

中国水工程安全与病害防治技术丛书

④

水工程结构缺陷一般加固技术

General
Reinforcement
Technology
for Hydraulic
Structural Defects

彭茂林 李进军 瞿霜菊 陈彦生 编著



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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 1000 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、施工工艺流程与工艺、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 1000km. 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 development 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

前 言

自1949年至今,全国共建成水工程8万余座,但由于种种原因其中已发现严重病害的有3万多座,约占水工程总座数的40%。

在这3万多座严重病害水工程中,大型病险水库约200多座,中型病险水库约1600座,重点小型病险水库约33800多座。这一座座病险水库就像一颗颗“炸弹”,严重威胁着下游人民的生命和财产安全。

1998年后,水利部先后完成了两批全国病险水库除险加固工程建设专项规划。目前第一批规划项目除险加固工程已基本实施完毕。据估算,这批项目完成除险加固任务后,相当于新建了540座库容为5000万 m^3 的中型水库,可直接保护下游耕地1.4亿亩,保护人口1.6亿人,新增灌溉面积近2000万亩,新增多年平均防洪效益80亿元。

在此基础上,2004年第二批规划项目的除险加固工作正式启动,到2006年底已实施了500余座规划项目除险加固工程建设,累计安排资金92亿元。

水利部最近完成的规划一期项目检查评估结果显示,我国大型水库病险率已由1999年底的42%降至目前的14%,中型水库病险率由41%降至25%,已有2000多座大中型病险水库通过除险加固解除了“警报”。但是,要实现国家在两三年内基本完成全国大中型和重点小型病险水库除险加固的目标,任务仍十分艰巨。

水工程除险加固的艰巨性表现之一,是量多面广。已发现的病险水库就数以万计,遍及全国各地。艰巨性表现之二,是涉及的

加固技术门类复杂。既有物理的,又有化学的;既有民用的,又有军工的;既有临时抢险的,又有永久安澜的;既有静态的,又有动态的;既有地面以上的,又有水下地下的;既有高温的,又有严寒的……总之,涵盖的“病理”多样,“救治”的方法广博。艰巨性表现之三,是水工程在我国仍处于不断开发进程中,兴建竣工后 20~30 年,随着时间的推移,不可避免地均要“劣化”、病害还会在后续工程上表现出来。也就是说,病险水工程的除险加固还任重道远。

《水工程结构缺陷一般加固技术》为“中国水工程安全与病害防治技术丛书”之四。它是在“概念加固”理念下,以“整体性理论”整合由工民建领域移植到水工程中,混凝土结构缺陷除险加固的十种工法。

《水工程结构缺陷一般加固技术》一书,采取集体讨论、分工合作的方式进行编著。全书由彭茂林、李进军、瞿霜菊、郭玉、董建军和陈彦生共同编著。其中,彭茂林执笔撰写前言、第 1~5 章、第 13 章的前 5 节及附录;李进军执笔撰写第 6~10 章;瞿霜菊执笔撰写第 11~13 章和附录;郭玉、董建军和陈彦生参加了部分章节的编撰。全书由郭玉、董建军和陈彦生共同策划,陈彦生统稿。本书的内容提要、编著者的话、前言和目录英文由周竹林翻译。

在《水工程结构缺陷一般加固技术》撰写中,引用和参考了水利部、国家电力公司、建设部、中国工程建设标准化协会,以及交通部、铁道部和湖北、福建、浙江、广东、江苏、湖南、安徽、江西、广西、河北、河南、北京、天津、四川、重庆、辽宁、新疆等省(自治区,直辖市)有关信息资料,在此一并表示谢意。

限于编著者的水平,书中难免有不当之处,恳请读者指正。

编著者

2007 年 3 月

Preface

Since 1949, 80000 water works have been constructed. Of those works, more than 30000 are at serious sick situation because of various reasons, accounting for 40% of total works.

There are about over 200 large scale sick reservoirs, 1600 medium scale reservoirs and about 33800 important small reservoirs. Like bombs, the sick reservoirs are seriously threatening the safety of lives and properties of the people living in the downstream.

