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BLM Manual Handbook H-9177-1

Dam Condition Assessment Guidelines for Embankment Dams

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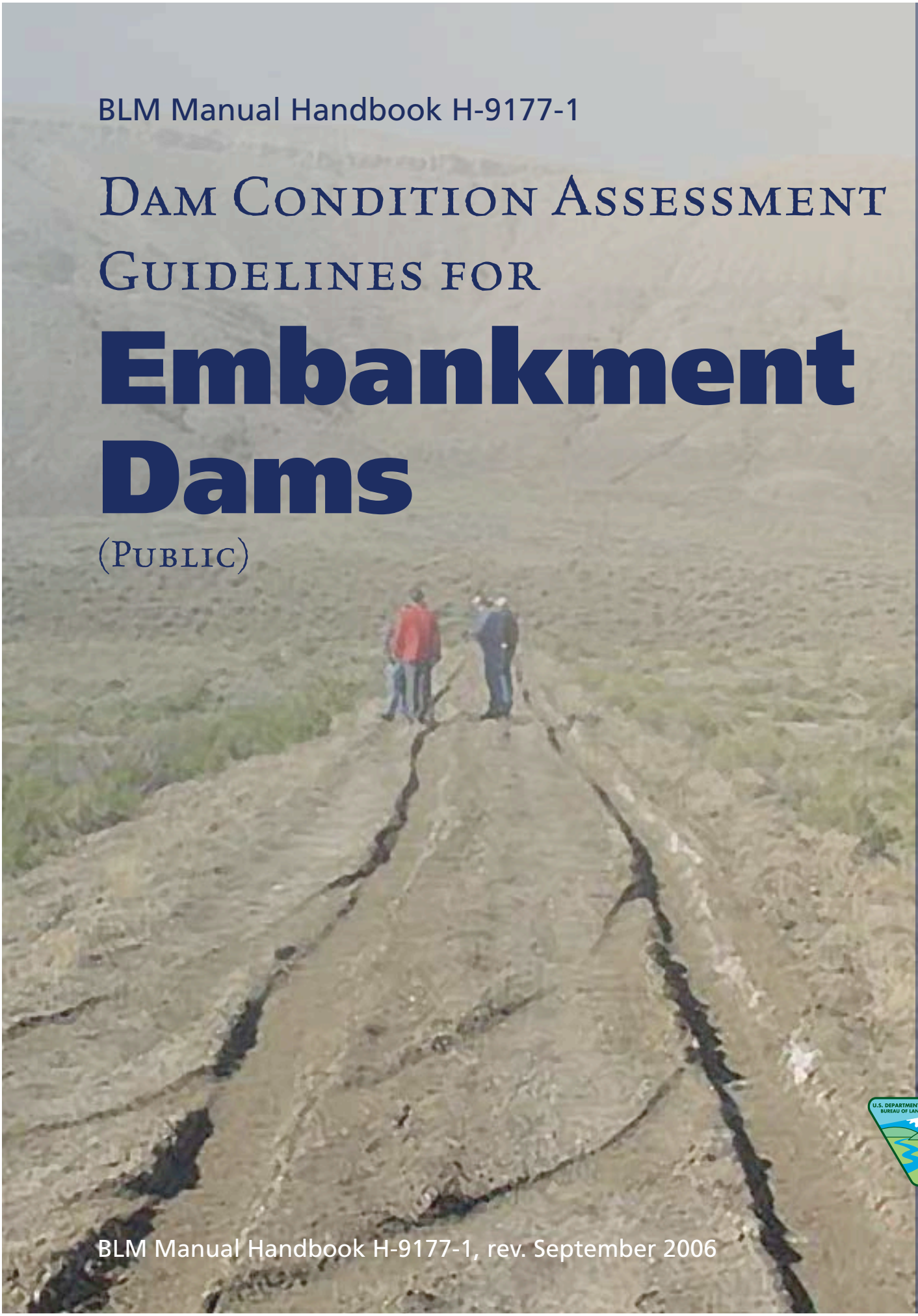

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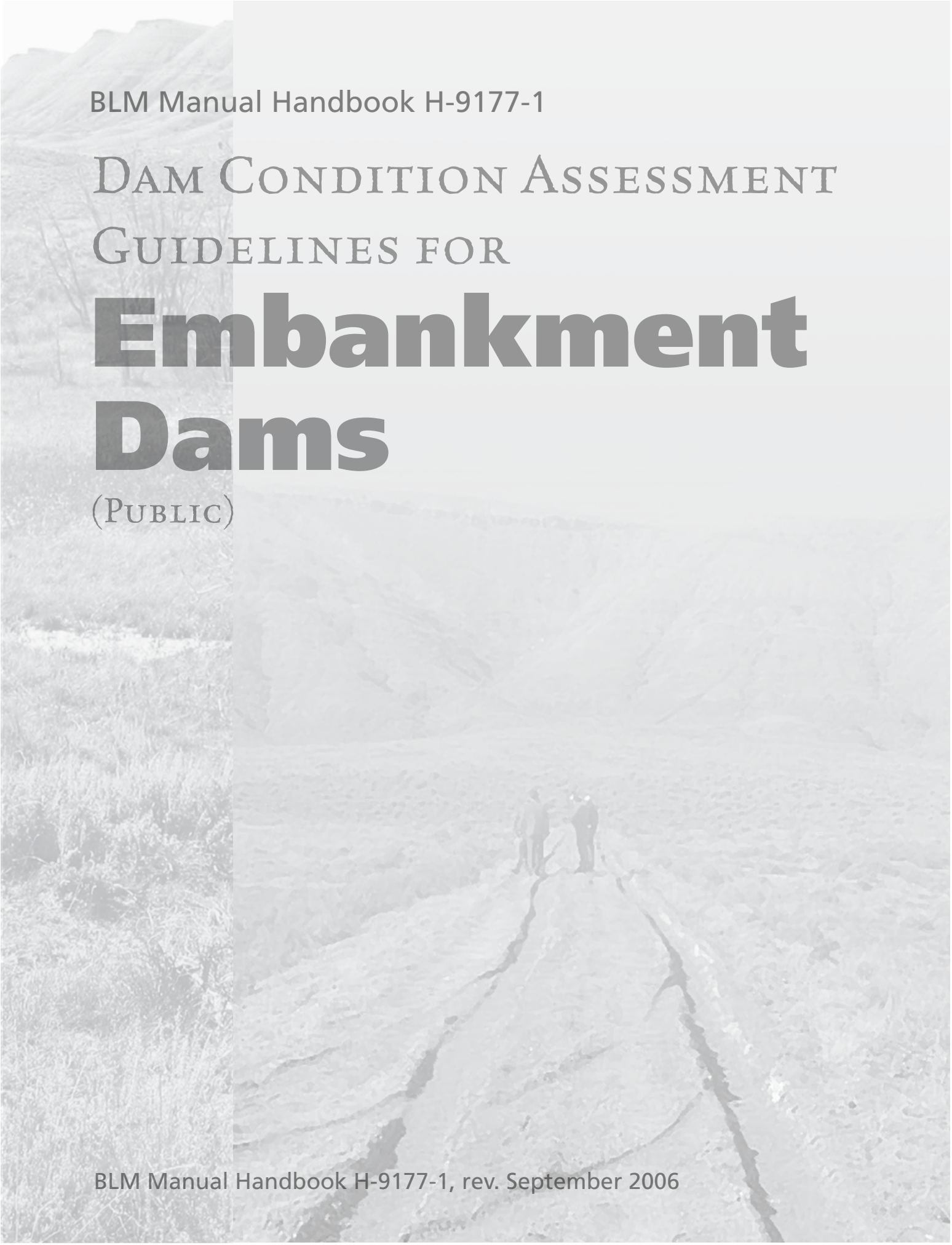

BLM Manual Handbook H-9177-1, rev. September 2006

Contents

I. Definitions 1

II. Determinants of Performance and Safety 9

A. Changes in Constituent Materials 9

1. Concrete 9
2. Rock 9
3. Soils 10
4. Metals 10
5. Timber 10
6. Liners 10
7. Joint Sealers 10

B. Generic Changes 10

1. Seepage and Leakage 10
2. Drainage 11
3. Ice Damage 11
4. Stress and Strain 11
5. Stability 11
6. Inadequate Seepage Control—Evidence and Clues 11
7. Erosion Control 11
8. Foundation 12
9. Other Endagerments 12

C. Spillways 12

1. Approach Channel 12
2. Log Booms 12
3. Hydraulic Control Structure 12
4 Headwater Control 12
5. Shafts, Conduits, and Tunnels 12
6. Bridges 12

7. Spillway (Open Channel or Conduit) 13
8. Terminal Structures 13
9. Return Channels 13
10. Trashracks and Raking Equipment 13
D. Environs 13
1. Reservoir 13
2. Reservoir Linings 14
3. Downstream Proximity 14
4. Watershed 14
5. Regional Vicinity 14
6. Downstream Flood Plain 14
III. Natural Events 15
A. Large Magnitude Floods 15
B. Seismic Events 15
C. High Winds 16
IV. Inspection of an Earth Embankment Dam and Reservoir 17
A. Procedure 17
1. Qualifications 17
2. Method 17
B. Cracks 22
1. Transverse Cracks 22
2. Horizontal Cracks 24
3. Longitudinal Cracks 25
4. Interior Cracks 26
5. Surface Drying Cracks 27
C. Sliding and Slumping 28
1. Pattern Cracking 28
2. Slow Slides 30
3. Rapid Slides 30
4. Sliding When Reservoir Is Full 30
5. Drawdown Slides 33
D. Seepage Problems 35
1. Piping Through Embankment 38

2. Piping Along Outlet Works 39
3. Piping Through the Abutments 40
4. Piping Through Foundation 40
5. Seepage Through Embankment 41
6. Seepage Due to Water-Soluble Materials 42
7. Seepage and Vegetation Growth 42
8. Burrowing Animals 43
E. Erosion Problems 44
F. Foundation Problems 45
G. Spillways and Outlets 45
H. Reservoirs and Impoundments 47
I. Other Appurtenances 47
J. Site and Surrounding Area 47
K. Safety Considerations 48
L. Photographs and Sketches 49
V. Classification Information for Dams 51
A. Seismic Peak Ground Accelerations 51
B. Size Classification 51
C. Hazard Classification 53
D. Safety Ratings 54
E Dam Safety Rating 60
VI. Selected References 61

List of Illustrations

Figure 1. Homogenous Earth Retention Dam 1
Figure 2. Common Failure Modes 16
Figure 3. Benchmark Location on Embankment Dam 18
Figure 4. Transverse Cracks 23
Figure 5. Transverse Cracks 23
Figure 6. Horizontal Cracks 24

Figure 7. Horizontal Cracks....25
Figure 8. Longitudinal Cracks....25
Figure 9. Longitudinal Cracks....26
Figure 10. Interior Cracks....26
Figure 11. Interior Cracks....27
Figure 12. Pattern Cracks....28
Figure 13. Slumping....29
Figure 14. Slow Slump....30
Figure 15. Rapid Slide....31
Figure 16. Deep Slide....32
Figure 17. Shallow Slide....33
Figure 18. Drawdown Slide....34
Figure 19. Piping Through Embankment....39
Figure 20. Piping Through Foundation....40
Figure 21. Blowout Through Foundation....41
Figure 22. Sloughing of Saturated Embankment....42
Figure 23. Muskrat Burrows....43
Figure 24. Horizontal Peak Ground Accelerations....52

1. Definitions

The following definitions related to dam safety and maintenance are provided here for the convenience of the reader. See Figure 1 for an illustration of the major features of a typical earth embankment dam.

