Training
Aids for
Dam
Safety

MODULE:

INSPECTION OF THE FOUNDATION, ABUTMENTS, AND RESERVOIR RIM

TADS

Training Aids for Dam Safety

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INSPECTION OF THE FOUNDATION, ABUTMENTS, AND RESERVOIR RIM

Subject-Matter-Expert Panel

Philip H. Smith
Soil Conservation Service,
Chairman

Lynn A. Brown
Bureau of Reclamation

Joel A. Reed
Association of Dam Safety
Officials (State of Ohio)

Arthur D. Soderberg
Tennessee Valley Authority

Richard C. Thompson
Corps of Engineers

Technical Consultant

Lynn A. Johnson
Bureau of Reclamation

PREFACE

There are presently more than 80,000 dams in use across the United States. Like any engineering works, these dams require continual care and maintenance, first to ensure that they remain operational and capable of performing all intended purposes, and then to preclude endangering people and property downstream.

The safety of all dams in the United States is of considerable national, state, and local concern. Given that, the principal purpose of the TADS (Training Aids for Dam Safety) program is to enhance dam safety on a national scale. Federal agencies have responsibility for the safe operation, maintenance, and regulation of dams under their ownership or jurisdiction. The states, other public jurisdictions, and private owners have responsibility for the safety of non-Federal dams. The safety and proper custodial care of dams can be achieved only through an awareness and acceptance of owner and operator responsibility, and through the availability of competent, well-trained engineers, geologists, technicians, and operators. Such awareness and expertise are best attained and maintained through effective training in dam safety technology.

Accordingly, an ad hoc Interagency Steering Committee was established to address ways to overcome the paucity of good dam safety training materials. The committee proposed a program of self-instructional study embodying video and printed materials and having the advantages of wide availability/marketability, low per-student cost, limited or no professional trainer involvement, and a common approach to dam safety practices.

The 14 Federal agencies represented on the National Interagency Committee on Dam Safety fully endorsed the proposed TADS program and have underwritten the cost of development. They have also made available technical specialists in a variety of disciplines to help in preparing the instructional materials. The states, through the Association of State Dam Safety Officials, also resolved to support TADS development by providing technical expertise.

The dam safety instruction provided by TADS is applicable to dams of all sizes and types, and is useful to all agencies and dam owners. The guidance in dam safety practice provided by TADS is generally applicable to all situations. However, it is recognized that the degree to which the methods and principles are adopted will rest with the individual agency, dam owner, or user. The sponsoring agencies of TADS assume no responsibility for the manner in which these instructional materials are used or interpreted, or the results derived therefrom.

ACKNOWLEDGMENTS

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Arthur H. Walz, Corps of Engineers
William S. Bivins, Federal Emergency Management Agency
Donald L. Basinger, Soil Conservation Service
Joseph J. Ellam, Association of State Dam Safety Officials
(Commonwealth of Pennsylvania)
Marshall L. Silver, U.S. Committee on Large Dams

TADS PROJECT MANAGER

Chris J. Veesaert, Bureau of Reclamation

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Robert L. James, Corps of Engineers, Chairman
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Chris J. Veesaert, Bureau of Reclamation
Harold C. Buttrey, Tennessee Valley Authority
Constantine G. Tjoumas, Federal Energy Regulatory Commission
Alan E. Pearson, Association of State Dam Safety Officials
(State of Colorado)

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Association of State Dam Safety Officials
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MODULE INTRODUCTION

INSPECTION OF THE FOUNDATION, ABUTMENTS, AND RESERVOIR RIM

MODULE INTRODUCTION

OVERVIEW OF THE MODULE

The purpose of this module is to provide you with a basic understanding of how geology plays a role in the overall safety and stability of a dam and reservoir. You will be introduced to the two basic categories of earth materials, and the properties that make them desirable or undesirable as foundation and abutment material, as well as their susceptibility to certain deficiencies. Treatments designed to prevent deficiencies or alleviate the effects of certain deficiencies will also be discussed.

Methods of inspecting the foundation, abutments, and reservoir rim are presented, along with methods of identifying deficiencies or conditions that might threaten the integrity and safety of a dam.

OBJECTIVES

At the completion of this module, you will be able to:

- Describe the properties of soil and rock that are most likely to affect strength and permeability in a foundation or abutment.
- Identify earth materials in terms of their suitability to support a particular type of dam.
- Identify the different types of treatments to control seepage through, and strengthen, the foundation or abutments of both concrete and embankment dams.
- Identify the types of earth materials that compose the reservoir rim, and describe the methods employed to control seepage and treat instability in the rim.
- Review information and gather the appropriate equipment to adequately conduct an inspection of the foundation, abutments, and reservoir rim.
- Select a method of inspecting the foundation and abutments of embankment or concrete dams that will provide the most accurate and complete coverage.
- Identify and inspect deficiencies in the foundation and abutments that either . . .
    - Directly affect the safety and integrity of the dam, or
    - May lead to more serious problems that will affect the safety and integrity of the dam.
- Evaluate the deficiency in the foundation and/or abutment and make a recommendation to either correct the deficiency or alleviate its effects.
- Explain the importance of including the reservoir rim in a dam safety inspection.

MODULE INTRODUCTION

OBJECTIVES (Continued)

- Select an appropriate method for inspecting the rim of a small, medium, and large reservoir.
- Identify and inspect deficiencies in the reservoir rim that either . . .
  - Directly affect the safety and integrity of the dam, or
  - May lead to more serious problems that will affect the safety and integrity of the dam.
- Evaluate the deficiency in the reservoir rim and make a recommendation to either correct the deficiency or alleviate its effects.
- Properly record your findings so that an accurate and useful record exists for future reference.

HOW TO USE THIS MODULE

This module is designed to be used in conjunction with other Training Aids for Dam Safety (TADS) modules. The TADS Learner's Guide lists all of the TADS modules and presents a recommended sequence for completing the modules. You may want to review the Learner's Guide before completing this module.

CONTENTS OF THIS MODULE

This module is divided into three units, followed by two appendixes:

- **Unit I. Geologic Considerations:** Presents information on the geologic areas covered in a dam safety inspection, divides earth materials into two basic categories, and discusses the different types of dams, the earth materials each dam is typically constructed on, and how the earth materials are treated to control seepage and improve their strength.
- **Unit II. Inspecting The Foundation And Abutments:** Describes techniques for inspecting the foundation and abutments of a dam, the types of deficiencies generally found in the foundation and abutments, and what should be done when these deficiencies are discovered.
- **Unit III. Inspecting The Reservoir Rim:** Discusses techniques for inspecting the reservoir rim, the types of deficiencies generally found in the reservoir rim, and what should be done when these deficiencies are discovered.
- **Appendix A. Glossary.** Defined technical terms used in the module.
- **Appendix B. References.** Lists recommended references that can be used to supplement this module.

DESIGN OF THIS MODULE

This module is a self-paced instructional package. You may move through it as slowly or as rapidly as is comfortable for you. You may stop and review the material at any time. Since the module is designed for independent study, you may take breaks whenever you wish.

There are several components of this module that are designed to help you master the material being presented. These components include:

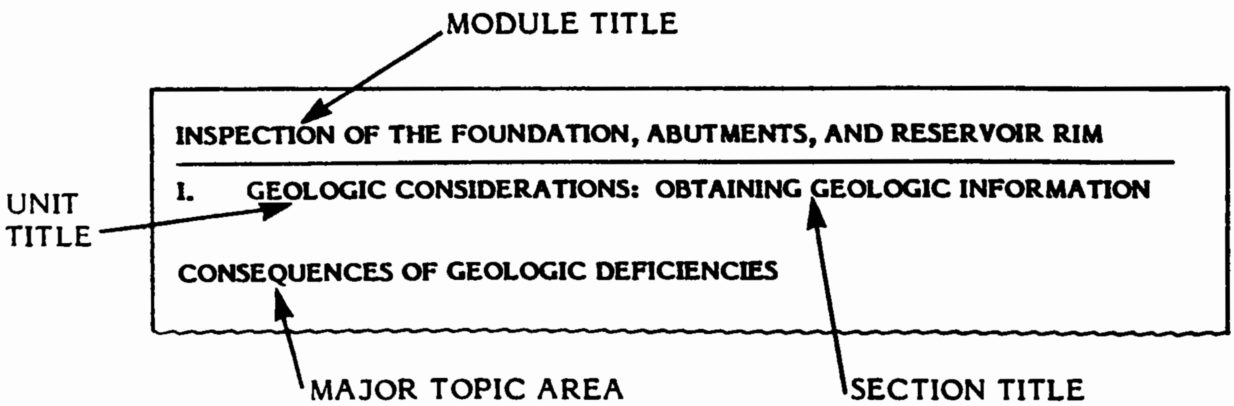
- Text Instruction
- Unit Exercises
- Final Review Exercise

We will now look at how you will use each component individually.

Text Instruction

The text instruction is presented in this workbook. Always begin by reading the text instruction because it explains how to proceed through a given block of instruction.

As you read the text instruction, you will notice that every page has a header. The header is designed to let you know where you are in the module. Let's look at how information is presented in the header.



Unit Exercises

Most units include exercises to help you determine how well you are mastering the information presented. These exercises are **not** tests and will not be used to grade you or to rate your performance. Rather, the exercises are tools to help you assess your own learning.

Instructions for completing the exercises appear at the beginning of every exercise. Answers to the exercises are presented immediately following each exercise.

MODULE INTRODUCTION

Final Review Exercise

After reading the text instruction, you will complete a final review exercise. The final review exercise is designed to help you determine how much you have learned from the module. The final review exercise will not be used to grade you or to judge your performance.

Instructions for completing the final review exercise are presented at the beginning of the exercise. After completing the final review exercise, check your answers against those presented in the answer key. The answer key is located immediately after the final review exercise.

If you miss several of the questions, you may want to review the page numbers or video segments referenced in the answer key. If you get most of the questions correct, you are ready to begin another module.

Video Presentations

This module is not accompanied by a video presentation. However, the modules entitled Inspection Of Embankment Dams and Inspection Of Concrete And Masonry Dams are accompanied by video presentations that demonstrate the inspection procedures and techniques required to inspect the foundation, abutments, and reservoir rim of an embankment or concrete dam.

REQUIRED MATERIALS

To complete this module, you will need this workbook and a pencil or pen. If you wish to view the video presentations for Inspection Of Embankment Dams or Inspection Of Concrete And Masonry Dams, you will also need a videotape player.

You may want to find a quiet place to work while you study these materials.

UNIT I

GEOLOGIC CONSIDERATIONS

INSPECTION OF THE FOUNDATION, ABUTMENTS, AND RESERVOIR RIM

I. GEOLOGIC CONSIDERATIONS: OVERVIEW

INTRODUCTION

This unit describes the geologic characteristics of areas inspected during a dam safety inspection, as well as reasons for obtaining geologic information, sources of geologic information, and the role geology plays in the design of a dam and reservoir.

Because soil and rock classification can be very detailed, and the properties of soil and rock vary from site to site, distinct definitions for every type of soil and rock cannot be presented in this module. For the purposes of inspecting the foundation, abutments, and reservoir rim, an inspector need only have a general knowledge of earth materials. Therefore, in this module, earth materials are divided into two basic types:

- Unconsolidated Materials (Soil)
  - Gravel
  - Sand
  - Silt
  - Clay
  - Organic Matter (Peat)
- Consolidated Materials (Rock)

Different types of embankment and concrete dams, the types of earth materials upon which they are typically constructed, and the treatments the earth materials receive to help control seepage and strengthen the foundation and abutment areas are also described. Lastly, the geologic conditions that may exist in the reservoir rim, and the various treatments used to control seepage or strengthen areas of potential slides are presented.

UNIT OBJECTIVES

After completing this unit, you will be able to . . .

- Describe the properties of soil and rock that are most likely to affect strength and permeability in a foundation or abutment.
- Identify earth materials in terms of their suitability to support a particular type of dam.
- Identify the different types of treatments to control seepage through, and strengthen, the foundation or abutments of both concrete and embankment dams.
- Identify the types of earth materials that compose the reservoir rim, and describe the methods employed to control seepage and treat instability in the rim.
- Review information and gather the appropriate equipment to adequately conduct an inspection of the foundation, abutments, and reservoir rim.

I. GEOLOGIC CONSIDERATIONS: IMPORTANCE OF GEOLOGY IN DAM DESIGN

INTRODUCTION

Inspecting a dam is much more than checking the physical features of the dam itself. The foundation, abutments, and reservoir rim play an important role in the integrity and safety of the dam because they provide support for the dam, and contain the water in the reservoir area. In many instances, the cause of dam failure has not been with the structure itself, but with the geologic conditions in the foundation and abutments.

The foundation, abutments, and reservoir rim are defined as follows:

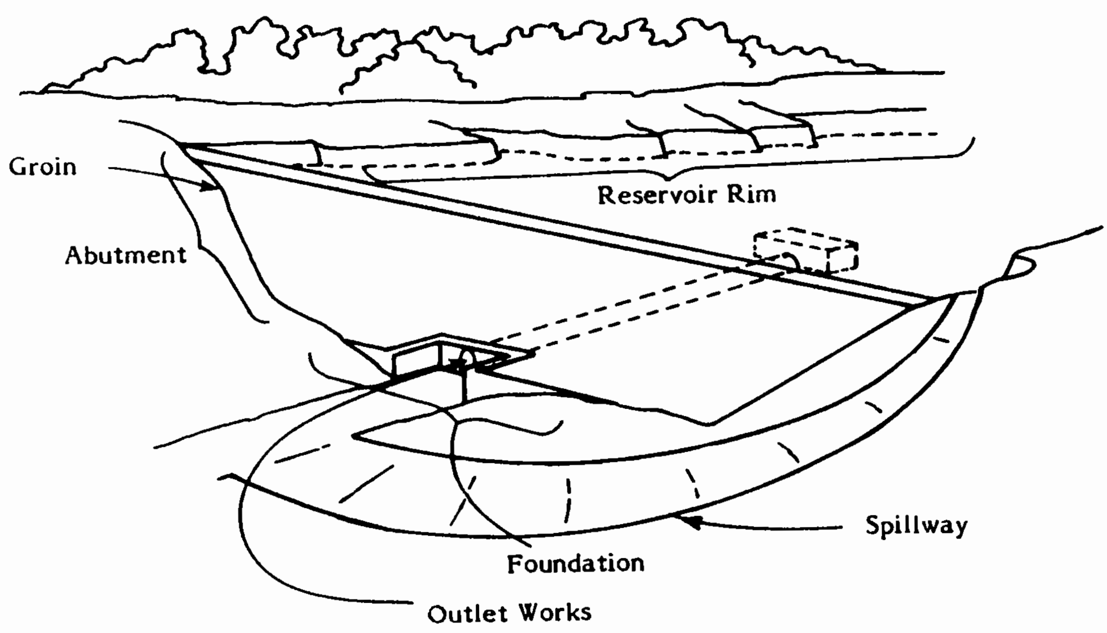
- **Foundation.** The foundation of the dam is the portion of the valley floor that underlies and supports the dam structure. Because the foundation is not actually or directly visible, you must rely on observations of conditions near the foundation to infer foundation performance.

- **Abutments.** The abutments are those portions of the valley sides which underlie and support the dam structure, and are usually also considered to include the valley sides immediately upstream and downstream from the dam.

- **Reservoir Rim.** The reservoir rim is the boundary of the reservoir which includes all areas along the valley sides above and below the water surface.

Figure I-1 illustrates a dam and reservoir, labeling the foundation, abutments, and reservoir rim.

FIGURE I-1. FOUNDATION, ABUTMENTS, AND RESERVOIR RIM



I. GEOLOGIC CONSIDERATIONS: IMPORTANCE OF GEOLOGY IN DAM DESIGN

THE ROLE OF GEOLOGY IN DAM DESIGN

Before a particular type of dam can be selected for a site, certain geologic factors must be taken into account. The topography of a proposed dam site plays a major role in determining the type of dam to be constructed at that site. For example, a narrow stream channel between high, rocky walls might suggest the construction of a concrete arch dam with an overflow spillway. The low, rolling plains country might suggest an earthfill dam with a side channel spillway. The location of the spillway is an item that is governed very largely by the local topography and geology, and generally has a significant impact on the final selection of the type of dam.

Another factor that determines the design of a dam is the earth materials found at the site. Site investigations may reveal that materials suitable for constructing a particular type of dam are available at the proposed site. For example, there might be suitable soils for constructing embankments; rock for embankments and riprap; or sand, gravel, or crushable stone that could serve as concrete aggregate. In addition, the loads and stresses imposed by a dam and by the water on the foundation and abutments, as well as the compressibility and strength of the foundation and abutment materials, will influence the type of dam to be constructed.

HOW GEOLOGIC CONDITIONS IMPACT DAM SAFETY

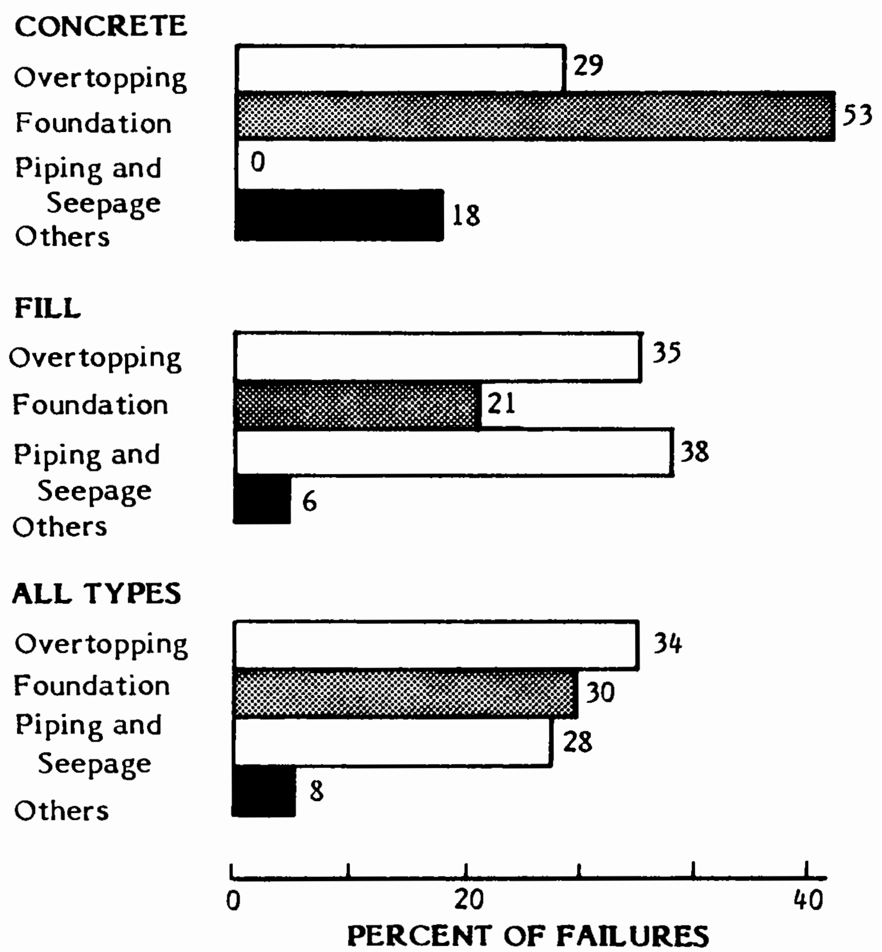
Figure I-2 on the following page shows that geologic conditions affecting foundations and seepage accounted for a large percentage of dam failures from 1900 to 1975. It is possible that even some of the instances of overtopping were ultimately caused by a geologic condition, such as a large mass of material sliding into the reservoir, blocking outlets, or causing large waves to overtop the dam.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: IMPORTANCE OF GEOLOGY IN DAM DESIGN

HOW GEOLOGIC CONDITIONS IMPACT DAM SAFETY (Continued)

FIGURE I-2. CAUSES OF DAM FAILURES FROM 1900 TO 1975



(Excluding failures during construction and acts of war)

I. GEOLOGIC CONSIDERATIONS: IMPORTANCE OF GEOLOGY IN DAM DESIGN

CONSEQUENCES OF GEOLOGIC DEFICIENCIES

The following case histories illustrate the need to identify geologic conditions that may jeopardize the integrity and safety of a dam structure. Only the highlights of the situations are presented. If you wish to learn more about these dam failures, as well as other failures, refer to the Bureau of Reclamation publication entitled Dams and Public Safety.

Baldwin Hills Dam, California

The 12-year-old Baldwin Hills Dam failed in 1963 following displacement of the foundation. Although the activity which precipitated the collapse was not attributed to earthquake, movement was concentrated at faults that were planes of foundation weakness. As a consequence, the reservoir's lining and underdrains were ruptured, and water under pressure entered the pervious and highly erodible soft sandstones and siltstones in the foundation. Destruction was rapid once the uncontrolled leakage began. This flood took 5 lives, destroyed 41 homes, and damaged 986 others.

Teton Dam, Idaho

On June 5, 1976, Teton Dam in Idaho failed, causing 11 deaths and 400 million dollars in property damage. A study to determine the cause of the failure attributed the failure to internal erosion (piping) of the core of the dam deep in the right foundation key trench. Eroded soil particles found exits through the inadequately-sealed, highly-pervious abutment rock to points at the right downstream groin of the dam. The foundation conditions and the characteristics of the soil used for filling the key trench were not adequately addressed in the design of the dam.

St. Francis Dam, California

On March 12, 1928, St. Francis Dam in California collapsed upon first filling, causing the deaths of approximately 450 people. St. Francis Dam was a concrete gravity-arch type dam. Failure of the dam was attributed to loss of strength in the foundation rock caused by seepage.

Vaiont Dam, Italy

One of the most damaging reservoir disasters of all time occurred on October 9, 1963, at Vaiont Dam in Italy. During the night, a rock mass measuring about 1.2 miles in length slid into the reservoir. The impact of the great mass raised gigantic waves which overtopped the structure by some 300 feet. The dam itself sustained no major damage, even though it was hit by a total force of about 4 million tons from the slide and overtopping pressures. This disaster took over 2,000 lives.

I. GEOLOGIC CONSIDERATIONS: OBTAINING GEOLOGIC INFORMATION

INTRODUCTION

Earth materials behave in different ways, depending upon the conditions to which they are subjected. Some of the conditions imposed upon earth materials by a dam and reservoir are . . .

- Loading
- Unloading
- Saturation
- Drying

Understanding how soil and rock will behave under these conditions will enable you to look for certain types of deficiencies. Also, knowing how soil and rock will perform may also affect the type of recommendation you make when certain deficiencies are found. For example, if you encounter turbid or cloudy seepage in an area of fine, sandy material, you should suspect that piping is taking place, and recommend that immediate actions be taken to confirm that piping is occurring, and to correct the situation before failure occurs. However, if the seepage is relatively clear and is emerging through rock, you may simply recommend that the area be monitored for increased flow.

Before inspecting the foundation, abutments, and reservoir rim, you should review information on . . .

- Surface and subsurface conditions at the site, including the soil or rock type(s)

- Seismic activity and fault zones at the site

- Conditions at or near the site that may cause subsidence

SOURCES OF GEOLOGIC INFORMATION

In many instances, before a dam is designed, investigations of the earth materials at the proposed site are conducted. Tests are performed on these materials to determine their permeability and their behavior under the loads and stresses that will be imposed upon them by a dam and reservoir. The types of materials found at the site, and the results of the tests performed on them, are recorded.

If an initial or formal dam safety inspection has already been conducted, there should be a Dam Safety File for that structure, and the records of the site investigation may be found within the file. If these records are not in the Dam Safety File, you may be able to get information on the site investigation from the owner of the dam, or from the designer or constructor of the dam.

If the records of a site investigation are not available, or a site investigation was not conducted, other sources of geologic information must be explored. Table I-1 lists other sources from which you might obtain information on the geology of a particular site.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: OBTAINING GEOLOGIC INFORMATION

SOURCES OF GEOLOGIC INFORMATION (Continued)

TABLE I-1. SOURCES OF GEOLOGIC INFORMATION

Documented Sources	Organizational Sources	Other Sources
. State Geologic Maps	. State and U.S. Geological Surveys	. People Who Live Near the Dam
. County Geologic Maps	. State Dam Safety Agency	. The Dam Owner or Operator
. Soil Survey Maps	. Local or County Extension Services	. Local or University Libraries
. Special Studies	. Department of the Interior	. Contractor
. Underground Mine Maps	. Soil Conservation Service	
. Maps Depicting Seismic and Fault Zones		

I. GEOLOGIC CONSIDERATIONS: REVIEWING GEOLOGIC INFORMATION

INTRODUCTION

There are many different classifications and descriptions for soil and rock. Rarely is any one single type of earth material present at a site. Most dam sites are comprised of many different materials that exhibit different engineering properties.

