ASCE Manuals and Reports on
Engineering Practice No. 135





MONITORING DAM PERFORMANCE

Instrumentation and Measurements

**Task Committee
to Revise Guidelines
for Dam Instrumentation**

Edited by
Kim de Rubertis, P.E., D.GE

ASCE

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Monitoring Dam Performance

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Prepared by the
Task Committee to Revise Guidelines for
Dam Instrumentation of the
Committee on Water Power of the
Energy Division of the
American Society of Civil Engineers

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ASCE AMERICAN SOCIETY OF CIVIL ENGINEERS

Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Names: American Society of Civil Engineers. Task Committee to Revise Guidelines for Dam Instrumentation. | de Rubertis, Kim, editor.
Title: Monitoring dam performance : instrumentation and measurements / prepared by the Task Committee to Revise Guidelines for Dam Instrumentation of the Committee on Water Power of the Energy Division of the American Society of Civil Engineers; edited by Kim de Rubertis, P.E., D.GE, F.ASCE.
Description: Reston, Virginia : American Society of Civil Engineers, [2018] | Includes bibliographical references and index.
Identifiers: LCCN 2017061624 | ISBN 9780784414828 (hardcover : alk. paper) | ISBN 9780784480984 (pdf) | ISBN 9780784480991 (ePub)
Subjects: LCSH: Dams–Inspection. | Dam safety. | Dam failures–United States–Prevention. | Hydraulic measurements.
Classification: LCC TC550 .A44 2018 | DDC 627/.80289–dc23
LC record available at https://lccn.loc.gov/2017061624

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191-4382
www.asce.org/bookstore | ascelibrary.org

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Errata: **Errata, if any, can be found at https://doi.org/10.1061/9780784414828.**

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All Rights Reserved.
ISBN 978-0-7844-1482-8 (print)
ISBN 978-0-7844-8098-4 (PDF)
ISBN 978-0-7844-8099-1 (ePub)
Manufactured in the United States of America.

25 24 23 22 21 20 19 18 1 2 3 4 5

Front cover photo (lower) courtesy of Paul Hames/California Department of Water Resources

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A manual or report in this series consists of an orderly presentation of facts on a particular subject, supplemented by an analysis of limitations and applications of these facts. It contains information useful to the average engineer in his or her everyday work, rather than findings that may be useful only occasionally or rarely. It is not in any sense a "standard," however; nor is it so elementary or so conclusive as to provide a "rule of thumb" for nonengineers.

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In February 1962 (and revised in April 1982), the Board of Direction voted to establish a series titled "Manuals and Reports on Engineering Practice" to include the manuals published and authorized to date, future Manuals of Professional Practice, and Reports on Engineering Practice. All such manual or report material of ASCE would have been refereed in a manner approved by the Board Committee on Publications and would be bound, with applicable discussion, in books similar to past manuals. Numbering would be consecutive and would be a continuation of present manual numbers. In some cases of joint committee reports, bypassing of journal publications may be authorized.

A list of available Manuals of Practice can be found at http://www.asce.org/bookstore.

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DEDICATION

This manual is dedicated to John Dunnicliff, Dist.M.ASCE, upon whose shoulders stand all who work with instrumentation. From his 1988 classic *Geotechnical Instrumentation for Monitoring Field Performance* to his continuing efforts to advance instrumentation knowledge in his contributions and editing for "Geotechnical Instrumentation News," all have benefited. It is with this committee's recognition of how integral Dunnicliff's work has become woven into the state of practice that, with great appreciation, this manual is dedicated.

ACKNOWLEDGMENTS

ASCE Energy Division Executive Committee Contact Member
Jason Hedien, P.E., M.ASCE

ASCE Hydropower Committee Control Group Members
Kim de Rubertis, P.E., D.GE., F.ASCE
Steven Fry, P.E., M.ASCE
Christopher Hill, P.E., M.ASCE
Jeffrey Auser, P.E., M.ASCE

Committee Members
Kim de Rubertis, P.E., D.GE, F.ASCE, *Chair*
Steven Fry, P.E., M.ASCE, *Vice Chair*
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Jeffrey Auser, P.E., M.ASCE
Bill Broderick, P.E., M.ASCE
Catrin Bryan, P.E., P.Eng.
Craig Findlay, Ph.D., P.E., G.E. M.ASCE
John France, P.E., D.WRE, M.ASCE
Ralph Grismala, P.E., M.ASCE
Justin Nettle, P.E.
Zakeyo Ngoma, P.E.
Minal Parekh, Ph D., P.E.
Elena Sossenkina, P.E., M.ASCE
Jay Statler, P.E., M.ASCE
Manoshree Sundaram, P.E., M.ASCE
Travis Tutka, P.E.
Jennifer Williams, P.E.
Karen Aguillard, P.E.

Organizations That Provided Support for Member's Committee Participation

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The committee expresses special appreciation to Dr. Pierre Choquet, without whose inspiration this committee might not have been formed and for his generous assistance in assembling and reviewing the manual.

PREFACE

This Manual of Practice for *Monitoring Dam Performance: Instrumentation and Measurements* is an addition to the series of publications by members of the Hydropower Committee of the Energy Division of the American Society of Civil Engineers (ASCE).

The Hydropower Committee of ASCE's Energy Division was formed to develop and distribute information on all aspects of hydroelectric power to the hydroelectric community. The Hydropower Committee prepares and publishes Manuals of Practice, Guidelines, and Technical Reports about engineering and scientific issues related to hydroelectric facilities. The Hydropower Committee seeks to serve an audience beyond civil engineers to include scientists, economists, and technologists with expertise in related areas. This focus is driven by the hydropower industry's desire to integrate science, environment, economics, operation, and maintenance into the scope of its activities.