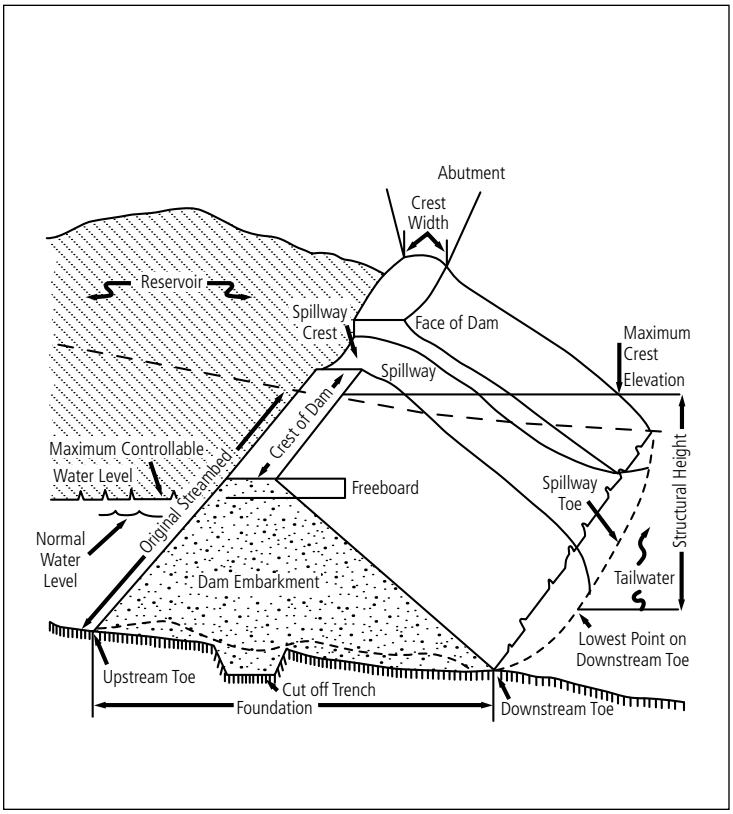

Figure 1. Homogeneous Earth Retention Dam

-A-

abutment: the natural valley or canyon side against which a dam is constructed (Figure 1).

acre-feet (AF): a measurement of volume; the amount of water that will cover 1 acre to a depth of 1 foot (1 acre-foot = 43,560 cubic feet).

-B-

batter: inclination from the vertical slope.

berm: a small embankment; also, a horizontal step on the sloped face of a dam.

-C-

chute: the body of a spillway or conduit: the portion between the head (inlet) and the toe (outlet).

crest of dam: the top of the embankment of a dam; usually, the elevation of the crest is taken at the highest point on the human-made embankment (Figure 1).

crest of spillway: the top or the highest point at the inlet or intake portion of the spillway.

cubic feet per second (CFS): "second-feet" (1 cfs = 448.8 gallons per minute). A measurement of volume over time; the amount of water passing a location at one moment in time.

cutoff: an impervious portion of the dam designed to minimize or prevent the movement of water through the embankment, the abutments, or the foundation.

cutoff collar: an impervious fitting placed around a conduit or pipe that is designed to prevent seepage or erosion around the outside of the conduit and to confine any flow of water to within the conduit.

cutoff trench: the excavated area that is later filled with impervious material to create a cutoff (Figure 1).

-D-

dam: any human-made structure erected for the purpose of retention, detention, or diversion of water. Structures less than 6 feet high (hydraulic height)—regardless of impoundment capacity—or structures with an impoundment capacity of less than 15 acre-feet—regardless of height—are not considered to be dams.

design flood or design storm: the flood or storm that a given structure or appurtenant device is designed to contain or pass without significant damage or failure. Design floods are usually expressed as return interval (100-year flood) or ratio to probable maximum event (1/2 PMF); design storms are usually expressed as return interval plus duration (100-year, 6-hour storm).

detention dam: a dam designed to slow or mitigate the force of flowing water or to stop sediment transport to downstream areas. Detention dams store little or no water except during and immediately after a flood.

diversion dam: a dam designed to modify the direction of flow of water but not generally designed to retain a permanent pool of water.

downstream toe: the junction of the downstream face of the dam with the ground or streambed. Generally, if the word "toe" is used without any qualifiers, it refers to the downstream toe (Figure 1).

drop structure: a dam designed to dissipate the force of flowing or falling water; usually, a drop structure stores no water except for a brief time during a flood.

-E-

embankment: fill material, usually earth or rock, placed with sloping sides and having a length greater than the height.

embankment (or earthfill) dam: a human-made barrier 6 feet high or higher erected to divert, retain, or detain 15 acre-feet or more of water that is constructed with more than 50% of the volume of the embankment of compacted, fine-grained material.

emergency spillway: a spillway or outlet built with its crest higher than the customarily used principal spillway, designed as additional relief for the structure in case of abnormally large flows. If there is only one spillway for a structure, it is usually an emergency spillway.

-F-

face of dam: the upstream or downstream sloped surface of the dam (Figure 1).

fetch (reservoir fetch): the distance over which wind can act upon a body of water to produce wave action. It is generally defined as the normal distance from the windward shore to the upstream face of the dam; however, in certain circumstances, the fetch may have a slightly curved path, such as when the wind is channeled downriver toward a dam by steep canyon walls.

fish ladder: a device designed to facilitate the passage of fish over or around an obstruction such as a dam; fish ladders are of special importance in streams that carry anadromous species (such as salmon).

flashboards: lengths of timber, sheet metal, and other items that are placed on the crest of a spillway or a dam to increase retention capacity, but that are moveable rather than permanent features of the dam.

flood frequency: a measure of how often a hydrologic event of given magnitude may, on the average, be equaled or exceeded; usually expressed as yearly return interval (50-year flood equals the flood that has a 2% probability of occurrence

in any given year; 100-year flood equals the flood that has a 1% probability of occurrence in any given year).

flood routing: a study of the changes that occur in the characteristics and magnitude of a flood wave as it moves through space and time.

foundation: the natural ground surface upon which a dam is constructed (Figure1).

freeboard: the vertical distance between the water level in the reservoir and the top of the dam (Figure 1). Net or flood freeboard is the vertical distance between the top of the dam and the maximum water level behind the dam.

-G-

gabions: wire baskets that are filled with rocks or gravel too large to pass through the mesh of the wire. Gabions are used as temporary or permanent devices for slowing or preventing erosion, for detention or diversion of water, or for the armoring of stream channels or embankments against the action of flowing water.

gate: a permanent device for regulating, preventing, or facilitating (depending on its position) the flow of water from a reservoir, through a channel or conduit, over a spillway.

groin: The area along the contact (or intersection) of the face of a dam with the abutments.

guzzler: a small-diameter pipe or conduit through or around a dam that is designed to provide drinking water for wildlife or livestock.

-H-

hydraulic height: the vertical distance between the lowest point in the natural streambed at the toe of the dam and the maximum controllable water level.

hydraulics: the science dealing with the practical properties and applications for liquids in motion.

hydrograph: a graph showing, for a given point in a watershed, the discharge, stage, velocity, or other property of water with respect to time.

hydrologic or hydrological properties: the physical characteristics of a structure that are related to its ability to withstand, modify, or divert the flow of water resulting from a given hydrological event.

hydrology: the science dealing with the properties, distribution, and circulation of water in the atmosphere, on the surface of the earth, and under the surface of the earth.

-I-

intake: any device through which water can enter to pass through a barrier or into a distribution system.

-L-

log boom: a device suspended in front of the entrance to a spillway or intake designed to prevent the movement of downed timber or other large debris into the spillway.

low-level, gated outlet: An opening at a low level from a reservoir, generally used for emptying or for scouring sediment and sometimes for irrigation releases.

-M-

maximum controllable water level: the maximum level that water can attain without overtopping the dam or otherwise causing flow in excess of the amount that the dam itself or its appurtenant structures are designed to pass without damage (Figure 1).

-N-

normal water level: the elevation of the water surface during the time when no runoff or flooding occurs.

-O-

outlet or outlet works: an opening or device through which water is discharged. "Outlet works" is sometimes used synonymously with "spillway."

-P-

phreatic line: the theoretical dividing line between the wetted or saturated portion of an embankment and the dry portion.

phreatophyte: one of the groups of plants or vegetative species that are water-seekers; i.e., that are deep-rooted and that derive their supply of water from the water table rather than from surface sources. Examples include willows and saltcedars. The presence of phreatophytes indicates seepage or underground movement of water that cannot be observed on the surface of the ground.

piping: the progressive development of internal erosion in an embankment from the downstream to the upstream side of the dam.

principal spillway: a chute or conduit designed to convey a certain predetermined, maximum amount of water over or through a dam without damage to the dam. In some instances, a dam may have both a principal and an emergency spillway.

