A WATER RESOURCES TECHNICAL PUBLICATION
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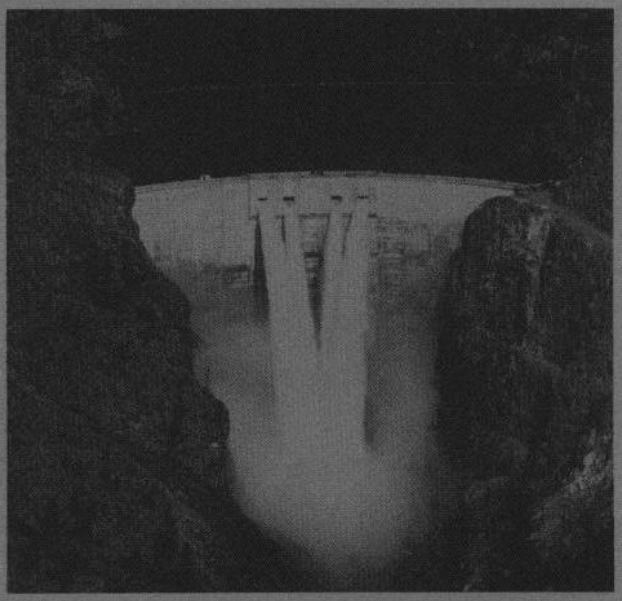

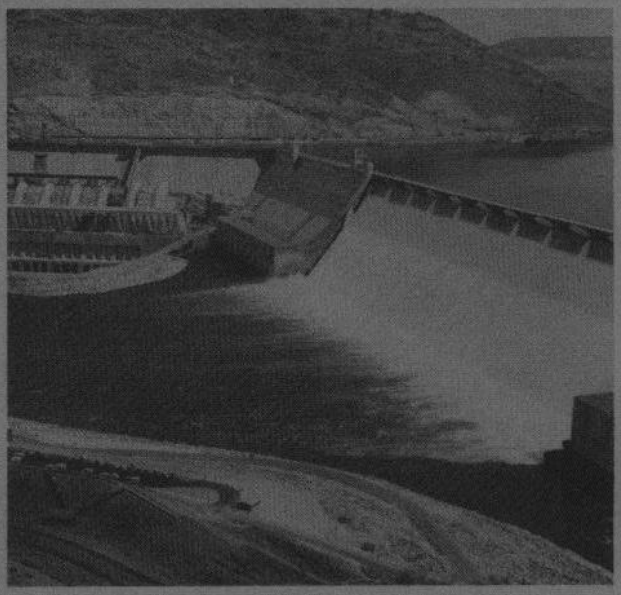

Design Criteria for Concrete Arch and Gravity Dams

UNITED STATES DEPARTMENT
OF THE INTERIOR
Bureau of Reclamation

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ENGINEERING MONOGRAPHS are published in limited editions for the technical staff of the Bureau of Reclamation and interested technical circles in Government and private agencies. Their purpose is to record developments, innovations, and progress in the engineering and scientific techniques and practices that are employed in the planning, design, construction, and operation of Reclamation structures and equipment. Copies may be obtained from the Bureau of Reclamation, Denver Federal Center, Denver, Colo., and Washington, D.C.

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Design Criteria for Concrete Arch and Gravity Dams

Office of Design and Construction
Engineering and Research Center
Denver, Colorado 80225

United States Department of the Interior
Bureau of Reclamation

Preface

This revision of Engineering Monograph No. 19 presents current Bureau of Reclamation design criteria upon which are based design decisions concerning mass concrete dams. The basic considerations and specific design criteria set forth in this monograph constitute the present-day standards for Bureau designs.

