

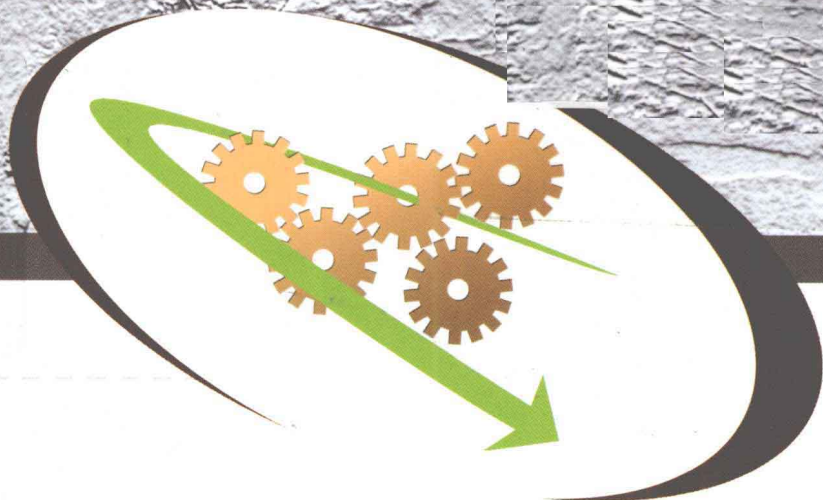
Construction of Underground Hydro Works in China

中国水利水电

地下工程施工 (下册)

马洪琪 周宇 和孙文 等 编著

By MA Hongqi, ZHOU Yu, HE Sunwen et al



中国水利水电出版社
www.waterpub.com.cn

中国水利水电 地下工程施工

(下册)

马洪琪 周宇 和孙文 等 编著



中国水利水电出版社
www.waterpub.com.cn

内 容 提 要

本书重点介绍了中国大型水利水电地下工程的施工新技术,包括在 Think Deep 理念下,将地下空间当成新型国土资源充分利用的水利水电地下工程施工总体科学规划、地下厂房洞室群施工、斜井与竖井施工、洞室灌浆施工、水工隧洞模板施工、压力管道施工、堵头施工、平洞施工等,概述了地质勘测、施工监测、围堰与岩埂拆除、地下洞室通风,并专列两章突出介绍了地下工程不良地段施工要点与施工设备。

本书概念清晰、系统完整,可为从事水利水电地下工程规划、设计、施工、监理及管理的技术人员应用,也可供军工、人防、城市地铁、铁道交通、矿山能源等有关地下工程的技术人员及高等院校的相关师生参考。

图书在版编目(CIP)数据

中国水利水电地下工程施工 / 马洪琪等编著. — 北京: 中国水利水电出版社, 2011. 1
ISBN 978-7-5084-8304-7

I. ①中… II. ①马… III. ①水利工程: 地下工程—工程施工②水力发电工程: 地下工程—工程施工 IV. ①TV554

中国版本图书馆CIP数据核字(2011)第001857号

书 名	中国水利水电地下工程施工(下册)
作 者	马洪琪 周宇 和孙文 等 编著
出版发行	中国水利水电出版社 (北京市海淀区玉渊潭南路1号D座 100038) 网址: www.waterpub.com.cn E-mail: sales@waterpub.com.cn 电话: (010) 68367658 (营销中心)
经 售	北京科水图书销售中心(零售) 电话: (010) 88383994、63202643 全国各地新华书店和相关出版物销售网点
排 版	中国水利水电出版社微机排版中心
印 刷	北京市兴怀印刷厂
规 格	184mm×260mm 16开本 65.5印张(总) 1568千字(总) 8插页
版 次	2011年1月第1版 2011年1月第1次印刷
印 数	0001—2000册
总 定 价	198.00元(上、下册)