The Ministry of Water Resources has made two special planings in succession for the risk removing and reinforcement construction of sick reservoirs since 1998. Nowadays, the construction for the projects in the first special planning has been basically completed. It is estimated that the completion of the first stage construction equals to 540 new reservoirs with another 50 million cubic metres of storage capacity, which could protect 140 million Mu of farmland in the downstream and 160 million inhabitant, increase 20 million Mu of irrigation area, and add 8 billion Yuan of mean annual flood control benefit.

Following the foresaid construction, the construction for the projects in the second special planning was commenced in 2004. Till the end of 2006, more than 500 risk removing and reinforcement projects have been implemented with an accumulated fund invested up to 9.2 billion Yuan.

The result of the assessment on the projects in the first special planning indicates that the percentage of the large scale sick

reservoirs has been reduced from 42% in 1992 to 14% at present, the percentage of the medium scale sick reservoirs has been reduced from 41% to 25%, and over 2000 large and medium scale sick reservoirs are no longer at "warning status" by reinforcement construction. However, we still have lots of work to do in achieving the goal of reinforcement on large and medium scale, and important small reservoirs nationwide in 2 or 3 years.

The first difficulty of risk removing and reinforcement for water works is the large quantity and the wide distribution. More than ten thousands of sick reservoirs were founded in different places in the whole country. The second difficulty is the complexity of reinforcement technologies involved, including physical and chemic, civil and military, temporary and permanent emergency action, static and dynamic, ground and underground, high and freezing temperature, etc. In summary, the "pathology" of sick reservoirs is greatly varied and the "therapy" is quite different. The third difficulty is that those completed works cannot avoid deteriorating, and damages will be revealed accordingly after 20~30 years, as most works are still in progress of developing. In other words, we still shoulder heavy responsibilities of repairing sick works.

General Reinforcement Technologies for Structural Defects of Water Works is the forth book of the Series of Safety and Disaster Prevention for Water Works in China. It introduces ten kinds of technologies for concrete structural defects reported from the Integrity Theory in civil construction field based on the "Conceptional Reinforcement" view.

General Reinforcement Technologies for Structural Defects was compiled through group discussions, separated work and cooperation. It was written by Peng Maolin, Li Jinjun, Qu

Shuangju, Guo Yu, Dong Jianjun and Chen Yansheng, in which Peng Maolin wrote the preface and chapters 1~5, Li Jinjun wrote chapters 6~10, Qu Shuangju wrote chapters 11~13 and appendix, while Guo Yu, Dong Jianjun and Chen Yansheng were involved in writing of some chapters. Guo Yu, Dong Jianjun and Chen Yansheng were planners of the series; Chen Yansheng was the organizer of the series. The abstract, authors' statement, preface and contents list of this book was translated by Zhou Zhulin.

In the process of compiling the book, we cited and referred to related information from Ministry of Water Resources, China State Power Corporation, Ministry of Construction, China Association for Engineering Construction Standardization, Ministry of Communication, and from Hubei, Fujian, Zhejiang, Guangdong, Jiangsu, Hunan, Anhui, Jiangxi, Guangxi, Hebei, Henan, Beijing, Tianjin, Sichuan, Chongqing, Liaoning, Xinjiang, etc. We sincerely appreciate all those people who gave us great support on this book.

Limited by the authors' knowledge, it might be some incorrectnesses. We welcome any corrections by readers.

Compilers

March 2007

术语表

已有结构加固 (Strengthening of Existing Structures):指对可靠性不足或雇主要求提高可靠度的承重结构、构件及其相关部分采取增强、局部更换或调整其内力等措施,使具有现行设计规范及雇主所要求的安全性、耐久性和适用性。

原构件 (Existing Structure Member):指实施加固前的原有构件。

重要构件 (Important Structure Member):指其自身失效将影响或危及承重结构体系整体工作的承重构件。

一般构件 (General Structure Member):指其自身失效为孤立事件,不影响承重结构体系整体工作的承重构件。

加大截面加固法 (Structure Member Strengthening with R. C.):指增大原构件截面面积或增配钢筋,以提高其承载力和刚度,或改变其自振频率的一种直接加固法。

