中国水工程安全与病害防治技术丛书

⑤

# 水工程地质缺陷常用加固技术

Common Reinforcement Technologies for Geological

李鹏云　姜小兰　王柱军　黄三堂　陈彦生　编著

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## 内 容 提 要

本书系“中国水工程安全与病害防治技术丛书”之一，主要介绍在“概念加固”理念下，以“整体理论”统筹水工程的主要地质缺陷及其加固治理常用技术。

全书共计8章，第1章凸显了水工程堰塞坝/湖的除险加固措施；第2章和第4章给出了水工程地质缺陷的基础理论和主要地质灾害作用机制；第3章为水工程地质缺陷和地质灾害勘察；第5章为水工程地质缺陷及其灾害防控处置；第6章～第8章为水工程地质缺陷常用的锚杆、锚喷和灌浆加固技术及案例。

本书概念新颖清晰、技术应用与时俱进，既可供水工程设计、施工、监理、科研与管理人员使用，又可供土木建筑、冶金采矿、石油化工、公路交通、铁道桥隧、供水工程、市政建设的科技人员和中职、中专及高等院校有关师生参考。

# Abstract

This book, one of the Series of Safety and Disaster Prevention for Water Works in China, mainly introduces the common geological defects of water works and the general technologies for their remedial enforcement with application of the 'Integrity Theory' based on the 'Conceptional Reinforcement' view.

The Book has eight chapters. Chapter 1 highlights the hazard mitigation and enforcement measures for earthquake - induced dam/lake; Chapter 2 and 4 present the basic theory of geological defects and the mechanism of geological hazard attacks; Chapter 3 expounds the geological defects and consequent hazards to water works and how the investigations are conducted; Chapter 6, 7 and 8 cover the common reinforcement technologies with case studies for defect enforcement, including bolting, bolting with shotcrete, and grouting.

The book follows clearly established concepts and keeps abreast of latest developments of applied technologies. It has been designed for the engineering practitioners engaged in design, construction, supervision, research and management of water works, and also for those in other fields such as civil engineering, metallurgy, mining, petro - chemical industry, highway transportation, railway, bridge, water supply works, municipal construction, as well as for the teachers and students in secondary schools and colleges of engineering.

Bianzhuzhedehua

# 编著者的话

江河湖海与地下水源的开发、利用、控制、调配和保护水资源的各类建筑物，称为“水工程”。

水工程包括挡水建筑物诸如闸、坝、堤、海塘等；泄水建筑物诸如溢洪道、泄洪隧洞等；输水建筑物诸如渠道、输水隧洞、管道等；治导建筑物诸如丁坝、顺坝等；专用建筑物诸如水电站及扬水站的厂房、船闸及升船机、防波堤及码头、鱼道、筏道以及给水的过滤池等。

水工程的一个共同点，就是必须承受水的各种作用诸如静水压力、动水压力、渗流压力和水流冲刷等。

根据中华人民共和国水利部《2005年全国水利发展统计公报》，全国已建各类水闸39839座，其中大型水闸405座；各类水库大坝85108座，其中大型水库大坝470座；江河堤277500km；海塘10000余km，它们对国民经济的发展发挥了重要作用，为水文明进步作出了有益贡献。

由于水工程基础和建筑物本身存在地质缺陷和结构缺陷，设计欠妥、施工材料选择不当、施工质量不佳、运行条件变化、运行年限增加、运行管理存在问题以及地震等不利因素日益凸现，致使约占水工程总量30%～40%的水工混凝土建筑物存在不同程度的病害，有的已严重影响工程正常运行，威胁着人民生命与财产的安全，党中央国务院对此给予高度的重视。

2006年中央经济工作会议强调，集中力量用两三年的时间基本完成全国大中型和重点小型病险水工程的改造，以求“一定不能出现垮坝等重大安全事故”，确保“以人为本”构建和谐社

会的自然生态与人文环境的平衡。

“中国水工程安全与病害防治技术丛书”编写宗旨是密切配合党中央国务院这一重大战略部署进行的一项有意义的工作。旨在“十五”期间共3259座病险水工程除险加固总结的基础上，以“概念加固”新思维，采取集体讨论、分工合作的方式，编著了《水工程安全与病害防治技术概论》、《水工程安全检测与评估》、《水工程概预算的原理与应用》、《水工程结构缺陷一般加固技术》、《水工程地质缺陷常用加固技术》、《病险水工程碳纤维补强加固技术》、《病险水工程裂缝修补技术》和《病害水工程维护与管理》共计8册一套系列丛书。

