RECLAMATION

Managing Water in the West

Design Standards No. 14

Appurtenant Structures for Dams (Spillway and Outlet Works) Design Standards

Chapter 1: Introduction

Final: Phase 4 (Post Final Document on Reclamation's Design Standards Web Site)

U.S. Department of Interior
Bureau of Reclamation

October 2011

Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Design Standards Signature Sheet

Design Standards No. 14

Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards

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Chapter 1: Introduction

Approved:

__________________________________ _____________________

Deputy Commissioner, Operations **Date**

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Design Standards No. 14

Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards

Chapter 1: Introduction

DS-14(1)-4:[1] Final: Phase 4 (Post Final Document on Reclamation's Design Standards Web Site)
October 2011

Design Standard 14 is a new document. Chapter 1 of this Design Standard was developed to provide:

- An overview of how the Bureau of Reclamation analyzes/designs spillways and outlet works appurtenant for dams and/or dikes.
- An outline of the following chapters for this design standard that provides details for spillway and outlet works analyses/designs.
- A list of key technical references used for each major task involved with spillway and outlet works analyses/designs.

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[1] DS-14(1)-4 refers to Design Standard No. 14, chapter 1, revision 4.

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Chapter 1

Introduction

1.1 Purpose

The design standards present clear and concise technical requirements and processes to enable design professionals to prepare design documents and reports necessary to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public. Compliance with these design standards assists in the development and improvement of Bureau of Reclamation (Reclamation) facilities in a way that protects the public's health, safety, and welfare; recognizes all stakeholder needs; and achieves the lasting value and functionality necessary for Reclamation facilities. The responsible designer(s) accomplishes this through processes that enable compliance with these design standards and all other applicable technical codes, as well as incorporation of the stakeholder's vision and values, that are then reflected in the construction project.

1.2 Application of Design Standards

All Reclamation design work, whether performed by the Technical Service Center (TSC), the regional offices, or an architectural/engineering (A&E) firm, will conform to the design standards.

Reclamation's use of its design standards requires designers to also integrate sound engineering judgment with applicable national standards, site-specific technical considerations, and project-specific considerations to ensure suitable designs and to protect public safety.

The design standards are not intended to provide cookbook solutions to complex engineering problems. Strict adherence to a handbook procedure is not a substitute for sound engineering judgment. The designer should be aware of and use state-of-the-art procedures. Designers are responsible for using the most current edition of referenced codes and standards and to be aware that Reclamation design standards may include exceptions to requirements of these codes and standards.

1.3 Deviations and Proposed Revisions

Design activities must be performed in accordance with established Reclamation design criteria, Reclamation engineering, architectural, or technical standards, and approved national design standards. Exceptions to this requirement will be pursued in accordance with provisions of Reclamation Manual Policy, *Performing Designs and Construction Activities*, FAC P03.

Reclamation designers should inform the TSC, via the Web site notification procedure, of any recommended updates or changes for the design standards to meet current design practices.

1.4 Scope

Design Standard No. 14 provides technical guidance concerning Reclamation's procedures/considerations for analyzing/designing two key appurtenant structures associated with dams and/or dikes. These appurtenant structures are spillways and outlet works. Chapter 1 provides an overview for the analysis/design of spillways and outlet works, while the following chapters provide detailed procedures/considerations that should be followed by Reclamation staff and others involved with analyzing/designing modifications to new spillways and/or outlet works. It should be stressed that this design standard will not duplicate other existing technical references, but wherever possible, it will reference existing procedures/considerations that should be used for the analysis/design of spillways and outlet works.

1.5 Definitions

The following definitions are provided to clarify the terminology used in Design Standard No. 14. These definitions are consistent with other technical references used by Reclamation.

1.5.1 Spillway

A spillway is a hydraulic structure that passes normal (operational) and/or flood flows in a manner that protects the structural integrity of the dam and/or dikes (reservoir impoundment structures). Spillways are hydraulically sized to safely pass the Inflow Design Flood (IDF).[2] The IDF will be equal to, or less than, the Probable Maximum Flood (PMF).[3] For more details and guidance about floods, refer to Chapter 2, "Hydrologic Considerations."

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[2] For significant- and high-hazard dams and/or dikes and their appurtenant structures, selection of the IDF will be based on a quantitative risk analysis. The IDF will be less than, or equal to, the PMF.

[3] The largest flood that may reasonably be expected to occur at a given maximum runoff condition resulting from the most severe combination of meteorological and hydrologic conditions that are considered reasonably possible for the drainage basin under study.

There are three types or classifications of spillways typically employed by Reclamation, which are based on frequency of use. They are explained in more detail below.

1.5.1.1 Service Spillway

A service spillway provides continuous or frequent regulated (controlled) or unregulated (uncontrolled) releases from a reservoir without significant damage to the dam, dike, or appurtenant structures due to releases up to and including the maximum design discharge. Service spillways are illustrated in figures 1.5.1.1-1 and 1.5.1.1-2.

1.5.1.2 Auxiliary Spillway

An auxiliary spillway is infrequently used and may be a secondary spillway, which is operated sparingly. During operation there could be some degree of structural damage or erosion to the auxiliary spillway due to releases up to and including the maximum design discharge. Auxiliary spillways are illustrated in figures 1.5.1.2-1 and 1.5.1.2-2.

1.5.1.3 Emergency Spillway

An emergency spillway is designed to provide additional protection against overtopping of a dam and/or dike and is intended for use under extreme conditions such as misoperation or malfunction of the service spillway or other emergency conditions or during very large, remote floods (such as the PMF). As with auxiliary spillways, some degree of structural damage and/or erosion would be expected due to releases up to and including the maximum design discharge. Emergency spillways are illustrated in figures 1.5.1.3-1 and 1.5.1.3-2.

1.5.2 Outlet Works

Outlet works consist of a combination of features (i.e., intake structures, conveyance features such as conduits, control structures, etc.) and operating equipment (electrical and mechanical) required for the safe operation and control of water released from a reservoir to meet downstream needs. The outlet works serves various purposes such as regulating streamflow and water quality, releasing floodwater, power generation, emergency evacuation, and providing irrigation, municipal, and/or industrial water. Features of outlet works are illustrated in figure 1.5.2-1.

1.6 Configurations

There are some common/typical and unique configurations (features) associated with spillways and outlet works. These features are further discussed in the following sections.

1.6.1 Spillway

Generally speaking, features common to most spillways are illustrated in figure 1.6.1-1 and include:

- Approach channel and safety/debris/log boom.

- Control structure, such as crest structure or grade sill, and gates, bulkheads, and stoplogs, along with associated operating equipment.

- Conveyance features, such as chute floor and walls and/or conduit(s)/tunnel(s).

- Terminal structure, such as hydraulic jump stilling basin, flip bucket, plunge pool, etc.

- Downstream channel.

Another consideration of the spillway configuration relates to the type of hydraulic control. With some exceptions,[4] the two types are uncontrolled or free-flow spillways and controlled or gated spillways. The hydraulic control is usually based on whether the spillway crest structure has gates or not. Finally, with some exceptions, the spillway is typically referred to by the type of crest structure, such as:

- For uncontrolled spillways:

    - Ogee crest (figure 1.6.1-2) and grade control sill spillway (figures 1.5.1.2-2 and 1.5.1.3-2).

    - Bathtub (or double side-channel) (figure 1.6.1-3) and side-channel ogee crest spillway (figure 1.6.1-4).

    - Morning glory (or glory hole) spillway (figure1.6.1-5).

    - Labyrinth weir spillway (figure 1.6.1-6).

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[4] There are exceptions, such as the morning glory spillway, that could experience hydraulic control shifts with increasing hydraulic head: crest or free flow control to throat or orifice control to pipe or pressure control.

- For controlled spillways:
    - Gated spillway (figures 1.6.1-7 through 1.6.1-9).
    - Fuseplug spillway (figure 1.6.1-10).
    - Fusegate spillway (figure 1.6.1-11).

Consideration should also be given to the location of the spillway, which should not be on or through an embankment dam/dike unless there is justification to deviate. The preferred locations would be on the dam abutments or through the reservoir rim.

For more detailed guidance, refer to Chapter 3, "General Spillway Design Considerations."

1.6.2 Outlet Works

Features common to most outlet works are illustrated in figure 1.6.2-1 and include:

- Intake structures, trashracks, gates/valves, and bulkheads (if appropriate).
- Conveyance features, such as conduit(s)/tunnel(s).
- Control structure, such as gate chamber, gates/valves, access shaft/adit/conduit, along with operating equipment.
- Terminal structure, such as hydraulic jump stilling basin, impact structure, plunge pool, etc.
- Downstream channel.

