

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

DESIGN OF SMALL DAMS

A WATER RESOURCES TECHNICAL PUBLICATION

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DESIGN OF SMALL DAMS



A Water Resources Technical Publication

First Edition, 1960

Second Edition, 1973

Revised Reprint, 1977

Third Edition, 1987

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.



Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

Preface to the Third Edition

The second edition of *Design of Small Dams* has been very popular throughout the world; it has been published in a number of different languages and used extensively in the United States. Since the second edition was published in 1974, there have been significant revisions in the approaches and procedures related to the design of dams. Because of these revisions and the continued demand for this manual, it was decided that this new third edition be prepared and published.

The purpose of this third edition has been changed in scope and intent from that of the second edition. The title *Design of Small Dams* has been retained even though some of the information in the third edition relates to large dams. Many of the theoretical concepts presented can be applied to large or small structures; however, it is recommended that the procedures and methods presented be used only as guidelines. When preparing the design of large or complicated structures, especially those located where they create a high hazard, the owner should rely on experienced dam engineers, experienced consultants, or refer to more detailed references.

Some of the chapters and appendixes have been revised extensively, while others reflect only minor revisions. Chapter 1, "Plan Formulation," has been condensed to briefly cover only the basic concepts of plan formulation. The authors of this chapter concluded that a detailed discussion of plan formulation was not appropriate because the primary focus of this manual is on design, not project planning. Also, a discussion of plan formulation, particularly with an emphasis on Federal plan formulation requirements, would not be of interest to a majority of dam designers. The chapter thus provides a brief discussion of the steps of plan formulation and some of the fundamental tests for the viability of proposed plans.

Chapter 2, "Ecological and Environmental Con-

siderations," has been revised to include a discussion on the management of fish and wildlife resources at completed projects, in addition to new design considerations. An expanded section on water quality implications to dam design and operation is also included.

Chapter 3, "Flood Hydrology Studies," has been completely revised, including incorporating the previous appendix A, "Estimating Rainfall Runoff from Soil and Cover Data," into the chapter. Reference to the Soil Conservation Services' curve number approach for assigning infiltration losses, the triangular unit-hydrograph approach, and all discussions and plates providing guidance for estimating probable maximum precipitation have been eliminated. These topics have been replaced by a treatment of infiltration losses as actually applied by the Bureau of Reclamation, expanded consideration and guidance relative to the development of unit hydrographs using the dimensionless unit-graph and S-graph approaches, and specific reference to the National Weather Service's Hydrometeorological Report series as the basis for developing probable maximum precipitation estimates for the contiguous United States.

Chapter 5, "Foundation and Construction Materials," has been updated to incorporate current standards in foundation and construction materials investigations. A reservoir studies section has been added to the section on scope of investigations. The sections on soil and rock classification have been updated to reflect current standards, and a new section on engineering geophysics has been added to summarize the capabilities of these methods. The sections on subsurface explorations and sampling have been revised extensively to represent new technology. The logging of explorations has also been revised to reflect current standards, and the field and laboratory test section has been updated. Changes in soil mechanics terminology and soil

testing procedures generated by revision of the Bureau's *Earth Manual* are reflected in this chapter. The previous table 8, "Average Properties of Soils," which is now table 5-1, was recompiled to include laboratory test results obtained since the last edition. Figure 5-14, "Permeability of Soils," was added to this edition to illustrate ranges of permeability measured on compacted soil specimens tested at the Bureau's laboratory in Denver. The bibliography has been updated to include selected sources of information for foundation and construction materials investigation.

Chapter 6, "Earthfill Dams," has been revised to update terminology and reflect design philosophy, procedures, and standards that have evolved since 1974. The major change is greater emphasis on internal filtering and drainage to control seepage and internal erosion within embankment dams. New figures have been added that show current dam embankments that have been designed and constructed by the Bureau of Reclamation. Other illustrations have been replaced or revised to reflect current thinking and technology. Liberal reference is made to design standards that have been developed as guides for Bureau engineers.

Chapter 7, "Rockfill Dams," required only minor revisions; however, the Bureau does not have extensive experience with the design and construction of rockfill dams. Design and construction procedures for rockfill dams have changed over the last two or three decades and continue to do so. The chapter gives a good general background for the design of rockfill dams; however, the designer should also refer to the literature on the subject.

Chapter 8, "Concrete Gravity Dams," now includes additional topics, clarification, and more detail. This chapter has also been revised to address concerns for concrete dams of any height. Sections on material properties and foundation considerations have also been added. More complete discussions are now included for forces acting on the dam, requirements for stability, and stress and stability analyses. Discussions addressing the analysis of cracked dams have been clarified and expanded to include analysis during an earthquake. Also, a general iterative approach for cracked dam analysis, applicable for static and dynamic conditions, is now included.