外粘型钢加固法 (Structure Member Strengthening with Externally Bonded Steel Frame):指对钢筋混凝土梁、柱外包型钢、扁钢焊成构架并灌注结构胶粘剂,以到整体受力,共同约束原构件要求的加固方法。

复合截面加固法 (Structure Member Strengthening with Externally Bonded Reinforced Materials):指通过采用结构胶粘剂粘接或高强聚合物砂浆喷抹,将增强材料粘于原构件的混凝土表面,使之形成具有整体性的复合截面,以提高其承载力和延性的一种直接加固法。根据增强材料的不同,可分为外粘型钢、外粘钢板、外粘纤维增强复合材料和外加钢丝绳网片—聚合物砂浆层等多种加固法。

绕丝加固法 (Compression Member Confined by Reinforcing wire):指通过缠绕退火钢丝使被加固的受压构件混凝土受到约束作用,从而提高其极限承载力和延性的一种直接加固法。

外加预应力加固法 (Structure Member Strengthening with Externally Applied Prestressing):指通过施加体外预应力,使原结构、构件的受力得到改善或调整的一种间接加固法。

植筋 (Bonded Rebars):指以专用的结构胶粘剂将带肋钢筋或全螺纹螺

杆锚固于基材混凝土中。

结构胶粘剂(Structural Adhesives):指用于承重结构构件粘接的、能长期承受设计应力和环境作用的胶粘剂,简称结构胶。

纤维增强复合材料(Fibre Reinforced Polymer, 简称 FRP):指采用高强度的连续纤维按一定规则排列,经浸渍适配的胶粘剂固化后形成具有增强效应的复合材料,简称纤维复合材。

复合砂浆[Composite Mortar (Polymer Mortar)]:指掺有改性环氧乳液或其他改性共聚酯乳液的高强度水泥砂浆,也称聚合物砂浆。适合承重结构用的复合砂浆除了应能改善其自身的物理力学性能外,还应能显著提高其锚固钢筋和粘结混凝土的能力。

有效的截面面积(Effective Cross-section Area):指扣除孔洞、缺损、锈蚀层、风化层等削弱、失效部分后的截面。

加固设计使用年限(Design Working Life for Strengthening of Existing Structure or Its Member):指加固设计规定的结构、构件加固后无需重新进行检测、鉴定即可按其预定目的使用的时间。

预应力锚固(Prestressed Anchorage):指对地基或连同建筑物用预应力锚索或锚杆加固,以提高抗滑或抗倾覆能力和阻止地基或建筑物产生滑动或倾覆的技术措施。

预应力锚索(Prestressed Anchor Cable):指借助钢丝编织绳自由段的弹性张拉施加预应力的锚索。

预应力锚杆(Prestressed Anchor):指借助杆体自由段的弹性伸长施加预应力的锚杆。

锚栓(Anchor Bolt):指将金属结构或设备锚定在坝体或圬工结构上的预埋螺栓。

绕丝(Wire-wrapping):指用退火的钢丝缠绕管道或圆形容器的水池等的一种加固工序。

玻璃钢加固法(Strengthening Glass Fibre Reinforced Polymer):指用玻璃纤维或其织物增强塑料来提高结构/构件承载力的一种技术。

喷射混凝土(Shotcrete):主要指借助喷射机械,利用压缩空气做动力,将水泥、粗砂、石子与水的拌和料,通过高压管以高速喷射到受喷面上硬化而成的一种加固工序。

聚合物水泥防水砂浆(Polymer Emulsion Modified Cementitious Waterproofing Mortar):指掺入适量聚合物乳胶改性的防水水泥砂浆。

聚合物水泥防水材料 (Polymer Modified Cementitious Waterproofing Materials): 指以聚合物乳胶和水泥作为主要材料组成的防水材料。

聚合物水泥防水胶粘材料 (Polymer Cement Waterproof Adhesive): 指以聚合物乳液或聚合物再分散性粉末等聚合物材料和水泥为主要材料组成, 用于粘结聚乙烯丙纶卷材, 并具有一定防水功能的材料。