Considerations that should be used, unless there is justification to deviate, include:

- Two gates or valves in series should be installed and operated in Reclamation outlet works. The downstream gate or valve provides regulating capabilities, while the upstream gate or valve provides emergency closure capabilities under unbalanced head (flow) conditions or routine closure capabilities under balanced head (nonflow) conditions.
- Although common throughout the water resource engineering industry, constructing an outlet works through/beneath an embankment dam and/or dike should be viewed as a second choice (i.e., avoid/limit contact/interface between the conduit and embankment). A preferred

alternative to minimize internal erosion potential is to construct a tunnel outlet works through the dam and/or dike abutment or through the reservoir rim.

Another aspect of outlet works configuration relates to the location of hydraulic control (i.e., the location of the regulating gate or valve). The four configurations [1][5] typically used by Reclamation are illustrated in figures 1.6.2-2 through 1.6.2-5 and include the following:[6, 7]

- **Preferred configuration**. Hydraulic control at intake with free-flow conditions downstream of the regulating gate or valve. Most often used for low head applications in embankment dams where pressurized flow is not required at the downstream end of the outlet works. When the outlet works is not being operated, there is access for inspection and maintenance through the entire length of the conduit (figure 1.6.2-4).

- **Preferred configuration**. Hydraulic control at downstream control structure, with guard/emergency gate/valve at/near centerline of dam/dike and downstream pressurized pipe (between dam/dike centerline and control structure) inside larger access conduit. Applicable for power generation or pressurized downstream flow. During both operation and nonoperation of the outlet works, there is excellent access for inspection and maintenance through the downstream conduit (figure 1.6.2-2).

- **Acceptable configuration**. Hydraulic control at/near the dam/dike centerline with free-flow conditions downstream of the regulating gate or valve. When the outlet works is not being operated, there is access for inspection and maintenance through the downstream conduit (figure 1.6.2-3).

- **Least acceptable configuration**. Hydraulic control at the downstream end of the outlet works, which may be near the downstream toe or face of the dam/dike (i.e., pressure flow conditions upstream of the regulating gate or valve along most of the outlet works). Commonly used in concrete dams. Accessibility for inspection and maintenance is limited (underwater inspection) without bulkheading upstream intake structure or draining the reservoir (figure 1.6.2-5).

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[5] Numbers in brackets indicate a reference listed at the end of this chapter.

[6] Outlet works configurations are listed in order of increasing potential of pressurizing the surrounding dam, dike, and/or foundation materials, which could lead to an incident or failure.

[7] Although the figures associated with following outlet works configurations illustrate an outlet works through/beneath an embankment dam/dike (which should be a second choice to a tunnel through the dam/dike abutment or reservoir rim), the focus is on the hydraulic control configuration, which would be applicable regardless of the location of the outlet works.

For more detailed guidance, refer to Chapter 4, “General Outlet Works and Diversion Design Considerations.”

1.7 Design Procedures/Considerations

Details of analysis/design procedures/considerations will be provided in the following chapters of Design Standard No. 14. An overview is provided in the following text of this chapter. Analysis and/or design (including both new and modification) for a spillway and/or outlet works will typically follow a number of key procedural guidelines, including:

- Design data collection guidelines [2].
- Feasibility design guidelines [3].
- Final design process [4].
- Cost estimating [5].
- Safety of Dams project management guidelines [6].

1.7.1 Spillway Design/Analysis

Tasks for analyzing/designing spillways are summarized in the following sections.

1.7.1.1 Location, Type, and Size

Selection of the location, type, and size of a spillway will be dependent on the evaluation of a number of factors, including:

- Site conditions (geology/topography).
- Dam and/or dike type.
- Hydrologic considerations.
- Hydraulic considerations.
- Seismic considerations.
- Construction/constructability considerations.
- Project objectives.

- Robustness of design.

- Risks associated with plausible Potential Failure Modes (PFMs), which must be tolerably below Reclamation's public protection guidelines [7].

- Operation and maintenance considerations.

- Economics.

Two factors that should be highlighted, which are somewhat unique to Reclamation facilities, are the robustness of design and the risks associated with PFMs. Because many of the spillways are associated with significant- and high-hazard dams/dikes, it is important that any new or modified appurtenant structure designs protect the public to levels consistent with Reclamation's public protection guidelines [7] (i.e., maintain and/or reduce risks to acceptable levels). This could mean some redundant features/equipment and designing to stricter requirements than commonly called for by professional codes, standards, and/or guidelines.

For more detailed guidance associated with locating, along with selecting a type and size of a spillway, refer to Chapter 3, "General Spillway Design Considerations."

1.7.1.2 Hydraulic Analysis/Design

The hydraulic analysis/design will be concurrent with the previous task of locating and selecting a type and size of spillway. The steps of hydraulic analysis/design include:

- Develop/verify discharge curves.

- Prepare initial flood routings of frequency floods up to the PMF to verify the appropriateness of the spillway type and size, and to select the IDF.

- Refine spillway control (crest) structure layout and associated discharge curves based on results from previous steps.

- Prepare final flood routings to estimate maximum reservoir water surfaces (RWS) and discharge ranges for various floods and operational conditions (part of the final flood routings will include a freeboard assessment, which is sometimes referred to as a robustness study).

- Prepare initial water surface profiles to lay out the spillway conveyance features and terminal structure size and type.

- Refine spillway conveyance features and terminal structure based on results from previous step.

- Prepare final water surface profiles to finalize size and type of the spillway conveyance features and terminal structure.

For more detailed guidance associated with hydrologic and hydraulic analysis/design for a spillway, refer to Chapter 2, "Hydrologic Considerations," and Chapter 5, "Hydraulic Considerations."

Technical references associated with the hydraulic analysis/design of spillways include:

- *Design of Small Dams*, third edition [8].

- Engineering Monograph (EM) No. 9 – *Discharge Coefficients for Irregular Overfall Spillways* [9].

- EM No. 25 – *Hydraulic Design of Stilling Basins and Energy Dissipators* [10].

- EM No. 42 – *Cavitation in Chutes and Spillways* [11].

- Reclamation – Engineering and Research Center (REC-ERC)-73-5 – *Hydraulic Model Studies of Chute Offsets, Air Slots, and Deflectors for High-Velocity Jets* [12].

- REC-ERC-78-8 – *Low Froude Number Stilling Basin Design* [13].

- REC-ERC-85-7 – *Hydraulic Model Studies of Fuseplug Embankments* [14].

- REC-ERC-88-3 – *Overtopping Flow on Low Embankment Dams – Summary Report of Model Test* [15].

- Dam Safety Office (DSO)-07-07 – *Uplift and Crack Flow Resulting from High Velocity Discharges Over Offset Joints* [16].

- Assistant Commissioner – Engineering and Research (ACER) Technical Memorandum (TM) No. 10 – *Guidelines for Using Fuseplug Embankments in Auxiliary Spillways* [17].

- *Hydraulic and Excavation Tables*, 11th edition [18].

- *Computing Degradation and Local Scour* [19].

- *Guide for Computing Water Surface Profiles* [20].

- *Design of Labyrinth Spillways* [50].

- *Research State-of-the-Art and Needs for Hydraulic Design of Stepped Spillways* [51].

- *Plastic Pipe Used In Embankment Dams: Best Practices for Design, Construction, Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [52].

- *Outlet Works Energy Dissipators: Best Practices for Design, Construction, Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [53].

1.7.1.3 Foundation Analysis/Design

The foundation analysis/design will start when a tentative type and size of spillway is located and selected, and it parallels the structural analysis/design efforts. The steps of foundation analysis/design include:

- Define site-specific foundation material and strength properties.

- Assist in identifying suitable sites based on site-specific foundation needs for a spillway.

- Define and analyze ground water conditions.

- Develop appropriate foundation designs, which include:

    - Drainage features such as underdrains, slope drainage, and filters (NOTE: Identify and evaluate drainage features/systems that will be accessible for inspection using closed-circuit television (CCTV) equipment).

    - Adequate support for the spillway, which could range from excavating to competent rock to driving piles or placing piers in a soil foundation.

    - Accommodating loading conditions on the spillway that could include static (hydrostatic, rock/soil, ice and frost heave), hydrologic (floods), and seismic (hydrodynamic, dynamic soil/rock) loads.

For more detailed guidance associated with foundation analysis/design for a spillway, refer to Chapter 6, “Foundation Considerations.”

Technical references associated with the structural and foundation analysis/design of spillways include:

- *Design of Small Dams,* third edition [8].
- EM No. 13 – *Estimating Foundation Settlement by One-Dimensional Consolidation Tests* [21].
- REC-ERC-74-10 – *Rock Mechanics Properties of Typical Foundation Rock Types* [22].
- REC-ERC-82-17 – *Frost Action in Soil Foundations and Control of Surface Structure Heaving* [23].
- ACER TM No. 9 – *Guidelines for Controlling Seepage Along Conduits Through Embankments* [24].
- *Drainage for Dams and Associated Structures* [25].
- *Guidelines, Foundation and Geotechnical Studies for Existing Concrete Dams* [41].