The "Spillways" and "Outlet Works" chapters, 9 and 10, respectively, now include two new hydraulic designs for energy dissipators. These designs are a

modified low Froude number basin as an alternative to basin 4 design, and modifications in the design criteria for baffled apron spillways to permit their use for higher unit discharges. Other contemporary spillway concepts are introduced, although design criteria are not included because they are still under development. Included in this category are labyrinth weirs where large flows must be discharged in a limited space such as a narrow canyon, and the use of air slots (aerators) in spillways where there is high potential for cavitation damage. Plunge-pool design criteria have been somewhat improved by the addition of several references to recent research. The suggested method for calculating the discharge under radial gates has been revised to reflect up-to-date criteria developed by the U.S. Army Corps of Engineers, Waterways Experiment Station. The section on siphon spillways has been omitted from this edition because they are seldom used as flow control structures for dams. The bibliography has been revised by the removal of references that were hard to obtain and by the addition of many new references that reflect the current state-of-the-art.

Chapter 12, "Operation and Maintenance," now includes additional topics, clarification, and more detail. The new topics added are "Changes in Operating Plan," which addresses modification to a structure to add additional storage or to change the purpose of allocation of storage; "Emergency Preparedness Plan," which addresses instructions to an operator during emergency situations; and "Dam Operators Training," which outlines the requirements for the training of operators to assure that operation and maintenance of a facility are performed in an accurate and responsible manner.

Chapter 13 is a new chapter dealing with dam safety. Although dam safety is always an underlying consideration in the design, construction, operation, and monitoring of a dam, the passage of legislation on Safety of Dams has placed additional emphasis on dam safety; and the inclusion of a chapter on this subject was believed to be important. This chapter presents procedures and references to other procedures for the evaluation and analyses of dam safety issues for both new and existing dam structures.

The appendix designations have been revised. The previous appendix A is now part of chapter 3, and the original appendix H, "Sedimentation," is now appendix A. A new appendix H, "Operation

and Maintenance," presents a checklist for Operation and Maintenance inspections.

Appendix D, "Soil Mechanics Nomenclature," was updated to reflect current terminology in use from ASTM Designation D-653, "Standard Definitions of Terms and Symbols Relating to Soil and Rock Mechanics," and from USBR 3900, "Standard Definitions of Terms and Symbols Relating to Soil Mechanics." The latter reference is from the Bureau's recently revised *Earth Manual*, volume 2, "Test Designations."

Appendix E, "Construction of Embankments," has been revised to emphasize and more fully describe construction control philosophy and procedures. Several photographs of more modern equipment and construction techniques have been added. The "Rapid Method of Compaction Control" has been eliminated; the reader is now referred to the Bureau's *Earth Manual* for that procedure. Terminology has been updated to that currently used within the Bureau of Reclamation.

A discussion on concrete erosion has been added, and the discussion on abnormal set of concrete has been expanded in appendix F, "Concrete in Construction." The design of concrete mixes has been revised and includes revisions to tables, forms, and the steps involved in concrete mix design.

Appendix G, "Sample Specifications," has been updated to include guide specifications currently used by the Bureau of Reclamation.

Throughout the third edition, figures and illustrations have been revised and many new figures

have been added.

The intent of this third edition is to expand discussion of concepts for design of small to large dams and to update the different approaches and procedures being employed in the current state-of-the-art of planning, design, construction, operation, and evaluation processes. The text is not intended in any way to encourage assumption of undue responsibility on the part of unqualified personnel, but rather to point out the importance of specialized training. Engineers who do not have specialized training in dam engineering should seek advice from experienced consultants.

This manual was prepared by personnel of the Bureau of Reclamation, U.S. Department of the Interior, Denver, Colorado, under the direction of Darrell Webber, Assistant Commissioner, Engineering and Research, with contributions from the staff of other Assistant Commissioners. Neil Parrett, Chief, Division of Dam and Waterway Design, established a three-man team to coordinate the assembly of this new edition: Harold K. Blair, Chairman, Head, Design Section No. 2 of the Concrete Dams Branch; Thomas N. McDaniel, Design Manager, Embankment Dams Branch; and Ronald D. Mohr, General Engineer, Document Systems Management Branch. Numerous engineers, technicians, and support personnel participated with this team in the preparation of this third edition and their efforts are greatly appreciated. Special recognition to the many authors, both current and past, is appropriate:

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The Bureau of Reclamation expresses appreciation to the organizations who have permitted the use of their material in this text. There are occa-

sional references to proprietary materials or products in this publication. These references are not to be construed in any way as an endorsement because the Bureau does not endorse proprietary products or processes of manufacturers or the services of commercial firms.

