

Dams and Appurtenant Hydraulic Structures

2nd Edition

Ljubomir Tanchev



 CRC Press
Taylor & Francis Group
A BALKEMA BOOK

Dams and Appurtenant Hydraulic Structures

2nd Edition

Ljubomir Tanchev

University professor, retired



CRC Press

Taylor & Francis Group

Boca Raton London New York Leiden

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

A BALKEMA BOOK

Illustration front cover:

Arch dam "Karun 3", 2004, Khuzestan Province, Iran, 205 m in height.

CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

© 2014 Taylor & Francis Group, London, UK

Typeset by MPS Limited, Chennai, India

Printed and Bound by CPI Group (UK) Ltd, Croydon, CR0 4YY

All rights reserved. No part of this publication or the information contained herein may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, by photocopying, recording or otherwise, without written prior permission from the publisher.

Although all care is taken to ensure integrity and the quality of this publication and the information herein, no responsibility is assumed by the publishers nor the author for any damage to the property or persons as a result of operation or use of this publication and/or the information contained herein.

Library of Congress Cataloging-in-Publication Data

Tanchev, Ljubomir, 1945–

[Brani i pridružni hidrotehnički objekti. English]

Dams and appurtenant hydraulic structures / Ljubomir Tanchev. — 2nd edition.
pages cm

"Translation of the publication which came out in Macedonian in 1999,
with certain improvements and additions"—Preface.

First English edition: CRC Press/Balkema, 2005.

Summary: "Comprehensive and complete overview of all kinds of dams and appurtenant hydraulic structures, now in its second edition. Discusses various topics: general questions, design, construction, surveillance, maintenance and reconstruction of various embankment and concrete dams, hydromechanical equipment, spillway structures, bottom outlets, some special hydraulic structures, composition of structures in river hydraulic schemes, reservoirs, environmental effects of river hydraulic schemes and reservoirs and environmental protection. Special attention is paid to advanced methods of static and dynamic analysis of embankment dams. Richly-illustrated, fully revised, updated and expanded. Intended for senior students, researchers and professionals in civil, hydraulic, and environmental engineering and dam construction and exploitation"—Provided by publisher.

Includes bibliographical references and index.

ISBN 978-1-138-00006-3 (hardback) — ISBN 978-0-203-57705-9 (ebook PDF)

1. Dams. 2. Hydraulic structures. 3. Dams—Design and construction. I. Title.

TC540.T3713 2014

627'.8—dc23

2013050934

Published by: CRC Press/Balkema
P.O. Box 11320, 2301 EH Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com — www.taylorandfrancis.com

ISBN: 978-1-138-00006-3 (Hbk)

ISBN: 978-0-203-57705-9 (eBook PDF)

Preface

It is now more than ten years since the manuscript of the first edition was completed. This new (second) edition gave me a good opportunity to correct some errors, to update the text and references throughout, and, most importantly, to rewrite and enlarge parts of the text in response to some important developments in the field of dam design, analysis and construction. Major changes were imposed by the development in the field of embankment dam analysis (Chapters 8 and 9), concrete faced rockfill dams (Chapter 12), rockfill dams with a geomembrane facing (Chapter 13), rockfill dams with internal non-earth core (Chapter 14), roller-compacted concrete gravity dams, and hardfill dams (Chapter 18), and roller-compacted concrete arch dams (Chapter 20).

The main aim of the book remains the same as that of the first edition, i.e. to provide a complete and comprehensive picture of dams and the appurtenant hydraulic structures which are essential for their safe functioning, to: engineers specialising in the design, construction and exploitation of dams, to researchers and higher degree candidates in science, and to post-graduates in the fields of civil engineering, hydraulic engineering and environmental protection. The author also hopes that it will prove a useful text for students in their final year of undergraduate studies in the relevant disciplines.

The author would like to thank the publisher for the great effort made in providing the opportunity for this second edition.

Ljubomir Tanchev
Skopje, October 2013

Preface to the first edition

Water, one of the few natural resources without which there is no life, is distributed throughout the world unevenly in terms of place, season and quality. For this reason it is essential to construct dams on rivers, thus forming reservoirs for the storage and the even use of water. To date, forty-two thousand large dams have been built worldwide, and hundreds of thousands of smaller ones, which have made possible a rational use of a certain amount of river water – the most important water resource for human life and activity. Dams, together with their appurtenant hydraulic structures, belong among the most complex engineering works, above all because of their interaction with the water, their great influence on the environment and their high cost. Therefore great significance is given to theoretical research relating to dams, to improving the methods of analysing and constructing them, and to the knowledge gained in the course of their exploitation. In the past forty years great progress has been made in this respect.