This section will not describe each and every classification of soil and rock. Such a description would require a more indepth approach to the detailed subject of geology than this inspection module warrants. Only a general knowledge of soil and rock is required to adequately perform a dam safety inspection. Therefore, only those characteristics of earth materials that are directly affected by the conditions imposed upon them by a dam and reservoir will be described.

Earth materials will be divided into two basic categories:

- Unconsolidated Materials (Soil)

- Consolidated Materials (Rock)

UNCONSOLIDATED MATERIALS (SOIL)

Unconsolidated materials may be defined as loosely arranged or uncemented particles, more commonly refered to as soil.

There are three basic divisions of soil:

- Coarse-grained,
- Fine-grained, and
- Highly organic.

Coarse-Grained Soils

The distinction between coarse-grained and fine-grained soils is based on the gradation (or grain-size distribution). A coarse-grained soil is a soil where a majority of the particles are coarse grains. The division between fine-grained particles and coarse-grained particles is the No. 200 sieve. All soil particles retained on a No. 200 sieve are coarse-grained. All soil particles that pass through a No. 200 sieve are fine-grained.

The coarse-grained particles are further divided into gravel-size particles and sand-size particles.

- Gravel. Soil particles ranging in size from 1/4-inch to 3-inches (or particles that pass a 3-inch sieve and are retained on a No. 4 sieve).

- Sand. Soil particles ranging in size from 0.074mm to 1/4-inch (or particles that pass a No. 4 sieve and are retained on a No. 200 sieve).

I. GEOLOGIC CONSIDERATIONS: REVIEWING GEOLOGIC INFORMATION

Fine-Grained Soils

As previously stated, all soil particles that pass a No. 200 sieve are fine-grained. Fine-grained soils consist of clays and silts. Clays and silts are both fine-grained particles (0.074mm or smaller). They are distinguished from each other by their **physical behavior.**

- Clay. Fine soil particles that exhibit plasticity (putty-like properties) within a range of moisture contents, and that exhibit considerable strength when air-dried.
- Silt. Fine soil particles that are nonplastic or very slightly plastic, and exhibit little or no strength when air-dried.

Highly Organic Soils

Highly organic soils are composed primarily of vegetable tissue in various stages of decomposition. These soils are identified by color, odor, a spongy feel, and frequently by a fibrous texture.

The highly organic soils are generally classified as **peat.** However, this classification is based on visual observation rather than laboratory tests. Also, there are no criteria for distinguishing between peat and organic soils.

If the material is primarily vegetable matter, it should be classified as peat. If the material does not contain fibers and appears to be primarily mineral but has organic characteristics (dark color, odor, spongy feel), it should be suspected of being an organic soil.

The descriptions of unconsolidated material presented above are only very basic. If you wish to obtain further information on the classification of soils, refer to the Unified Soil Classification System in Laboratory Classification Of Soils, Training Manual No. 4, published by the Bureau of Reclamation, or to any soil mechanics textbook.

Engineering Properties Of Unconsolidated Materials

Basic descriptions of engineering properties of the five categories of unconsolidated materials appear below. However, when these materials are mixed, the engineering properties will change, depending upon the composition of mixture.

- **Gravel.** Well-graded, compacted gravels are stable materials. When devoid of fines, gravel is pervious, easy to compact, and little affected by moisture or frost action.
- **Sand.** Sand, like gravel, is also a stable material when well-graded and compacted. However, sand is less pervious and not as stable as gravel. As sand becomes finer and more uniform, it approaches the characteristics of silt, with a corresponding decrease in permeability and reduction in stability in the presence of water.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: REVIEWING GEOLOGIC INFORMATION

Engineering Properties Of Unconsolidated Materials (Continued)

- **Clay.** Clays are plastic "fines." They have low resistance to deformation when wet, but they dry to hard, cohesive masses. Clays are virtually impervious, difficult to compact when wet, and difficult to drain. Large expansion and contraction with changes in water content are characteristic of clays.

- **Silt.** Silts are slightly plastic or nonplastic fines. They are inherently unstable in the presence of water, and have a tendency to liquify when saturated and subjected to shaking (earthquake), assuming the character of a viscous fluid. Silts are fairly impervious, difficult to compact (although easier than clays), and highly susceptible to frost heaving.

  Many of the fine soils, including silt, shrink on drying and expand on wetting, which may adversely affect structures built upon them.

- **Organic Matter.** Organic matter in the form of partly decomposed vegetation is the primary constituent of peaty soils. Organic soils are dark grey or black in color, and usually have a characteristic odor of decay. The tendency for soils high in organic content to create voids by decay or to change the physical character of a soil mass through chemical alteration makes them undesirable for engineering use.

Characteristics Of Unconsolidated Materials

Usually, unconsolidated materials found at a site are a mixture of gravel, sand, silt, clay, and/or peat. When a site exploration is performed, tests of the soils are made to determine, among other things . . .

- Gradation
- Permeability
- Shear strength and load-bearing capacity

Because earth materials differ from site to site, you must rely on geologic studies of the area to determine the basic composition of foundation and abutment materials. Unconsolidated materials have certain characteristics that can present structural problems in the foundation or abutments. These characteristics include their susceptibility to . . .

- Piping
- Sliding
- Liquefaction
- Subsidence
- Settlement

I. GEOLOGIC CONSIDERATIONS: REVIEWING GEOLOGIC INFORMATION

Piping

Unconsolidated materials are susceptible to internal erosion by reservoir seepage. This erosion, called piping, can ultimately lead to failure of the foundation or abutments, and hence the dam, if left uncorrected. While gravels may not pipe, they generally contain a certain amount of "fines" (sand, silt) that may be washed through. When the fines are removed, voids are created and the gravel may become unstable.

Sliding

Unconsolidated materials may be susceptible to sliding, depending on depth to bedrock, steepness of the slope on which they rest, the shear strength of the material, and ground water conditions.

Liquefaction

Liquefaction may occur in saturated foundations and embankments comprised of loosely compacted, nonplastic soils such as sands and silts. When subjected to earthquake shaking, these materials may become "quick" and may "flow," resulting in deformation or failure of the dam.

Subsidence

In regions of aeolian (wind-laid) deposits or mudflows, subsidence may be a concern when the material becomes saturated. Subsidence may also be caused by the extraction of ground water or oil, or by certain types of mining activities. The appearance of cracks or large depressions may indicate the occurrence of subsidence.

Settlement

Foundation settlement may occur when relatively loose foundation soil is loaded by the weight of the overlying embankment. Differential foundation settlement may occur when a foundation comprised of materials with substantially different settlement characteristics, such as soil and rock, is loaded by the weight of the dam. The soil will settle while the rock generally will not.

CONSOLIDATED MATERIALS (ROCK)

Consolidated materials, or rock, are classified as . . .

- An aggregate of one or more minerals (e.g, granite, shale, marble), or
- A mass of minerals undetectable individually by the unaided eye (e.g., obsidian), or
- A mass of solid organic material (e.g., coal).

Continued . . .

CONSOLIDATED MATERIALS (ROCK) (Continued)

There are three basic classifications for all rock:

- **Sedimentary Rock**--Rock formed from the consolidation of loose sediment or organic material. Sedimentary rocks are generally less competent than other rock types, and tend to weather more rapidly.

  The most common sedimentary rocks are:

  - Shale
  - Sandstone
  - Limestone (Dolomite)

- **Metamorphic Rock**--Any rock derived from pre-existing rocks by reason of mineralogical chemical and structural changes. These structural changes are in response to marked changes in temperature, pressure, shearing stress, and chemical environment at depth in the earth. Metamorphic rocks are generally more competent than sedimentary rocks and do not weather as rapidly. They are layered, and not uniform in strength.

  The most common metamorphic rocks are:

  - Slate
  - Schists
  - Gneiss

- **Igneous Rock**--Rock that has solidified from molten or partly molten material. Igneous rocks range from plutonic (formed at depth) to extrusive (ejected onto the earth's surface). Igneous rocks are the most isotropic (uniform in all directions), and generally the hardest of the rock types.

  The most common igneous rocks are:

  - Rhyolite
  - Basalt
  - Gabbro
  - Granite

Characteristics Of Consolidated Materials

A number of characteristics are taken into consideration before a rock formation is determined to be suitable to support a dam. These characteristics include . . .

- Hardness and strength
- Discontinuities (openings or fractures)
- Weathering
- Solutioning

I. GEOLOGIC CONSIDERATIONS: REVIEWING GEOLOGIC INFORMATION

Hardness And Strength

The hardness and compressive strength of rock are determined in order to get an idea of how the rock mass will behave under the loads and stresses imposed upon it by a dam and reservoir. Hardness and strength in a particular rock mass are determined by how the rock was originally formed, the composition of the particles forming the rock, and the earth pressures exerted on it during formation. Needless to say, the stronger the rock, the more stable a foundation it provides.

Information on hardness and compressive strength may be available as part of the geologic data found in the Dam Safety File or from other sources.

Discontinuities

Discontinuities or openings in rock may affect a dam in several ways. They . . .

- Provide passages for ground water or reservoir water to seep through.
- Provide unstable foundation and abutment areas if highly fractured, or if fractures run in a direction that allows slippage.

Discontinuities include faults, shears, joints, and foliation (the crystalline formation of rock into leaflike layers). Of all the different types of discontinuities, faults are of greatest concern. Faults are fractures that result from the shearing failure of rock because of the great stresses exerted upon them. The release of these stresses can result in an earthquake. The main effect of a fault is displacement of one or both of the rock masses lying on either side of it. In most small faults, the displacement will not be large. However, great movements along faults can have a profound influence on structures built upon them. Faults can also act as zones along which ground water can move more rapidly than through the surrounding rock mass.

Geologic records from the Dam Safety File or other sources should have information on any faults under or around the dam site. If the dam is located over or very near a fault zone, it may be susceptible to instability during seismic activity.

Weathering

Weathering is the deterioration of rock due to temperature variations, freeze and thaw actions, sun, wind, rain, plant and animal activity, and chemical action. Weathering is the chemical or mechanical alteration of rock that can significantly affect the engineering properties of the rock and rock mass. Weathering effects generally decrease with depth. Weathering can increase the compressibility of rock, decrease shear and compressive strength, decrease resistance to erosion, and increase permeability.

I. GEOLOGIC CONSIDERATIONS: REVIEWING GEOLOGIC INFORMATION

Solutioning

Solutioning is the dissolving of rock by seepage water moving through joints, cracks, or other openings. These openings then become larger, and the seepage flow increases. Eventually, the stability of the rock mass may be jeopardized. Limestone, dolomite, gypsum, and halites are particularly susceptible to solutioning. Solutioning may be detected by surface staining and deposits on the outside of rock, or by water quality testing.

SUMMARY

This section briefly described the characteristics of soil and rock that are taken into consideration when determining their suitability for the foundation, abutments, and reservoir rim. These characteristics must be considered before a dam is designed and constructed.

Now, let's look at the basic types of dams you will be inspecting in relation to the topography and geology deemed suitable for each type of dam. Even though specific earth materials and topographic sites may be termed suitable for a particular type of dam, you may encounter situations where a dam was built upon material other than that which would appear to be suitable. If you are inspecting a dam that was built upon material you feel may not be suitable, you should . . .

- ✓ Carefully review the geologic records and construction records in the Dam Safety File to determine why that site was selected, and why that particular type of dam was constructed on that site.

- ✓ Check the construction records to determine if the foundation and abutment materials were treated to . . .

  - Improve their strength and bearing capacity

  - Control seepage and prevent piping (permeability)

  - Improve the earth materials in any way that will make them more suitable as a foundation or abutment.

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

INTRODUCTION

Embankment dams are defined as those constructed primarily of the natural materials of the earth, namely soil and rock. Generally speaking, embankment dams have certain advantages over concrete dams with regard to site topography and economy.

- **Topography Of The Site:** Because embankment dams are more flexible and can tolerate some settlement, they can be built on soil foundations. The rock foundation and abutments required to support the loads of a concrete dam are not necessary. Thus, embankment dams can be built at many sites where concrete dams could not be constructed, and embankment dams are likely to be well suited to an open-country location.

- **Economy:** Embankment dams are built from materials excavated at or near the dam site, usually with only minimal processing. This type of construction is often considerably less costly than construction involving the production and placement of mass concrete.

The principal disadvantage of an embankment dam is that it will be damaged or may even be destroyed by water erosion if insufficient height or spillway capacity allows overtopping. This section describes . . .

- The different types of embankment dams,

- The types of earth materials upon which embankment dams are typically constructed, and

- The different treatments used to control seepage through, and strengthen, foundation and abutment materials.

TYPES OF EMBANKMENT DAMS

There are two major categories of embankment dams: earthfill and rockfill. Although several different definitions of earthfill and rockfill dams are used by various authors and organizations, the most commonly used definitions are the following:

- **Earthfill Dam:** A dam containing more than 50 percent, by volume, earthfill materials (fill composed of soil and rock materials that are predominantly gravel sizes or smaller).

- **Rockfill Dam:** A dam containing more than 50 percent rockfill materials (predominantly cobble sizes or larger).

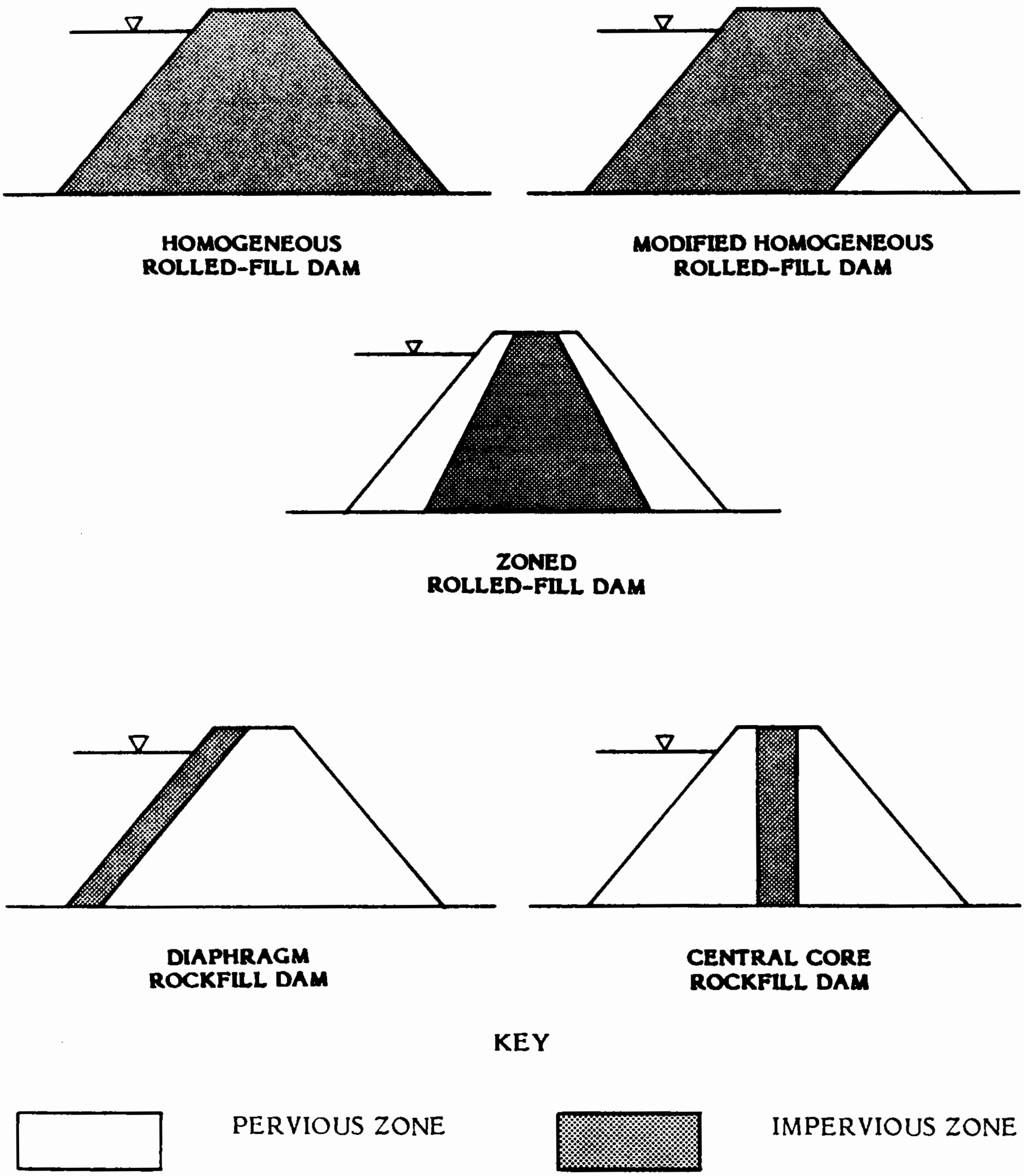
The two main types of embankment dams can be subdivided further, based on the configuration of materials or construction methods. Figure I-3 on the following page shows the common types of earthfill and rockfill dams.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

TYPES OF EMBANKMENT DAMS (Continued)

FIGURE I-3. TYPES OF EMBANKMENT DAMS



I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Earthfill Dams

Some older earthfill dams, known as hydraulic-fill dams, were constructed by using water for transporting embankment material to its final position in the dam. In this method of construction, the material is discharged from pipes along the outside edges of the fill. Coarser material is deposited soon after discharge, while the fines are carried into the central portion of the fill. The result is a zoned embankment with a relatively impermeable core.

Several significant problems are inherent to this type of construction. Since the fill is saturated when placed, high pore pressures develop in the core, and the embankment may be susceptible to instability under these pressures. Because of the slow drainage of water from the core, considerable settlement over a long period of time is expected in a hydraulic-fill dam. Perhaps most significant, but unrecognized at the time most hydraulic-fill dams were built, is that this type of construction leaves a relatively loose soil structure that is subject to liquefaction during an earthquake, and failure of the dam can result.

Hydraulic-fill construction was economical prior to the advent of large earth-moving and compaction equipment. The advent of this equipment made practical the construction of modern rolled-fill embankments. In a rolled-fill dam, materials from borrow pits and suitable materials from excavations for other structures are delivered to the embankment and spread in layers, and each layer is thoroughly compacted and bonded with the preceding layer by power-operated rollers. Rolled-fill dams are of two basic types: homogeneous and zoned.

Rockfill Dams

Rockfill dams have two basic structural components--an impervious membrane and a rockfill zone that supports the membrane. Rockfill dams may be classified based on the characteristics of the membrane into two basic types: diaphragm and central core.

FOUNDATION AND ABUTMENT MATERIALS

There is no standard embankment dam design that is generally suitable for any given type of site. Embankment dams should be designed and constructed specifically for the conditions at a particular site. The selection of dam type most suited to a site depends on careful consideration of several factors, including:

- Site topography, geology, and foundation conditions
- Availability of construction materials
- Requirements for spillway and outlets
- Hydrologic requirements
- Reservoir operations
- River diversion during construction

Continued . . .

FOUNDATION AND ABUTMENT MATERIALS (Continued)

Failure of designers to have addressed one or more of these factors could have implications with regard to the safety of an existing dam. Once all factors have been considered, the cost of construction then usually becomes the deciding factor in determining the type of dam that will be built. Listed below are types of earth materials upon which embankment dams are constructed.

- **Rock**, because of its relatively high bearing capacity and resistance to erosion and seepage, is a suitable foundation for the construction of an embankment dam. Most rockfill dams are founded on rock. However, because of discontinuities in the rock (joints, cracks, fissures, etc.), some treatment, such as grouting or surface sealing, is still required.

- **Gravel**, if in a dense configuration, is also suitable as a foundation for earthfill and rockfill dams. However, gravel foundations frequently are subject to high seepage flow, and special precautions must be taken to provide effective seepage cutoffs or seepage controls and drainage.

- **Silt or fine sand** may be suitable foundations for earthfill dams if treated properly and the dam is designed properly. The potential problems with these materials are liquefaction, settlement, piping, and seepage.

- **Clay** can be used as a foundation for earthfill dams, but may require special treatment. Usually, tests of the material in its natural state are required to determine the consolidation characteristics (settlement) of the material and its ability to support the imposed loads.

FOUNDATION AND ABUTMENT TREATMENTS

Soil and rock can be treated to control seepage and to improve their strength. The methods of treatment may vary, depending on the material being treated and the type of dam to be constructed. The remainder of this section will provide a basic description of the most common treatments used to control seepage and strengthen foundation and abutment materials.

INSPECTION TIP: Even though the foundation and abutment areas of an embankment dam may have been treated, this does not necessarily mean there will not be seepage, settlement, or instability problems in these areas. Various treatments can be affected by time, materials used for the treatments, treatment design, and/or errors made during construction.

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

TREATMENTS TO CONTROL SEEPAGE

The control of seepage through the foundation and abutments is very important. Seepage can lead to piping, as well as rendering soil masses unstable. A number of methods are used to control seepage, including the following:

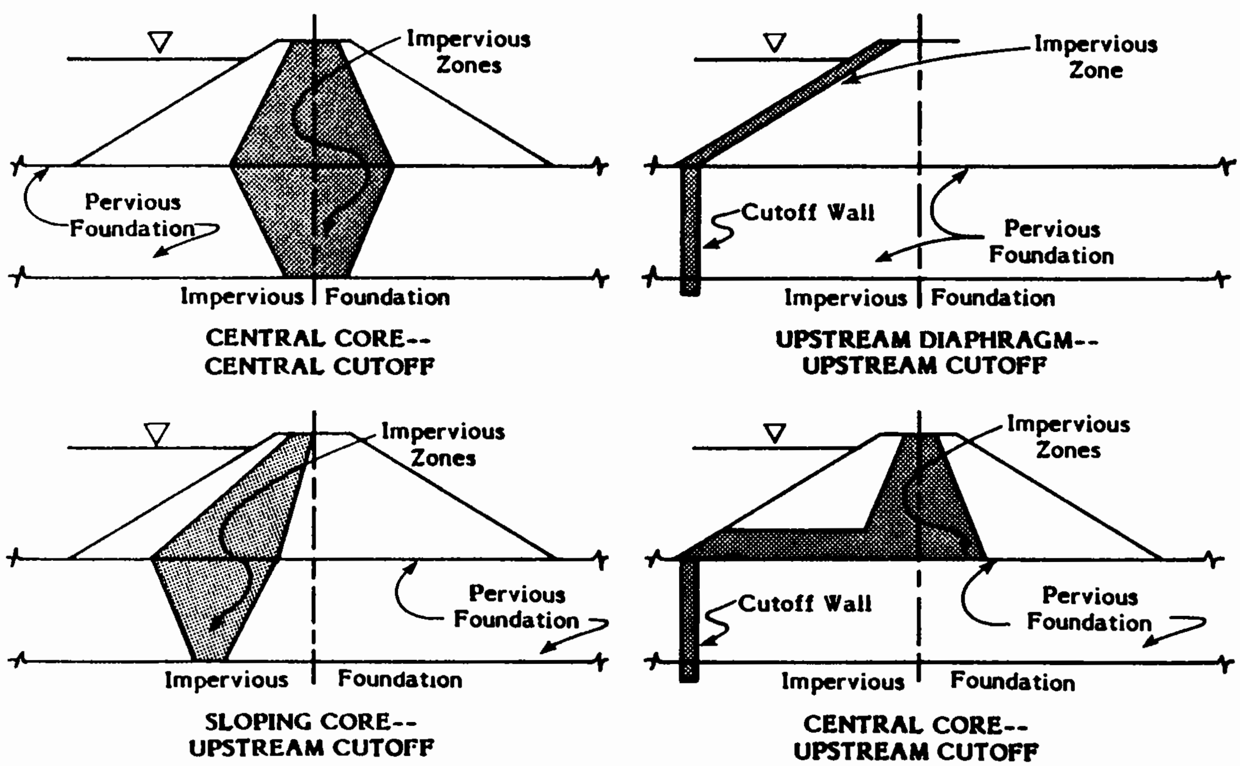
- Cutoffs
- Upstream impervious blankets
- Downstream drains
- Grouting

Cutoffs

Cutoffs are designed to lengthen or cut off the seepage flow path through the foundation and abutments and reduce the amount of seepage to a rate that can be handled by a drainage facility. A cutoff is an extension of the impervious zone of an embankment dam, and is constructed either to impervious soil layers, or to bedrock. The location of the cutoff will depend on how the dam is zoned. The cutoff will usually be located under the impervious zone of the dam (see Figure I-4).

Several different types of cutoffs are described on the following pages.