Preface to the Second Edition

The first edition of "Design of Small Dams" was published to serve primarily as a guide to safe practices for those concerned with the design of small dams in public works programs in the United States. Its publication was warmly received and, in the intervening years since then, it has been widely used in the United States, reprinted numerous times, and translated into many foreign languages, including Korean, Spanish, Japanese, and Chinese.

Since publication of the first edition of "Design of Small Dams," a large body of new literature has become available to dam designers, and many new design procedures used at the Bureau of Reclamation have been changed to reflect more modern techniques. As the number of changes in design techniques increased, it became apparent that their incorporation in a second edition would be beneficial to those individuals and agencies concerned with small dams.

The purpose of the second edition remains essentially the same as for the first edition. Many of the design procedures proposed in the first edition remain virtually unchanged. However, a number of new procedures have been developed by the Bureau and are currently in use. To make this new information available generally, it is included in the second edition. The increased concern of the Bureau of Reclamation with environmental problems is reflected by the inclusion of chapter II, "Ecological and Environmental Considerations." This chapter outlines some of the practical measures which may be taken to reduce the environmental and ecological impact of a project. Chapter III has been extensively revised to include current methods of design flood computation and to incorporate new graphical data.

Chapter V has been revised to reflect the availability of current information concerning foundation design and to include supplemental foundation investigation procedures. Chapter VI contains additional material on the design of earth dams, a

discussion of the slurry trench method of cutoff construction, earthquake considerations, soil-cement design criteria, additional design details, and a more extensive reference list. The discussion of rockfill dam design has been considerably expanded in chapter VII to reflect the recent interest in rockfill dams and the growth of available information on this subject. Baffled spillway design procedures have been incorporated in chapter IX, and additional information on tunneling has been presented in chapter X. Appendix A includes new information on the estimation of rainfall runoff from soil cover data, and an expanded discussion of flow in natural channels is contained in appendix B. Appendix C includes new tables for the design of both reinforced concrete pressure pipe and cast-in-place conduits, and appendix E has a more complete discussion of the rapid method of compaction control. Appendix G has been expanded to include specifications concerning air and water pollution, and each specification has been updated to reflect current Bureau requirements. A new appendix on reservoir sedimentation is presented in appendix H, which outlines current procedures used to estimate the rate of sedimentation and the period of time before sediment will interfere with the useful functions of the reservoir. A convenient list of conversion factors is presented in appendix I to facilitate the increased utilization of metric units. Many minor changes have been made throughout the text to reflect current design and construction techniques.

It is intended that this book will provide the designer with an important source of information. However, this text is not intended in any way to encourage the assumption of undue responsibility on the part of unqualified personnel, and the use or application of the methods and data contained herein is strictly the responsibility of the person utilizing the material. Designs should reflect the actual site conditions and should not merely be pat-

tered after a successful design used at another location.

Periodically, the names of Bureau of Reclamation projects and features are changed by acts of Congress, Federal agencies, etc., and therefore there may be a few inconsistencies in the project and feature names referred to in the text.

Some recent changes include the following:

Cachuma Dam to Bradbury Dam
Wasco Reservoir to Clear Lake
Soap Park Reservoir to Milly K. Goodwin Lake
Missouri River Basin Project to Pick-Sloan
Missouri Basin Program.

There are occasional references to proprietary materials or products in this publication. These must not be construed in any way as an endorsement since the Bureau cannot endorse proprietary products or processes of manufacturers or the services of commercial firms for advertising, publicity, sales, or other purposes.

The second edition was prepared by the engineers of the Bureau of Reclamation, U.S. Department of the Interior, at its Engineering and Research Center in Denver, Colo. A number of engineers and technicians participated in the preparation of the second edition and in its critical review, and the efforts of these persons are greatly appreciated. Special

recognition is given to H. G. Arthur, Director of Design and Construction, for his overall guidance in preparation of the text and to Dr. J. W. Hilf, Chief of the Division of Design, for his technical advice.

The second edition of the text was coordinated, edited, and much supplemental technical information provided by L. W. Davidson, Civil Engineer, Earth Dams Section. Detailed editorial guidance, final review, and preparation of the manuscript for publication was performed by W. E. Foote of the Technical Services Branch.