More than twenty large dams and over a hundred smaller ones have been built in the Republic of Macedonia, which have still only partially exploited the available water, and flood control remains incomplete. The majority of the large dams were built in the period from 1952 to 1982 while, principally because of the lack of investment, the past twenty years have seen the construction mainly of smaller dams with a height of up to twenty metres and a reservoir volume of 300,000 cubic metres. In the next few years some two or three more large dams will be completed which will still not satisfy the need for water for the water supply, for irrigation and for the production of electrical energy, which are continually on the increase. The situation in all developing countries is similar, so that dams will continue to be built in the future despite the resistance on the part of devotees of the unobstructed flow of rivers.

The volume you have before you is a translation of the publication which came out in Macedonian in 1999, with certain improvements and additions. The text has been written with the intention of providing the reader with a comprehensive picture of dams and the appurtenant hydraulic structures which are essential for their safe functioning. The author hopes that it will prove useful to engineers specialising in the design, construction and exploitation of dams, to researchers and higher degree candidates in science, and to post-graduates in the fields of civil engineering, hydraulic engineering and environmental protection. Three years of experience of the Macedonian edition of the book have also demonstrated that a remarkable interest in it has also been shown by students in their final year of undergraduate studies in the relevant subjects.

Some 70% of the book is concerned with dams, while 30% is devoted to appurtenant hydraulic structures, hydromechanical equipment and to river hydraulic

schemes. The material is divided into five parts and thirty-five chapters. The *First Part* considers general questions about dams and appurtenant hydraulic structures (Chapters 1–5). The *Second Part* is devoted to embankment dams (Chapters 6–15) and the *Third Part* to concrete dams (Chapters 16–22). The *Fourth Part* deals with hydromechanical equipment and appurtenant hydraulic structures at dams (Chapters 23–30) while the *Fifth Part* is concerned with river hydraulic schemes as follows: Chapters 31 and 32 with the composition of structures in various different designs and types of hydraulic schemes, Chapter 33 with reservoirs, and Chapter 34 with the negative effects of river hydraulic schemes and with environmental protection, while Chapter 35 looks into questions of major importance relating to the repair and reconstruction of river hydraulic structures.

The most important achievements of the author's 25 years of research and practical work in the field of dams and hydraulic structures together with the achievements and experience of colleagues at the Department of Hydraulic Structures of the Faculty of Civil Engineering at the Ss. Cyril and Methodius University in Skopje have been incorporated into this book, and at appropriate points virtually all the more important dams in the Republic of Macedonia are described.

The list of people and institutions who have supported and assisted me in preparing this edition of the book is a long one. I would like to thank the *Fund of Waters – Skopje*, and the *Institute for Testing of Materials and New Technology 'Skopje'*, which financially supported the translation that was accomplished by Mr. Blagoja Neškoski and Prof. Graham Reid. I would also like to express my gratitude to the publisher who has made an English edition possible.

Ljubomir Tančev
Skopje, January 2005

Table of contents

<i>Preface</i>	xv
<i>Preface to the first edition</i>	xvii

PART I

Dams and appurtenant hydraulic structures – General **I**

I	Utilization of water resources by means of hydraulic structures	3
1.1	Introduction	3
1.2	Hydraulic structures (definition, classification)	6
1.3	General features of hydraulic structures	8
1.4	Intent of dams. Elements of a dam and a reservoir	18
1.5	Appurtenant hydraulic structures	19
1.6	Short review of the historical development of hydraulic structures	22
2	Foundations of dams	25
2.1	Foundations for hydraulic structures in general	25
2.2	Rock foundations	26
2.3	Semi-rock and soil foundations	30
2.4	Requirements for the foundation	32
2.5	Investigation works regarding dam foundations	40
2.5.1	Indirect investigation methods	41
2.5.2	Direct investigation methods	43
2.5.3	Sampling	45
2.5.4	Testing	46
2.6	Improvement of foundations	47
3	Seepage through dams	59
3.1	Action of seepage flow	59
3.2	Mechanical action of seepage flow on the earth's skeleton	60
3.3	Seepage resistance of earth foundations and structures	63
3.4	Theoretical aspects of seepage	64
3.5	Practical solution of the problem of seepage	70
3.6	Seepage in anisotropic soil conditions	74
3.7	Seepage in non-homogeneous soil conditions	77

