Session X

INSPECTION OF EMBANKMENT DAMS

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INTRODUCTION

Understanding how embankment dams are designed and constructed enables a dam inspector to be especially alert for certain deficiencies or to concentrate on certain features of the dam during examinations. Some types of embankment dams are more susceptible than others to certain kinds of deficiencies. Therefore, a brief discussion of embankment dam design and construction characteristics precedes the discussion of embankment inspection.

EMBANKMENT DAM CHARACTERISTICS

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**: Embankment dams can be built on either rock or soil foundations, because 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 considerably less costly than construction involving production of mass concrete.

The principal disadvantage of embankment dams versus concrete dams is that they are far more likely to fail if overtopped.

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:

- Site topography, geology, and foundation conditions
- Availability of construction materials
- Requirements for spillway and outlets
- Climatic conditions

- Reservoir operations

Failure of designers to properly address one or more of these factors could have implications with regard to the safety of an existing 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.

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 material's 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.

Earthfill Dams

Hydraulic-Fill 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.

Rolled-Fill Dams

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.

Homogeneous Rolled-Fill Dams

A purely 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. In a modified homogeneous dam, small amounts of carefully placed pervious materials control the action of seepage so as to permit steeper slopes.

Zoned Rolled-Fill Dams

The most common type of rolled earthfill dam is the zoned type, in which a central impervious zone, called the core, is flanked by zones of materials generally more pervious, called shells. The shell material is coarser and usually considerably stronger than the core, and the shells enclose, support, and protect the impervious core. The upstream pervious shell affords stability against rapid drawdown; and the downstream pervious shell provides stability and may act as a drain to control the line of seepage.

A zoned embankment is said to have a thin core if the horizontal width of the impervious zone at any elevation is either less than 10 feet (3 meters) or less than the height of embankment above that elevation in the dam.

Rockfill Dams

Rockfill dams have two basic structural components -- an impervious core or a membrane and a rockfill zone which supports the impervious core or membrane.

Diaphragm Rockfill Dams

In a diaphragm rockfill dam, the embankment is constructed of rock (cobble sizes or larger), and a thin diaphragm of impermeable material is provided to form the water barrier. The diaphragm may be a blanket on the upstream face or a thin vertical core, and it may consist of earth, concrete, asphalt, or other impervious material.

Diaphragm rockfill dams have several advantages. They have greater stability against downstream sliding 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 subject to damage from weathering.

Central Core Rockfill Dams

Central core rockfill dams are similar in configuration to zoned earthfill dams, but coarse, free-draining rockfill is much stronger than fine-grained soils, allowing steeper external slopes, and hence an economical design because less material is required. 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 does have a high resistance to deformation during earthquakes.

INSPECTION TECHNIQUES

The purpose of inspection is to identify deficiencies or concerns that potentially affect the safety of the dam. Thus, it is important to look at the entire surface area of an embankment. The general technique is to walk over the slopes and crest as many times as is necessary in order to see the entire surface area clearly. From a given point on the dam, small details can usually be seen for a distance of perhaps 10 to 30 feet (3 to 10 meters) in any direction, depending on the roughness of the surface, vegetation, or other surface conditions. Therefore, to ensure that the entire surface of a dam has been covered, several passes must be made. It is not really that important what approach is used, as long as it is systematic such that all of the surface area is covered.

At regular intervals while walking the slope and crest of a dam, an inspector should stop and look around in all directions to:

- Observe the surface from a different perspective, which sometimes reveals a deficiency that might otherwise go undetected.

- Check the alignment of the surface.

In addition, viewing a slope from a distance may also reveal a number of anomalies such as distortions of the embankment surfaces and subtle changes in vegetation. Often these types of observations are not apparent when viewing them close up.

The areas where the embankment contacts the abutments (sometimes referred to as the groins) should be inspected carefully.

Inspection of the groins is important because:

- These areas are susceptible to surface runoff erosion.

- Seepage often appears along the groins because the embankment/abutment contacts are more susceptible to seepage.