More than two decades have elapsed since the first issuance of this monograph in 1953. The intent of the publication at that time was to document basic concepts bearing on Bureau of Reclamation designs of concrete arch and gravity dams that had evolved during the preceding 50 years. Compilation of the criteria that were essential to successful construction and operation of many notable concrete dams on Reclamation water resource projects, such as Hoover, Grand Coulee, Shasta, and Hungry Horse Dams, resulted in the first orderly record of the Bureau's philosophy and basic criteria affecting the conception and development of concrete dams. The Bureau's recognition of the importance of keeping abreast of changing design technology was evidenced by revision of the monograph in 1960.

In the nearly 15 years following the first revision of the monograph, design technology advanced at a rapid rate. Such new knowledge as finite element analysis, geologic advances leading to increased understanding of foundations and abutments of dams, improved techniques of seismic analyses, development of computer techniques for trial-load analyses, and other advances accompanied by the progress in computer technology opened new avenues to design and, in turn, brought about refinements in the basic concepts guiding dams design. Dams completed during this period, including Glen Canyon, Flaming Gorge, Morrow Point, and Yellowtail Dams, reflect this progress.

Concrete dams on Bureau of Reclamation projects continue to be key elements in project development, as indicated by such major structures as Grand Coulee Forebay, Crystal, Nambe Falls, and Auburn Dams that are under construction or in advanced stages of design.

Assurance that Bureau design practices for concrete dams remain up-to-date and consistent with currently accepted good engineering practice can be achieved only through a program of continuing review, evaluation, modification of standards, and development of new criteria as required. The review must be made in light of developing technology in all fields associated with concrete dam design. In this effort, the Bureau of Reclamation is continuing

its investigations to develop new knowledge and to help resolve as yet unanswered questions.

Following its introduction, this monograph is divided into Part I, Arch Dams, and Part II, Gravity Dams. Within Parts I and II, each criterion is discussed under its appropriate subject heading. Each discussion is composed of two parts, the basic considerations and the criterion statement. The basic considerations are intended to supply the reader with some brief background to introduce the subject and support and help explain the criterion statement.

The reiteration of certain common information in Parts I and II obviates the necessity of the reader having to refer back and forth between the two parts.

The review and evaluation of the 1960 edition of Monograph No. 19, the development of new criteria, and the technical writing of this edition of the monograph were accomplished by the engineers in the Analytical Design and Performance Unit of the Concrete Dams Section in the Hydraulic Structures Branch of the Division of Design.

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Introduction

Design Philosophy

The Bureau of Reclamation's philosophy of concrete dam design is founded on rational and consistent criteria which provide for safe, economical, functional, durable, and easily maintained structures. It is desirable, therefore, to establish, maintain, and update design criteria. Under special conditions, consideration can be given to deviating from these standards. In those situations the designer bears the responsibility for any deviation and, therefore, should be careful to consider all ramifications. Accordingly, each of the criteria definitions in this monograph is preceded by a discussion of the underlying considerations to explain the basis of the criterion. This serves as a guide in appraising the wisdom of deviating from a particular criterion for special conditions.

Loadings.—The designer can assure the safety of concrete dams by designing for all combinations of loads including those whose simultaneous occurrence is highly improbable and by using unduly large safety factors. This may lead to overly conservative, uneconomical designs. A structure designed for the loading combinations and corresponding safety factors listed in this monograph should be safe, yet economical.

Design Data.—Modern methods of analysis are powerful and sophisticated; yet, without meaningful and accurate input data, they may produce useless and even erroneous results. Design data must be determined as accurately and completely as possible. The data should be derived from field and laboratory tests plus measurements taken from in-service dams. For occasional situations where the data are incomplete, the designer may supplement these data by referring to other dams with similar conditions. When data are absolutely unavailable, he may estimate them by using conservative engineering judgment. This approach may lead to overly conservative designs and emphasizes the advantage of conducting comprehensive programs to obtain adequate design data.