1.7.1.4 Structural Analysis/Design

The structural analysis/design of the spillway typically follows the hydraulic analysis/design. The steps of structural analysis/design include:

- Identify which features are considered "critical"[8] and "noncritical."[9] [26]
- Identify and define loading conditions for both critical and noncritical features, which will typically fall into four categories, including:
  - Construction.
  - Operational (normal or static).
  - Flood (hydrologic).
  - Earthquake (seismic).[10]

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[8] A critical feature is one in which its failure or damage could lead to failure and/or damage of the dam/dike or other appurtenant structures, which, in turn, may lead to the uncontrolled release of part or the entire reservoir or leave the appurtenant structure inoperable, preventing releases needed to protect the dam/dike.

[9] A noncritical structure is one in which failure or damage would not lead to failure of and/or damage to the dam/dike, nor would it inhibit operations of the structure to protect the dam/dike.

[10] For significant- and high-hazard dams and/or dikes and their appurtenant structures that have been identified as "critical," selection of the seismic design load will be based on a quantitative risk analysis. For noncritical structures, a minimum earthquake loading will be used that approximates a design basis earthquake (DBE) or about a 500-year event.

- Identify, evaluate, and select material types and associated properties. Materials could include concrete (reinforced, conventional mass, roller compacted, and precast), steel, and plastic such as high-density polyethylene (HDPE).

- Apply appropriate structural analysis/design methods, which are based on the crawl, walk, and run philosophy (i.e., using the simplest approach that is technically adequate to prepare the analysis/design). These include:

  - **For analyses**. Pseudostatic, linear elastic finite element modeling (FEM) using response spectra and nonlinear, elastic FEM using time histories are employed to analyze a structure.

  - **For designs**. Design methods are typically based on Reclamation technical references, such as *Design of Small Dams* [8], and industry codes are used, such as the American Concrete Institute (ACI) manuals.

For more detailed guidance associated with structural analysis/design for a spillway, refer to Chapter 6, "Structural Considerations."

Technical references associated with the structural and foundation analysis/design of spillways include:

- *Design of Small Dams*, third edition [8].

- EM No. 14 – *Beggs Deformeter-Stress Analysis of Single-Barrel Conduits* [27].

- EM No. 14 Supplement – *Beggs Deformeter-Analysis of Additional Shapes* [28].

- EM No. 27 – *Moments and Reactions for Rectangular Plates* [29].

- EM No. 34 – *Control of Cracking in Mass Concrete Structures* [30].

- *Concrete Manual*, eighth edition [31].

- Current ACI 318 and ACI 350 building codes.

- EM 1110-2-2104 – *Strength Design for Reinforced Concrete Hydraulic Structures, U.S. Army Corps of Engineers* [32].

- ACI SP-3 – *Reinforced Concrete Design Handbook* (Working Stress Method), third edition [33].

- *Design Criteria for Retaining Walls* [34].

- *Roller-Compacted Concrete: Design and Construction Considerations for Hydraulic Structures* [35].

1.7.1.5 Mechanical/Electrical Design

The mechanical/electrical design takes place concurrently with the structural analysis/design. The steps of mechanical/electrical design include:

- Select, size, and design gates/valves, if applicable.

- Select, size, and design trashracks, stoplogs, and/or bulkhead gates, if applicable.

- Select, size, and design gate/valve operators and generators, if applicable.

- Select, size, and design heating, ventilation, and cooling (HVAC) systems, if applicable.

- Select, size, and design hoists and/or cranes, if applicable.

- Design lighting and electrical control systems for gate/valve operations, HVAC systems, and supervisory control and data acquisition (SCADA) systems.

- Address life safety considerations as noted in the National Fire Protection Association (NFPA) 100, *Life Safety Code Handbook*, 2009 edition.

For more detailed guidance associated with mechanical/electrical design for a spillway, refer to Chapter 7, "Mechanical/Electrical Considerations."
Selection of type and size of a spillway gate and operating system will be dependent on the evaluation of a number of factors, including:

- Site conditions.

- Spillway configuration.

- Access.

- Available power.

- Hydraulic considerations.

- Seismic considerations.

- Construction/constructability considerations.
- Ice loading.
- Navigation needs.
- Sediment and debris loading.
- Operation and maintenance considerations.
- Economics.

Because many of the spillways are associated with significant- and high-hazard dams/dikes, and failure of gates/valves may result in uncontrolled release of large flows, some redundant features/equipment might be required. Therefore, it may be advisable to design to stricter requirements than commonly called for by professional codes, standards, and/or guidelines.

Technical references associated with the mechanical/electrical design of spillways include:

- American Institute of Steel Construction (AISC) *Manual of Steel Construction*, thirteenth edition - refer to American National Standards Institute (ANSI)/AISC 360-05, Specifications for Structural Steel Buildings).
- American Welding Society (AWS) AWS D1.1/D1.1M Structural Welding Code – Steel; AWS D1.6 Structural Welding Code - Stainless Steel.

1.7.1.6 Risk Analysis (Only for Significant- and High-Hazard Dams/Dikes)

Probabilistic (in the form of a quantitative risk analysis), rather than deterministic, considerations will be part of any analysis/design for significant- and high-hazard dams and/or dikes, along with associated appurtenant structures (such as spillways) or critical components of associated appurtenant structures. The steps will be integrated with the previous design/analysis and include:

- Identify and define credible PFMs for the existing, modified, and/or new spillway. Although each spillway may have some unique PFMs, common PFMs include:
    - Flood-induced overtopping of dam and/or dike.

  - o Flood-induced spillway operations that exceed the original/maximum design discharge, leading to overtopping of the chute wall and/or terminal structure walls, pressurizing the conduit and/or tunnel, or sweepout of the terminal structure, and leading to erosional headcutting of the spillway foundation or erosion of the dam and/or dam foundation.

  - o Flood-induced spillway operations that result in cavitation damage of the chute and/or conduit, leading to erosion of the foundation.

  - o Flood-induced operations that result in stagnation pressure (hydraulic jacking) and/or structural collapse of the chute and/or terminal structure, leading to erosion of the foundation.

  - o Seismic-induced structural collapse of the spillway crest structure or features (such as piers, walls, and/or gates).

- Based on Reclamation's public protection guidelines [7], estimate the sum of the baseline (existing) risks[11] for all credible PFMs for all loading conditions[12] associated with existing and/or new dams, dikes, and all appurtenant structures such as spillways and outlet works.

- If an existing spillway is to be modified, estimate the sum of the modified annualized failure probability (AFP) and annualized life loss (ALL) for all credible PFMs.

- For the modified or new spillway, if the estimated sum of AFP and/or ALL for all credible PFMs are "tolerably"[13] below Reclamation guidelines (1E-4 or a 1 in 10,000 chance during a given year for AFP; and 1E-3 or a 1 in 1,000 chance during a given year for ALL), designs may be acceptable; however, if not tolerably below Reclamation guidelines, additional design considerations/features will be necessary to lower the estimated AFP and/or ALL for the modified or new spillway.

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[11] Risk includes the AFP and ALL.

[12] All loading conditions include static or normal operations, hydrologic or flood conditions, and seismic or earthquake conditions.

[13] Tolerably below Reclamation guidelines will be unique to each condition/situation and will be mutually agreed to by the designer of record and Reclamation's Dam Safety Office along with concurrence by Reclamation management. Consideration will include the level of uncertainty associated with estimates and future conditions that could increase the estimates (such as changes in downstream consequences).

- To address the uncertainties associated with using quantitative risk analysis to select an IDF, a robustness study is done to evaluate plausible operational and hydrologic/hydraulic scenarios that could increase the maximum RWS above the IDF-induced RWS. Typical scenarios that are evaluated include:

    - Misoperation.
    - Change in hydrology.
    - Debris blockage.
    - Change in downstream consequences.
    - Wind-generated waves.

For more detailed guidance associated with risk analysis/design for a spillway, refer to Chapter 2, “Hydrologic Considerations” and Chapter 3, “General Spillway Design Considerations.”

Technical references associated with the risk analysis/design of spillways include:

- *Interim Dam Safety Public Protection Guidelines* [7].

- REC-ERC-88-3 – *Overtopping Flow on Low Embankment Dams – Summary Report of Model Test* [15].

- DSO-07-07 – *Uplift and Crack Flow Resulting from High Velocity Discharges Over Offset Joints* [16].

- DSO-99-06 – *A Procedure for Estimating Loss of Life Caused by Dam Failure* [36].

- Final Technical Report No. 99DG81029 – *Considerations for Estimating Structural Response Probabilities in Dam Safety Risk Analysis* [37].

