RECLAMATION

Managing Water in the West

Design Standards No. 13

Embankment Dams

Chapter 1: General Design Standards
Phase 4 (Final)

U.S. Department of the 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. 13

Embankment Dams

DS-13(1)-4: Phase 4 (Final)
October 2011

Chapter 1: General Design Standards

Approved:

Deputy Commissioner, Operations	**Date**

Chapter Signature Sheet
Bureau of Reclamation
Technical Service Center

Design Standards No. 13

Embankment Dams

Chapter 1: General Design Standards

DS-13(1)-4:[1] Phase 4 (Final)
October 2011

Chapter 1 - General Design Standards is an existing chapter within Design Standards No. 13 and was revised to include the addition of:

- Assessment of existing embankment dams based on observed performances in the field; current understanding of soil mechanics, seismic, and hydrologic loadings; and construction methods and equipment

- Current practices in dam engineering, including regulatory requirements

- Photos of dams cited in the text of this chapter

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[1] DS-13(1)-4 refers to Design Standards No. 13, chapter 1, revision 4.

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Chapter 1

General Design Standards

1.1 Introduction

1.1.1 Purpose

The purpose of this chapter is to present general concepts of embankment dam design in order to give the designer some broad background to use as a basis during the embankment dam design process, including remedial measures for existing embankment dams with known deficiencies.

1.1.2 Scope

Various types of dams are discussed, as well as general design requirements that must be fulfilled by embankment dams.

1.1.3 Revisions of Standard

This chapter will be revised as its use indicates. Comments or suggested revisions should be forwarded to the Chief, Geotechnical Services Division (86-68300), Bureau of Reclamation, Denver, Colorado 80225; they will be comprehensively reviewed and incorporated as needed.

1.1.4 General

Dams may be classified into a number of different categories depending upon the purpose of the classification. In this design standard, three broad classifications are used: purpose, hydraulic design, and materials comprising the structure. The examples of different types of dams listed throughout this standard are dams constructed by the Bureau of Reclamation (Reclamation) unless otherwise specified.

1.2 Types of Dams

1.2.1 Classification According to Purpose

Dams may be classified according to the broad function that they are to serve, such as storage, diversion, or detention. Refinements of classification can also be made by considering specific functions involved.

1.2.1.1 Storage Dams

Storage dams are constructed to impound water in periods of surplus supply for use in periods of deficient supply. These periods may be seasonal, annual, or longer. Many dams in the Western United States impound the spring runoff for use in the summer dry season. Storage dams may be further classified according to the purpose of the storage, such as water supply, recreation, fish and wildlife, hydroelectric power generation, irrigation, etc. The specific purpose or purposes that are to be served by a storage dam often have an influence in the design of the structure and may establish criteria such as the amount of reservoir fluctuation that may be expected and the amount of reservoir seepage that may be permitted. McPhee Dam (photo 1.2.1.1-1) near Dolores, Colorado, is an example of an embankment storage dam, and Glen Canyon Dam (photo 1.2.1.1-2) near Page, Arizona, is an example of a concrete storage dam.

1.2.1.2 Diversion Dams

Diversion dams are ordinarily constructed to provide hydraulic head or lift for diverting water into ditches, canals, or other conveyance systems to the place of use and are often designed to be overtopped. Such dams are used for irrigation developments, for diversion from a natural flowing stream to an off-channel-location storage reservoir, for municipal and industrial uses, or for any combination of the preceding. Examples of diversion dams can be found on many western rivers. Sun River Diversion Dam (photo 1.2.1.2-1) near the city of Great Falls, Montana, is an example of a concrete diversion dam.

1.2.1.3 Detention Dams

Detention dams are constructed to retard flood runoff and minimize the effect of sudden floods. Detention dams fall into two main types. In the more common type, the water is temporarily stored and released through an outlet structure at a rate that will not exceed the carrying capacity of the channel downstream. In other types, the water is held as long as possible and, during the growing season, is released through a gated outlet and travels though a dike system that irrigates the vegetation within the dike system. The latter type is both a detention and retention dam and is part of a water spreading dike system. Triple Crossing Dam (photo 1.2.1.3-1) near Glasgow, Montana, is an example of a retention, detention, and water spreading dam. It is called a water spreading dam or dike because its main purpose is to recharge the underground water supply. The Triple Crossing Dam is owned and operated by the Bureau of Land Management. Detention dams are also constructed to trap sediment; these often are called debris dams. An example of a detention dam for flood control purposes is Bear Creek Dam (photo 1.2.1.3-2) in Denver, Colorado, designed and constructed by the U.S. Army Corps of Engineers.

1.2.1.4 Multipurpose Dams

Often dams are constructed to serve more than one purpose. When multiple purposes are involved, a reservoir allocation is usually made to each of the

Photo 1.2.1.1-1. McPhee Dam (near Dolores, Colorado).

Photo 1.2.1.1-2. Glen Canyon Dam (near Page, Arizona).

Photo 1.2.1.2-1. Sun River Diversion Dam (near Great Falls, Montana).

Photo 1.2.1.3-1. Triple Crossing Dam (near Glasgow, Montana). Photo courtesy of Bureau of Land Management.

Photo 1.2.1.3-2. Bear Creek Dam (near Denver, Colorado). Photo courtesy of U.S. Army Corps of Engineers.

separate uses. A common multipurpose project might combine storage, flood control, and recreational uses. McGee Creek Dam (photo 1.2.1.4-1) near Atoka, Oklahoma, is an example of a multipurpose dam.

1.2.2 Classification by Hydraulic Design

Dams may also be classified as overflow or nonoverflow dams.

1.2.2.1 Overflow Dams

Overflow dams are designed to carry discharge over their crests. They must be made of materials that will not be eroded by such discharges. Concrete, masonry, steel, and wood have been used to construct overflow dams. Overflow structures only a few feet high may require less protection. Gibson Dam (photo 1.2.2.1-1) near Augusta, Montana, is an example of an overflow dam.

1.2.2.2 Nonoverflow Dams

Nonoverflow dams are those that are not designed to be overtopped. This type of design extends the choice of materials to include earthfill and rockfill dams. Often a concrete dam combined with an overflow spillway and earthfill or rockfill wing dams are used to form a composite structure. Pueblo Dam (photo 1.2.2.2-1) near Pueblo, Colorado, is an example of composite design.

1.2.3 Classification by Material

The most common classification used for purposes of discussion of design procedures is based upon the materials comprising the structure. This classification also usually recognizes the basic type of design such as concrete gravity dam, concrete buttress dam, concrete arch dam, roller-compacted concrete dam, earthfill dam, or rockfill dam. This standard is limited in scope to consideration of the earthfill and rockfill dams – called embankment dams.

