The Monitoring Prewarning and Project Practice about Collapse Landslide in Three Gorges Reservoir Region

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三峡库区崩塌滑坡监测预警与工程实践

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内 容 简 介

本书系统地总结了三峡工程库区包括链子崖危岩体在内的重大危险性、崩塌滑坡监测预警实践与研究的最新成果，重点介绍链子崖危岩体防治可行性论证、施工、防治效果检验三个阶段全过程监测预报，以及三峡大坝库首段重大危险性滑坡预警应急监测实践与研究。

本书可供水电工程、岩土工程、地质工程、测绘工程、交通工程、工业与民用建筑工程及地质灾害勘察、设计、防治、监测等应用领域的科技、管理人员及高等院校有关专业师生参考。

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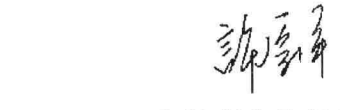
序

王尚庆教授等在承担完成长江三峡滑坡监测预报研究项目的基础上，吸收国内外滑坡监测预报方法的先进经验，撰写了《三峡库区崩塌滑坡监测预警与工程实践》一书，这是一件值得祝贺的事。该书是系统总结我国长江三峡链子崖危岩体防治可行性研究、施工、防治效果检验三个阶段长达16年监测，以及三峡水库蓄水初期库首段重大危险性滑坡险情监测预警实践与研究的专著，是崩塌滑坡防治与监测预报防灾研究的优秀成果，获得2010年中国岩石力学与工程学会科技进步一等奖。该书的出版，对于我国长江三峡乃至国内外崩塌滑坡等地质灾害防治与监测预报，具有科学意义和应用参考价值。因此，我乐意作序并向读者推荐这本书。

我国是世界上崩塌滑坡等地质灾害较严重的国家之一。近30年来，自然和人类活动诱发的崩塌滑坡等地质灾害频繁发生。长江三峡地区自然、地质条件复杂，生态环境脆弱，是崩塌滑坡地质灾害的频发区。据调查，三峡库区规模较大的崩塌滑坡有2100余处，受三峡水库蓄水及库水位变动影响而不稳定和潜在不稳定的涉水滑坡有1130余处，严重威胁着库区人民生命财产、移民工程建设及长江航运的安全与生态环境保护。依据崩塌滑坡的危险性、防治难度及危害对象的可迁移程度，国内外一般的防治措施主要分为工程治理、搬迁避让和监测预报，而监测预报是技术可行、经济合理、安全可靠的首选防治措施之一。例如，链子崖危岩体就存在发生大规模崩滑的危险征兆，若任其发展，一旦大规模崩滑入江，将有可能严重碍航，甚至断航，造成巨大的经济损失，产生不良的社会影响，并危及三峡工程建设的安全。因此，国务院列专项采取了链子崖危岩体底部煤层采空区承重阻滑、中上部锚索加固为主的防治措施。监测预报工作始终贯穿于危岩体防治前、中、后全过程，特别是在优化危岩体防治设计，指导施工，反馈防治设计，及时调整施工的进度、强度、工艺，保护承重阻滑，锚索加固施工，以及作业人员的安全等方面起到了重要作用。

当然，由于滑坡问题的复杂性，监测预报是国内外地学领域正在探索研究而尚未完全攻克的科技难题。但我相信，这本书的出版将对国内外崩塌滑坡等地质灾害防治与监测预报的研究发挥重要的参考作用。

中国科学院院士



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前　言

本书是我们近20年来开展长江三峡工程库区崩塌滑坡防治、监测预警实践与研究的系统总结。素材来源于“长江三峡链子崖危岩体防治监测预报研究”、“三峡库区重大危险性滑坡监测预警体系研究”、“滑坡多源信息数据融合理论与方法”等多个项目的科研成果。长江三峡地区自然、地质条件复杂，生态环境脆弱，是崩塌滑坡等地质灾害的频发区。据长期调研，链子崖危岩体未防治以前，存在发生大规模崩滑的危险征兆，若任其发展，一旦崩滑入江，将有可能造成长江严重碍航，甚至断航，造成巨大的经济损失，产生不良的社会影响，危及下游26.5km处三峡工程建设的安全。三峡库区发育有规模较大的滑坡2100余处，受三峡水库蓄水及库水位变动影响而不稳定和潜在不稳定的涉水滑坡有1130余处，严重威胁着库区人民生命财产、移民工程建设及长江航运的畅通。依据崩塌滑坡的危险性、防治难度及危害对象的可迁移程度，主要采取工程治理、搬迁避让、监测预报等三种防治措施。显然，监测预报是技术可行、经济合理、安全可靠的首选措施之一。由于滑坡问题的复杂性，至今尚未形成经得起大量实践验证的预报理论与方法，尤其是对滑坡发生时间的预测预报。因此，探索研究崩塌滑坡等地质灾害监测预报的理论与技术方法，很有必要。