Safety Factors.—Safety factors have been established to limit the allowable stresses in the materials as determined by analysis. The need for safety factors is due primarily to uncertainties in (1) the service loads, (2) the variability of materials, (3) construction practices, and (4) the correctness of analyses. These uncertainties also preclude determining the safety of the dam exactly; therefore, factors of safety are selected based upon experience and judgment.

In addition to the safety factors specified, additional allowances for safety tend to enter into a design as a consequence of overly conservative treatment of successive uncertainties encountered in sequential design operations. Structures so designed may possess margins of safety in excess of the designer's intent and are uneconomical. The safety factors recommended herein are considered to provide for all underlying uncertainties and should be used without additional provision for safety, except under conditions of unusual uncertainty or hazard. For such conditions, some additional margin of safety may be provided by a judicious increase in the appropriate safety factor.

The general philosophy of safety of dams is that the magnitude of safety factors can be reduced as the probability of occurrence for particular loading conditions decreases. Also, as methods of analysis are improved and conditions associated with the safety factors are more accurately determined, the safety factors should be reduced. Although some structural damage may be foreseen under certain extreme loading conditions, damage resulting from sudden release of the reservoir must be prevented.

Analytical Basis.—Methods of analysis used to design arch- and gravity-type concrete dams should be the best available. The considerations used to develop the criteria in this monograph were based on the Bureau of Reclamation's analytical methods, which are described in references [1] and [2].[1] Therefore, it is recommended that these criteria not be used in conjunction with other analytical methods without careful consideration.

Construction Quality.—The methods of analysis and design criteria used by the Bureau of Reclamation have been developed on the assumption that dams will be constructed with concrete having uniformly good quality. Good concrete can be assured only through careful attention to quality control. Many factors enter into quality control: (1) testing and inspection of materials selected for use, (2) proper proportioning and adequate mixing of the materials, (3) use of proper handling, placing, and consolidating procedures, (4) proper preparation of placing surfaces, and (5) proper curing.

The best of materials and design practices will not be sufficiently effective unless the actual construction practices and procedures are properly performed. Building modern, well-designed concrete dams imposes upon those in charge of construction work the responsibility for assuring that the concrete is of uniformly good quality.

[1] Numbers in brackets refer to items in the bibliography.

Part I Arch Dams

Arch Dams

CONCRETE PROPERTIES—STATIC

Strength

Basic Considerations.—An arch dam should be constructed of concrete that meets the design criteria for strength, durability, permeability, and other required properties. Because of the sustained loading generally associated with them, the concrete properties used for the analyses of static loading conditions should include the effects of creep. Properties of concrete vary with age, the type of cement, aggregates, and other ingredients, as well as their proportions in the mix [3]. Since different concretes gain strength at different rates, measurements must be made of specimens of sufficient age to permit evaluation of ultimate strengths.

Although the concrete mix is usually designed only for compressive strength, appropriate tests should be made to determine the tensile and shear strength values.

The mix should be proportioned to produce concrete of sufficient strength to meet the design requirements. Concrete strengths should be determined by tests of the full mass mix in cylinders of sufficient size to accommodate the largest size aggregate to be used. The compressive strength of concrete, determined as specified above, should satisfy early load and construction requirements and at some specific age should have a ratio to the allowable working stress as determined by the designer.

The specific age is often 365 days, but it may vary from one structure to another. The strength should be based on an evaluation of ultimate strength and safety factor requirements discussed later in these criteria.

Tensile strength of the concrete mix should be determined as a companion test series to the tests for the compressive strength.

Shear strength is a combination of cohesive strength and internal friction which varies with the normal compressive stress. Companion series shear strength tests should be conducted at several different normal stress values covering the range of normal stresses to be expected in the dam. These should then be used to obtain a curve of shear strength versus normal stress for test cylinders of the same age as required for compressive and tensile test cylinders.

Elastic Properties

Basic Considerations.—Poisson's ratio, the sustained modulus of elasticity of the concrete, and the latter's ratio to the deformation modulus of the foundation have significant effects on stress distribu-