FIGURE I-4. CUTOFF LOCATIONS

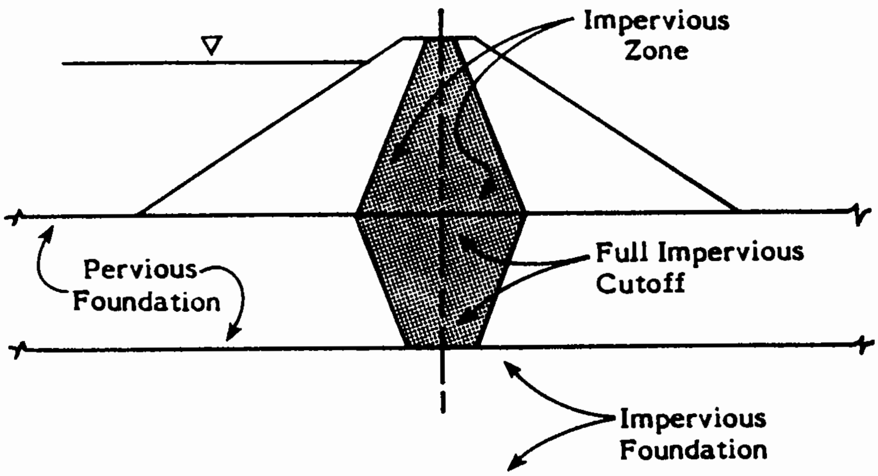


I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Full Cutoffs

If the depth to relatively impervious bedrock is not too great, a full cutoff can be excavated to rock, and backfilled with impervious material. Figure I-5 shows a full cutoff under a central core rockfill embankment dam.

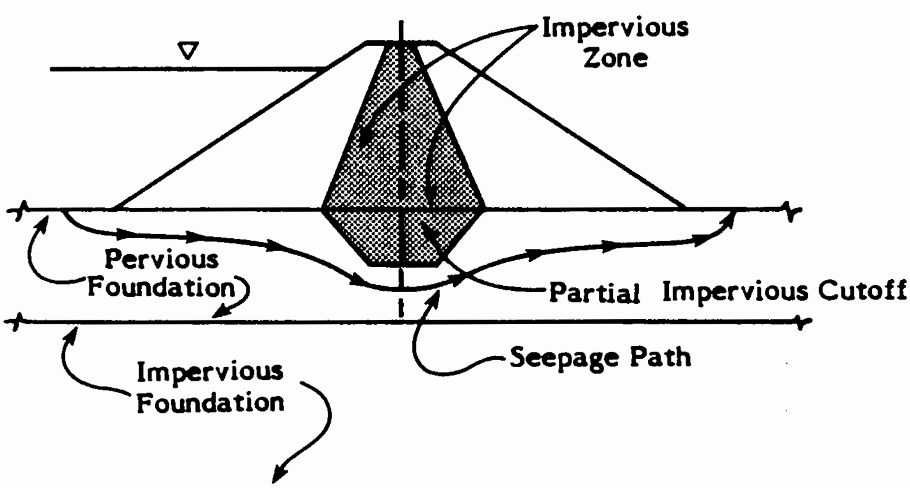
FIGURE I-5. FULL CUTOFF



Partial Cutoffs

At times, a partial cutoff may be excavated. This type of cutoff does not fully extend to the impervious layer or to bedrock. A partial cutoff lengthens the seepage path and thus decreases uplift at the downstream toe, but will not completely cut off seepage. Figure I-6 illustrates a partial cutoff.

FIGURE I-6. PARTIAL CUTOFF



I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Deep Cutoffs

When the depth of excavation is great, or when the control of ground water is difficult, a cutoff can be achieved using slurry trench construction. A trench is excavated through the pervious foundation, and the sides of the trench are supported by a slurry. The trench is then backfilled with an impervious mixture of soil and bentonite slurry or concrete.

Concrete is generally used where the depth of cutoff is very deep. These walls are 2-1/2 to 3 feet thick. The concrete is placed in the trench by tremies, with the discharge end low enough so that discontinuities and segregation in the concrete wall will not occur.

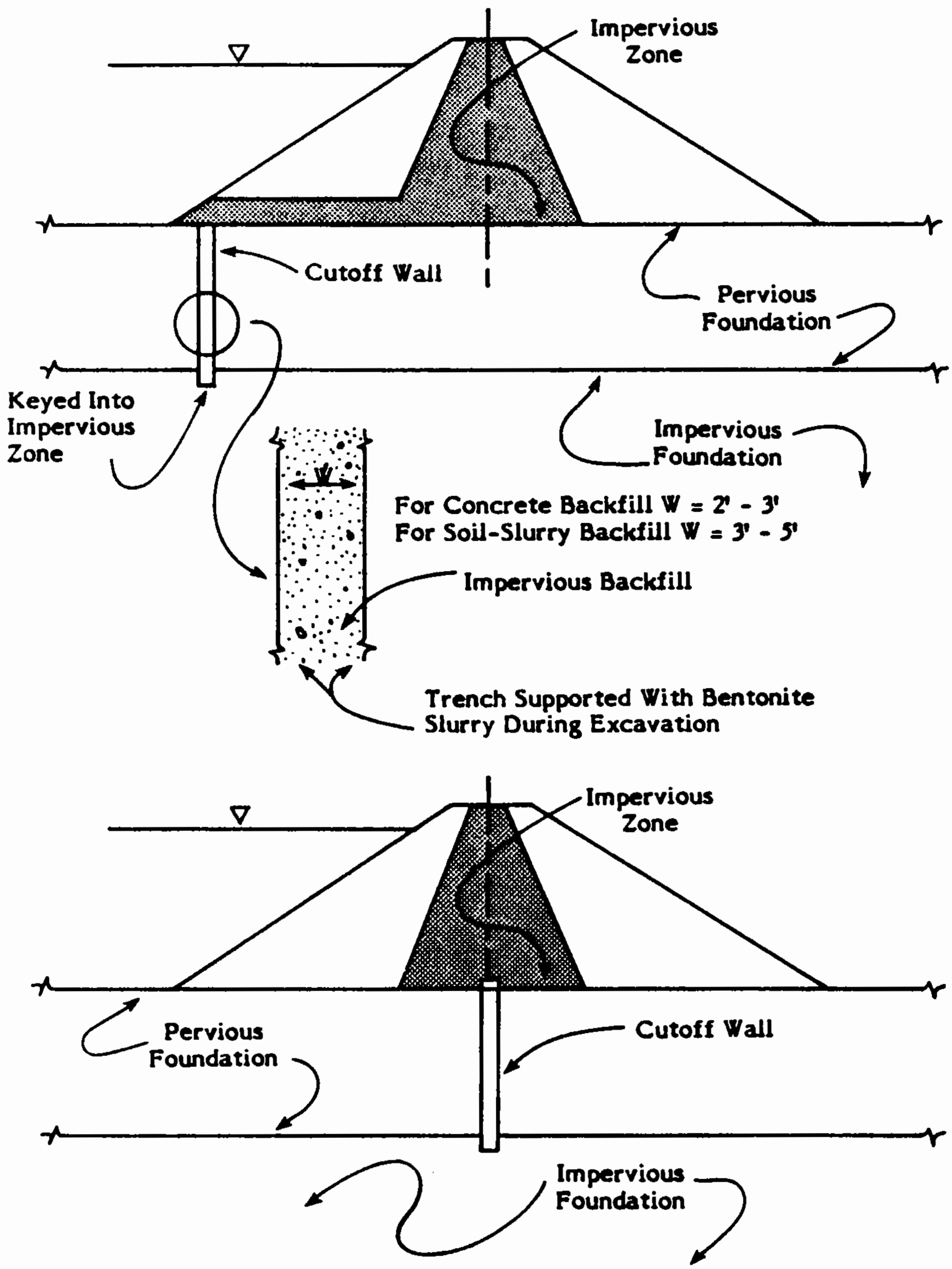
Figure I-7 shows concrete cutoffs in two locations: one cutoff wall located beneath the upstream impervious blanket of a central core rockfill dam, and the other located directly beneath the central core.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Deep Cutoffs (Continued)

FIGURE I-7. CONCRETE CUTOFF WALLS



I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Sheet Pile Cutoffs

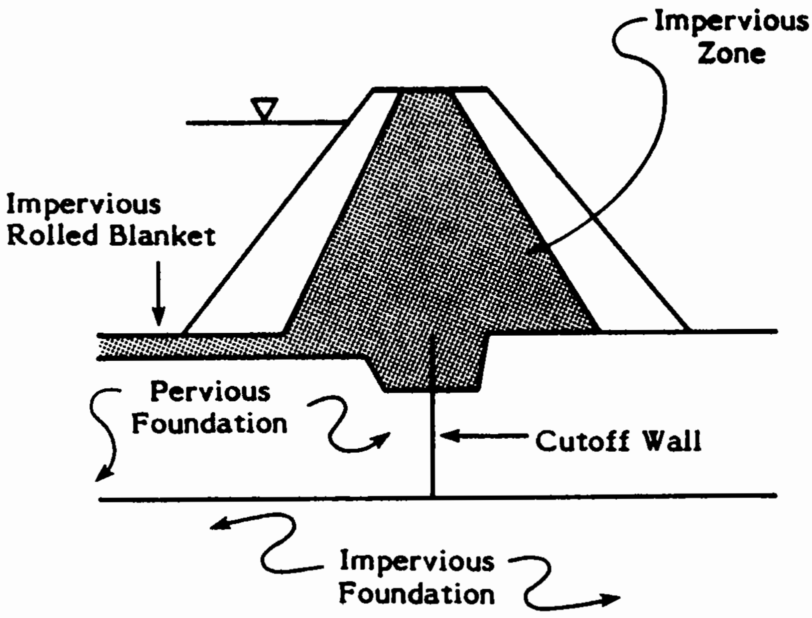
Steel sheet pile cutoffs have been used in the past, but not often in recent years. Seepage can occur through the interlocks, butt splices, and spaces where the sheets are driven out of the interlocks. A minor imperfection in the steel sheet piling can render the cutoff less effective.

Upstream Impervious Blankets

Upstream impervious blankets are used to minimize foundation seepage by connecting a blanket of impervious material upstream of the toe of the dam to lengthen the path of seepage. The blanket is normally tied to the core of the dam. Upstream blankets are commonly used when cutoffs to bedrock or to an impervious layer are not practicable because of excessive depth. These blankets are sometimes used in conjunction with partial cutoff trenches.

Figure I-8 shows the location of the upstream impervious blanket for a hydraulic fill dam. This dam used the blanket in conjunction with a steel sheet pile cutoff extended to an impervious layer.

FIGURE I-8. UPSTREAM IMPERVIOUS BLANKET



Continued . . .

Upstream Impervious Blankets (Continued)

Upstream impervious blankets are generally used for a stream channel or valley floor of sand and gravel, but may also be required for portions of the abutments. These blankets may not reduce the seepage forces in the foundation enough to prevent piping failures. The natural stratification that occurs in almost every earth foundation may allow high pressures to exist in one or more foundation strata at the downstream toe of the dam. It is important that downstream seepage control measures be used with these blankets to collect the seepage that will occur.

Downstream Drains

The use of upstream measures to reduce seepage is usually supplemented with downstream seepage control devices. These devices include . . .

- Downstream drainage blankets
- Pipe drains
- Toe drains
- Relief wells

Downstream Drainage Blankets

Downstream drainage blankets are used in nearly all modern embankment dams. A downstream drainage blanket is designed to collect seepage from both the foundation and the embankment. These drains are generally placed over the downstream foundation and abutments to collect seepage emerging from these areas. Figure I-9 shows the location of a downstream drainage blanket with details for dams with full cutoffs and partial or no cutoffs.

Pipe Drains

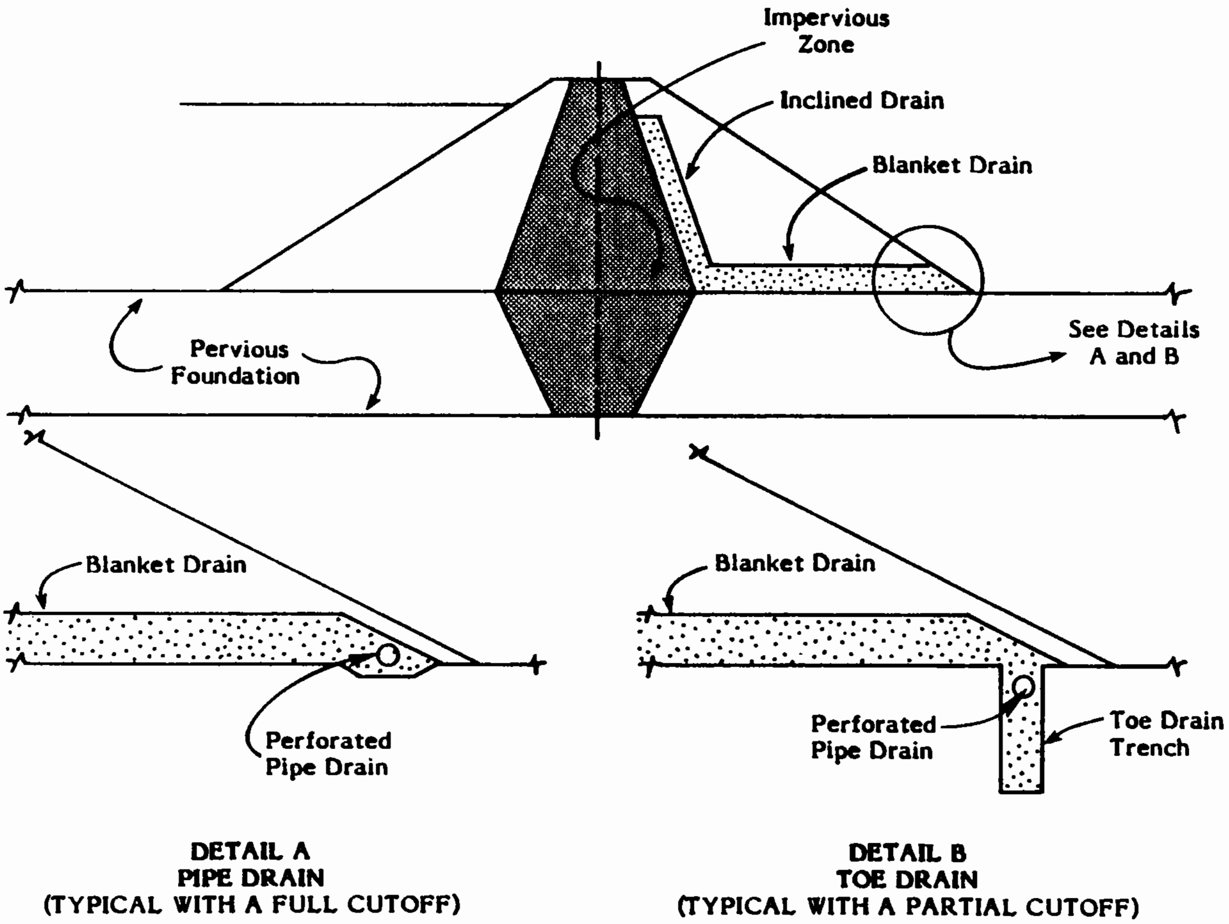
The seepage from drainage blankets should be collected and discharged at low spots. This can be done using pipe drains (see Figure I-9). Pipe drains should not be extended under the earth dam. If broken by the weight of the dam, or corroded, a drain pipe could become an uncontrolled seepage channel. Drain pipes should be readily accessible for repairs and maintenance.

Toe Drains

A toe drain is a trench cut into the foundation and filled with free draining material, and may include a perforated pipe to collect foundation seepage (see Figure I-9). Seepage is then discharged through an outlet to the downstream area.

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

FIGURE I-9. DOWNSTREAM DRAINAGE BLANKET



<u>Relief Wells</u>

Pressure relief wells are designed to help control hydrostatic pressures (uplift pressures) that could lead to piping or instability by collecting seepage and providing for safe, controlled discharge downstream where the dam will be unaffected.

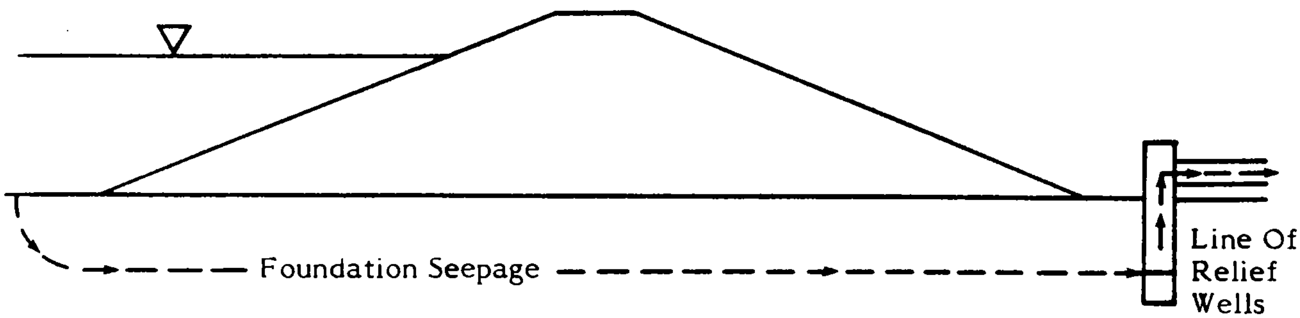
Also, relief wells may aid in controlling the direction and quantity of seepage under the dam. Relief wells may be used in conjunction with other seepage drains. Figure I-10 shows a line of relief wells used to intercept and discharge foundation seepage in a safe manner.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Relief Wells (Continued)

FIGURE I-10. RELIEF WELLS



If there are several wells, they will feed into a collection system, consisting of an open channel or a pipe system. This system is used to collect discharged water from the relief wells and convey this water to a point downstream of the dam. Typically, this water is discharged back into the natural stream.

Grouting

Foundation grouting for embankment dams is performed to minimize . . .

- Seepage beneath or around the dam.
- Hydrostatic pressures (uplift) under the downstream portion of the dam.
- The possibility of piping of embankment materials into the foundation.
- The possibility of piping of embankment materials due to seepage entering the embankment from the foundation.
- The piping of soil from rock joints and seams, and preclude the development of solution cavities.
- Piping at the soil-bedrock interface.

Rockfill zones of embankment dams are usually quite pervious and free draining. If the zone contains coarse-grained material, erosion and piping are generally not of concern. However, fine-grained core material must be protected against displacement by underseepage and through-seepage through the use of filter zones and the grouting and surface treatment of foundation rock.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Grouting (Continued)

There are two types of grouting that are commonly used in and adjacent to the core foundation area, namely, blanket grouting and curtain grouting.

Blanket grouting is performed over a broad area of an excavated foundation when the foundation rock is closely jointed or fractured. This method is used to seal the upper 10 to 30 feet of rock so as to minimize the possibility of piping of fines from the core into the rock crevices, and to seal the near surface rock against loss of grout during the high-pressure curtain grouting that generally follows.

Curtain grouting is performed to reduce deep underseepage through the foundation and abutments.

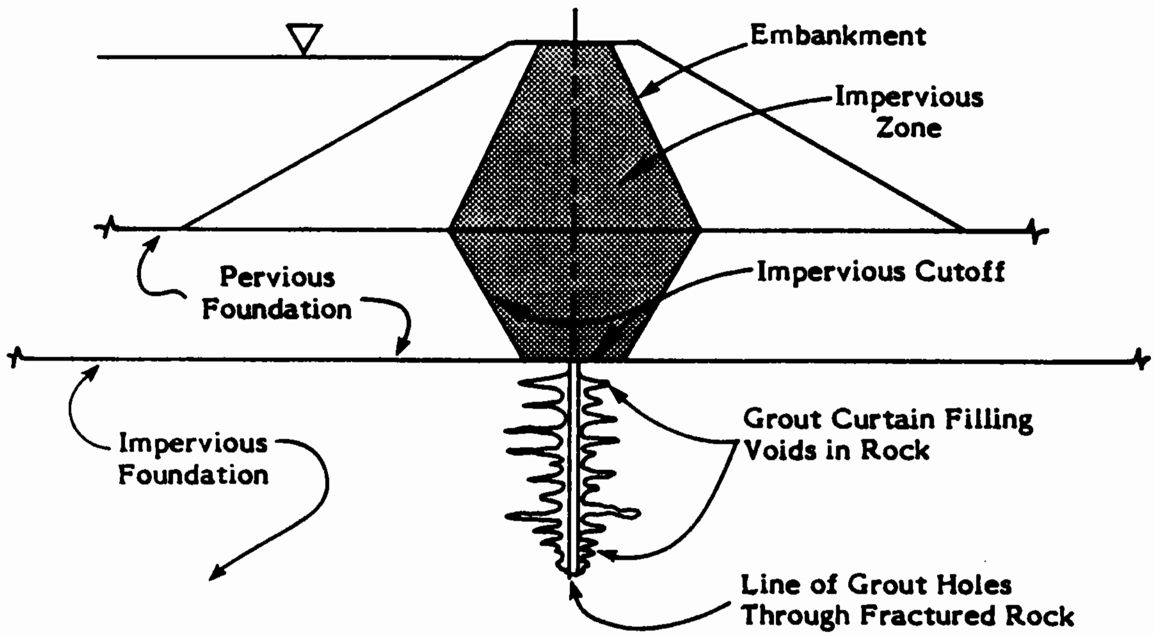
Figure I-11 illustrates how grouting fills voids in a dam foundation, and how a grout curtain is designed to solidify and strengthen a foundation.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Grouting (Continued)

FIGURE I-11. GROUT CURTAIN



PROFILE OF GROUT CURTAIN

NOTE: The holes in a grout curtain are spaced as necessary to fill the voids. Usually spacing is not wider than 20 feet, and may be as close as 2 feet to 5 feet. The above shows a single line curtain; but it could have a double or triple line curtain.

TREATMENTS TO STRENGTHEN FOUNDATION AND ABUTMENT MATERIALS

At times, it is necessary to treat soil and rock so that they will be stronger and withstand the stresses exerted upon them by the dam. The type of treatment depends upon the material to be treated and the type of dam to be constructed. The most common types of treatments include the following:

- Removal of undesirable material
- Stability berms
- Consolidation of soils

I. GEOLOGIC CONSIDERATIONS: TYPES OF EMBANKMENT DAMS

Removal Of Undesirable Material

Undesirable material is removed and replaced with selected, compacted material or, in some cases, concrete. This helps to prevent differential settlement, instability, and/or seepage. Undesirable material can be loose or weak soils or organic materials, or rock that is highly fractured, weathered, or susceptible to solutioning.

Overhangs and sharp changes in the abutment slope are smoothed so that there is not too great a change in the angle of the slope. This smoothing also helps to prevent differential settlement. After smoothing, if needed, the surface is consolidated by grouting.

Stability Berms

Stability berms can be designed to compensate for a weakness in the foundation and/or abutments. Stability berms may be designed to protect weak abutments against the seepage forces caused by a sudden drawdown of the reservoir. In general, these potentially unstable abutments are composed of soil, or of rock that is either badly faulted or has a joint system dipping toward the pool at an unstable angle.

Consolidation Of Soils

Soil foundations can be strengthened in various ways. Clay can be strengthened by preloading, or staged construction, while loose sands and silts can be densified by dynamic compaction, vibroflotation, or other methods.

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

INTRODUCTION

A concrete dam is defined as a dam constructed mainly of cast-in-place or roller-compacted concrete.

Concrete dams are thinner than embankment dams and impose more concentrated loads on the foundation and abutments. A narrow canyon with an adequate rock foundation is a typical site for concrete dams, which require a solid foundation that is relatively free of faults, shears, and major changes in foundation strength.

This section describes . . .

- The different types of concrete dams and the types of earth materials upon which they are typically constructed, and
- The different methods used to control seepage and strengthen the foundation and abutment materials.

TYPES OF CONCRETE DAMS

There are three basic structural types of concrete dams: gravity, buttress, and arch. In addition, gravity or buttress dams are sometimes built as composite dams, with embankment sections flanking the concrete portion of the dam.

Gravity Dams

Gravity dams are the most common type of concrete dam and the simplest to design and build. They are massive and roughly triangular in cross-section, and they depend on their weight and shape to withstand reservoir loads and transfer the loads to the foundation. In gravity dams, uplift pressures are a concern because they can lead to weakening of the foundation and failure of the dam by overturning or sliding. Figure I-12 shows a sectional view of a gravity dam.

Although gravity dams are suitable for use with most canyon widths and shapes, some topographic features favor the use of a gravity-type dam. One of these favorable features is a wide site with a relatively flat canyon floor. The nearly uniform height of the blocks reduces the tendency for twisting transmitted by keyed joints between adjacent blocks.

Many earth materials may be used as a foundation for a concrete gravity dam under 50 feet in height, and with a difference between headwater and tailwater less than 20 feet. However, if a gravity dam has a headwater/tailwater differential of more than 20 feet or is greater than 50 feet in height, sound rock generally is required.

