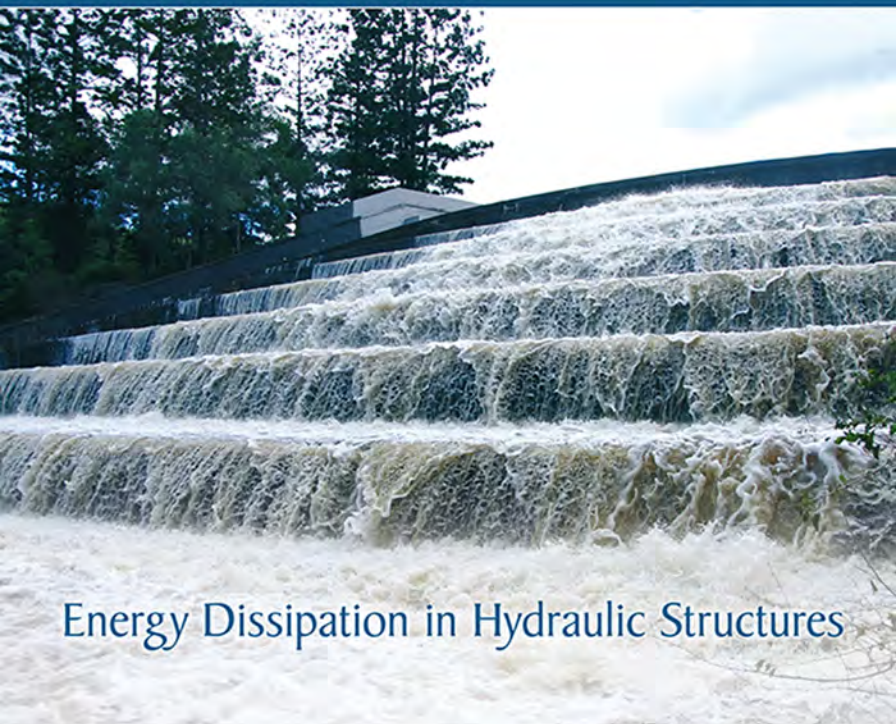




Energy Dissipation in Hydraulic Structures

Editor: Hubert Chanson

Energy Dissipation in Hydraulic Structures

IAHR Monograph

Series editor

Peter A. Davies

*Department of Civil Engineering,
The University of Dundee,
Dundee,
United Kingdom*

The International Association for Hydro-Environment Engineering and Research (IAHR), founded in 1935, is a worldwide independent organisation of engineers and water specialists working in fields related to hydraulics and its practical application. Activities range from river and maritime hydraulics to water resources development and eco-hydraulics, through to ice engineering, hydroinformatics and continuing education and training. IAHR stimulates and promotes both research and its application, and, by doing so, strives to contribute to sustainable development, the optimisation of world water resources management and industrial flow processes. IAHR accomplishes its goals by a wide variety of member activities including: the establishment of working groups, congresses, specialty conferences, workshops, short courses; the commissioning and publication of journals, monographs and edited conference proceedings; involvement in international programmes such as UNESCO, WMO, IDNDR, GWP, ICSU, The World Water Forum; and by co-operation with other water-related (inter)national organisations. www.iahr.org



Energy Dissipation in Hydraulic Structures

Hubert Chanson

*School of Civil Engineering, University of Queensland,
Brisbane, Australia*



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

Cover photo credit: Gold Creek dam stepped spillway in operation on 23 February 2015 (Photograph H. Chanson)

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

© 2015 Taylor & Francis Group, London, UK

Typeset by V Publishing Solutions Pvt Ltd., 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 prior permission in writing from the publisher. Innovations reported here may not be used without the approval of the authors.

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.

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

Library of Congress Cataloging-in-Publication Data

Chanson, Hubert.

Energy dissipation in hydraulic structures / Hubert Chanson.

p. cm. – (IAHR monograph)

Includes bibliographical references and index.

ISBN 978-1-138-02755-8 (hardcover : alk. paper) – ISBN 978-1-315-68029-3

(ebook : alk. paper) 1. Hydrodynamics. 2. Hydraulic structures. 3. Energy dissipation. 4. Diversion structures (Hydraulic engineering) I. Title.