- Appendix D – *Toolbox for Handling Loads by Upstream Dams and Incorporating Consequences for Failure of Downstream Dams* [38].

- DSO-98-004 – *Prediction of Embankment Dam Breach Parameters: A Literature Review and Needs Assessment* [39].

- *Interim Guidelines for Addressing the Risk of Extreme Hydrologic Events* [40].

- *Risk Analysis Facilitator’s Notebook* [42].

- *Dam Safety Risk Analysis Best Practices Training Manual* [43].

1.7.2 Outlet Works Design/Analysis

Tasks for analyzing/designing outlet works are summarized in the following sections.

1.7.2.1 Location, Type, and Size

Similar to the spillway, selection of the location, type, and size of an outlet works will be dependent on the evaluation of a number of factors, including:

- Site conditions (geology/topography).
- Dam and/or dike type.
- Hydrologic considerations.
- Hydraulic considerations.
- Seismic considerations.
- Construction/constructability considerations.
- Project objectives.
- Robustness of design.
- Risks associated with credible PFMs, which must be tolerably below Reclamation's public protection guidelines [7].
- Operation and maintenance considerations.
- Economics.

Also, the two factors that were highlighted for the spillway are also highlighted for the outlet works, which are the robustness of design and the risks associated with PFMs. It is worth restating that because many of the outlet works are associated with significant- and high- hazard dams/dikes, it is important that any new or modified appurtenant structure designs protect the public to levels consistent with Reclamation's public protection guidelines [7]. This could mean some redundant features/equipment and designing to stricter requirements than commonly called for by professional codes, standards, and/or guidelines. Additionally, it should be restated that, as a starting point, an outlet works should include:

- Two gates or valves in series (one guard or emergency gate/valve and one regulating gate/valve) that can be operated under unbalanced head conditions.

- Hydraulic control at or upstream of the projected centerline of the dam/dike with either a pressurized pipe inside a larger access conduit and/or tunnel or a free-flow conduit and/or tunnel downstream of hydraulic control, particularly when associated with embankment dams/dikes.

- Stoplogs or bulkhead and slots provided near the intake structure.

- For embankment and/or rockfill dams/dikes, isolate the outlet works from the dam/dike (i.e., consider tunnel through the dam/dike abutments or reservoir rim, rather than a cut-and-cover outlet works through or beneath the dam/dike).

There will be cases where deviation from the above considerations will occur. However, there should be strong justification to not incorporate these considerations.

For more detailed guidance associated with locating, along with selecting a type and size of an outlet works, refer to Chapter 4, “General Outlet Works and Diversion Design Considerations.”

1.7.2.2 Hydraulic Analysis/Design

Similar to the spillway, the hydraulic analysis/design will be concurrent with the previous task of locating and selecting a type and size of outlet works. The steps of hydraulic analysis/design include:

- Develop/verify discharge curves.

- Evaluate intake structure and conveyance features (such as conduit) sizes along with gate/valve types/sizes based on:

    - **Diversion**. If an outlet works will be used for diversion during construction, initial flood routings of diversion floods (sometimes referred to as construction floods) should be done to size conveyance features and temporary cofferdams.

    - **Normal operations**. Evaluate conveyance feature size and gate/valve type/size for passing operational flows.

  - **Emergency evacuation**. Evaluate ability of outlet works to lower the reservoir in a timely fashion pursuant to guidelines noted in *Criteria and Guidelines for Evacuating Storage Reservoirs and Sizing Low-Level Outlet Works* [45].

  - **Floods**. Although not typical, some outlet works are used in passing floods. If this is the case, flood routing steps similar to those noted for the spillway should be employed.

- Refine discharge curves based on results from previous steps and finalize intake structure and conveyance features sizes along with gate/valve types/sizes.

- Depending on type/configuration of the outlet works, initial water surface profiles to layout conveyance features (such as chute/conduit) and terminal structure size and type.

- Prepare final water surface profiles to finalize size and type of outlet works conveyance features and terminal structure.

For more detailed guidance associated with hydraulic analysis/design for an outlet works, refer to Chapter 2, “Hydrologic Considerations,” and Chapter 5, “Hydraulic Considerations.”

Technical references associated with the hydraulic analysis/design of outlet works include:

- *Conduits through Embankment Dams: Best Practices for Design, Construction, Problems Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [1].

- *Design of Small Dams,* third edition [8].

- EM No. 25 – *Hydraulic Design of Stilling Basins and Energy Dissipators* [10].

- REC-ERC-73-5 – *Hydraulic Model Studies of Chute Offsets, Air Slots, and Deflectors for High-Velocity Jets* [12].

- REC-ERC-78-8 – *Low Froude Number Stilling Basin Design* [13].

- DSO-07-07 – *Uplift and Crack Flow Resulting from High Velocity Discharges Over Offset Joints* [16].

- *Hydraulic and Excavation Tables*, 11th edition [18].

- *Computing Degradation and Local Scour* [19].

- *Guide for Computing Water Surface Profiles* [20].

- ACER TM No. 3 – *Criteria and Guidelines for Evacuating Storage Reservoirs and Sizing Low-Level Outlet Works* [44].

- EM No. 7 – *Friction Factors for Large Conduits Flowing Full* [45].

- REC-ERC-78-24 – *Hydraulic Design of Stilling Basin for Pipe or Channel Outlets* [46].

- EM No. 41 – *Air-Water Flow in Hydraulic Structures* [47].

- ACER TM No. 4 – *Criteria for Bulkheading Outlet Works Intakes for Storage Dams* [48].

- *Plastic Pipe Used In Embankment Dams: Best Practices for Design, Construction, Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [52].

- *Outlet Works Energy Dissipators: Best Practices for Design, Construction, Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [53].

1.7.2.3 Foundation Analysis/Design

The foundation analysis/design will start when locating and selecting a type and size of outlet works and parallels the structural analysis/design efforts. The steps of foundation analysis/design include:

- Define site-specific foundation material and strength of properties.

- Assist in identifying suitable sites based on site-specific foundation needs for an outlet works.

- Define and analyze ground water conditions.

- Develop appropriate foundation designs, which include:

    - Drainage features, which in many cases are the key foundation design feature. (NOTE: Identify and evaluate drainage features/systems that will be accessible for inspection using CCTV equipment).

  - Adequate support for the outlet, which could range from excavating to competent rock to driving piles, placing piers in a soil foundation, or supporting excavated tunnels with rock bolts, shotcrete, etc.

- Accommodating loading conditions on the outlet works that could include static (hydrostatic, rock/soil, ice, and frost heave), hydrologic (floods), and seismic (hydrodynamic, dynamic soil/rock) loads, etc.

For more detailed guidance associated with foundation analysis/design for an outlet works, refer to Chapter 6, "Foundation Considerations."

Technical references associated with the structural and foundation analysis/design of outlet works include:

- *Conduits through Embankment Dams: Best Practices for Design, Construction, Problems Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [1].

- *Design of Small Dams,* third edition [8].

- EM No. 13 – *Estimating Foundation Settlement by One-Dimensional Consolidation Tests* [21].

- REC-ERC-74-10 – *Rock Mechanics Properties of Typical Foundation Rock Types* [22].

- REC-ERC-82-17 – *Frost Action in Soil Foundations and Control of Surface Structure Heaving* [23].

- ACER TM No. 9 – *Guidelines for Controlling Seepage Along Conduits Through Embankments* [24].

- *Drainage for Dams and Associated Structures* [25].

1.7.2.4 Structural Analysis/Design

Similar to the spillway, the structural analysis/design of the outlet works typically follows the hydraulic analysis/design. The steps of structural analysis/design include:

- Identify which features are considered "critical"[7] and "noncritical"[8] [26].

- Identify and define loading conditions for both critical and noncritical features, which will typically fall into four categories, including:

  - Construction.
  - Operational (normal or static).

  - Flood (hydrologic).
  - Earthquake (seismic).

- Identify, evaluate, and select material types and associated properties. Materials could include concrete (reinforced, conventional mass, roller compacted, and precast), steel, and plastic such as HDPE.

- Apply appropriate structural analysis/design methods that are based on the crawl, walk, and run philosophy (i.e., using the simplest approach that is technically adequate to prepare the analysis/design). These include:

  - **For analyses**. Pseudostatic, linear elastic FEM using response spectra and nonlinear, elastic FEM using time histories.

  - **For designs**. Design methods are typically based on Reclamation technical references such as *Design of Small Dams* [8], and industry codes are used, such as the ACI manuals.

For more detailed guidance associated with structural analysis/design for an outlet works, refer to Chapter 6, "Structural Considerations."

Technical references associated with the structural and foundation analysis/design of outlet works include:

- *Conduits through Embankment Dams: Best Practices for Design, Construction, Problems Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair* [1].

- *Design of Small Dams*, third edition [8].