1.3 Embankment Dams

1.3.1 Earthfill

Earthfill dams are the most common type of dam principally because their construction uses materials from required excavations and locally available, natural materials, requiring a minimum of processing. Using large quantities of required excavation and locally available borrow are economic factors favoring the earthfill dam. Moreover, earthfill dams can be constructed on weaker foundations than other dam types and in areas where topography is less favorable to other dam types. Earthfill dams will probably continue to be more prevalent than other types for storage purposes.

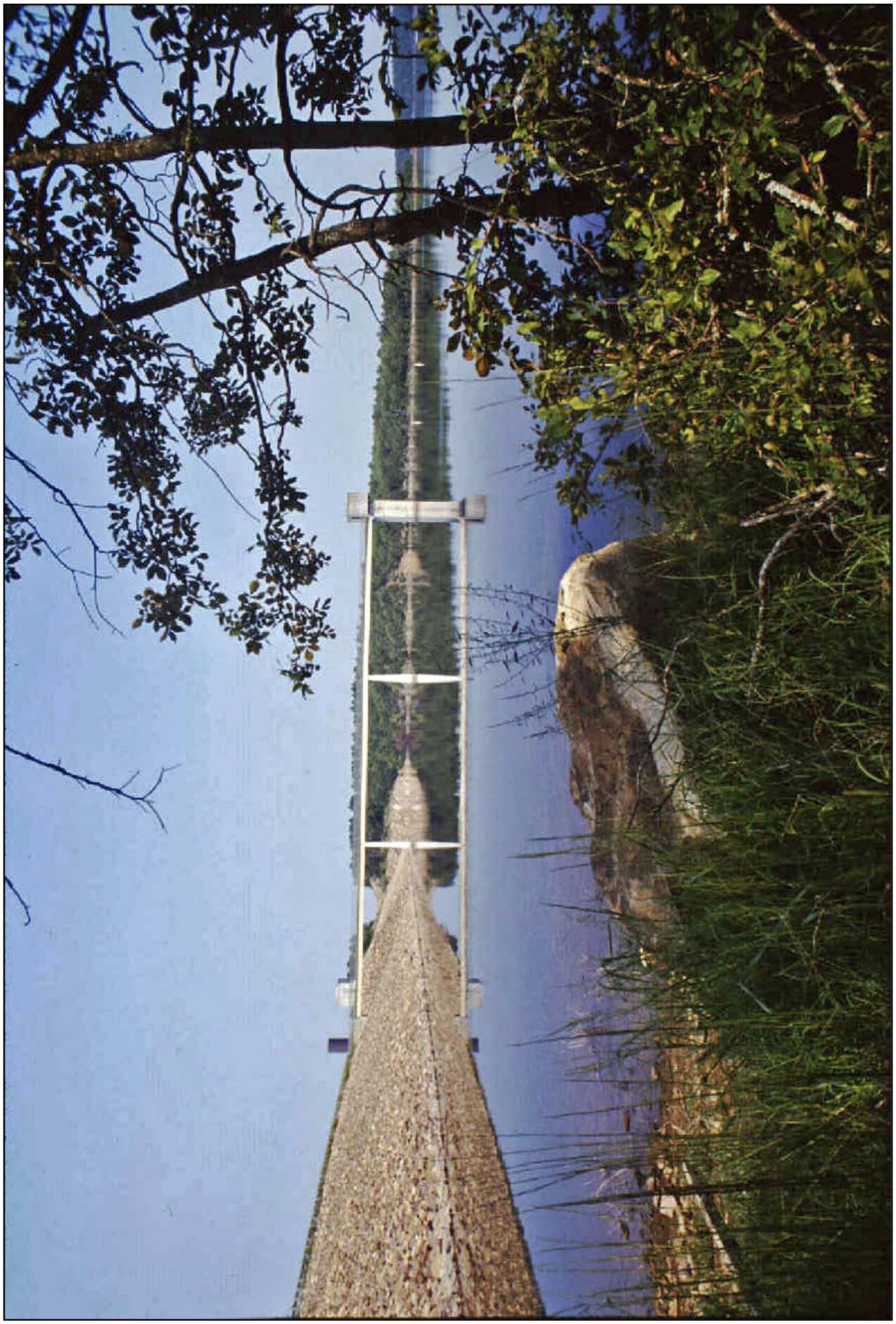


Photo 1.2.1.4-1. McGee Creek Dam (near Atoka, Oklahoma).

Photo 1.2.2.1-1. Gibson Dam (near Augusta, Montana).

