Inspection of Embankment Dams

Course No: G06-004

Credit: 6 PDH

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Training
Aids for
Dam
Safety

MODULE:

INSPECTION OF EMBANKMENT DAMS

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Unit 1 Inspection of Embankments

Unit 2 Inspection of Deficiencies:

- Part 1- Seepage
- Part 2-Cracks, Depressions, Sinkholes, Maintenance Concerns

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Training Aids for Dam Safety

Inspecting the Dam Embankment

Unit I

Inspecting the Dam Embankment

Note - Reference is made to a video portion of this course. This course material does not include the video which is available at www.damsafety.org. The course quiz does not require access to the video. To avoid confusion, references to the video are crossed out.

I. INSPECTING THE DAM EMBANKMENT: OVERVIEW

INTRODUCTION

This first unit of the Embankment Dams module will introduce you to:

- Embankment Dam Fundamentals
  - Characteristics of Embankment Dams
  - Types of Embankment Dams
- Embankment Dam Features
- Embankment Dam Inspection Techniques

If you are new to dam safety inspection, the material presented in this unit will provide important background information. The discussion of the inspection process is designed to provide you with guidance for conducting a comprehensive inspection of a dam embankment.

If you have experience with embankment dams, this unit will provide a brief refresher on key terminology used in embankment dam inspection. Since terminology can differ from agency to agency, you may find it helpful to review this section to become familiar with how terms will be used in this module.

UNIT OBJECTIVES

After completing this unit, you will be able to:

- Describe the characteristics of embankment dams.
- Describe the different types of embankment dams.
- List the principal features of an embankment dam and describe the functions of each feature.
- Describe the procedures for inspecting the upstream slope, downstream slope, crest, abutments, downstream toe, and seepage collection drains of an embankment dam.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FUNDAMENTALS

INTRODUCTION

This section provides background information on the characteristics and types of embankment dams. Some types of embankment dams may be more susceptible than others to certain kinds of deficiencies. Understanding how embankment dams are designed and constructed may help when conducting your inspections.

EMBANKMENT DAM CHARACTERISTICS

Embankment dams are defined as those constructed primarily of the natural materials of the earth, namely soil and rock.

Embankment dams generally have certain advantages over concrete dams with regard to site conditions and economy.

- **Site Conditions:** Embankment dams can be built on a wider variety of foundations and topography than can concrete dams.

- **Economy:** Embankment dams are typically built from materials excavated at or near the dam site, and usually only require minimal processing.

The principal vulnerability of an embankment dam is that it may be damaged or even destroyed if insufficient height or spillway capacity allows overtopping and erosion of the dam, or if uncontrolled seepage results in internal erosion of the embankment and its foundation.

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 a dam type most suited to a site depends on careful consideration of several factors:

- Site topography, geology, and foundation conditions
- Availability of construction materials
- Requirements for spillways and outlets
- Climatic conditions
- Reservoir operations
- Maintenance considerations

Failure of designers to properly address one or more of these factors could have implications with regard to the safety of a dam. These factors having been considered, the cost of construction then usually becomes the deciding consideration in determining the type of dam that will be built.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FUNDAMENTALS

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).

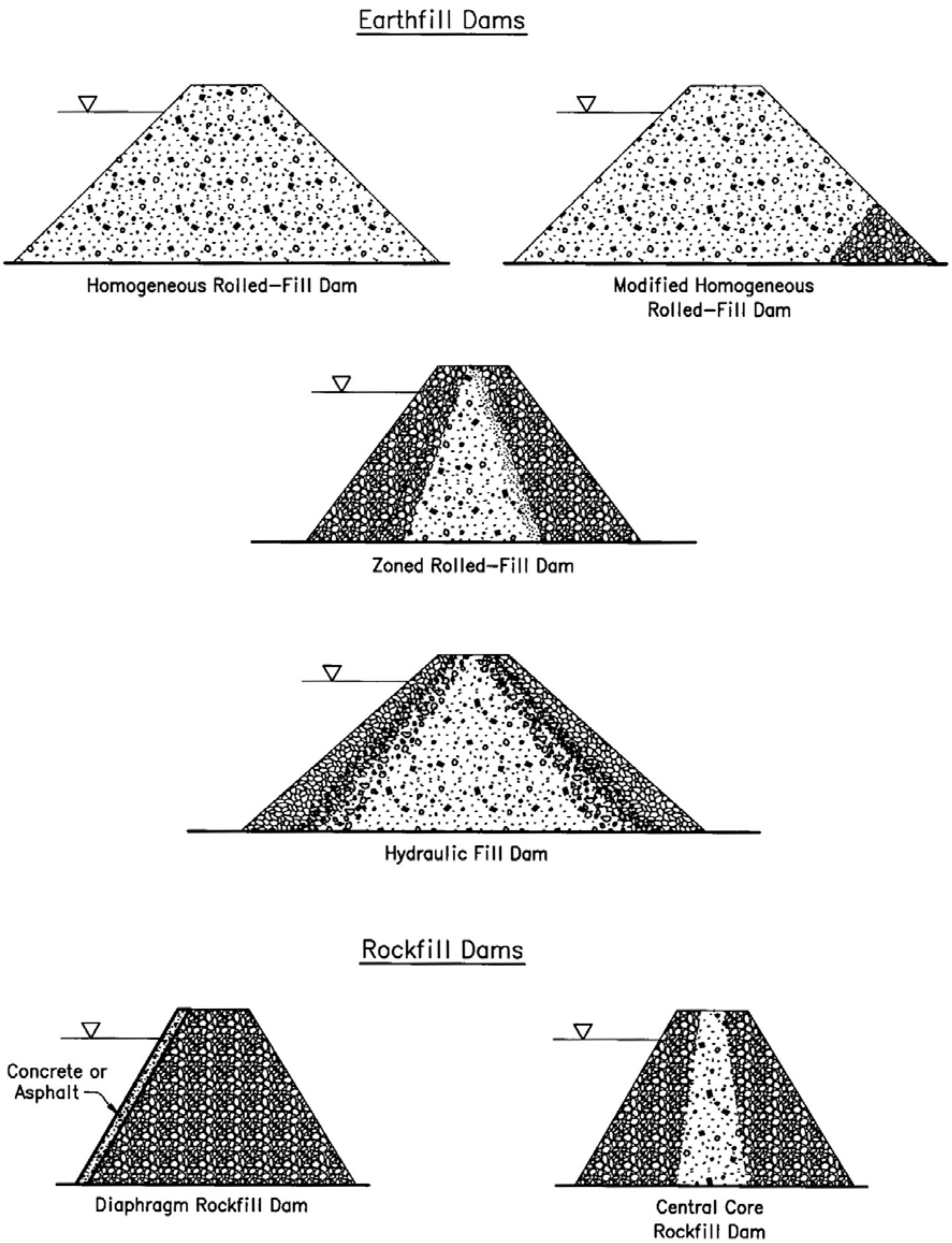
These two main types of embankment dams can be subdivided further based on the configuration of materials or construction methods. Figure I-1, on the following page, shows the common types of earthfill and rockfill dams.

Earthfill Dams

The advent of large earth-moving and compaction 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.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FUNDAMENTALS

FIGURE I-1. SCHEMATIC OF THE MAJOR TYPES OF EMBANKMENT DAMS



I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FUNDAMENTALS

Homogeneous Rolled-Fill Dams

A homogeneous dam is composed of a single kind of material, exclusive of slope protection. The material must be sufficiently impervious to provide an adequate water barrier, and the slopes must be relatively flat for stability and adequate dissipation of reservoir head as water seeps through the dam. In a modified homogeneous dam, small amounts of carefully placed pervious materials control seepage through the dam. (See Figure I-1.)

Zoned Rolled-Fill Dams

The most common type of rolled earthfill dam is the zoned type, in which a central impervious core is flanked by zones of materials considerably stronger than the core and generally more pervious, called shells. These shells enclose, support, and protect the impervious core; the upstream pervious zone affords stability against rapid drawdown; and the downstream pervious zone provides stability and may act as a drain to control seepage through the dam. (See Figure I-1.)

Hydraulic-Fill Dams

Some older earthfill dams, known as hydraulic-fill dams, were constructed by using water to transport 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 to the central portion of the fill. The result is a zoned embankment with a relatively impervious core, but embankment materials are in a loose saturated state, making these type dams susceptible to large deformations during earthquakes. This method of construction was economical, and hence popular prior to the advent of modern earth moving equipment.

Rockfill Dams

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

Diaphragm Rockfill Dams

In a diaphragm rockfill dam, the body of the dam is constructed of rock (cobble sizes or larger), and a thin diaphragm of impermeable material is provided to form the water barrier. The diaphragm is an impervious barrier placed on the upstream face or a thin vertical core, and it may consist of earth, concrete, asphalt, or other material. (See Figure I-1.)

Diaphragm rockfills have several advantages. They have greater stability against downstream instability than a central core rockfill dam. If the use of the reservoir permits, the reservoir can be drawn down periodically to check the integrity of an upstream diaphragm, and repairs can be made if necessary. Uplift pressures present no problems, and benefits also arise from the fact that an upstream diaphragm can be installed after the rockfill zone has been placed and any construction settlement that could potentially rupture the diaphragm has occurred.
On the negative side, because an upstream diaphragm is exposed, it is susceptible to damage.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FUNDAMENTALS

Central Core Rockfill Dams

Central core rockfill dams are similar in configuration to zoned earthfill dams, but are constructed with outer zones of coarse, free-draining rockfill which are more stable than finer grained soils, allowing steeper external slopes, and hence an economical design because less material is required. (See Figure I-1.) The central earthen core of this type of rockfill dam is placed in the same way as for a rolled earthfill dam. The shells of modern rockfill dams are compacted with large vibratory rollers, and hence little post-construction settlement occurs. However, before the advent of such equipment, the rockfill of the shells was often simply dumped into place, and as a result, settled considerably with time. Differential settlement between zones—the loose shell material and the well-compacted core—has occurred on many of these older rockfill dams. A central core rockfill dam of good design and careful construction techniques has a high resistance to deformation during earthquakes.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FEATURES

INTRODUCTION

This section presents information on the features of a typical embankment dam. Figure I-2, on the following page, shows the principal features of an embankment dam. The figure also shows some of the common deficiencies that you will learn more about later in this module. Let's briefly look at each of the features.

UPSTREAM SLOPE

The upstream slope is the inclined surface of the dam that is in contact with the reservoir. The upstream slope of an embankment dam must be protected from the erosive action of waves. Erosion protection may include vegetation, the placement of riprap or some other slope protection material, or the configuration of the slope. The shells of central core rockfill dams offer their own protection against wave erosion.

DOWNSTREAM SLOPE

The downstream slope is the inclined surface of the dam away from the reservoir. The downstream slope also requires some form of protection from the erosive effects of surface runoff. Grass or rock is often used for erosion protection on the downstream slope.

The upstream and downstream slopes may be described as relatively steep or flat. The slopes can also be described as a ratio of the horizontal dimension (H) to the vertical dimension (V). For example, a slope ratio of 2H:1V describes a slope that is moderately steep.

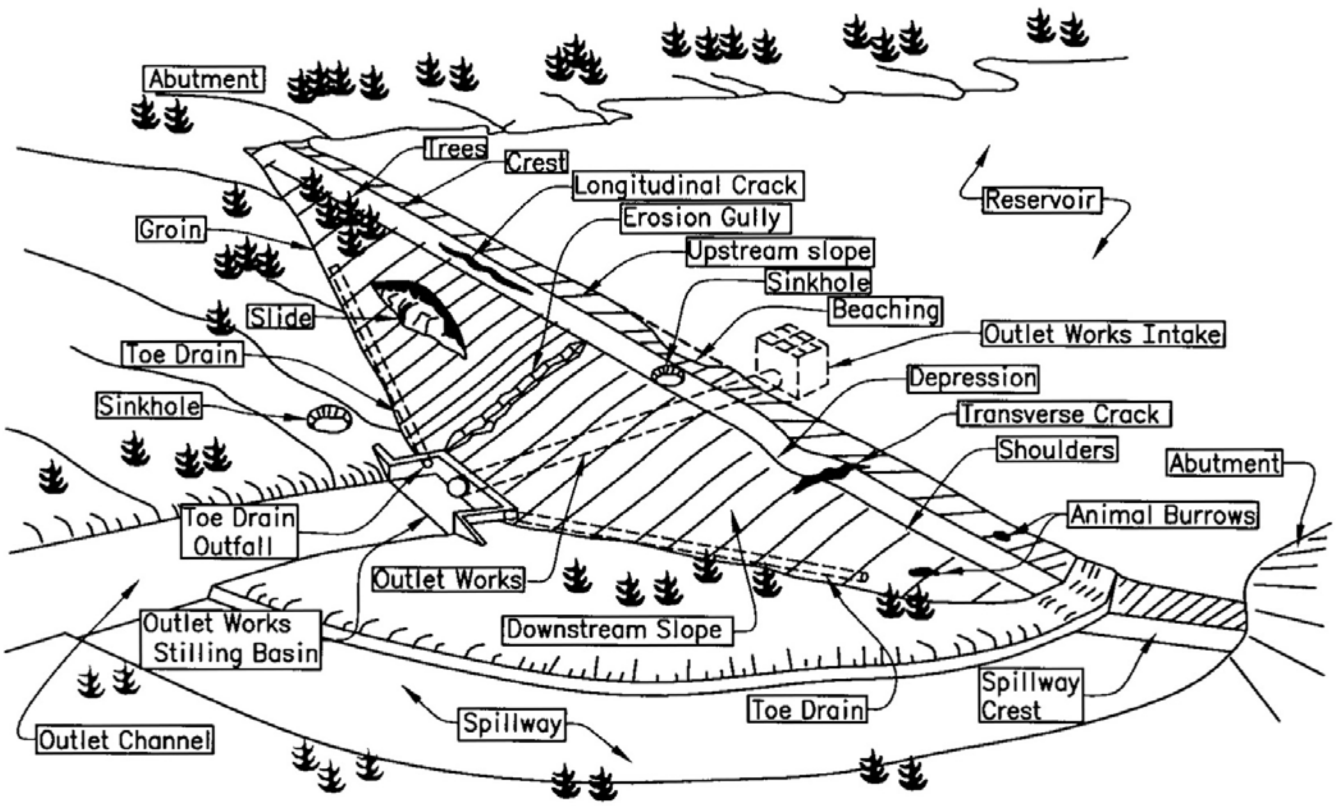
CREST AND SHOULDERS

The **crest** is the top surface of the dam. A roadway is often established across the crest for traffic or to facilitate dam operation, inspection, and maintenance.