3.8	Seepage of water through rock foundations	78
3.9	Lateral seepage	81
3.10	Seepage through the body of concrete dams	82
4	Forces and loadings on dams	85
4.1	Forces and loadings on dams in general	85
4.2	Forces from hydrostatic and hydrodynamic pressure	87
4.3	Influence of cavitation and aeration on hydraulic structures	89
4.4	Influence from waves	91
4.5	Influence of ice and water sediment	97
4.6	Seismic forces	98
4.7	Temperature effects	103
4.7.1	Temperature effects on embankment dams	103
4.7.2	Temperature effects on concrete structures	104
5	Designing hydraulic structures	107
5.1	Basic stages in the process of the creation and use of hydraulic structures	107
5.2	Investigation for design and construction of hydraulic structures	109
5.3	Contents of the hydraulic design and design phases	112
5.4	Project management and the role of legislation	116
PART 2		
Embankment dams		119
6	Embankment dams – general	121
6.1	Introduction, terminology, and classification	121
6.2	Historical development of embankment dams	126
6.3	Dimensions of the basic elements of embankment dams	128
6.4	Choice of the dam site	134
6.5	Materials for construction of embankment dams	136
6.6	Choice of type of embankment dam	143
6.7	Tailings dams	147
6.7.1	Definition and general features	147
6.7.2	Classification of tailings dams	148
6.7.3	Methods of construction of tailings dams	149
7	Seepage through embankment dams	155
7.1	Kinds of seepage through the embankment dam body	155
7.2	Seepage line and hydrodynamic net in embankment dams	158
7.3	Measures against the harmful effect of seepage	163
7.3.1	Action against local seepage rising	163
7.3.2	Action against internal erosion	164
7.4	Calculations of the casual seepage strength of earthfill dams	173

8	Static stability of embankment dams	177
8.1	Introduction	177
8.2	Classical methods	177
8.2.1	Method of slices	178
8.2.2	Wedge method	181
8.2.3	States in which stability of embankment dams is examined	183
8.2.4	Stability of rockfill dams	189
8.3	Advanced methods	190
8.3.1	Application of the Finite Element Method	190
8.3.2	Specific properties of the application of the Finite Element Method (FEM) for analysis of embankment dams	194
8.3.3	Choice of constitutive law	195
8.3.4	Simulation for dam construction in layers	204
8.3.5	Simulation for filling the reservoir and the effect of water	208
8.3.6	Collapse settlement	217
8.3.7	Simulation of behaviour at the interfaces of different materials	223
8.3.8	Analysis of consolidation	228
8.3.9	Creep of materials in the body of embankment dams	235
8.3.10	Three-dimensional analysis	241
9	Dynamic stability of embankment dams	261
9.1	Effect of earthquakes on embankment dams	261
9.2	Assessment of design earthquake	263
9.2.1	Strength, attenuation, and amplification of earthquakes	263
9.2.2	Design earthquake	267
9.3	Liquefaction	270
9.4	Analysis of stability and deformations in embankment dams induced by earthquakes	273
9.4.1	Pseudo-static method	273
9.4.2	Pseudo-static methods with a non-uniform coefficient of acceleration	275
9.4.3	Equivalent linear method	279
9.4.4	Pure nonlinear response method	281
9.5	Case studies of recent actual events	288
9.5.1	Case study of Aratozawa dam (Japan, 2008)	288
9.5.2	Case study of Zipingpu dam (China, 2008)	292
10	Earthfill dams	297
10.1	Classification and construction of earthfill dams	297
10.2	Structural details for earthfill dams	298
10.2.1	Slope protection	299
10.2.2	Water-impermeable elements	305
10.2.3	Drainages	312
10.3	Preparation of the foundation and the joint between earthfill dams and the foundation	320
10.3.1	Preparation of the general foundation	321