When checking the alignment of the crest of a straight-axis dam, as well as any berms on the upstream and downstream slopes, an inspector should center his/her eyes along each shoulder of the crest or berm and move from side to side in order to view this line from several angles.

Some tools or techniques that are helpful in sighting are:

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

- **Reference Lines**: The use of a reference line can also be of great assistance in sighting. Reference lines can be existing features such as guardrails, a row of posts, pavement stripes on a roadway on the crest of the dam, parapet walls, etc.

The sighting techniques described above are also useful for detecting a change in the uniformity of embankment slopes. 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.

The alignment of the slope at the waterline can be checked by standing at one end of the dam and sighting along the waterline. Non-linearity of the waterline may indicate erosion or movement of the slope.

DETECTING DEFICIENCIES

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

- Seepage

- Cracking

- Instability

- Depressions
  - Settlement
  - Sinkholes

- ! Maintenance Concerns
  - Inadequate slope protection
  - Surface runoff erosion
  - Inappropriate vegetative growth
  - Animal burrows

SEEPAGE

All embankment dams pass water through the embankment or foundation materials. The passage of water through the embankment or foundation is called seepage.

Seepage becomes a problem when embankment or foundation materials are moved by the water flow, or when excessive pressure builds up in the dam or its foundation. Seepage that is not controlled by designed seepage/drainage features incorporated in the dam and foundation is often referred to as uncontrolled seepage.

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 toe drains, horizontal blanket drains, and chimney 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.

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 internal erosion of foundation material or embankment instability.

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.

If there are several wells, they will 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 of the dam. Typically, this water is discharged back into the natural stream.

Seepage Problems

Uncontrolled seepage is a major cause of embankment dam failure. Seepage problems can be divided into the following two categories:

- Stability problems
- Seepage erosion

Seepage may cause instability when high water pressure and saturation in the embankment or foundation cause the earth materials to lose strength. If uncontrolled seepage emerges on the lower downstream slope, very often the seepage will cause sloughing or even massive slides.

Seepage associated with high hydraulic gradient conditions can lead to seepage erosion. Hydraulic gradient is the ratio of the difference in hydraulic head (water levels) over the length of the seepage flow path.

High gradient seepage along conduits or other appurtenant structures, or along the abutment or foundation contact, or through cracks can cause erosion of the adjacent earth material all along the seepage pathway. This is referred to as internal erosion. If high gradient seepage is concentrated through earth materials such as sands or cohesionless silts, the force of the flowing water can start to remove material at the seepage exit point, and when the erosion progresses headward toward the reservoir, it is known as piping.

When seepage exits the ground surface in a churning or boiling action due to excessive seepage pressures caused by high hydraulic gradient conditions, it is referred to as a sand boil. Earth material may or may not be exiting with the seepage. Signs that exiting seepage is carrying earth materials are discussed below.

Seepage Appearance

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

Viewing the downstream slope from a distance is sometimes helpful in detecting subtle changes in vegetation. Greener or more lush vegetation below a certain elevation on the downstream slope may indicate the intersection of the seepage line through the dam with the slope.

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

Difficulties with compaction also make areas adjacent to conveyance structures like outlet works, spillway conduits, or penstocks more susceptible to uncontrolled seepage problems.

Seepage exiting from around or adjacent to 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 internal erosion and an eventual breach of the dam can result.

For rockfill dams with impervious upstream membranes, the appearance of seepage coming through the downstream rockfill shell (or sometimes just the sound of seepage heard running through the downstream shell) indicates that the upstream membrane is no longer water tight. Cracks or joint separations have probably occurred in the membrane which should be verified by inspection at lower reservoir levels or with underwater cameras. If water losses are significant, repairs to the membrane should be recommended.

Seepage: Inspection Actions

If uncontrolled seepage is observed, then it should be monitored. To monitor seepage, the following should be recorded:

- The location of all seepage exit points.
- Seepage flow rates and clarity.
- The occurrence of recent precipitation that could account for what appears to be seepage, or that could affect the appearance and quantity of actual seepage.
- The level of the reservoir at the time of the observation.