“中国水工程安全与病害防治技术丛书”分别介绍了除险加固技术的简史、现状、技术基础理论、设计计算经验公式、施工技术流程与工艺、安全、质量检测与评估、施工采用的材料与主要设备，以及病害水工程的技术维护与科学管理方法等。在每个分册前汇集了相应术语与符号；书尾载有相关工程应用典型案例。丛书内容简明新颖，文字通俗易懂，集知识性、实用性与可操作性于一体，可谓当今水工程安全与病害防治技术小百科。

“兴建容易修补难”，这是先人为我们总结出来的至理名言。“中国水工程安全与病害防治技术丛书”的出版发行，既有助于近期全国大范围除险加固水工程施工，又前瞻性地为“概念加固”理论发展提供了上升平台。

编著者

2007年5月于武汉

# Authors' Statement

"Water works" is defined as all kinds of structures constructed for the development, utilization, control, operation and protection of water resources in rivers, lakes, and oceans and underground water head.

Water works include water retaining structures, such as sluice, dam, levee, seawall; water release structures, such as spillway, spillway tunnel; water conveyance structures, such as channel, conveyance tunnel, pipeline; river control structures, such as groin, longitudinal dike; and special structures, such as power house, ship lock, ship lift, breakwater, dock, fish way, log chute, filter basin for water supply of hydropower station and pumping station.

A common feature of water works is it has to endure all kinds of actions, such as hydrostatic pressure, hydrodynamic pressure, seepage pressure and current erosion.

According to the 2005 Statistic Bulletin about National Water Resources Development, 39839 water gates has been constructed nationwide, including 405 large ones; 85108 dams and reservoirs, including 470 large ones; levees of 277500 km; seawalls of more than 10000 km. All those constructed structures have played an important role in the development of national economy, greatly contributing to the progress of water civilization.

As more and more unfavorable factors appear in the foundation of water works and structures gradually, including inherent geological and structural defects, faulty designs, inappropriate construction materials, low quality of construction, changes in operation conditions, increased years of operation, problems in operation management and earthquake, some hydraulic concrete structures accounted for 30% ~ 40% of total amount of water works have various damages at different level, which have seriously affected normal operations, and threatened the safety of people's lives and properties. However, the Communist Party and the Government have attached great importance to those situations.

It was emphasized on 2006 Central Working Conference for Economy that we should concentrate ourselves to basically complete the reconstruction of medium, large and important small sick water works in 2 or 3 years' time in order to avoid fatal safety accidents with a firm hand, such as dam breach, ensuring a balance between natural ecology and culture environment for a harmonious and human oriented society.

The compiling of the Series of Safety and Disaster Prevention for Water Works in China is a significant task closely following the important strategy of the Central Government and the State Council. Based on the summarized experiences drawn from the risk removing and reinforcement of 3259 sick and risk water works during the "Tenth Five" program, with the new view of "Conceptional reinforcement", through group discussions, separated work and cooperation, we compiled the series of 8 volumes, including the General of Water Works Safety and Damage Prevention Technologies, Detection and Assessment of Water Works Safety, Principles and Application of Water Works Estimation, General Reinforcement Technology for Hydraulic structural Defects, Common Reinforcement Technologies for Geological Defects of Water Works, Reinforcement Technologies by Carbon Fiber for Sick and Risky Water Works, Crack Repairing Technologies for Sick and Risky Water Works, and Maintenance and Management of Sick Water Works.

In each volume, the authors respectively introduce risk removing and reinforcement technology, including its develop-ment history, current situation, technological foundation theory, calculation formulas, construction flow, technics, safety, quality test and assessment, materials and equipments during construction, as well as the methods of technical maintenance and scientific management for sick water works. The corresponding terms and symbols were listed at the beginning and typical application cases of relevant works was listed at the end of each book. The series is concise and easy to understand. At the same time, it combines technology with practice and the feature of operation. It can be regarded as a technical encyclopedia for the safety and damage prevention of water works.

"Easy to construct but difficult to repair" is wisdom that our ancestor summarized for us. The publication of the series is not only beneficial for the risk removing and reinforcement construction of water works nationwide recently, but also provides a rising space in a forward-looking way for the development of conception reinforcement.