The Bureau of Reclamation again expresses grateful appreciation to those organizations which have permitted the use of material from their publications, especially the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, for material used in chapter III; the Soil Conservation Service, U.S. Department of Agriculture, whose material was used in appendix A; the U.S. Geological Survey of the Department of the Interior, who supplied material used in chapter V; and the Corps of Engineers, U.S. Department of the Army, whose report on slurry trench construction was used in the preparation of chapter VI. Acknowledgments to other organizations which furnished lesser amounts of material are given throughout the text.

Preface to the First Edition

This book presents instructions, standards, and procedures for use in the design of small dams. It is intended to serve primarily as a guide to safe practices for those concerned with the design of small dams in public works programs in the United States. The book will serve this purpose in three ways: (1) It will provide engineers with information and data necessary for the proper design of small dams, (2) it will provide specialized and highly technical knowledge concerning the design of small dams in a form that can be used readily by engineers who do not specialize in this field, and (3) it will simplify design procedures for small earthfill dams.

An earlier publication, "Low Dams" which was prepared in 1938 by the National Resources Committee, presented much useful information on the design of small dams. In the 20 years that have elapsed since the printing of that book, however, there have been many technical advances in the design of dams, and the need for a new work incorporating the latest design techniques has become increasingly evident. It is believed that this book, "Design of Small Dams," will fill that need. The new book retains much of the format of "Low Dams" and some of the material from the earlier publication has been incorporated in the new one, but most of the text is wholly new.

Although this text is related almost exclusively to the design of small dams and appurtenant structures, it is important that the designer be familiar with the purposes of the project, the considerations influencing its justification, and the manner of arriving at the size and type of structure to be built. For these reasons, an outline discussion of a desirable project investigation has been included in chapter I.

Only the more common types of small dams now being constructed are discussed. These include concrete gravity, earthfill (rolled-type), and rockfill dams. Emphasis is placed on the design of rolled

earthfill dams because they are the most common type. For the purpose of this book, small dams include those structures with heights above streambed not exceeding 50 feet except for concrete dams on pervious foundations. For the latter structures, the maximum height is further limited to dams whose maximum net heads (headwater to tailwater) do not exceed 20 feet. The text is not intended to cover dams of such large volumes that significant economies can be obtained by utilizing the more precise methods of design usually reserved for large dams. In recognition of the limited engineering costs justified for small dams, emphasis is placed on efficiency and relatively inexpensive procedures to determine the necessary design data. Simplified design methods are given to avoid the complex procedures and special investigations required for large dams or for unusual conditions. Adequate but not unduly conservative factors of safety are used in the simplified design methods.

Small dams are properly considered to be associated with small streams and drainage areas of limited extent. For these situations or for those in which spillway capacity is obtainable at relatively low cost, a sufficient approximation of the inflow design flood discharge may be determined by procedures given in this text. For important projects, particularly where the spillway cost is a major item of project cost and thus may have an important bearing on project feasibility, more exact and complex studies which are beyond the scope of this text may be justified.

This text is addressed to the designer of the structure and does not include in its scope the field of construction practices or methods. However, as the integrity of the design requires adherence to limiting specifications for materials and to the practice of good workmanship in construction, appendixes are included on "Construction of Embankments," "Concrete in Construction," and "Sample Speci-

fications." More detailed specifications will be required to ensure proper construction of any specific dam.

This text is not intended in any way to encourage assumption of undue responsibility on the part of unqualified personnel, but rather to point out the importance of specialized training and to stimulate wider use of technically trained and experienced consultants.

This text should be of service to all concerned with the planning of small water storage projects, but in no way does it relieve any agency or person using it of the responsibility for safe and adequate design. The stated limitations of the design procedures should be heeded.

This book was prepared by the engineers of the Bureau of Reclamation, U.S. Department of the Interior, at Denver, Colo., under the direction of Grant Bloodgood, Assistant Commissioner and Chief Engineer, and L. G. Puls, Chief Designing Engineer. More than 30 engineers and many technicians participated in the preparation of the book

or in its critical review, and the efforts of all of these are gratefully acknowledged. Special recognition is given to O. L. Rice, Chief of the Dams Branch, for his guidance and counsel, especially in determining the scope and treatment of the text.

The text was coordinated and edited by H. G. Arthur, Supervisor, Design Unit, Earth Dams Section, and final review and preparation of the manuscript for the printer was by E. H. Larson, Head, Manuals and Technical Records Section.

The Bureau of Reclamation expresses grateful appreciation to those organizations which have permitted the use of material from their publications, especially the Soil Conservation Service, U.S. Department of Agriculture, whose material was used in appendix A; and the Corps of Engineers, U.S. Department of the Army, whose Technical Manual TM 5-545 was freely used in the preparation of part D of chapter V. Acknowledgments to other organizations furnishing a lesser amount of material are given throughout the text.

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