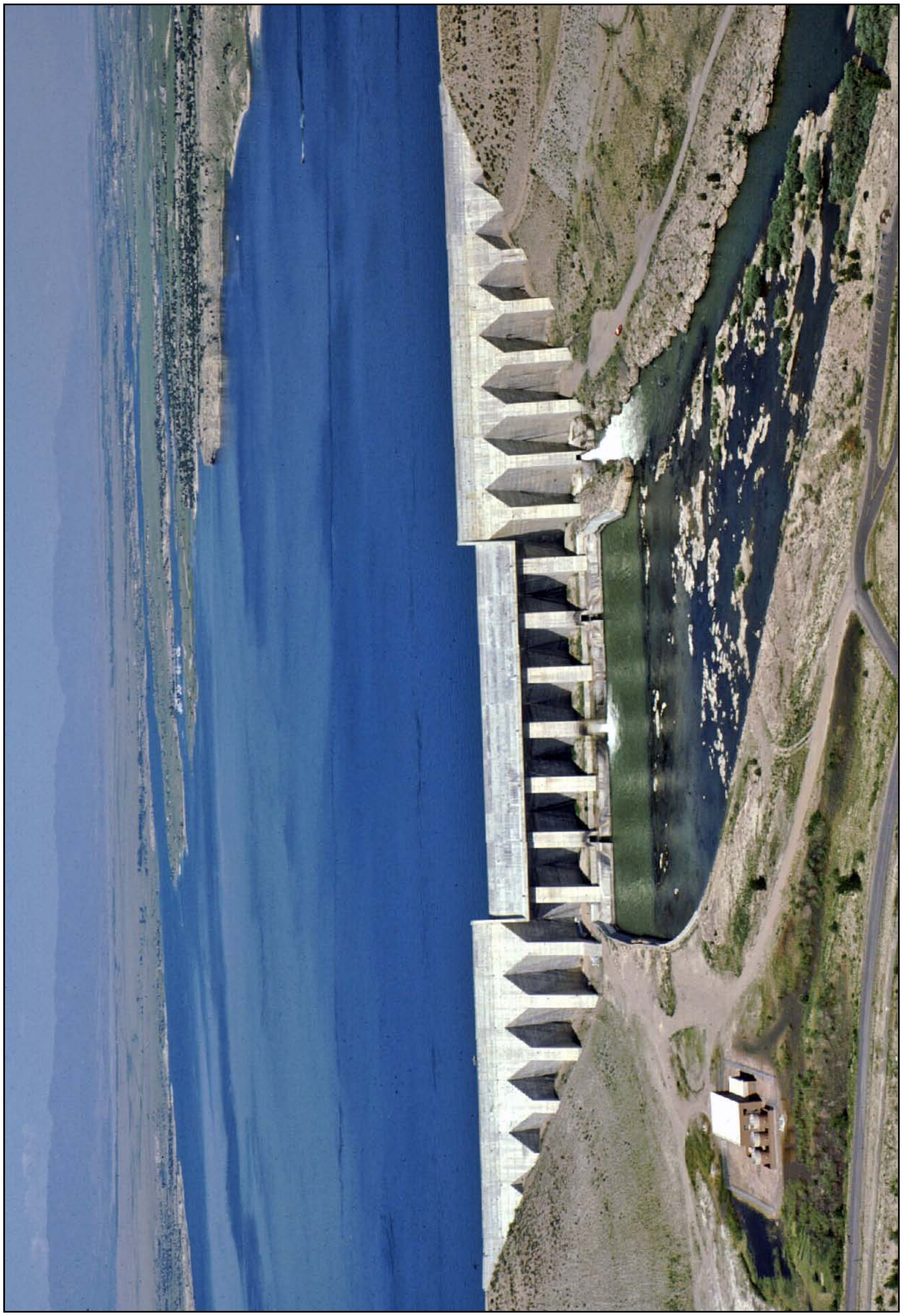


Photo 1.2.2.2-1. Pueblo Dam (near Pueblo, Colorado).

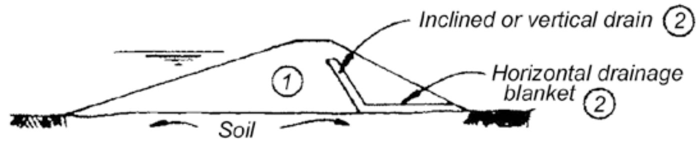
Although the earthfill classification includes several types, the development of modern excavating, hauling, and compacting equipment for earth materials has made the compacted-fill type so economical as to virtually replace the semihydraulic- and hydraulic-fill types of earthfill dams constructed by mixing soil with water, pumping the slurry to the fill where it is stilled, and then allowing the soil to settle out of the water. Additionally, compacted-fill dams are much more stable against earthquake loading as compared to hydraulic-fill dams. For these reasons, only the compacted-fill type of earthfill dam is treated in this design standard. Earthfill dams of the compacted-fill type are further classified as "homogeneous" or "zoned with central or inclined impervious core" as shown on figure 1.3.1-1. Zoning is performed to ensure safety in terms of adequate strength and control of seepage and cracking. For many dams, it is possible to design several safe types of zoning. The final selection of the zoning, therefore, is a matter of designing the cross section that results in an ideal balance between safety and economical use of materials from excavation and available borrow materials. As a defense against potential for cracking, the downstream portion of the dam is drained by a horizontal drainage layer combined with a vertical or inclined filter drainage layer. A drained downstream shell permits use of lower quality materials, a random zone, in a section downstream of the internal drain. Examples of different zonings in dams built by Reclamation are included in reference [1].

Earthfill dams generally require appurtenant structures to serve as spillways and outlet works. The principal disadvantage of an earthfill dam is that it may be damaged or totally breached under the erosive action of water flowing over it. This can happen if sufficient spillway and water passage release capacity is not provided. This disadvantage is more prevalent during construction. More attention and planning for diversion and generally more elaborate diversion schemes are required for earthfill dams than for other dam types. Special provisions such as channels, additional tunnels, conduits, or the use of heavy rock or steel reinforced rockfill sections to permit overflowing of the embankment during construction are often required.

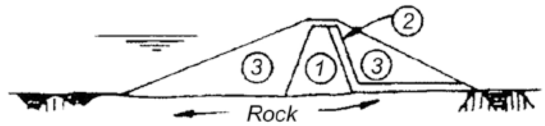
1.3.2 Rockfill

Rockfill dams rely on rock compacted in relatively thin layers as a major structural element [2]. This design standard has a further qualification that "rock" shall include angular fragments such as those produced by quarrying or occurring naturally as talus and subangular or rounded fragments such as coarse gravel, cobbles, and boulders [3]. Rockfill dams use an impervious "membrane" to provide watertightness. The membrane may be an upstream impervious facing or an interior impervious core. Impervious zones or membranes such as concrete pavings, asphaltic concrete paving, geomembranes, steel plate, and wooden decks have been constructed upstream of pervious rockfill zone. Interior impervious

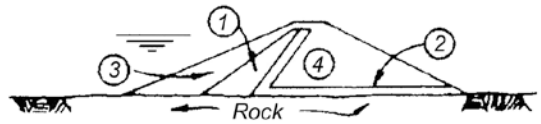
EARTHFILL DAM SECTIONS



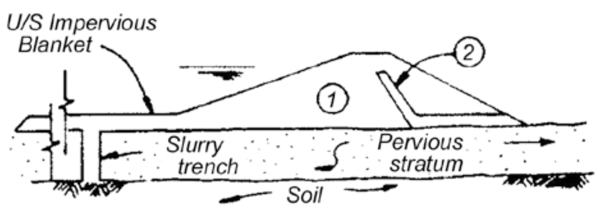
a. Homogenous dam with internal drain on impervious foundation



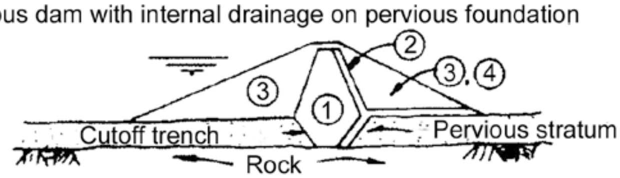
b. Central core, zoned dam on impervious foundation



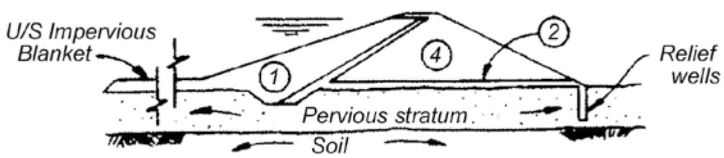
c. Inclined core, zoned dam on impervious foundation



d. Homogenous dam with internal drainage on pervious foundation



e. Central core, zoned dam on pervious foundation



f. Zoned dam with upstream impervious zone on pervious foundation

Note: Sections are modified from those presented in Fig. 1-1, EM 1110-2-2300, Dept. of the Army, Corps of Engineers, May 10, 1982

LEGEND:

- (1) - Zone 1, impervious soil
- (2) - Zone 2, filter drain material (may require a two-stage system - usually processed sands and gravels)
- (3) - Zone 3, pervious soil (sands and gravels)
- (4) - Zone 4, random soil (requires adequate engineering properties, but plasticity and gradation are less critical considerations)

Figure 1.3.1-1. Types of earthfill dam cross sections.

cores such as thin impervious soil zones, concrete, asphaltic concrete, and geomembranes have been constructed in rockfill dams. Many rockfill dam configurations include a central or inclined core with upstream and downstream filter and drain (or transition) zones. Some examples are shown on figure 1.3.2-1. Reference [1] includes additional examples of world practices of zonings in rockfill dams.