**Compilers**

May 2007 in Wuhan

*Qianyan*

# 前　　言

随着“人类生存、发展和享受三个基本需要”的进步，人类活动作为一种“应力（Stress）”已逐渐接近甚至超过某些自然地质作用的“强度（Strength）”，越来越强烈地影响着地质环境、恶化地质缺陷、增加地质灾害的程度和频度。例如，人类工程（含水工程）开挖和堆积、回填的速度已逐渐超过自然地质作用的剥蚀和沉积的速度。

据统计❶，人类每年消耗的矿产资源约为500亿t，而大洋中脊每年新生的岩石圈物质约为300亿t；全球河流每年搬运物质约为165亿t；人类建筑工程（含水工程）面积于2000年就已达到陆地面积的15%以上；地面以上建筑的高度（含水坝高度）已超过300～400m；地面以下的地下工程、石油和矿井开挖等的深度已达数千米……所有这些均表明，地球外层圈的现代地壳外貌及其内部千疮百孔，同46亿年前形成的地球不可同日而语。

因此，必须大力加强人类工程（含水工程）活动与地质环境互馈作用机理及对策的研究，不仅研究现有地质环境对于拟建或待建工程（含水工程）的作用，还必须重视已建工程（含水工程）运行、修补加固作用对地质环境与地质缺陷的变化，预测这些变化的趋势和给出相应的技术措施，从而不仅保证工程（含水工程）的安全稳定与正常运用，同时要使地质环境向良好、平衡方向发展，而不致使地质缺陷恶化并诱发新的地质灾害，最终使

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❶ 工程安全与防灾减灾. 北京：中国建筑工程工业出版社，www. buildbook. com. cn，2007

人类工程（含水工程）兴建与除险加固达到可持续发展的目标。

我国是一个自然灾害特别是地质灾害、地震灾害和洪涝灾害严重的国家，同时也是一个防灾、减灾与抗灾顽强奋战的国家。从某种意义上讲，中华文明的延续与进步，是炎黄子孙几千年来与上述灾难斗争的结果。

“多难兴邦”，既是我们将过去灾难中的教训变成今天灾难中的经验，又是将今天灾难中的教训变成明天灾难经验的总结。

从专业角度而言，地质缺陷与地质灾害构成了一定的因果关系，如同“有断层就必然有地震，有地震就必然有断层”一样，人类工程（含水工程）因地质环境改变、地质岩体中的褶皱、断层、节理、裂隙、软弱破碎带和泥化类层等变异出现的崩塌、滑坡、泥石流、地裂缝、地面沉降、地面塌陷、岩爆、坑（隧）道突水、突泥和突瓦斯、土地冻融、地热害、火山和地震，以及水土流失、土地沙漠化、土地沼泽化、土壤盐碱化、砂土液化、岩土膨胀、黄土湿陷等，已逐渐成为普世认知共识。

与此同时，人类在保护环境中开发利用地球资源，在利用地球资源中有序有效地摸索加固地质缺陷的技术，使原有地质缺陷不恶化或尽量少恶化，以避免或最大限度地减少地质、地震、洪涝等自然灾害，也成为当今发展的趋势。

历史经验告诉我们，水工程地质缺陷的加固技术常用的有两大类（按水工程在地壳表面与内部划分）：一是地面工程诸如水闸、水坝、堤防、海塘、泄洪道、引水与泄水渠系等的基础及边坡表层与内部的地质缺陷加固；二是地下工程诸如水电站地下厂房、水工隧洞等的围岩（土）地质缺陷加固。两类加固的技术思路，均围绕地质缺陷在水工程荷载作用下，以确保水工建筑物整体稳定为目标。稳定的核心是安全，包括静载与动载（尤其是地震）作用下水工程能正常运行，至少不出现溃决堤坝等二次灾害。

我们必须承认，在人与自然不知伊于胡底[1]的战斗中，人多

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[1] 伊于胡底——走到哪里去，结果不堪设想之意（《辞海》1999年版缩印本第270页）。

数时候是弱小的一方，人定胜天迄今仍是一个未曾完全实现的梦想。在防治灾害的漫漫征途中，改进人与自然博弈的技术细节、创新水工程在强震之后的受损加固方法，时不我待地迫在眉睫。