- EM No. 14 – *Beggs Deformeter-Stress Analysis of Single-Barrel Conduits* [27].

- EM No. 14 Supplement – *Beggs Deformeter-Analysis of Additional Shapes* [28].

- EM No. 27 – *Moments and Reactions for Rectangular Plates* [29].

- EM No. 34 – *Control of Cracking in Mass Concrete Structures* [30].

- *Concrete Manual*, eighth edition [31].

- Current ACI 318 and ACI 350 building codes.

- EM 1110-2-2104 – *Strength Design for Reinforced-Concrete Design of Hydraulic Structures* [32].

- ACI SP-3 – *Reinforced Concrete Design Handbook (Working Stress Method),* third edition [33].

- *Design Criteria for Retaining Walls* [34].

- *Roller-Compacted Concrete: Design and Construction Considerations for Hydraulic Structures* [35].

1.7.2.5 Mechanical/Electrical Design

The mechanical/electrical design takes place concurrently with the structural analysis/design. The steps of mechanical/electrical design include:

- Select, size, and design gates/valves.

- Select, size, and design bulkhead gates, if applicable.

- Select, size, and design trashracks.

- Select, size, and design steel pipe.

- Select, size, and design gate/valve operators and generators.

- Select, size, and design HVAC systems.

- Select, size, and design hoists and/or cranes, if applicable.

- Design lighting and electrical control systems for gate/valve operations, HVAC systems, and SCADA systems.

- Address life safety considerations as noted in NFPA 100, *Life Safety Code Handbook*, 2009 edition.

For more detailed guidance associated with mechanical/electrical design for an outlet works, refer to Chapter 7, “Mechanical/Electrical Considerations.”

Selection of type and size of an outlet gate or valve and operating system will be dependent on the evaluation of a number of factors, including:

- Site conditions.

- Outlet works configuration.

- Access.
- Available power.
- Hydraulic considerations.
- Seismic considerations.
- Construction/constructability considerations.
- Ice loading.
- Sedimentation and debris loading.
- Operation and maintenance considerations.
- Economics.

Because reliable operation of outlet works may be critical in maintaining the safety of dams, some redundant features/equipment might be required, and it may be advisable to design to stricter requirements than commonly called for by professional codes, standards, and/or guidelines. Of special note, gate and/or valve controls should be located outside of flooded area, should a failure occur, to ensure that emergency/guard gates and/or valves can be operated.

Technical references associated with the mechanical/electrical design of outlet works include:

- AISC *Manual of Steel Construction,* thirteenth edition (refer to ANSC/AISC 360-05, Specifications for Structural Steel Buildings).
- AWS D1.1/D1.1M Structural Welding Code – Steel; AWS D1.6 Structural Welding Code - Stainless Steel.
- *Hydraulic Downpull Forces on Large Gates*, Research Report No. 4 [49].

1.7.2.6 Risk Analysis (Only for Significant- and High-Hazard Dams/Dikes)

Similar to the spillway, probabilistic (in the form of a quantitative risk analysis), rather than deterministic, considerations will be part of any analysis/design for significant- and high-hazard dams and/or dikes along with appurtenant structures such as outlet works. The steps will be integrated with the previous design/analysis and include:

- Identify and define credible PFMs for the existing, modified, and/or new outlet works. Although each outlet works may have some unique credible PFMs, common PFMs have included:

    - Flood-induced overtopping of dam and/or dike (if outlet works are used to help pass floods).

    - Flood-induced outlet works operations that exceed the original/maximum design discharge, leading to overtopping of the chute wall and/or terminal structure walls, or sweepout of the terminal structure, and leading to erosional headcutting of the outlet works foundation or erosion of the dam and/or dam foundation, overstressing the conduits and/or tunnels, introducing pressurized seepage through cracks/joints in the conduit and/or tunnels into surrounding embankment or foundation materials.

    - Operational- and/or flood-induced cavitation damage typically downstream of gates/valves in the chute and/or conduit, leading to erosion of the foundation.

    - Stagnation pressure (hydraulic jacking) and/or structural collapse of the chute and/or terminal structure, leading to erosion of the foundation.

- Based on Reclamation's public protection guidelines [7], estimate the sum of the baseline (existing) risks[11] for all credible PFMs for all loading conditions[11] associated with existing and/or new dams, dikes, and appurtenant structures such as spillways and outlet works.

- If an existing outlet works is to be modified, estimate the sum of the modified AFP and ALL for all credible PFMs.

- For the modified or new outlet works, if the estimated sum of AFP and/or ALL for all credible PFMs are "tolerably" below Reclamation guidelines (1E-4 or a 1 in 10,000 chance during a given year for APF; and 1E-3 or a 1 in 1,000 chance during a given year for ALL), designs may be acceptable; however, if not tolerably below Reclamation guidelines, additional design considerations/features will be necessary to lower the estimated AFP and ALL for the modified or new outlet works.

For more detailed guidance associated with risk analysis/design for an outlet works, refer to Chapter 2, "Hydrologic Considerations" and Chapter 4, "General Outlet Works and Diversion Design Considerations."

Technical references associated with the risk analysis/design of spillways include:

- *Interim Dam Safety Public Protection Guidelines* [7].
- REC-ERC-88-3 – *Overtopping Flow on Low Embankment Dams – Summary Report of Model Test* [15].
- DSO-07-07 – *Uplift and Crack Flow Resulting from High Velocity Discharges Over Offset Joints* [16].
- DSO-99-06 – *A Procedure for Estimating Loss of Life Caused by Dam Failure* [36].
- Final Technical Report No. 99DG81029 – *Considerations for Estimating Structural Response Probabilities in Dam Safety Risk Analysis* [37].
- Appendix D – *Toolbox for Handling Loads by Upstream Dams and Incorporating Consequences for Failure of Downstream Dams* [38].
- DSO-98-004 – *Prediction of Embankment Dam Breach Parameters: A Literature Review and Needs Assessment* [39].
- *Interim Guidelines for Addressing the Risk of Extreme Hydrologic Events* [40].
- *Risk Analysis Facilitator's Notebook* [42].
- *Dam Safety Risk Analysis Best Practices Training Manual* [43].

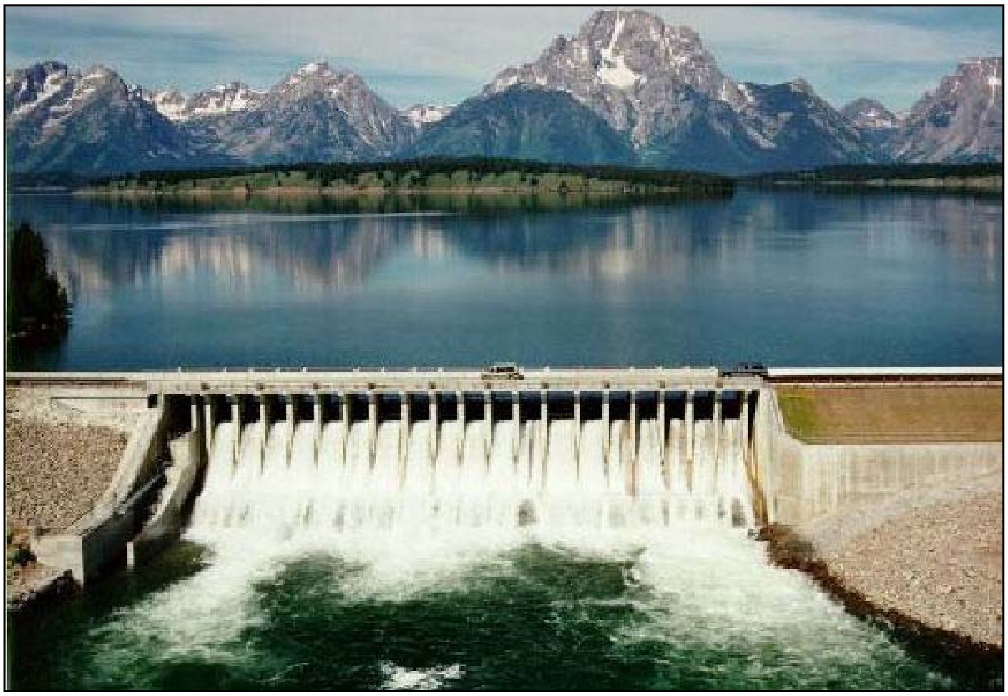


Figure 1.5.1.1-1. Example: Service spillway (gated), Jackson Lake Dam, Wyoming.