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. An increase in a seepage flow rate for a similar reservoir elevation is cause for concern.

In some cases, dye can be used to confirm that the reservoir is the source of seepage. A dye test is not a routine procedure. The length of time it takes to conduct a test may vary since the dye may take different amounts of time to penetrate the embankment or foundation. In most cases, records of seepage volumes that correlate with reservoir elevations are needed to show that seepage comes from the reservoir.

If sand boils are observed:

- They should be photographed and their location documented.
- The clarity of the exiting seepage should be noted. If there are any deposition cones around the seepage exit points, this should also be recorded.

- Flow rates should be measured or estimated along with the corresponding reservoir elevation. However, the seepage flow rates may be difficult to ascertain since sand boils are often under water.

Sometimes as a temporary measure, a sandbag dike can be placed around a sand boil to increase the depth of water (head) over the boil and thereby decrease the hydraulic gradient across the seepage flow path sufficiently to reduce the potential for piping. By the same token, draining a seepage pond at the toe of a dam may increase the hydraulic gradient sufficiently to induce piping.

A piping condition does not always appear first as a sand boil. In fact, piping can occur into voids in rock foundations. This type of piping is difficult to detect since nothing is visible until the embankment starts to collapse into the underlying void, or until a vortex appears in the reservoir. A vortex is the rotational movement on the reservoir surface that can appear as water rapidly enters a seepage pathway.

Weirs and flumes should be installed to quantitatively monitor seepage exiting from the embankment or foundation. When properly calibrated and kept free of silt and vegetation, weirs and flumes can measure seepage accurately. Weirs that become silted-in may indicate that embankment or foundation material is being piped out of the dam, or simply that sediment from surrounding surface runoff erosion is collecting in the structure.

Many embankment dams have toe drains that collect and discharge internal embankment and foundation seepage. Before conducting an examination of an embankment dam that has toe drains, the following should be reviewed:

- The design drawings to determine the location of the toe drains and their outfalls.

- 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 in determining if there is a problem. If flow from a drain is atypical for the given reservoir level, more investigation may be warranted.

During the inspection, the inspector should:

- Locate each toe drain outfall.

- 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 to 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 anticipated for the current reservoir level based on previous readings.

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 a drain has never functioned, it could mean that the drain was designed or installed incorrectly. If it flowed at one tune but has now stopped flowing, it may have become plugged. A plugged drain can be a serious problem because seepage may begin to exit down slope, or may contribute to 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 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. Recording drain flow rates and reservoir levels over time will help in assessing a dam's seepage conditions.

Some embankment dams employ relief wells to collect foundation seepage and relieve uplift pressures at the downstream toe. Before conducting an inspection of an embankment dam that has relief wells, the following should be reviewed:

- Design drawings should be reviewed to determine the location of the wells.

- Previous data on both the reservoir level and well flow should be reviewed. 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 determine if there is a problem. If well flow is atypical for the given reservoir level, more investigation may be warranted.

During the inspection the inspector 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 an 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. Weirs, flumes, or a bucket and stopwatch can be used to measure the flow rate.

- The amount of well flow measured should be compared with the amount of flow anticipated for the current reservoir level based on previous readings.

If the well flow is less than the amount anticipated, the well screens or filters may have become clogged. Cleaning the wells should be considered.

If the well flow is greater than the amount anticipated, there may be excessive seepage. The flow should be accurately recorded along with the reservoir level and compared with well-flow trends previously observed.

In addition to measuring the flow rate of seepage, the clarity of any seepage observed should be evaluated. 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. Thus, turbidity is cause for concern. Each time seepage is measured, the clarity of the seepage should also be visually checked.

Sometimes the seepage can be clear, but still contain dissolved material from the foundation. This may be indicated if, for instance, seepage has increased. In such cases, it may be necessary to perform water quality testing to verify whether dissolution is occurring.