TC171.C473 2015

627–dc23

2015011109

ISBN: 978-1-138-02755-8 (Hbk)

ISBN: 978-1-315-68029-3 (eBook PDF)

About the IAHR Book Series

An important function of any large international organisation representing the research, educational and practical components of its wide and varied membership is to disseminate the best elements of its discipline through learned works, specialised research publications and timely reviews. IAHR is particularly well-served in this regard by its flagship journals and by the extensive and wide body of substantive historical and reflective books that have been published through its auspices over the years. The IAHR Book Series is an initiative of IAHR, in partnership with CRC Press/Balkema – Taylor & Francis Group, aimed at presenting the state-of-the-art in themes relating to all areas of hydro-environment engineering and research.

The Book Series will assist researchers and professionals working in research and practice by bridging the knowledge gap and by improving knowledge transfer among groups involved in research, education and development. This Book Series includes Design Manuals and Monographs. The Design Manuals contain practical works, theory applied to practice based on multi-authors' work; the Monographs cover reference works, theoretical and state of the art works.

The first and one of the most successful IAHR publications was the influential book *"Turbulence Models and their Application in Hydraulics"* by W. Rodi, first published in 1984 by Balkema. I. Nezu's book *"Turbulence in Open Channel Flows"*, also published by Balkema (in 1993), had an important impact on the field and, during the period 2000–2010, further authoritative texts (published directly by IAHR) included *Fluvial Hydraulics* by S. Yalin and A. Da Silva and *Hydraulicians in Europe* by W. Hager. All of these publications continue to strengthen the reach of IAHR and to serve as important intellectual reference points for the Association.

Since 2011, the Book Series is once again a partnership between CRC Press/Balkema – Taylor & Francis Group and the Technical Committees of IAHR and I look forward to helping bring to the global hydro-environment engineering and research community an exciting set of reference books that showcase the expertise within IAHR.

Peter A. Davies
University of Dundee, UK
(Series Editor)

This page intentionally left blank

Table of contents

	<i>Preface</i>	ix
1	Introduction: Energy dissipators in hydraulic structures <i>H. Chanson</i>	I
2	Energy dissipation at block ramps <i>S. Pagliara & M. Palermo</i>	II
3	Stepped spillways and cascades <i>H. Chanson, D.B. Bung & J. Matos</i>	45
4	Hydraulic jumps and stilling basins <i>H. Chanson & R. Carvalho</i>	65
5	Ski jumps, jets and plunge pools <i>M. Pfister & A.J. Schleiss</i>	105
6	Impact dissipators <i>B.P. Tullis & R.D. Bradshaw</i>	131
7	Energy dissipation: Concluding remarks <i>H. Chanson</i>	159

This page intentionally left blank

Preface

Recent advances in technology have permitted the construction of large dams, reservoirs and channels. This progress has necessitated the development of new design and construction techniques, particularly with the provision of adequate flood release facilities. Chutes and spillways are designed to spill large water discharges over a hydraulic structure (e.g. dam, weir) without major damage to the structure itself and to its environment. At the hydraulic structure, the flood waters rush as an open channel flow or free-falling jet, and it is essential to dissipate a very significant part of the flow kinetic energy to avoid damage to the hydraulic structure and its surroundings. Energy dissipation may be realised by a wide range of design techniques. A number of modern developments have demonstrated that such energy dissipation may be achieved (a) along the chute, (b) in a downstream energy dissipator, or (c) a combination of both.

The magnitude of turbulent energy that must be dissipated in hydraulic structures is enormous even in small rural and urban structures. For a small storm waterway discharging $4 \text{ m}^3/\text{s}$ at a 3 m high drop, the turbulent kinetic energy flux per unit time is 120 kW! At a large dam, the rate of energy dissipation can exceed tens to hundreds of gigawatts; that is, many times the energy production rate of nuclear power plants. Many engineers have never been exposed to the complexity of energy dissipator designs, to the physical processes taking place and to the structural challenges. Several energy dissipators, spillways and storm waterways failed because of poor engineering design. It is believed that a major issue affecting these failures was the lack of understanding of the basic turbulent dissipation processes and of the interactions between free-surface aeration and flow turbulence.

In that context, an authoritative reference book on energy dissipation in hydraulic structures is proposed here. The book contents encompass a range of design techniques including block ramps, stepped spillways, hydraulic jump stilling basins, ski jumps and impact dissipators.