聚合物水泥防水涂料 (Polymer Modified Cementitious Waterproofing Coating): 指以聚合物乳液和水泥为主要原料, 加入其他外加剂制得的双组分水性防水涂料。

渗透结晶型防水材料 (Penetrating and Crystalling Waterproofing Materials): 指以水为载体的活性化学物质向混凝土内部渗透, 在混凝土的毛细孔道和微小裂隙中形成不溶于水的结晶体, 从而使混凝土致密防水的材料。

结构耐久性 (Durability of Structure): 指结构在预期作用和预定的维护条件下, 能在规定期限内长期维持其设计性能要求的能力。

腐蚀 (Deterioration): 指材料与环境因素发生物理、化学或电化学作用而呈现的渐近性损伤与破坏。对钢材常称腐蚀为锈蚀 (Corrosion)。

附加防腐蚀措施 (Additional Corrosion Prevention Measures): 指在改善混凝土密实性和增加保护层厚度等手段提高混凝土结构耐久性的基础上所采取的防腐蚀措施诸如使用环氧涂层钢筋、钢筋阻锈剂、混凝土表层涂层、混凝土防腐面层和阴极保护等。

环境作用 (Environmental Attack): 指引起结构材料性能劣化或腐蚀的环境因素诸如温度、湿度及各种有害物质等施加于结构上的作用。

劣化 (Degradation): 指材料性能逐渐降低的行为。

严寒地区 (Severe Cold Region): 指最冷月平均气温低于 -10°C 的地区。

寒冷地区 (Cold Region): 指最冷月平均气温在 $-10\sim-3^{\circ}\text{C}$ 的地区。

温和地区 (Mild Region): 指最冷月平均气温高于 -3°C 的地区。

符 号 表

E_{so} : 原构件钢筋弹性模量	σ_{so} : 原构件纵向受拉钢筋或受压较小边钢筋的应力
E_s : 新增钢筋弹性模量	σ_a : 新增型钢受拉肢或受压较小肢的应力
E_a : 新增型钢弹性模量	ϵ_{fo} : 纤维复合材滞后应变
E_{sp} : 新增钢板弹性模量	ω : 构件挠度或预应力反拱
E_f : 新增纤维复合材弹性模量	h_o, h_d : 构件加固后和加固前的截面有效高度
f_{co} : 原构件混凝土轴心抗压强度设计值	h_w : 构件截面的腹板高度
f_{yo} : 原构件钢筋抗拉、抗压强度设计值	h_n : 受压区混凝土的置换深度
f_y : 新增钢筋抗拉、抗压强度设计值	h_{sp} : 梁侧面粘贴钢箍板的竖向高度
f_a : 新增型钢抗拉、抗压强度设计值	h_f : 梁侧面粘贴纤维箍板的竖向高度
f_{sp} : 新增钢板抗拉、抗压强度设计值	h_{ef} : 锚栓有效锚固深度
f_f : 新增纤维复合材抗拉强度设计值	A_{so} : 原构件受拉区、受压区钢筋截面面积
$f_{f,v}$: 纤维复合材与混凝土粘结强度设计值	A_s : 新增构件受拉区、受压区钢筋截面面积
f_{od} : 结构胶粘剂粘结强度设计值	A_{fe} : 纤维复合材有效截面面积
f_{ud} : 锚栓抗拉强度设计值	A_{cor} : 环向围束内混凝土截面面积
ϵ_f : 纤维复合材拉应变设计值	A_{sp} : 新增受拉钢板、受压钢板截面面积
ϵ_{fe} : 纤维复合材环向围束有效拉应变设计值	A_a : 新增型钢受拉肢、受压肢截面面积
N : 构件加固后轴向力设计值	I_s : 植筋基本锚固深度
M : 构件加固后弯矩设计值	I_d : 植筋锚固深度设计值
V : 构件加固后剪力设计值	I_l : 植筋受拉搭接长度
M_{ok} : 加固前受弯构件验算截面上原作用的初始弯矩标准值	D : 钻孔直径
σ_s : 新增纵向钢筋受拉应力	W_{et} : 锚栓截面抵抗矩
	α_1 : 受压区混凝土矩形应力图的应