凡购买我社图书,如有缺页、倒页、脱页的,本社营销中心负责调换

版权所有·侵权必究

目 录

上 册

序一

序二

前言

1 概 论	1
1.1 大型地下引水发电系统快速施工技术	1
1.2 大断面长隧洞快速施工技术	2
1.3 无钢衬高压钢筋混凝土岔管施工技术	3
1.4 高压长斜（竖）井快速施工技术	4
1.5 地下工程混凝土模板施工技术	5
参考文献	6
2 施工总体规划	7
2.1 概述	7
2.2 水利水电地下工程建设程序	9
2.3 施工总布置	23
2.4 施工通道设计	27
2.5 施工通风设计	29
2.6 施工环境保护	33
2.7 文明施工	34
2.8 施工总体规划案例之 1：溪洛渡水电站导流洞与左、右岸地下电站工程规划	36
2.9 施工总体规划案例之 2：水布垭水利枢纽工程导流洞施工规划	40
2.10 施工总体规划案例之 3：大朝山水电站导流洞与地下引水发电系统施工规划	44
2.11 施工总体规划案例之 4：小湾水电站导流洞施工规划	49
2.12 施工总体规划案例之 5：龙滩水电站施工导流与地下厂房施工规划	56
参考文献	60
3 施工地质	61
3.1 概述	61
3.2 影响地下洞室围岩稳定的地质因素	61
3.3 围岩分类	82

3.4	施工地质工作	90
3.5	施工地质案例之 1: 引硫济金工程冷龙岭引水隧洞和虎家崖水电站引水隧洞 施工地质超前预报	99
3.6	施工地质案例之 2: “引大济涅”总干渠引水隧洞 TBM 施工地质	102
3.7	施工地质案例之 3: 溪洛渡水电站地下厂房围岩分类	105
3.8	施工地质案例之 4: 蒲石河抽水蓄能电站地下厂房可行性研究阶段与技术设计 施工阶段围岩分类	111
3.9	施工地质案例之 5: 荣地水电站引水隧洞围岩分类	115
3.10	施工地质案例之 6: 张峰水库导流泄洪洞围岩分类	118
3.11	施工地质案例之 7: “引大济涅”调水总干渠深埋隧洞围岩分类	120
3.12	施工地质案例之 8: 隧洞 TBM 施工围岩分类	123
3.13	施工地质案例之 9: 岩溶地区隧洞围岩分类	127
3.14	施工地质案例之 10: 膨胀岩隧洞围岩分类	130
	参考文献	136
4	施工测量	138
4.1	概述	138
4.2	地下洞室施工测量规定	141
4.3	水工隧洞盾构施工测量规定	144
4.4	搜集资料及放样准备	149
4.5	贯通精度估算	150
4.6	洞外平面、高程控制测量	155
4.7	洞内平面、高程控制测量	156
4.8	洞内施工测量	157
4.9	竖井联系测量与高程传递	159
4.10	资料整理	162
4.11	施工测量案例之 1: 锦屏二级水电站引水隧洞 TBM 施工测量	163
4.12	施工测量案例之 2: 宜兴抽水蓄能电站地下工程施工控制测量	166
4.13	施工测量案例之 3: 汤河水库斜长小断面隧洞施工贯通测量	171
4.14	施工测量案例之 4: 阿海水电站导流洞施工测量	174
4.15	施工测量案例之 5: 松山水库引水隧洞开挖断面测量	178
4.16	施工测量案例之 6: 黄龙水库发电输水隧洞施工测量	179
4.17	控制测量误差计算	182
	参考文献	186
5	平洞施工	188
5.1	概述	188
5.2	洞口施工	189
5.3	隧洞开挖方法	191