-R-

reach: a specified length of a stream, river, or watercourse chosen for convenience of definition or for study. Generally, individual reaches are designated according to common characteristics—common topography, vegetation, flow, or other features that allow the reach to be treated as a homogeneous unit.

reservoir: the body of water confined behind a dam that would not be present without the dam; usually refers to a permanent pool of water such as that found behind a retention dam (Figure 1).

reservoir routing: flood routing through a reservoir to study the changes in the characteristics of a flood wave due to the hypothetical or actual presence of a dam, reservoir, or detention pool, and appurtenant structures.

retention dam: a dam designed to retain a permanent pool or reservoir of water.

richter scale: a method of measuring relative earthquake intensity and assessing seismic risk and providing for earthquake-resistant design.

riprap: a layer of uncoursed, unmortared stones or rubble placed in random fashion on the face of an embankment, shoreline, or sides of a channel to protect against wave action and erosion.

-S-

sedimentation: the gradual accumulation of solid material carried in by water behind a dam.

seepage: the interstitial movement of water through the dam embankment, abutments, or foundation.

seismic zone: for purposes of assessing relative seismic risk, the United Sates has been divided into seismic risk zones ranging from 0 (no known earthquake potential) to 4 (high potential for earthquakes of large magnitude).

spur dike: relatively short embankments generally in the shape of a quarter of an ellipse and constructed at the upstream side (and sometimes the downstream side) of either or both sides of a dam for the purpose of directing the flood flow into or around the dam or reducing the sediment load to the dam.

structural height: the vertical distance between the lowest point in the natural streambed at the toe of the dam to the highest point on the top or crest of the dam (Figure 1).

-T-

tailwater: water found in the natural steam channel at the downstream toe of the dam (Figure 1).

thrust block or anchor block: a massive block of solid material (usually concrete) designed to withstand a thrust, pull, or lateral motion and used to secure conduits, pipes, etc., in place against the force exerted by the water flowing through the conduit.

trashrack: a screen or bar device located in front of an intake to prevent debris from entering or obstructing the intake.

-U-

upstream toe: the junction of the upstream face of the dam with the ground or streambed surface (Figure 1).

-V-

volume of dam or embankment: the volume of earth or the fill material used to construct the dam embankment; usually expressed as "cubic yards" or "yards."

-W-

wier: a structure built across a steam or channel to measure the amount or rate of water flowing past the point or to temporarily create a small impoundment.

II. Determinants of Performance and Safety

The performance and safety of dams and appurtenant structures depend on design, the characteristics of the constituent materials, the nature of the foundation on which the structure is built, and the characteristics of the region in which the structure is located.

The objective of dam safety inspections is to detect any existing or developing structural or hydraulic weakness, foundation weakness, or changes in downstream land use that depend on or are affected by the continuing operation of the structure.

A. Changes in Constituent Materials

In general, look for evidence of defective, inferior, unsuited, or deteriorated materials. The quality and durability of individual components must be determined in order to assess the condition of the structure as a whole.

1. Concrete

Changes in the condition or the strength of concrete structures include alkali-aggregate reactions, pattern crazing and cracking, leaching, frost action, abrasion, spalling, and crumbling and structural cracking. Note any cracking, spalling, or other visible signs of deterioration in concrete spillways, walls, embankments, pipes, energy dissipaters, or inlet and outlet boxes. These conditions may indicate serious problems, particularly for areas experiencing high-velocity flows. Cracking can be caused by relatively harmless temperature expansion or shrinkage, but cracks should be noted and observed carefully for signs of enlargement or progression.

2. Rock

Changes in rock composition include disintegration, exfoliation, softening, and dissolution. Note any signs of changes in rock facing, riprap, abutments, and foundations.

3. Soils

Soil changes that may cause stability and maintenance problems for dams include degradation, dissolution, loss of plasticity or cementation, mineralogical shift, susceptibility to shearing, crumbling, and shrinkage–swelling. Note any signs of change in soil characteristics or signs of soil movements.

4. Metals

Metals used for dam components are subject to deterioration from electrolysis, corrosion, stress-accelerated corrosion, metal fatigue, tearing and rupture, and galling. Note any signs of deterioration in metal components.

5. Timber

Timber constituents are subject to rotting, shrinkage, attack by organisms, and combustion damage. Note any signs of timber deterioration.

6. Liners

Lining fabrics, whether of homogeneous, human-made materials (such as asphalt, concrete, polyethylene, or fiberglass) or of placed natural materials (such as bentonite), are subject to deterioration from punctures, gouges, and tears; disintegration of seams and boundary seals; loss of plasticity and flexibility; and ultraviolet (light) deterioration. Note any such changes.

7. Joint Sealers

Materials used to seal joints in paving, linings, faces, or conduits may deteriorate or fail because of loss of plasticity and brittleness, shrinkage, extrusion and loss, and melting. Note signs of pulling, gapping, extrusion, or other deterioration of joint seals.

B. Generic Changes

Generic conditions are those common to all dams, regardless of individual construction or design characteristics. Generic changes are caused by an interaction of factors rather than by isolated failure of one component or constituent of the dam. Though construction materials and design features may differ, the signs are similar, as are the remedies.

1. Seepage and Leakage

Seepage and leakage under, through, or around the dam can be detected by observing changes in water quality indicators such as

downstream turbidity, dissolved solids, temperature, and color; and physical indicators such as changes in discharge–stage relation, pressure differentials, vegetation change on the downstream toe of the dam, and quantity of flow.

2. Drainage

To detect drainage problems, note the presence of chemical precipitates and deposits, areas of stagnation, and areas of algal or bacterial growth.

3. Ice Damage

The movement of ice may cause evidence of decreased stability of structures and appurtenances, such as cracking, heaving, abrasion, and warping or jamming of gates and pipes.

4. Stress and Strain

Evidence that certain components of the dam are being stressed beyond their design capabilities includes (in concrete) cracks, crushing, displacements, and offsets, shearing and creeping; (in steel) cracks, extensions or contractions, bending, and buckling; (in timber) crushing, buckling, warping and bending, and splintering; and (in rock and soil) cracks, displacements, settling, consolidation, subsidence, and zones of extension and compression.

5. Stability

Problems with stability are evidenced by (in concrete and steel structures) tilting, tipping, sliding, and overturning; (in embankments, natural slopes, and cuts) bulging, sloughing, slumping, sliding, shrinkage, cracking and undercutting of escarpments, and sinking; (in rocks structures, slopes and foundations) slumping, sliding, falls, bulging, and cracking.

6. Inadequate Seepage Control—Evidence and Clues

Wet spots; new vegetal growth, seepage, and leakage; boils; saturation patterns on slopes, hillsides, and in streambeds; depressions and sinkholes; and evidence of high escape gradients.

7. Erosion Control

Loss, displacement, and deterioration of upstream face riprap, underlayment, and downstream face slope protection; and beaching.

8. Foundation

Weaknesses in the foundation could occur through consolidation or liquefaction potential.

9. Other Endangerments

Utility pressure conduits on, over, or through embankments; and diversion ditches along abutment hillsides.

C. Spillways

1. Approach Channel

Dangers to the approach channel include obstructions; and slides, slumps, and cracks in cutslopes.

2. Log Booms

Errors in the workings of the log booms could be caused by submergence, uncleared accumulated drift, parting, loss of anchorage, and inadequate slack for low reservoir stages.

3. Hydraulic Control Structure

Malfunctions in hydraulic control structures include stability, retention of capacity rating, erosion at toe, unauthorized installations on crest, raising storage level, and decreasing spilling capacity, gate piers, trash control systems, nappe and crotch aeration, and siphon prime settings.

4. Headwater Control

(Gates, Flashboards, Fuse Plugs, and Fabric Dams)

Mechanical errors in the headwater control could occur by unauthorized position, wedging, gate trunnion displacements, loss of gate anchorage post tensioning, undesirable eccentric loads from variable positions of adjacent gates, gate-seal binding, and erosive seal leakage.

5. Shafts, Conduits, and Tunnels

Weaknesses include vulnerability to obstruction; evidence of excessive external overloading pressure jets, contorted cross-sections, cracks, displacements, and circumferential joints; serviceability of linings (concrete and steel), materials deterioration, cavitation, and erosion; rockfalls; and severe leakage about tunnel plugs.

6. Bridges

Concerns include the possibility of collapse with consequent flow obstruction, and serviceability for operational and emergency equipment transport.

7. Spillway (Open Channel or Conduit)

Spillway deficiencies include vulnerability to obstruction; evidence of excessive external sidewall loading—large wall deflections, cracks, and differential deflections at vertical joints; invert anchorage and foundation support—drummy soundings, buckled lining, and excessive uplift; observation or evidence of dangerous hydraulic flow patterns—cross-waves, inadequate freeboard, wall climb, unwetted surfaces, uneven distribution, ride up on horizontal curves, negative pressures at vertical curves, pressure flow, and deposition; drain system serviceable; air ingestion and expulsion; tendency for jump formation in conduits; buckling and slipping of slope lining; erosion of unlined channels; seepage or leakage along external periphery of conduit; and extension strains in conduits extending through embankments.

8. Terminal Structures

Deficiencies include the inadequate dissipation of energy, jump sweep out, undercutting, retrogressive erosion, loss of foundation support for flip bucket substructure, unsafe jet trajectory and impingement, and erosive endangerment of adjacent dam or other critical structures.

9. Return Channels

Concerns include impaired outfalls; obstructions; slides, slumps, and cracks in cutslopes; erosion or deposition creating dangerous tailwater elevations or velocities; and evidence of destructive eddy currents.

10. Trashracks and Raking Equipment

Malfunctions include clogging of bar spacing, lodged debris on horizontal surfaces, and collapse.

D. Environs

1. Reservoir

Noteworthy items include the stage at time of examination; indications of recent noteworthy stages; depressions and sinkholes in exposed reservoir basin surfaces; massive water displacing slide potentials—leaning trees, escarpments, and hillside distortions; flood pool encroachments; and siltation adversely affecting loading on dam and forming approach channel and waterway obstructions.