As mentioned previously, the rate and turbidity of seepage flow should be recorded at each examination. If seepage problems are suspected, then more frequent examinations or further investigation should be considered.

CRACKING

Another potentially serious deficiency is embankment cracking. Cracks may appear in the crest or slopes of the dam. Cracking in an embankment dam falls into the following three major categories:

- Longitudinal cracking
- Transverse cracking
- Desiccation cracking

Longitudinal Cracking

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

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

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 longitudinal cracking is observed the inspector should:

- Photograph and record the location, depth, length, width, and offset of each crack observed.

- Closely monitor the crack for changes.

- Recommend that the cause of the cracking be determined.

Transverse Cracking

Transverse cracking appears in a direction roughly perpendicular to the length 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, and in U-shaped or trapezoidal-shaped valleys.

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

- Compressible embankment material overlies steep or irregular rock abutments.

- There are zones of compressible material in the foundation.

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.

Transverse Cracking: Inspection Actions

If transverse cracking is observed, the inspector should:

- Photograph and record the location, depth, length, width, and offset of each crack observed.

- Closely monitor the crack for changes.

- Recommend that the cause of the cracking be determined.

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 desiccation cracking is observed, the inspector should:

- Probe the more severe cracks to determine their depth, especially if they are oriented in an upstream/downstream direction.

- Photograph and record the location, length, width, depth and orientation of any severe cracks observed.

- Compare these measurements with past measurements to determine if the condition is worsening.

If the depth of the cracking extends below the reservoir level or potential reservoir level, appropriate remedial measures should be recommended.

INSTABILITY

Instability of an embankment can be very serious. Embankment instability is referred to variously as slides, displacements, slumps, slips, and sloughs.

Slides can be grouped into two major categories:

- Shallow slides

- Deep-seated Slides

Shallow Slides: Upstream Slope

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 post no immediate threat to the integrity of the dam. However, shallow slides may lead to:

- The obstruction of water conveyance structure inlets.
- Larger, deep-seated slides.

Shallow Slides: Downstream Slope

Shallow slides in the downstream slope also indicate an overly steep slope. In addition, these slides may also indicate a loss of strength in the embankment material. A loss of strength in the embankment material can be the result of saturation of the slope from either seepage or surface runoff. Additional loads from snow banks or structures can aggravate the condition.

Shallow Slides: Inspection Actions

If shallow slides are observed, an inspector 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 side.
- Check for seepage near the slide.
- Monitor the area to determine if the condition is becoming worse.

Deep-Seated Slides

Deep-seated slides are serious threats to the safety of the dam. Deep-seated slides are characterized by:

- Well-defined scarping (a scarp is a steep back slope).
- Toe bulge (a toe bulge is produced by the rotational or horizontal movement of embankment material.
- 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 as it begins to move downward).

Deep-Seated Slides: Inspection Actions

A deep-seated slide in either the upstream or downstream slope may be an indication of serious structural problems. In most instances, deep-seated slides will require the lowering or draining of the reservoir to prevent the possible breaching of the dam.

If a slide is suspected, the inspector should:

- Closely inspect the area for cracking or scarps which indicate that a slide is the cause.

- Recommend an investigation to determine the magnitude and cause, if a deep-seated slide is considered probable.

- Recommend possible lowering and restricting the reservoir if release of the reservoir is threatened by continued movement of the slide.

DEPRESSIONS

Depressions are low spots in embankment surfaces and may be localized or widespread. They may be caused by:

- Settlement in the embankment or foundation. Such settlement may result in a loss of freeboard and represent a potential for overtopping of the dam during large floods.

- 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.

- Internal erosion or piping and subsequent collapse of overlying material.

Some areas of the embankment surface that look like depressions may be the result of improper final grading during construction, but the cause of depressions should be determined. Depressions can be minor or they can be very serious. Sinkholes are a serious type of depression. A good way of distinguishing between localized settlement and sinkholes is to look at their profiles:

- Localized settlement usually has gently sloping, bowl-like sides.