The **shoulders** are the intersection of the crest with the upstream and downstream slopes.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FEATURES

FIGURE I-2. TYPICAL EMBANKMENT DAM WITH DEFICIENCIES



Boxed titles indicate major features of an embankment dam. The remaining titles are deficiencies commonly found on embankment dams.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FEATURES

DOWNSTREAM TOE OR TOE

The junction of the downstream slope of the dam with the ground surface is called the **downstream toe** or **toe.**

ABUTMENT

The **abutment** is that part of the valley side against which the dam is constructed. The contact between the abutment and the embankment slope is called the **embankment-abutment contact.** Embankment-abutment contacts are also referred to as **groins.**

RESERVOIR

The **reservoir** is the body of water impounded by a dam.

WATER CONVEYANCE STRUCTURES

The passage of water through and around the dam is accomplished by **water conveyance structures** including:

- **Spillway:** The **spillway** is the primary structure over or through which flood flows are discharged from a reservoir. If the rate of flow is controlled by mechanical means, such as gates, the structure is considered a controlled spillway. If the geometry of the spillway is the only control, the structure is considered an uncontrolled spillway.

  As illustrated in Figure I-2, spillways usually draw water from the top of the reservoir pool.

- **Outlet Works:** The **outlet works** are the structures through which normal reservoir releases are made. Outlet works can also be used to drain the reservoir. Outlet works can either be conduits which pass through the embankment or its foundation, or tunnels which are excavated through abutment rock.

Outlet works usually draw water through the dam from near the bottom of the reservoir. Spillways and outlet works may be combined into one structure. A dam can have multiple spillways and outlet works structures.

- **Penstocks: Penstocks** are pipelines or pressure conduits leading from the reservoir to the power-generating turbines. Penstocks are usually found on dams with power-generating plants.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT DAM FEATURES

TOE DRAIN

Toe drains are the most common type of internal drain. Toe drains collect and carry internal seepage away from the dam. A toe drain consists of a relatively pervious zone of material placed within the toe of the dam or laid in a trench beneath the toe, and often encloses a collector pipe surrounded by filter material. A toe drain collects seepage from the embankment and foundation and carries it to an outfall pipe that discharges the seepage into the spillway or outlet-works basin or otherwise safely away from the dam. The toe drain **outfall** is the discharge point for the toe drain. The outfall is a convenient point for measuring seepage quantities.

REFERENCE CONVENTIONS

Convention dictates that when you refer to right or left on a dam, your perspective should always be facing downstream (with the reservoir behind you). For example, the right abutment would be on your right-hand side when you are standing on the crest looking downstream.

Following this convention will help individuals who use your reports to orient themselves and will eliminate any confusion about where deficiencies were observed.

SUMMARY

This section described the principal features of an embankment dam. Now you will be introduced to how these features are inspected.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT INSPECTION TECHNIQUES

INTRODUCTION

The purpose of inspection is to identify deficiencies at an early stage so that corrective action can be taken before the safety of the dam is jeopardized. A deficiency is an anomaly or condition that affects or interferes with the proper safe operation of the dam.

An effective inspection requires thorough preparation. You may want to review the TADS module, "Preparing to Conduct a Dam Safety Inspection." A team approach should be used during the inspection when feasible. Team inspections often result in a more thorough examination. It is critical that inspectors follow all applicable safety standards. Inspections of a particular dam should be conducted at different times of the year. Varying inspection times allows you to examine the dam under different reservoir loading conditions and with different amounts of vegetation. However, it is also beneficial to inspect the dam at similar reservoir levels in order to identify changing conditions for similar loading.

This section presents some general guidelines for inspecting the dam embankment.

INSPECTING THE SLOPES

The general technique for inspecting the slopes of the dam is to walk over the slopes as many times as is necessary in order to see the entire surface area clearly. From a given point on the slope, you can usually see small details for a distance of 10 to 100 feet in each direction, depending on the roughness of the surface, vegetation, and other surface conditions. Therefore, to ensure that you have covered the entire broad surfaces of the dam, you must repeatedly walk back and forth across the slope until you have clearly seen the entire area. The following approaches can be used for walking across the slope and crest.

PATTERN	DESCRIPTION
Zigzag	A zigzag path is one recommended approach for ensuring that you have covered the slopes and crest. It may be preferable to use a zigzag path on small areas or slopes that are not too steep. Figure I-3, on the following page, illustrates the use of a zigzag path to walk a dam slope.
Parallel	A second approach is to make a series of passes parallel to the crest of the dam across the slope. It is usually preferable to use parallel passes on larger slopes or on slopes that are very steep, since this method is less arduous. Figure I-4, on the following page, illustrates the use of parallel passes to walk a dam slope.

Both of these techniques are acceptable methods for walking the dam slopes and crest. Remember, the goal is to be able to see the entire surface of the embankment clearly. Reaching this goal may require that you walk the surfaces several times.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT INSPECTION TECHNIQUES

INSPECTING THE SLOPES (Continued)

FIGURE. I-3 ZIGZAG PATTERN OF INSPECTING THE SLOPE

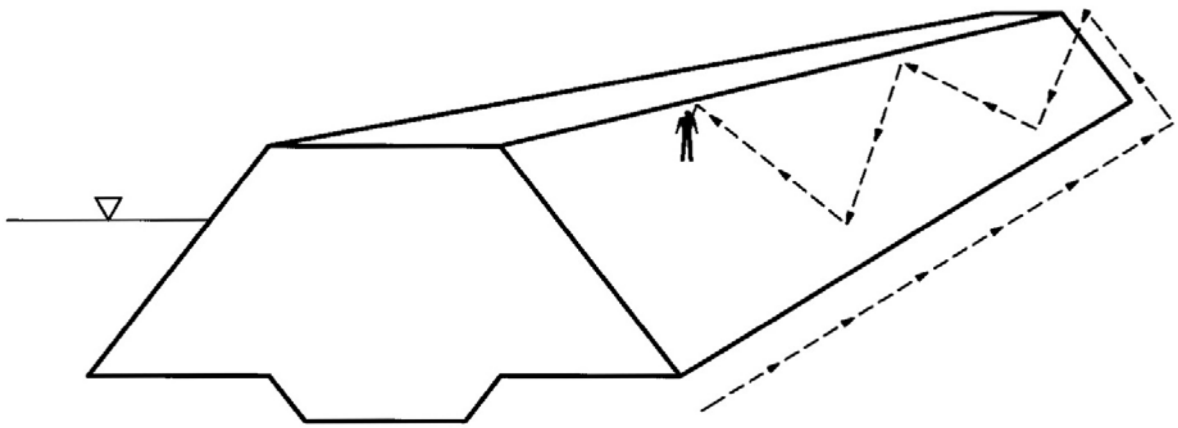
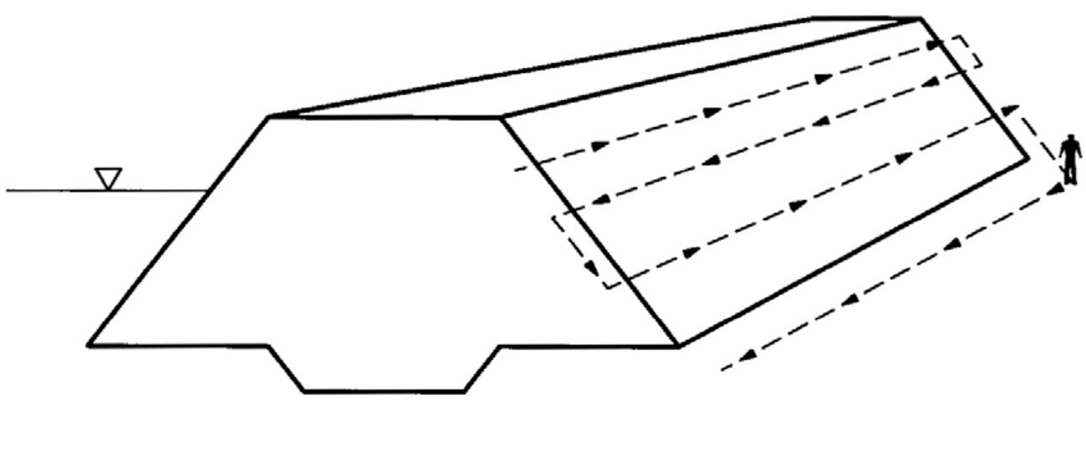


FIGURE I-4. PARREL PATTERN OF INSPECTING THE SLOPE



I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT INSPECTION TECHNIQUES

INSPECTING THE SLOPES (Continued)

At regular intervals while walking the slope, you should stop and look around for 360 degrees to:

- ✓ Check the uniformity of all visible surfaces.
- ✓ Double check that you have not overlooked some deficiency.

By stopping and looking around, you are able to view the slope from different perspectives. Seeing the slope from different perspectives sometimes reveals a deficiency that might otherwise be undetected.

In addition, viewing the slope from a distance may also reveal a number of anomalies such as distortions of the embankment surfaces and subtle changes in vegetation as will be discussed later. Often these types of observations are not apparent when viewing them close up. Also, viewing from a distance may reveal areas of greener or more lush vegetation that may indicate seepage. Such areas should be inspected more closely.

INSPECTING A ROCKFILL DAM

On embankments where the outer slopes are comprised of rockfill, distortion of the slopes is best discerned from a more remote perspective than from directly on the slope of the dam. This is because the slope surface is irregular and distortions are often difficult to see close up. The crest, reservoir/embankment contacts, abutments, groins, and the downstream toe are good vantage points for assessing potential slope movements. When observations from off the slope or historic data identify a potential problem on a rock slope, a closeup inspection of that area should be undertaken.

INSPECTING THE GROINS

You should carefully inspect the embankment-abutment contacts or groins by walking these areas.

Inspection of the groins is important because these areas are susceptible to:

- Surface runoff erosion.
- Seepage.

You will learn more about detecting these deficiencies later in this module.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT INSPECTION TECHNIQUES

INSPECTING THE CREST

Inspecting the crest is similar to inspecting the slopes. You can use either a zigzag pattern or a parallel pattern to inspect the crest. When inspecting the crest, remember to:

- ✓ Walk the crest as many times as needed to cover the entire area to ensure that no deficiencies go undetected. The key is that you look at every bit of the surface area. Inspect pavements and parapet walls for signs of distress such as cracking, displacement or depressions

- ✓ View the crest from many different perspectives. Some deficiencies can be spotted close up, while other deficiencies can be observed only from a distance.

SIGHTING TECHNIQUES

When checking the alignment of the crest and any berms on the upstream and downstream slopes, a useful sighting technique is to center your eyes along the line being viewed and move from side to side in order to view the line from several angles.

Some tools to help in sighting are:

- **Binoculars and Telephoto Lens:** The use of binoculars or a telephoto lens can help you observe irregularities because distances are foreshortened and distortions perpendicular to the line of sight become more apparent.

- **Reference Lines:** On a straight axis dam, linear features can serve as reference lines and be of great assistance in determining embankment movements. Reference lines can be such features as guardrails, a row of posts, pavement stripes on the crest roadway, parapet walls, and permanent monuments that serve as horizontal or vertical control points along the surface of the dam. If you identify misalignments of these reference features, be aware that they may be caused by factors other than dam deficiencies. A closer observation is required.