2. Reservoir Linings

Deficiencies include depressions and sinkholes, erosion, and animal disruption.

3. Downstream Proximity

Noteworthy items include tailwater stage at time of examination, reservoir connected springs; endangering seepage or leakage regardless of source; and river obstructions creating unanticipated tailwater elevations or interference with outfall channel capacities of the spillway and outlets.

4. Watershed

Noteworthy items include surface changes that might materially affect runoff characteristics.

5. Regional Vicinity

Noteworthy items include subsidence indications—sinkholes, trenches, subsidence surveys, settlements of buildings, highways, and other structures in the region; assessment of land forms and regional geologic structure; and records of mineral, hydrocarbon, and ground-water extractions, locations, producing horizons, accumulated production, and current rate of production.

6. Downstream Flood Plain

Noteworthy items include the limits of natural, improved, or leveed channel; areas of potential inundation for spillway design flood and for hypothetical failure; proximity of developed areas; and habitation, population, communication, and transportation corridors.

III. Natural Events

No structure can be engineered to withstand every conceivable magnitude of natural event. Structures will be damaged or will fail on occasion because of natural events, such as unusually large floods, earthquakes, or extremely high winds. If a natural event of greater magnitude than the structure is designed to withstand occurs, the structure should be inspected as soon as it is accessible to ensure that excessive damage or failure has not occurred. If the structure is in a critical location or is already suspect, and if a large magnitude natural event such as a flood can be predicted in advance, try to observe the performance of the structure during the actual event. If a trained observer cannot be on-site during the event, the site should be inspected as soon as it is possible to do so safely.

A. Large Magnitude Floods

During or after a flood of a magnitude that exceeds the design of the structure, observe any evidence of overtaxing or damage, such as overtopping; undesirable or dangerous spillway flow patterns (either as observed directly or as deduced from erosion trails, swept vegetation, debris trails, and deposition of sediments); and high-water marks (either as gauged or observed directly, or as deduced from drift-marks, water-staining, or bank undercutting).

B. Seismic Events

After earthquake tremors have occurred in the vicinity of the dam site, check the structure for signs of damage such as cracks, displacements, undercut escarpments, settling, and downstream sand boils. Note any evidence of leakage or of incipient failure of the structure. Describe events in the vicinity of the structure that may affect the stability of the structure, such as landslides and rock falls (particularly those that affect the course or the capacity of the stream-channel and reservoir), tilted trees and shrubs that may indicate bank or slope movement, and the appearance of cracks, heaves, or sinkholes in the surface of the earth in the vicinity of the dam.

C. High Winds

High winds, particularly those with directional shifts (such as tornadoes) may damage a structure, either directly or indirectly. Indirect damage can include erosion of the crest and slopes due to unusually high wave run-up, and spillway jamming and damage by debris brought down by the winds. If the winds are accompanied by heavy rainfall, bank and slope saturation and erosion can occur. Check structures that may be subjected to storms of unusual ferocity of damage, even though the accompanying rainfall may not exceed the design capacity of the structure and reservoir. See Figure 2 for a summary of common failure modes.

Failure	Cause
Foundation deterioration	Removal of solid and soluble materials Rock plucking Undercutting
Foundation instability	Liquefaction Slides Subsidence Fault movement
Defective spillways	Obstructions Broken linings Evidence of overtaxing or available capacity Faulty gates and hoists Silt accumulation
Concrete deterioration	Alkali-aggregate reaction Freezing and thawing Leaching
Embankment defects	Liquefaction potential Slope instability Excessive leakage Removal of solid and soluble materials Slope erosion

Figure 2. Common Failure Modes

IV. Inspection of an Earth Embankment Dam and Reservoir

A. Procedure

1. Qualifications

See Bureau Manual 9177 for the Bureau requirements for being a qualified inspector.

2. Method

Inspections should be performed through use of this Handbook in coordination with the Bureau of Land Management *Dam Condition Assessment Checklist*. The Bureau *Dam Condition Assessment Checklist* is for use when performing inspections on earth embankment dams, as are common across the majority of the Bureau. Items to be measured under the Dimensional Data heading should be measured consistently across the Bureau. Methods to be used are taught in training classes as required under the qualifications for being an inspector, in addition to the guidance provided in this Handbook.

Every Bureau dam should have a benchmark from which all elevation measurements are referenced. Specifications for placing benchmarks are illustrated in Figure 3.

Benchmarks should be located in undisturbed ground at either of the abutments where measurements can be most easily taken. Stationing should be matched with previous inspections and should be from left to right looking downstream. The location at which a line drawn perpendicular from the benchmark intersects the centerline of the dam should be used as a reference for ensuring that stationing is matched.

This Handbook and the Bureau *Dam Condition Assessment Checklist* have inspection criteria for dams with both a principal spillway and an emergency spillway. The majority of Bureau dams are constructed with

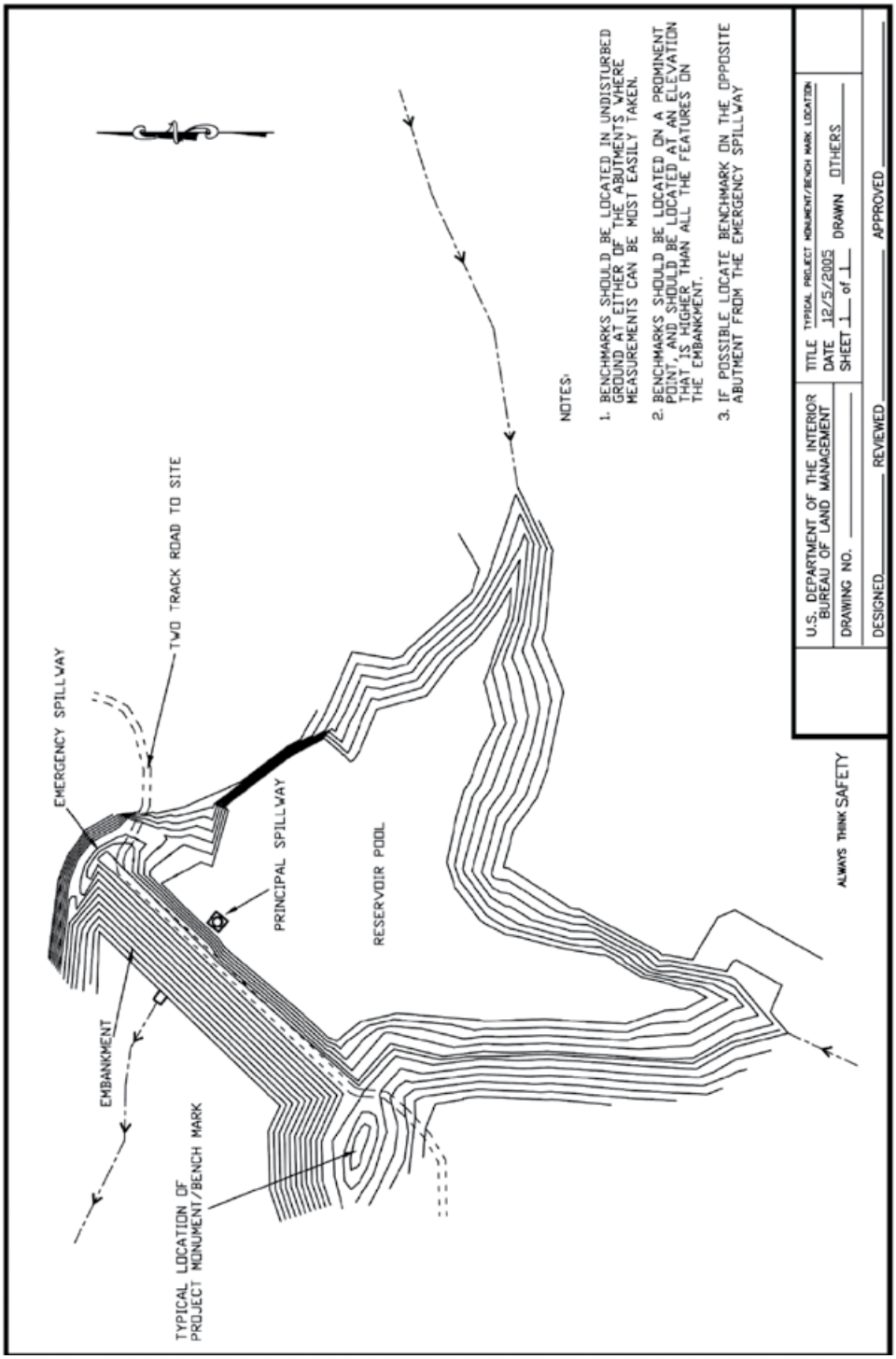

Figure 3. Benchmark Location on Embankment Dam

a conduit through the dam serving as the principal spillway. Design standards for intake structures and the location of the conduit in the embankment vary across the Bureau. When inspecting Bureau dams that do not utilize a principal spillway and have only an earthen spillway, perform only the maximum storage measurements as described below. When performing an inspection on a dam that has multiple principal spillway outlets, utilize additional copies of the appropriate pages (6, 7, and 8) of the *Dam Condition Assessment Checklist* for each principal spillway. The majority of Bureau dams are constructed with an earthen emergency spillway. Emergency spillways may be either constructed or the designer may utilize the existing natural topography. Constructed spillways are generally trapezoidal in shape and may be lined with either riprap or concrete. When performing an inspection of a dam with a constructed trapezoidal channel, measure the width perpendicular to the channel at the narrowest section. Emergency channels that utilize existing natural topography should be measured perpendicular to the channel at the narrowest section where applicable. If the spillway is natural, this should be noted on the *Dam Condition Assessment Checklist.* For those dams where additional spur dikes (training dikes) exist, utilize additional copies of the *Dam Condition Assessment Checklist*for each individual structure.