10.3.2	Preparation of the foundation when using a dam cutoff trench	321
10.3.3	Joint of the earthfill dam and the foundation	322
11	Earth-rock dams	327
11.1	Construction of earth-rock dams	327
11.2	Earth-rock dams with vertical core	330
11.3	Earth-rock dams with a sloping core	333
11.4	Earth-rock dams of 'soft' rocks	346
11.5	Fissures in the core of earth-rock dams	348
11.5.1	Kinds of fissures and causes for their occurrence	348
11.5.2	Measures for preventing the occurrence of fissures	351
11.6	Designing earth-rock dams in seismically active areas	358
12	Rockfill dams with reinforced concrete facing	361
12.1	Definition, field of application and construction	361
12.2	Modern dams with reinforced concrete facing	368
12.2.1	Rockfill dam body	368
12.2.2	Concrete plinth	371
12.2.3	Concrete face slabs	374
12.2.4	Joints for reinforced concrete facing slabs	380
12.2.5	Perimeter joint	382
12.2.6	Parapet wall and camber	385
12.3	Construction of the reinforced concrete facing	387
12.4	Examples of modern CFRDs	390
12.4.1	Examples from the period 1971–1980	390
12.4.2	Examples from the period 1982–2000	393
12.4.3	First decade of XXI century	397
12.5	Concrete facings of non-conventional concrete	413
13	Rockfill dams with asphaltic concrete and other types of facings	415
13.1	Rockfill dams with asphaltic concrete facing	415
13.1.1	General characteristics	415
13.1.2	Composition and characteristics of hydraulic asphaltic concrete	416
13.1.3	Construction of the asphaltic concrete facings	420
13.1.4	Joint of the lining with a gallery or concrete cutoff in dam's toe	426
13.1.5	Joint of the facing with dam's crest	431
13.2	Rockfill dams with steel facing	431
13.3	Rockfill dams with facing of geomembrane	435
13.3.1	General	435
13.3.2	Examples of rockfill dams with geomembrane facing	435
14	Rockfill dams with internal non-earth core	447
14.1	Rockfill dams with asphaltic concrete core	447
14.1.1	Function, conditions of work and materials	447
14.1.2	Structure of the asphaltic concrete cores	450
14.1.3	Recent examples	465

14.1.4	Joint of asphaltic concrete core with the foundation and lateral concrete structures	473
14.2	Other types of non-earth cores	478
14.2.1	Concrete core walls	478
14.2.2	Grout and plastic concrete walls (cores)	480
14.3	Stability of earth-rock dams with asphaltic concrete core	484
15	Monitoring and surveillance of embankment dams	491
15.1	Task and purpose of monitoring	491
15.2	Monitoring of pore pressure and seepage	492
15.2.1	Hydraulic piezometers	492
15.2.2	Electric piezometers	495
15.2.3	Monitoring of seepage	497
15.3	Monitoring of displacements	502
15.3.1	Measurement of displacements at the surface of the dam	503
15.3.2	Measuring displacements in the interior of the dam	504
15.4	Measurements of stresses	512
15.5	Seismic measurements	513
15.6	General principles on the selection and positioning layout of measuring instruments	514
PART 3		
Concrete dams		519
16	Gravity dams on rock foundations	521
16.1	Gravity dams in general	521
16.2	Mass concrete for dams	523
16.2.1	General	523
16.2.2	Constituent elements of mass concrete	523
16.2.3	Parameters of concrete mixture	524
16.2.4	Fabrication and placing of concrete	526
16.3	Cross-section of gravity dams	526
16.3.1	Cross-sections in general	526
16.3.2	Theoretical cross-section	528
16.3.3	Practical cross-section	531
16.4	Dimensioning of concrete gravity dams	533
16.4.1	Elementary methods	536
16.4.2	Modern methods	537
16.5	Determination of stresses	540
16.5.1	Determination of stresses by the gravitational method	541
16.5.2	Calculation of stresses by using the theory of elasticity	544
16.5.3	Calculation of stresses by using the Finite Element Method	546
16.5.4	Influence of temperature changes, shrinkage and expansion of concrete on stresses in dams	549
16.5.5	Permissible stresses and cracks	550
16.6	General structural features of gravity dams	551