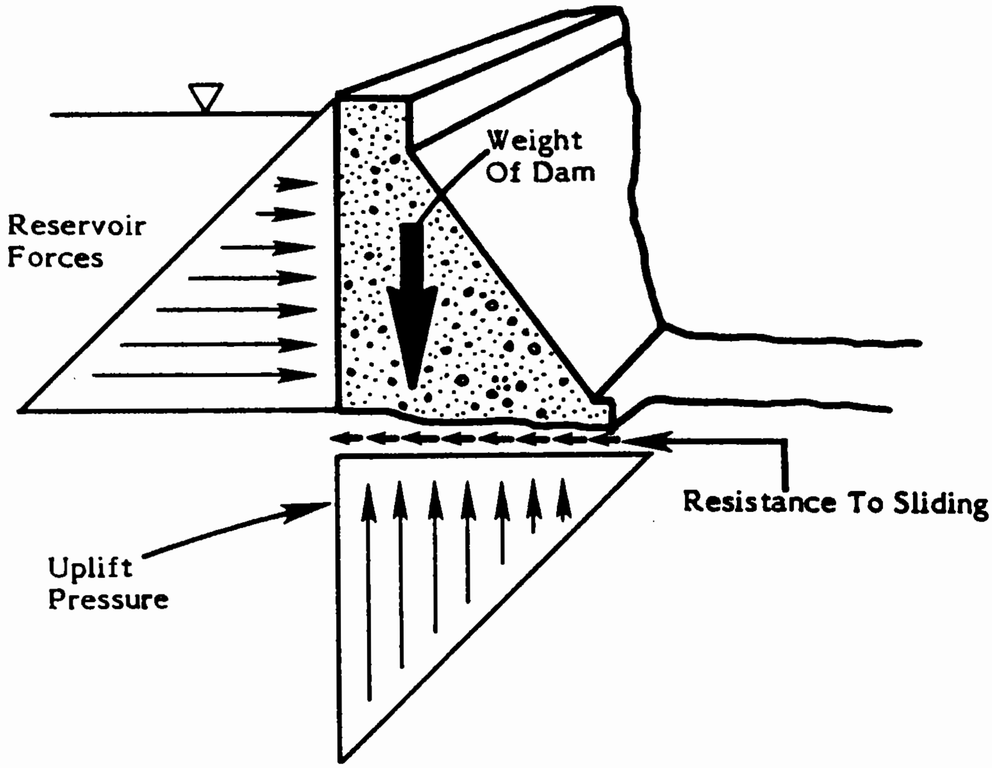
Materials that decompose or deteriorate upon exposure to water or the atmosphere, or creep when loaded, should be seriously questioned as suitable foundation materials for all dams.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

Gravity Dams (Continued)

FIGURE I-12. SECTIONAL VIEW OF A GRAVITY DAM



Buttress Dams

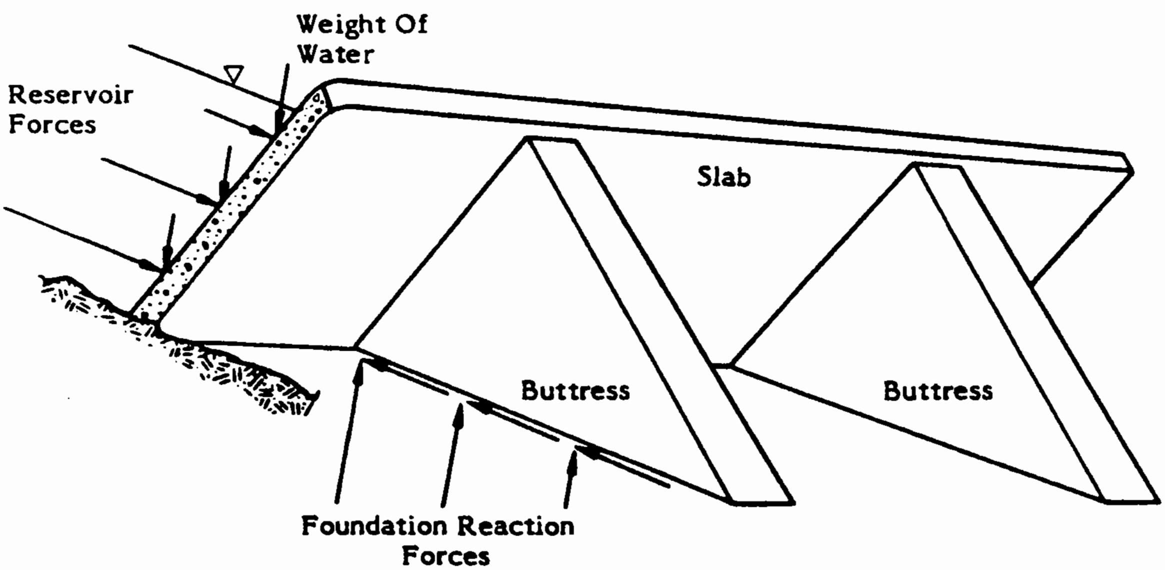
Buttress dams, a form of gravity dam, depend on their own weight and the weight of the water on the face to maintain stability. They are comprised of two basic structural elements: a watertight inclined upstream face and a series of buttresses, or near-vertical walls, that support the face and transfer the load from the face to the foundation.

One type of buttress dam, as shown in a simplified manner in Figure I-13, is the flat-slab buttress dam, in which the upstream flat-slab is of reinforced concrete. Configurations vary, however, and you may encounter buttress dams with arched slabs or other features. The thin slab of buttress dams carries the design loads, and any deficiencies in the slab can lead to instantaneous failure.

Continued . . .

Buttress Dams (Continued)

FIGURE I-13. SIMPLIFIED VIEW OF A FLAT-SLAB BUTTRESS DAM



Buttress dams are suitable for a variety of canyon shapes and widths. The most desirable canyon is one having gently sloping walls. This condition permits a more desirable connection between the canyon wall, and results in more stable buttresses.

Generally, buttress dams should only be constructed on a rock foundation. Low buttress dams can be constructed on poor rock or soil foundations if footing slabs are used to keep bearing pressures within allowable limits. Buttress dams are rarely constructed today because of the great expense of erecting the formwork necessary to construct these dams.

Arch Dams

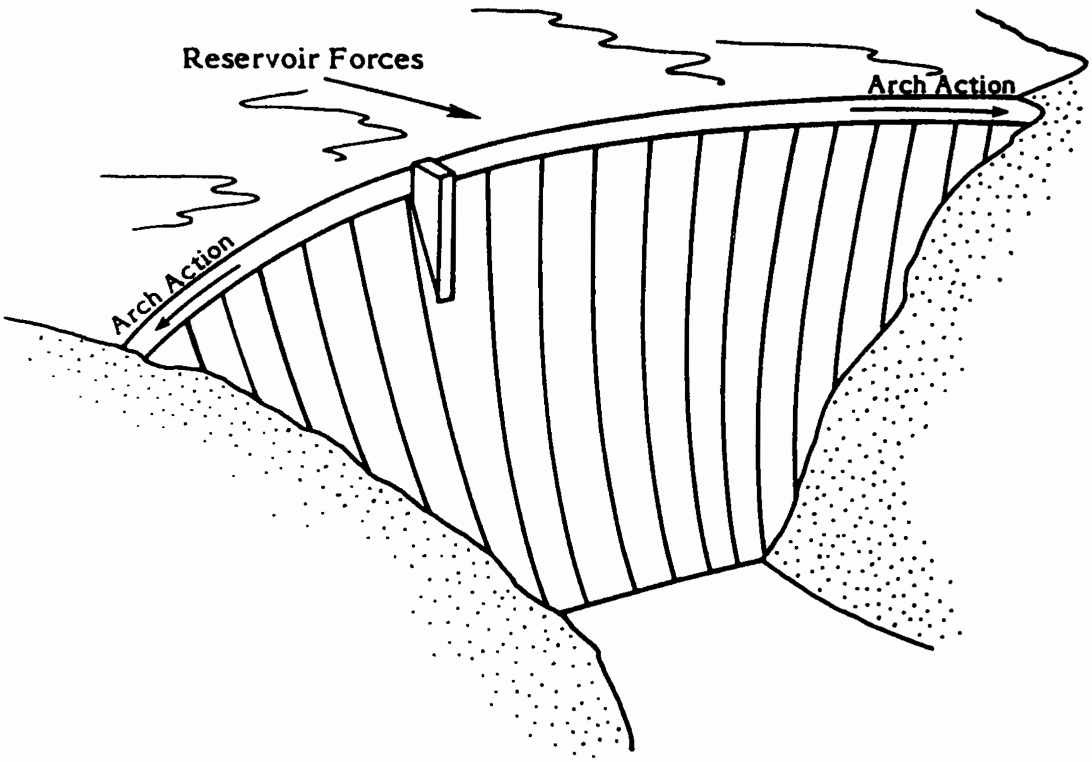
An arch dam is a solid concrete dam that is arched upstream and normally is thinner than a gravity dam. Although arch dams transfer a small part of the reservoir load by their own weight into the foundation, they obtain most of their stability by transmitting the load into the canyon walls (abutments) by arch action (thrust). Because arch dams are thin, stress is a more critical factor in the safety of the dam. Figure I-14 shows a simplified view of an arch dam.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

Arch **Dams** (Continued)

FIGURE I-14. SIMPLIFIED VIEW OF AN ARCH DAM



One of the primary factors in determining the suitability of a site for an arch dam is the width-to-height ratio of the proposed site (3.0 or less). Ideally, the ratio should be relatively small for the use of a thin arch dam. However, arch dams can be designed for the wider sites.

Canyon shape is also an important consideration in the design of an arch dam. The V-shaped sites are generally more favorable to the design of an acceptable arch dam than are the U-shaped sites. The stress distributions in dams designed for the V-shaped sites are usually more acceptable because a larger percentage of the load is resisted by arch action in the lower part of the dam.

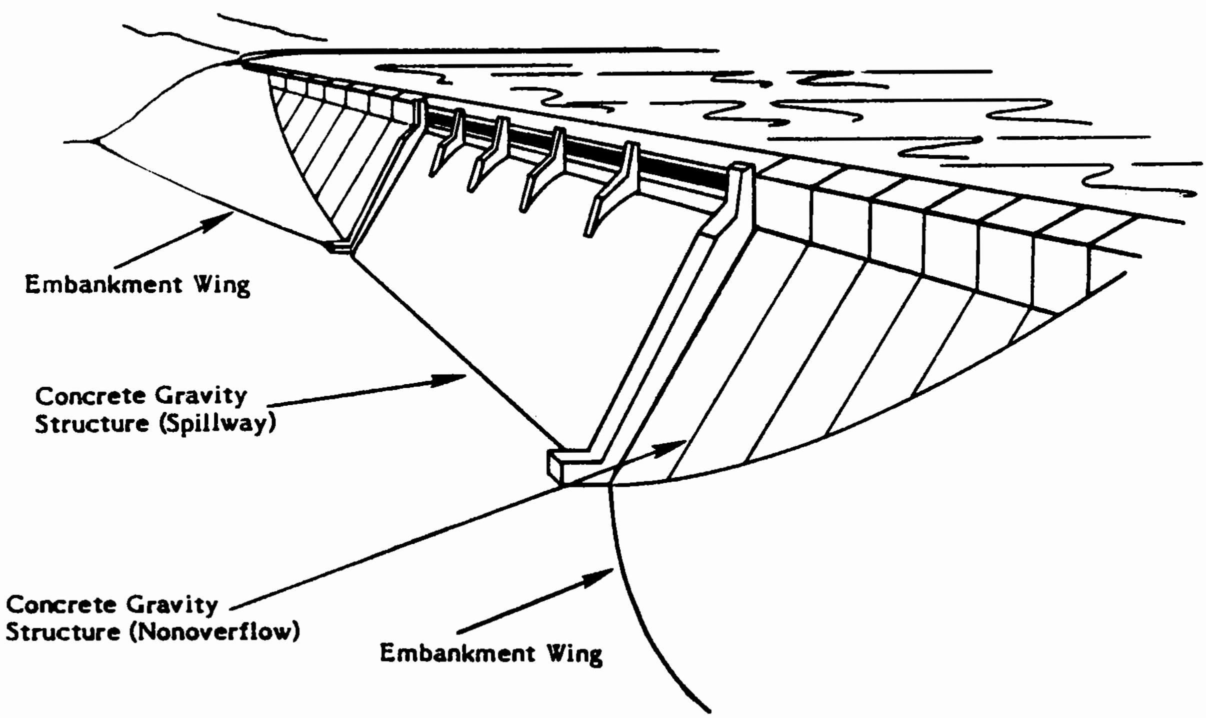
Arch dams should be constructed on sound and durable rock. Rocks that decompose or deteriorate upon exposure to water, atmosphere, or pressure are unacceptable. Also, the orientation of joints, cracks, seams, etc. may be very important. If deposits of these undesirable rock materials are present, they must generally be removed and replaced with concrete.

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

Composite Dams

A composite dam often consists of a concrete gravity or buttress section in combination with earthfill or rockfill embankment sections. Composite dams incorporate the advantages of a concrete dam--the ability to act as the spillway (that is, to be safely overtopped)--with the advantages of an embankment dam--low construction costs and the use of locally available construction materials. Figure I-15 shows an example of a composite dam.

FIGURE I-15. COMPOSITE DAM



Topography is the determining factor when a composite dam is chosen for a particular site. Composite dams are suited for wide valleys, plains locations, or locations where plains and mountains meet, but seldom mountainous terrain itself.

Foundation conditions are also given careful consideration for construction of a composite dam. The concrete portion of the dam must be constructed on a foundation acceptable for concrete dams. If the concrete part of the dam has a maximum net head of more than 20 feet, it should have a rock foundation. If the net head is less than 20 feet, it may be constructed on soil or poor rock materials, provided the allowable bearing pressures are not exceeded.

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

GALLERIES

A **gallery** is a passageway within a concrete dam. Galleries may run longitudinally or transversely, may be horizontal or on a slope, and may serve a variety of purposes. Galleries can provide . . .

- Access into the dam for operations, maintenance, observation, and inspection.
- Paths for utility lines.
- A site for control equipment.
- A drainageway for water within the dam.
- Access for grouting the foundation and abutments.

Galleries contain drainage gutters in the floor, into which drains may empty. The gutters facilitate the flow and measurement of drainage water within the dam.

An **adit** is a passageway used as an entrance to a gallery system or that serves as a connecting passageway between galleries or other features in the dam. **Tunnels** are sometimes constructed into the abutments off the gallery system to provide access for grouting and drainage. Many times, adits and tunnels are unlined, allowing inspection of the actual foundation and abutment materials.

FOUNDATION AND ABUTMENT TREATMENTS

Rock can be treated to control seepage and to improve its capability to support a dam. The methods of treatment may vary, depending on the type of rock being treated and the type of dam to be constructed. The following descriptions of rock treatments will provide a basic description of how these treatments are designed to control seepage and strengthen rock foundations.

☞ **INSPECTION NOTE:** As with embankment dams, even though the foundation and abutment areas of the concrete dams you will be inspecting may have been treated, this does not necessarily mean there will not be seepage, settlement, or instability problems in these areas. Various treatments can be affected by time, materials used for the treatments, treatment design, and/or errors made during construction.

TREATMENTS TO CONTROL SEEPAGE

The control of seepage through the foundation and abutments is very important. Seepage can cause piping, solutioning, and excessive uplift pressures leading to instability. A number of methods are used to control seepage in the foundation and abutments of concrete dams, including the following:

- Grouting
- Foundation and abutment drains

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

Grouting

Construction of a deep grout curtain near the heel of the dam helps to control seepage and uplift pressures. This type of grouting is essentially the same as grouting for embankment dams. Spacing, length, and orientation of grout holes and the procedure to be followed in grouting a foundation are dependent on the height of the structure and the geologic characteristics of the foundation.

Controlling seepage pressure under gravity dams and buttress dams is important because uplift is critical. Uplift pressures on these types of dams may cause the dam to slide or overturn.

It is important that a competent grout curtain be constructed for thin arch or buttress dams, because seepage head must be dissipated over a very short distance.

Foundation And Abutment Drains

Foundation drains are designed to intercept the water that will percolate through and around the grout curtain. If not removed, this water may build hydrostatic pressures on the base of the dam. Drainage is usually accomplished by drilling one or more lines of holes downstream from the grout curtain.

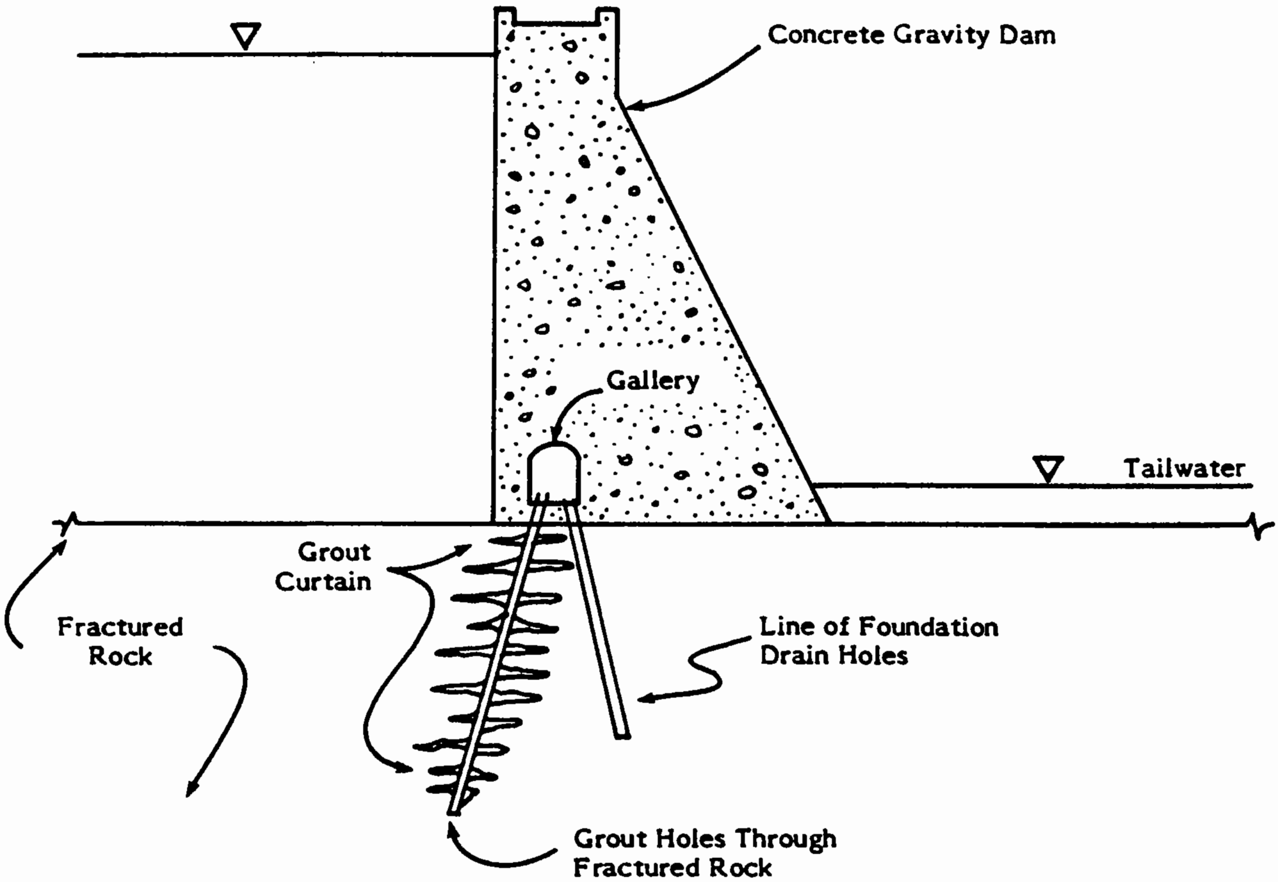
Figure I-16 shows the location of the grout curtain and foundation drains beneath a typical concrete dam. Also note the location of the gallery.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

Foundation And Abutment Drains (Continued)

FIGURE I-16. FOUNDATION DRAINS



Drainage holes are usually 3 inches in diameter. Spacing, depth, and orientation are all influenced by the foundation conditions. Usually, the holes are spaced 10 feet apart, with depths dependent on the grout curtain and reservoir depth. Holes may vary from 20 to 40 percent of the reservoir depth, and 35 to 75 percent of the deep curtain grouting depth.

TREATMENTS TO STRENGTHEN FOUNDATION AND ABUTMENT MATERIALS

At times, it is necessary to treat rock so that it will be more capable of supporting the dam. The type of treatment depends upon the material to be treated and the type of dam to be constructed. Three of the most common types of treatments are . . .

- Smoothing the abutment areas
- Removal and replacement
- Rock reinforcements

I. GEOLOGIC CONSIDERATIONS: TYPES OF CONCRETE DAMS

Smoothing The Abutment Areas

Removing overhangs and smoothing sharp breaks in the slope between the foundation and abutments helps to relieve stress concentrations that can cause cracking in the dam after construction. These areas are smoothed and, if necessary, reinforced with grout.

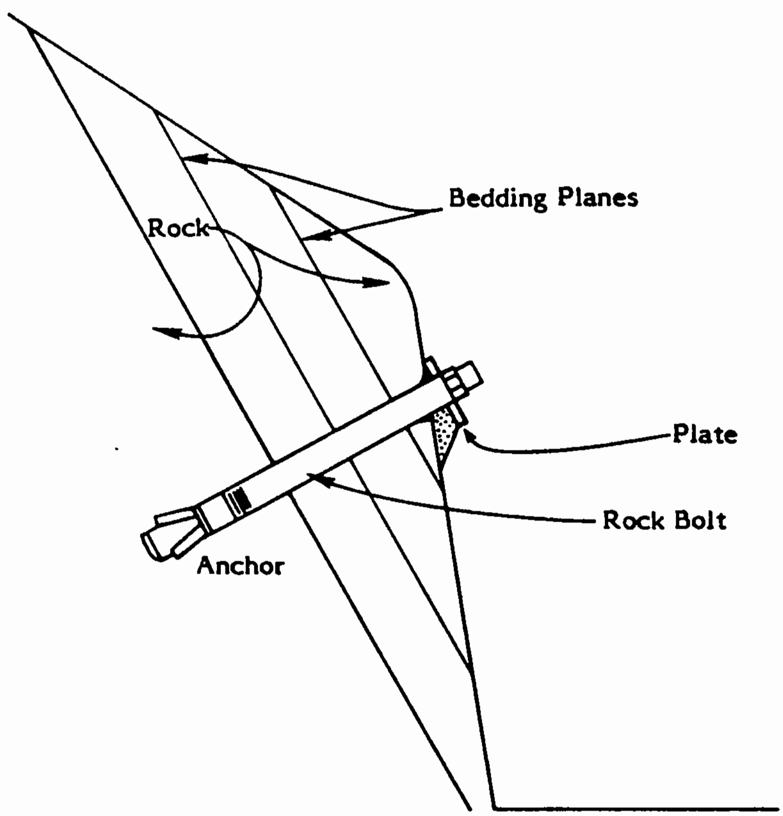
Removal And Replacement

Overburden and weathered or badly fractured rock is removed to the competent rock formation. It may be replaced with concrete to smooth the area and provide a more stable foundation.

Rock Reinforcements

Rock reinforcements, such as rockbolts, anchors, and tendons, stabilize slopes and increase the overall strength of abutments and adjacent areas. Rockbolts, anchors, and tendons are steel rods or cables that are inserted through unstable rock or even structures to reinforce and anchor the unstable element to a stable mass. Figure I-17 illustrates how a rockbolt holds together unstable masses of rock.

FIGURE I-17. ROCK BOLT



I. GEOLOGIC CONSIDERATIONS: RESERVOIR RIM

INTRODUCTION

The reservoir rim is the boundary of the reservoir which includes all areas along the valley sides above and below the water surface. When conducting a dam safety inspection, it is important to include an inspection of the rim because it may have deficiencies that can affect the safety and proper operation of the dam. Of particular concern are areas of potential slides, and leakage through the rim, especially in areas close to the dam or appurtenant structures.

RESERVOIR RIM MATERIALS

The earth materials in the reservoir rim close to the dam are usually similar to the materials comprising the foundation and abutment areas before construction, and before any treatments were made. Earth materials in the reservoir rim are likely to be mixed, and exhibit a number of the characteristics mentioned earlier in this unit.

RESERVOIR RIM TREATMENTS

Any treatment of the reservoir rim is usually intended to improve either the stability of the rim or the water-holding capability of the reservoir.

The stability of the rim close to the dam or appurtenant structures where slides may damage structures or block intakes is critical and must be corrected if necessary. Otherwise, rim stability must be assessed in relation to causing waves (seiches) which could overtop and damage the dam or cause the dam to fail.

During the exploration and design phases of a dam project, areas of potential instability in the reservoir rim may be identified, and plans to stabilize them or account for their future movement included in the design of the dam. Two common methods of reducing the effects of slides are:

- Setting limitations in operating criteria, such as limiting the rates of filling and/or drawdown.
- Imposing a maximum allowable water surface at some level that will accommodate movement of the slide into the reservoir.