本书共5章，其撰写者及主要内容为：第1章绪论（王尚庆），简述本书出版的研究背景、意义、内容及方法；第2章滑坡预测信息系统（王尚庆、马凯），叙述基于地质分析的滑坡监测关键技术优化、典型滑坡监测预报系统优化与滑坡监测数据库系统；第3章滑坡预测理论及模型（陆付民、王尚庆、徐进军），重点讨论滑坡变形预测模型和基于多源信息的综合预报判据新方法；第4章滑坡监测预警系统（徐进军、王尚庆），研究滑坡险情预警应急监测新方法和三峡库区重大危险性滑坡险情监测预警典型实例；第5章链子崖危岩体防治监测预警研究与工程实践（王尚庆、陆付民、徐进军），重点介绍链子崖危岩体防治及监测预报系统、危岩体防治监测数据库、底部煤层采空区承重阻滑、中上部锚索加固施工安全监测预报，讨论了危岩体防治监测预报方法与判据、变形预测模型，分析了防治工程施工及三峡水库蓄水对危岩体的稳定性影响。

本书主体内容是依据著者近20年来承担完成三峡库区崩塌滑坡防治与监测预报项目的研究报告著述的。系统总结了三峡大坝库首段包括链子崖危岩体在内的重大危险性崩塌滑坡监测预报实践与研究的最新成果。由于目前滑坡时间的准确预测预报还是一个正在探索研究的世界性科学难题，加之著者水平有限，书中难免存在不足，敬请读者批评指正。

著者要感谢三峡大学土木与建筑学院、湖北长江三峡滑坡国家野外科学观测研究站和三峡库区地质灾害教育部重点实验室的资助，以及武汉大学测绘学院、湖北省岩崩滑坡研究所的大力支持；感谢中国科学院武汉分院原院长许厚泽院士在百忙之中为本书作序；同时，还要特别感谢长期坚守在三峡大坝库首段链子崖危岩体及重大危险性滑坡监测预警一线的同事们，对他们所给予的帮助与合作，谨此表示真诚的谢意！

著者　王尚庆

2011 年 1 月 20 日

Abstract

Brief introduction about monitoring and prewarning and engineering practice of Collapsing Landslides in Three Gorges Reservoir Area.

The book summarizes systematically new study achievements about the monitoring and forecast of significant and dangerous collapsing landslides in Three Gorges Reservoir Area of Yangtze River. It is a work that introduces importantly the monitoring and forecast to Lianziya hazardous rock mountain in the process of the feasibility study and the construction and the test of the control efficiency.

Chapter 1 Introduction

The background and the significance and the content and the method of the study are described.

Chapter 2 The information system of the landslide forecast

The optimization of the landslide monitoring system based on the geological analysis and the landslide monitoring forecast system and the landslide monitoring database system are described. On the basis of analyzing the feature and the function and the practicability of the deformation monitoring technology of the landslide, the optimization method about the landslide monitoring based on geological analysis is put forward, the landslide monitoring database system of Gorges reservoir area based on Java EE technology is erected, and the portal and the management system are erected, the function is completed.

Chapter 3 The forecast theory and model of the landslide

The deformation forecast model of the landslide and the synthetical forecast criterion method based on the pleophyletic information are discussed. Time-frequency conjoint analysis method and exponential trend model and discrete Kalman filter method are put forward, these methods are new methods to do the deformation analysis to landslides and to erect forecast models, the forecast method for the landslide and the criterion are studied, the multiple-resource information synthetical

forecast criterion method that considers the macroscopical premonitory information and the deformation velocity of the key location and some relative influential factors such as the impoundment of the reservoir and the swing of the reservoir level and the excessive rain and heavy rain and the human activity and the shock load is proposed, the practicability is good, the operation is simple.