The volume of the embankment is necessary for calculating the current replacement value (CRV) of the structure and should be noted in Calc10. on page 3 of the *Dam Condition Assessment Checklist*. The preferred method for obtaining this value should be by reference of the design drawings or as-built drawings for the dam. If these documents cannot be located, the equation found on the *Dam Condition Assessment Checklist* should be utilized as a good estimate of the embankment volume. The equation is

$$V_e = \frac{LH\left[\left(W + \frac{HS_u}{2}\right) + \frac{HS_D}{2}\right]}{54}$$

where

V_e = the estimated volume of the embankment (cy)

S_u = slope ratio of upstream face (H:V)

L = the dam crest length along the centerline of the dam (feet)

S_D = slope ratio of downstream face (H:V)

H = the structural height of the dam (feet)

54 = conversion factor

W = dam crest width (feet).

The ability to take storage depth measurements may be dependent on the amount of water in the reservoir at the time of the inspection. Many Bureau dams may be dry during times of the year and inspections should be timed accordingly. For those Bureau dams that have water year-round, measurements are still necessary for the assessment of the dam's condition. Many Bureau dams have the potential for siltation, which has an affect on the condition of the site. Methods for obtaining measurements when the reservoir is not dry should be acquired by the Bureau-qualified Dam Inspector. The methods for estimating the storage capacity of a reservoir are as follows:

a. Storage Depth (Maximum, feet)

The storage depth available is measured from the upstream toe of the embankment at the maximum section to the invert of the emergency spillway.

b. Reservoir Surface Area (Maximum, acres)

Maximum storage is measured as the storage in the reservoir to the elevation of the invert of the emergency spillway. The area must be measured in the field. The water line at maximum storage should be attained by use of a hand level, an auto level, and a Philadelphia rod, a total station, or a survey grade GPS unit. The water line at the maximum storage elevation should be located around the pool of the reservoir. The area of the pool can then be measured by use of a GPS unit or total station.

c. Reservoir Storage (Maximum, acre-feet)

The value should be calculated as described:

Maximum storage is calculated by multiplying the storage depth by the reservoir surface area at maximum storage and dividing the total by 3. Storage Depth (feet) × Reservoir Surface Area at Maximum Storage (acres) ÷ 3 = Estimated Maximum Storage (acre-feet)

Before traveling to the field and performing the inspection, an in-house data review should be completed. This portion of the evaluation is devoted to reviewing, analyzing, and evaluating available data regarding design, construction, and operation of the dam and appurtenant features. With this background, the Inspector will be fully acquainted with the dam and its history of operation and maintenance so that he or she may effectively examine and evaluate its capability to perform as expected in the future. Previous inspection reports provide a valuable source of information relating to the operational history and recent condition of the dam. The notes and recommendations arising from these previous reports reveal the history, progress, and status of repair or modification of the dam. Previous inspection reports may also prove to be valuable in tracking any changes or deficiencies with the dam.

As most Bureau dams are partly or completely constructed of earth, detailed guidelines are given for conducting condition surveys for this type of structure. The onsite inspection and evaluation must be guided and determined by continual awareness, recognition, and understanding of the primary causes of dam failures. The detection of changes, indications of impending changes, and developing structural and hydraulic weaknesses is a fundamental objective of the dam safety evaluation.

The external surfaces of an embankment dam can often provide clues to the behavior of the interior of the structure. For this reason, a thorough examination of all exposed surfaces of the

dam should be made. If possible, field examinations should be performed when the reservoir is full and the embankment is subject to its maximum loadings. The embankment should be carefully examined for any evidence of displacement, cracks, sinkholes, springs, wet spots, surface erosion, animal burrows, vegetation, and others. Any of these conditions, if not corrected, can ultimately lead to failure of the embankment. Surface displacement on an embankment can often be detected by visual examination. Sighting along the alignment of embankment roads, parapet walls, utility lines, guardrails, longitudinal conduits, or other distinctive lines parallel or concentric to the embankment can reveal evidence of surface displacement. The crest should be examined for depressions, which could decrease the freeboard. The upstream and downstream slopes and areas downstream of the embankment should be examined for any sign of bulging or other variance from smooth, uniform face planes. Any suspected movements identified by these methods should be verified by survey measurements.

B. Cracks

Cracks on the surface of an embankment can be indicative of many potentially unsafe conditions. Surface cracks are often caused by desiccation and shrinkage of materials near the surface of the embankment; however, the depth and orientation of the cracks should be determined to better understand their cause. Openings or escarpments on the embankment crest or slopes can identify slides and a close examination of these areas should be made to outline the location and extent of the slide mass. Surface cracks near the embankment–abutment contacts can be an indication of settlement of the embankment and, if severe enough, a path for leakage can develop along the contact. Therefore, these locations must be thoroughly examined. Cracks can also indicate differential settlement between embankment zones.

1. Transverse Cracks

Transverse cracks, or cracks through the structure from front slope to back slope, are usually of the greatest concern, as they can provide a path for seepage from the reservoir to the face of the dam. Transverse

cracks can result from a compressible foundation under the central portion of the dam coupled with incompressible rock foundation and abutments at the end portions of the dam (Figure 4).

Transverse cracking may be caused by the presence of rolled earth trench within the embankment. For example, a rolled earth trench for an outlet pipe through compressible natural foundation material may cause cracking at the outer limit of the trench (Figure 5). Transverse cracking may also be caused by compressible embankment materials placed on steep or irregular rock abutments.

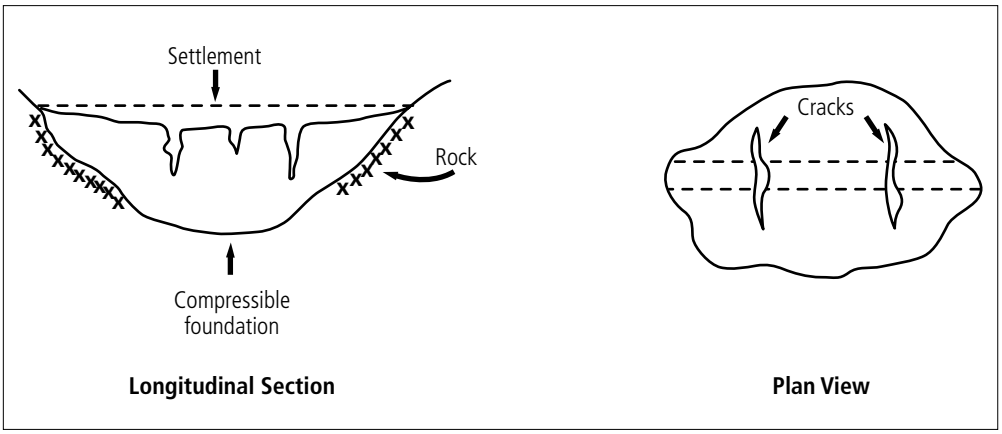

Figure 4. Transverse Cracks

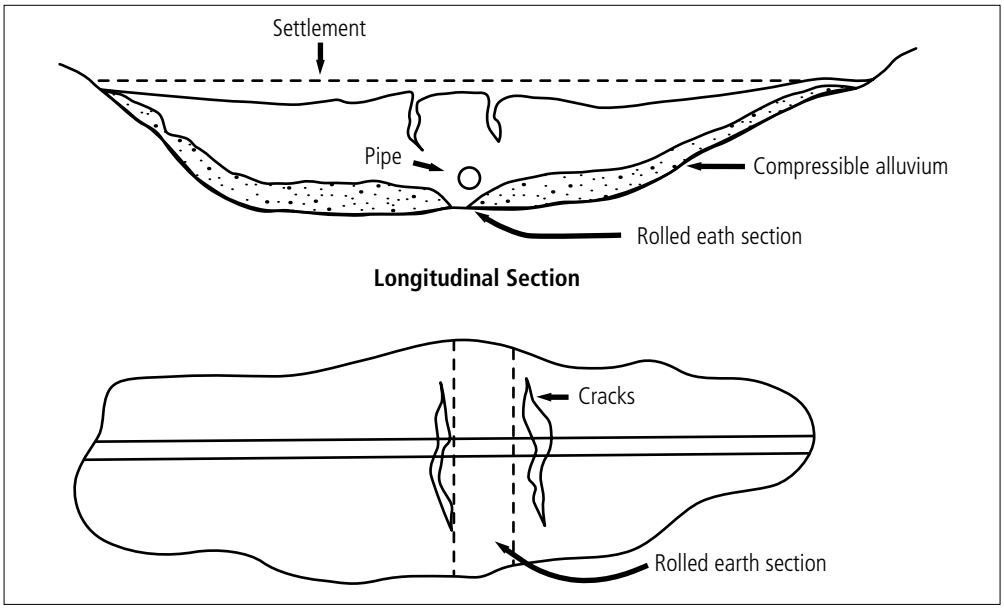

Figure 5. Transverse Cracks

2. Horizontal Cracks

Horizontal cracks below the crest of the dam can occur in structures built in narrow valleys with rock abutments. Arching may occur in the upper portion of the embankment; this prevents the crest of the embankment from settling as much as the foundation. Horizontal cracks may then occur at the bottom of the arched portion of the embankment (Figure 6).

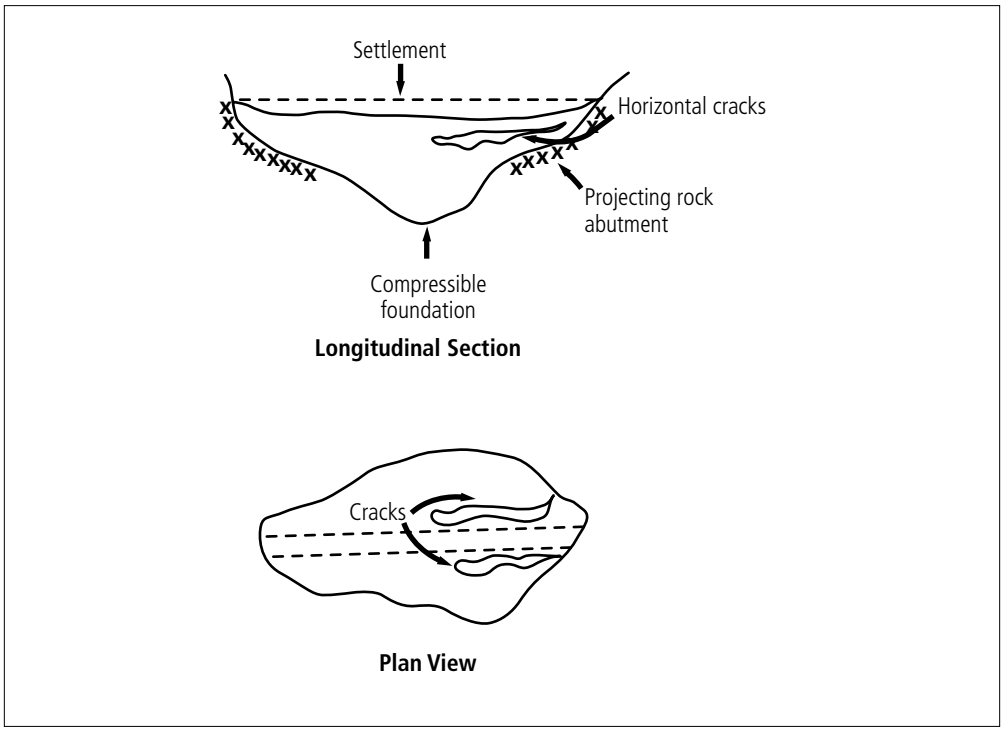

Figure 6. Horizontal Cracks

Horizontal cracking can also occur when settlement occurs because of compression of the embankment. This type of cracking can be seen in the closure sections, and is caused by the narrowness of the section and the rapidity of the construction work. Horizontal cracks may appear across the width of the closure section (Figure 7).

