Dam Failure Mechanisms and Risk Assessment

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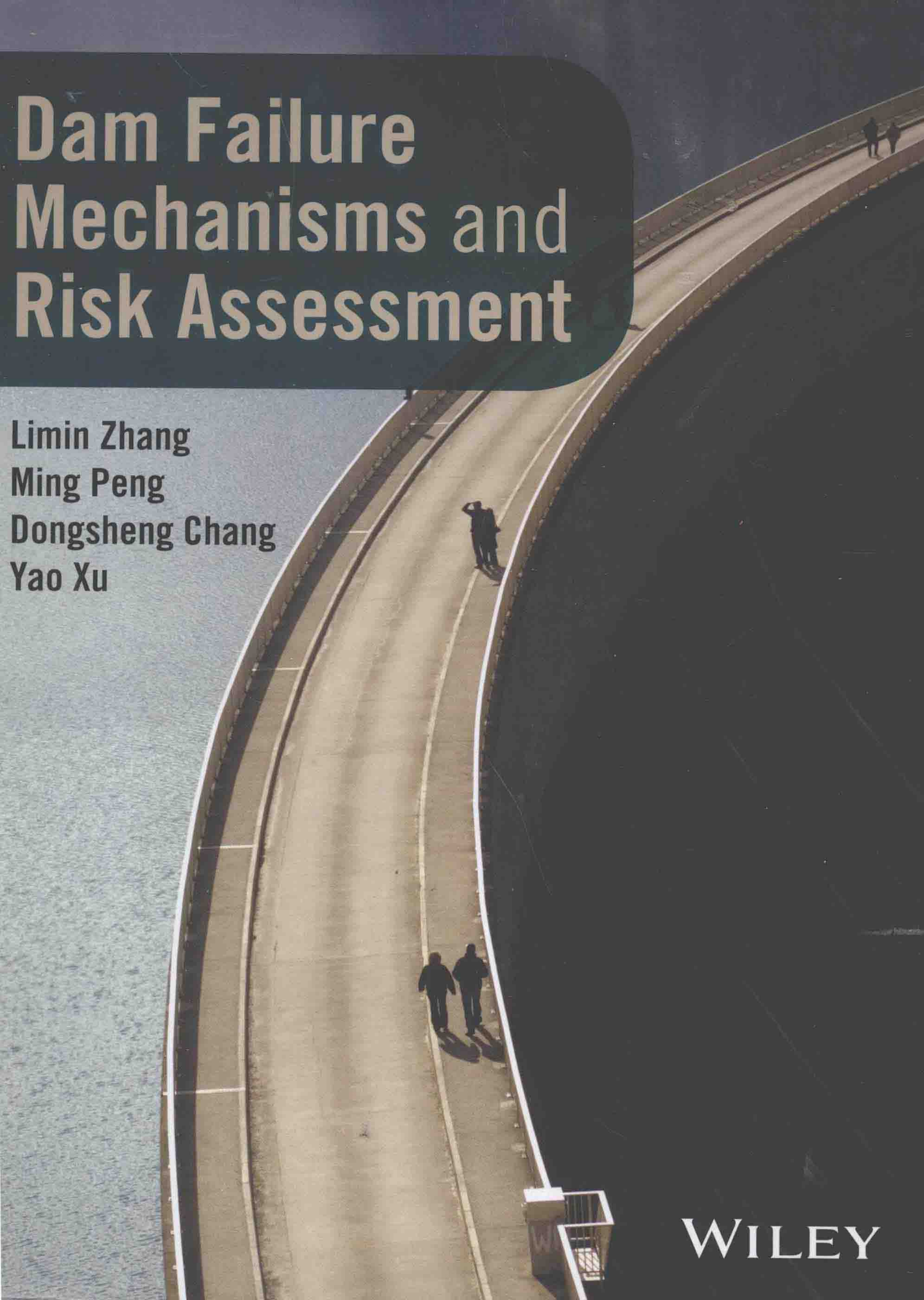

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Foreword

I felt privileged to write the foreword for the book by Desmond Hartford and Gregory Baecher (2004) *Risk and Uncertainty in Dam Safety*, published by Thomas Telford Ltd in 2004. In that book, the authors described probabilistic analysis tools for dam risk analysis and decision-making, including guiding principles for risk analysis, methods for reliability analyses, and decision-making tools such as event tree and fault tree analyses.

