Editors: Miguel Á. Toledo, Rafael Morán & Eugenio Oñate

Dam Protections against Overtopping and Accidental Leakage

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PROCEEDINGS OF THE 1ST INTERNATIONAL SEMINAR ON DAM PROTECTIONS AGAINST OVERTOPPING AND ACCIDENTAL LEAKAGE, MADRID, SPAIN, 24–26 NOVEMBER 2014

Dam Protections against Overtopping and Accidental Leakage

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Preface

During the last decades, and especially in the recent years, the technology of dam protection against overtopping and accidental leakage, mainly due to internal erosion, has undergone major advancement. Although they are different technical problems, frequently the available technology for the solution is the same, so both issues are considered together in this book.

The increasing demand for safety in modern societies, combined with the limited availability of financial resources, has created the need for cost-effective solutions. Different technologies have been successfully applied to a considerable number of dams all over the world, but cases are scattered across the technical publications. Also the increasingly wide scientific work related to this subject is dispersed and disconnected from the professional work. So it was considered convenient to promote an international forum for showing and discussing cases and researches related to dam protection.

The book contains a selection of the proceedings of the 1st International Seminar on Dam Protection against Overtopping and Accidental Leakage held in Madrid (Spain) in 24–26 November 2014. The latest advances on dam protections and a portfolio of applications in representative case studies are included. Topics of the book are: failure analysis of embankment dams; soft and hard protections for embankment dams; failure and protection of concrete dams and additional issues related to dam protections. The book also includes a summary of the technical manual "Overtopping Protection for Dams", published by the US Federal Emergency Management Agency (FEMA) in March 2014, that was presented in Europe during the seminar.

This book can be considered as a comprehensive summary of the background about dam protections including case studies and applied research worldwide.

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The editors want to highlight the unconditional dedication of the members of the Dam Safety Research group (SERPA) of the UPM for the organization of the 1st International Seminar on Dam Protections against Overtopping and Accidental Leakage, and for the publication of this book: León Morera, Javier Caballero, Ricardo M. Alves, Alfonso Roa, Raffaella Pellegrino, Gloria Cachaza and Cristian Ponce; and also thanks to Fernando Salazar and Antonia Larese, from CIMNE, for their disinterested collaboration.

A summary of the information contained in the FEMA Technical Manual: Overtopping Protections for Dams*, is included in this book. The editors thanks the Federal Emergency Management Agency of the U.S. for the permission.

Our deepest gratitude to our friend Bill Fiedler and to Thomas E. Hepler for their invaluable contribution to the success of the seminar and to the high technical level of this book.

Thanks to all the authors because this book is their creation.

Miguel Á. Toledo, Rafael Morán and Eugenio Oñate

*FEMA P-1015, Technical Manual: Overtopping Protection for Dams, Federal Emergency Management Agency, U.S. Department of Homeland Security, Washington D.C., May 2014.

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This book is dedicated
to Alfonso Álvarez *in memoriam*,
a pioneer and a master.

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Technical manual: Overtopping protection for dams

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ABSTRACT: This paper provides an overview of *Technical Manual: Overtopping Protection for Dams*, which was recently released by the Federal Emergency Management Agency (FEMA) of the United States, to be included in the Proceedings of *International Seminar on Dam Protection against Overtopping and Accidental Leakage*. U.S. customary units have been converted to S.I. metric units for purposes of this international seminar.

Keywords: Dam, Embankment, Overtopping, Protection, Spillway

1 INTRODUCTION

Inadequate spillway capacity is a common problem with many dams. Reservoir inflow that exceeds available storage and/or spillway discharge capacity can lead to dam overtopping, failure, and potential for loss of life and significant downstream damages. The design and construction of overtopping protection for dams is increasingly being viewed as a viable alternative to constructing larger spillways or increasing reservoir storage by raising the dam crest. However, the decision to pursue overtopping protection for a dam must give strong consideration to the risk of failure of the protection system, which could lead to a full breach of the dam. Overtopping protection should generally be reserved for situations with a very low annual probability of operation (typically less than 1 in 100); with physical or environmental constraints on constructing other methods of flood conveyance and with a prohibitive cost of other alternatives; or where downstream consequences of dam failure are demonstrated to be low.