In 1997, task committee volunteers studied and reported means and methods of monitoring dam performance with instruments and measurements. The outcome of that committee's work was *Guidelines for Instrumentation and Measurements for Monitoring Dam Performance* published in 2000. Since that publication, there have been many innovations in both means and methods of monitoring dam performance. This manual presents the current state of practice with the intent of providing a convenient reference for owners, engineers, regulators, and others with an interest in dam safety.

There are no simple rules or standards for determining the proper level of instrumentation and measurements to monitor dam performance. Each dam is unique. The consequences of failure, complexity of dam and foundation, known problems and concerns, and degree of design conservatism all require consideration in deciding both what to measure and how to measure. With that understanding, the purposes of this manual are to consider the following:

- Recognizing vulnerabilities affecting dam performance,
- Identifying performance indicators,
- Understanding means and methods of measuring performance indicators,
- Planning and implementing a monitoring program,
- Acquiring data,
- Managing, presenting, and evaluating data, and
- Making decisions and taking action.

Additional advances in monitoring technology will bring new and better means and methods for monitoring, but the principles outlined in this manual will have enduring value.

This manual is intended to be informative but not prescriptive. With its foundation and appurtenant works, each dam presents its own set of challenges. Deciding on how to monitor its behavior requires skill and judgment beyond the scope of this manual.

CHAPTER 1
INTRODUCTION

> When you can measure what you are speaking about, and express it in numbers, you know something about it. . . .
>
> Lord Kelvin

Welcome to *Monitoring Dam Performance—Instrumentation and Measurements*. This manual reviews the current state of practice for monitoring dam performance as part of the American Society of Civil Engineers commitment to serve the worldwide community of dam engineering professionals.

Monitoring dam performance is a global enterprise. Almost every country in the world has dams that are monitored for performance by their owners and engineers. Many countries have agencies with monitoring guidelines and regulations for safe practice. These include agencies such as the CWC in India, U.S. Federal Energy Regulatory Commission (FERC), China's Ministry of Energy, Canadian Dam Association, The Environment Agency in England and Wales, France's Permanent Technical Committee, and ANCOLD in Australia. The intent of this manual is to capture the fundamentals and current state of practice of instrumented measurements for monitoring dam performance in the global dam engineering community.

Dam-performance monitoring is a blend of visual surveillance coupled with instruments to measure indicators that answer a basic question: "How is this dam performing?"

Visual surveillance is the backbone of all performance-monitoring programs.

> Monitoring of every dam is mandatory because dams change with age and may develop defects. There is no substitute for

> systematic intelligent surveillance. But monitoring and surveillance are not synonymous with instrumentation.
>
> Ralph Peck

Instruments can supply measurements of performance indicators that evade visual surveillance. It is difficult for the eyes to accurately estimate the flow or amount of embankment settlement. There are instruments to measure both. But are they required?

> Certainly the fundamental rule today should be that no instrument should be installed that is not needed to answer a specific technical question pertinent to the safe performance of the dam.
>
> Ralph Peck

Specific technical questions are unique to every dam. Like people, no two dams are exactly alike. The questions to ask rely upon an understanding of a dam's vulnerabilities. Designs are intended to provide adequate defenses against perceived vulnerabilities. Monitored instrumentation is intended to provide measurements to validate the design or point to performance that could lead to loss of reservoir control. This manual describes the process of using instrumented monitoring to answer the basic question of how a dam is performing.

- First: Understand what sequence of events could cause a dam to fail to retain its reservoir.
- Second: Select which performance indicators to measure and the appropriate instruments to measure them.
- Third: Plan and implement the program to make observations and measurements.
- Fourth: Gather, manage, and present measured data in a form amenable to decision making.
- Fifth: Evaluate the data.
- Last: Make decisions based on the monitoring results and take action as needed.

Chapter 2 reviews the importance of dam safety not only to protect the public but also to sustain the benefits that dams provide. The case for developing a responsible performance-monitoring program is presented.

The vulnerabilities of different types of dams are the subject of Chapter 3. Modes of failure and their performance indicators vary for different types of dams. Understanding a dam's potential modes of failure sets the stage for asking performance questions for which answers may be provided by instrumentation and measurements.

Chapter 4 describes how to plan and implement a monitoring program tailored to provide answers to questions about a dam's performance.

Many new means of measuring have been added to performance-monitoring practice in recent years. Instruments to measure a variety of loads and responses are described in Chapter 5.

Chapter 6 introduces geodetic monitoring and its role in measuring a dam's response to loads.

Chapters 7 and 8 describe data acquisition, presentation, and management to provide a basis for evaluating the measurements from the performance-monitoring program.

Chapter 9 discusses the process of acquiring the measurements to answer the questions asked, evaluating those measurements, deciding what action to take, if any, and then acting on those decisions.

Typical instrumented monitoring of embankment, concrete, and other dams are the subjects of Chapter 10, 11, and 12, respectively.

Sample data forms and plots are illustrated in Chapter 13.

Monitoring dam performance has a long and colorful history. Chapter 14 captures that history.

Four appendices provide a

- List of references about dam-performance monitoring,
- Procedure for conducting failure mode analyses,
- Discussion of precision and accuracy, and
- Glossary.

This manual of practice is not intended to establish a standard for the design, installation, operation, or use of dam instrumentation systems. This manual presents the current state of practice. Each dam is unique in its geologic setting, physical loads, materials of construction, purpose, design life, and method of operation and presents its own distinct set of challenges in understanding its behavior.

Dam instrumentation and measurement provide a key part of the information that owners, engineers, and regulators consider to understand how a dam is performing compared to design estimates and historic performance, to identify any sequence of events that could cause a loss of reservoir control, and to inform decisions about dam safety actions.