If allowing for a slide is not practical, other measures to prevent movement of the slide or to remove the slide must be taken. These measures are described below.

- **Drainage.** Measures to prevent saturation or increased water pressure along the slip surface may be adequate to prevent a slide. If surface runoff is a contributor to the problem, surface drainage should be directed away from these areas. Installation of drains to relieve water pressure may also be effective.

Continued . . .

RESERVOIR RIM **TREATMENTS** (Continued)

- Rock **Bolting.** A rockbolting plan, including tendons, may be used to pin the unstable mass to its parent formation.

- **Unloading the Head of the Slide.** Removing some of the material at the top of a slide area can sometimes stabilize the slide. However, if the slide is large, this method can be costly unless the material to be removed can be used for structural fill.

- **Stability Berms.** If the slide is too large to economically remove the unstable material, placing a stability berm or other mass at the toe of the slide may be used to support the area.

- **Plugging Old Mine Shafts and Cavities.** Old mine shafts or natural cavities are sources of potential collapse, as well as entry points for seepage. Plugging these openings will help to stabilize the area and prevent reservoir water from entering the opening.

I. GEOLOGIC CONSIDERATIONS: PREPARING FOR THE INSPECTION

INTRODUCTION

The module on Preparing To Conduct A Dam Safety Inspection describes things you should do prior to your arrival at the dam site. After you arrive at the site, there are additional preliminary activities you should perform. This section describes preparation activities for inspecting the foundation, abutments, and reservoir rim.

REVIEWING DATA

The kind and amount of data that are available will vary considerably from one dam to another. There may be a Dam Safety File available for the dam you are assigned to inspect. A review of this file may reveal geologic data pertinent to the dam you will be inspecting. The information category and types of items that may be included in this file are shown in Table I-2.

TABLE I-2. GEOLOGIC DATA THAT MAY BE INCLUDED IN A DAM SAFETY FILE

Information Category	Typical Items That May Be Included
Geologic Information	• Regional Information • Site Information • Seismicity • Correspondence
Foundation and Abutment Information	• Description • Design and Analyses • Treatments • Construction Records, Changes, and Modifications • Instrumentation • Deficiencies (e.g., seepage, etc.) • Correspondence
Reports	• Previous Inspection Reports • Special Studies • Instrumentation Data • Operations and Maintenance Reports • Correspondence
Drawings	• Design, As-Built, and Modification Drawings of Major Structures and Features • Topographic Maps • Correspondence
Photographs	• Aerial Photographs • Construction Photographs of Foundation and Abutments

Continued . . .

I. GEOLOGIC CONSIDERATIONS: PREPARING FOR THE INSPECTION

REVIEWING DATA (Continued)

If an initial inspection has already been performed on the dam, chances are there will be a Dam Safety File with geologic information readily available. However, if there is not, other sources of geologic information may be explored, including . . .

- Local and regional geological maps, plans, and sections
- Soil survey reports
- Geological literature
- Well logs
- Aerial photographs of the site and vicinity
- Topographic maps
- As-built drawings
- Foundation treatment records
- Materials test records (soil and rock)
- Interviews with individuals knowledgeable about the dam site

In addition to reviewing geologic data, you should review past inspection reports. These reports will allow you to track conditions and potential problems to determine how and to what degree they are changing over time. Historical and design information can alert you to conditions and features that are of special concern and that should be checked and documented.

TALKING WITH DAM PERSONNEL

Personnel at the dam are an extremely valuable source of information about potential deficiencies in a dam. Operators who are at the dam on an ongoing basis have a better opportunity to observe the dam under various weather and loading conditions than an inspector has in a single visit, and they may provide information that might not be obtained during a visual inspection.

For example, if the reservoir is low at the time of your inspection, you may not observe a problem that occurs when the reservoir is high. If the weather is hot, you may overlook a problem that tends to occur when temperatures drop. Therefore, you should talk to onsite personnel about their experiences and observations to ensure that you know what to look for when you conduct your inspection. It is also strongly recommended that you have someone who is familiar with the structure accompany you on the inspection.

TOOLS AND EQUIPMENT

It is important to have the proper tools with you. Table I-3 lists tools and equipment you will find useful in conducting an inspection of the foundation, abutments, and reservoir rim.

Continued . . .

TOOLS AND EQUIPMENT (Continued)

TABLE I-3. INSPECTION TOOLS AND EQUIPMENT

Tools/Equipment	Uses
Binoculars or telephoto lens for a camera	Viewing inaccessible areas from the crest, the other abutment, downstream of the dam, or from a boat or plane
Camera	Recording conditions and deficiencies
Measuring tape	Measuring dimensions of features or abnormalities; measuring crack width and depth
Probe (rod)	Probe depth of cracks, depressions, or sinkholes and identify soft areas
Pocket knife	Scraping rock, probing, etc.
Rock hammer or pick	Checking soundness of rock or probing joint fillings or soft seams
Shovel	Clearing drains and exposing covered structures
Bucket of known volume and a stopwatch	Measuring seepage and other flow rates
Flashlight	Looking into pipes, etc.
Water sample containers	Taking water samples for water quality tests
Jars, cans, sacks	Taking soil and rock samples (if your agency requires you to do so)

GENERAL GUIDELINES

When you conduct an inspection, there are several things to keep in mind:

- The purpose of an inspection is to gather facts. Be **creative** in the way you conduct inspections. Ask questions; probe for causes until you are satisfied.
- Don't stop with identifying individual deficiencies. Look for continuities or relationships among deficiencies.

Continued . . .

I. GEOLOGIC CONSIDERATIONS: PREPARING FOR THE INSPECTION

GENERAL GUIDELINES (Continued)

- Thoroughly inspect all areas of the foundation, abutments, and reservoir rim close to the dam or appurtenant structures. In most cases, it is not necessary to inspect the entire reservoir rim. Don't take shortcuts. Take your time and allow enough time for the inspection. Pay particular attention to areas where data indicate that change is occurring or where past deficiencies have been noted.

- Know your limits. Consult with an experienced engineer, geologist, or other specialist when you have a specific question or concern.

- Take good notes and make thorough records. Experienced inspectors carry a set of project drawings and make their inspection observations on the drawings. Use sketches, photographs, and measurements to supplement descriptive notes.

- Use the SMPL (pronounced "Simple") rule for all recordings:

  S **Sketch** the deficiency and note its important characteristics

  M **Measure** the deficiency

  P **Photograph** the deficiency or describe its characteristics in writing

  L **Locate** the deficiency relative to some standard reference point

DEVELOPING YOUR INSPECTION CHECKLIST

The module on Preparing To Conduct A Dam Safety Inspection provides information on how to develop a site-specific checklist that will incorporate inspection-specific objectives.

If a checklist is available for the site you will be inspecting, enhance the list by . . .

- Reviewing the geologic data in the Dam Safety File and noting areas that are susceptible to seepage, piping, sliding, or other deficiencies.

- Reviewing past inspection reports and listing any deficiencies or problems encountered so that you can pay particular attention to these areas. Note whether recommendations were made or actions taken to remedy the deficiencies.

- Listing any instruments or structures to be inspected as part of the inspection of foundations and abutments.

  - Note the areas to be inspected.

  - Note any problems found on the previous inspection and recommendations made regarding those problems.

I. GEOLOGIC CONSIDERATIONS: UNIT EXERCISE

INSTRUCTIONS: Use the information presented in this unit to answer the following questions. When you have completed all of the questions, check your answers against those presented in the answer key. The answer key can be found immediately following this exercise.

1. Match the types of unconsolidated material in the left-hand column with their descriptions in the right-hand column.

UNCONSOLIDATED MATERIALS		DESCRIPTIONS
a. Gravel	___	Particles 0.074mm or smaller, with plastic or putty-like properties
b. Sand	___	Particles ranging in size from 1/4-inch to 3 inches
c. Clay	___	Soil comprised primarily of vegetable tissue
d. Silt	___	Particles ranging in size from 0.074mm to 1/4-inch
e. Organic Matter	___	Particles 0.074mm or smaller that are nonplastic or very slightly plastic

2. Of the following types of unconsolidated material, which is **NOT** susceptible to piping (by itself)?

- ☐ Sand
- ☐ Silt
- ☐ Gravel
- ☐ Clay

3. Describe the type of soil subject to liquefaction.

____

____

4. Name two of the characteristics of rock that may affect its performance as material for foundation and abutments.

a. ____

b. ____

Continued . . .

I. GEOLOGIC CONSIDERATIONS: UNIT EXERCISE

5. After a dam has been designed, the next step is to find a suitable location.

   ▯ TRUE ▯ FALSE

6. Listed below are earth materials upon which embankment dams can be built. Check the type of embankment dam(s) that are best suited for each type of material.

   - **Gravel**

     ▯ Earthfill
     ▯ Rockfill
     ▯ Earthfill and Rockfill

   - **Rock**

     ▯ Earthfill
     ▯ Rockfill
     ▯ Earthfill and Rockfill

   - **Silt or Fine Sand**

     ▯ Earthfill
     ▯ Rockfill
     ▯ Earthfill and Rockfill

   - **Clay**

     ▯ Earthfill
     ▯ Rockfill
     ▯ Earthfill and Rockfill

7. What types of seepage control measures lengthen the flow path through the foundation?

   ▯ Downstream drains
   ▯ Partial Cutoffs
   ▯ Relief wells
   ▯ Grouting

Continued . . .

I. GEOLOGIC CONSIDERATIONS: UNIT EXERCISE

8. Why is it important to control water pressure in the foundation of a concrete dam?

____

____

____

____

9. Concrete gravity dams under 50 feet in height, with a headwater/tailwater differential of less than 20 feet, may be constructed on material other than competent rock.

☐ TRUE ☐ FALSE

10. It is recommended that buttress dams be constructed on competent rock.

☐ TRUE ☐ FALSE

11. Which of the two sites below are more favorable to the design of an arch dam?

☐ V-shaped site
☐ U-shaped site

12. Describe how a foundation that has overburden and/or weathered and badly fractured rock overlying competent rock is treated to make it acceptable for construction of a gravity dam.

____

____

____

____

13. Name two measures used to prevent earth materials from sliding into the reservoir.

a. ____

b. ____

I. GEOLOGIC CONSIDERATIONS: UNIT EXERCISE--ANSWER KEY

INSTRUCTIONS: Compare your answers to those given below to see how well you learned the information presented in this unit.

1. Match the types of unconsolidated material in the left-hand column with their descriptions in the right-hand column.

UNCONSOLIDATED MATERIALS		DESCRIPTIONS
a. Gravel	c	Particles 0.074mm or smaller, with plastic or putty-like properties
b. Sand	a	Particles ranging in size from 1/4-inch to 3 inches
c. Clay	e	Soil comprised primarily of vegetable tissue
d. Silt	b	Particles ranging in size from 0.074mm to 1/4-inch
e. Organic Matter	d	Particles 0.074mm or smaller that are nonplastic or very slightly plastic

2. Of the following types of unconsolidated material, which is **NOT** susceptible to piping (by itself)?

- ☐ Sand
- ☐ Silt
- ☑ **Gravel**
- ☐ Clay

3. Describe the type of soil subject to liquefaction.

Uniformly fine-grained nonplastic soils are susceptible to liquefaction, especially when they have been deposited by water.

4. Name two of the characteristics of rock that may affect its performance as material for foundation and abutments.

(Any two of the following are correct.)

Hardness and strength
Discontinuities (openings)
Weathering
Solutioning

Continued . . .

I. GEOLOGIC CONSIDERATIONS: UNIT EXERCISE--ANSWER KEY

5. After a dam has been designed, the next step is to find a suitable location.

   ☐ TRUE ☑ **FALSE**

   First the site is selected and explorations of the subsurface material are conducted. Then, based on the findings, a dam is designed to fit within the geologic constraints of the dam site.

6. Listed below are earth materials upon which embankment dams can be built. Check the type of embankment dam(s) that are best suited for each type of material.

   - Gravel

     ☐ Earthfill
     ☐ Rockfill
     ☑ **Earthfill and Rockfill**

   - Rock

     ☐ Earthfill
     ☐ Rockfill
     ☑ **Earthfill and Rockfill**

   - Silt or Fine Sand

     ☑ **Earthfill**
     ☐ Rockfill
     ☐ Earthfill and Rockfill

   - Clay

     ☑ **Earthfill**
     ☐ Rockfill
     ☐ Earthfill and Rockfill

7. What types of seepage control measures lengthen the flow path through the foundation?

   ☐ Downstream drains
   ☑ **Partial Cutoffs**
   ☐ Relief wells
   ☐ Grouting

Continued . . .

I. GEOLOGIC CONSIDERATIONS: UNIT EXERCISE--ANSWER KEY

8. Why is it important to control water pressure in the foundation of a concrete dam?

   If water pressures in the foundation are allowed to build up, they could eventually cause the dam to overturn, or slide downstream.

9. Concrete gravity dams under 50 feet in height, with a headwater/tailwater differential of less than 20 feet, may be constructed on material other than competent rock.

   ☑ **TRUE** ☐ FALSE

10. It is recommended that buttress dams be constructed on competent rock.

    ☑ **TRUE** ☐ FALSE

11. Which of the two sites below are more favorable to the design of an arch dam?

    ☑ **V-shaped site**
    ☐ U-shaped site

    A larger percentage of the stress is resisted by arch action in the lower part of the dam at a V-shaped site.

12. Describe how a foundation that has overburden and/or weathered and badly fractured rock overlying competent rock is treated to make it acceptable for construction of a gravity dam.

    Remove unacceptable material and replace it with concrete.

13. Name two measures used to prevent earth materials from sliding into the reservoir.

    (Any two of the following are correct.)

    - **Drainage**
    - **Rock bolting**
    - **Unloading the head of the slide**
    - **Stability berms**

I. GEOLOGIC CONSIDERATIONS: SUMMARY

IMPORTANCE OF GEOLOGY

This unit explained the importance of considering the topography and geology of a site before designing a suitable dam, and discussed the engineering and geologic properties of soil and rock that are affected by the loads and stresses imposed by a dam and reservoir.

Unit I also described the types of dams typically constructed on certain materials. Table I-4 reviews the different types of dams, the materials suitable for foundation and abutments, and some of the basic characteristics of these materials. This unit also stressed the importance of inspecting the reservoir rim for possible geologic deficiencies, and described several treatments used in the rim area to improve the stability and the water-holding capability of the reservoir and to mitigate the effects of a slide.

Finally, Unit I discussed procedures for preparing to inspect the foundation, abutments, and reservoir rim.

TABLE I-4. FOUNDATION MATERIALS FOR DAMS

Type Of Foundation	Type Of Dam	Characteristics/Types Of Treatments
Rock	All types	Often fractured and weathered. Remove disintegrated rock; seal seams and fractures by grouting and surface treatment.
Gravel	Earthfill Rockfill Low concrete gravity	Gravel are occasionally loose and may be pervious. May require densification and special effort to provide effective seepage control.
Silt or Fine Sand	Low concrete gravity Earthfill	Subject to liquefaction, settlement, and piping. May require removal or densification and careful control of seepage.
Clay	Earthfill	Subject to settlement and instability. May require removal or special treatment to consolidate and improve strength and prevent settlement.
Nonuniform (Mixed Material)	All types	Various treatments based on careful exploration and design.

UNIT II

INSPECTING THE FOUNDATION AND ABUTMENTS

II. INSPECTING THE FOUNDATION AND ABUTMENTS: OVERVIEW

INTRODUCTION

Because the foundation and abutments support the dam, they play a major role in the stability and safety of a dam. Deficiencies in the foundation and abutments can, if not addressed, lead to severe problems or even failure of a dam. Problems or areas of concern include . . .

- Seepage (piping, solutioning, excessive pressures)
- Instability (e.g., cracks, slides, bulges, and depressions)
- Maintenance

This unit describes procedures that can be used to inspect the foundations and abutments of either embankment dams or concrete dams, the types of deficiencies commonly found in these areas, and the steps you should take to inspect and record these deficiencies.

UNIT OBJECTIVES

After you complete this unit, you will be able to . . .

- Select a method of inspecting the foundation and abutments of embankment or concrete dams that will provide the most accurate and complete coverage.

- Identify and inspect deficiencies in the foundation and abutments that either . . .

  - Directly affect the safety and integrity of the dam, or

  - May lead to more serious problems that will affect the safety and integrity of the dam.

- Evaluate the deficiency in the foundation and/or abutments and make a recommendation to either correct the deficiency or alleviate its effects.

- Properly record your findings so that an accurate and useful record exists for future reference.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSPECTION PROCEDURES

INTRODUCTION

In most cases, abutments and foundations cannot actually be inspected because these are the areas upon which the dam rests. Therefore, the areas adjacent to the foundation and abutments are inspected for clues of what might be happening in the foundation and abutments. However, some dams have unlined tunnels and adits that allow actual inspection of foundation and abutments. Other areas, such as downstream borrow areas, channel banks, excavation slopes, or road cuts, may also provide an indication of what the foundation and abutment areas are comprised of.

Judgment must be used as to how far downstream you should inspect. Very often, seepage through an abutment may emerge from the valley wall at some distance downstream. You should inspect far enough downstream to satisfy yourself that there are no problems that will affect the safety of the dam.

INSPECTING THE ADJACENT AREAS

There are several methods for inspecting the areas adjacent to the foundation and abutments. You should use the methods that you feel will allow the most complete and thorough inspection. The possible inspection methods include:

- Walking the adjacent areas
- Viewing the adjacent areas from the dam crest or opposite abutment
- Viewing the adjacent areas from downstream
- Underwater inspection

Walking The Adjacent Areas

One method of inspecting the abutments and foundation is to walk the adjacent areas. If the slope is not too steep, walking these areas will provide a more thorough and close-up inspection. You should walk these areas as many times as is necessary in order to see the entire surface area clearly. A zigzag, parallel, or other systematic pattern can be used to walk across adjacent areas, as long as the coverage is complete.

Personal Safety Considerations

When inspecting areas adjacent to the abutments, do not attempt to climb down the slope if it is too steep. It is better to view the area from the dam crest or from downstream than to risk falling. Use special equipment if it is necessary to gain access when close inspection is needed.

Items of clothing relevant to personal safety should be worn. For example . . .

- Proper footwear designed for both protection and outdoor use should be worn.

- A life jacket will be needed when inspecting areas around deep water.

- A hard hat should be worn when inspecting areas subject to falling rock.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSPECTION PROCEDURES

Viewing The Adjacent Areas From The Crest Or Opposite Abutment

When abutment slopes are too steep to climb safely, or another perspective is needed, other methods of inspection should be used. One method is to view these areas from the crest of the dam, or from the opposite abutment. When viewing the adjacent areas . . .

- ✓ Use binoculars or a telephoto lens to make systematic passes of the foundation or abutment areas.
- ✓ Use a reference point or "placemark" when stopping to note a particular area of concern. Then you can continue scanning without missing an area.

Special equipment, such as climbing equipment or mechanical lifts, may be required to allow you to more closely inspect areas of concern located on steep abutments. If possible . . .

- ✓ Try to identify steep areas before conducting your inspection. Geologic information, construction information, or past inspection reports found in the Dam Safety File may help you locate these areas.
- ✓ Arrange for any special equipment you will need beforehand. Certain types of equipment, such as a mechanical lift or other type of platform, may not be available at the site, and dam personnel may have to make arrangements to ensure they are available for the inspection.
- ✓ Do **not** attempt to climb up or down the slope using climbing equipment unless you are experienced in climbing. It is better to view the area from the crest or from downstream than to risk falling.

Viewing The Adjacent Areas From Downstream

Using binoculars or a telephoto lens to view foundation and abutment areas from downstream will allow you to view these areas from another perspective. Also, areas not easily seen from the crest (e.g., groin areas) may also be viewed. Making systematic passes with your binoculars or lens should enable you to cover the area thoroughly.

Underwater Inspection

There are three methods of inspecting areas that are normally under water:

- **Conducting the inspection during a period when the water level has been lowered.** If you feel it is necessary to inspect features that are usually under water, try to schedule the inspection when the water level has been lowered. To do so, call the dam owner or operator and find out when water releases are scheduled, or what time of year the reservoir is at its lowest point.

Continued . . .

Underwater Inspection (Continued)

- **Having a trained inspection diver perform the underwater inspection.** If it is not possible to inspect at a lowered reservoir level, and there is an area of particular concern under water, a diver who is knowledgeable in hydraulic structures and experienced in conducting underwater inspections may be used. A diver might, for instance, inspect an area of suspected abutment instability near an outlet works intake structure. Inexperienced divers may become disoriented, or may not report items of significance. Perspective schematics can be helpful in aiding diver orientation, and you may wish to review these with the diver prior to the inspection. However, because underwater inspections are generally performed as a special inspection, you may not have this opportunity. In that case, the dam operator or other personnel can review the schematics with the diver.

- **Using special TV equipment designed for underwater use to view and record underwater conditions.** Black and white or color closed-circuit television cameras and high resolution color still photography may be used to record deficiencies in abutment areas near the dam that are covered by water. Measurement devices used to indicate the size of cracks or other conditions to be recorded must be large enough to be viewed clearly when pictures are taken. If camera equipment is being operated by a diver, narration by the diver during the inspection may be accomplished by a tape recorder.

INSPECTING INSTRUMENTATION

In addition to observing conditions on the foundation and abutment areas, you may also be responsible for taking instrument readings or ensuring that the instruments are working properly. For more information on inspecting instrumentation, refer to the module entitled <u>Instrumentation For Embankment And Concrete Dams</u>.

Certain devices, such as weirs, flumes, drains, and relief wells, may provide information on seepage and piping, and should be included in your inspection of the foundation and abutment areas.

Weirs, Flumes, And Other Flow-Measuring Devices

Weirs and flumes are installed to measure seepage, especially seepage exiting from the foundation or abutments at random locations. When properly calibrated and kept free of silt and vegetation, weirs and flumes measure seepage accurately.

Weirs and flumes that are silted-in may indicate that . . .

- Foundation or abutment material is being piped, or

- Sediment from surrounding surface runoff erosion is collecting in the structure.

If weirs and flumes become silted-in, you should evaluate the situation carefully to determine the cause of the siltation.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSPECTION PROCEDURES

Weirs And Flumes: Inspection Actions

When inspecting weirs and flumes . . .

✓ Clear the device of any silt, debris, and/or vegetation that might be blocking the flow.

✓ Read the staff gauge, and using the appropriate conversion table, convert the reading to a flow rate and record the measurement.

Relief Wells

Relief wells are designed to help control seepage pressures that could lead to piping or instability by collecting foundation seepage and discharging it safely downstream. Relief wells should be monitored and maintained on a regular basis.

Before conducting an inspection of a dam equipped with relief wells, you should . . .

✓ Review the site plan to determine the location of the wells.

✓ Review previous data on both the reservoir level and well flow. Data on well flow must be looked at in conjunction with reservoir-level data. Knowing how the reservoir level affects the well flow can help you to determine if there is a problem. If you observe a well flow that is unusual for a given reservoir level, more investigation may be warranted.

Relief Wells: Inspection Actions

During the inspection, you should . . .

✓ Locate each relief well.

✓ Visually check whether or not flow is occurring.

IF NO WATER IS FLOWING . . . Determine if a flow should be present based on your assessment of the previous readings and the current reservoir level.

IF WATER IS FLOWING . . . Measure the rate of flow. The rate of flow can be measured either at the well or at the collector pipe discharge. You can use weirs, flumes, or a bucket and stopwatch to measure the flow rate.

Continued . . .

Relief Wells: Inspection Actions (Continued)

✓ Compare the amount of well flow measured with the amount of flow you anticipated for the current reservoir level based on previous readings.

IF THE WELL FLOW IS LESS than the amount you anticipated, the well screens or filters may have become clogged. Clogged wells can contribute to the development of sand boils or uplift at the toe of the dam. If you suspect that the well is not functioning properly because it is clogged, cleaning should be recommended. Sound the depth of the well and compare it to the installed depth. A shallower depth could mean an accumulation of piped material in the bottom of the well.

IF THE WELL FLOW IS GREATER than the amount you anticipated, there may be excessive seepage. Make sure that you accurately record the flow amount and reservoir level. You should also note that there has been a change from the well-flow trends previously observed.

✓ Check the clarity of the water. If the water is cloudy, turbid, or if there is an accumulation of sediment, this indicates material is being piped. Make a note of this, and consult with an experienced and qualified engineer or geologist.

INSPECTING DRAINS

Drains designed to control seepage or water flow through the foundation and abutments should be inspected to ensure that they are not clogged, and are working as designed. Drains should be checked for changes in the rate or amount of flow from previous inspections. Also, remember to check the clarity of the flow.

Toe Drains

Many toe drains have collector pipes that discharge embankment seepage and, in some cases, foundation seepage. Before conducting an inspection of a foundation that has toe drains, you should . . .