5.4	隧洞钻爆孔的布置	192
5.5	爆破振动控制	200
5.6	初期支护	202
5.7	支护材料	206
5.8	隧洞施工进度网络图	212
5.9	过水隧洞糙率系数	214
5.10	混凝土衬砌	214
5.11	平洞施工案例之 1: 锦屏一级水电站不良地质带平洞施工	218
5.12	平洞施工案例之 2: 引额济乌引水工程顶山平洞强膨胀岩段施工	221
	参考文献	224
6	不良地质段施工	226
6.1	概述	226
6.2	软弱破碎地质条件下的隧洞施工	226
6.3	浅埋复杂地下洞室施工	236
6.4	岩溶及地下水富集区施工	237
6.5	其他复杂地质条件下的地下洞室施工	242
6.6	不良地质段施工案例之 1: 紫坪铺水电站导流洞泥岩软化不良地质段 支护施工	245
6.7	不良地质段施工案例之 2: 构皮滩水电站导流洞软岩不良地质段施工	250
6.8	不良地质段施工案例之 3: 糯扎渡水电站导流洞断层破碎带开挖施工	253
6.9	不良地质段施工案例之 4: 大伙房水库输水工程不良地质段 TBM 施工	257
6.10	不良地质段施工案例之 5: 锦屏二级水电站 3 号引水隧洞岩爆区 的 TBM 施工	261
6.11	不良地质段施工案例之 6: 广州抽水蓄能电站二期工程尾水洞进、出口 不良地质段施工	264
6.12	不良地质段施工案例之 7: 徐村水电站左岸泄洪(导流)洞出口塌方处理	268
	参考文献	271
7	地下厂房等大型洞室施工	273
7.1	概述	273
7.2	施工原则和施工程序	274
7.3	施工的重点与难点	275
7.4	大型地下厂房开挖与支护	276
7.5	混凝土施工	299
7.6	主变室、尾调室(井)、电梯井、电缆井等的混凝土施工	302
7.7	爆破控制	302
7.8	岩壁吊车梁的施工	304
7.9	地下厂房等大型洞室施工案例之 1: 长江三峡水利枢纽工程右岸地下厂房开挖及	

岩壁梁混凝土防裂控制施工技术	319
7.10 地下厂房等大型洞室施工案例之 2: 小湾水电站地下厂房快速开挖综合 施工技术	321
7.11 地下厂房等大型洞室施工案例之 3: 龙滩水电站特大断面地下洞室群施工支护 综合施工技术	326
7.12 地下厂房等大型洞室施工案例之 4: 溪洛渡水电站右岸地下厂房高边墙开挖 技术	326
7.13 地下厂房等大型洞室施工案例之 5: 锦屏一级水电站高地应力区低抗压强度 岩石条件下地下厂房开挖	332
7.14 地下厂房等大型洞室施工案例之 6: 彭水水电站地下主厂房钢垫墩锚索施工	339
7.15 地下厂房等大型洞室施工案例之 7: 构皮滩水电站地下厂房强岩溶处理技术	342
7.16 大型水电站地下洞室群施工通道规划	352
7.17 水布垭水电站地下厂房软岩置换研究与分析	356
7.18 水电站地下厂房蜗壳二期混凝土施工技术	361
参考文献	369
8 斜井与竖井施工	370
8.1 概述	370
8.2 斜井、竖井施工特点及工艺流程	376
8.3 斜井、竖井的全断面开挖支护	378
8.4 导井施工	381
8.5 扩挖及支护	394
8.6 混凝土衬砌及灌浆	398
8.7 施工安全问题及预防措施	406
8.8 斜井与竖井施工案例之 1: 紫坪铺水电站引水隧洞斜井施工	411
8.9 斜井与竖井施工案例之 2: 泗南江水电站通风竖井施工	414
8.10 斜井与竖井施工案例之 3: 宝泉抽水蓄能电站复杂地质结构斜井施工	418
8.11 斜井与竖井施工案例之 4: 桐柏抽水蓄能电站陡倾角大直径长斜井施工	422
8.12 斜井与竖井施工案例之 5: 长江三峡水利枢纽工程地下电站引水隧洞斜井 施工	426
8.13 斜井与竖井施工案例之 6: 大伙房水库输水隧洞投料竖井施工	431
8.14 斜井与竖井施工案例之 7: 周宁水电站高压引水竖井施工	434
8.15 斜井与竖井施工案例之 8: 泰安抽水蓄能电站引水竖井施工	438
8.16 斜井与竖井施工案例之 9: 惠州抽水蓄能电站斜井采用 RHINO-400H 型 反井钻机施工技术	441
8.17 斜井与竖井施工案例之 10: 小湾水电站缓倾角全断面长斜井滑模施工技术	453
参考文献	459