The rockfill type is adapted to locations where the supply of good rock is ample, foundation rock is at or near the ground surface, suitable soil for an earthfill dam may not be readily available or long periods of high rainfall may make construction of an earthfill dam impracticable, and the construction of a concrete dam is less economical. Rockfill dams are popular in tropical climates because their construction is adaptable to long periods of high rainfall. Rockfill dams are attractive if significant amounts of the fill can be acquired from required excavations (spillways, tunnels, etc.).

Like the earth embankments, rockfill dams are subject to damage or destruction by the overflow of water and generally must be provided with a spillway of adequate capacity to prevent overtopping of the dam. Rockfill dams require foundations whose settlement will not be large enough to rupture the watertight membrane. The only suitable foundations, therefore, are rock or very compact sand and gravel.

Rockfill dams are typically built with steeper slopes than earthfill dams because compacted rockfill (when drained) is much stronger than compacted earthfill. Steeper slopes result in a smaller dam-foundation contact area, which means less foundation requiring treatment.

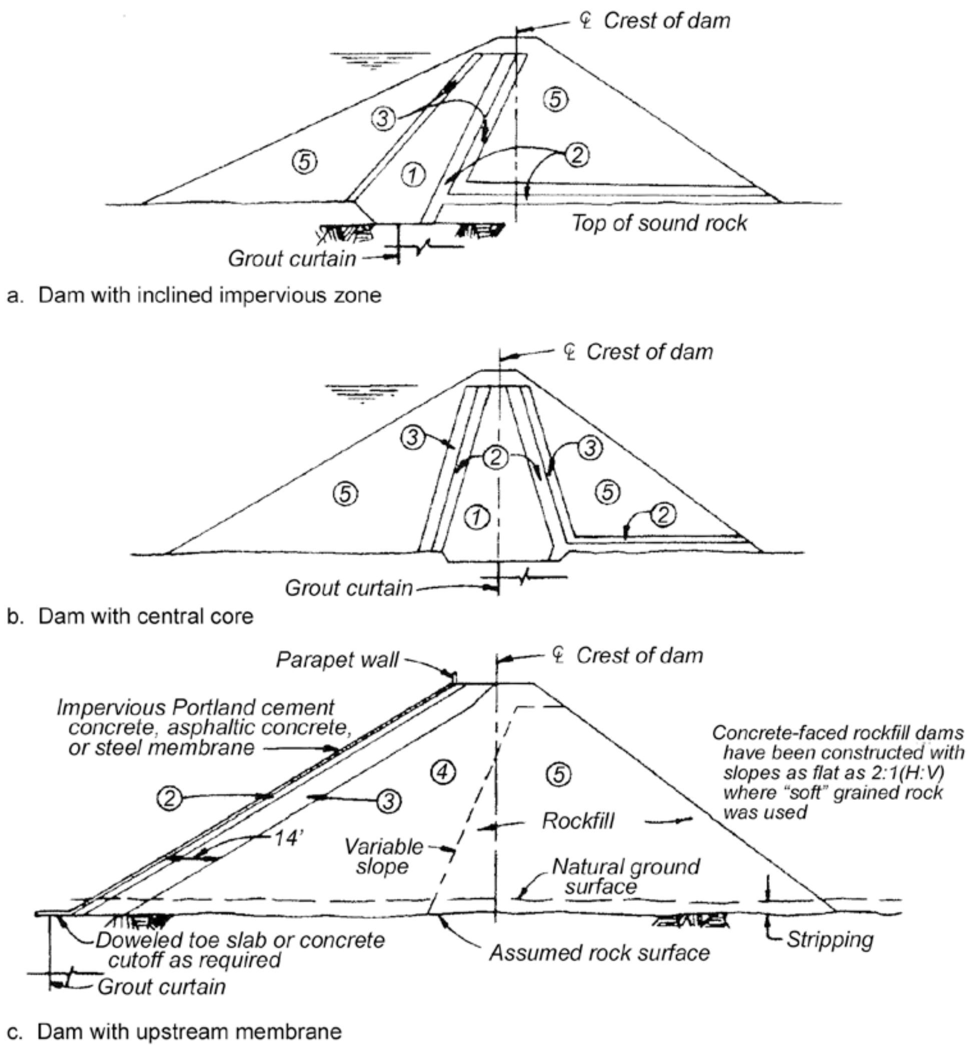
1.3.3 Basic Requirements of Embankment Dams

The following criteria must be met to ensure satisfactory earth and rockfill structures:

- The embankment, foundation, abutments, and reservoir rims must be stable and must not develop unacceptable deformation under all loading conditions brought about by construction of the embankment, reservoir operation, and earthquake.

- The reservoir rim must be stable under the most severe operating conditions to eliminate the possibility of an unstable thin rim or the possibility that large existing landslides, when inundated by the reservoir or during rapid drawdown, would be triggered and cause a large volume of slide material to fill the reservoir and create a large wave that would overtop the dam.

ROCKFILL DAM SECTIONS



Note: Sections a. and b. are modified from those presented in Fig. 1-2, EM 1110-2-2300, Dept. of the Army, Corps of Engineers, May 10, 1982. Section c. is modified from Fig. 202, Design of Small Dams, USBR, 1977.

① - Impervious earth fill
② - Filter zone
③ - Well graded, selected compacted rock used to provide drainage and bearing support for membrane, and/or transition
④ - Smaller sized rock from quarry and rock of lesser quality from foundation excavations, compacted to reduce membrane settlement, and/or provide transition
⑤ - Best quality, higher strength rock, compacted to provide section stability

Figure 1.3.2-1. Types of rockfill dams.

- Seepage through the embankment, foundation, abutments, and reservoir rim must be controlled to prevent excessive uplift pressures, internal erosion and piping, instability, sloughing, removal of material by solutioning, or erosion of material by loss into cracks, joints, and cavities. In addition, the purpose of the project may impose a limitation on the volume of seepage.

- Filters must be *required* for any high or moderate hazard embankment dam, not just something to consider.

- Freeboard must be sufficient to prevent overtopping by waves.

- Camber should be sufficient for allowance for settlement of the foundation and embankment. It is not included as part of the freeboard except in rare cases.

- Spillway and outlet capacity must be sufficient to prevent overtopping of the embankment and encroachment on freeboard.