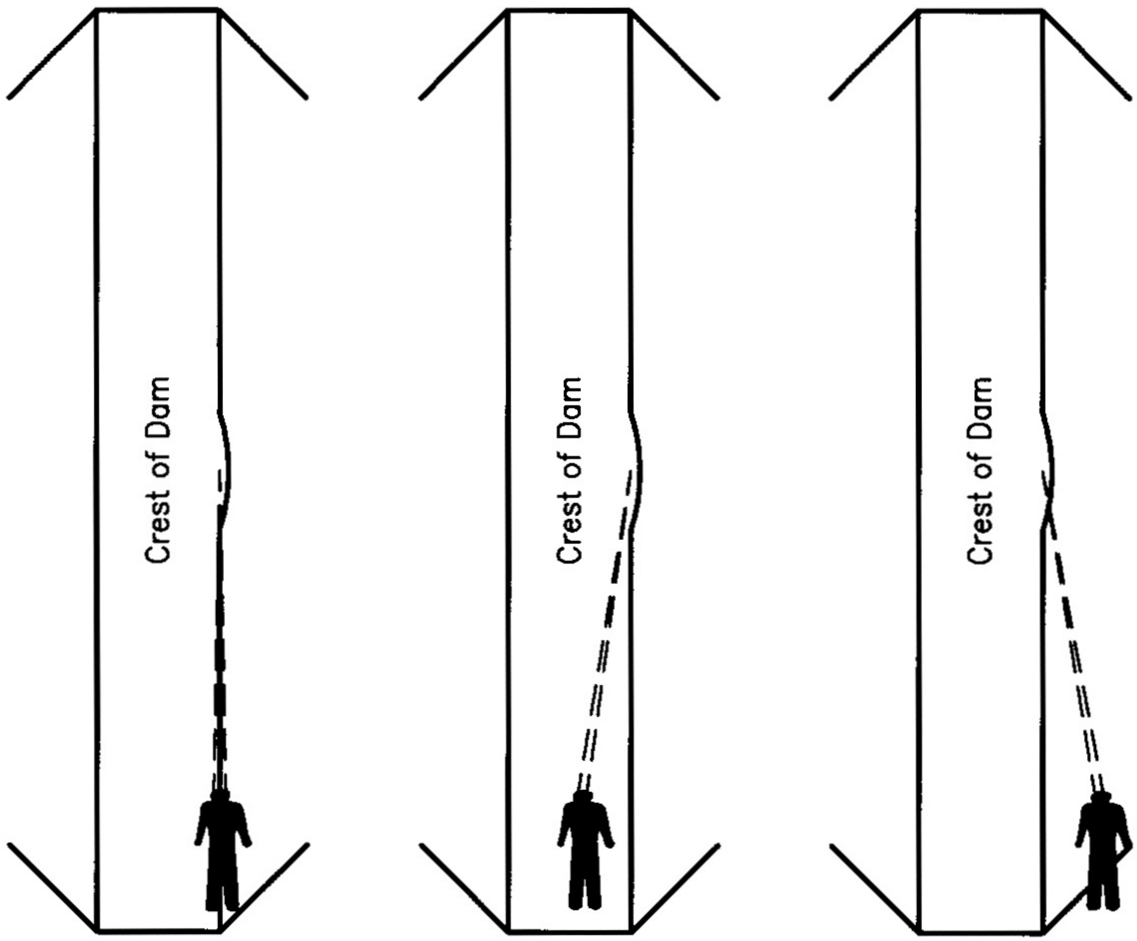
- **Hand Level or Transit:** A hand level or transit can be used as a straight line of sight to determine any horizontal or vertical misalignment. When used in conjunction with a leveling rod, exact measurements can be recorded.

Figure I-5, on the following page, illustrates the sighting technique used along the crest of the dam.

I. INSPECTING THE DAM EMBANKMENT: EMBANKMENT INSPECTION TECHNIQUES

SIGHTING TECHNIQUES (Continued)

FIGURE I-5. SIGHTING ALONG THE CREST



In sighting along the crest, you need to view your chosen reference line from a number of different perspectives. First sight on a direct line; then move to either side. ~~The technique of sighting along the crest using the naked eye, a telephoto lens, and binoculars is shown in the videotape presentation you are about to watch.~~

The sighting technique described in this section is also useful for detecting a change in the uniformity of the slope. The contact between the reservoir waterline and the upstream slope should parallel the alignment of the dam axis. In other words, the reservoir waterline should be a straight line if the dam has a straight axis.

I. INSPECTING THE DAM EMBANKMENT: SUMMARY

This section provided some general guidelines for inspecting the dam embankment. In the next unit, you will learn how to detect seepage problems. Seepage problems are one of the major types of deficiencies you will encounter as a dam safety inspector.

~~VIDEO PRESENTATION~~

~~At this point you should watch the first video presentation, which reviews the inspection procedures presented in this section of the module. To watch the video presentation . . .~~

- ~~Turn on your video player.~~
- ~~Load the videocassette.~~
- ~~Watch video segment #1.~~

A~~fter watching video segment #1, return to the next unit in this text. Do not rewind the videocassette.~~

Unit II

Inspecting for Deficiencies

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

INTRODUCTION

The purpose of inspection is to identify existing or potential dam safety deficiencies. This unit presents information on:

- The kinds of deficiencies you will be expected to identify.
- The impact deficiencies have on the safety of a dam.
- The actions you should take if you find deficiencies.

Embankment dams are subject to several different types of deficiencies. These deficiencies include:

- Seepage
  - Controlled
  - Uncontrolled
- Cracking
- Instability
  - Slides
  - Lateral Spreading
- Sinkholes
- Depressions
- Maintenance Concerns
  - Inadequate Slope Protection
  - Surface Runoff Erosion
  - Inappropriate Vegetative Growth
  - Debris
  - Animal Burrows

Each type of deficiency will be discussed in detail in this unit. You may have noticed that some of the above-listed deficiencies are shown in Figure I-2 in Unit I of this module. You may want to refer to that figure as you learn about each type of deficiency.

UNIT OBJECTIVES

After completing this unit, you will be able to:

- Identify and explain the characteristics and potential consequences of seepage, cracking, instability, sinkholes, depressions, and inadequate maintenance.
- Explain what actions should be taken to protect the dam embankment.

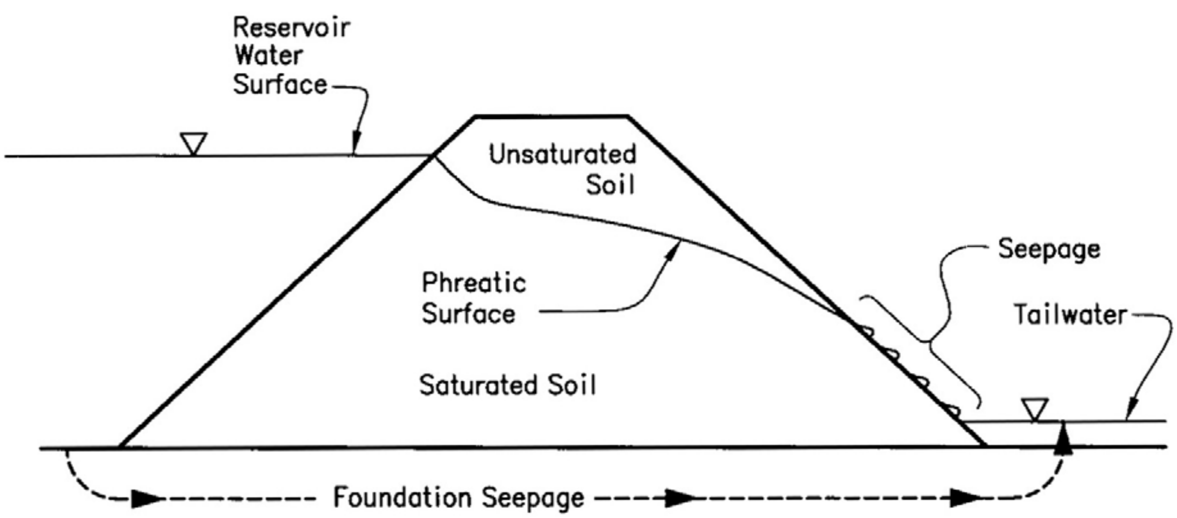
II. INSPECTING FOR DEFICIENCIES: SEEPAGE

WHAT IS SEEPAGE?

All embankment dams pass water through the embankment and foundation materials. The passage of water through the embankment and foundation materials is called seepage. (The TADS module entitled Evaluation of Seepage Conditions contains more detailed information on seepage control measures, as well as the various modes of failure directly related to seepage.)

Seepage becomes a problem when embankment or foundation materials are moved by the water flow, or when excessive water pressure builds up in the dam or its foundation. Uncontrolled seepage can be a problem. Figure II-1 illustrates uncontrolled seepage through an embankment dam and its foundation.

FIGURE II-1. EXCESSIVE SEEPAGE THROUGH AN EMBANKMENT



SEEPAGE CONTROL THROUGH INTERNAL DRAINS

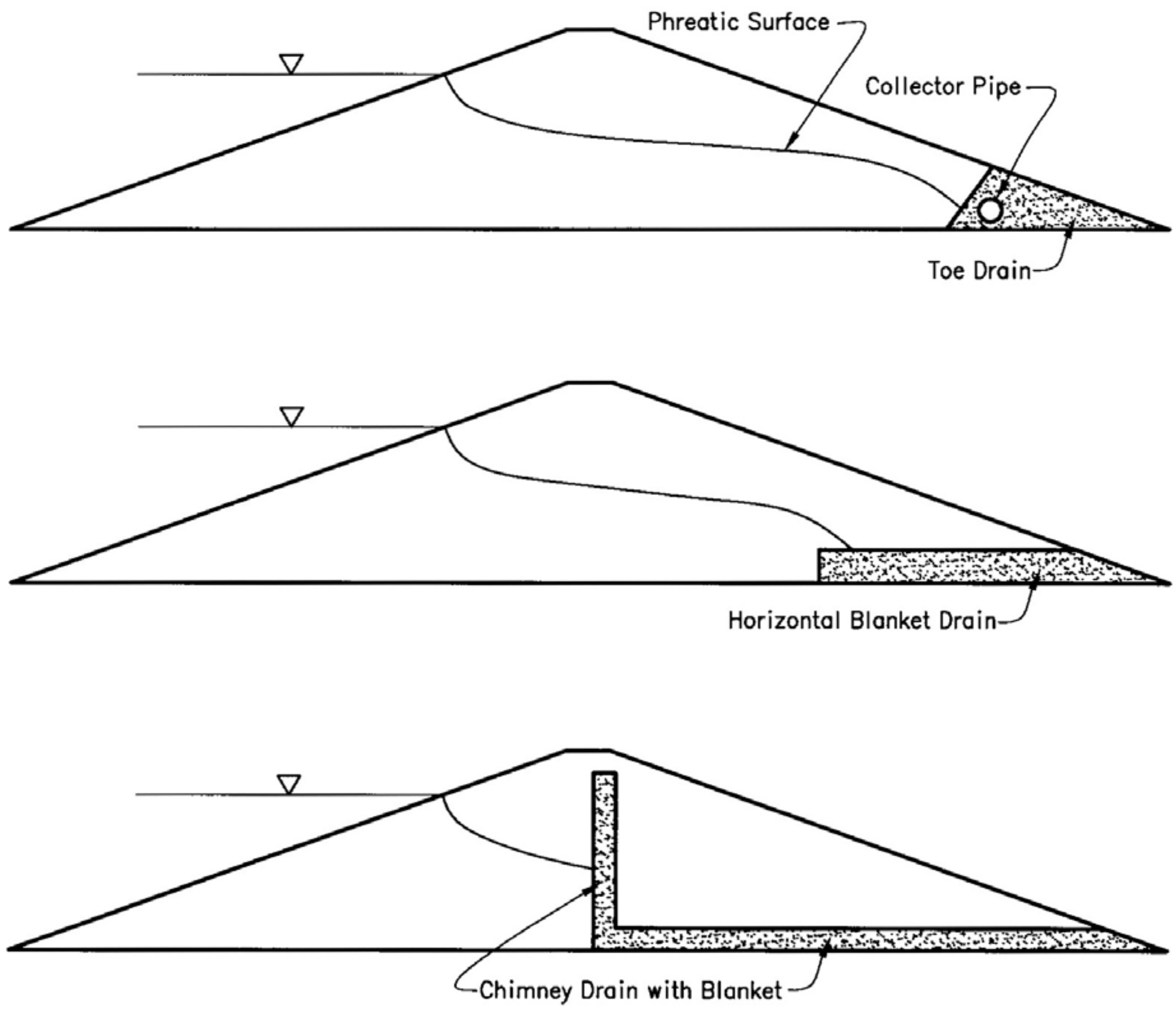
Most modern embankment dams have **internal drains** to control seepage. Internal drains are designed to intercept seepage and to discharge it safely. Many different types of drains can be used to control seepage. Three common types of drains are a toe drain, a blanket drain, and a chimney drain with blanket drain. Figure II-2, on the following page, illustrates these common types of drains.