This page intentionally left blank

Introduction: Energy dissipators in hydraulic structures

H. Chanson

*School of Civil Engineering, The University of Queensland,
Brisbane, QLD, Australia*

ABSTRACT

Many regions on our planet are subjected to hydrological extremes. Dams and reservoirs constitute a very efficient means to provide both long-term water reserves and flood protection. During major rainfall events, large water inflows into the reservoir induce a rise in the reservoir level, and a spillway system must be installed to spill safely the flood waters. Two key challenges during the spillway design are conveyance and energy dissipation. Energy dissipation on dam spillways can be achieved by a range of dissipator designs. A massive challenge is the magnitude of the rate of energy dissipation in the spillway structure during major floods.

1.1 PRESENTATION

The dependence of life on water is absolute on Earth. Plants, animals and humans depend all upon the availability of water to sustain life. Water constitutes the primary constituent of the oceans, rivers and subterranean fluids on our planet. In its various forms, water occupies about $1.4 \times 10^{18} \text{ m}^3$ on Earth (Berner and Berner 1987). The water cycle on the planet includes the evaporation of water, atmospheric circulation of vapour, precipitations and flowing streams both above and below ground. Through this cycle, air and water constantly interact: in the atmosphere, at the sea surfaces and on the mainland. These continuous exchanges are most important for the biological and chemical equilibrium of the planet including the balance between nitrogen, oxygen and carbon dioxide in the atmosphere.

Despite the continuous water cycle, the rainfall pattern on our planet is not uniform. Many regions are subjected to hydrological extremes with high spatial and temporal variability. On one hand, extreme rainfalls can be experienced: e.g., 3,721 mm of rain in 4 days at Cherrapunji (India) on 12–15 September 1974 constitutes a world's record for that duration (WMO 1994). Intense rainfalls convert into some surface runoff down gullies and brooks, converging into valleys and streams to generate large river floods. Recent catastrophes included the inundations of Vaison-la-Romaine (France) in 1992, Nîmes (France) in 1998, Rockhampton, Bundaberg, and Brisbane, Queensland (Australia) during the 2010–2011 summer and again in summer 2013, the flood of the Mississippi River (USA) in spring 2011, the Thames Valley (UK) in winter 2014. IAHS (1984) presented a catalogue of the world's maximum floods highlighting astonishing record flow rates, although most maximum discharge estimates are of poor precision with no or little information on measurement accuracy. On the other hand, many countries can experience hot

and dry periods including long droughts. As an illustration, Australia, a dry continent, has experienced recurrent long droughts for the last 250 years: e.g., the longest drought (1958–1967) in arid Central Australia, the WWII drought (1939–45) during which 30 millions sheep died, the Federation drought (1900s) during which the Murray River stopped flowing for 6 months and the country's sheep population dropped from 106 millions down to 54 millions.

Dams and reservoirs constitute one of the most efficient means to provide our community with long-term water reserves and flood protection. Although some projects are built for flood mitigation or water supply only (e.g. Grande Dixence, Switzerland), most reservoirs are multi-purpose encompassing both water supply and flood mitigation. A dam is basically a man-made hydraulic structure built across a valley to provide water storage (Fig. 1.1). During major rainfall events, large water inflows into the reservoir induce a rise in the reservoir level, with the risk of dam overtopping during extreme floods. A spillway system must be installed: that is, an aperture designed to spill safely the flood waters above, below or besides the dam wall (Fig. 1.2).

Recent advances in technology have permitted the construction of large man-made dams and reservoirs. These progresses have necessitated the development of new designs and construction techniques, particularly for the provision of adequate flood release facilities. The spillways must be designed to spill large water discharges over a hydraulic structure without major damage to the structure itself and to its environment.

1.2 SPILLWAYS AND ENERGY DISSIPATORS

1.2.1 Basic considerations

The spillway system is designed to pass safely flood waters above, below, within or around the dam. A safe spillway operation is critical. Many dam failures were caused by poor spillway design and insufficient spillway discharge capacity (Smith 1971, Lempérière 1993). The latter is particularly critical in the case of earthfill and rock-fill embankments, while concrete dams are more likely to withstand some moderate overtopping. Most dam design and construction require some conservatism, because a failure may cause a serious hazard to human life.

A large majority of dams are equipped with an overflow spillway system which includes typically a crest, a chute and an energy dissipator at the downstream end. The preliminary design stages include the selection of the maximum outflow discharge and the type of spillway (USBR 1965, Novak et al. 2001). The spillway capacity is derived from hydrological studies (Probable Maximum Precipitation, Probable Maximum Flood), together with Maximum Observed Floods (MOF). The design discharge is selected as a function of the surcharge storage capacity and maximum reservoir inflow. The type of spillway is a function of a number of parameters, including the flood hydrograph characteristics, damage to upstream and downstream catchments, damage to the dam and spillway in case of failure, and the possible combined use of outlet(s) and spillway(s).