✓ Review the site plan to determine the location of the toe drains and outfalls.

✓ Review previous data on both the reservoir level and flow rate from the drain(s). Data on drain flow must be looked at in conjunction with reservoir-level data. Knowing how the reservoir level affects the drain flow can help you to determine if there is a problem. If you observe a drain flow that is unusual for the given reservoir level, more investigation may be warranted.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSPECTION PROCEDURES

Toe Drains: Inspection Actions

While conducting the inspection, you should . . .

- ✓ Locate each toe drain outfall and measure the flow. A simple method of measuring the flow from a toe drain outfall is to catch the flow from the pipe in a container of known volume and time how long it takes to fill the container. The flow rate is usually recorded in gallons per minute.

- ✓ Compare the amount of flow with the amount of flow you anticipated for the current reservoir level based on previous readings.

- ✓ Check the flow for turbidity or the drain for accumulation of sediment, as these conditions are indications of piping.

Blocked Drains

A drain that has no flow at all could simply mean that there is no seepage in the area of the dam serviced by the drain. However, an absence of flow could also indicate a problem.

If the drain . . .

- Has never functioned, it could mean that the drain was designed or installed incorrectly.

- Flowed at one time but has now stopped flowing, it may have become plugged.

A plugged drain can be a serious problem because seepage may begin to exit downslope, or may contribute to increased internal pressure and instability. If possible, blocked drains should be cleaned so that the controlled release of seepage may be restored. Decreasing amounts of flow, over time, from a drain for the same reservoir level may indicate that the drain is becoming blocked or that siltation is making the reservoir less pervious.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSPECTION PROCEDURES

INSPECTING ADITS, GALLERIES, AND TUNNELS

If the dam is equipped with unlined drainage adits or tunnels, you should inspect these to look at the foundation and abutment material for any signs of weakness or seepage.

If you notice seepage in adits, galleries, or tunnels, you should . . .

- ✓ Compare what you see against previously reported seepage at similar reservoir levels.
- ✓ Photograph and record the location of new or increased seepage.
- ✓ Check the rate of flow, and check for signs of turbidity.
- ✓ If the water appears turbid, recommend that the seepage area be checked by an experienced and qualified engineer.

Staining and deposits may indicate solutioning, and these areas should be noted, and water samples taken.

Rockfalls should also be noted, as they indicate instability that may threaten the safety of the dam as well as the safety of individuals working in these areas. The reason for the falls should be further examined by an experienced and qualified engineer or geologist.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SEEPAGE PROBLEMS

INTRODUCTION

Seepage passes through the foundation and abutment materials of all dams. Seepage must be controlled in both pressure and quantity. If uncontrolled, it can progressively erode the material from the foundation and abutments. This erosion is called piping, and, if allowed to progress, can result in the failure of the dam. Seepage and internal pressure may also cause earth materials to lose their strength, and can cause sloughing or massive slides.

When inspecting for seepage, you should look for these signs . . .

- Flowing water
- Turbidity
- Sand boils
- Surface staining and deposits (possible solutioning)
- Standing water
- Lush vegetation

FLOWING WATER

Nearly all dams will have some flowing water. In most cases, the flow is harmless and expected. Controlled flow through designed drainage systems (e.g., toe drains, foundation drains, and relief wells) and surface drainage is expected. However, flow from uncontrolled seepage must be carefully evaluated because it may indicate conditions that might affect the safety of the dam.

Flowing Water: Inspection Actions

If you encounter flowing water during your inspection . . .

✓ Record the level of the reservoir at the time of the observation. The amount of seepage usually correlates with the level of the reservoir. Generally, as the level of the reservoir rises, the seepage flow rate increases. Any changes in seepage flow rate which deviate from past seepage history are cause for concern.

✓ Photograph and record the location of the flowing water.

✓ Follow the flowing water upstream to find the source of the water.

✓ Follow the flowing water downstream a sufficient distance to ensure that it is not causing erosion or saturation of soils that may present a hazard to the dam or appurtenant structures.

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SEEPAGE PROBLEMS

Flowing Water: Inspection Actions (Continued)

✓ Check the rate of flow and record the measurement of flow in terms of volume per unit of time (e.g., gallons per minute (gpm)). There are a number of methods you can use to measure the rate of flow:

- Using a stopwatch or second-hand sweep on a wristwatch, time how long it takes to fill a bucket of known volume.
- Portable or permanent flow measurement devices such as weirs, flumes, or orifice plates may be used to measure flow.
- In the absence of more precise measuring devices, a blade of grass, leaf, or other debris can be dropped into the water at a specific point and timed to see how long it takes to travel a measured distance. This yields the approximate velocity of the flow. Then estimate the cross-sectional area of the flow. Multiplying these together yields the flow rate.

✓ Fill a glass container and check the clarity of the water.

- If the water is clear and the flow rate slow, you may just want to note the location of the seepage and recommend that it be monitored in subsequent inspections.
- If the water is cloudy (turbid), it may indicate piping and needs to be evaluated promptly by an experienced and qualified engineer.

TURBIDITY

Turbid (cloudy) seepage indicates that soil particles are suspended in the water and that the water passing through the foundation or abutment is carrying soil with it, and may be creating a "pipe."

When seepage flows through materials such as sand or cohesionless silts, the force of the flowing water can start to remove material at the exit point, and cause progressive erosion known as piping. Piping is serious because it can rapidly progress and ultimately cause the dam to fail. Piping may be accompanied by turbid water, sinkholes, or sand boils, and in advanced stages by a whirlpool or vortex in the reservoir at the seepage entrance point.

☞ **INSPECTION TIP:** Turbidity is cause for extreme concern. Each time seepage is measured, the clarity of the seepage should also be evaluated for change.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SEEPAGE PROBLEMS

Checking Turbidity

A good way of detecting a change in turbidity is to collect a number of water samples as follows . . .

STEP	DESCRIPTION
1	Collect a sample of the water in a quart jar. Date the jar and note the clarity. Store the jar in a safe location.
2	Repeat step 1 each time seepage flow is measured until several samples have been collected.
3	Each time you collect a sample, shake up each jar and visually compare the new sample with the samples collected previously. Look for changes in cloudiness of the samples. Also note the amount of sediment that accumulates in the bottom of the jars as suspended material settles out.

If seepage is clear, but you suspect that it contains dissolved material from the foundation (because, for instance, seepage is new or has increased), it may be necessary to perform water quality testing to determine the type and amount of dissolved solids in the seepage.

Turbidity: Inspection Actions

If you encounter an area of flowing turbid water, you should . . .

- ✓ Photograph and record the exact location of the problem. You may wish to locate the problem on a set of drawings or aerial photograph of the area.
- ✓ Record the rate of flow using a calibrated measuring device.
- ✓ Compare the rate of flow and the amount of turbidity with past records (if this is an area noted on a previous inspection). If there is an increase in the flow or an increase in turbidity, recommend that an experienced and qualified engineer examine the area immediately.

SAND BOILS

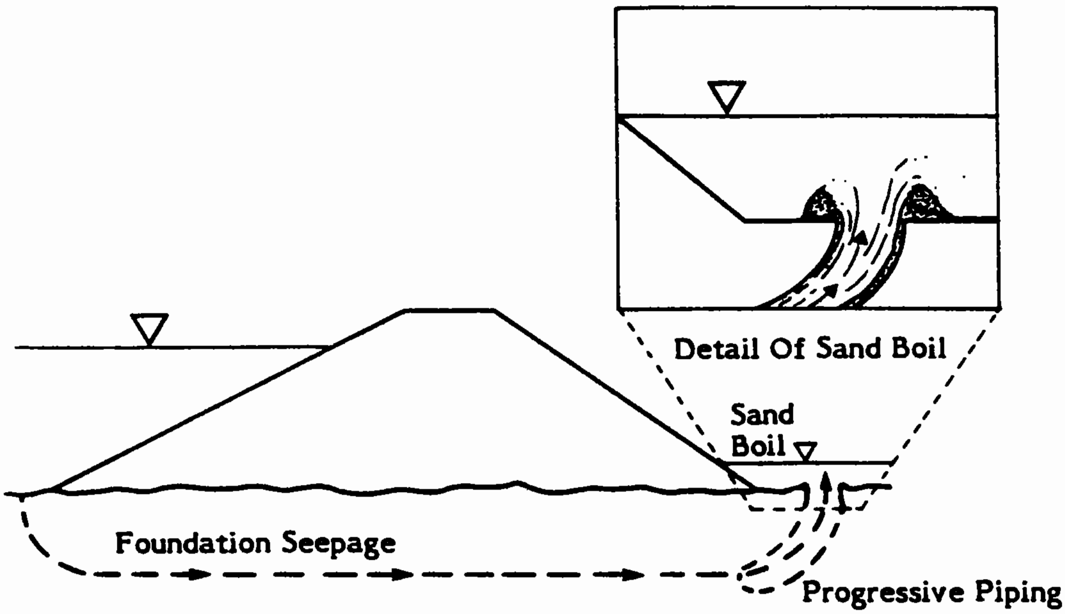
Sand boils are one manifestation of piping, and indicate high seepage pressures. In Figure II-1, seepage is exiting near the downstream toe of an embankment dam, and has caused a sand boil.

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SEEPAGE PROBLEMS

SAND BOILS (Continued)

FIGURE II-1. SAND BOIL



Sand Boils: Inspection Actions

If you observe a sand boil, you should . . .

- ✓ Photograph and record the size of the deposition cone.
- ✓ Monitor the flow rate, if possible. The flow rate may be difficult to ascertain because sand boils are often under water.
- ✓ Make sure that all sand boils are evaluated by an experienced and qualified engineer so that appropriate remedial action can be taken.

Sometimes placing sandbags around the boil to increase the depth of water (head) over the boil will prevent continued growth of the boil. This is called back pressuring, and is generally only a short-term solution. A reverse filter (one or more layers of progressively smaller-sized pervious materials) placed over the area to allow seepage to exit but prevent material from moving is often the best treatment.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SEEPAGE PROBLEMS

SURFACE STAINING AND DEPOSITS

Surface staining or deposits on rock may indicate solutioning. Ground water moving through pores or rock fractures is often chemically charged with minerals. These minerals precipitate out of solution when chemical or physical conditions change. Staining is a very thin film on a fracture surface on a rock outcrop. The most common stains are iron (red) and manganese (brown or black). Deposits are similar to stains, except thicker. A common deposit, found in areas of limestone, is white or yellow calcite.

Stains and deposits can indicate weakening of the foundation or abutments. New stains and deposits may indicate a change in seepage paths.

Surface Staining And Deposits: Inspection Actions

If you observe stains or deposits on rock outcrops in the foundation or abutment areas . . .

- ✓ Photograph and record the location of the stains and the type of deposits.
- ✓ Take a sample of the water from both the seepage area and the reservoir to determine if there has been a change in water quality.

STANDING WATER

There are a number of causes of standing water. Standing water may be caused by seepage, or may be caused by . . .

- Controlled water releases from outlet works, spillway, or power houses
- Surface runoff collecting due to poor grading or drainage of an area
- Beaver dams, sediment bars, debris, or vegetation blocking discharge channels
- Recent precipitation

Standing water, or ponding, may conceal the location and nature of seepage or other deficiencies such as cracks, erosion, and depressions, and should be eliminated. However, care must be exercised in draining areas of standing water because doing so increases the hydraulic head (the difference between reservoir and tailwater elevations), and could aggravate seepage conditions. An experienced and qualified engineer should make the decision to drain a seepage pond.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SEEPAGE PROBLEMS

Standing Water: Inspection Actions

If you encounter standing water during your inspection . . .

- ✓ Photograph and record the location of the standing water.
- ✓ Record the occurrence of recent precipitation that may have created the standing water, or that may affect the appearance and quantity of seepage.
- ✓ Record flooded or ponded conditions, giving a description of the location, dimensions, elevation, and probable cause.

LUSH VEGETATION

If lush vegetation appears in areas where it would not generally flourish, it may be an indicator of . . .

- Seepage
- Standing water due to poor surface drainage
- An underground spring

This type of vegetation may obstruct the view of a particular area, or block drainage exits.

Lush Vegetation: Inspection Actions

If you notice water-loving plants growing on the foundation or abutment areas, you should . . .

- ✓ Photograph and record the area of vegetation.
- ✓ Clear the area yourself, or have it cleared, so that it can be properly evaluated.
- ✓ Investigate the source of water feeding the vegetation, and note the location on a set of drawings, a photograph, or a notebook.
- ✓ Estimate the flow and check the clarity of the water.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSTABILITY

INTRODUCTION

In addition to seepage problems, instability of the foundation and abutments of a dam also contribute to dam failure. Signs of instability include . . .

- Cracks
- Slides
- Bulges
- Depressions

CRACKS

All cracks in the foundation and abutment areas should be examined. Cracks can be stress-related, and can be caused by slumping, subsidence, or differential settlement. Cracks appearing at the base of the dam may be caused by foundation movement.

Cracks to significant depths or with scarps can indicate instability of the abutments and adjacent areas.

Cracks: Inspection Actions

Treat every crack as a serious problem until determined otherwise. If cracks are found . . .

✓ Photograph and record your findings.

✓ Record the location, depth, width, length, pattern, and direction of the crack.

✓ Evaluate cracks noted during past inspections for any changes.

✓ Recommend that cracks be examined by an experienced and qualified engineer and/or geologist.

SLIDES

Slides on the dam abutments are mass movements of earth materials, and appear as bulging zones of material accompanied by a scarp or exposed slip surface at the top of the slide. Slides are of concern because . . .

- They can block the intake or discharge structures of a spillway, outlet works, or other essential appurtenance.

- They may affect a dam's stability by reducing the support in that area.

Also, in rare cases, severe slides can cause overtopping of the dam by wave action. Overtopping is especially serious with embankment dams because it can quickly erode embankment material.

Continued . . .

SLIDES (Continued)

Slides are the result of instability of the embankment or abutment areas. Instability may occur because of . . .

- Poor compaction during treatment
- A slope that is too steep
- Excessive seepage
- Uplift pressures
- Seismic activity
- Sudden reservoir drawdown against saturated slopes
- Leakage or structural failure of an appurtenance
- Failure to remove unsuitable foundation material during construction

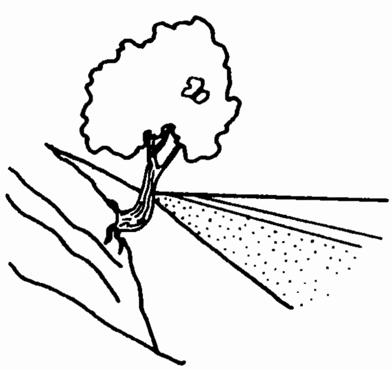
Slide phenomena have various names, including displacements, slumps, creep, slips, and sloughs. Slides can be grouped into two main categories: shallow slides and deep-seated slides. These categories of slides are discussed below in more detail. Following the discussion of the two types of slides and their corresponding inspection actions is a brief mention of rock and slope reinforcements, which are often used to prevent sliding. Some inspection actions for these reinforcements are also suggested.

Shallow Slides

Shallow slides of the abutment areas are sometimes referred to as sloughs. They may be soft, and are often saturated. The beginnings of a shallow slide generally can be recognized from the following conditions:

- **Leaning or Pistol-Handled Trees.** Trees growing on an area that is slowly sliding downhill will develop a curve in the trunk that is described as being "pistol-handled" (see Figure II-2). This shape develops because of a plant's natural tendency to grow vertically toward the source of sunlight. If the slide is fairly recent, the tree may just appear to be growing at an angle.

FIGURE II-2. PISTOL-HANDLED TREE



Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSTABILITY

Shallow Slides (Continued)

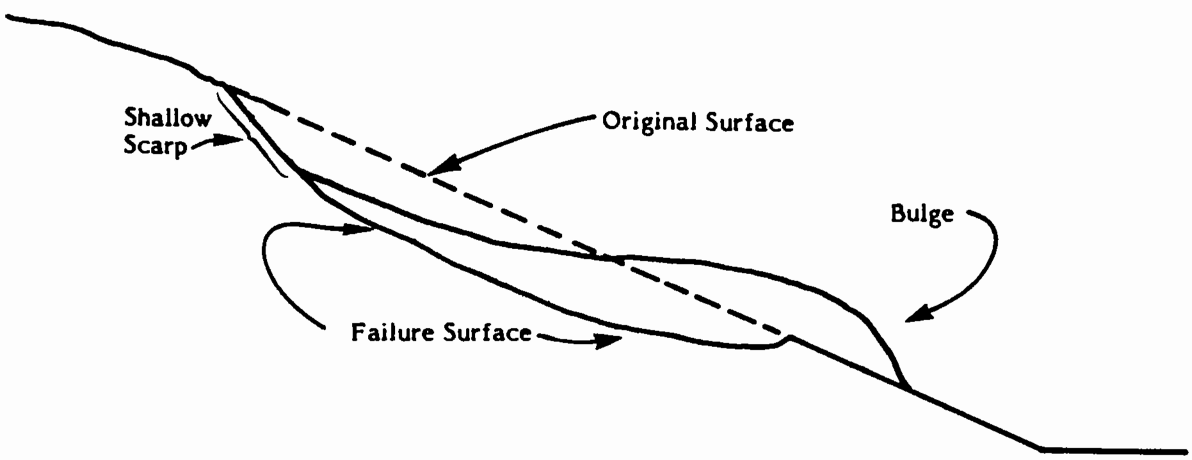
- **Scarps.** A scarp is the exposed slip surface at the top of a slide (see Figure II-3). Scarps that have less steep backslopes indicate a shallow slide.

- **Cracks.** Cracks in the abutment areas may also indicate the beginnings of a slide. However, it may be difficult to distinguish cracks that indicate instability from cracks that are part of the natural geology or that result from dessication or settlement. Arc-shaped cracks or cracks that are perpendicular to the slope are indications that a slide may be starting. Arc-shaped cracks can develop into a scarp in the slope at the top of the slide.

- **Wet and Soft Areas.** Seepage and wet conditions may help precipitate a slide, especially in areas of fine, uncompacted material. Also, seams of pervious material in rock formations may contribute to sliding, if seepage exists through that area and is not controlled.

Figure II-3 illustrates a shallow slide.

FIGURE II-3. SHALLOW SLIDE



Shallow Slides: Inspection Actions

If you observe a shallow slide, you should . . .

✓ Photograph and record the location of the slide.

✓ Measure and record the extent and displacement of the slide.

✓ Look for any surrounding cracks, especially uphill from the slide.

Continued . . .

Shallow Slides: Inspection Actions (Continued)

- ✓ Probe the entire area to determine the condition of the surface material.
- ✓ Check for seepage areas near the slide.
- ✓ Recommend that the area be monitored to determine if the condition is becoming worse.

☞ **INSPECTION TIP:** You should consult with an experienced and qualified engineer or geologist if you are unsure whether the slide presents a threat to the dam or appurtenant structures.

Deep-Seated Slides

Deep-seated or large slides pose a serious threat to the safety of the dam. If the slide is on the upstream abutment, it can block or damage outlet works or other drainage features. If large enough, the slide can cause wave action to overtop the dam. If the slide is on the downstream abutment, it can cause damage to or block drainage systems, wells, or other appurtenances. Abutment slides can result in loss of support for the dam.

To recognize deep-seated slides, look for . . .

- **Well-Defined Scarping.** Scarps on deep-seated slides have a high steep back slope.
- **Toe Bulge.** A large toe bulge is produced by the rotational or horizontal movement of slope material.
- **Cracks.** As in shallow slides, arc-shaped cracks at the top of the slide or cracks that are perpendicular to the slope may also be present.

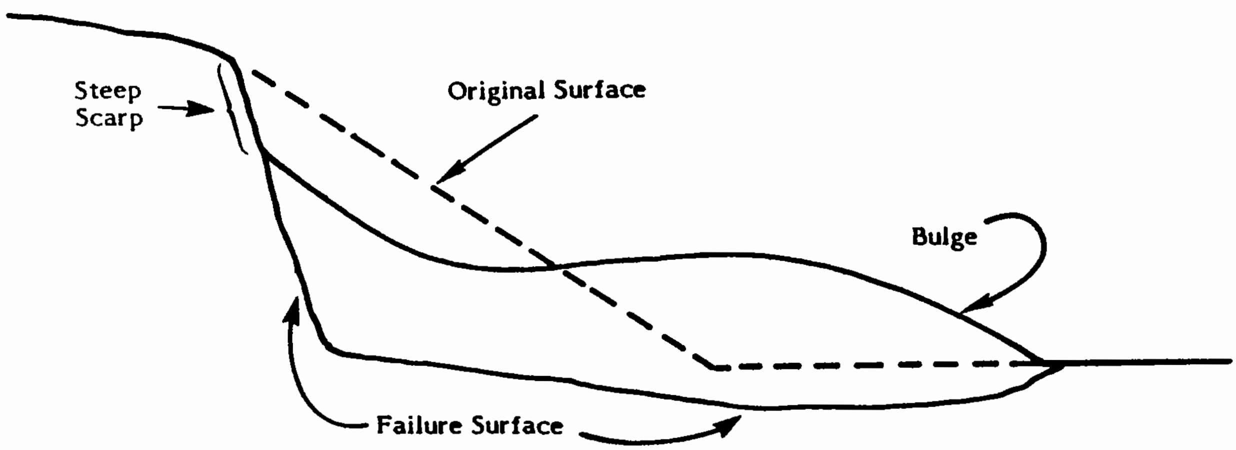
Figure II-4 illustrates a deep-seated slide showing the scarp and toe bulge.

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSTABILITY

Deep-Seated Slides (Continued)

FIGURE II-4. DEEP-SEATED SLIDE



Deep-Seated Slides: Inspection Actions

If you see signs of a deep-seated or large slide and are not sure of the cause, seek advice from an experienced and qualified engineer or geologist. You should . . .

- ✓ Determine the probable cause of the slide if you can. An investigation probably will be required and should be recommended.
- ✓ Determine what the adverse effects to the dam might be.
- ✓ Recommend that remedial measures be taken to mitigate the effects of the slide.

Also . . .

- ✓ Photograph and record the location of the slide.
- ✓ Measure and record the extent and displacement of the slide.
- ✓ Look for any surrounding cracks, especially uphill from the slide.
- ✓ Probe the entire area to determine the condition of the surface material.
- ✓ Check for seepage areas near the slide.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSTABILITY

Rock And Slope Reinforcements

Rockbolts, anchors, tendons, and/or retaining structures may be used to reinforce slopes or rock walls, and prevent sliding. These reinforcements should be inspected to ensure they are still functioning as intended. When inspecting rock or slope reinforcements, check for . . .

- ✓ Loose or fallen soil or rock.
- ✓ Displacement of the structures.

If you suspect that the reinforcements have become ineffective, consult with an experienced and qualified engineer or geologist and recommend that additional supports be installed.

BULGES

Bulges develop as earth materials slide down a sloping area. Often, it is difficult to determine if bulges are the result of slides, poor grading of slopes during construction, or possible frost heave.

Figure II-4, on the previous page, illustrates a deep-seated slide, showing a bulge that developed as a result of the slide.

Bulges: Inspection Actions

If you see a bulge, you should . . .

- ✓ Record the location of the bulge on a map, photograph, or notebook.
- ✓ Inspect the area above it for cracks and scarps.
- ✓ Probe the bulge to determine if the material is excessively moist or soft.

If your inspection reveals any of these conditions . . .

- ✓ Recommend that the area be further inspected by an experienced and qualified engineer or geologist to determine the cause of the bulging and recommend a course of action.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSTABILITY

DEPRESSIONS

A depression is a sunken area of the ground that does not have a natural outlet for surface drainage. What may appear to be a depression may have been created by excavation during the construction of the dam. Depressions may also be caused by . . .

- Decay of buried organic material
- Thawing of frozen material
- Consolidation or settlement of the foundation
- Subsurface erosion or piping (sinkholes)

Depressions in the foundation area at the toe of the dam may pond water that can obscure the toe and possibly conceal seepage. Ponding may also saturate foundation soils which can lead to further instability.

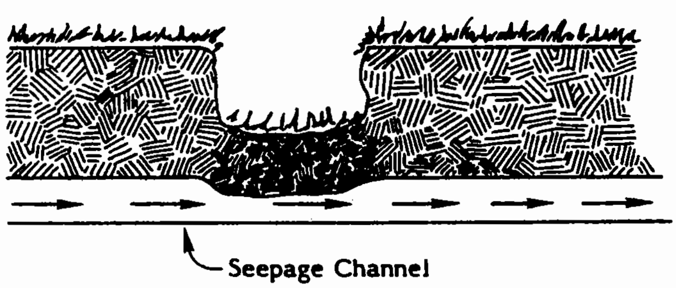
Depressions can be minor or they can be very serious. Sinkholes are a serious type of depression because they indicate removal of foundation material (piping), and generally have an underground outlet. A good way to distinguish between minor depressions and sinkholes is to look at their profiles (see Figure II-5).