- Sinkholes usually have steep sides from the soil shearing as it collapses into an underlying void.

Depressions as well as other misalignment in the crest and embankment slopes often can be detected by sighting along linearities such as guardrails, parapet walls, or pavement striping. Some apparent misalignment may be due to irregular placement of those features. 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.

Settlement: Inspection Actions

Although settlement, in most cases, does not represent an immediate danger to the dam, it may be early indicators of more serious problems. Therefore, an inspector should:

- Photograph and record the location, size or extent, and depth of any settlement. Have a survey performed of the crest if there is a concern about loss of freeboard.
- Probe the bottom of localized depressions to determine whether or not there is an underlying void or flowing water that would indicate that a sinkhole exists, that is caused by the removal of subsurface material by internal erosion or piping.
- Inspect the depression frequently to ensure it is not continuing to settle or enlarge.

Sinkholes: Inspection Actions

If a sinkhole is encountered, an inspector should:

- Probe the bottom of the sinkhole to determine if a larger void exists.
- Photograph and record the location, size, and depth of the sinkhole.
- Recommend that the cause of the sinkhole be investigated immediately and the threat to the dam be determined.

MAINTENANCE CONCERNS

Maintenance includes the routine measures taken to protect and maintain the dam. Deficiencies associated with inadequate maintenance include:

- Inadequate slope protection
- Surface runoff erosion
- Inappropriate vegetative growth
- Animal burrows

INADEQUATE SLOPE PROTECTION

Slope protection is designed to prevent erosion of the embankment slopes. The two primary types of slope protection used on embankment dams are riprap vegetative cover (grasses). Gravel, soil cement, concrete, asphalt, and other types of slope protection are also used. The type of slope protection selected depends upon economics, and rainfall conditions, and the size of the reservoir and wind conditions found at the site.

Riprap

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

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 properly sized and graded to prevent the underlying embankment from being washed out through the voids in the larger rocks found in the outer layer.

- **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 wave erosion.

Vegetative Cover

The outer portion of the embankment that consists of fine-grained soil must be protected from wind and rainfall runoff erosion as well as wave erosion. Failure to protect the slope could result in the formation of significant erosion rills or gullies that will eventually have to be repaired. In most geographic areas, a properly cultivated cover of grass provides satisfactory crest and downstream slope protection. The root system of the vegetative cover holds the surface soil in place and protects the slopes from wind and surface runoff erosion.

Using a grass cover to protect the upstream slope may also be effective for small reservoirs and dams that have insignificant wave action. It may be necessary to use other types of slope protection in arid climatic regions, where riprap is unavailable or too costly to use, in areas where surface runoff is excessive or concentrated, such as along the groins, and where conditions combine to create severe wave action.

The constant action of waves on the upstream slope may result in 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. The effects of severe wave action on the upstream slope can be:

- **Beaching**: Beaching is the displacement, by wave action, of a portion of the upstream slope of the embankment. When beaching 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 can be removed. A relatively flat area, or beach, with a steep back slope or scarp is formed. The continuance of this process can lessen the width and possibly height of the embankment, and could lead to increased seepage, instability, or overtopping of the dam.

- **Degradation**: Degradation of the slope protection may occur when the protective material cracks and breaks down due to weathering and wave action. Even the best designed slope protection will experience some degradation over time. Degraded riprap, soil cement, 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.

Inadequate slope protection: Inspection Actions

It is important to check that the riprap is large enough and sufficiently angular and durable such that it is not displaced by wave action and that it is not breaking down into smaller fragments. 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 typically a relatively thin blanket of protection. Hand-placed 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.

An inspector should make sure that the slope protection is adequate enough to prevent erosion, and look for beaching, scarping, and degrading of the slope protection.

If inadequate slope protection is observed:

- The findings should be recorded and the area photographed.
- The extent of embankment damage (i.e., embankment material removed) should be determined.
- Corrective action should be recommended to repair or to replace the inadequate slope protection.