Material for the drains is sized to pass anticipated flows and retain soils in place.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

SEEPAGE CONTROL THROUGH INTERNAL DRAINS (Continued)

FIGURE II-2. COMMON TYPES OF INTERNAL DRAINS



Dams without internal drains rely on material properties and the configuration of the materials to help control seepage. Dams without internal drains are more likely to have seepage problems.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

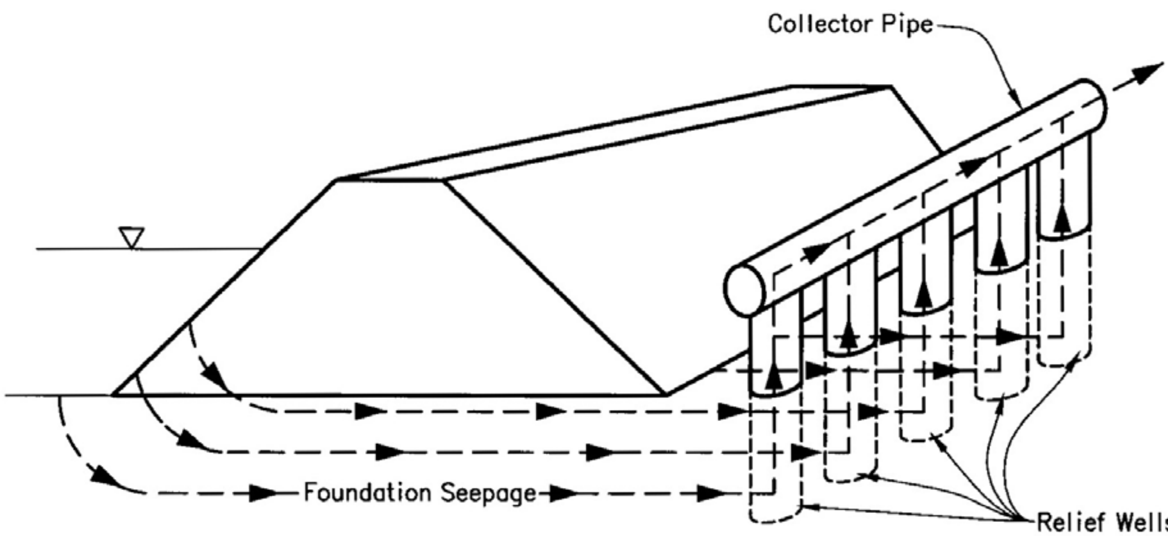
SEEPAGE CONTROL THROUGH RELIEF WELLS

Relief wells may be installed in the downstream toe area to reduce potentially damaging uplift pressure from foundation seepage through pervious materials that were not cut off. Uplift pressure from excessive seepage can cause piping of foundation material or embankment instability.

Relief wells may aid in controlling and safely discharging seepage from under the dam. Relief wells may be used in conjunction with other seepage drains.

Figure II-3 shows a line of relief wells used to intercept and control foundation seepage in a safe manner.

FIGURE II-3. RELIEF WELLS



If there are several wells, they may feed into one collection system, consisting of an open channel or a pipe system. The collection system is used to collect discharge from the relief wells and convey this water to a point downstream from the dam. Typically, this water is discharged back into the natural stream, often through a flow-measuring device.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

SEEPAGE PROBLEMS

Now let's look at some specific seepage problems. Excessive seepage is a major cause of embankment dam failure. Problems due to seepage can be divided into the following three categories:

- Instability
- Piping
- Internal Erosion

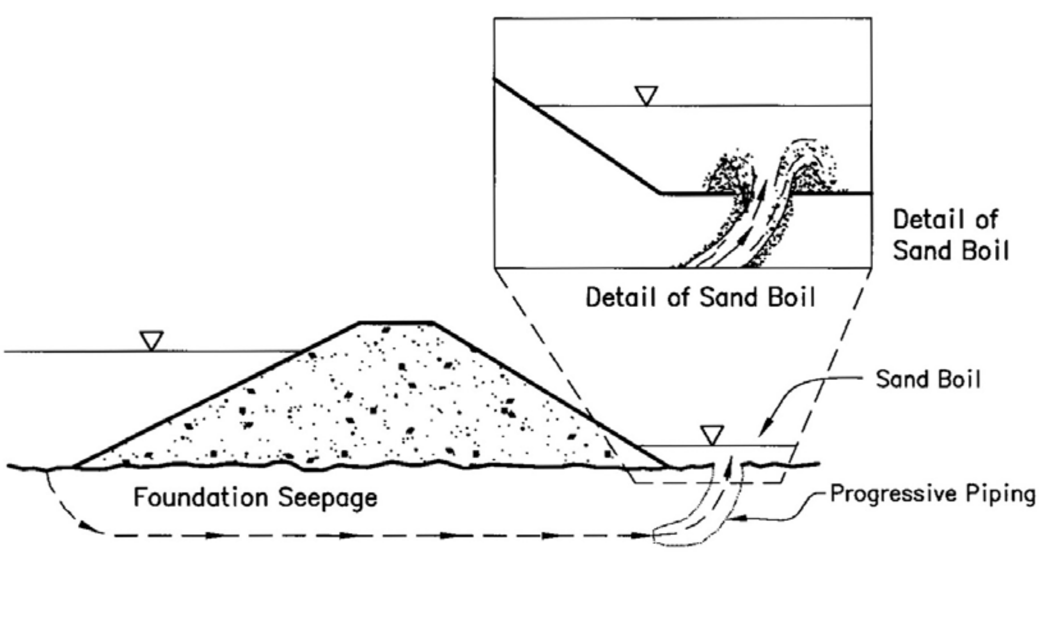
Instability

Seepage causes stability problems when high water pressure and saturation in the embankment and foundation soils cause the earth materials to lose strength. If embankment seepage comes close to or emerges on the lower downstream slope, as illustrated previously in Figure II-1, very often the seepage will cause sloughing, shallow slides, or even deep-seated slides.

Piping

Piping occurs when reservoir water moving through the pores of the dam or foundation soil (i.e., seepage) exerts a tractive force on the soil particles through which it is flowing, sufficient to remove them at the seepage exit point. This erosion progresses in an upstream direction forming a “pipe” through the dam or foundation; hence the term piping. In a piping failure, the pipe continually enlarges as erosion removes soil adjacent to the pipe. Usually the overlying embankment eventually collapses causing a breach of the dam. Figure II-4 illustrates a piping failure developing through the foundation.

FIGURE II-4. PIPING



II. INSPECTING FOR DEFICIENCIES: SEEPAGE

Piping (continued)

In the above illustration, the seepage is exiting near the downstream toe and has caused a sand boil. A sand boil is the circulation of fine cohesionless surficial soil in a “boiling action” due to high seepage exit velocity. Sand boils may indicate that piping is occurring. If exiting seepage is cloudy or turbid, it is an indication that fines are being removed with the exiting seepage. The formation of a deposition cone around the seepage exit or sand boil is further indication that piping is taking place.

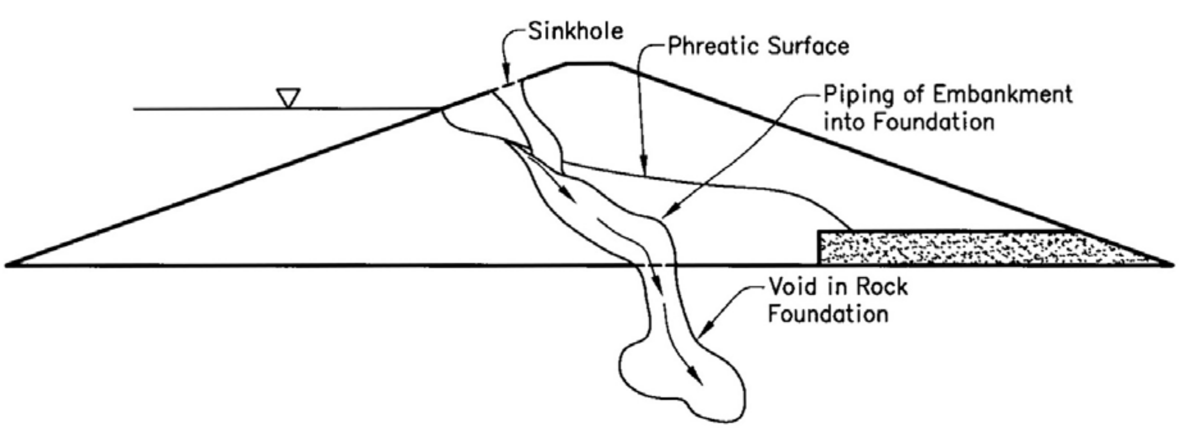
If you observe a sand boil, you should:

- ✓ Record the reservoir's water surface elevation, and approximate the sand boil elevation.
- ✓ Photograph and record the size of any deposition cone.
- ✓ Measure or estimate the flow rate. The flow rate may be difficult to ascertain because sand boils are often under water.
- ✓ Make sure that all sand boils are evaluated by a qualified engineer so that appropriate remedial action, if necessary, 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. Sandbags should be placed high enough to stop soil particles from moving, if possible, but not to prevent water movement.

Not all piping causes sand boils. Sand boils may not occur when concentrated seepage occurs through an embankment, along the groins, or in contact with concrete structures. In fact, severe piping problems can occur when seepage moves embankment material into voids in rock foundations. Figure II-5 illustrates embankment piping into voids in a rock foundation.

FIGURE II-5. EMBANKMENT PIPING INTO VOIDS IN ROCK FOUNDATIONS



II. INSPECTING FOR DEFICIENCIES: SEEPAGE

Piping (continued)

The type of seepage illustrated above is difficult to detect because nothing is visible until the embankment starts to collapse, or until a vortex appears in the reservoir. A vortex is the rotational movement that will appear as the water rapidly enters the foundation. This same type of rotational movement can be seen when you pull the plug in a sink full of water.

Soils most susceptible to piping are non-cohesive, loose, poorly graded fine sands. Also highly susceptible are non-cohesive silts and sands with low-plasticity fines, as well as loose, well-graded sand and gravel mixtures that are very broadly graded and have low-plasticity fines. Clay soils with significant cohesion are not susceptible to piping. However, some soils that are not susceptible to piping may be susceptible to internal erosion failures (described in the following section).

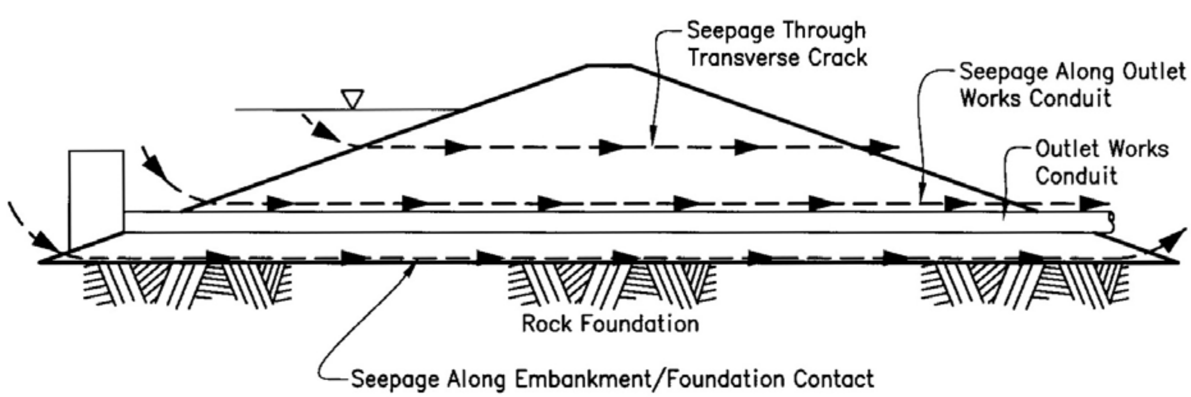
Piping is a dangerous seepage problem. If you believe piping is occurring, you should contact the dam owner and a qualified engineer immediately.

Internal Erosion

Internal erosion may appear to be the same as piping because in either case soil particles are moved by the erosive force of flowing water. A failure resulting from internal erosion may look very similar to a failure caused by piping. However, the mechanisms of piping and internal erosion failures are very different. Internal erosion occurs when seepage flows along established pathways, such as:

- Along cracks or other defects in the soil or bedrock in the cross-section,
- Along boundaries between soil and bedrock, or
- Between soil and appurtenant structures.

FIGURE II-6. Internal Erosion



II. INSPECTING FOR DEFICIENCIES: SEEPAGE

Soils that are not susceptible to piping may be highly susceptible to internal erosion. A good example is a dispersive clay soil. Some natural clay soils disperse or deflocculate in relatively pure water. This type of soil is virtually impervious and not susceptible to piping. However, if a crack occurs within dispersive soil, or between the dispersive soil and bedrock or appurtenant structures, the erosive force of water flowing through or along the crack can quickly lead to an enlargement of the flow path and a failure.

Internal Erosion (Continued)

> ☞ **INSPECTION TIP:** A simple test for indicating whether a soil is dispersive is to drop an intact clod of soil in a container of water. If the water rapidly becomes cloudy, it may indicate that the soil is dispersive. This test is referred to as a crumb test.

You'll learn more about dispersive soils in the sections on cracking and surface runoff erosion later in this module.

> ☞ **INSPECTION TIP:** Be alert for internal erosion by looking for evidence of seepage of embankment or foundation materials around appurtenant structures, near embankment-abutment contacts, and at transverse cracks.

Internal erosion is a dangerous seepage problem. If you believe internal erosion is occurring, you should contact the dam owner and a qualified engineer immediately.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

APPEARANCE OF SEEPAGE

Seepage varies in appearance. Seepage may appear as a wet area or as a flowing "spring." Vegetation is another indicator of seepage. Areas with a lot of water-loving vegetation, such as cattails, reeds, and mosses, should be checked for seepage. Also, areas where the normal vegetation appears to be greener or more lush should be checked for seepage. These patches of rich vegetation are more obvious in arid environments.

> ☞ **INSPECTION TIP:** Viewing the downstream slope from a distance is sometimes helpful in detecting subtle changes in vegetation. A distinct line of vegetation probably indicates the intersection of the seepage line with the slope.

AREAS PRONE TO SEEPAGE

The contacts between the downstream slope and the abutments (known as the embankment-abutment contacts, or groins) are especially prone to seepage because the embankment fill near the abutments is often less dense than other parts of the embankment, and therefore more pervious. The embankment fill near the abutments is less dense because compaction is difficult along the embankment/abutment interface. Also, improperly sealed porous abutment rock can introduce abutment seepage into and along the embankment.