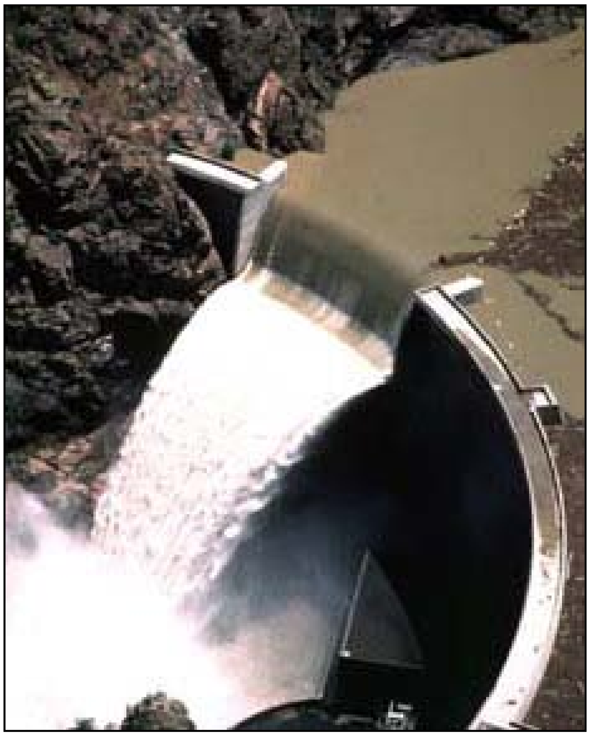


Figure 1.5.1.1-2. Example: Service spillway (ogee crest), Crystal Dam, Colorado.

Figure 1.5.1.2-1. Example: Auxiliary spillway (gated) in foreground and service spillway (gated) in background, Stewart Mountain Dam, Arizona.

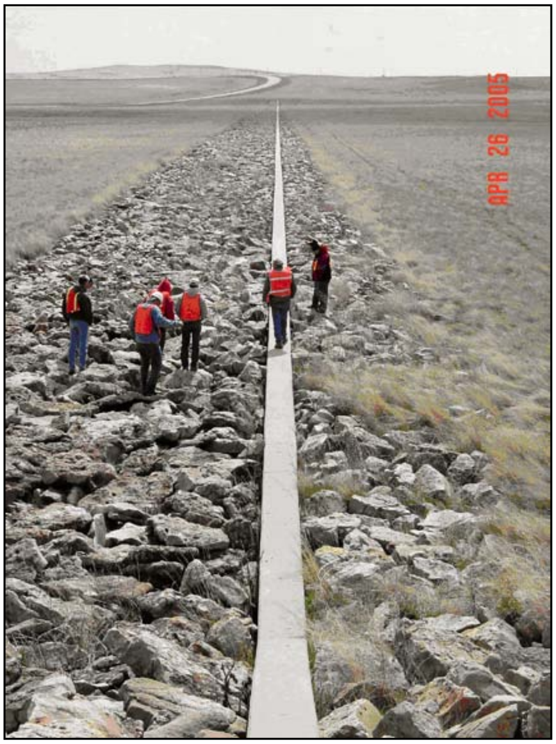


Figure 1.5.1.2-2. Example: Auxiliary spillway (grade control sill), Heart Butte Dam, North Dakota.

Figure 1.5.1.3-1. Example: Emergency spillway (fuseplug) in foreground and auxiliary spillway (ogee crest) in background, New Waddell Dam, Arizona.

Figure 1.5.1.3-2. Example: Emergency spillway (grade control sill), San Justo Dam, California.

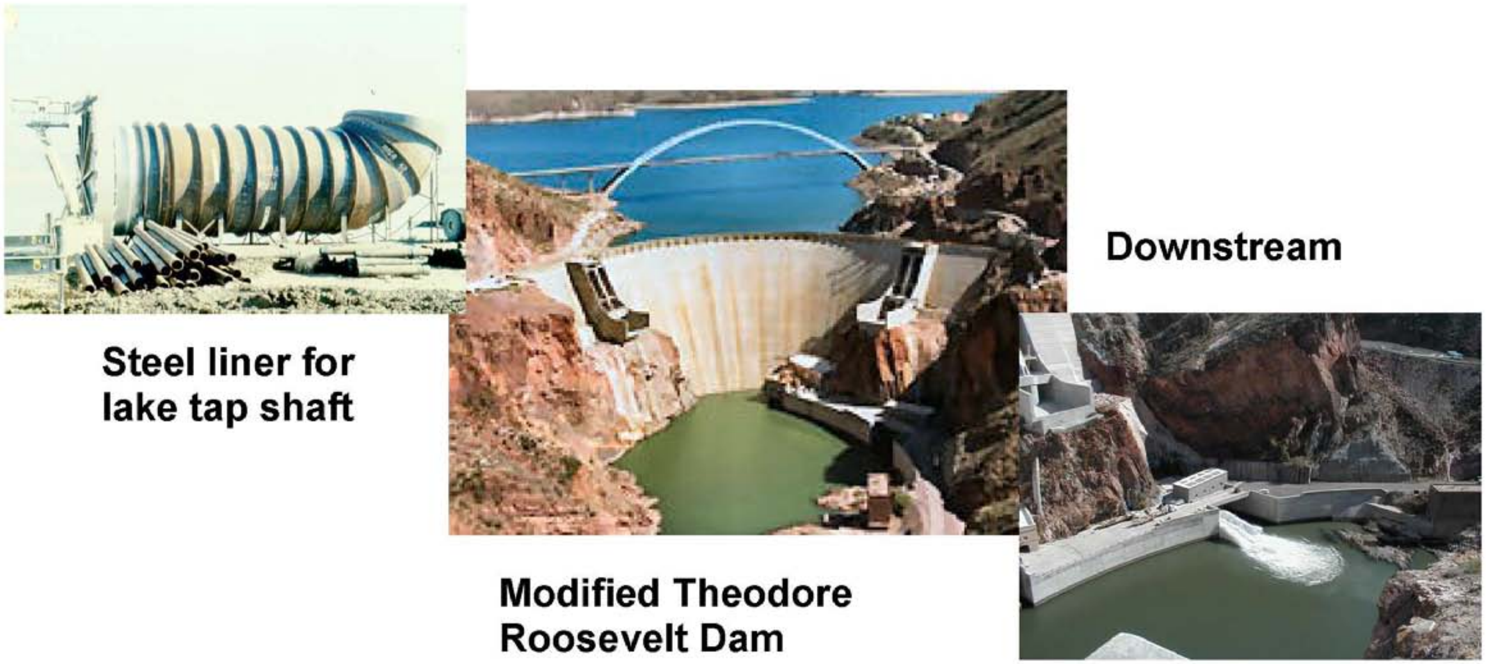


Figure 1.5.2-1. Example: Combination tunnel outlet works and power penstock, highlighting a number of features such as the upstream intake structure and the downstream structures. Theodore Roosevelt Dam, Arizona.

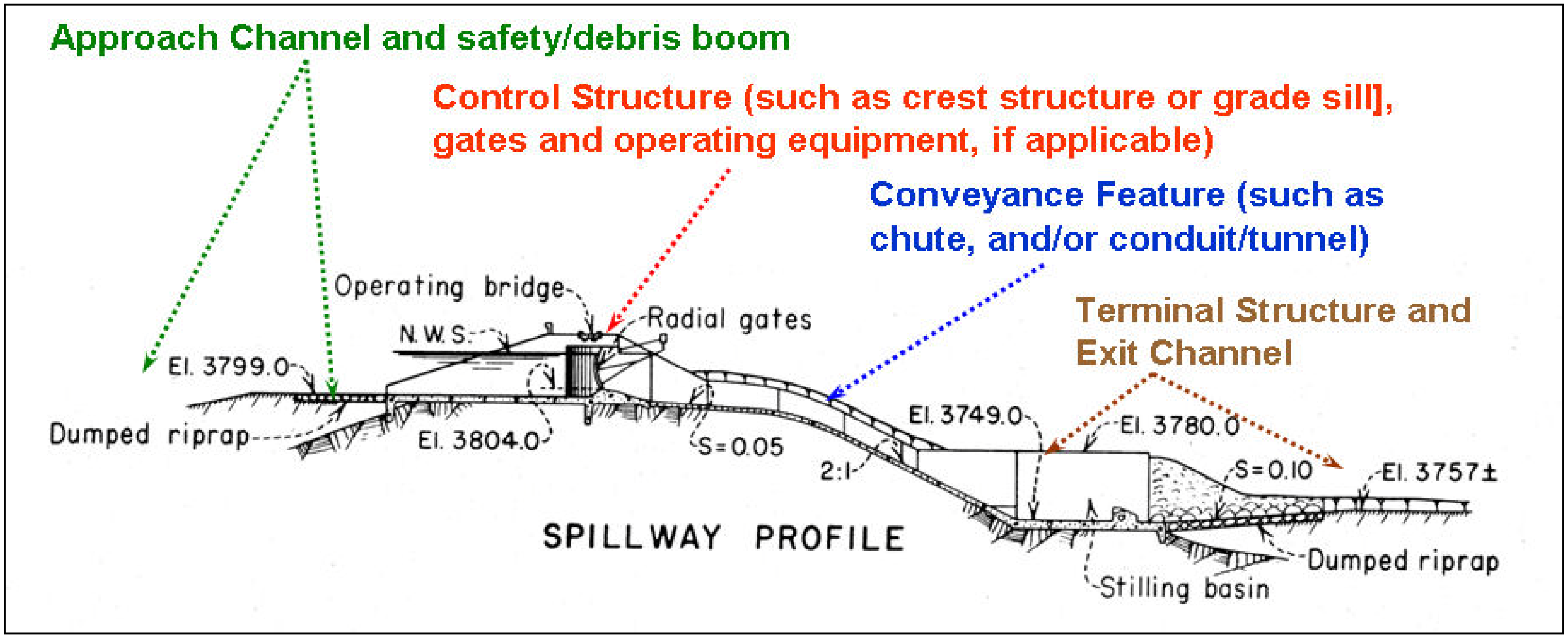


Figure 1.6.1-1. Common features of spillways.