- **Minor Depressions.** Minor depressions have gently sloping, bowl-like sides.

- **Sinkholes.** Sinkholes usually have steep, bucket-like sides due to the shearing action of the soil as it collapses into the underlaying void.

FIGURE II-5. DIFFERENCE BETWEEN MINOR DEPRESSIONS AND SINKHOLES

MINOR DEPRESSION



SINKHOLE

II. INSPECTING THE FOUNDATION AND ABUTMENTS: INSTABILITY

Depressions: Inspection Actions

Although minor depressions, in most cases, do not represent an immediate danger to the dam, they may be early indicators of more serious problems. If you observe a depression . . .

✓ Photograph and record the location, size, and depth of the depression.

✓ Probe the floor of the depression to determine whether or not there is an underlying void. An underlying void is indicative of a sinkhole.

✓ Recommend that the depression be observed frequently to determine whether it has stopped growing or not.

If you observe a sinkhole . . .

✓ Cautiously, with regard for your personal safety, probe the sinkhole to determine if the void is larger than it appears.

✓ Photograph and record the location, size, and depth of the sinkhole.

☞ **INSPECTION TIP:** Sinkholes can be very serious. Request that an experienced and qualified engineer or geologist evaluate sinkholes immediately.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: MAINTENANCE CONCERNS

INTRODUCTION

Maintenance includes the routine measures taken to protect and maintain the foundation and abutment areas as well as the rest of the dam. Deficiencies in the foundation and abutment areas associated with inadequate maintenance include . . .

- Surface runoff erosion
- Debris
- Animal burrows
- Inappropriate vegetative growth
- Accumulation of sediment
- Poor grading or drainage

We will now look at how to detect maintenance concerns that may adversely affect the foundation and abutment areas, and corrective actions that can be taken.

SURFACE RUNOFF EROSION

Erosion of abutment and foundation surfaces can result in loss of structural support for walls and appurtenant structures, and can also lead to sloughs and slides. Erosion can also cause undercutting and/or gullies in the groin areas. If undercutting is severe, it can cause stability problems, as well as shorten the path of seepage through the abutment areas.

Inspect surface drains and ditches along the groin areas to ensure they are operating properly. Water not flowing in these drains and ditches, or eroded or undermined supporting material around or under the drains, probably indicates an error in design or construction, or a lack of maintenance.

Surface Runoff Erosion: Inspection Actions

During the inspection, you should . . .

- ✓ Make sure that surface drains have provisions for the discharge of water that avoid eroding foundation or abutment material.
- ✓ Look for gullies or other signs of surface runoff erosion. Make sure you check the low points along the upstream and downstream shoulders and groins since surface runoff can collect in these areas.
- ✓ Look for vehicle ruts because, in many cases, erosion is precipitated by off-road vehicles causing ruts that damage protective vegetation and concentrate runoff.

If surface runoff erosion is observed . . .

- ✓ Record your findings and photograph the area.

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: MAINTENANCE CONCERNS

Surface Runoff Erosion: Inspection Actions (Continued)

- ✓ Determine the extent or severity of the damage.
- ✓ Determine the amount and location of sediment deposits caused by the erosion (if any).
- ✓ Clear surface drains and ditches of deposits caused by erosion (if possible).
- ✓ Recommend that corrective action be taken to repair the areas damaged by surface runoff and that measures be taken to prevent more serious problems.
- ✓ If vehicle rutting is a problem, recommend barriers be erected to prevent access to sensitive areas.

DEBRIS

While the accumulation of debris does not impose a serious threat to the safety of the dam, if left unattended, it can lead to serious problems. The buildup of brush and logs on the foundation and abutment areas can obscure certain areas from adequate visual inspection. Also, the buildup of brush and logs on the downstream foundation area can act as a dam, causing shallow flooding of areas and preventing adequate inspection for seepage. Excessive debris upstream can block the spillway or outlet works.

Debris: Inspection Actions

If you see debris in the foundation and abutment areas . . .

- ✓ Photograph and record your observation.
- ✓ Recommend that appropriate corrective actions be taken to remove the debris and that, if possible, measures be taken to prevent the future accumulation of debris.

ANIMAL BURROWS

Burrowing animals make nests and passageways in embankment dams, abutments, and groin areas. These passageways may appear as small mounds of soil. Animal burrows pose a threat to the structural integrity of a dam because they can weaken an area and become paths for seepage. Burrows are also damaging because they may lead to surface runoff erosion.

☞ **INSPECTION TIP:** If burrows are so prevalent that they honeycomb an embankment or the groin area, the integrity of the area is suspect. You should consult with an experienced and qualified engineer to determine the severity of the problem, and how to correct the damage. A biologist or wildlife specialist may assist in recommending how to rid the dam of burrowing rodents in the future.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: MAINTENANCE CONCERNS

Animal Burrows: Inspection Actions

If burrowing animals are evident . . .

- ✓ Photograph the area and record your findings.
- ✓ Recommend that measures be taken before serious damage occurs to the dam. Eradication or removal of the animals is usually the recommended course of action.

INAPPROPRIATE VEGETATIVE GROWTH

Some vegetation growing on or around the abutment and foundation areas is helpful in controlling erosion. However, inappropriate vegetative growth is another common maintenance problem. Inappropriate vegetative growth generally falls into two categories . . .

- Excessive vegetative growth
- Deep-rooted vegetation

Excessive Vegetative Growth

Excessive vegetation on the abutment and foundation areas can . . .

- Obscure areas of the foundation and abutment, preventing adequate visual inspection. Problems that may threaten the integrity of the dam can develop and remain undetected if they are obscured by vegetation.
- Prevent access to areas around the foundation and abutments. Limited access is a problem for both inspection and maintenance, especially during emergency situations, when access is crucial.
- Provide a habitat for rodents and burrowing animals. Burrowing animals can pose a threat to the groin areas of dams by burrowing through these areas and creating pathways for seepage.
- Obstruct inlets, discharges, and drains. Discharge and drainage areas that cannot function as intended can have an adverse effect on the dam.

Vegetative growth should be controlled on the abutments and foundation for a reasonable distance away from the groins and toe of the dam. Periodic mowing and clearing are the usual means of control.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: MAINTENANCE CONCERNS

Deep-Rooted Vegetation

Although a healthy cover of grass or other smaller types of vegetation is desirable as slope protection, the growth of deep-rooted vegetation, such as large shrubs and trees, is undesirable. Large trees could be blown over and uprooted during a storm. The resulting large hole left by the root system could shorten the seepage path and initiate piping.

Root systems associated with deep-rooted vegetation develop and penetrate into the dam's cross section. When the vegetation dies, the decaying root system can provide paths for seepage and cause piping to occur. Even healthy root systems of large vegetation can pose a threat by providing seepage paths. These seepage paths eventually can lead to internal erosion and threaten the integrity of the dam.

☞ **INSPECTION TIP:** It is generally agreed that it is undesirable for trees and shrubs more than 2 feet in height to grow on foundation and abutment areas within 10 to 50 feet or more of the dam. However, there is some debate in the engineering community over when and how to remove well- developed trees and root systems that are already in place. The location, size, type of tree, and prevailing policy will determine the course of action at a given site.

The best approach to control trees and shrubs is to cut them down **before** they reach significant size. If large trees have been cut down, but the root system not removed, carefully monitor the area around the remaining stumps for signs of seepage as the roots begin to decay.

Inappropriate Vegetative Growth: Inspection Actions

During the inspection you should . . .

- ✓ Look for excessive and deep-rooted vegetation on the foundation and abutments.
- ✓ Check for signs of seepage around any remaining stumps or decaying root systems on the downstream slope or toe area.

If inappropriate vegetation is observed . . .

- ✓ Photograph the area and record your findings.
- ✓ Note the size and extent of the inappropriate vegetation.
- ✓ Recommend that appropriate corrective action be taken to eliminate inappropriate vegetation and that measures be taken to prevent future growth.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: MAINTENANCE CONCERNS

ACCUMULATION OF SEDIMENT

Erosion and the subsequent sediment transport is a natural process occurring in all watershed streams or where water flows over or through soil. Sedimentation or the deposition of soil particles occurs in impoundments, in spillway approach channels, at the inlet to a drain or outlet structure, in discharge channels, in stilling basins, or at the outlets of internal drainage systems.

Sediment deposits at the outlet of an internal drain may indicate the removal of soil particles from an embankment, its foundation, or a filter zone of the drain itself. Sediment deposits from other sources such as erosion of soil from normal runoff may also obstruct the internal drain outlet.

Accumulation Of Sediment: Inspection Actions

If you see sediment collecting in the exits of drains or outlet works . . .

- ✓ Photograph and record your observations.
- ✓ Clean the sediment from the area to free the flow of water (if possible).
- ✓ Try to determine the source of the sediment.
- ✓ Recommend that an experienced and qualified engineer or geologist check out the situation if you suspect sediment deposits are a result of any internal erosion.

POOR GRADING OR DRAINAGE

If the downstream area of the dam is not sloped away from the dam, or if there is inadequate drainage, seepage, or surface runoff, water may stand or pond at the toe of the dam.

Poor Grading Or Drainage: Inspection Actions

If you see standing or ponding water at the toe of the dam . . .

- ✓ Photograph and record your observations.
- ✓ Try to determine the cause of the ponding water.

  If you suspect ponding is due to inadequate drainage, recommend that proper drainage be installed.

  If you suspect ponding is due to poor grading, recommend that an experienced and qualified engineer further examine the area.

II. INSPECTING THE FOUNDATION AND ABUTMENTS: UNIT EXERCISE

INSTRUCTIONS: Use the information presented in this unit to answer the following questions. When you have completed all of the questions, check your answers against those presented in the answer key. The answer key can be found immediately following this exercise.

1. While preparing to inspect a concrete dam, you become aware that the areas adjacent to the abutments are quite steep. Because you do not have experience in climbing, you decide not to inspect the area on foot. From where else might you inspect the abutments?

   - ____

2. Describe how to identify each of the seepage deficiencies described below.

   - Piping

     ____

     ____

   - Sand Boils

     ____

     ____

   - Solutioning

     ____

     ____

3. You are inspecting a relief well and discover the well flow is less than the amount you expected. What might be the cause of the decreased flow?

   ____

   ____

   ____

   ____

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: UNIT EXERCISE

4. You should be concerned about plugged drains because . . .

- ☐ Unrelieved seepage may contribute to increased internal water pressure and instability
- ☐ Seepage may increase at other drains
- ☐ The drain may become damaged
- ☐ There is no cause for concern

5. One visible indicator of a shallow slide is . . .

- ☐ Lush vegetation
- ☐ Pistol-handled trees
- ☐ Fractured rock at the top of a slope
- ☐ Loose material over bedrock

6. A bulge may be an indication of . . .

- ☐ Piping
- ☐ Seepage
- ☐ Subsidence
- ☐ Sliding

7. Why is a sinkhole more serious than other depressions?

____

____

____

____

8. Name one way in which debris can threaten the safety of a dam.

____

____

____

____

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: UNIT EXERCISE

9. During an inspection, you encounter an area of flowing water. Based on your knowledge of the dam, you know the flow is not coming from toe drains, foundation drains, or other controlled flow. What inspection actions should you take?

____

____

____

____

10. Upon examining seepage water in a glass jar, you notice the water is very cloudy, and fine sand has settled to the bottom of the jar. You suspect piping might be taking place. What recommendation would you make regarding this problem?

____

____

____

____

11. List the actions you should take when you encounter a slide area.

- ____
- ____
- ____
- ____
- ____

II. INSPECTING THE FOUNDATION AND ABUTMENTS: UNIT EXERCISE--ANSWER KEY

INSTRUCTIONS: Compare your answers to those given below to see how well you learned the information presented in this unit.

1. While preparing to inspect a concrete dam, you become aware that the areas adjacent to the abutments are quite steep. Because you do not have experience in climbing, you decide not to inspect the area on foot. From where else might you inspect the abutments?

   - **From the crest of the dam**
   - **From downstream using binoculars or a telephoto lens**

2. Describe how to identify each of the seepage deficiencies described below.

   - Piping

     Cloudy or turbid water emerging from area of seepage.

   - Sand Boils

     A mound of sand piled around the exit of a seepage area.

   - Solutioning

     Staining and/or deposits on the face of rock where seepage is exiting. Water quality testing is necessary to confirm solutioning.

3. You are inspecting a relief well and discover the well flow is less than the amount you expected. What might be the cause of the decreased flow?

   The well screens or filters may be clogged.

4. You should be concerned about plugged drains because . . .

   - ☑ **Unrelieved seepage may contribute to increased internal water pressure and instability**
   - ☐ Seepage may increase at other drains
   - ☐ The drain may become damaged
   - ☐ There is no cause for concern

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: UNIT EXERCISE-- ANSWER KEY

5. One visible indicator of a shallow slide is . . .

- ☐ Lush vegetation
- ☑ **Pistol-handled trees**
- ☐ Fractured rock at the top of a slope
- ☐ Loose material over bedrock

6. A bulge may be an indication of . . .

- ☐ Piping
- ☐ Seepage
- ☐ Subsidence
- ☑ **Sliding**

7. Why is a sinkhole more serious than other depressions?

A sinkhole may indicate that piping of foundation or abutment material is taking place, and could lead to dam failure.

8. Name one way in which debris can threaten the safety of a dam.

(Any of the following three answers is correct.)

Debris can plug outlet works and spillways.

Debris can damage outlet works and drains.

Buildup of brush and trees on the downstream foundation area can cause water to be ponded, saturating the downstream slope, and leading to possible instability.

9. During an inspection, you encounter an area of flowing water. Based on your knowledge of the dam, you know the flow is not coming from toe drains, foundation drains, or other controlled flow. What inspection actions should you take?

- **Record the level of the reservoir at the time of the observation.**
- **Photograph and record the location of the flowing water, and check the clarity.**
- **Follow the flowing water upstream to find the source of the water.**
- **Follow the flowing water downstream to ensure that it is not causing saturation of slopes that might lead to instability.**

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: UNIT EXERCISE-- ANSWER KEY

10. Upon examining seepage water in a glass jar, you notice the water is very cloudy, and fine sand has settled to the bottom of the jar. You suspect piping might be taking place. What recommendation would you make regarding this problem?

    Recommend that an experienced and qualified engineer examine the area immediately.

11. List the actions you should take when you encounter a slide area.

    - **Photograph and record the location of the slide.**
    - **Measure and record the extent and displacement of the slide.**
    - **Look for any surrounding cracks, especially uphill from the slide.**
    - **Probe the entire area to determine the condition of the surface material.**
    - **Check for seepage areas near the slide.**

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SUMMARY

INSPECTION PROCEDURES

This unit described various methods of inspecting the foundation and abutments of either concrete or embankment dams. Those procedures included . . .

- Walking the areas adjacent to the foundation and abutments
- Viewing the adjacent areas from the dam crest or opposite abutment
- Viewing the adjacent areas from downstream
- Underwater inspection

Weirs, flumes, relief wells, and drains were discussed in terms of how they could indicate adverse conditions in the foundation and abutments. For example, they can show . . .

- An increase or decrease in seepage flow.
- Sediment in seepage water samples that may indicate foundation and/or abutment material is being piped.
- Internal water pressures are building in the foundation and/or abutments.

DEFICIENCIES TO LOOK FOR

The types of deficiencies commonly found when inspecting the foundation and abutments of embankment and concrete dams are listed in Table II-1. Each deficiency includes a list of things to look for when inspecting for that deficiency.

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SUMMARY

DEFICIENCIES TO LOOK FOR (Continued)

TABLE II-1. COMMON DEFICIENCIES IN THE FOUNDATION AND ABUTMENT AREAS

TYPE OF DEFICIENCY	LOOK FOR . . .
SEEPAGE	✓ Flowing water unrelated to controlled flow through spillways, designed drainage systems, natural springs, or surface drainage ✓ Turbid (cloudy) seepage that may indicate piping ✓ Sand boils that indicate high seepage pressures and piping ✓ Surface staining and deposits on rock faces that may indicate solutioning and weakening of the foundation or abutments ✓ Standing water that may be due to seepage ✓ Lush water-loving vegetation that may be fed by seepage ✓ Depressions in the foundation area, especially sink-holes
INSTABILITY	✓ Cracking to significant depths ✓ Slides on abutment areas that may block or damage water conveyance inlets or outlets, or cause over-topping ✓ Bulges that are a result of earth material sliding or moving down a slope

Continued . . .

II. INSPECTING THE FOUNDATION AND ABUTMENTS: SUMMARY

DEFICIENCIES TO LOOK FOR (Continued)

TABLE II-1. COMMON DEFICIENCIES IN THE FOUNDATION AND ABUTMENT AREAS (Continued)

TYPE OF DEFICIENCY	LOOK FOR . . .
MAINTENANCE CONCERNS	✓ Surface runoff erosion that may undercut abutment slopes leading to instability ✓ Debris (trees, brush, other vegetation) that can block water conveyances ✓ Animal burrows that may provide pathways for seepage through the foundation or abutments ✓ Inappropriate vegetative growth that can inhibit visual inspection of the area where it is growing or, in the case of deep-rooted vegetation, provide pathways for seepage ✓ Accumulation of sediment deposits in impoundments, spillway approach channels, at the inlet to a drain or outlet structure, in discharge channels, stilling basins, or at the outlets of internal drainage systems that can block these areas, and may indicate piping ✓ Poor grading or drainage that may cause ponding at the toe of the dam

UNIT III

INSPECTING THE RESERVOIR RIM

III. INSPECTING THE RESERVOIR RIM: OVERVIEW

INTRODUCTION

Unit III describes the importance of inspecting the reservoir rim, and discusses the types of deficiencies commonly encountered and how these deficiencies affect the safety of the dam. Inspection actions and recommendations are provided for each deficiency.

UNIT OBJECTIVES

At the completion of this unit, you will be able to . . .

- Explain the importance of including the reservoir rim in a dam safety inspection.
- Select an appropriate method for inspecting the rim of a small, medium, and large reservoir.
- Identify and inspect deficiencies in the reservoir rim that either . . .
  - Directly affect the safety and integrity of the dam, or
  - May lead to more serious problems that will affect the safety and integrity of the dam.
- Evaluate the deficiency in the reservoir rim and make a recommendation to either correct the deficiency or alleviate its effects.
- Properly record your findings so that an accurate and useful record exists for future reference.

III. INSPECTING THE RESERVOIR RIM: INSPECTION PROCEDURES

INTRODUCTION

A key consideration in selecting a site for a dam and reservoir is the ability of the reservoir to safely contain water throughout the planned lifetime of the project. Therefore, when conducting a dam safety inspection, it is important to include an inspection of the reservoir rim to ascertain if it is still functioning as intended. Of particular concern are areas of potential slides. Although very rare, large slides can generate waves that may overtop the dam, possibly causing the dam to fail. More commonly, however, the concern is that slides will block or damage the appurtenant structures.

Piping or solutioning from seepage through a narrow rim could result in the release of the reservoir water potentially as destructive as the failure of the dam itself.

BEFORE THE INSPECTION

Before inspecting the reservoir rim, review the geologic data for the site to determine the types of materials in the rim. Also note whether areas of potential slides were identified during the design phase, and make a note of these areas on a map, on aerial or other photographs, or on your checklist. Then identify any treatments that were made to control seepage or stabilize slide areas.

INSPECTION TECHNIQUES

There are a number of ways to inspect the reservoir rim. The method used will depend upon the type of inspection being performed, the size of the reservoir, and the resources available for conducting the inspection. The methods of inspection described in this unit are . . .

- Inspecting the rim by boat
- Viewing the rim from adjacent areas
- Inspecting the rim by air
- Inspecting the rim by walking around it (if the reservoir is small)

Inspecting The Rim By Boat

The most practical way of inspecting the reservoir rim, especially if the reservoir is large, is by boat. The boat can be guided slowly around the reservoir, stopping at areas of concern to allow you to check the area visually, with binoculars, or to get out of the boat and inspect the area by foot.

Viewing The Rim From Adjacent Areas

If it is not possible to inspect the reservoir rim by boat, you may wish to view the rim from the crest of the dam or an area adjacent to the rim. Binoculars or a telephoto lens can be used. Systematically sweep the area until you are confident you have covered it completely. If you note certain deficiencies that require closer inspection, note the problem area on an aerial photograph, on a map, or in your notebook. Then make arrangements to visit the area for an inspection on foot (if possible). Certain deficiencies, such as bulging, may be easier to spot from a distance rather than close up.

III. INSPECTING THE RESERVOIR RIM: INSPECTION PROCEDURES

Inspecting The Rim By Air

An airplane or helicopter can also be used to inspect the reservoir rim. Observations from higher altitudes can often help spot problems that may be difficult to see at close range.

Inspecting The Rim On Foot

If the reservoir is small, it may be possible to inspect the rim by walking around the reservoir. This will allow a closer, more careful inspection.

☞ **INSPECTION TIP:** Regardless of the inspection method used, if you observe a condition that requires further observation or inspection by an engineer, note the deficiency on an aerial photograph or drawing of the reservoir to help others accurately locate the area.

SAFETY CONSIDERATIONS

In addition to exercising plain common sense, there are some basic safety rules you should always adhere to, namely:

- ✓ Always wear a life jacket when conducting your inspection from a boat.
- ✓ Never attempt to climb high, steep areas unless you are experienced in doing so and have the proper equipment (ropes, proper climbing shoes, etc.).

III. INSPECTING THE RESERVOIR RIM: INSPECTING FOR DEFICIENCIES

INTRODUCTION

The deficiencies found along the reservoir rim are essentially the same as those found on the foundation and abutments. Deficiencies common to the reservoir rim are . . .

- Slides
- Seepage and leakage
- Debris
- Erosion
- Excessive sedimentation

This section will examine these deficiencies in relation to the reservoir rim, focusing on how they affect the safety of the dam, and what to do if you notice any of these deficiencies during your inspection.

SLIDES

Slides along the reservoir rim exhibit the same warning signs as those on abutment areas; specifically, cracking, scarping, pistol-handled trees, and bulging.

Slides in the reservoir area can affect the safety of the dam in several ways, including . . .

- Reducing the amount of flood storage.
- Dumping trees, bushes, and other vegetation into the reservoir that could block or even damage water conveyance structures.
- Causing large waves to overtop the dam (a very rare possibility involving very large slides and narrow, confined canyons).

Slides: Inspection Actions

Before inspecting the rim, check any past inspection reports to determine if slides or areas of potential slides were identified.

✓ Check these areas to see if there has been any movement since the last inspection.

✓ Look for other evidence of slides, such as:

  - Cracks
  - Scarps
  - Bulges
  - Pistol-handled trees
  - Saturated areas in very loose, relatively fine-grained material

Continued . . .

III. INSPECTING THE RESERVOIR RIM: INSPECTING FOR DEFICIENCIES

Slides: Inspection Actions (Continued)

- ✓ Locate these areas on a photograph, map, sketch, or notepad.
- ✓ Check active slide areas for debris that could block water conveyances.

If you notice the beginnings of a slide . . .

- ✓ Photograph and record your findings.
- ✓ Recommend that a contingency plan be made to clean up any debris that may be dumped into the reservoir as a result of the slide.
- ✓ If you feel that a potential slide could be large, recommend that an experienced engineer or geologist examine the area and take appropriate actions to prevent the slide or alleviate the effects of the slide.

SEEPAGE

Seepage from a reservoir may be a critical economic consideration and even interfere with the intended uses of the reservoir. From the standpoint of dam safety, seepage through the reservoir rim or floor, particularly through a narrow ridge or near the dam or appurtenant structures, could cause piping, solutioning, or instability or even an uncontrolled release of the reservoir.

Because a dam is at the lowest point in the reservoir, most seepage will appear in the area downstream. Techniques for identifying seepage in the foundation and abutments were presented in Unit II.

Whirlpools

Whirlpools may be a serious manifestation of piping or large solution channels. Whirlpools indicate that piping or solutioning has progressed to a point that rapid draining of the reservoir could occur or is in progress. As draining continues, the opening may rapidly increase in size, and can cause loss of the reservoir through the rim within hours.

> **NOTE:** If the whirlpool is the result of piping through soils, then the problem can get serious very fast. If the whirlpool is the result of flow through solutioned rock, the increase in size of the opening may be very slow.

Whirlpools: Inspection Actions

If you observe a whirlpool, especially in the vicinity of the dam, you should **treat it as an emergency.**

- ✓ Notify appropriate officials **immediately.**

III. INSPECTING THE RESERVOIR RIM: INSPECTING FOR DEFICIENCIES

DEBRIS

Trees, brush, bushes, and other vegetation may present a threat to the dam if deposited into the reservoir by a slide or by wind. Debris can block intakes to outlets or spillways, causing loss of freeboard and overtopping.