Difficulties with compaction also make areas around conveyance structures like outlet works, spillway conduits, or penstocks more susceptible to uncontrolled seepage problems. Seepage exiting from around conveyance structures is particularly alarming because it may also indicate that there is a crack or opening in the structure that is allowing reservoir water under pressure into the embankment. Rapid erosion and an eventual breach of the dam can result.

> ☞ **INSPECTION TIP:** Seepage around a conveyance structure may be a serious problem. You should contact a qualified engineer immediately if this is observed.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

MONITORING SEEPAGE

If seepage is observed, then it should be monitored. To monitor seepage, you should record:

- ✓ The location and quantity or flow rate of all seepage at exit points, if possible.
- ✓ The occurrence of recent precipitation that may affect the appearance and quantity of seepage.
- ✓ The temperature of the discharge as compared to the reservoir.
- ✓ The level of the reservoir at the time of the observation.
- ✓ The turbidity of the discharge.

> ☞ **INSPECTION TIP:** Notes, sketches, and photographs are useful in documenting and evaluating seepage conditions.

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.

> ☞ **INSPECTION TIP:** Changes in seepage flow rate or turbidity which deviate from past seepage history may indicate a worsening seepage condition.

In some cases, a dye test can be used to help diagnose a seepage condition.

Weirs and Flumes

Weirs and flumes can be installed to measure seepage exiting from the embankment or foundation. Weirs and flumes can measure seepage accurately when properly calibrated and kept free of silt and vegetation.

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

- Embankment or foundation material is being piped out of the dam, 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 situation.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

Piezometers

Devices used to measure water pressure are called **piezometers**. Piezometers are used to measure the water pressure and locate the seepage surface. Such measurements can be critical because of possible piping or seepage-induced conditions of instability, such as excess hydrostatic uplift pressures.

Drains

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

- ✓ Review the site plan to determine the location of 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 atypical for the given reservoir level, more investigation may be warranted.

During the inspection, you should:

- ✓ Locate each drain outfall.
- ✓ Measure the flow. A simple method of measuring the flow from a drain outfall is to catch the flow from the pipe in a container of known volume and to time how long it takes to fill the container. The flow rate is usually recorded in gallons per minute. If no pipe exists, you will need to estimate the flow or recommend the installation of a weir.
- ✓ Compare the amount of flow with the amount of flow you anticipated for the current reservoir level based on previous readings.

Blocked Drains

A drain that has no flow at all could 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 at uncontrolled locations or may contribute to internal water pressure and instability. You should recommend that further investigation be conducted to determine the cause of the blockage.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

Blocked Drains (Continued)

Decreasing amounts of flow from a drain for the same reservoir level may indicate that the drain is becoming blocked. Conversely, a sudden increase in drain flow may indicate that the core is becoming less watertight, possibly as the result of transverse cracking.

> ☞ **INSPECTION TIP:** Recording drain flow rates and reservoir levels will help you to assess a dam's seepage conditions.

Relief Wells

Before conducting an inspection of an embankment dam that has relief wells, you should:

- ✓ Review the site plan to determine the location of the wells.
- ✓ Review data on well flow 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 atypical for the given reservoir level, more investigation may be warranted.

During the inspection, you should:

- ✓ Locate each relief well.
- ✓ Visually check whether or not water 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.

- ✓ 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. Relief wells should periodically be sounded to determine if there is an accumulation of sediment. If you suspect that the well is not functioning properly because it is clogged, cleaning should be recommended.

If the well flow is greater than the amount you anticipated, you may need to recommend that the situation be evaluated further. 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.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

TURBIDITY

In addition to measuring the flow rate of seepage, you should evaluate the clarity of the seepage. Turbidity is cloudy seepage, which indicates that soil particles are suspended in the water. Turbidity means that the water passing through the embankment or foundation is carrying soil with it.

> ☞ **INSPECTION TIP:** Each time seepage is measured, the turbidity of the seepage should also be evaluated for change.

If seepage is clear, but you suspect that it contains dissolved material from the foundation (because, for instance, seepage has increased), it may be necessary to perform water quality testing.

> ☞ **INSPECTION TIP:** As mentioned previously, the rate and turbidity of seepage flow should be recorded at each inspection. If seepage problems are suspected, then the frequency of inspections should be set by a qualified engineer. If seepage problems do occur, further testing should be conducted by a qualified engineer. Remember, excessive seepage is a major cause of embankment dam failure.

II. INSPECTING FOR DEFICIENCIES: SEEPAGE

~~VIDEO PRESENTATION~~

~~At this point you should watch the second video presentation, which reviews the inspection procedures presented in this section of the module. To watch the video presentation . . . .~~

- ~~Turn on your video player.~~
- ~~Load the videocassette, if it is not in the player.~~
- ~~Advance the tape to video segment #2, if the tape has been rewound.~~
- ~~Watch video segment #2.~~

~~After watching video segment #2, return to the next section of this unit, which covers cracking. Do not rewind the videocassette.~~

II. INSPECTING FOR DEFICIENCIES: CRACKING

WHAT IS CRACKING?

Another serious deficiency is cracking. Cracks are linear separations that appear in the crest or slopes of the dam separating previously intact embankment material. Cracking in an embankment dam falls into the following three major categories:

- Transverse Cracking
- Longitudinal Cracking
- Desiccation Cracking

Each type of cracking is discussed below.

TRANSVERSE CRACKING

Transverse cracking appears in a direction roughly perpendicular to the axis of the dam. If these cracks extend into the core below the reservoir level, they are especially dangerous because they could create a path for concentrated seepage through the core. Transverse cracks usually appear on the dam crest near abutments.

The presence of transverse cracking indicates differential settlement within the embankment or underlying foundation. This type of cracking frequently develops when:

- Compressible material overlies abutments consisting of steep or irregular rock.

- Areas of compressible material are in the foundation.

- Sections of the embankment have been excavated and replaced, such as for conduits.

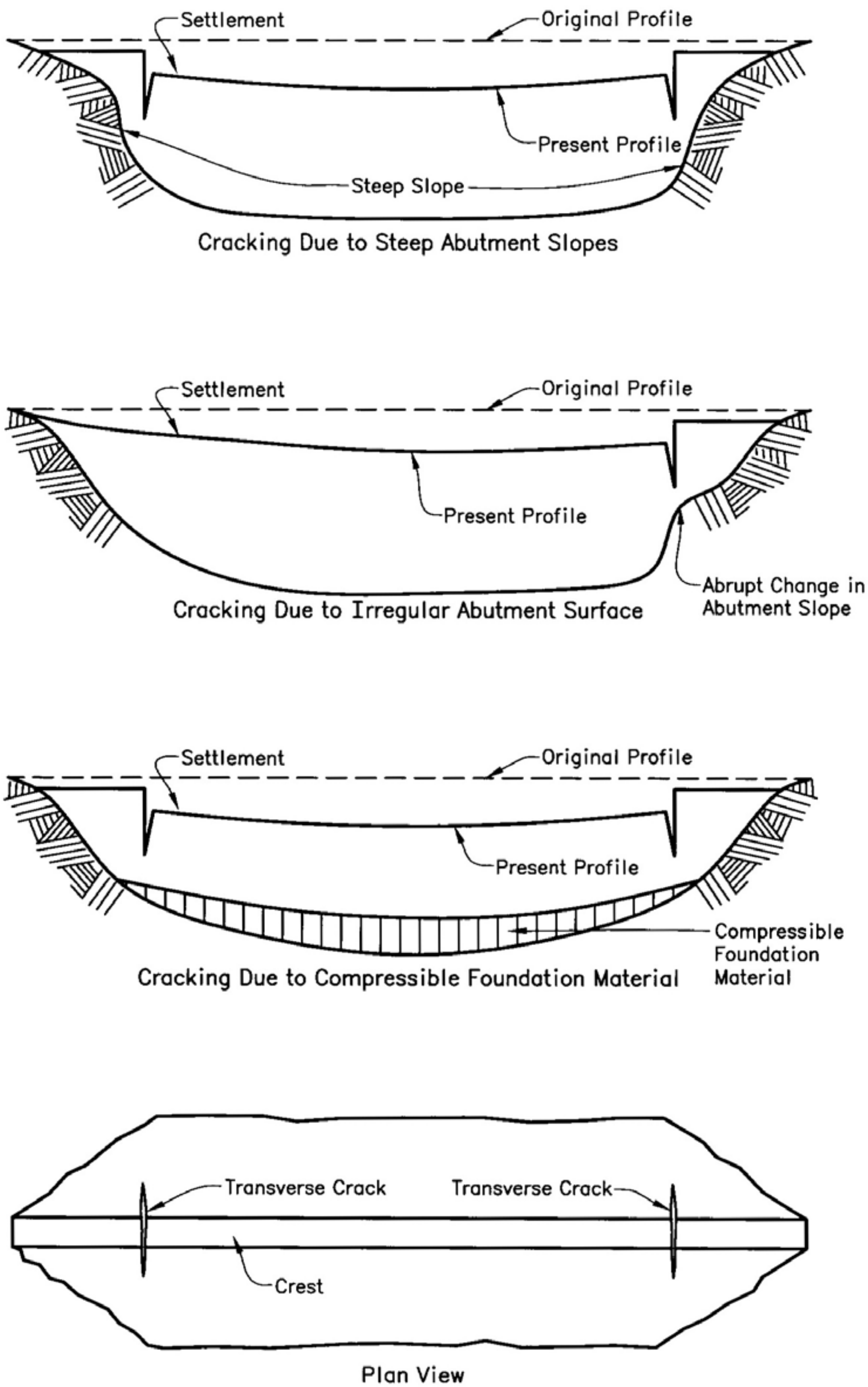
Figure II-7, on the following page, shows how transverse cracks form in an embankment dam.

Transverse cracks may provide a path for seepage through the embankment. When the depth of the crack extends below the level of the reservoir, very rapid erosion of the dam may occur, eventually breaching the dam.

II. INSPECTING FOR DEFICIENCIES: CRACKING

TRANSVERSE CRACKING (Continued)

FIGURE II-7. HOW TRANSVERSE CRACKS FORM



II. INSPECTING FOR DEFICIENCIES: CRACKING

Transverse Cracking: Inspection Actions

If you observe transverse cracking, per earlier style, you should:

- ✓ Photograph, probe, and record the location, depth, length, width, and offset of each crack observed.
- ✓ Monitor the crack for changes.
- ✓ Check for evidence that the embankment may be comprised of dispersive soil. The passage of reservoir water through a transverse crack in this type of soil can lead to the rapid failure of the dam.

> ☞ **INSPECTION TIP:** If the depth of the cracking appears to extend below the reservoir level or potential reservoir level, a qualified engineer should identify appropriate investigative and remedial measures.

LONGITUDINAL CRACKING

Longitudinal cracking occurs in a direction roughly parallel to the axis of the dam. Longitudinal cracking is an indication of:

- Uneven settlement between adjacent embankment zones of differing compressibility.
- The beginning scarp of an unstable slope. In this case, the crack may appear arc-shaped.

Figure II-8, on the following page, illustrates longitudinal cracking.

Longitudinal cracks allow water to enter the embankment. When water enters the embankment the strength of the embankment material adjacent to the crack may be lowered. The lower strength of the embankment material can lead to or accelerate slope stability failure.

Longitudinal Cracking: Inspection Actions

As with transverse cracking, if you observe longitudinal cracking, you should:

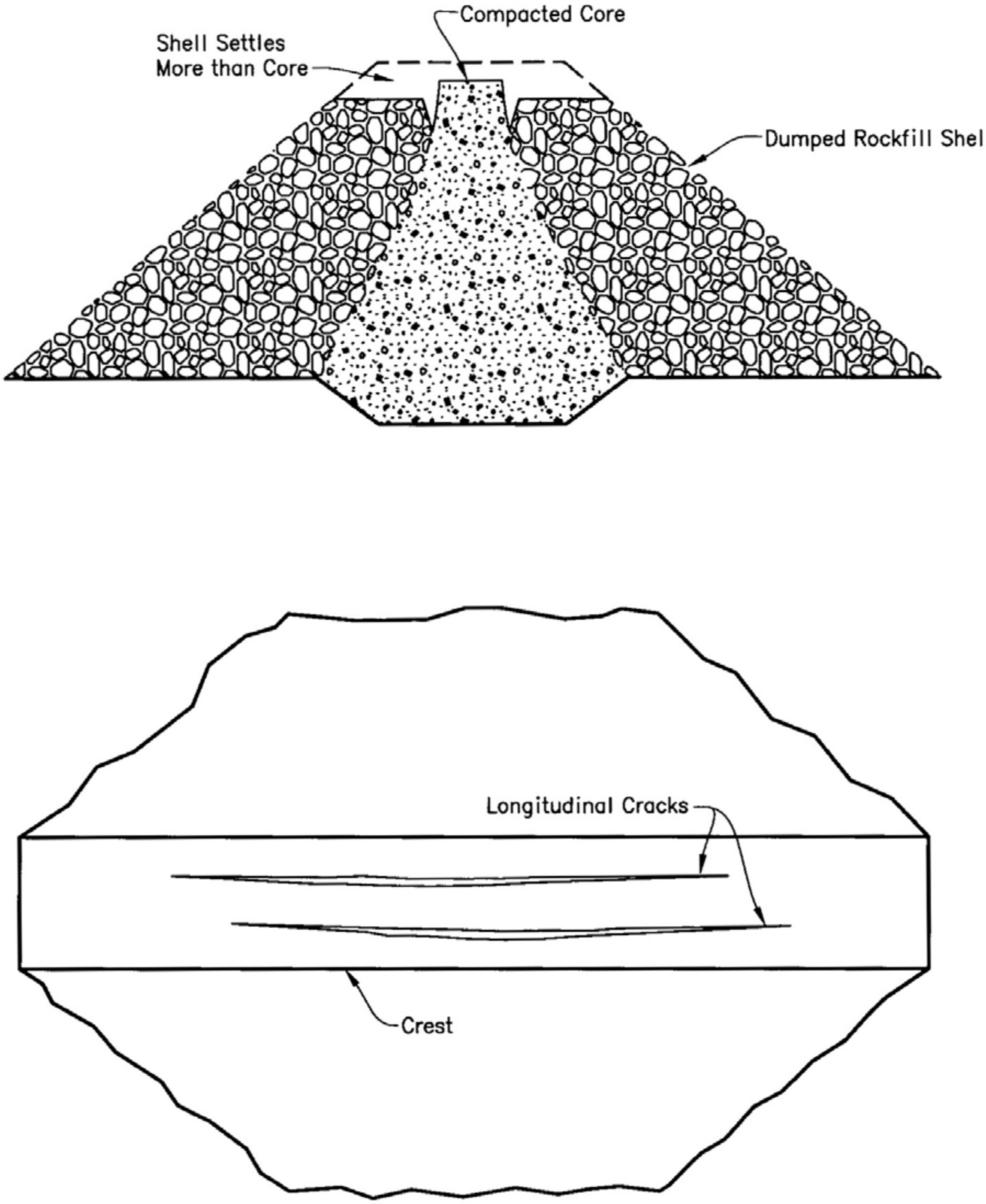
- ✓ Photograph and record the location, depth, length, width, and offset of each crack observed.
- ✓ Monitor the crack for changes. A useful monitoring tool is to establish a reference line using stakes.