The two key challenges during the spillway design process are conveyance and energy dissipation. Conveyance means the (safe) transport of large amount of waters

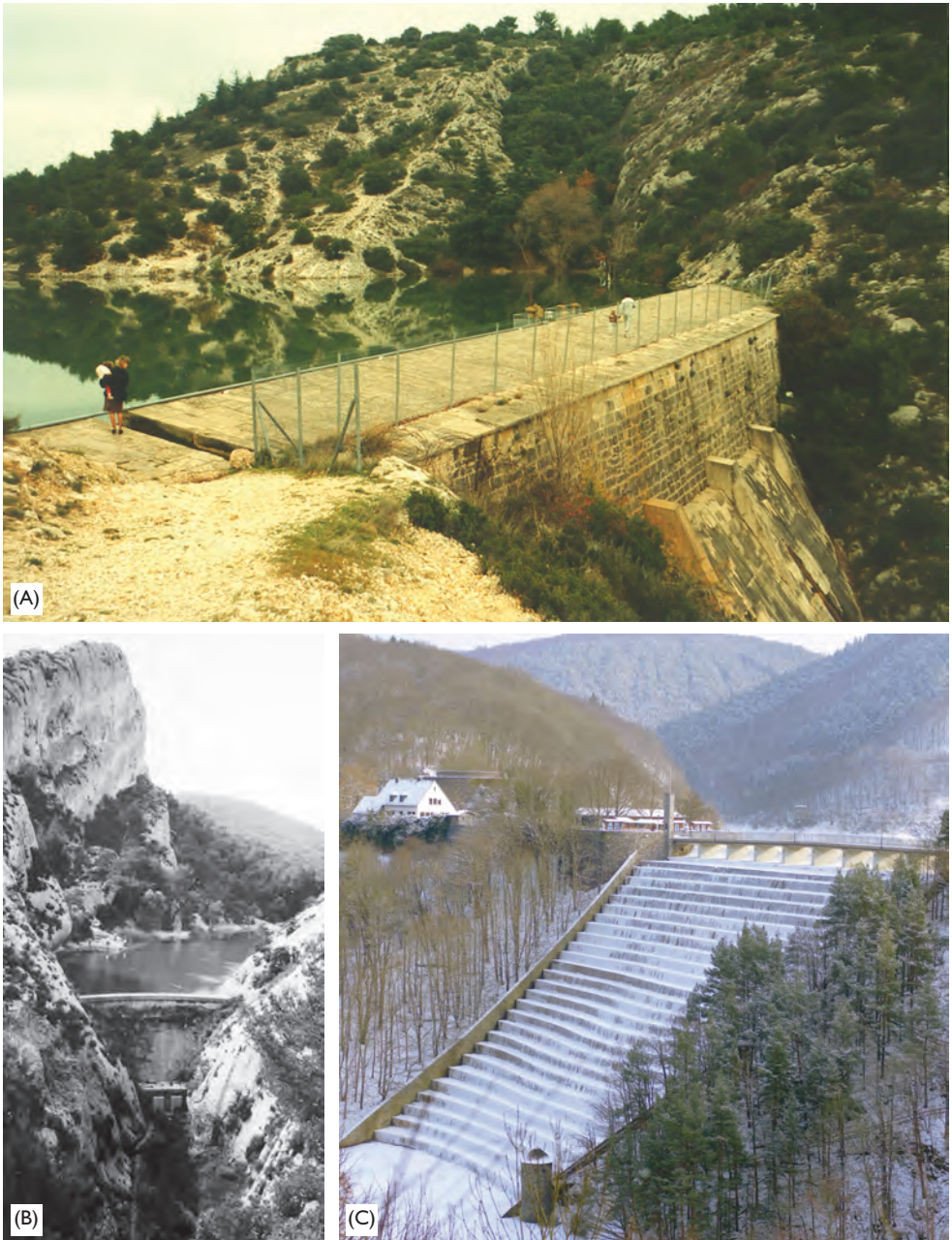


Figure 1.1 Old hydraulic structures. (A) Caromb dam or *Barrage du Paty* (France) in December 1994, dam completed during the 18th century. (B) Les Peirou dam (France) in June 1998. Completed in 1891, the 19 m high arch dam was built on the Glanum Roman dam foundations. (C) Urft dam (Germany) in February 2013. Completed in 1905, the 55 m high dam is equipped with a large stepped cascade.