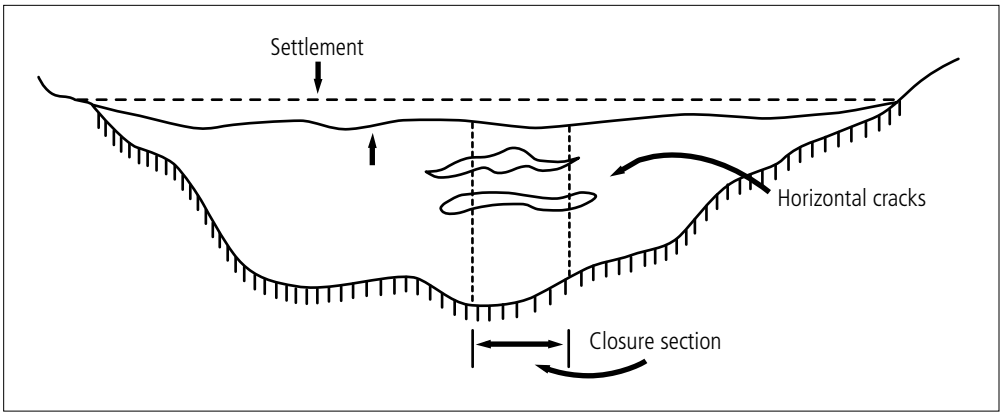

Figure 7. Horizontal Cracks

3. Longitudinal Cracks

Longitudinal cracks by themselves are not normally dangerous; however, the presence of longitudinal cracks on the surface can be an indication of more serious internal problems; for example, hidden inclined transverse cracks.

Longitudinal cracking can occur in conjunction with rolled earth cut-offs. The slopes of the embankment, which are over a more compressible natural foundation, settle more than the crest of the dam, which is located over the less compressible rolled earth cutoff section. As the slopes settle, longitudinal cracks appear at the outer limits of the less compressible foundation section (Figure 8).

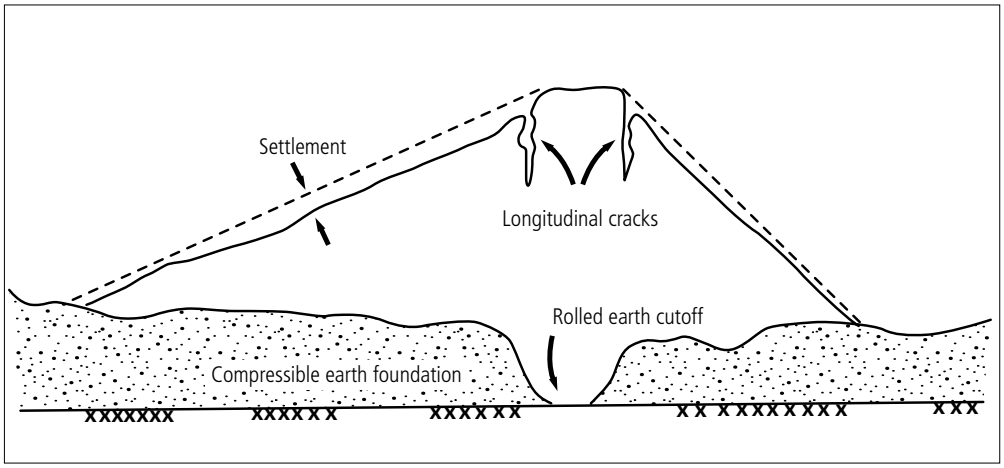

Figure 8. Longitudinal Cracks

Longitudinal cracking can also occur in structures with a rolled earth core and upstream and downstream shell zones of dumped rock. The embankment may crack at the junction between the earthen and rock zones from differential settling; the rock shells settle more than the rolled earth core (Figure 9).

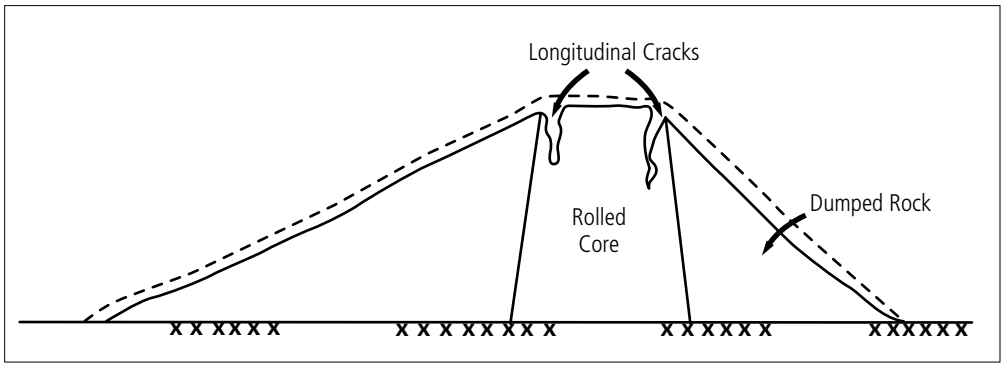

Figure 9. Longitudinal Cracks

4. Interior Cracks

Interior cracking cannot be seen on the face of the dam, but may be suspected if certain areas of the dam show signs of greater settlement than surrounding sections. An example of this would be in dams constructed with a narrow vertical central core of compressible impervious material and outer slopes of relatively less compressible materials. The core tends to compress, forming a depression at the crest of the dam. As a portion of the core weight is transferred to the outer shell through shearing and arching, interior horizontal cracks may occur in the core (Figure 10).

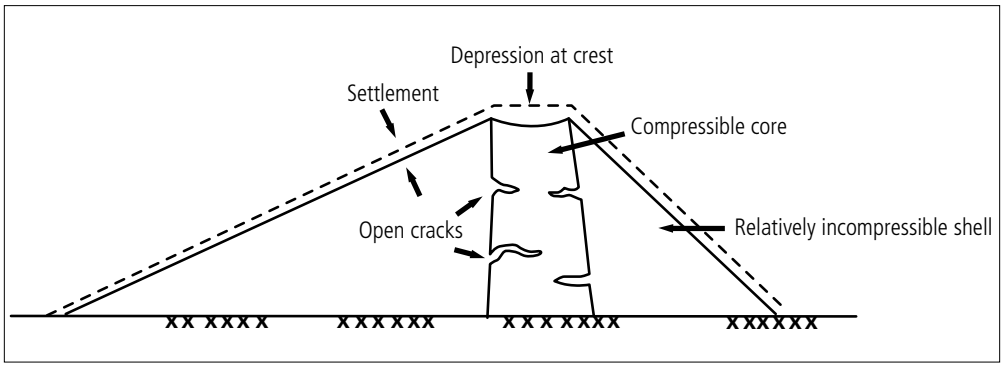

Figure 10. Interior Cracks

Interior vertical tension cracks can develop in the lower portion of a dam when a short length of the dam embankment is underlain by a more compressible foundation than the rest of the embankment. A greater amount of settlement occurs over the more compressible foundation, resulting in sagging, tension stress, and vertical cracking at the lower interior portion of the dam (Figure 11).

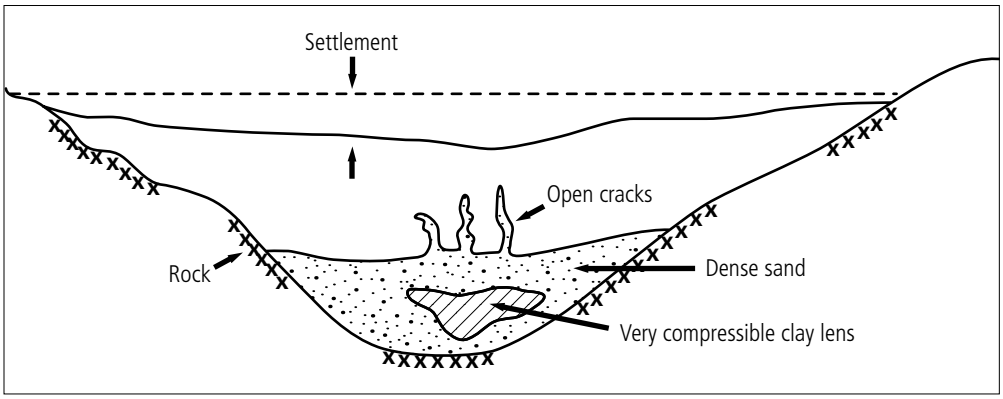

Figure 11. Interior Cracks

5. Surface Drying Cracks

Cracks due to surface drying can occur during both construction and the operational life of the dam. Surface drying of one or more levels of the embankment during construction can be caused by construction delays or suspensions that expose the embankment to the wind and the sun. Fine-grained soils are especially vulnerable to surface drying and cracking; the permeability of the embankment material may be greatly increased.