Figure 1.6.1-2. Ogee crest (uncontrolled) spillway, Bumping Lake Dam, Washington.

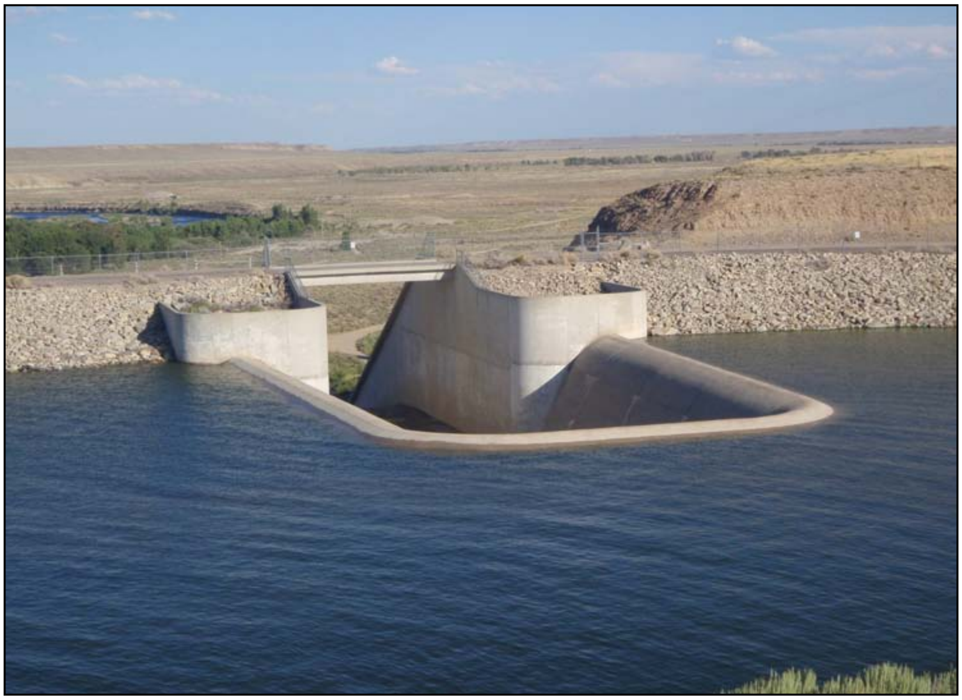


Figure 1.6.1-3. Double side-channel (bathtub) crest (uncontrolled) spillway, Fontenelle Dam, Wyoming.

Figure 1.6.1-4. Side-channel crest (uncontrolled) spillway, Big Sandy Dam, Wyoming.

Figure 1.6.1-5. Morning glory (glory hole) crest (uncontrolled) spillway, Whiskeytown Dam, California.

Figure 1.6.1-6. Labyrinth crest (uncontrolled) spillway, Ute Dam, New Mexico.

Figure 1.6.1-7. Radial gated (controlled) spillway, Bradbury Dam, California.

Figure 1.6.1-8. Crest (Obermeyer type) gated (controlled) spillway, Friant Dam, California.

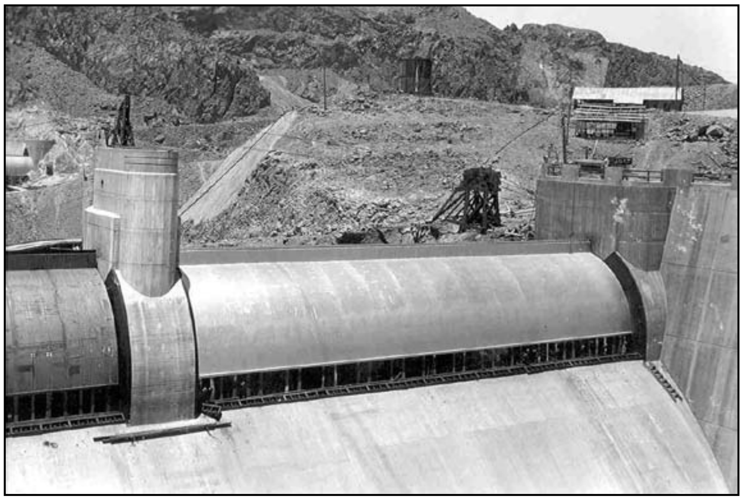


Figure 1.6.1-9. Drum gated (controlled) spillway, Hoover Dam, Arizona-Nevada.

Figure 1.6.1-10. Fuseplug crest (controlled) spillway (reservoir rim), Horseshoe Dam, Arizona.

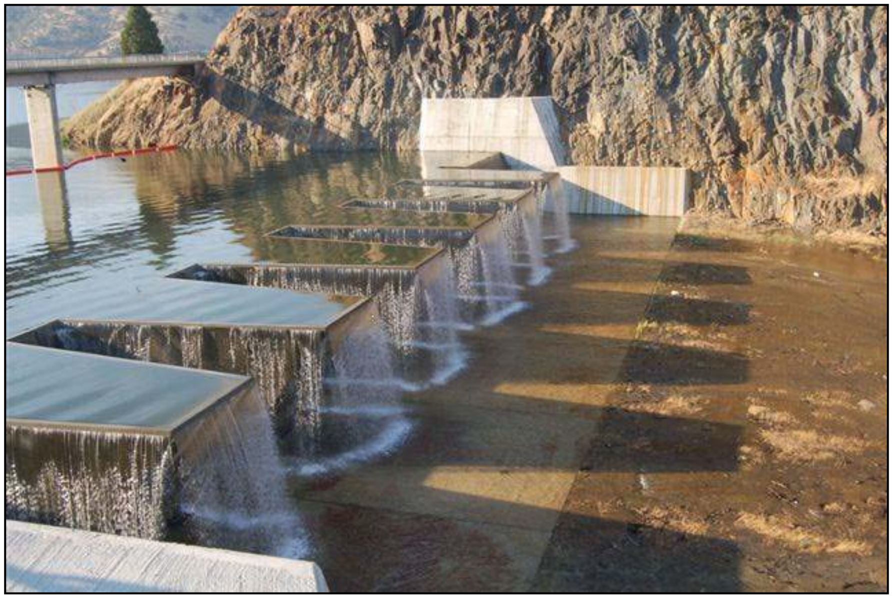


Figure 1.6.1-11. Fusegate crest (controlled) spillway, Terminus Dam, California (courtesy of the U.S. Army Corps of Engineers, Sacramento District, Rick Poeppelman).