2008年5月12日，我国汶川发生8级地震，在距震中17km的紫坪铺水电站大坝，没有出现坝基滑动失稳，再次证明采用固结与帷幕灌浆技术，确保大坝在动载与静载作用下的安全是可靠而有效的。

毋庸置疑，由于强震，从震中汶川沿龙门山断层约250km范围的断裂带直至北川，地质缺陷还带来了高山河谷两岸山体崩塌、滑坡、泥石流等地质灾害，并衍生出二次灾害——堰塞坝与堰塞湖，成为困扰坝下游百余万人民的生命安全问题。

现实表明：汶川8级地震共造成全国2473座水库出险，其中有溃坝险情的69座、高危险情的331座、次高危险情的2073座。四川省有1803座水库出险，占全国出险水库的73%，占全省水库总数的27%。全国有822座水电站因地震受损，总装机容量691万kW，其中四川省有481座水电站受损，装机容量555万kW；岷江干支流上的映秀湾等9座水电站一度出现高危险情。

该地震对江河堤防有不同程度破坏。全国共有899段、1057km堤防因地震发生损毁，涉及保护区人口512.27万人。四川震损堤段500段、长722.6km，占全省堤防总长度的14.5%，涉及保护区人口421.6万人。

该地震对城乡供水设施有大量损毁。全国因地震损毁农村供水工程7.24万处，损毁供水管道4万km，影响人口955.6万人，其中四川乡村供水设施损毁3.4万处，管道损毁2.93万km，影响人口575.18万人。

所有这些告诉国人，地震是造成水工程损伤的导火线，而内在的缘由源于水工程所在地域的地质缺陷。

对水工程兴建与加固而言，地质缺陷难以避免甚至可以说地质缺陷与水工程共同存在，只能通过科学技术的手段加以协调和

谐。本书的宗旨正是基于此点应运而生。

《水工程地质缺陷常用加固技术》采取集体讨论、分工合作的方式进行编著。全书由李鹏云、姜小兰、王柱军、黄三堂、郭玉、董建军、李艳红和陈彦生共同编著。其中，由李鹏云执笔撰写前言、术语、符号、绪论、水工程地质缺陷和地质灾害勘察，以及附录1～附录7；由姜小兰执笔撰写水工程地质缺陷的基础理论、水工程主要地质灾害作用机制及水工程锚喷加固技术的7.4～7.6节；由王柱军执笔撰写水工程地质缺陷及其灾害防控处置；由黄三堂执笔撰写水工程锚杆加固技术和水工程锚喷加固技术的7.1～7.3节；由李艳红执笔撰写水工程地质缺陷灌浆防渗加固技术；郭玉、董建军和陈彦生参加了部分章节的撰写；刘运飞和郭国兰编译了附录8。全书由郭玉、董建军和陈彦生共同策划，由陈彦生统稿。

在撰写中，引用了水利部、国家电力公司、四川、重庆、云南、陕西、甘肃、湖北、江苏、浙江、安徽、河南、山东、福建、新疆、上海、湖南、广西、广东等省（自治区、直辖市）的有关信息，长江科学院陈元明研究员给予了帮助，在此一并表示诚挚的谢意。

鉴于编著者的水平，书中难免有欠妥失误之处，敬请读者不吝指正。

**编著者**

2008年8月

# Preface

While the human beings struggle for survival, development and better life, their activities for these purposes have increasingly imposed a kind of 'stress' on the nature, which is approaching or even exceeding the allowed 'strength' of the geological environment. Their impact on the geological environment is so dramatic that they have resulted in worsened geological defects and more frequent and intensive geological hazards. One example of the intensified human activities is that the excavation and backfill in engineering operations (including that of water works) have outpaced the denudation and deposition in the geologically evolving process.

Statistics show: the annual consumption of mineral resources all over the world is some 50 billion tons; whereas the materials of the lithosphere re-generated annually at the central ridges of the oceans amount to about 30 billion tons; every year the rivers transport materials of 16.5 billion tons; the site areas of various artificial constructions including water works covered over 15 percent of the Earth's terrestrial surface; the man-made structures (including dams) have risen 300 to 400 meters above the ground; and the underground structures, i.e. oil wells and mining tunnels, have gone to a depth of thousands of meters. All these demonstrate that the outer crust of the Earth today is a highly altered one as compared to what it was when the Earth came into being 4.6 billion years ago.