> ☞ **INSPECTION TIP:** A qualified engineer should be consulted in order to determine the cause of the cracking.

II. INSPECTING FOR DEFICIENCIES: CRACKING

LONGITUDINAL CRACKING (Continued)

FIGURE II-8. HOW LONGITUDINAL CRACKS FORM



II. INSPECTING FOR DEFICIENCIES: CRACKING

DESICCATION CRACKING

Desiccation cracking is caused by the drying out and shrinking of certain types of embankment soils. Desiccation cracks usually develop in a random, honeycomb pattern. Typically, desiccation cracking occurs in the crest and the downstream slope.

The worst desiccation cracking develops when a combination of the following factors is present:

- A hot, dry climate accompanied by long periods in which the reservoir remains empty.
- An embankment that is composed of highly plastic soil, such as clay.

Usually, desiccation cracking is not harmful unless it becomes severe. The major threat of severe desiccation cracking is that this type of cracking can contribute to the formation of gullies. Surface runoff erosion concentrating in the desiccation cracks or gullies can result in eventual damage to the dam.

Also, heavy rains can fill up these cracks and cause portions of the embankment to become unstable and to slip along crack surfaces where the water has lowered the strength of the embankment material. Deep cracks that extend through the core conceivably can cause a breach of the dam when the reservoir rises and the cracks fail to swell rapidly enough to reseal the area.

Desiccation Cracking: Inspection Actions

If you observe desiccation cracking, you should:

- ✓ Probe the more severe cracks to determine their depth.
- ✓ Photograph and record the location, depth, length, and width of any severe cracks observed.
- ✓ Compare your measurements with past measurements to determine if the condition is worsening.

> ☞ **INSPECTION TIP:** If the depth of the cracking appears to extend below the reservoir level or potential reservoir level, a qualified engineer should identify appropriate investigative and remedial measures.

II. INSPECTING FOR DEFICIENCIES: INSTABILITY

INSTABILITY

Instability of the embankment is very serious. The primary visual indicators of instability are:

- Slides
- Bulges
- Seepage
- Cracks

Other clues include cracking and misalignment of features (e.g., walls, guardrails, pavement stripes, appurtenant structures, or reservoir upstream contacts).

SLIDES

Slide phenomena have various names including displacements, slumps, slips, and sloughs. Slides can be grouped into two major categories:

- Shallow Slides
- Deep-Seated Slides

Slides may lead to:

- The obstruction of water conveyance structures and drains.
- Larger, deep-seated slides.
- Surface erosion or maintenance problems.

Next you will learn more about each category of slides.

Shallow Slides

Shallow slides in the upstream slope are often the result of an overly steep slope aggravated by a rapid lowering of the reservoir. Shallow slides in the upstream slope pose no immediate threat to the integrity of the dam.

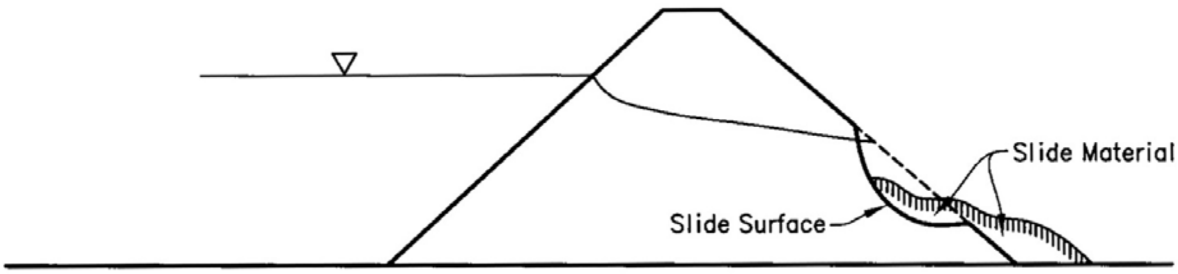
Shallow slides in the downstream slope also indicate an overly steep slope. In addition, these slides may also indicate low strength or a loss of strength in the embankment material. Low strength or a loss of strength can be the result of poorly compacted material, and can also be caused by saturation of the slope due to seepage, infiltration of surface runoff, or a clogged drain. Additional loads from snow banks or structures can aggravate the condition.

Figure II-9, on the following page, shows a diagram of a shallow slide on the downstream slope.

II. INSPECTING FOR DEFICIENCIES: INSTABILITY

Shallow Slides (Continued)

FIGURE II-9. 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.
- ✓ Probe the entire area to determine the depth and extent of the slide.
- ✓ Determine if there are seepage areas near or in the slide.
- ✓ Monitor the area to determine if the condition is becoming worse. A useful monitoring tool is to establish a reference line using stakes.

☞ **INSPECTION TIP:** You should consult with a qualified engineer if you are unsure whether the slide presents a serious threat to the integrity of the dam.

II. INSPECTING FOR DEFICIENCIES: INSTABILITY

Deep-Seated Slides

Deep-seated slides are serious threats to the safety of the dam. To recognize deep-seated slides, look for:

- **Well-Defined Scarp**

  A scarp is a relatively flat area with a steep back slope.

- **Toe Bulge**

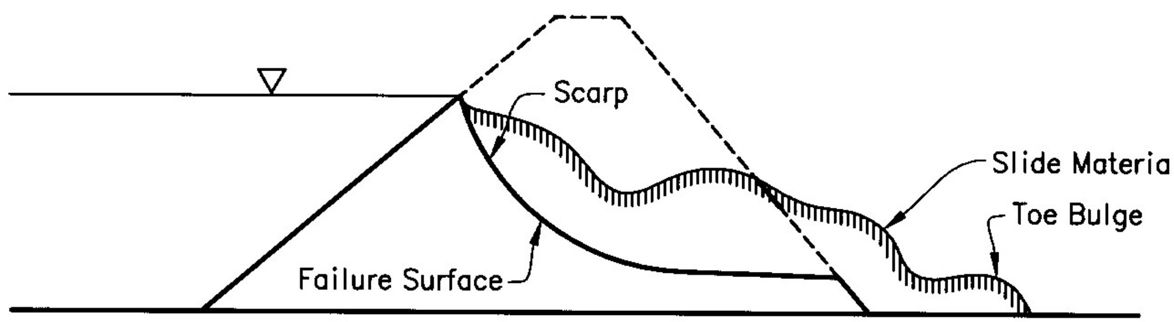
  A toe bulge is the lower portion of a deep seated failure and is produced by the rotational or horizontal movement of embankment material. (Bulges are discussed in the next part of this section.)

- **Arc-Shaped Cracks**

  Arc-shaped cracks in the slope are indications that a slide is beginning. This type of crack may develop into a large scarp in the slope at the top of the slide.

Figure II-10 presents a diagram of a deep-seated slide.

FIGURE II-10. DEEP-SEATED SLIDE



II. INSPECTING FOR DEFICIENCIES: INSTABILITY

Deep-Seated Slides: Inspection Actions

A deep-seated slide or scarp in either the upstream or downstream slope is an indication of serious structural problems.

☞ **INSPECTION TIP: IMMEDIATE ACTION IS NECESSARY!** In most instances, deep-seated slides will require the lowering or draining of the reservoir to prevent the possible breaching of the dam. The owner should be notified.

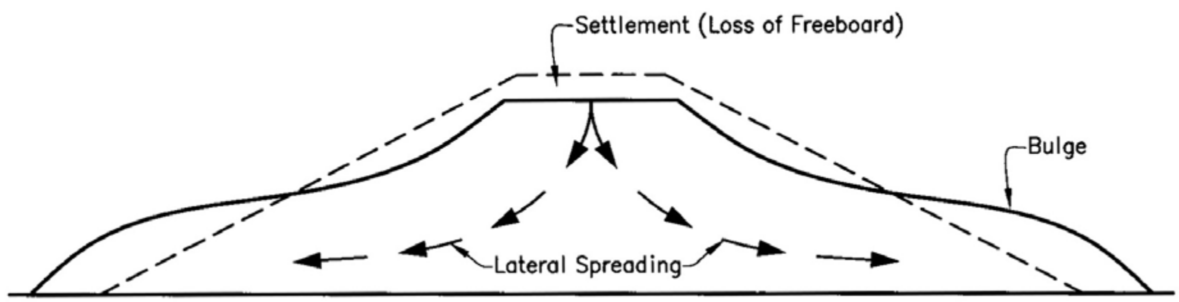
A qualified engineer should be consulted:

- To determine whether the reservoir must be lowered or drained to prevent possible breaching of the dam.
- To evaluate the cause of deep-seated slides.
- To prescribe remedial action.

LATERAL SPREADING

Excessive settlement may result in lateral spreading and bulges, which may be accompanied by parallel longitudinal tension cracks on the slope. Bulges are most evident at the toe of the dam. Figure II-11 illustrates how bulges form due to lateral spreading of the dam.

FIGURE II-11. LATERAL SPREADING



Bulges Due To Lateral Spreading: Inspection Actions

A toe bulge due to lateral spreading may mean that there has been some loss of freeboard. Freeboard is the distance between the maximum water elevation and the crest of the dam.

☞ **INSPECTION TIP:** If you suspect loss of freeboard, a survey of the crest should be performed. A survey will verify if there has been a loss of freeboard.

II. INSPECTING FOR DEFICIENCIES: INSTABILITY

LATERAL SPREADING (Continued)

In addition to checking for freeboard loss:

- ✓ Closely inspect the area above the bulge for scarps which indicate that a slide is the cause.
- ✓ Probe the bulge to determine if material is excessively moist or soft. Excessive moisture or softness also indicates that a slide is the cause.

II. INSPECTING FOR DEFICIENCIES: SINKHOLES

SINKHOLES

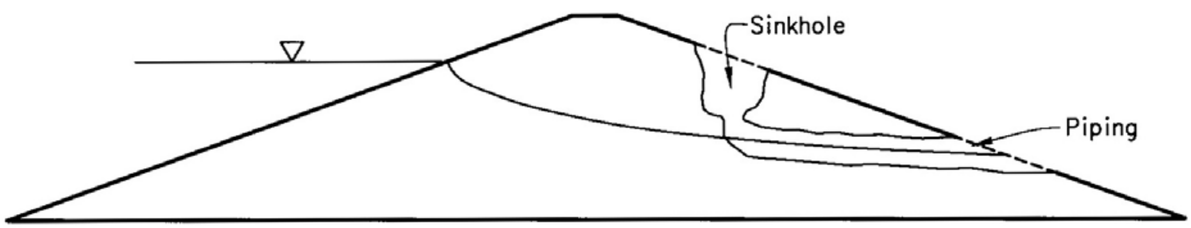
Sinkholes are formed when the removal of subsurface embankment or foundation material causes overlying material to collapse into the resulting void.

The presence of a sinkhole may indicate that material is being or has been transported out of the dam or foundation through the process of internal erosion or piping. (See the section on seepage for more information on internal erosion and piping.) The decomposition of buried wood or other vegetative matter, and animal burrows can also cause sinkholes.

Sinkholes are often associated with a karst foundation. Karst refers to a region characterized by distinctive features such as caverns, "lost" rivers, large springs, barren uplands, and thin soils. Such topography usually exists in areas of limestone bedrock which has formed these features due to solutioning and weathering of the bedrock.

Figure II-12 illustrates how a sinkhole is formed.

FIGURE II-12. FORMATION OF A SINKHOLE



Sinkholes: Inspection Actions

If you observe a sinkhole:

- ✓ 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 a qualified engineer evaluate the situation immediately.

II. INSPECTING FOR DEFICIENCIES: DEPRESSIONS

DEPRESSIONS

A depression is a form of settlement in the embankment or foundation that is less serious than a sinkhole.

