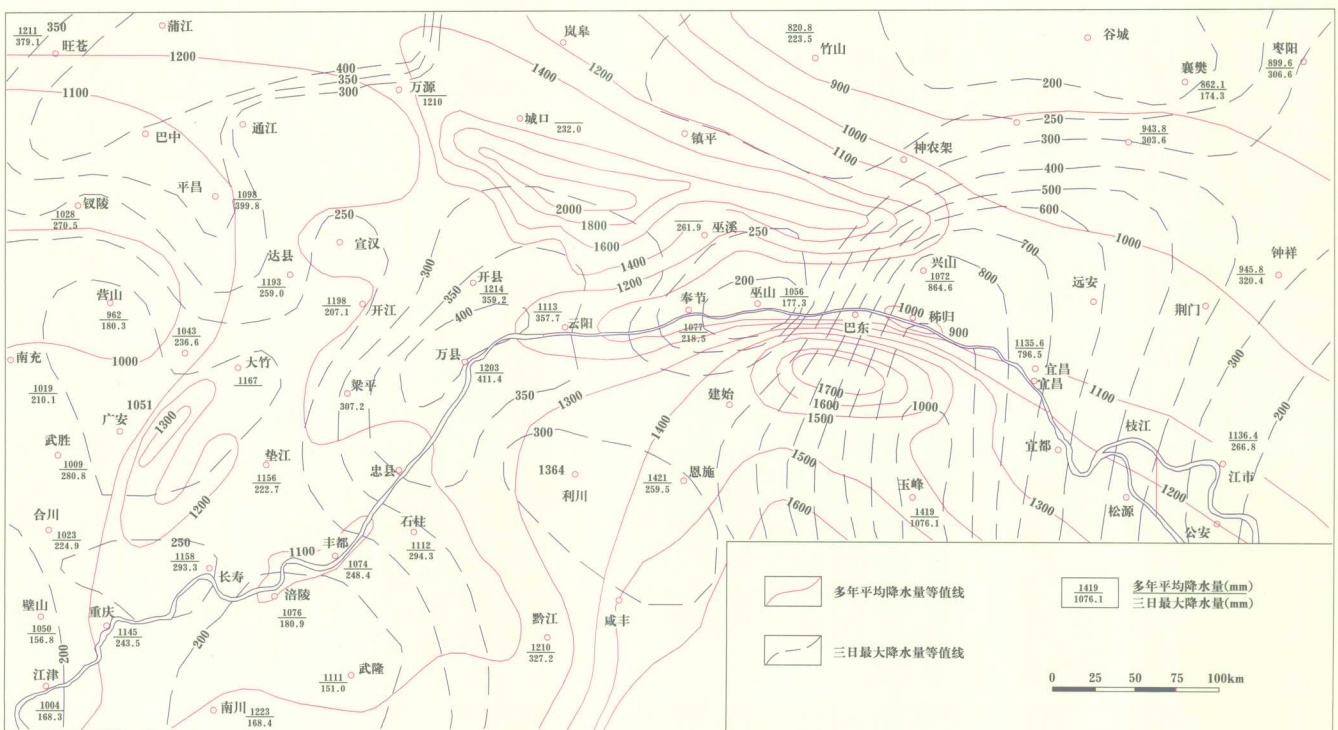


# 1 Geologic Background to Town Construction in the Three Gorges Reservoir Areas

## 1.1 Geographical Environment

The reservoir area of the Three Gorges Project spans the south side of the Daba Mountain and the west of Hubei Province. The region to the east of Fengjie County, a mountainous area bordering between Sichuan Province and Hubei Province, is composed mainly of middle mountain canyons. The Yangtze River cuts the canyons perpendicularly or at an angle forming many valleys, whose elevation variations are 800 ~ 1,500 m. These valleys are narrow and their slopes are steep. Most slopes have gradients of 30°~50°. The region to the west of Fengjie County is a hilly valley segment. It comprises a series of anticline low mountains in a NE ~ SW direction, arranged in a parallel spread in the area. The elevation declines gradually from the east to the west, from middle or low mountains with elevations of 800 ~ 1,000 m gradually to hills with elevations of 400 ~ 600 m. About 74% of the Three Gorges Reservoir Areas are mountainous regions, 21.7% are hilly areas and 4.3% are valleys and flat land.

The Three Gorges Reservoir Areas has a subtropical monsoon climate with a large quantity of heat, abundant rainfall and a mean annual precipitation of about 1,100 mm. The mean annual temperature of the valley areas with elevations lower than 500 m is 17~19°C. The mean annual runoff of the Yangtze River segment at damsite is  $4.51 \times 10^{11} \text{ m}^3$  and its mean annual sediment discharge is 0.53 billion tonnes.



长江三峡地区多年平均降雨量等值线图

Isoline map of mean annual precipitation in the Three Gorges area



## 1.2 地质环境

### 1.2.1 库首段

库首地段处于淮阳山字型西翼反射弧的脊柱和盾地，为新华夏系NNE向隆起带的组成部分，发育黄陵背斜和秭归向斜，以及九畹溪、仙女山和新华断裂。湖北省秭归县和宜昌市夷陵区位于黄陵背斜核部及周边地区，主要出露花岗岩及变质岩。花岗岩呈块状，新鲜岩石坚硬，完整性较好，但是花岗岩强风化后呈松散沙土状，结构强度较低。

### 1.2.2 库中段

湖北省巴东县至重庆市奉节县库段处于大巴山弧形褶皱带与新华夏系交接复合部位，发育七岳山断裂带及一系列紧密褶曲。长江河谷与构造线多近于平行或小角度斜交。本段主要出露巴东组泥质灰岩和泥岩。泥质灰岩受地质构造扰动和溶蚀、风化作用影响后，结构破碎；泥岩经开挖后受雨水等作用，表层迅速风化剥落，并逐渐向深部发展。

### 1.2.3 库尾段

本段属新华夏系第三沉降带的川东褶皱带，构造形迹近于平行呈NE向展布，为一系列紧密背斜和宽缓向斜组成的“隔档式”右行雁列褶皱带。

重庆市云阳县、万州区库段为侏罗系砂页岩及其互层地层，以宽缓的隔档式褶皱为主要构造形态，地层产状多较平缓；开县地区多为单斜地层；忠县、涪陵以上库段主要为碎屑岩类地层，褶皱较为发育，岩层产状变化较大。



长江三峡地区典型的层状结构岩体

*The typical rock structures in the bedding planes in Three Gorges*