1.3.4 Seepage Control

The design should consider seepage control measures such as:

- Foundation cutoffs

- A core of appropriate width of nonbrittle impervious materials

- Upstream impervious blankets

- Transition zones and filters; internal drainage such as inclined or vertical drains, drainage blankets, or pervious zones

- Toe drains

- Relief wells

- Defensive measures against seepage and piping at all embankment/structure interfaces

In addition, close construction control is required to ensure proper foundation treatment, use of fill materials, gradation control, water content control, compaction control, and installation of cutoffs and/or drainage facilities.

1.3.5 Pore Pressures

Special attention should be given to possible development of high pore pressures in foundations, particularly in stratified compressible materials such as clay deposits containing pervious layers, foundation materials containing clay seams, or stratified layers with sand layers or varved clays. In such foundations, migration of pore pressures may induce pore pressures in the foundation beyond the toes of the embankment, where the weight of the overlying material produces little counterbalancing load. Thus, the effective strengths of foundation soils beyond the embankment toes may also be reduced, resulting in an unstable structure. The effect of construction pore pressures must also be evaluated when the foundation consists of "soil-like" shales, clay shales, or compaction shales.

1.3.6 Erosion Protection

Finished embankment surfaces should be properly graded and protected from wave and surface erosion to prevent beaching or serious maintenance problems. This protection is provided by riprap and bedding, soil cement, turf, vegetation, etc. Erosion control is required at embankment-abutment contacts because surface flows concentrate there. The final lines and grades of the embankment and surface protection should control erosion and be aesthetically pleasing.

1.4 Physical Factors Governing Site Selection and Type of Embankment Dam

1.4.1 General

During the early stages of planning and design, site selection and type of dam are carefully considered. Only in exceptional circumstances is only one type of dam or appurtenant structure suitable for a given damsite. Generally, preliminary designs and estimates will be required for several types of dams and appurtenant structures before one can be shown to be most suitable and economical. It is emphasized that site selection and type of dam be based on adequate study to prevent undue expense.

The selection of dam type requires cooperation among persons representing several disciplines, including planners; hydrologists; geotechnical, hydraulic, and structural engineers; and engineering geologists, seismologists, and geophysicists to ensure an economical and appropriate design for physical factors such as topography, geology and foundation conditions, available materials, hydrology, and seismicity.

Factors affecting the final choice of the dam type are:

- Limitations of outlet works
- The problem of diverting the stream during construction
- Availability of labor and equipment
- Accessibility of the site
- Physical features of the site
- Size and location of spillway
- Availability of construction materials
- Foundation conditions
- Seismicity
- Environmental concerns
- The purpose of the dam
- Dam safety

Usually, the final choice of type of dam will be based on the comparative cost to construct the various dam types studied. The following paragraphs discuss important physical factors in the choice of the type of dam.

1.4.2 Topography

Topographic considerations include the surface configuration of the damsite and the reservoir area, accessibility to the site, and construction materials. Topography, in large measure, dictates the first choice of dam type. A narrow stream flowing between high, rocky walls would naturally suggest a rockfill or a concrete dam. Conversely, the low, rolling plains country would suggest an earthfill dam. Intermediate conditions might suggest other choices such as a composite structure. Topography is of major significance in choosing the dam type.

Topography may also have an important influence on the selection of appurtenant structures. For example, if there are natural saddles, it may be possible to locate a spillway through a saddle. If the reservoir rim is high, as compared to the dam height, and unbroken, a chute or tunnel spillway might be necessary.

1.4.3 Geology and Foundation Conditions

Geologic considerations include the various types of rock and soil present and their suitability as foundation and construction materials. The foundation geology at a damsite often dictates the type of dam suitable for that site. The strength, thickness, and inclination of strata; permeability; fracturing; jointing; and faulting are all important considerations when considering a dam type. Some of the differing foundations commonly encountered are discussed below:

- *Rock foundations* – Competent rock foundations, free of significant geologic defects, with their relatively high shear strength and resistance to erosion and percolation, offer few restrictions as to the type of dam that can be built upon them. Economy of materials or overall cost will be the ruling factor. The removal of disintegrated or weathered rock, together with the sealing of seams and fractures by grouting, will frequently be necessary. Weaker rocks such as some shales and clay shales may offer significant problems to the design and construction of a dam and have a strong influence on the type of dam selected.

- *Gravel foundations* – Gravel foundations, if well compacted, are suitable for earthfill or rockfill dams. As gravel foundations are frequently very pervious, special precautions must be taken to provide adequate seepage control and/or effective water cutoffs or seals.

- *Silt or sand foundations* – Silt or sand foundations can be used for the support of earthfill dams if properly designed, but they are generally not suitable for rockfill dams. Design concerns include: liquefaction potential under seismic loads, nonuniform settlement, potential soil collapse upon saturation, the prevention of piping, the prevention of excessive percolation losses, the prevention of excessive uplift forces, and protection of the foundation at the downstream embankment toe from erosion.

- *Clay foundations* – Clay foundations can be used for the support of earthfill dams, but require flat embankment slopes because of relatively lower foundation shear strengths. Clay foundations under dams can also consolidate significantly. Because of the requirement for flatter slopes and the tendency for large settlements of clay foundations, it is usually not economical to construct a rockfill dam on a clay foundation. In situ testing of the foundation material in its natural state is usually required to determine the consolidation and shear strength characteristics of the foundation strata and their ability to support the superimposed load.

- *Nonuniform foundations* – Occasionally, situations may occur in which reasonably uniform foundations of any of the foregoing descriptions cannot be found and when a nonuniform foundation of rock and soft material must be used if the dam is to be built. Such conditions can often be overcome by special design features. Typically, each damsite presents special problems requiring appropriate treatment selected by experienced engineers.

The details of the foundation treatments mentioned previously are given in the appropriate chapters (2, 3, 5, 8, and 9) of this design standard.

1.4.4 Available Materials

Materials for dams of various types, which may sometimes be available at or near the site, are:

- Soils for embankments
- Rock for embankments and riprap
- Concrete aggregate (sand, gravel, crushed stone)

The most economical type of dam will often be the one for which materials in sufficient quantity are found onsite or within a reasonable haul distance from the site. Embankment dams, therefore, are designed to make the best use of the closest, suitable materials. Elimination or reduction of transportation expenses for construction materials, particularly those used in great quantity, will result in a considerable reduction in total cost of the project.

The availability of suitable rock for rockfill is a factor favorable to the use of a rockfill dam. On the other hand, if suitable soils for an earthfill dam can be found in nearby borrow pits, an earthfill dam may prove to be the most economical. Advantage should be taken of every local resource to reduce the cost of the project without sacrificing the efficiency and quality of the final structure.