It becomes imperative to investigate deep into the mechanism of interaction between the human activities for building various works (including water works) and the geological environment in search of countermeasures. Not only the studies shall cover the potential impacts of proposed or planned works, but also emphasis be put on the impacts of the operations and remedies of existing works on geological environment and consequently on the development of geological defects with prediction of such development tendency and provision of technical solutions. The aim is to secure the normal operation of all the works (including water works) in safe and stable conditions, and moreover, to get the geological environment on the track of benign development without inducing emerging geological hazards, leading to the ultimate goal of achieving sustainability.

China is a nation that has ever since been seriously impacted by various forms of natural hazards, especially the geological hazard, earthquake and flooding. On the other hand, China has never given up its painstaking efforts in preventing, mitigating and fighting against them. In some sense, the continuation and development of the Chinese civilization have resulted from such hazard and disaster alleviating efforts over thousands of years.

As an ancient Chinese saying goes, "Trials and tribulations serve only to revitalize a nation". It can be paraphrased that lessons learned from the past can serve to improve ourselves in similar undertakings for today and tomorrow.

From the technical perspective, geological defect and hazard constitute a cause-and-effect relationship to some extent, just as existence of 'faults' and occurrence of 'earthquakes' are twin factors. It is universally recognized that man-made works (including water works) tend to deteriorate due to altered geological environment and structural weaknesses present in the rock-mass, such as folds, faults, joints, fissures, fragmented zones, and argillized intercalation. In consequence, great varieties of hazards and disasters take place, including collapse, landslide, debris flow, ground cracking, ground settlement/subsidence, rock, water, mud and gas bursting in tunnels, soil freezing and thawing, adverse geothermal activity, volcanic activity and earthquake, soil erosion, desertification, land swampization, salinization, sand liquefaction, soil swelling, and collapse of wetted loess.

In response, people have realized to protect the environment in the process of exploiting natural resources and have in the process developed systematic approaches to reinforcing the geological defects, in order to prevent existing defects from worsening and to minimize the damages out of geological, earthquake and flooding hazards.

The reinforcement technology for geological defects in water works, according to past experience, can generally fall into two categories: one is the reinforcement of geological defects at the foundation or slope of structures built on ground surface, such as sluice gate, dam, dike, seawall, spillway, diversion and discharge channels, etc. the other is the reinforcement of geological defects found in underground structures, i. e. the surrounding rock (soil) masses of underground powerhouse and hydraulic tunnels, etc. The technical methodologies for reinforcement of the two categories both aim at ensuring the overall stability of the water works with the geological defects subjected to hydraulic loads, which means the safe operation of the water works under static and dynamic (seismic) loads must be guaranteed without occurrence of such significant induced disasters as dam or embankment breaching.

We have to be aware of the fact that human beings are in most of the time on the weaker side in the battle of fighting against the natural hazard and disaster. To win the battle remains a dream, but light has been shed by improving and innovating technologies for reinforcing damaged water works as a matter of urgency.

On May 12, 2008, a devastating earthquake measuring 8 on Richter scale hit Wenchuan region in Sichuan Province of China. The Zipingpu Dam, located 17km from the epicenter, was not subjected to sliding failure at its foundation, demonstrating for another time the effectiveness and reliability of consolidation and curtain grouting.

This intensive earthquake has caused numerous geological hazards including rock avalanches, landslides and debris flows, whose occurrences were facilitated by the existing geological defects, mainly the Longmenshan Fault that extends about 250km from Wenchuan to Beichuan. The induced hazards were mainly the dams and lakes formed by the materials sliding into the river courses, imposing severe threats on safety of millions of people and their properties downstream.

The Wenchuan Earthquake has claimed varying degrees of emergency conditions to 2473 reservoirs nationwide, of which 69 ones are at breaching risk, 331 ones at high risk, and 2073 ones at lower risk levels. With the Sichuan province, there are 1803 reservoirs at risk as a result of this earthquake, accounting for 73% of the total ill-conditioned reservoirs in China and 27 % of the province's existing number of reservoirs. 822 hydropower stations nationwide have suffered damages due to this earthquake with total installed capacity of 6910 MW, of which 481 hydropower stations (5550 MW) are located in Sichuan. The 9 hydropower stations, i. e. Yingxiuwan Hydropower Station, on the