下 册

9 钻孔灌浆施工	461
9.1 概述	461
9.2 灌浆原材料及浆液	463
9.3 水工隧洞、竖井与地下洞室灌浆	470
9.4 地下灌浆施工布置	473
9.5 地下工程钻孔灌浆	476
9.6 预应力灌浆	486
9.7 钻孔灌浆施工案例之 1: 彭水水电站地下厂房高边墙常压固结灌浆	490
9.8 钻孔灌浆施工案例之 2: 南盘江天生桥二级水电站不良地质引水洞钻爆法和 TBM 施工中高压固结灌浆	494
9.9 钻孔灌浆施工案例之 3: 龙滩水电站引水管道进水口钢衬与混凝土之间接触灌浆	500
9.10 钻孔灌浆施工案例之 4: 向家坝水电站地下厂房帷幕灌浆	504
9.11 钻孔灌浆施工案例之 5: 锦屏二级水电站引水隧洞涌水封堵灌浆	511
9.12 钻孔灌浆施工案例之 6: 回龙抽水蓄能电站高压隧洞预应力灌浆	515
9.13 钻孔灌浆施工案例之 7: 水布垭水电站地下厂房衬砌混凝土裂缝化学灌浆	517
9.14 钻孔灌浆施工案例之 8: 广州抽水蓄能电站高压隧洞 6.5MPa 固结灌浆	521
9.15 钻孔灌浆施工案例之 9: 小湾水电站抗力体固结灌浆施工	527
参考文献	534
10 水工隧洞模板施工	537
10.1 概述	537
10.2 平洞钢模台车	538
10.3 钢模台车弯道技术	553
10.4 竖井模板	556
10.5 斜井模板	561
10.6 清水混凝土模板	567
10.7 水工隧洞模板施工案例之 1: 桐柏抽水蓄能电站水工隧洞模板施工	567
10.8 水工隧洞模板施工案例之 2: 长江三峡水利枢纽工程引水隧洞衬砌模板施工	571
10.9 水工隧洞模板施工案例之 3: 刘河坝水电站引水隧洞平洞滑模设计与应用	574
10.10 水工隧洞模板施工案例之 4: 莲花田水库输水隧洞竖井滑模施工	578
10.11 水工隧洞模板施工案例之 5: 锦屏二级水电站引水隧洞底拱衬砌刮模施工	582
10.12 水工隧洞模板施工案例之 6: 龙滩水电站特大型断面斜井滑模混凝土施工技术	584
10.13 水工隧洞模板施工安全技术比较分析	591

参考文献	594
11 地下洞室施工通风	595
11.1 概述	595
11.2 大型地下洞室施工技术和施工通风	596
11.3 洞室通风的形式、特点和基本原理	597
11.4 大型地下洞室群施工通风动态仿真	599
11.5 施工通风设计	609
11.6 施工通风系统布置	615
11.7 通风设计中几个问题的进一步研究	622
11.8 有竖井洞室自然风压的研究	626
11.9 水利水电地下洞室施工通风标准	630
11.10 新鲜空气的定义及隧道通风的目的	634
11.11 隧道通风需要考虑的基本因素	636
11.12 隧道通风用的风机种类与适用性	637
11.13 隧道通风用的各种风机及特性	638
11.14 地下洞室施工通风案例之 1: 大伙房水库输水深埋长隧洞 TBM 施工 通风除尘	645
11.15 地下洞室施工通风案例之 2: 南水北调西线工程深埋长隧洞施工通风方案	648
11.16 地下洞室施工通风案例之 3: 溪洛渡水电站大型地下洞室群施工通风	652
11.17 地下洞室施工通风案例之 4: 龙滩水电站地下厂房洞室群建筑通风	655
11.18 地下洞室施工通风案例之 5: 锦屏二级水电站西端引水隧洞施工通风	659
参考文献	663
12 压力钢管道施工	665
12.1 概述	665
12.2 钢管制作	673
12.3 钢管运输	686
12.4 钢管安装	691
12.5 压力钢管道施工案例之 1: 彭水水电站大型压力钢管制造安装	698
12.6 压力钢管道施工案例之 2: 景洪水电站压力钢管道设计施工	702
12.7 压力钢管道施工案例之 3: 西龙池抽水蓄能电站引水压力钢管道一管两机 制造安装	706
12.8 压力钢管道施工案例之 4: 瑞丽江一级水电站压力钢管安装施工	710
参考文献	714
13 地下工程施工监测	716
13.1 概述	716
13.2 水利水电地下工程监测设计与布置	721