Embankments constructed of homogeneous, clayey soils are especially prone to surface drying and cracking after construction is completed and during the operation life of the dam. These cracks usually seem to be more severe in areas influenced by tensile stress (at the top of the embankment slope, for example). This type of surface drying and cracking is often caused or exacerbated by hot, dry climatic conditions during a period when the reservoir is very low or empty.

C. Sliding and Slumping

Stability problems in dam embankments are evidenced by cracks, displacements, sloughing and sliding, bulges, and creeping. Look for sags and misalignments in parapet walls, guardrails, and conduits; bulges at the toe of the dam or in the ground below the toe; longitudinal cracking near the crest; and other indications that the embankment is moving. Sliding or slumping of either or both the upstream and downstream embankment slopes can occur during construction or rehabilitation of a structure. This type of sliding or slumping can be slow (time-scale on the order of days or weeks) or rapid (time-scale on the order of minutes). Landslides and slumps in dam embankments are mechanically similar to mass movements in natural soils. Slides in earthen dam embankments tend to be a slump or series or slumps, rather than planar shearing and sliding or mass falls.

1. Pattern Cracking (Slip–Circle Failure)

As soil pattern cracks are indicative of an incipient slump or slide, any evidence of pattern cracking should be identified. (See Figure 12 for an illustration of typical pattern cracking indicative of an incipient slump.)

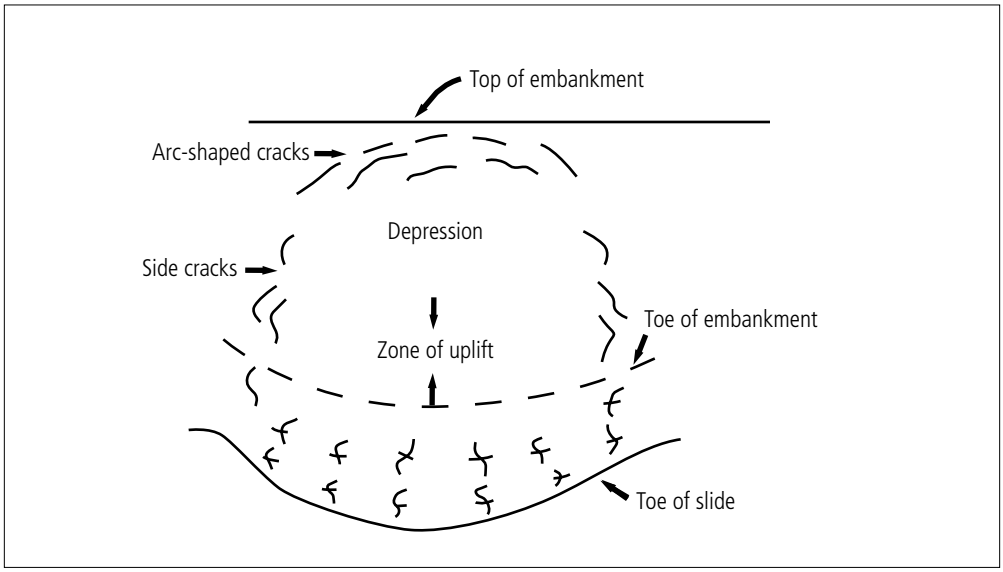

Figure 12. Pattern Cracks (face of slope)

Note the arc-shaped pattern of cracks in the upper portion of the face of the slope (Figure 12); these cracks are a reliable indicator of impending slump. The cracks that run more or less vertically along the side of the incipient slump are not as readily visible; however, try to discern their location, as these cracks indicate the width of the slump area. An estimate of the size (and therefore the seriousness) of the slump can be made based on the dimensions of the area contained within the pattern of cracking. The failure area is assumed to be roughly circular (Figure 13). The greater the distance between the top of the crack pattern and the toe, the deeper the slump mass will extend into the body of the dam embankment.

If a crack pattern similar to that illustrated in Figure 12 is observed during a condition survey of a structure, report the situation immediately, particularly if the cracks are large, the depression and uplift zones are noticeable, or if the cracks have widened or progressed since the last inspection. Document the condition with photos, sketches, and measurements of the areal extent of the pattern cracking. If the dam is high hazard, it should be observed more frequently until an assessment of the seriousness of the situation can be made and necessary corrective actions taken.

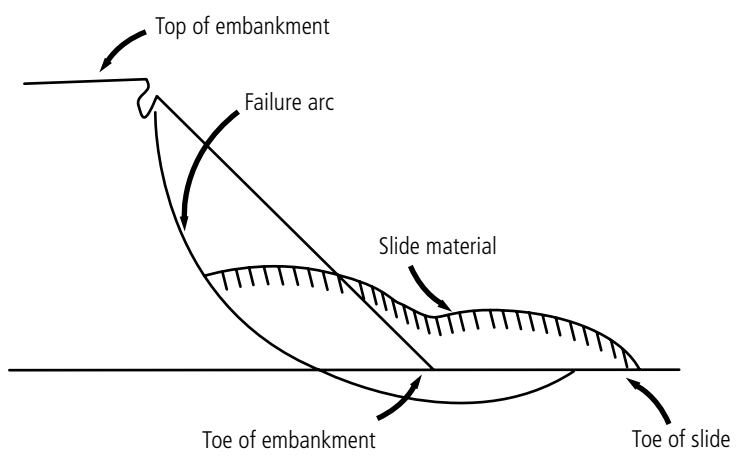

Figure 13. Slumping (cross-section)

2. Slow Slides

Slow sliding or slumping can occur when the embankment is underlain by foundation materials of homogeneous soft clay, which is not sensitive (i.e., the clay does not react to shearing by loss of strength). The slumping progresses gradually, usually at a relatively uniform rate, for a period of a week or more. Typically, the total horizontal and vertical displacement of the slump is equal to 5% to 15% of the structural height of the dam (Figure 14).

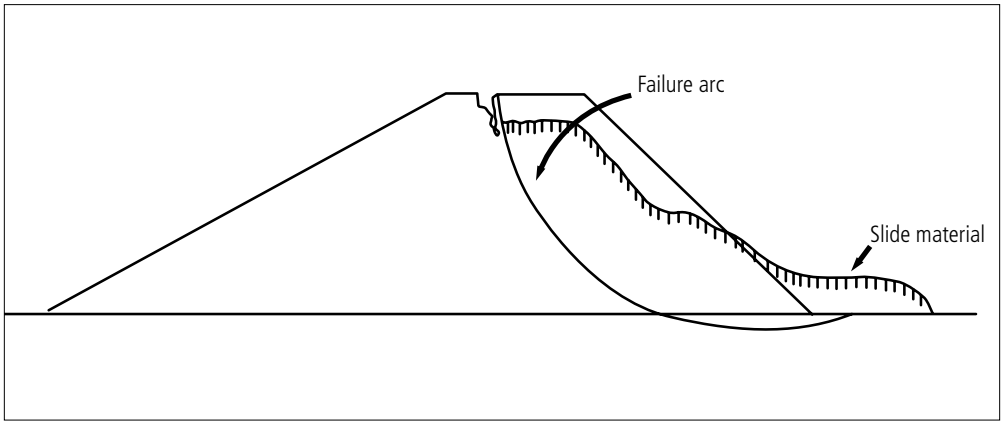

Figure 14. Slow Slump (cross-section)

3. Rapid Slides

Rapid sliding can occur when the foundation material for the dam contains horizontal bedding planes, lenses, or layers of coarse silt or fine sand. These allow the transmission of high pore water pressures under the center of the embankment outward toward the toe. The slumping or sliding is abrupt, and typically is completed within a few minutes. The vertical and horizontal displacement of the slump is usually 50% or more of the structural height of the dam (Figure 15).

If the foundation conditions mentioned (soft, homogeneous, nonsensitive clay or clay containing horizontal bedding planes, lenses, or layers of coarse silt or fine sand) are known to exist at the dam site, the embankment should be observed carefully for cracking, pattern cracking, depressions, and bulges that could indicate an incipient slump area. Any sign of an incipient slump should be reported immediately so that corrective actions may be attempted.

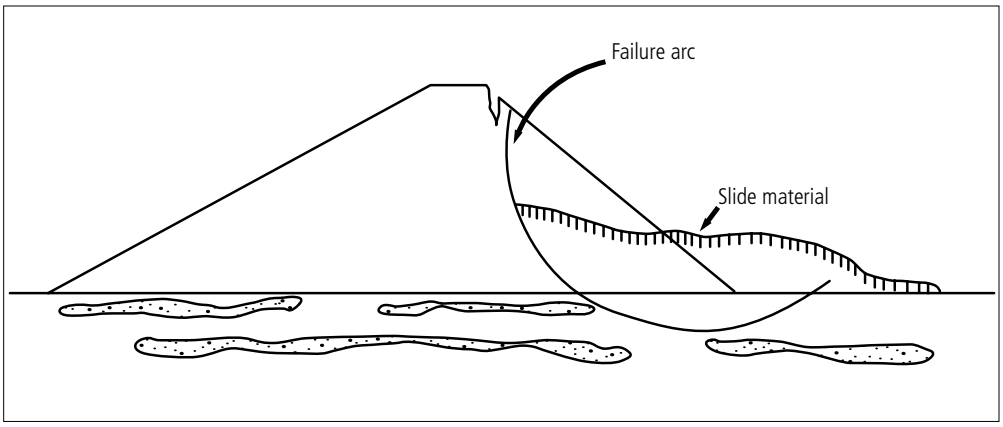

Figure 15. Rapid Slide (cross-section)

4 Sliding When Reservoir Is Full

Sliding can occur during reservoir operation. This type of sliding usually involves only the downstream slope of the embankment. Deep slides, with a failure arc passing through the clay foundation, nearly always occur when the reservoir is full or almost full. Deep slides of this type are caused by elevated internal pore water pressures as a result of seepage from the reservoir through or under the dam. As the elevated pore pressure is not relieved by the slide, the unstable slide scarp often slides again. Deep slides are generally slow slides, with slumping occurring gradually over days or weeks. Often, the slump will proceed 3 to 4 feet during the first day, and will then proceed at a lower, steady rate for a period of several days or weeks. See Figure 16 for an illustration of the configuration of a deep slide of this type.