Chapter 4 The monitoring and prewarning system of the landslide

The prewarning and the emergency monitoring technology of the landslide is studied, when the landslide is in the accelerating deformation or approaching slide, especially, when the creep curve shows "inflexion" and "carryover", and the variation of the displacement is great, "single-point" measurement shall be replaced by "dot-matrix" measurement to capture the deformation information of the landslide, in other words, the three-dimensional laser scanning shall be used to do the emergency monitoring of the landslide, this pioneers a new way for the emergency monitoring of the landslide. On the basis of the development evolvement stage and the deformation velocity of the key location and the macroscopical deformation sign and the generant probability and the possible generant time of the landslide, the dangerous case is divided into the attention stage and the caution stage and the warning stage and the alarm stage, and they are marked with the blue and the yellow and the orange and the red respectively. The main influential factors of the landslide deformation influenced by the impoundment and the variation of the reservoir level in Three Gorges reservoir are studied, it is proposed that the early period of the impoundment of Three Gorges reservoir is the concentrated period of the deformation and the damage of landslides of the reservoir bank, the main reason is that the permeation and the transudation of water caused by the variation of water level change the stable water condition of landslides of the reservoir bank after the reservoir impounded, and the landslide that relate to water produces the deformation damage because of the variation of the reservoir level, the impoundment of the reservoir and the variation of the reservoir level cause the deformation of landslides, landslides show the tractive or retrogressive deformation feature, the rainfall and the groundwater accelerate the deformation of landslides, improper human project activities destroy the stability of landslides directly.

Chapter 5 The prewarning study and engineering practice about the control monitoring of Lianziya hazardous rock mountain

The control and the monitoring forecast system of Lianziya hazardous rock

mountain and the control monitoring database of the hazardous rock mountain and the bearing and anti-sliding key of the bottom goaf of the coal layer and the consolidated construction safety monitoring and forecast of mid and upper anchor lines are introduced mainly. The control monitoring and the forecast method and the criterion and deformation forecast models are discussed, the influence of the construction of the control project and the impoundment of Three Gorges reservoir to the hazardous rock mountain are analyzed.

5.1 Considering the fundamental property and the structure of the rock body and the forming mechanism and the stability condition and the construction safety monitoring and forecast of Lianziya hazardous rock mountain, the monitoring and forecast system is established and optimized, and the three-dimensional monitoring and forecast system is formed.

5.2 The division of the construction area and the crack segment and the monitoring time segment of the control project of Lianziya hazardous rock mountain is studied, the management system of the control monitoring database of the hazardous rock mountain is established by means of Java EE technology, the informatization management of the monitoring data is realized initially. The system has the function of the area segment management and the monitoring point management and the monitoring data management and the data service management, The system can produce figures about the deformation analysis automatically, the interface of the system is very friendly, the system has the reliability and the safety and the expansibility.

5.3 Some perturbations are produced by the bearing and anti-sliding key and the construction of the anchor line reinforcement to the hazardous rock mountain of T8 to T11 crack segments, the deformation of these areas is great, "sphenoid" swoops along the soft layer, and the settlement is obvious, it displaces towards N. N. E. or N. E, after the construction, the deformation of"Wuwanfang" hazardous rock mountain and "Qiqianfang" surface landslide body is no longer active, the displacement is slow, the deformation is stable through the stress adjustment of five years.

5.4 By means of the theoretical study and the monitoring data analysis, the deformation characteristic and the variation law of Lianziya hazardous rock mountain is illustrated before the control construction and during the control construction and after the control construction, this provides abundant experiences for the control and the forecast of collapsing landslides. The deformation velocity of the hazardous

rock mountain increases with time before the construction, the deformation velocity of the hazardous rock mountain increases with the construction strength during the construction, the deformation velocity of the hazardous rock mountain decreases with time, it become stable finally.

5.5 The construction location of the bearing and anti-sliding key of the goaf of the coal layer is coincident with the deformation location of the upper hazardous rock mountain in the space, the construction time is coincident with the deformation time, the construction strength is coincident with the deformation velocity.