16.7	Stability of gravity dams on rock foundation	563
16.7.1	Dam sliding and shearing across foundation	564
16.8	Hollow gravity dams	568
17	Gravity dams on soil foundations	573
17.1	Fundamentals of gravity dams on soil foundation	573
17.2	Schemes for the underground contour of the dam	575
17.3	Determination of basic dimensions of underground contour	577
17.4	Construction of elements of the underground contour	579
17.5	Construction of dam body	583
17.6	Dimensioning and stability of gravity dams on soil foundation	592
18	Roller-compacted concrete gravity dams	597
18.1	Introduction	597
18.2	Characteristics of roller-compacted concrete	601
18.2.1	Roller-compacted concrete mixture, placement and properties	601
18.2.2	Lift joint bond	608
18.3	Types of roller-compacted concrete	612
18.4	Trends in development of dams made of roller-compacted concrete	614
18.5	Improving the water-impermeability of dams made of roller-compacted concrete	619
18.6	Cost of dams made of roller-compacted concrete	623
18.7	Examples of dams made of roller-compacted concrete	625
18.7.1	Examples of the early period of construction of RCC dams	626
18.7.2	Examples from recent practice	637
18.7.3	RCC dam construction practice in China	648
18.7.4	RCC dam construction practice in Spain	650
18.7.5	RCC dam construction practice in Japan	656
18.8	Hardfill dams	660
18.8.1	Basic idea and concept	660
18.8.2	Hardfill as a dam construction material	663
18.8.3	Design of hardfill dams	664
18.8.4	Main features and field of application	667
19	Buttress dams	669
19.1	Definition, classification, and general conceptions	669
19.2	Massive-head buttress dams	671
19.3	Flat-slab buttress dams	676
19.4	Multiple-arch buttress dams	682
19.5	Conditions for application of buttress dams	691
20	Arch dams	693
20.1	Arch dams in general – classification	693
20.2	Development of arch dams through the centuries	696

20.3	Methods of designing arch dams	701
20.3.1	Basic design	701
20.3.2	Arch dams with double curvature	710
20.3.3	Form of arches in plan and adaptation to ground conditions	720
20.4	Structural details of arch dams	724
20.5	Roller-compacted concrete arch dams	729
20.6	Static analysis of arch dams	732
20.6.1	Method of independent arches	733
20.6.2	Method of central cantilever	737
20.6.3	The trial-load method	740
20.6.4	The Finite Element Method	741
20.6.5	The experimental method	743
21	Dynamic stability of concrete dams	747
21.1	Earthquake effects on concrete dams	747
21.2	Methods for dynamic analysis of concrete dams	752
21.2.1	Linear analysis and response of the structure	755
21.2.2	Nonlinear analysis and the response of the dam	756
21.2.3	Dynamic analysis of RCC and hardfill dams	759
21.3	Knowledge gained from practice and experiments	761
21.3.1	Knowledge gained from case studies	761
21.3.2	Laboratory and field experiments	763
21.4	Recommendation for design and construction of concrete dams in seismically active areas	765
22	Monitoring and surveillance of concrete dams	767
22.1	Monitoring, surveillance, and instrumentation of concrete dams – general	767
22.2	Monitoring by precise survey methods	768
22.3	Surveillance with embedded instruments	772
22.4	Automatization and computerization of monitoring	776
PART 4		
Hydromechanical equipment and appurtenant hydraulic structures		781
23	Mechanical equipment and appurtenant hydraulic structures – general	783
23.1	Hydromechanical equipment – general	783
23.1.1	Introduction	783
23.1.2	Classification of gates and valves	784
23.1.3	Forces acting on gates and valves	785
23.2	Mechanisms for lifting and lowering of the gates and valves. Service bridges	785
23.3	Installation and service of gates and valves	788