Depressions are caused by:

- Erosion. Wave action against the upstream slope that removes embankment fines or bedding from beneath riprap may form a depression as the riprap settles into the vacated space.

- Localized settlement in the embankment due to poor compaction or foundation due to compressible materials.

- Loss of sub-surface material through the decay of vegetative matter, or through internal erosion or piping.

Some areas that appear to be depressions may be the result of improper final grading following construction.

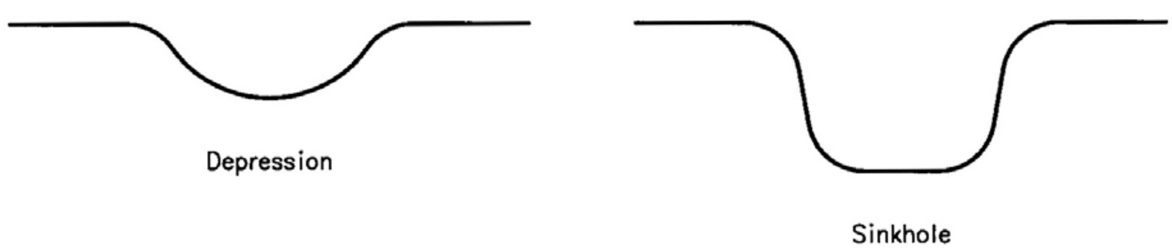
Sometimes a way to distinguish between depressions and sinkholes is to look at their profiles. A localized depression may be the initial manifestation of a sinkhole to follow.

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

- **Sinkholes:** Sinkholes usually have steep, bucket-like sides.

Figure II-13 illustrates the difference between depressions and sinkholes.

FIGURE II-13. DEPRESSION AND SINKHOLE



II. INSPECTING FOR DEFICIENCIES: DEPRESSIONS

Detecting Depressions

Depressions and other misalignment in the crest and embankment slopes often can be detected by sighting along fixed points. You should sight and take photographs along guardrails, parapet walls, pavement striping, and across the slope. Some apparent misalignment may be due to irregular placement of the fixed points. For this reason, irregularities should be evaluated over time to verify suspected movement.

Sighting irregularities is facilitated by surveying permanent monuments across the crest to determine the exact location and the extent of misalignment. A record of survey measurements also can establish the rate at which movement is occurring.

Depressions: Inspection Actions

Although 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.
- ✓ Frequently observe the depression to ensure it has stopped developing.

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

MAINTENANCE CONCERNS

Maintenance refers to the routine measures taken to protect and keep the dam in good condition. Some maintenance concerns may not immediately pose a threat to the dam, but may turn into problems if not dealt with in a timely manner. Deficiencies associated with inadequate maintenance include:

- Inadequate Slope Protection
- Surface Runoff Erosion
- Inappropriate Vegetative Growth
- Debris
- Animal Burrows

In this section you will learn how to detect common maintenance concerns and what corrective actions should be taken.

INADEQUATE SLOPE PROTECTION

Before discussing inadequate slope protection, let's briefly review the different types of slope protection.

Slope protection is designed to prevent erosion of the embankment slopes. There are two primary types of slope protection used on embankment dams:

- Riprap
- Vegetative Cover (Grass)

Soil cement, concrete, asphalt, roller-compacted concrete, and other types of slope protection also may be used. The type of slope protection selected depends upon economics and the prevailing conditions found at the site.

Riprap

Riprap is broken rock or boulders placed on the upstream and downstream slopes of embankment dams. Riprap provides protection from erosion caused by wind or wave action, surface runoff erosion, and wind scour.

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

Riprap (Continued)

Properly designed upstream riprap slope protection is made up of at least two layers of material:

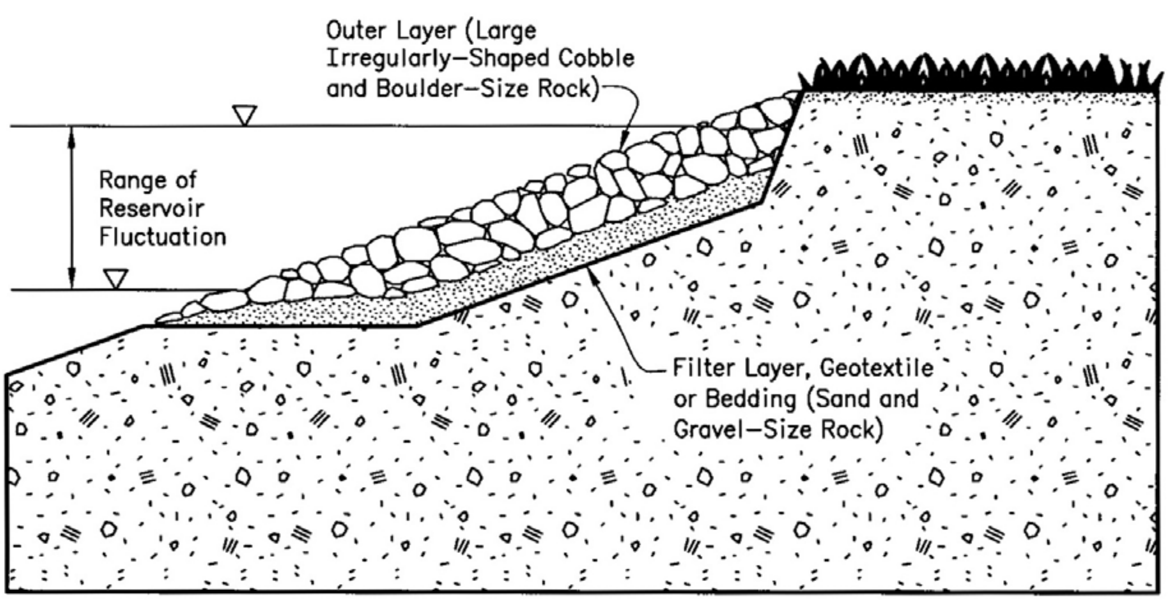
- **The Inner Layer(s):** The inner layer(s), called the filter layer or bedding, is sand and gravel-size rock. These smaller rocks prevent the underlying embankment from being washed out through the voids in the larger rocks found in the outer layer. Geotextile filter fabric can also serve this purpose.

- **The Outer Layer:** The outer layer is cobble-size and boulder-size rock that is large enough not to be displaced by wave action. These larger rocks prevent erosion.

It is important to make sure that rocks of various sizes and shapes are used in the outer layer. Irregular sized and shaped rocks create an interlocking mass that prevents waves from passing between the larger rocks of the outer layer and removing the underlying material from the inner layer(s).

The slope upon which the riprap is placed must be flat enough to prevent riprap from dislodging and moving down the slope. Hand-placed riprap, while usually providing good protection, is a relatively thin blanket of protection. Thinly layered riprap is susceptible to failure because the dislodging of one large rock may cause displacement of the surrounding rock due to a lack of adequate support. However, most modern riprap is dumped in place, resulting in a much thicker-layered blanket of protection. Figure II-14 presents a diagram of riprap that is appropriately designed and placed on an upstream slope.

FIGURE II-14. RIPRAP



II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

Vegetative Cover

The outer portion of the embankment that consists of fine-grained soil must be protected from erosion. Failure to protect the slope could result in significant erosion. If significant erosion occurs there will be a need for considerable maintenance and repair, especially on the crest and the downstream slope. The planting of some type of vegetative cover (usually grass) on the slopes can provide erosion protection. The root system of the vegetative cover holds the surface soil in place and protects the slopes from wind and surface runoff erosion.

In most geographic areas, a well-established cover of grass provides satisfactory crest and downstream slope protection. Using a grass cover to protect the upstream slope often is effective for small reservoirs and dams that have insignificant wave action. The grass cover should be maintained to a maximum height of approximately six inches to allow proper embankment inspection. In addition, well-maintained grass helps prevent animal burrowing and controls deep-rooted vegetation.

Vegetative wave berms may be used to dissipate wave energy and protect the slope from erosion. If improper or sparse vegetation is present, the wave berm may not adequately dissipate the wave energy, allowing erosion and beaching to develop on the upstream slope.

It may be necessary to use other types of slope protection:

- In arid climatic regions.
- In areas of the dam where surface runoff is excessive or concentrated, such as the groins.
- Where conditions combine to create severe wave action.

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

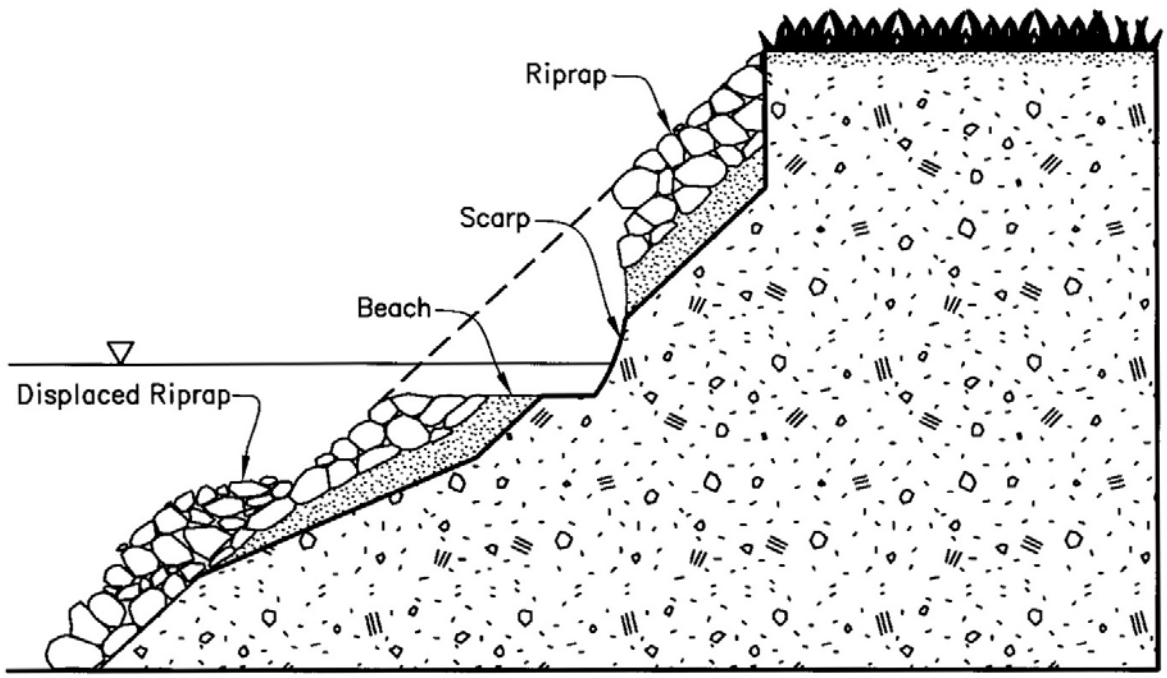
Wave Action Erosion and Slope Protection

The constant action of waves on the upstream slope may result in wave action erosion (beaching) and degradation of the slope protection. Unless measures are taken to maintain adequate slope protection, wave action will begin to erode the embankment material. Let's look at the different effects of constant wave action on the upstream slope.

- **Wave Action Erosion (Beaching):** Wave action erosion causes the removal of a portion of the upstream slope of the embankment. When this occurs, embankment material is deposited farther down the slope. In this form of erosion, the slope protection (i.e., riprap or vegetative cover) and underlying material are removed. A relatively flat beach area with a steep back slope or scarp is formed. On smaller dams, wave action erosion could lessen the width of the embankment, possibly leading to increased seepage, instability, or overtopping of the dam. Ice action on the upstream slope can also lead to the removal or displacement of the slope protection.

- **Degradation:** Degradation of the slope protection may occur when the protective material cracks, becomes weathered, or breaks down. The degrading of the slope protection is accelerated by wave action. Even the best designed slope protection will experience some degradation over time. Degraded riprap, soil cement, concrete, roller-compacted concrete, or other slope protection should be monitored. If evidence shows that serious damage to the embankment is occurring, degraded slope protection must be repaired or replaced.

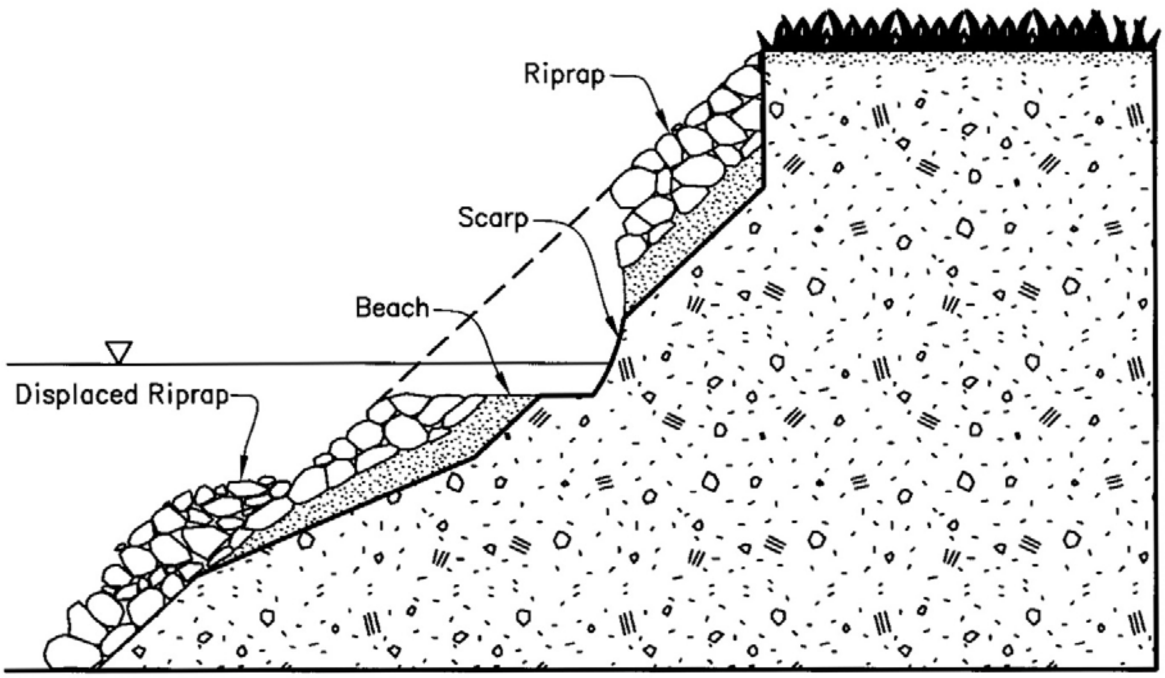
Figure II-15, on the following page, illustrates the effect of wave action on slope protection.