This new book by Zhang, Peng, Chang, and Xu, *Dam Failure Mechanisms and Risk Assessment*, published by John Wiley & Sons, Ltd in 2016, presents the subjects in more detail by emphasizing practical applications of the analyses. The book describes the causes, processes, and consequences of dam failures. It covers up-to-date statistics of past dam failures and near-failures, mechanisms of dam failures, dam breaching process modeling, flood routing and inundation analyses, flood consequence analyses, and dam-breaching emergency management decisions. The authors integrate the physical processes of dam breaching and the mathematical aspects of risk assessment and management and describe methodologies for achieving optimal decision-making under uncertainty. The book emphasizes the two most common failure mechanisms for embankment dams: internal erosion, which has received increased attention in recent years, and overtopping. Empirical and numerical methods are used to determine dam breaching parameters such as breach geometry and peak flow rate, and for analyzing the dam breaching flood routing downstream.

The methodologies described by the authors may be used by government dam regulatory agencies for evaluating risks, and by dam owners to evaluate dam safety and the planning and prioritizing of remedial actions. I strongly recommend this up-to-date book, as it represents a most valuable contribution to the state of the art, paving the way for practical applications of probabilistic analysis tools to dam risk assessment and management.

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Foreword

As of 2015, the International Commission on Large Dams (ICOLD) has registered more than 60,000 large dams higher than 15 m around the world. Among these, 38,000 are in China. With functions of flood control, irrigation, hydropower, water supply, etc., dams contribute significantly to social-economic development and prosperity. On the other hand, dam failures do occur sometimes and can result in huge loss of life and property. Accordingly dam safety is of great importance to society. China alone has reported more than 3500 cases of failures of constructed dams. In the past 15 years or so, China also faced the mitigation of risks of large landslide dams, particularly those triggered by the 2008 Wenchuan earthquake.

Dam risk management requires not only a good understanding of dam failure mechanisms and probability, but also rapid evaluation of flood routing time and potential flooding areas. For instance, in the mitigation of the risks of the Tangjiashan landslide dam in June 2008, three likely overtopping failure modes were considered, the dam breaching impact area for each failure mode was evaluated and the flooding routing time was forecast. Consequently, approximately 250,000 people downstream of the dam were evacuated before the breaching of the large landslide dam. The book *Dam Failure Mechanisms and Risk Assessment* by Zhang, Peng, Chang, and Xu covers the wide spectrum of knowledge required for such a complex dam risk analysis and management case. This book is unique in that:

1. It is the first book that introduces the causes, processes, consequences of dam failures and possible risk mitigation measures in one nutshell;
2. It integrates the physical processes of dam failures and the mathematical aspects of risk assessment in a concise manner;
3. It emphasizes integrating theory and practice to better demonstrate the application of risk assessment and decision methodologies to real cases;
4. It intends to formulate dam-failure emergency management steps in a scientific structure.

ICOLD published statistics of dam failures in 1995, which have not been updated in the past 20 years. This book publishes three of the most updated and largest databases: a database of 1443 cases of constructed dam failures, a database of 1044 cases of landslide dam failures, and a database of 1004 cases of dike failures. The latest statistics of failures of constructed dams, landslide dams and dikes are reported accordingly. I consider the compilation of these latest databases one of the most important contributions to dam safety in the past 20 years.

I am confident this book will assist dam or dike safety agencies in evaluating the risks of dams, making decisions for risk mitigation, and planning emergency actions.

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Preface

Every dam or dike failure touches the nerve of the public, as in the cases of the Banqiao dam failure in China in August 1975, the New Orleans dike failures during Hurricane Katrina in August 2005 and the Tangjiashan landslide dam breach in China in June 2008. The Banqiao dam failure caused the inundation of an area of 12,000 km^2 and the loss of more than 26,000 lives. The dike failures in New Orleans resulted in a death count of approximately 1,600 and an economic loss of US$100-200 billion, making it the single most costly catastrophic failure of an engineered system in history. The failure of the Tangjiashan landslide dam in June 2008 prompted the evacuation of 250,000 residents downstream the dam for two weeks.

Dam or dike risk analysis involves not only the calculation of probability of failure, but also the simulation of the failure process, the flood routing downstream the dam or dike, and the evaluation of flood severity, elements at risk, the vulnerability of the elements at risk to the dam-breaching flood and the flood risks. Once the risk is analyzed, it must be assessed against risk tolerance criteria. If the risk level is deemed too high, proper risk mitigation measures, either engineering or non-engineering, should be taken to lower the risk level. The effectiveness of any risk mitigation measures and the impact of any mitigation measures on the overall risk profile should also be evaluated. Non-engineering risk mitigation measures such as warning and evacuation are often the most effective. When a dam or dike failure is imminent, a dynamic assessment of hazard propagation and scientific decisions for risk mitigation are preferred. The worldwide trend is to make accountable decisions by quantitatively expressing the dam-failure risks.