Debris: Inspection Actions

When conducting your inspection of the reservoir rim, look for . . .

- ✓ Debris floating in the reservoir.
- ✓ Vegetated potential slide areas.

If you notice these conditions . . .

- ✓ Photograph and record your findings.
- ✓ Recommend that a contingency plan for the removal of debris be developed in the event of a slide.
- ✓ Recommend that trash racks, log booms, or other features designed to prevent debris from blocking outlet works and spillways be installed (if none presently exist).

EROSION

Erosion of the reservoir rim is generally caused by surface runoff, wave action, and currents, and can result in localized slumping or undercutting failures. These problems are usually not a concern for dam safety unless located near an abutment. The deposition of eroded material can interfere with proper dam functions by blocking entrance channels, outlet works, and downstream drains.

Erosion: Inspection Actions

If you see areas of erosion during your inspection . . .

- ✓ Photograph and record:
  - The location and extent of the erosion
  - The amount and location of deposits
  - The probable source of flowing water causing the erosion
- ✓ Evaluate the seriousness of the problem.
- ✓ Recommend that actions be taken to alleviate the problem, if you determine that it is serious.

III. INSPECTING THE RESERVOIR RIM: INSPECTING FOR DEFICIENCIES

EXCESSIVE SEDIMENTATION

Whenever there is water flowing over soil, sediments will naturally be transported. Efforts can be made only to control the problem, not solve it. Sedimentation of the reservoir is generally taken into account during the design stage of the reservoir. However, whenever sedimentation becomes excessive, problems arise.

Excessive sedimentation usually occurs as a delta at the head of the reservoir. Sediment materials are generally unstable. Underwater density currents involving unstable material can move rapidly along the bottom of the reservoir to the dam and obstruct intake structures and interfere with the safe operation of the dam, especially during seismic activity.

Excessive Sedimentation: Inspection Actions

When looking for evidence of sedimentation, inspect the reservoir rim as well as the head of the reservoir when the reservoir is drawn down. Soundings are often made by boat to get an accurate estimate of sediment deposition. These are referred to as hydrographic surveys. As an inspector, you should . . .

- ✓ Photograph and record any areas where sediment is visible.
- ✓ Determine if the deposits are sufficient to block intake structures. Hydrographic surveys or underwater inspection may be necessary to determine the existence or extent of sediment deposition, and whether the sediment needs to be removed around structures.
- ✓ If the sediment poses a threat to the safe operation of the dam, recommend that the situation be checked out by an experienced and qualified engineer or geologist, and that actions be taken to alleviate the situation.

III. INSPECTING THE RESERVOIR RIM: UNIT EXERCISE

INSTRUCTIONS: Use the information presented in this unit to answer the following questions. When you have completed all of the questions, check your answers against those presented in the answer key. The answer key can be found immediately following this exercise.

1. Name two methods for inspecting the reservoir rim.

   a. ______________________________

   b. ______________________________

2. Name one possible effect of earth materials sliding into the reservoir.

   ____

   ____

3. Where will most seepage from the reservoir appear?

   ____

   ____

4. How can you recognize piping from other types of seepage?

   ____

   ____

5. The appearance of a whirlpool should be considered an emergency.

   ☐ TRUE ☐ FALSE

III. INSPECTING THE RESERVOIR RIM: UNIT EXERCISE--ANSWER KEY

INSTRUCTIONS: Compare your answers to those given below to see how well you learned the information presented in this unit.

1. Name two methods for inspecting the reservoir rim.

   (Any two of the following are correct.)

   - **Inspecting the rim by boat**
   - **Viewing the rim from adjacent areas**
   - **Inspecting the rim by air**
   - **Inspecting the rim by walking around it**

2. Name one possible effect of earth materials sliding into the reservoir.

   (Any one of the following is correct.)

   - **Slides can reduce the amount of flood storage.**
   - **Slides can dump debris into the reservoir that may block and/or damage outlet works and spillways.**
   - **Slides can damage or block appurtenant structures.**
   - **Slides can cause large waves to overtop the dam.**

3. Where will most seepage from the reservoir appear?

   Downstream, near the dam.

4. How can you recognize piping from other types of seepage?

   Piping can be identified by cloudy, turbid seepage water that is carrying suspended solids.

5. The appearance of a whirlpool should be considered an emergency.

   ☑ TRUE ☐ FALSE

   A whirlpool may indicate that serious piping is occurring, and the failure of the dam is imminent. Emergency action should be taken immediately.

III. INSPECTING THE RESERVOIR RIM: SUMMARY

DEFICIENCIES TO LOOK FOR

This unit discussed procedures for inspecting the reservoir rim, the types of deficiencies commonly found on the reservoir rim, and how these deficiencies can impact the safety of the dam. Table III-1 provides things to look for when checking for these deficiencies.

TABLE III-1. COMMON DEFICIENCIES IN THE RESERVOIR RIM

TYPE OF DEFICIENCY	LOOK FOR . . .
SLIDES	✓ Cracks ✓ Scarps ✓ Bulges ✓ Pistol-handled trees ✓ Saturated areas in very loose, relatively fine-grained material
SEEPAGE	✓ Whirlpools
DEBRIS	✓ Trees, brush, bushes, or other vegetation that might block outlet works or spillways
EROSION	✓ Slumping ✓ Undercutting ✓ Deposition of eroded material at entrance channels, outlet works, and drains
EXCESSIVE SEDIMENTATION	✓ Deposits of sediment at the head of the reservoir or near the rim

FINAL REVIEW EXERCISE

INSPECTION OF THE FOUNDATION, ABUTMENTS, AND RESERVOIR RIM

FINAL REVIEW EXERCISE

INSTRUCTIONS: A situation is described below. After reviewing the situation, answer the questions using the information presented in this module.

When you have completed all of the questions, check your answers against those presented in the answer key. The answer key can be found immediately following the last page of this exercise.

THE SITUATION: You have been assigned to inspect Naff Dam. This is a 39-year-old dam located in Arkansas. It is an earthfill, central core dam designed for recreation, flood control, and water supply. The dam has a partial cutoff to 60 feet. Located in the left abutment is an outlet works, with an intake structure 30 feet from the abutment. There are relief wells located at the downstream toe. The valley floor has a 120-foot-deep channel filled with alluvium. The abutments are moderately fractured, interbedded limestone, sandstone, and shale. The plans show a grout curtain in each abutment. The abutment areas are not too steeply sloped, and can be walked during an inspection. The reservoir rim is moderately sloped near the dam itself, and is heavily forested.

---

1. You arrive at the dam and begin your inspection with the upstream abutment areas. The rocks in the abutments have hard and soft layers. You note that waves have eroded some of the softer material from under the harder portions. What can be the most likely consequence?

____

____

2. You notice an arc-shaped crack on the upper portion of the upstream left abutment, indicating the beginnings of a slide. What other indicators of a slide might you look for?

____

____

____

Continued . . .

FINAL REVIEW EXERCISE

3. Why might this particular slide be of concern?

____

____

4. While walking up the right groin drainage gutter, you notice several small dry mounds of soil at several different elevations that cover the gutter along the valley side. What is the best possible explanation?

____

____

5. You are inspecting a seepage problem through some of the limestone located in the right abutment near the groin area. The rock all around the seepage area has been stained white. What would be the most likely cause of the white stain?

____

____

6. What should you do if you notice surface staining on the face of rocks in the abutments where seepage is occurring?

____

____

____

7. Further down the downstream abutments you notice a significant amount of seepage. You fill a jar with some of the water and notice the water is quite cloudy. What might be happening?

____

____

Continued . . .

FINAL REVIEW EXERCISE

8. You have now progressed to the foundation area of the dam. Looking back over the abutments, you think you notice a slight bulge in the middle of the left abutment area, but are not sure. What is the best way you could check to see if there is in fact a bulge?

____

____

____

9. Your observations reveal that a bulge definitely exists. Upon closer inspection, the following observations were made:

   - There was an arc-shaped crack pattern with an opening from 1/2 to 1 inch, and 1 foot deep.
   - There were shale outcrops on a gently sloping area in the valley side 30 feet above and downstream of the crest of the dam.
   - The crack pattern extended for 20 feet horizontally.

   What condition may result?

____

____

10. There is dense vegetation in the right abutment, with trees in the groin area. Why would you be most concerned?

____

____

11. There is a system of abutment drains located just downstream of the toe of the dam. Water is flowing not only out of the drains, but also around them. What should you do?

____

____

Continued . . .

FINAL REVIEW EXERCISE

12. While inspecting the downstream area of the foundation, you notice two sand boils around a seepage area. Why would sandboils appear in this particular area?

____

____

13. You are inspecting the relief wells located at the downstream toe of the dam. One relief well has a cloudy discharge and contains sediments. What is happening?

____

____

14. Another relief well shows a diminished discharge, indicating the well may be plugged. What is the possible consequence of the plugged well?

____

____

15. You notice standing water at the toe of the dam. What are two possible sources of this water?

____

____

16. You have observed and recorded a large area of cattails downstream from the dam adjacent to the left valley side in the flood plain. Name two conditions this might indicate.

____

____

17. In the valley floor, you discover a large depression. What is your course of action?

____

____

Continued . . .

FINAL REVIEW EXERCISE

18. While inspecting the reservoir rim, you notice an area above the rim with downhill leaning trees below a bare area. What is the cause for this?

____

____

19. There are numerous shallow slides in the reservoir rim two miles from the dam. What is the major significance of these slides?

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20. The reservoir has an upstream impervious blanket. When the reservoir is drawn down, you notice several depressions in the impervious blanket on the right abutment area. Why should you be concerned?

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FINAL REVIEW EXERCISE

ANSWER KEY

FINAL REVIEW EXERCISE--ANSWER KEY

INSTRUCTIONS: Compare your answers to those given below. For more information review the referenced text pages and video segment.

	REFERENCES
1. You arrive at the dam and begin your inspection with the upstream abutment areas. The rocks in the abutments have hard and soft layers. You note that waves have eroded some of the softer material from under the harder portions. What can be the most likely consequence? **Undercutting failures** Wave action can wash away soft material, leaving a ledge that can eventually collapse.	Text Page: III-6
2. You notice an arc-shaped crack on the upper portion of the upstream left abutment, indicating the beginnings of a slide. What other indicators of a slide might you look for? **Bulging, wetness, leaning trees** Bulging and leaning trees indicate that the earth mass is moving downhill. Wetness can indicate seepage that might have been the cause of the instability.	Text Pages: II-16 - II-18 III-4
3. Why might this particular slide be of concern? (Either of the following answers is correct.) **Debris from the slide might block the outlet works inlet.** **The slide itself may block the outlet works inlet.** Any slides located near an inlet or outlet works present a threat because they can damage or block the structure.	Text Pages: II-15 III-4

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

REFERENCES

4. While walking up the right groin drainage gutter, you notice several small dry mounds of soil at several different elevations that cover the gutter along the valley side. What is the best possible explanation?

   Text Pages: II-24, II-25

   Animals are burrowing in the adjacent area.

   The soil could block the gutter and cause runoff to erode or saturate the slope. Also, animal burrows can provide pathways for seepage, and must be filled, and the animals causing the burrowing removed or destroyed.

5. You are inspecting a seepage problem through some of the limestone located in the right abutment near the groin area. The rock all around the seepage area has been stained white. What would be the most likely cause of the white stain?

   Text Page: II-13

   White calcite solutioned from the limestone.

   White calcite will cause a white stain. White and yellow calcite are common deposits found in areas of limestone.

6. What should you do if you notice surface staining on the face of rocks in the abutments where seepage is occurring?

   Text Page: II-13

   Take a water sample from both the reservoir and the seepage.

   Tests conducted on the water samples may show whether solutioning is occurring.

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

	REFERENCES
7. Further down the downstream abutments you notice a significant amount of seepage. You fill a jar with some of the water and notice the water is quite cloudy. What might be happening? **Seepage through or bypassing the abutment grout curtain is removing joint filling material from the rock.** The cloudy appearance of the water is caused by soil particles, which is a strong indication of piping.	Text Pages: I-18 II-10 II-11
8. You have now progressed to the foundation area of the dam. Looking back over the abutments, you think you notice a slight bulge in the middle of the left abutment area, but are not sure. What is the best way you could check to see if there is in fact a bulge? **Walk downstream for a distance and check the area with your binoculars.** Certain deficiencies, such as bulging, are easier to detect from a distance.	Text Page: II-3 II-20
9. Your observations reveal that a bulge definitely exists. Upon closer inspection, the following observations were made: • There was an arc-shaped crack pattern with an opening from 1/2 to 1 inch, and 1 foot deep. • There were shale outcrops on a gently sloping area in the valley side 30 feet above and downstream of the crest of the dam. • The crack pattern extended for 20 feet horizontally.	Text Pages: II-18 II-19

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

	REFERENCES
9. Your observations reveal that a bulge definitely exists. Upon closer inspection, the following observations were made: (Continued) What condition may result? **A slide may be occurring.** The depth and length of the crack indicate a large, deep slide. Slides are often loose material sliding off of bedrock or rock material, and the observation of rock shale outcrops indicates that this condition may exist.	Text Pages: II-18 II-19
10. There is dense vegetation in the right abutment, with trees in the groin area. Why would you be most concerned? **Piping can occur along the roots of the trees.** Deep root systems can provide a path for seepage and initiate piping if the tree or shrub is somehow uprooted, or if the tree or shrub dies and the root system decays.	Text Page: II-26
11. There is a system of abutment drains located just downstream of the toe of the dam. Several of the drains are not flowing. What should you do? **Recommend that the drain system be investigated to determine if it was designed or installed properly, or whether there is a blockage of these drains.** An inadequate or blocked drain system can result in increased seepage forces that could cause piping or instability.	Text Page: II-7

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

	REFERENCES
12. While inspecting the downstream area of the foundation, you notice two sand boils around a seepage area. Why would sandboils appear in this particular area? **The dam has only a partial cutoff.** Partial cutoffs do not fully extend to the impervious layer or to bedrock; therefore, they do not completely cut off seepage.	Text Page: I-20
13. You are inspecting the relief wells located at the downstream toe of the dam. One relief well has a cloudy discharge and contains sediments. What is happening? **The well screen and filter may have become clogged, and material is entering the well.** Cloudy discharge or sediments in water indicate that soil is being washed through an opening, or piping.	Text Page: II-6
14. Another relief well shows a diminished discharge, indicating the well may be plugged. What is the possible consequence of the plugged well? **Development of sand boils and uplift at the toe of the dam.** Relief wells are designed to help control hydrostatic pressures that can lead to piping or instability.	Text Pages: I-25 II-5 - II-6

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

	REFERENCES
15. You notice standing water at the toe of the dam. What are two possible sources of this water? (Any two of the following are correct.) **There has been recent precipitation.** **There is inadequate surface drainage.** **There is an accumulation of seepage.** **Beaver dams, sediment bars, debris, or vegetation may be blocking discharge channels.** It is not desirable to have standing water at the toe of the dam because it hampers inspection, and can also saturate the downstream toe, leading to instability.	Text Page: II-13
16. You have observed and recorded a large area of cattails downstream from the dam adjacent to the left valley side in the flood plain. Name two conditions this might indicate. (Any two of the following are correct.) **Seepage is occurring.** **There is standing water due to poor surface drainage.** **Saturation of the flood plain by a spring in the valley wall has occurred.** Cattails are a water-loving plant. If they are thriving in this area, it means that they are receiving an adequate water supply, possibly from seepage.	Text Page: II-14

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

	REFERENCES
17. In the flood plain, you discover a large depression. What is your course of action? **Probe the depression to check for softness, wetness, or flowing water. Probe the depression to determine if an underlying void exists that may indicate a sink-hole. Record the location and dimensions.** Depressions should be checked to make sure they are not sinkholes, which are serious and should be further investigated by an experienced and qualified engineer.	Text Page: II-22
18. While inspecting the reservoir rim, you notice an area above the rim with downhill leaning trees below a bare area. What is the cause for this? **Shallow or deep sliding.** Downhill leaning trees, accompanied by a bare area or scarp, indicate that material has been sliding.	Text Pages: II-15 - II-19 III-4
19. There are numerous shallow slides in the reservoir rim two miles from the dam. What is the major significance of these slides? **They can lead to larger slides, and can dump debris into the reservoir.** The vegetated debris from the slides may float down-stream and block the outlet works and spillway.	Text Page: III-4

Continued . . .

FINAL REVIEW EXERCISE--ANSWER KEY

REFERENCES
Text Pages: I-23 - I-24 II-21

20. The reservoir has an upstream impervious blanket. When the reservoir is drawn down, you notice several depressions in the impervious blanket on the right abutment area. Why should you be concerned?

    Blanket material may be piping into the abutment.

    Piping in areas near the dam is of extreme concern. If left to progress, it can lead to failure of the dam. Piping of blanket material also indicates that the effectiveness of the blanket as a seepage control measure is decreasing.

APPENDIX A

GLOSSARY

GLOSSARY

ABUTMENTS - Those portions of the valley sides which underlie and support the dam structure, and are usually also considered to include the valley sides immediately upstream and downstream from the dam.

ADIT - A gallery that is used for entrance to a gallery system or that serves as a connecting passageway between galleries or other features in the dam. Also, a closed-end tunnel.

BEARING CAPACITY - The maximum pressure that can be permitted on foundation soil or rock, giving consideration to all pertinent factors, with adequate safety against rupture of the soil or rock mass or movement of the foundation of such magnitude that the structure is impaired.

BEDDING - The arrangement of a sedimentary rock in beds or layers of varying thickness and character. The term may also be applied to the layered arrangement and structure of an igneous or metamorphic rock.

BEDROCK - A general term for the rock, usually solid, that underlies soil or other unconsolidated, superficial material.

BERM - A step in the sloping profile of an embankment dam. A step in a rock or earth cut. Also, a placement of fill at the toe of a slide to buttress it against further movement.

BLANKET DRAIN - A layer of pervious material placed to facilitate drainage of the foundation, abutment, and/or embankment.

BREACH - An eroded opening through a dam that drains the reservoir. A controlled breach is a construction opening. An uncontrolled breach is an unintentional opening that allows uncontrolled discharge from the reservoir.

CLAY - Soil particles 0.074 mm or smaller, which exhibit plasticity (putty-like properties) within a range of moisture contents, and which exhibit considerable strength when air-dried.

CREST - The top surface of the dam or high point of the spillway control section.

DAM FAILURE - The uncontrolled release of impounded water. There are varying degrees of failure.

DEFICIENCY - An anomaly or condition that affects or interferes with the proper and safe operation of the dam.

DOWNSTREAM FACE - The inclined surface of a concrete dam that faces away from the reservoir.

DOWNSTREAM SLOPE - The inclined surface of an embankment dam that faces away from the reservoir.

GLOSSARY

DRAINAGE CURTAIN (also called DRAINAGE WELLS or RELIEF WELLS) - A series of wells or boreholes to facilitate drainage of the foundation and abutments and to reduce water pressure. (This terminology generally is used with concrete dams.)

EARTHFILL DAM - A dam containing more than 50 percent, by volume, earthfill materials (fill composed of soil and rock materials that are predominantly gravel-sized or smaller).

EMBANKMENT - Fill material, usually earth or rock, placed with sloping sides.

EMBANKMENT DAM - Any dam constructed of excavated natural materials (includes both earthfill and rockfill dams).

FAULT - A fracture or fracture zone in the earth crust along which there has been relative displacement of the two sides.

FILL DAM - See **EMBANKMENT DAM.**

FINES - A term describing the fraction of a soil sample that is smaller than the 0.074 mm (No. 200) sieve. For example, a material such as gravel may be described as having a certain percentage of fines (meaning that the gravel is mixed with silt or clay).

FOUNDATION - The portion of the valley floor that underlies and supports the dam structure.

FREEBOARD - The vertical distance between a stated water level and the top of a dam or spillway crest.

FROST HEAVE - The raising of a surface due to the accumulation of ice in the underlying soil or rock.

GALLERY - A passageway in the body of a concrete dam used for inspection, operation, foundation grouting, and/or drainage. Galleries may run longitudinally or transversely, horizontally, or on a slope.

GRAVEL - Soil particles ranging in size from 1/4 inch to 3 inches.

GROIN - See **SLOPE-ABUTMENT INTERFACE.**

GROUT - A fluidized material that is injected into soil, rock, concrete, or other material to seal openings, lower the permeability, and/or provide additional structural strength. There are four major types of grouting materials: chemical, cement, clay, and bitumen.

HEADWATER - The water upstream from a structure, as behind a dam.

HEEL - The junction of the upstream face of a concrete dam with the ground surface.

GLOSSARY

INSTRUMENTATION - An arrangement of devices installed into or near dams (e.g., piezometers, inclinometers, strain gages, measurement points, etc.) that provide measurements used to evaluate the structural behavior and performance of the structure.

LIQUEFACTION - a) The process whereby soil behaves as a viscous liquid. b) A condition whereby soil undergoes continued deformation at a constant low residual stress or with low residual resistance, due to the buildup and maintenance of high-pore water pressures, which reduces the effective shearing resistance to a very low value. Pore pressure buildup leading to liquefaction may be due either to static or cyclic stress applications. The possibility of its occurrence will depend on the void ratio or relative density of a cohesionless soil and the confining pressure.

LOG BOOM - A chain of logs, drums, or pontoons secured end-to-end and floating on the surface of a reservoir to control floating debris, trash, and logs.

ORGANIC MATTER - A soil composed primarily of vegetable tissue in various stages of decomposition with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous.

OUTLET WORKS - A system of dam components that regulates or releases water impounded by a dam. Components of an outlet works include an entrance channel, intake structure, conduit, gate or valve housing, energy dissipators, and return channel.

PIPING - The progressive internal erosion of embankment, foundation, or abutment material.

RELIEF WELLS - Vertical wells or boreholes designed to reduce uplift pressure and collect and control seepage through or under a dam.

RESERVOIR - The body of water impounded by a dam.

RESERVOIR RIM - The boundary of the reservoir including all areas along the valley sides above and below the water surface.

RIPRAP - Broken rock or boulders placed on upstream and downstream slopes of embankment dams to provide protection from erosion.

ROCK - a) An aggregate of one or more minerals (e.g., granite, shale, marble). b) A body of undifferentiated mineral matter (e.g., obsidian). c) A body of solid organic material (e.g., coal).

ROCKFILL DAM - A dam containing more than 50 percent rockfill materials (predominantly cobble sized or larger).

SAND - Soil particles ranging in size from "just visible" to 1/4 inch.

GLOSSARY

SAND BOIL - A condition resulting from the upward flow of seepage under pressure and characterized by a boiling action of the surface seepage. Often accompanied by a cone of material around the boil which develops from the deposition of foundation or embankment material carried by the seepage.

SCARP - An over-steepened surface on a slope resulting from instability or erosion (i.e., head of a slide).

SEEPAGE - The passage of water through embankment, foundation, or abutment material.

SHOULDERS - The upstream and downstream edges of the crest of the dam.

SILT - Soil particles 0.074 mm or smaller, which are nonplastic or very slightly plastic, and exhibit little or no strength when air-dried.

SINKHOLE - A depression resulting from loss of material underlying the surface.

SLIDE - The unplanned descent of a mass of earth or rock down a slope.

SLOPE-ABUTMENT INTERFACE - The contact between the abutment and the embankment slopes.

SPILLWAY - A structure over or through which flood flows are discharged. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the elevation of the spillway crest is the only control, it is considered an uncontrolled spillway.

STRENGTH - The maximum stress that a material can resist without failing for any given type of loading.

STRESS - A load or force acting on a unit of area (such as pounds-per-square-foot); for example, the force per unit area acting within the soil mass.

TAILWATER - Water at the toe of a spillway or outlet works, such as water in a stilling basin, plunge pool, or stream. The water downstream from a structure or dam.

TOE DRAIN - A seepage control drain located along or beneath the toe that carries internal seepage water away from the dam.

TOE OF DAM - The junction of the downstream slope of a dam with the ground surface; also referred to as the **downstream toe.** For an embankment dam, the junction of the upstream face with the ground surface is called the **upstream toe.**

TRASHRACK - A structure of metal or reinforced concrete bars located at the intake of a waterway to prevent entrance of floating or submerged debris above a certain size.

TURBIDITY - The discoloration or cloudiness of seepage water proportionate to the amount of soil particles suspended in the water.

GLOSSARY

UPLIFT PRESSURE - Upward water pressure in the pores of a material or on the base of a structure.

UPSTREAM FACE - The vertical or near-vertical surface of a concrete dam that is in contact with the reservoir.

UPSTREAM SLOPE - The inclined surface of an embankment dam that is in contact with the reservoir.

WEIR - A structure of given shape and dimensions built across a stream or channel to control or measure flow quantities.

APPENDIX B

REFERENCES

INSPECTION OF THE FOUNDATION, ABUTMENTS, AND RESERVOIR RIM

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