13.3	监测项目的实施	725
13.4	安全监测资料的整理	745
13.5	监测结果的分析及反馈	746
13.6	地下工程施工监测案例之1:鲁布革水电站地下相邻洞室开挖监测	752
13.7	地下工程施工监测案例之2:大朝山水电站尾水隧洞收敛监测	757
13.8	地下工程施工监测案例之3:鲁布革水电站地下厂房监测	760
13.9	地下工程施工监测案例之4:二滩水电站地下厂房洞室群监测	768
13.10	地下工程施工监测案例之5:锦屏一级水电站地下厂房监测	774
13.11	地下工程施工监测案例之6:官地水电站地下厂房施工围岩监测	778
13.12	地下工程施工监测案例之7:白山抽水蓄能电站地下厂房监测	782
13.13	地下工程施工监测案例之8:武都水库大型溶洞安全监测	787
13.14	地下工程施工监测案例之9:十三陵抽水蓄能电站引水洞塌方监测与加固	793
13.15	地下工程施工监测案例之10:TBM在隧洞施工中的状态监测	799
	参考文献	802
14	水工隧洞堵头施工	804
14.1	概述	804
14.2	堵头设计原则	804
14.3	堵头形式及其选择	805
14.4	堵头长度的确定	806
14.5	封堵体的受力特性分析	808
14.6	堵头混凝土施工	809
14.7	堵头灌浆	809
14.8	温度控制	810
14.9	水工隧洞堵头施工案例之1:隔河岩水电站导流洞封堵的临时堵头	812
14.10	水工隧洞堵头施工案例之2:水布垭水电站导流洞堵头优化设计	818
14.11	水工隧洞堵头施工案例之3:二滩水电站导流洞封堵施工	822
14.12	水工隧洞堵头施工案例之4:天生桥一级水电站导流洞堵头设计与施工	826
	参考文献	829
15	施工围堰与岩埂拆除爆破	831
15.1	概述	831
15.2	混凝土围堰与岩埂拆除爆破的有害效应分析	835
15.3	混凝土围堰及岩埂拆除爆破设计	839
15.4	混凝土围堰及岩埂拆除爆破的安全设计内容要点	841
15.5	围堰及岩埂拆除爆破案例之1:大朝山水电站尾水隧洞出口围堰及岩埂 拆除爆破	841
15.6	围堰及岩埂拆除爆破案例之2:小湾水电站导流洞混凝土围堰及岩埂 拆除爆破施工	845

15.7	围堰及岩埂拆除爆破案例之 3: 洪家渡水电站 2 号导流洞岩石围堰及岩埂拆除	849
15.8	围堰及岩埂拆除爆破案例之 4: 糯扎渡水电站导流洞土石围堰拆除施工	853
15.9	围堰及岩埂拆除爆破案例之 5: 大盈江二级水电站导流洞混凝土围堰拆除	857
15.10	围堰及岩埂拆除爆破案例之 6: 溪洛渡水电站左岸导流洞浆砌石围堰及岩埂拆除	864
15.11	围堰及岩埂拆除爆破案例之 7: 柘溪水电站岩埂拆除精细爆破	870
	参考文献	873
16	水利水电地下工程施工设备配置	874
16.1	水利水电地下工程钻爆法施工的常规设备与配置	874
16.2	水工隧洞 TBM 施工设备	880
16.3	地下工程施工用凿岩机械主要参数	886
16.4	地下工程施工用挖掘机械主要参数	894
16.5	地下工程施工用装载机械主要参数	899
16.6	地下工程施工用混凝土机械主要参数	903
	参考文献	922
附录 1	水利水电地下工程施工术语及其释义	923
附录 2	国外现行岩体分类标准集锦——工程岩体分级系统使用标准指南	935
附录 3	20 世纪国外已建深埋长水工隧洞和大型水电站地下厂房洞室特性表	974
附录 4	中国大型水利水电(含抽水蓄能)地下工程一览表	990
	后记	994