1.4.5 Hydrology

Hydrologic studies determine the extent to which the project developed water supply will meet the project purposes (section 1.2.1.1 – Storage Dams) under a fully developed project condition. There is a close relationship between the hydrologic and economic factors governing the choice of the type of dam and appurtenant structures. Streamflow characteristics and precipitation may appreciably affect the cost of construction by influencing the care and diversion of water and extending the construction time of an earthfill dam. When large tunnels are required for diversion, conversion of the tunnels to tunnel spillways may provide the most economical spillway alternative.

1.4.6 Seismicity

Site seismicity may dictate the type of dam suitable for the site. When there is a postulated foundation movement, a rockfill dam is more suitable than an earthfill dam unless the earthfill dam has a very wide core. If the dam lies in an area that is subject to earthquake loadings, the design must include provisions to defend against the effects of the added loading and increased stresses. See earthquake design considerations in Chapter 13 - Seismic Design and Analysis and Chapter 2 - Embankment Design of this design standard.

1.5 Appurtenant Structures

1.5.1 Outlet Works

The outlet works is an important consideration to the embankment designer and is typically incorporated into the diversion scheme during construction. For maintenance purposes or in emergencies, it might be used to draw the reservoir down.

An outlet works consists of a combination of features (intake structure, conveyance features such as conduits, control structures, etc.) and operating equipment (electrical and mechanical) required for the safe operation and control of water releases from a reservoir to meet downstream needs. The outlet works serves various purposes such as regulating streamflow and water quality, releasing floodwaters, power generation, emergency evacuation, and providing irrigation, municipal, and/or industrial water.

From a dam safety perspective, constructing an outlet works through/beneath an embankment dam and/or dike should be avoided to limit contact between the outlet works conduit and embankment materials and to minimize the potential for internal erosion of embankment soils into or along the conduit. A preferred alternative is to construct a tunnel outlet works through the reservoir rim area including the abutments where the embankment soils are not in direct contact with the outlet works.

If an outlet works must be placed through or beneath an embankment dam, special care and attention must be provided to the embankment zoning adjacent to the outlet works. These special considerations include avoidance of abrupt geometry changes, such as those associated with seepage collars or counterforts, and narrow cuts that require special compaction of backfill soils within them. The embankment zoning around outlet works should include properly designed filter materials that prevent loss of fine-grained soils from the impervious core with the seepage flows through the dam. During construction, extra attention is required in the placement and compaction of filter zones around outlet works conduits.

The outlet works requires close coordination between outlet works and embankment designers to ensure that the needs of both specialties are adequately fulfilled.

1.5.2 Spillway

The spillway is a vital appurtenance to an embankment dam to prevent overtopping during floods. Spillway requirements are dictated primarily by the runoff and streamflow characteristics as well as elevation and water retention capabilities of the reservoir rim, independent of type or size of the dam. The selection of specific spillway type will be influenced by the magnitudes of the floods to be passed. On streams with large flood potential, the spillway takes on even greater design significance.

A spillway is a hydraulic structure that passes normal (operational) and/or floodflows in a manner that protects the structural integrity of the dam and/or dikes. Spillways are hydraulically sized to safely pass the Inflow Design Flood and are classified according to the frequency of their use—service spillway for continuous or frequent releases, auxiliary spillway for infrequent releases, and emergency spillway for flood releases to prevent dam overtopping due to extreme flood events.

The cost of constructing a large spillway is frequently a considerable portion of the total cost of the dam. In certain instances, excavated material from spillway channels can be used in the dam embankment, thus contributing to reducing overall costs.

With the exception of low debris dams, the spillway should not be on or through an embankment dam/dike unless necessary. The preferred locations would be on the dam abutments or through the reservoir rim. If there are no other alternative locations (other than over or through the embankment dam), more conservative design assumptions (redundancies) and added care are needed to ensure safe operations of spillways. Inherent problems associated with such designs are: unequal settlements of the structure due to differential consolidations of the embankment and foundation after the reservoir loads are applied; the need for special provisions to prevent cracking of the concrete or opening of joints that could permit leakage from the channel into the fill, and consequent piping or washing away of the surrounding material; potential for piping to occur along the spillway walls, and the preference for having a fully completed embankment and seasoned dam before spillway construction can be started. Consideration of these factors, coupled with increased costs brought about by more conservative construction details such as increased lining thickness, increased reinforcement steel, cutoffs, joint treatment, drainage, and preloading, have generally led to selection of alternative solutions for the spillway design.

The spillway structure is usually placed over or through the natural material (preferably rock) of the abutment or reservoir rim. This eliminates the concerns associated with a spillway over or through the embankment. Where the spillway discharge is close to the embankment toe, severe erosion damage to the embankment can be caused by high velocity, high volume releases. The designers must ensure that adequate channel armoring and toe protection are provided in such cases.

Spillway and embankment designers should coordinate their efforts closely so that a spillway scheme is compatible to both their needs.

1.6 Existing Dams

Safety assessment of dams designed and built in the past using the then-available state-of-knowledge of soil mechanics, seismic and hydrologic loadings, and construction methods and equipment is a continual process. Existing dams may need to be modified to withstand larger earthquake loads or pass larger flood flows through spillways and outlet works. Also, dam modifications may be needed to correct for inadequacies in design and construction based on observed dam performances under normal operating conditions. This work is generally carried out under the Safety of Dams program as required by the Reclamation Safety of Dams Act of 1978.

A commonly encountered dam safety deficiency in existing embankment dams is lack of adequate means to control loss of fine-grained soils in embankment and foundation materials with the seepage flows passing through them. Similarly, presence of liquefiable soils in the foundation without adequate design components in the dam to safely accommodate the deformations and cracking can lead to failure of an embankment dam during a significant earthquake in the near vicinity to the dam. Hydraulic deficiencies in existing dams are due to inadequate release capacities of the spillways and outlet works during large flood events. Assessment of such issues is commonly performed in a risk context. Design measures to correct these deficiencies are discussed in various chapters of this design standard.

Some examples of completed dam modifications are shown on figures 1.6-1a, b, and c. There are others included in embankment dam modification database [4].