23.4	Appurtenant hydraulic structures	789
23.4.1	Definition, function and capacity	789
23.4.2	Classification of spillways and bottom outlets	791
23.5	Evacuation of overflowing waters via a chute spillway	794
23.6	Energy dissipation of the spillway jet	798
23.7	Selection of type of spillway structure	807
24	Surface (crest) gates	811
24.1	Basic schemes of surface (crest) gates	811
24.2	Surface (crest) gates transferring water pressure to side walls or piers	814
24.2.1	Ordinary plain metal gates	814
24.2.2	Special plain gates	820
24.2.3	Stop-log gates	822
24.2.4	Radial gates	823
24.2.5	Roller gates	828
24.3	Surface (crest) gates transferring the water pressure to the gate sill	832
24.3.1	Sector and drum gates	832
24.3.2	Flap gates	835
24.3.3	Bear-trap gates	837
24.3.4	Inflatable gates	839
25	High-head gates and valves	841
25.1	General characteristics – classification	841
25.2	High-head gates transferring pressure to the structure directly through their supports	844
25.2.1	Plain high-head gates	844
25.2.2	Radial (tainter) high-head gates	848
25.2.3	Diaphragm gate	851
25.3	Valves transferring the pressure through the shell encasing the valve	854
25.3.1	Waterworks valve types	854
25.3.2	Disc-like or butterfly valves	856
25.3.3	Cone valve	858
25.3.4	Needle valves and spherical valves	859
25.4	Cylindrical balanced high-head valves	860
26	Spillways passing through the dam's body	861
26.1	Crest spillways	861
26.1.1	Crest spillways at concrete dams	861
26.1.2	Crest spillways at embankment dams	867
26.2	High-head spillway structures	871
27	Spillways outside the dam's body	879
27.1	Introduction	879
27.2	Overfall (ogee) spillway structure	879
27.3	Side-channel spillway	888

27.4	Shaft (morning glory) spillway	896
27.4.1	Shaft spillway with circular funnel crest	896
27.4.2	Special types of shaft spillways	905
27.4.3	Tower spillway	906
27.5	Labyrinth spillway	908
27.6	Siphon spillways	910
28	Bottom outlet works	915
28.1	Basic assumptions on designing bottom outlet works	915
28.2	Bottom outlet works in concrete dams	916
28.3	Bottom outlet works in embankment dams	918
29	Special hydraulic structures	929
29.1	Introduction	929
29.2	Transport structures	929
29.3	Hydraulic structures for the admission and protection of fish	934
30	River diversion during the construction of the hydraulic scheme	943
30.1	River diversion during the construction of dams and appurtenant hydraulic structures – general	943
30.2	Construction of the structures without river diversion from the parent river channel	944
30.2.1	Method with damming of the construction (foundation) pit	944
30.2.2	Method without damming of the construction pit	947
30.3	Construction of the structures with river diversion from the river channel	950
30.3.1	Types of cofferdams	952
PART 5		
Hydraulic schemes		955
31	Composition of structures in river hydraulic schemes	957
31.1	Definition and classification of hydraulic schemes	957
31.2	General conditions and principles for the composition of hydraulic schemes	958
31.3	Characteristics of river hydraulic schemes for different water economy branches	960
31.4	Aesthetic shaping of hydraulic schemes	962
31.5	River hydraulic schemes without pressure head	965
31.6	Low-head hydraulic schemes	967
31.7	Medium-head river hydraulic schemes	968
32	High-head river hydraulic schemes	971
32.1	High-head river hydraulic schemes on mountain rivers (type I)	971
32.2	High-head hydraulic schemes on middle and low parts of rivers	983
32.3	Pumped-storage hydraulic scheme	990

33	Reservoirs	995
33.1	Introduction	995
33.2	Formation and safety of reservoirs	996
33.2.1	Stability of reservoir banks	997
33.2.2	Water-impermeability of the reservoir	1000
33.2.3	Seismicity of the ground in the zone of the reservoir	1003
33.2.4	Water absorption of the ground in the zone of the reservoir	1005
33.2.5	Evaporation	1006
33.2.6	Sediment accumulation	1006
33.3	Resettlement of population and relocation of structures	1011
33.4	Sports and recreational facilities	1013
34	Negative effects of hydraulic schemes and environmental protection	1017
34.1	Types of negative effects on the environment	1017
34.1.1	Changing the land into the area of the reservoir	1018
34.1.2	Change of the flow downstream of the dam	1020
34.1.3	Damming the migration paths of fish and wild animals	1022
34.1.4	Change in the surrounding landscape and the microclimate	1023
34.2	Social and ecological monitoring	1025
34.3	Environmental protection – selection of a solution with minimum negative effects on the environment	1026
35	Restoration and reconstruction of hydraulic schemes	1029
35.1	Need for restoration and reconstruction	1029
35.2	Restoration of dams and hydraulic schemes	1030
35.3	Reconstruction of hydraulic schemes	1037
	<i>References</i>	1047
	<i>Subject index</i>	1075
	<i>Index of dams</i>	1093

Part I

Dams and appurtenant hydraulic structures – General