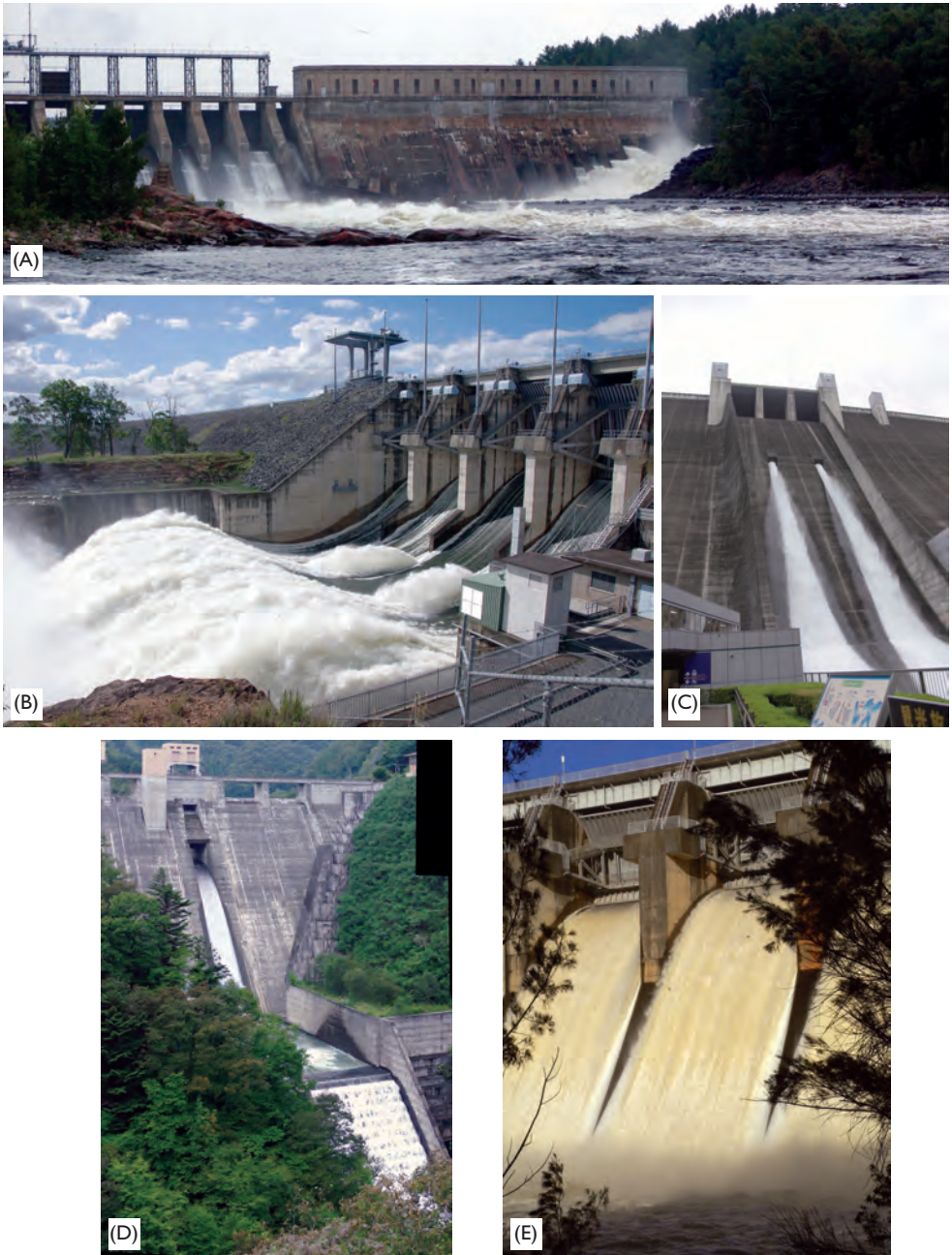


Figure 1.2 Spillway systems. (A) Barrage Mercier (Canada) and spillway operation on 14 July 2002. (B) Wivenhoe dam spillway (Australia) on 21 December 2010. (C) Miyagase dam (Japan) on 3 October 2012. Chute spillway with mid-level outlets in operation. (D) Fukushima dam (Japan) on 3 October 2012. Note the counterweir in the foreground right. (E) North Pine dam (Australia) on 22 May 2009.