Alternatives for overtopping protection may utilize a variety of different materials, such as roller-compacted concrete and continuously-reinforced concrete slabs (for "hard" protection); or articulated concrete blocks, gabions, grass cover, turf reinforcement mats, flow-through rockfill, reinforced rockfill, riprap, and various types of geosynthetic materials (for "soft" protection). Not all materials are applicable in every situation. In most cases, significant research and hydraulic testing has been conducted on these materials, but since most overtopping protection is designed to function at an infrequent recurrence interval, practical experience on constructed projects that have been subjected to overtopping flows is limited. New materials and methods of analysis are always being developed, so design engineers may need to rely upon manufacturers' design recommendations, always mindful of the limitations of product testing and analysis. Independent analysis should always be considered when appropriate.

It is critically important that when an overtopping protection alternative is considered, the designer must understand all aspects of its design, construction, and long-term maintenance needs. Regulatory agencies should also be consulted to confirm the circumstances for which overtopping protection can be approved. Due to the absence of any single recognized standard for overtopping protection alternatives for dams, there has been some inconsistency in the design and construction rationale to date. The goal of the FEMA technical manual, *Overtopping Protection for Dams* [1] is to provide a source of information on various overtopping protection alternatives for both embankment and concrete dams, to promote greater consistency between similar overtopping project designs, facilitate review, and aid in the design of safer, more reliable facilities. The manual is intended

for use by personnel familiar with dams, such as dam designers, inspectors, construction oversight personnel, dam safety engineers, and decision-makers, but is not intended to provide detailed design procedures for all potential applications. FEMA, as the lead agency for the National Dam Safety Program in the United States, sponsored the development of the technical manual in conjunction with the U.S. Bureau of Reclamation. Part 1 (Chapters 1–10) provides general guidance on the design and construction considerations associated with overtopping protection alternatives for embankment dams, while Part 2 (Chapters 11–16) provides similar guidance for concrete dams. The manual concludes with a selection of case histories demonstrating field applications of the various overtopping protection systems presented. This paper and associated presentation will focus on the design and application of various types of overtopping protection systems for embankment dams. A second paper will present overtopping protection systems for concrete dams.

2 GENERAL CONSIDERATIONS FOR EMBANKMENT DAMS

Many early dams were designed to accommodate floods based on the largest experienced local flood or a standardized probable maximum flood (PMF) considered appropriate at that time. Over the years, significant technological and analytical advances have led to better watershed and rainfall information, improvements in the analysis of extreme floods, and tools for evaluating hydrologic events in a risk-based context, which have resulted in the reclassification of some dams as being hydrologically deficient. Guidance for the evaluation of the hydrologic safety of both new and existing dams in the United States based on flood loading is provided by the FEMA manual, *Selecting and Accommodating Inflow Design Floods for Dams* [2].

The FEMA technical manual, *Overtopping Protection for Dams* [1] assumes that a hydrologic deficiency exists at a dam and that traditional approaches to safely accommodate a larger design flood, such as increasing reservoir storage by raising the dam crest or increasing release capability by increasing the spillway discharge capacity, have first been investigated and found to be cost prohibitive or impractical. Overtopping protection may then be an attractive alternative because of its potential economic advantages and could offer an economical solution to a hydrologic deficiency that would otherwise not be addressed. Maintaining the existing hydraulic conditions at the dam to the extent possible is also increasingly important as downstream river corridors are developed in close proximity to the channel.

Where applicable, overtopping protection may involve all or a portion of the dam crest. This may be more cost effective than constructing an auxiliary spillway on either abutment at dams where increased hydraulic capacity is required. A major concern with overtopping protection for embankment dams is that if the protection fails during a flood event and the underlying embankment is exposed, erosion and headcutting in the embankment materials could progress rapidly. This could lead to a breach of the dam during the flood event, with no potential for preventing the failure. A careful analysis of all potential failure modes for the dam and appurtenant features must be performed for both the existing (baseline) conditions and for the proposed modified conditions.

Understanding the behavior of an embankment dam during an overtopping event provides a basis for the design of protective measures. Flow over an embankment dam, as shown in Figure 1, generally proceeds from a subcritical velocity over the upstream portion of the crest, through critical velocity on the crest and supercritical velocity across the remainder of the crest, to accelerating turbulent flow on the downstream slope until reaching the hydraulic jump. The hydraulics of overtopping flow in terms of unit discharge, depth, and velocity can be estimated by conventional open-channel flow theories. The unit discharge of the overtopping flow, q, in $m^3/s/m$, is a function of the overtopping depth, H, in meters, as follows:

$$q = C\,H^{1.5} \tag{1}$$

where C = a discharge coefficient dependent upon the geometry of the embankment and the depth of flow.