Contents

Volume One

Preface 1

Preface 2

Foreword

1 Introduction	1
1.1 Fast construction technology for large-scale underground power diversion system	1
1.2 Fast construction technology for large cross-section and long tunnels	2
1.3 Construction technology for unlined high-pressure reinforced concrete bifurcated pipelines	3
1.4 Fast construction technology for high-pressure and long (inclined) shafts	4
1.5 Concrete Formwork Construction technology for underground works	5
References	6
2 Overall construction planning	7
2.1 General description	7
2.2 Procedures for construction of underground works in hydro projects	9
2.3 General construction layout	23
2.4 Access design	27
2.5 Ventilation design	29
2.6 Environment protection during construction operations	33
2.7 Proper construction operations	34
2.8 Case 1 of overall construction planning: Diversion tunnel and underground powerhouses of the Xiluodu Hydropower Project	36
2.9 Case 2 of overall construction planning: Diversion tunnel of the Shuibuya Hydropower Project	40
2.10 Case 3 of overall construction planning: Diversion tunnel and underground power diversion system	44
2.11 Case 4 of overall construction planning: Diversion tunnel of the Xiaowan Hydropower Project	49
2.12 Case 5 of overall construction planning: Diversion tunnel and underground powerhouse of the Longtan Hydropower Station	56
References	60
3 Geological investigation during construction	61
3.1 General description	61

3.2	Geological factors affecting stability of surrounding rocks	61
3.3	Classification of surrounding rocks	82
3.4	Geological investigation during construction	90
3.5	Case 1 of geological investigation during construction; Geological prediction for the diversion tunnel at Lenglongling of a water transfer project and the diversion tunnel of the Hujiayan Hydropower Station	99
3.6	Case 2 of geological investigation during construction; Construction of diversion tunnel using TBM on the trunk canal of the Yin-Da-Ji-Huang water transfer project	102
3.7	Case 3 of geological investigation during construction; Classification of surrounding rocks in the underground powerhouse of the Xiluodu Hydropower Project	105
3.8	Case 4 of geological investigation during construction; Classification of surrounding rocks in the underground powerhouse of the Pushihe Pump Storage Station during feasibility study and design stages	111
3.9	Case 5 of geological investigation during construction; Classification of surrounding rocks in the diversion tunnel of the Rongdi Hydropower Station	115
3.10	Case 6 of geological investigation during construction; Classification of surrounding rocks in the diversion and flood discharge tunnel of the Zhangfeng Reservoir	118
3.11	Case 7 of geological investigation during construction; Classification of surrounding rocks in the deep-embedded tunnel as part of the trunk canal of the Yin-Da-Ji-Huang water transfer project	120
3.12	Case 8 of geological investigation during construction; Classification of surrounding rocks in tunnels constructed by TBM	123
3.13	Case 9 of geological investigation during construction; Classification of surrounding rocks in tunnels excavated in Karst areas	127
3.14	Case 10 of geological investigation during construction; Classification of surrounding rocks in tunnels excavated in swelling rock mass	130
	References	136
4	Construction surveying	138
4.1	General description	138
4.2	Regulations on surveying during construction of underground spaces	141
4.3	Regulations on surveying during construction of hydraulic lunnels using shield tunneling method	144
4.4	Data collection and preparation for alignment	149
4.5	Estimate of holing through accuracy	150
4.6	Plane and vertical control surveying outside tunnel	155
4.7	Plane and vertical control surveying inside tunnel	156
4.8	Construction surveying inside tunnel	157
4.9	Connection survey and elevation transferring for shafts	159
4.10	Data collation	162
4.11	Case 1 of construction surveying; TBM diversion tunnel of the Jinping Hydropower Project (Cascade II)	163
4.12	Case 2 of construction surveying; Construction control surveying for underground works of the Yixing Pump Storage Station	166
4.13	Case 3 of construction surveying; Holing through surveying for the long and inclined small diameter tunnel of the Tanghe Reservoir Project	171