II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

Wave Erosion and Slope Protection (Continued)

FIGURE II-15. WAVE EROSION



Inadequate Slope Protection: Inspection Actions

During the inspection, you should:

- ✓ Make sure that the slope protection is adequate to prevent erosion.
- ✓ Look for signs of wave action erosion and degradation of the slope protection.

If inadequate slope protection is observed:

- ✓ Record your findings and photograph the area.
- ✓ Determine the extent to which the embankment has been damaged (i.e., embankment material has been removed).
- ✓ Recommend that corrective action be taken to repair or replace the inadequate slope protection.

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

SURFACE RUNOFF EROSION

Surface runoff erosion is one of the most common maintenance problems of embankment structures. Bald areas or areas where the protective cover is sparse are more susceptible to surface runoff erosion problems. If not corrected, surface runoff erosion can become a more serious problem.

Gullies

The worst damage from surface runoff is manifested by the development of deep erosion gullies on the slopes, both at the groins and in the central portion of the dam.

Severe gullies can:

- Cause breaching of the crest.
- Shorten the seepage path through the dam, possibly leading to piping.

Gullies can develop as a result of poor grading or sloping of the crest, which leads to improper drainage. Surface water then collects and runs off at the low points along the upstream and downstream shoulders. Gullies caused by this type of runoff eventually can reduce the cross-sectional area of the dam.

Slope and Crest Protection

Erosion may undermine the upstream slope protection and cause it to settle. This undermining of the protection may lead to the eventual degradation of the slope itself.

The crest also can experience weathering and erosion if it is not protected. Crest erosion protection may consist of a road surfacing such as gravel, asphalt, or concrete pavement. The type of crest protection used depends on the amount of traffic anticipated. If little or no traffic is expected on the crest, a grass cover should be adequate. Remember to check that the crest surfacing is providing adequate protection from erosion. Too much traffic on gravel- or grass-covered crests, especially during rainy periods, can lead to ruts in the crest surface. Ruts are undesirable because they will pond water, potentially causing stability problems.

There are a number of special circumstances that can contribute to or initiate surface erosion of the crest and downstream slope. In some areas, people and animals may establish trails on the embankment. This traffic can damage the slope's vegetative cover. Recreational vehicles can cause ruts in the crest and can damage the slope protection. Waves overtopping the crest of the dam can damage the crest and the downstream slope. You need to be aware of any unique problems that may be common in a particular location or past problems that were noted on previous inspections. Make sure to look for these types of problems in your inspection.

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

Surface Runoff Erosion: Inspection Actions

During the inspection, you should:

- ✓ Make sure that the slope and crest protection is adequate to prevent erosion. Remember, bald areas or areas where the surface protection is sparse are more susceptible to surface runoff problems.

- ✓ Look for gullies, ruts, 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 concentrate in these areas.

- ✓ Check for any unique problems, such as people, animal, or recreational vehicle traffic, that may be contributing to erosion.

If surface runoff erosion is observed:

- ✓ Record your findings and photograph the area.

- ✓ Determine the extent or severity of the damage.

- ✓ Recommend that corrective action be taken to repair the areas damaged by surface runoff and that measures be taken to prevent more serious problems.

  ☞ **INSPECTION TIP:** In areas where dispersive soils are present, a particular pattern of erosion is often evident. Water percolates vertically downward several feet in cracks before flowing out to the surface of slopes, resulting in "jugs" or tunnels in the slopes.

INAPPROPRIATE VEGETATIVE GROWTH

Inappropriate vegetative growth is another common maintenance problem. Inappropriate vegetative growth generally falls into two categories:

- Excessive Vegetative Growth

- Deep-Rooted Vegetation

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

Excessive Vegetative Growth

Excessive vegetation is a problem wherever it occurs on an embankment dam. Excessive vegetation can:

- Obscure portions of the dam, the embankment-abutment contact, and the downstream toe that prevents adequate visual inspection. Problems that threaten the integrity of the dam can develop and remain undetected if they are obscured by vegetation.

- Prevent access to the dam and surrounding areas. Limited access is an obvious problem both for inspection and maintenance, and especially during emergency situations, when access is crucial.

- Provide a habitat for rodents and burrowing animals. Burrowing animals can pose a threat to embankment dams by causing piping.

- Block sunlight to a grass cover, causing the cover to wither and die.

Also, there should be no vegetation in the riprap on the upstream slope. Vegetation in the riprap promotes displacement and degradation of the slope protection.

Vegetative growth should be controlled by periodic mowing or other means.

> ☞ **INSPECTION TIP:** To ensure that you will have the greatest visibility of the slopes and crest, try to schedule your inspection shortly after mowing has been completed.

Deep-Rooted Vegetation

Although a healthy cover of grass 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 breach the dam or 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 embankment.

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

Deep-Rooted Vegetation (Continued)

Trees and shrubs are undesirable growing on or adjacent to embankment dams. The location, size, type of tree, and prevailing policy will determine the course of action at a given site.

The best approach to trees in the crest, slopes, and adjacent to the dam 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.

Inappropriate Vegetative Growth: Inspection Actions

During the inspection, you should:

- ✓ Look for excessive and deep-rooted vegetation on all areas of the dam.
- ✓ Make sure that there is **no** deep-rooted vegetation growing in the riprap.
- ✓ 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 the future growth of undesirable vegetation.

✓ For more information on the affects of plants on earthen dams, see our course "Impacts of Plants on Earthen Dams"

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

DEBRIS

The collection of debris on and around the dam is not an immediate danger to the integrity of the dam. However, unattended debris can lead to serious problems. Listed below are some common problems associated with debris.

- The buildup of brush and logs on the dam can obscure the upstream slope and can prevent adequate inspection.

- Debris can accelerate the process of degradation of the riprap or other slope protection by impact from wave action.

- Woody debris can become waterlogged and sink, possibly blocking an outlet-works inlet or spillway inlets. The blocking of these inlet structures can cause overtopping of the dam in the event of a flood.

Certain animals, such as beavers, can contribute to the accumulation of debris in and around the dam. As you will see in the next section, beavers are not the only animals to cause potential harm to an embankment dam.

Debris: Inspection Actions

If you see debris in and around the dam:

✓ Photograph and record your observations.

✓ Ensure that the appurtenant structures' intakes are clear and functioning properly.

✓ Recommend that appropriate corrective action be taken to remove the debris and, if possible, measures are taken, such as the installation of a logboom, to prevent the future accumulation of debris.

ANIMAL BURROWS

Animal burrows can be dangerous to the structural integrity of the dam because they weaken the embankment and can create pathways for seepage. The following animals can cause destruction to embankment dams (the first three have proven to be the most problematic):

- Muskrats
- Beavers
- Groundhogs (Woodchucks)
- Ground Squirrels
- Prairie Dogs
- Badgers
- Gophers

II. INSPECTING FOR DEFICIENCIES: MAINTENANCE CONCERNS

ANIMAL BURROWS (Continued)

Burrowing animals make nests and passageways. These passageways may cause internal erosion failures when they:

- Connect the reservoir to the downstream slope or shorten seepage pathways through the dam.
- Penetrate the dam's core.

Shallow burrows or burrows that are confined to one side of the embankment may be less dangerous than these deep or connective passageways.

> ☞ **INSPECTION TIP:** If shallow burrows are so prevalent that they honeycomb an embankment, the integrity of the embankment is suspect. You should consult with a qualified engineer to determine how the deficiency might be corrected.

Burrowing Animals: 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 is usually the recommended course of action.

✓ For more information on damage by animals to earthen dams, see our course "Animal Impacts on Earthen Dams"

II. INSPECTING FOR DEFICIENCIES: SUMMARY

DEFICIENCIES TO LOOK FOR

In this unit information was presented on detecting deficiencies. Listed below are the key points to remember. In addition to noting different types of deficiencies, look for changes in the features.

TYPE OF DEFICIENCY	LOOK FOR:
SEEPAGE	A water flow or sand boil on the lower portion of the downstream slope or toe area, especially at the groins. Leakage around conveyance structures such as outlet works, spillway conduits, or penstocks. Wet areas or areas where the vegetation appears greener or more lush on the embankment slope or toe area. Blocked toe drains and relief wells. An increase in the amount of water being released from toe drains and relief wells. (Remember to take into account changes in the reservoir level.) Turbidity or cloudiness of the seepage.
CRACKING	**Transverse Cracking:** Cracks perpendicular to the axis of the dam, usually found on the crest. **Longitudinal Cracking:** Cracks parallel to the axis of the dam. Longitudinal cracks may be associated with stability problems in the slopes. **Desiccation Cracking:** A random honeycomb pattern of cracks usually found on the crest and the downstream slope.
INSTABILITY	Slides, scarps, or cracks on the upstream and downstream slopes. Misalignments in the crest and embankment slopes found by sighting along fixed points. Bulges, especially at the toe of the dam.
DEPRESSIONS	Misalignments in the crest and embankment slopes found by sighting along fixed points. Sinkholes found by checking and probing each depression. Remember, sinkholes usually have steep, bucket-like sides while localized depressions have gently sloping, bowl-like sides.

II. INSPECTING FOR DEFICIENCIES: SUMMARY

DEFICIENCIES TO LOOK FOR (Continued)

TYPE OF DEFICIENCY	LOOK FOR:
MAINTENANCE CONCERNS	**Inadequate Slope Protection:** Check for bald areas or areas where the protection is sparse or damaged. **Surface Runoff Erosion:** Check for gullies or other signs of erosion. Make sure to check the low points along the upstream and downstream shoulders and groins because surface runoff can collect in these areas. **Inappropriate Vegetative Growth:** Check for excessive and deep-rooted vegetative growth. **Debris:** Check for debris on and around the dam. **Animal Burrows:** Check for damage caused by burrowing animals.

WHEN TO GET FURTHER ASSISTANCE

Several of the deficiencies covered in this unit are very serious. If you observe any of the following deficiencies, you may need to consult with a qualified engineer:

- Sand boils or turbid seepage.
- Seepage that has increased since the last inspection (taking the reservoir level into consideration).
- Cracking that extends below the reservoir level or potential reservoir level.
- Transverse and longitudinal cracking.
- Deep-seated slides or bulging associated with slides.
- Sinkholes or other large depressions.
- Deep-rooted vegetation that needs to be removed.
- Drains that are no longer flowing.

Remember, whenever you are unsure whether or not a condition poses a threat to the safety of the dam, you should discuss your findings with a qualified engineer.

II. INSPECTING FOR DEFICIENCIES: SUMMARY

REMEMBER TO "SIMPLE”

If deficiencies are observed, remember to:

S	**Sketch** what you have observed if a photograph would not capture important aspects of the deficiency.
I	**Investigate** the extent of the deficiency.
M	**Measure** and record the dimensions of the deficiency in your notes.
P	**Photograph** the deficiency and describe its characteristics in your notes.
L	**Locate** the deficiency in relation to some standard reference point (e.g., a feature of the dam or permanent monument) and record the location in your notes.
E	**Engage** the services if a qualified engineer if the deficiency could pose a threat to the safety of the dam.

II. INSPECTING FOR DEFICIENCIES: SUMMARY

~~VIDEO PRESENTATION~~

~~At this point you should watch the final video presentation. This video segment presents information on detecting the following types of deficiencies:~~

DEFICIENCIES	CORRESPONDING TEXT PAGES
Inadequate Slope Protection	II-28 to II-32
Inappropriate Vegetative Growth	II-34 to II-36
Cracking	II-15 to II-19
Slides	II-20 to II-23
Sinkholes & Depressions	II-25 to II-27
Lateral Spreading	II-23 to II-24
Debris	II-37
Animal Burrows	II-37 to II-38
Surface Runoff Erosion	II-33 to II-34

~~The video presents the deficiencies in the order listed above. Because this video segment presents so many different deficiencies, you may want to stop and review the accompanying text as information is presented. Also, you may want to watch the video presentation more than once.~~

~~To watch the video presentation:~~

- ~~Turn on your video player.~~
- ~~Load the videocassette, if it is not in the player.~~
- ~~Advance the tape to video segment #3, if the tape has been rewound.~~
- ~~Watch video segment #3.~~