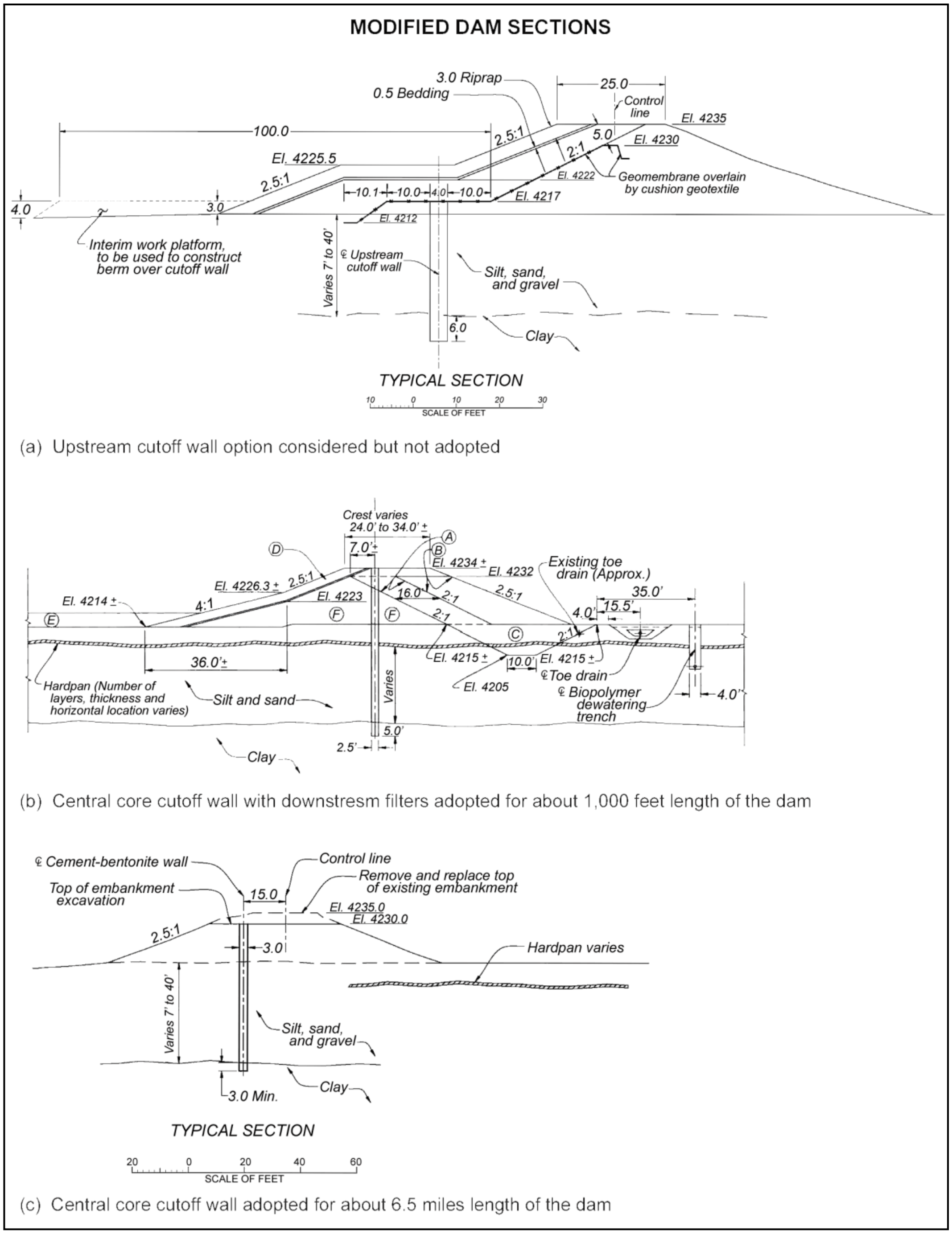


Figure 1.6-1a. Typical sections for A.V. Watkins Dam modifications for protection against internal erosion.

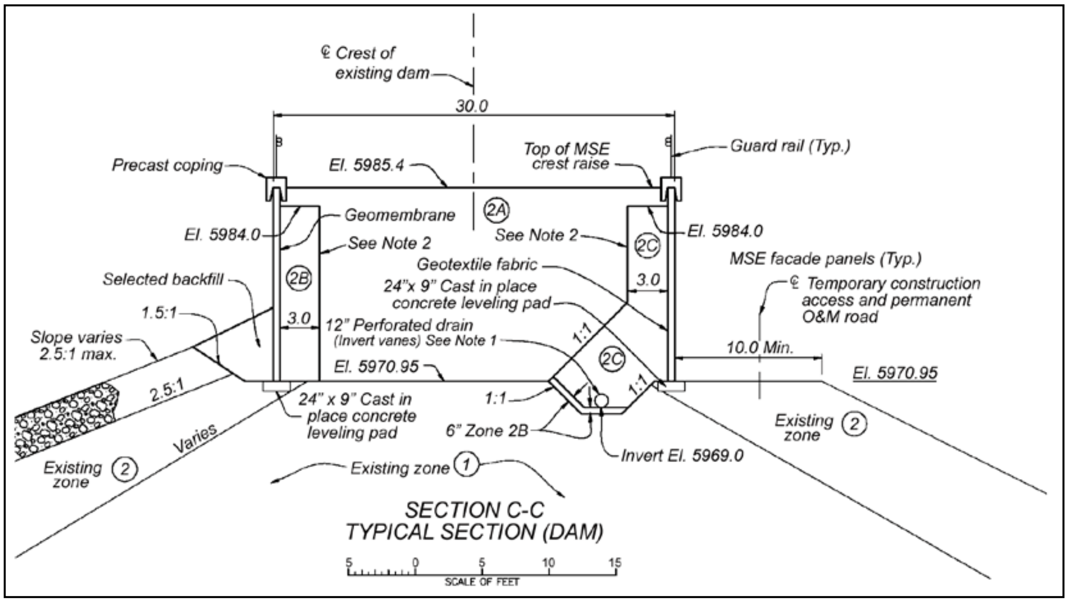


Figure 1.6-1b. Typical section for Stampede Dam modifications for protection against overtopping.

1.7 Legal, Economic, Aesthetic, and Environmental Considerations

1.7.1 Statutory Restrictions

Statutory restrictions exist with respect to control of the waters of navigable streams. Plans for diversion or control of waters in such streams are subject to approval by the U.S. Army Corps of Engineers. There are numerous other Federal and State regulations relating to dam construction and operation that may be determining factors in the design process. Every State has laws and regulations governing the design, construction, and operation of all dams and reservoirs. Engineers need to be aware that Federal, State, and regional legal requirements must be satisfied as part of the planning, design, construction, and operations process. Complying with these requirements may affect the design process.

1.7.2 Appearance

Every type of structure should have a finished appearance, compatible with its functional purpose. The alignment and texture of finished surfaces should be true to the design requirements and free from unsightly irregularities. Aesthetic considerations are an important part of the design process.