4. 14	Case 4 of construction surveying; Diversion tunnel of the A'hai Hydropower Station	174
4. 15	Case 5 of construction surveying; Cross-section excavation of the diversion tunnel of the Songshan Reservoir	178
4. 16	Case 6 of construction surveying; Power diversion tunnel of the Huanglong Reservoir	179
4. 17	Error estimation for control surveying	182
	References	186
5	Adit construction	188
5. 1	General description	188
5. 2	Portal construction	189
5. 3	Tunneling method	191
5. 4	Arrangement of drill-and-blast holes	192
5. 5	Control of blast induced vibration	200
5. 6	Initial stage support	202
5. 7	Supporting materials	206
5. 8	Tunnel construction schedule network diagram	212
5. 9	Roughness coefficient of water conveyance tunnel	214
5. 10	Concrete lining	214
5. 11	Case 1 of adit construction; Adit construction with unfavorable geological settings at Jinping Hydropower Project (Cascadel)	218
5. 12	Case 2 of adit construction; Adit construction in swelling rock mass for the Yin-E-Ji-Wu water transfer project	221
	References	224
6	Construction in unfavorable geological settings	226
6. 1	General description	226
6. 2	Tunneling through soft and fissured zones	226
6. 3	Caving at shallow embedding depth and with complex geological conditions	236
6. 4	Construction in zones of karst and groundwater abundance	237
6. 5	Construction of underground chambers under other types of unfavorable geological conditions	242
6. 6	Case 1 of construction in unfavorable geological settings; Tunneling and supporting of diversion tunnels excavated in softened mudstone at the Zipingpu Hydropower Project	245
6. 7	Case 2 of construction in unfavorable geological settings; Diversion tunneling in soft rocks at the Goupitan Hydropower Project	250
6. 8	Case 3 of construction in unfavorable geological settings; Diversion tunneling through fault zones at the Ruzhadu Hydropower Project	253
6. 9	Case 4 of construction in unfavorable geological settings; TBM tunneling at the Dahuofang Reservoir for water conveyance	257
6. 10	Case 5 of construction in unfavorable geological settings; TBM tunneling for diversion through rock blast zones at the Jinping Hydropower Project (Cascade II)	261
6. 11	Case 6 of construction in unfavorable geological settings; Inlet and outlet sections	

of the tailrace tunnel, Phase II of the Guangzhou Pump Storage Station	264
6. 12 Case 7 of construction in unfavorable geological settings; Treatment of rock falling at the outlet of the left-bank diversion tunnel at the Xuchun Hydropower Station	268
References	271
7 Construction of large underground chambers like powerhouse	273
7. 1 General description	273
7. 2 Principles and procedures	274
7. 3 Focal points and challenges	275
7. 4 Excavation and support	276
7. 5 Concreting	299
7. 6 Concreting for main transformer chamber, tailrace surge chamber (shaft), elevator shaft and cable shaft	302
7. 7 Controlling blast induced vibration velocity	302
7. 8 Construction of the crane supporting girder on side walls	304
7. 9 Case 1 of large underground powerhouse; TGP right-bank underground powerhouse excavation and cracking control concreting of side-wall girder	319
7. 10 Case 2 of large underground powerhouse; Synthetic fast excavation technology applied in the Xiaowan Hydropower Project	321
7. 11 Case 3 of large underground powerhouse; Synthetic construction and support technology applied in extra-large cross-section of underground chambers at the Longtan Hydropower Project	326
7. 12 Case 4 of large underground powerhouse; Excavation of high walls of the right- bank underground powerhouse at the Xiluodu Hydropower Project	326
7. 13 Case 5 of large underground powerhouse; Excavation of underground powerhouse in high earth stress and low compressive rock strength zones at the Jinping Hydropower Project (Cascade I)	332
7. 14 Case 6 of large underground powerhouse; Anchoring cable construction in the main underground powerhouse at the Pengshui Hydropower Project	339
7. 15 Case 7 of large underground powerhouse; Treatment of intensively karstic zones in the underground powerhouse of the Goupitan Hydropower Project	342
7. 16 Planning of underground chamber construction accesses for larges scale hydropower stations	352
7. 17 Study and analysis on replacement of soft rocks in the underground powerhouse of the Shuibuya Hydropower Project	356
7. 18 Phase II concreting technology for underground spiral cases of hydropower stations	361
References	369
8 Construction of (inclined) shafts	370
8. 1 General description	370
8. 2 Construction features and procedures	376
8. 3 Full cross-section excavation and support	378
8. 4 Pilot shaft construction	381