The aforementioned dam risk analysis and management process involves physical aspects of dam failure mechanisms, failure processes, flood routing and flood damage, as well as risk assessment and management methodologies. Several excellent books are available on selected topics of dam safety. For instance, Hartford and Baecher (2004) describe uncertainties in dam safety and present probability theory and techniques for dam risk assessment; Singh (1996) introduces hydraulics of dam breaching modelling. In this book, we intend to introduce in one nutshell the essential components that enable a quantitative dam risk assessment. The mechanisms, processes and consequences of dam failures as well as risk assessment and decision methodologies for dam emergency management are introduced.

This book consists of three parts, with Part I devoted to dam and dike failure databases and statistics, Part II to dam failure mechanisms and breaching process modeling and Part III to dam failure risk assessment and management.

Part I (Chapters 1–5) presents three latest databases of the failure of 1443 constructed dams, 1044 landslide dams and 1004 dikes. The statistical analyses of failures of constructed embankment dams, landslide dams, concrete dams and dikes are presented separately. International Commission on Large Dams (ICOLD) released a statistical analysis of dam failures in 1995 and an updated analysis is long-awaited. In this book, the statistics for the failure of various types of dams are updated including the latest failure cases around the world and failure cases in China that were not included in the ICOLD analysis in 1995. The detailed failure cases are presented in Appendices A and B, which are of retention value to the dam safety community.

Part II (Chapters 6–9) presents two most common dam failure mechanisms (i.e. internal erosion in dams and their foundations and overtopping erosion of dams) and dam breaching modeling. The initiation, continuation and progression of concentrated leak erosion, backward erosion, contact erosion and suffusion are described separately in Chapter 6. The mechanics of overtopping erosion, methods for determining soil erodibility parameters and classification of soil erodibility are presented in Chapter 7. These two chapters lay the foundation for understanding and simulating the process of dam failure. Subsequently, we present methodologies of dam breaching process modeling and flood routing analysis following the time sequence of a dam failure: dam breach modeling and determination of dam breaching parameters such as breach geometry and peak flow rate (Chapter 8), and analysis of dam-breach flood routing downstream the dam (Chapter 9).

Part III (Chapters 10–14) presents key components in assessing the risks of a specific dam. This part begins with the introduction of several methods for analyzing the probability of failure of dams (Chapter 10). Subsequently, we present methodologies for the evaluation of inundation zones and vulnerability to dam-breaching floods (Chapter 11), the assessment of dam failure risks (Chapter 12), and dam breach contingency risk management and optimal decision making under uncertainty (Chapter 13). Finally, risk-based decision making is illustrated in the case study of the Tangjiashan landslide dam failure (Chapter 14).

Limin Zhang

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Many individuals have contributed to the methodologies presented in Dam Failure Mechanisms and Risk Assessment. Several graduate students and post-doctoral research fellows, over the years, developed numerical methods for simulating dam and dike failure processes and flood routing, and assessing dam-failure risks. Special thanks go to, in alphabetical order, Kit Chan, Chen Chen, Hongxin Chen, Qun Chen, Jozsef Danka, Liang Gao, Mingzi Jiang, Jinhui Li, Yi Liu, Tianhua Xu, Jie Zhang, Lulu Zhang, Shuai Zhang, and Hongfen Zhao.

In the past decade, we collaborated closely with several research teams on contemporary dam safety issues, particularly with Prof. Jinsheng Jia of China Institute of Water Resources and Hydropower Research (IWHR) on compilation of a database of dam failures and distresses, with Prof. Jianmin Zhang of Tsinghua University on dam safety under extreme seismic and blasting loading conditions, with Prof. Runqiu Huang of State Key Laboratory for Geohazard Prevention and Environmental Protection and Prof. Yong You of Institute of Mountain Hazards and Environment of the Chinese Academy of Sciences on mitigating the risks of the landslide dams triggered by the Wenchuan earthquake, with Prof. Dianqing Li and Prof. Chuangbing Zhou of Wuhan University on the life-cycle safety of dam abutment slopes, and with Sichuan Department of Transportation on risk-based decision for mitigating the risks of debris flow dams for highway reconstruction near the epicenter of the Wenchuan earthquake. We were fortunate to have had so many opportunities to solve contemporary practical dam safety problems. The research collaborators are gratefully acknowledged.

The late Prof. Wilson Tang is fondly remembered by all the co-authors of this book. He offered enthusiastic encouragement for us to initiate the book project. We sincerely thank Professors Alfred Ang, Hongwei Huang, Bas Jonkman, Suzanne Lacasse, Chack Fan Lee and Farrokh Nadim who provided critical comments on the PhD theses supervised by the first author. These theses form part of this book. We also appreciate the efforts of Nithya Sechin, Maggie Zhang, Adalfin Jayasingh and Paul Beverley of John Wiley & Sons, Ltd, who edited the book, and those who reviewed the book proposal.

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To Linda Li, Yan Zhu, Xin Wang, and Jing Bai

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