SURFACE RUNOFF EROSION

Surface runoff erosion is one of the most common maintenance problems of embankment structures. 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. Conceivably severe gullies could cause breaching of the crest, or shorten the seepage path through the dam, possibly leading to piping.

Gullies can develop from poor grading or sloping of the crest that leads to improper drainage, causing surface water to collect and to run 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

Bald areas or areas where the protective cover is sparse are more susceptible to surface runoff erosion problems. In the upstream slope, erosion may undermine the riprap and cause it to settle. Settlement of the riprap 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. 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, livestock may establish trails on the embankment. Livestock traffic can damage the slope's vegetative cover. Recreational vehicles can cause ruts in the crest and can damage the slope protection.

Surface Runoff Erosion: Inspection Actions

An inspector should:

- Make sure that the slope and crest protection is adequate to prevent erosion. 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 that the upstream and downstream shoulders are checked for low spots since surface runoff can concentrate in these areas.

- Check for any unique problems, such as livestock or recreational vehicles, that may be contributing to erosion.

If surface runoff erosion is observed:

- The findings should be recorded and area photographed.

- The extent or severity of the damage determined.

- Corrective action should be taken to repair the areas damaged by surface runoff and measures taken to prevent more serious problems.

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

Excessive Vegetative Growth

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

- Obscure large portions of the dam, preventing 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.

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. To ensure that the greatest visibility of the slopes and crest, examinations should be scheduled 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 seepage erosion.

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 seepage erosion 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.

It is generally agreed that trees and shrubs more than 2 feet (0.6 meters) in height are undesirable growing on or adjacent to embankment dams. 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 in the dam. The location, size, type of tree, and prevailing policy will determine the course of action at a given site.

The best approach to trees on 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, the area around the remaining stumps should be carefully monitored for signs of seepage.

Inappropriate Vegetative Growth: Inspection Actions

An inspector should:

- Look for excessive and deep-rooted vegetation on all areas of the dam.
- Make sure that there is **no** vegetation growing in the riprap on the upstream slope.
- 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:

- ! The size and extent of the vegetation should be recorded and photographed.
- ! Appropriate corrective action should be recommended to remove inappropriate vegetation and measures taken to prevent the future growth of undesirable vegetation.
- ! Removal of large trees should include the removal of their root systems and the surrounding disturbed soil, and backfilling of the excavation with suitable compacted material.

ANIMAL BURROWS

In some instances, animal burrows can be dangerous to the structural integrity of a dam, since they weaken the embankment and can create pathways for seepage.

The animals that can cause the most problems for embankment dams are:

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

These animals make nests and passageways in embankment dams; or in the case of badgers, can disturb significant areas of the dam by digging out otherwise small burrows in search of prey. Animal burrows may lead to seepage erosion failures when they connect the reservoir to the downstream slope or shorten seepage pathways, and penetrate the core of the dam.
In addition to burrowing, beavers are usually of greater concern because of their habit of building dams in spillways to raise reservoir water levels.

The location and depth of burrows and the cross-sectional width of the embankment determine the seriousness of the problem. Burrows on the lower downstream slope and toe area are of most concern because they may intercept the seepage line through the dam or foundation. But for dams with narrow cross-sections, burrows higher on such dams, but still below typical reservoir levels, also pose significant risk.

Burrowing Animals: Inspection Actions

If burrowing animals are evident:

- Look for evidence of seepage coming from any of the burrows on the downstream slope or foundation.

- The location and estimated depth of the burrows should be recorded and the areas photographed for comparison during future inspections to determine if the problem is getting worse.

- If the location, extent, or depth of burrows represent a threat to the dam, it should be recommended that the burrowing animals be removed or eradicated, and the burrow damage repaired.

Trapping is considered to be the most effective and efficient method for removal of burrowing animals. Animal burrows penetrating significantly into the embankment should be excavated and backfilled with suitable compacted material.