8.5	Excavation expansion and support	394
8.6	Concrete lining and grouting	398
8.7	Construction safety and preventive measures	406
8.8	Case 1 of (inclined) shaft construction; Inclined shaft of the diversion tunnel at the Zipingpu Hydropower Project	411
8.9	Case 2 of (inclined) shaft construction; Ventilation shaft at the Sinanjiang Hydropower Station	414
8.10	Case 3 of (inclined) shaft construction; Inclined shaft in complex-structured geological setting at the Baoquan pump storage station	418
8.11	Case 4 of (inclined) shaft construction; Steeply inclined, large diameter and long shaft at the Tongbai pump storage station	422
8.12	Case 5 of (inclined) shaft construction; Inclined shaft of the power diversion tunnel at the underground powerhouse of the TGP	426
8.13	Case 6 of (inclined) shaft construction; Shaft for material feeding at the water conveyance tunnel of the Dahuofang Reservoir	431
8.14	Case 7 of (inclined) shaft construction; High pressure diversion shaft at the Zhouning Hydropower Station	434
8.15	Case 8 of (inclined) shaft construction; Diversion shaft at the Tai'an pump storage station	438
8.16	Case 9 of (inclined) shaft construction; Inclined shaft tunneled with RHINO-400H drilling technology at the Huizhou pump storage station	441
8.17	Case 10 of (inclined) shaft construction; Slipform construction technology for the long and gentle-inclined shaft for the Xiaowan Hydropower Project	453
	References	459

Volume Two

9	Borehole grouting	461
9.1	General description	461
9.2	Grouting material and slurry	463
9.3	Grouting of shaft and underground chamber	470
9.4	Layout of underground grouting operation	473
9.5	Borehole grouting for underground engineering	476
9.6	Pre-stress grouting	486
9.7	Case 1 of borehole grouting construction; Normal pressure consolidation grouting at the high sidewalls of the underground powerhouse at the Pengshui Hydropower Project	490
9.8	Case 2 of borehole grouting construction; High pressure consolidation grouting at Tianshengqiao Hydropower Station (Cascade II)	494
9.9	Case 3 of borehole grouting construction; Concrete contact grouting at the Longtan Hydropower Project	500
9.10	Case 4 of borehole grouting construction; Curtain grouting for underground powerhouse of the Xiangjiaba Hydropower Project	504

9.11	Case 5 of borehole grouting construction; Grouting for clogging of water burst at the Jinping Hydropower Project (Cascade II)	511
9.12	Case 6 of borehole grouting construction; Pre-stressing grouting in the high pressure tunnel at the Huilong Hydropower Station	515
9.13	Case 7 of borehole grouting construction; Chemical grouting into the cracking concrete lining of the underground powerhouse at the Shuibuyan Hydropower Project	517
9.14	Case 8 of borehole grouting construction; Consolidation grouting in the high pressure tunnel (6.5 MPa) at the Guangzhou pump storage station	521
9.15	Case 9 of borehole grouting construction; Consolidation grouting for the sliding resistance rock mass at the Xiaowan Hydropower Station	527
	References	534
10	Formwork construction of hydraulic tunnels	537
10.1	General description	537
10.2	Steel form jumbo inside adits	538
10.3	Shaft forms	553
10.4	Inclined slipform	556
10.5	Forms for inclined shaft	561
10.6	Bare concrete forms	567
10.7	Case 1 of formwork construction; LSD inclined shaft slip form for the Tongbai Hydropower Station	567
10.8	Case 2 of formwork construction; Formwork construction of diversion tunnel linings at the TGP	571
10.9	Case 3 of formwork construction; Design and application of adit formwork for the diversion tunnel of the Liuheba Hydropower Project	574
10.10	Case 4 of formwork construction; Shaft formwork inside the water conveyance tunnel of the Lianhuan Reservoir	578
10.11	Case 5 of formwork construction; Slipform construction of invert lining of the diversion tunnel at the Jinping Hydropower Project (Cascade II)	582
10.12	Case 6 of formwork construction; Extra large diameter inclined shaft slipform construction at the Longtan Hydropower Project	584
10.13	Comparative analysis on safety techniques for formwork construction of hydraulic tunnels	591
	References	594
11	Ventilation during construction of underground chambers	595
11.1	General description	595
11.2	Large dimension underground chamber construction technology and construction period ventilation	596
11.3	Ventilation patterns, characteristics and basic principles	597
11.4	Dynamic simulation of ventilation	599
11.5	Ventilation design	609
11.6	Layout of ventilation system	615
11.7	In-depth studies on some key aspects of ventilation design	622