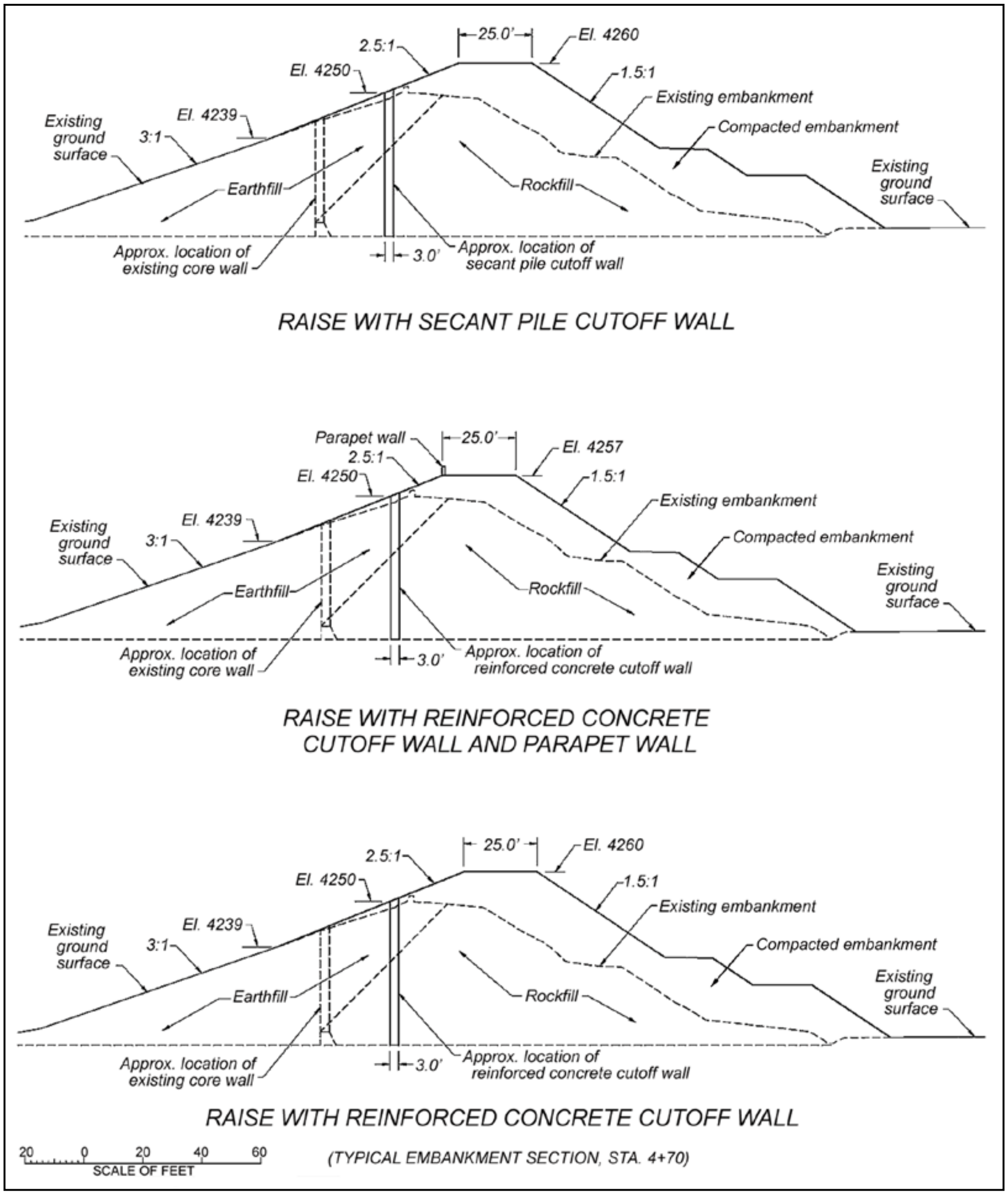


Figure 1.6-1c. Typical sections for proposed Minidoka Dam modifications for increase in reservoir capacity.

1.7.3 Environmental

Environmental protection considerations have become very important in the design of dams and can influence the type and dimensions of a dam and the location of the spillway and appurtenant facilities.

Public Law 91-190, National Environmental Policy Act of 1969, as amended, and the Clean Water Act of 1972 with amendments in 1977, created the national policy for promoting efforts to prevent or mitigate damage to the Nation's rivers and to the environment. The goal is to achieve clean and healthy watersheds that support aquatic life, economic development, and human needs. Managing water resources in a river basin, including the design and construction of an embankment dam, has an impact on a river basin's natural water cycle. The scale of the impact depends on the actual size and natural condition of the area to be developed and the extent of development.

Mitigation measures are essential elements in the planning, design, construction, and operation of an embankment dam, including clearing of vegetation in the area to be flooded, multilevel outlet structures to optimize downstream water temperature and quality, provisions for the migration of fish and other aquatic organisms, and operational rules for regulating downstream flows at critical times to protect habitat for reproduction or migratory routes. Appropriate site selection, along with the implementation of these techniques, will result in both new and rehabilitated projects that minimize unacceptable environmental impacts. The following environmental considerations should be incorporated into the design, construction, and operation phases of embankment dams:

(1) Minimal or no construction outside of the footprint of the dam and spillway.

(2) Minimal or no disturbance to ground cover during and after construction.

(3) Minimizing erosion during and after construction.

(4) Provision of adequate control of sedimentation.

(5) Minimizing impact on water quality during construction.

(6) Minimal or no impact during future operation.

1.7.4 Economics

The designers should continually strive to strike an equitable balance between economy, purpose, safety, and environmental concerns. The dam must fulfill project purposes and dam safety requirements, but at the same time be economically feasible. Infrastructure investments shall be based on systematic analysis of expected benefits and costs, including both quantitative and qualitative measures. Good engineering incorporates a good balance between adequate design and economy.

1.7.5 Value Study

Value Studies are multifunctional team activities that are based on the value method, a problem solving and decisionmaking process. Value Planning Studies occur during the conceptual stage of the design process. Value Engineering Studies occur during the design stage of the design process. Each study uses the value method, which is a systematic and organized way to develop and compare alternatives that will get the job done (provide all of the essential functions) with the greatest value (economy, quality, and the least delay).

Value study teams usually include five to seven individuals with relevant expertise for the project. A baseline cost estimate and project schedule are typically completed prior to the study for use by the team.

1.8 Additional Information

References [5, 6, and 7] contain useful information of interest pertaining to embankment dams.

1.9 References

[1] United States Department of the Interior, Bureau of Reclamation, Maximum sections and earthwork control statistics of earthfill dams built by the Bureau of Reclamation, Denver, Colorado, 1994.

[2] American Society of Civil Engineers, *Symposium on Rockfill Dams*, 1960.

[3] Golze, Alfred R. *Handbook of Dam Engineering*, Van Nostrand Reinhold Co., New York, 1977.

[4] United States Department of the Interior, Bureau of Reclamation, *Embankment Dam Modification Database*, Denver, Colorado, 2011.

[5] United States Department of the Interior, Bureau of Reclamation, *Design of Small Dams*, Denver, Colorado, 1987.

[6] Department of the Army Corps of Engineers, *Earth and Rockfill Dams General Design and Construction Considerations*, Engineering Manual EM 1110-2-2300, 1982.

[7] Sherard, J., R. Woodward, S. Gizienski, and W. Clevenger, *Earth and Earth-Rock Dams*, John Wiley and Sons, Inc., New York, 1963.