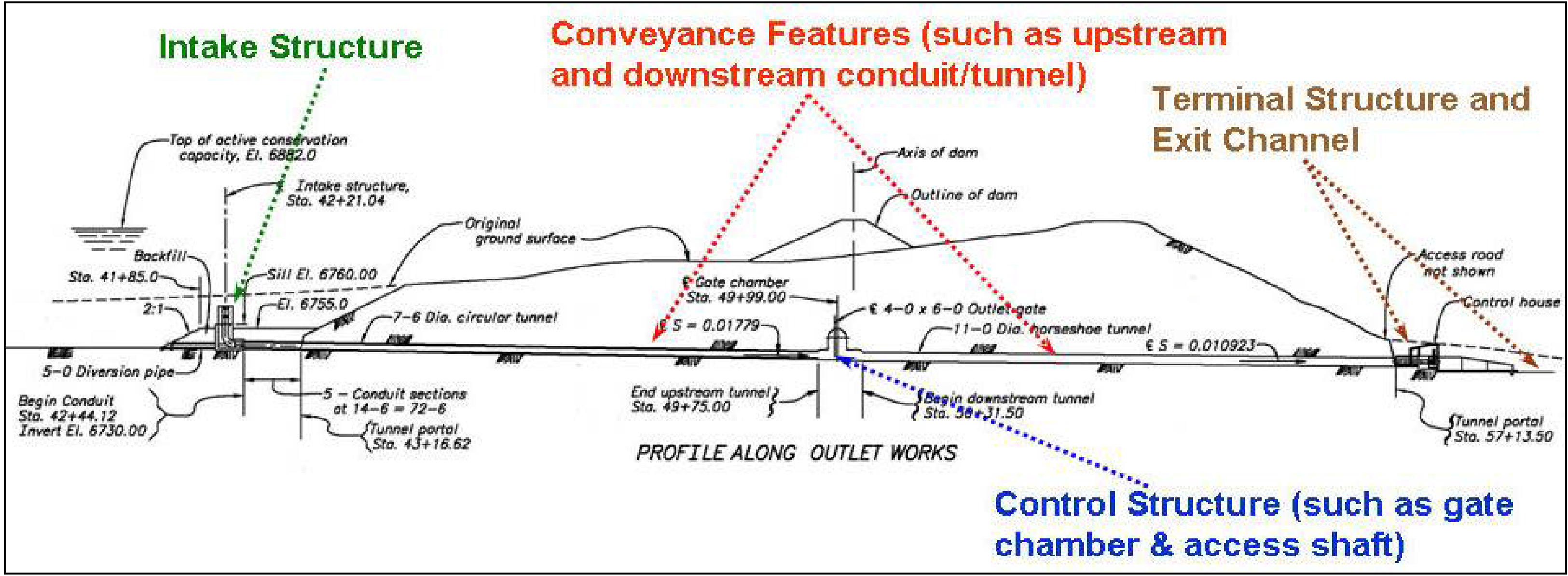
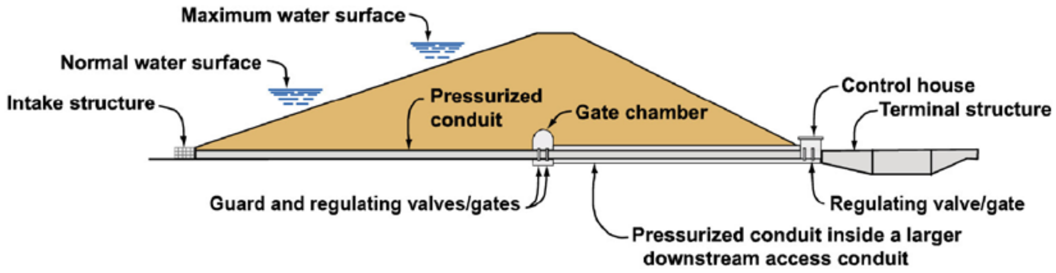
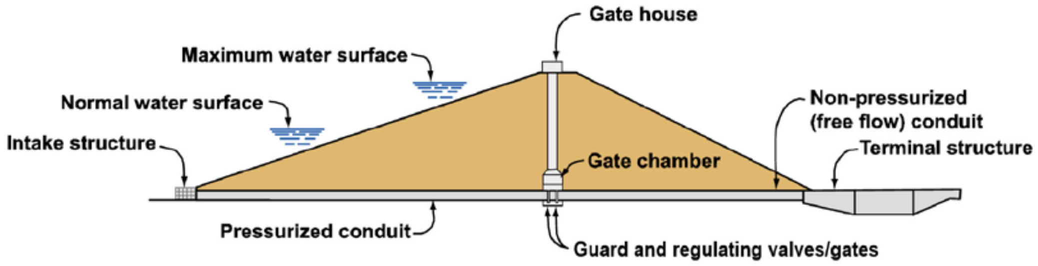


Figure 1.6.2-1. Common features of outlet works.



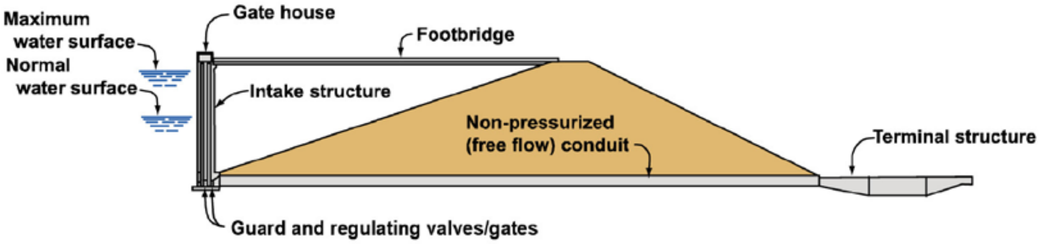
Arrangement 1—Intermediate control with downstream access.—The control feature is located at an intermediate point within the conduit.

Figure 1.6.2-2. Preferred outlet works configuration for high-head embankment dams: hydraulic control at downstream control structure, with guard/emergency gate/valve at/near centerline of dam/dike, and downstream pressurized pipe (between dam/dike centerline and control structure inside larger access conduit) [1].



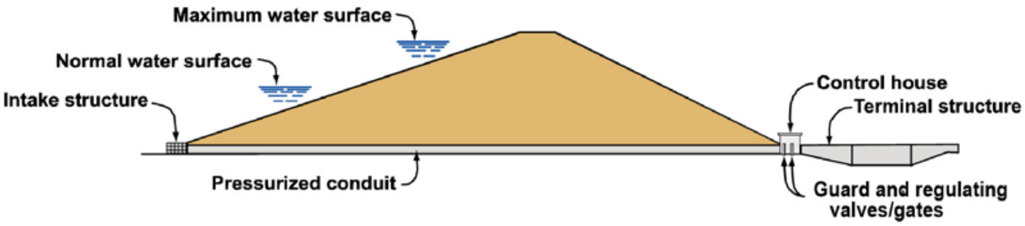
Arrangement 2—Intermediate control without downstream access.—The control feature is located at an intermediate point within the conduit.

Figure 1.6.2-3. Acceptable outlet works configuration for embankment dams: hydraulic control at/near centerline of dam/dike, with free flow conditions downstream of the regulating gate/valve [1].



Arrangement 3—Upstream control.—The control feature is located at the upstream end of the conduit.

Figure 1.6.2-4. Preferred outlet works configuration for low-head embankment dams: hydraulic control at upstream intake with free flow conditions downstream of the regulating gate/valve [1].



Arrangement 4—Downstream control.—The control feature is located at the downstream end of the conduit.

Figure 1.6.2-5. Least acceptable outlet works configuration for embankment dams: hydraulic control at downstream control structure (i.e., pressurized flow conditions upstream of the regulating gate/valve along most of the outlet works) [1].

1.8 References

[1] Conduits through Embankment Dams – Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair, technical manual, Federal Emergency Management Agency, September 2005.

[2] Reclamation Manual – Design Data Collection Guidelines, Bureau of Reclamation, September 2007.

[3] Feasibility Design Guidelines, Bureau of Reclamation, July 2008.

[4] Final Design Process, Bureau of Reclamation, April 2008.

[5] Reclamation Manual – Cost Estimating, Bureau of Reclamation, October 2007.

[6] Safety of Dams Project Management Guidelines, Bureau of Reclamation, March 2003.

[7] Interim Dam Safety Public Protection Guidelines, Bureau of Reclamation, August 2011.

[8] Design of Small Dams, third edition, Bureau of Reclamation, 1987.

[9] EM No. 9 – Discharge Coefficient for Irregular Overfall Spillways, Bureau of Reclamation, March 1952.

[10] EM No. 25 – Hydraulic Design of Stilling Basins and Energy Dissipators, Bureau of Reclamation, March 1984.

[11] EM No. 42 – Cavitation in Chutes and Spillways, Bureau of Reclamation, April 1990.

[12] REC-ERC-73-5 – Hydraulic Model Studies of Chute Offsets, Air Slots, and Deflectors for High-Velocity Jets, Bureau of Reclamation, March 1973.

[13] REC-ERC-78-8 – Low Froude Number Stilling Basin Design, Bureau of Reclamation, August 1978.

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TSC Security Review of Proposed Public Disclosure of Technical Information

Type: Design Standard

Design Standard: Design Standards No. 14 – Appurtenant Structures for Dams (Spillway and Outlet Works) Design Standards

Chapters: 1. Introduction

Brief Description of Information: An overview of how the Bureau of Reclamation analyzes/designs spillways and outlet works appurtenant for dams and/or dikes. An outline of the following chapters for this design standard that provides details for spillway and outlet works analyses/designs. A list of key technical references used for each major task involved with spillway and outlet works analyses/designs.

Requesting/Sponsoring Organization: Director, Technical Service Center

Program Office: Deputy Commissioner, Operations

Is Information Official Use Only / SENSITIVE? (Y [✓ N])
(to be completed by reviewer)

Is Information Official Use Only / RESTRICTED? (Y [✓ N])
(to be completed by reviewer)

(Sensitive or Restricted information shall not be included in a design standard.)

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