5.6 By means of analysis the safety monitoring data of the control construction, it is indicated that the deformation of the hazardous rock mountain produced by the construction disturbance is normal, if the disturbance is too great, it may cause the incontrollable deformation to the hazardous rock mountain, it will produce severe unfortunate results. By means of the monitoring and forecast, if the process and the strength and the sequence and the procedure are adjusted on time, the influence of the construction of the bearing and anti-sliding key and the anchor wire reinforcement to the deformation and the stability of the hazardous rock mountain can be decreased to the scope of the safety, this attains the aim to direct the construction, the construction of the bearing and anti-sliding key influences directly the deformation velocity of the upper hazardous rock mountain, the stress centralization near the excavation zone is obvious after the key body is excavated, the horizontal displacement and the settlement increase significantly, and the deformation direction is disordered, the deformation rate decreases, and the stress increases slowly after the key body is backfilled.

5.7 The perturbation of the construction of the bearing and anti-sliding key of the goaf of the coal layer to the hazardous rock mountain is great, the perturbation of the construction of the anchor wire reinforcement to the hazardous rock mountain is less, the deformation of the hazardous rock mountain is influenced by the strength of the construction, and the deformation is related with the geological condition and the boundary condition and the stress condition and the stable condition of the construction area and the hazardous rock mountain.

5.8 DDA numerical simulation method and exponential trend model and dynamic Kalman filter method considering multiple factors and combined forecast model and AR(n) model are used to do the deformation analysis and the deformation forecast to Lianziya hazardous rock mountain, the effect is better, it is almost consistent with the actual deformation of Lianziya hazardous rock mountain, this

provides the reference foundation for the advanced forecast.

5.9 The key of the landslide forecast is the forecast method and the criterion analysis, the multiple-resource information synthetical forecast criterion method that considers the macroscopical premonitory information and the deformation velocity of the key location and some relative influential factors such as the impoundment of the reservoir and the swing of the reservoir level and the excessive rain and heavy rain and the human activity and the shock load is proposed firstly, the method is used in the control construction of Lianziya hazardous rock mountain, the safety of the construction of bearing and anti-sliding key and the anchor wire reinforcement and construction operators is protected effectively.

5.10 The influence of the construction of the control project of the hazardous rock mountain of T8 to T12 crack segment of Lianziya hazardous rock mountain to the hazardous rock mountain of the southern T0 to T6 crack segment and the western Leipishi landslide is not obvious. If the improper exploration and the construction method is used, the geological condition of the the hazardous rock mountain will be worsened, and the rock body will be disturbed, and the structure and original stress balance of the rock body will be destroyed, and the stability of the rock body will be influenced.

5.11 By means of the analysis of the effect monitoring data and the stability calculation after the construction, the impoundment of Three Gorges reservoir (the water level raises about 70m) and the variation of the reservoir level(from 135m to 139m) influence the deformation of Lianziya hazardous rock mountain, but the effect is not great, it indicates that the control is useful to the stability of the hazardous rock mountain, the hazardous rock mountain is stable.

5.12 The monitoring and forecast work impenetrate in the process of the feasibility study of the control project and the construction and the effectiveness test of the control, it provides the intuitionistic and quantitative foundation for the feasibility study of the control of the hazardous rock mountain, and it has the very important function in optimizing the control design of the hazardous rock mountain and directing the construction and feedbacking the construction design and adjusting the process and the strength and the procedure on time and protecting the safety of the construction of the bearing and anti-sliding key and the anchor wire reinforcement and operators.

5.13 By means of the study of the necessity and the importance and the action of the monitoring and forecast to the control of Lianziya hazardous rock mountain,

it is shown that before Lianziya hazardous rock mountain was controlled, 2.5 million cubic meters of hazardous rock mountain beside Yangzi River are almost stable, but the security is not very good, it is necessary to control early in order to grasp the opportune time that the hazardous rock mountain is not in the stage of the accelerative deformation. The decided control aims to Lianziya hazardous rock mountain are to improve the stable condition and to prevent fall bodies to enter the river to cause blocking the waterway. The important location of the control is the hazardous rock mountain between T0 crack and T6 crack, it is proper to implement the project of bearing and anti-sliding key to the the bottom goaf of coal layer and to implement the project of anchor wire reinforcement to the mid and upper hazardous rock mountain. Before the geological hazard happens, to put into little funds to do some projects and to control the possible geological hazard can avoid or reduce the significant losses once the hazard occurs.

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