As deep slides on the downstream slope of the embankment of a full reservoir are likely to result in immediate or eventual failure of the structure, any signs of incipient sliding or sliding that has already occurred are of great concern. The situation should be reported immediately so that corrective action may be taken .If the dam is located in an area where failure may cause danger to or loss of human life, downstream authorities must be warned of the degree of danger and the likelihood of failure. As for other types of sliding, warning signs include cracking, depression and bulging, and creeping and cracking at the toe

of the dam. In addition, look for evidence of seepage through or under the face of the dam, wet spots, precipitates or deposits, unusually lush vegetative growth, and other signs.

Shallow slides on the downstream slope of an operating reservoir may follow heavy rainstorms and are due to saturation of the slope of the embankment by rainwater. The arc of failure generally does not extend more than 5 feet into the face of the embankment (Figure 17). A shallow slide on the face of an embankment is not cause for grave concern; however, more than one slide or evidence of a progressive slide involving several shallow slides may indicate more serious slope stability problems or leakage through the face of the dam. Any evidence of sliding should be reported so that an assessment of the magnitude of the problem can be made, and so that maintenance and repair work can be scheduled.

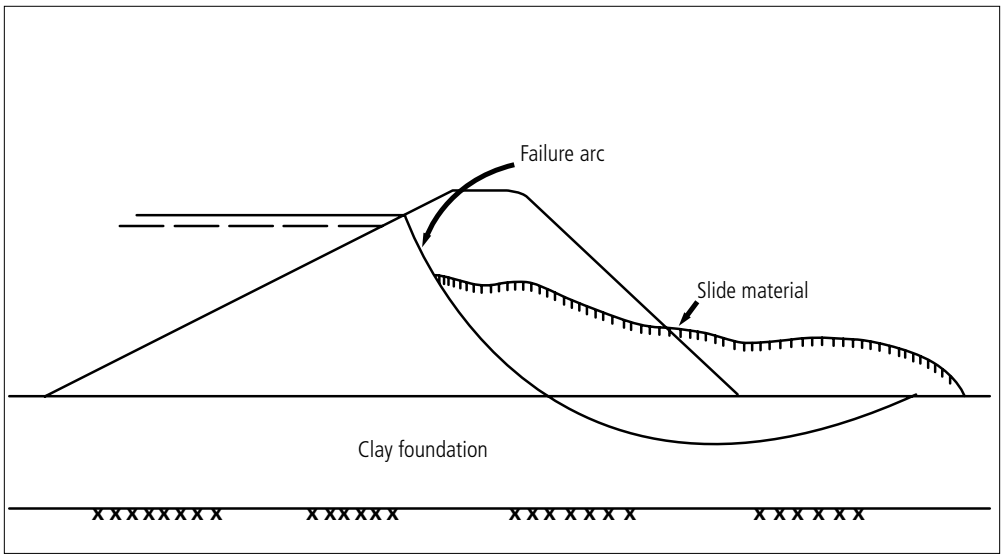

Figure 16. Deep Slide (cross-section)

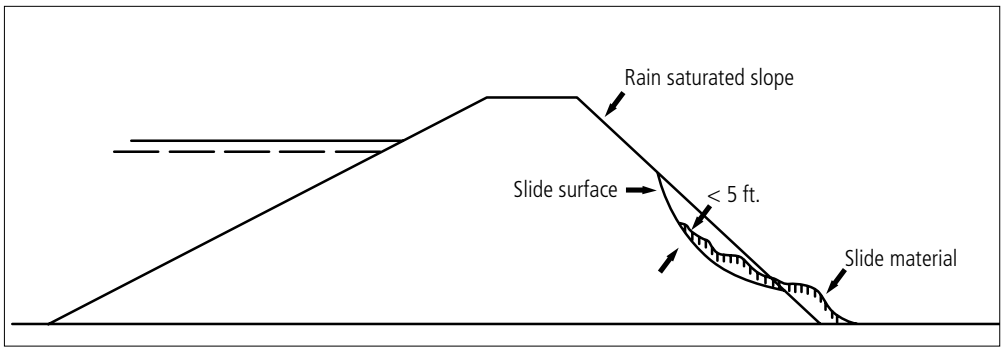

Figure 17. Shallow Slide

5. Drawdown Slides

Sliding can also occur after reservoir drawdown. This type of slide usually involves the upstream slope of the embankment. Drawdown slides on the upstream slope result from slope instability caused by removal of the overlying reservoir load and by elevated internal pore water pressures within the embankment, which do not dissipate as quickly as the rate of reservoir drawdown. If the upstream portion of the embankment is constructed of free-draining materials such as rock or gravel, the water will flow out of the pores in the embankment as the reservoir is lowered; thus, the pore pressure will be lowered as rapidly as the reservoir load is removed. If, however, the embankment is composed of materials that tend to retain water, there will be a period when the internal pore pressure of the embankment is elevated and the reservoir loading is lessened or removed. The consequent loss of stability within the embankment may cause drawdown slides on the upstream face of the embankment.

The likelihood of this type of slide relates to the fineness of the embankment soils. Soils with an average grain size (D_{50}) of 0.006 to 0.02 mm seem to be particularly susceptible to drawdown slumping or sliding. Soils with an average grain size (D_{50}) of 0.06 mm or larger have little susceptibility to drawdown sliding. Susceptibility to drawdown sliding is increased for all dam embankments constructed of soils with an average grain size (D_{50}) of less than 0.06 mm. If the embankment seems to be largely constructed of extremely fine to fine soils, note the likelihood of drawdown sliding.

The mechanism for drawdown sliding is similar to that for other types of sliding caused by seepage or elevated pore pressure in the embankment or foundation. Unlike deep slides that occur when the reservoir is full, the sliding or slumping tends to relieve the elevated pore pressure; thus, there is less potential for continued sliding or slumping. Drawdown slides are most likely to occur the first time the reservoir level is lowered after filling. If a drawdown slide occurs after several cycles of filling and lowering, it is usually due to more rapid or more extreme drawdown than is usual for that reservoir. This type of slide is usually deep-seated, with a failure arc extending into the foundation; the upper extent of the slide area does not usually extend beyond the upstream edge of the crest of the dam (Figure 18). Generally, the slide is slow, occurring over a period of hours or days. If the reservoir is low or empty when the slide comes to equilibrium, complete failure of the dam is unlikely. However, should the reservoir begin to fill after a drawdown slide has occurred, the likelihood of failure is appreciable.

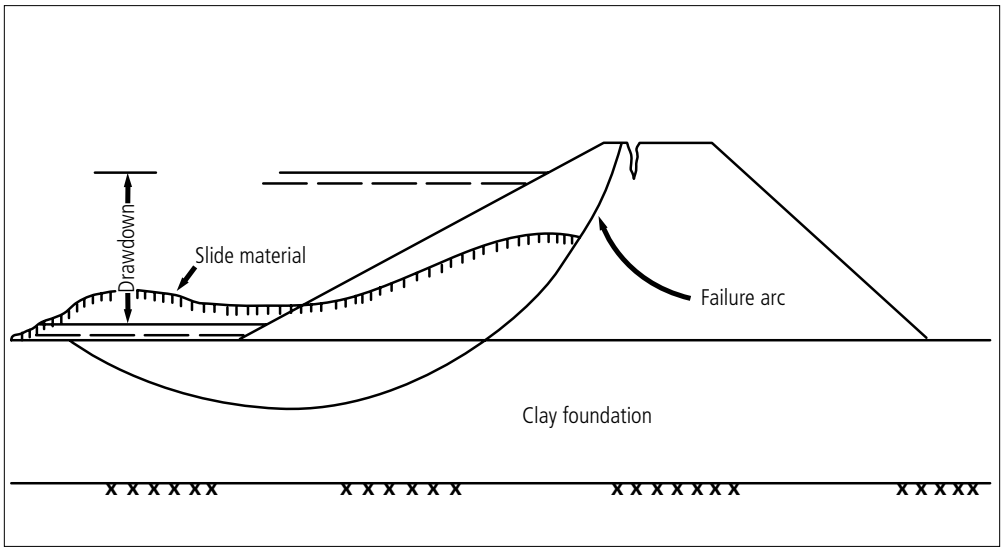

Figure 18. Drawdown Slide (cross-section)

Signs of impending drawdown slides are similar to those for other types of sliding. Note any signs of cracking, pattern cracking, bulging, or depressions on the upstream face of the embankment during or after drawdown of the reservoir. Drawdown rates in excess of 6 inches per day, particularly following prolonged high reservoir levels, are the most likely to cause drawdown sliding. Dams subjected to high drawdown rates should be monitored during drawdown (particularly if the embankment material contains fine soils), if possible, or checked after drawdown to ensure that drawdown sliding has not occurred or is not about to occur.

D. Seepage Problems

Seepage problems can occur in either concrete or embankment dams as well as through or along the foundations. The main source of seepage within a concrete dam is through contraction joints or along unbonded construction joints or lift lines. Cracks in the mass concrete are also a potential source of seepage in the structure. Formed drains installed in the dam are designed to intercept the seepage and reduce the pressures that could develop along lifts or cracks.

Uncontrolled seepage through an embankment dam can cause the movement of soil to unprotected exits, creating voids and leading to “piping” failures. Improper compaction; differential settlements; pervious embankment materials; or the presence of ice lenses, roots, stumps, or debris in an embankment resulting from inadequate construction control can cause excessive seepage through the embankment.

Uncontrolled seepage through the abutment or foundation of a concrete dam can form “pipes” or voids, causing the bridging of sections of the abutment and resulting in concentration of the stresses in the concrete. In the abutment or foundation of an earth dam, uncontrolled seepage can also form “pipes” or “tunnels” under the embankment. These can cause the collapse of surrounding materials, which can lead to the formation of settlement cracks or, ultimately, to breaching of the embankment.

Uncontrolled seepage can result in excessive pore pressures in an embankment or foundation. This can cause a weakening of the soil mass

and can result in springs, sand boils, abutment failures, and upstream or downstream slope failures. Excessive pore pressures can be caused during construction by placing embankment material too rapidly or by placing material that is too wet, by percolation of water through areas of pervious material in the embankment or along joints in the foundation that are connected to the reservoir, or by a rapid drawdown of the reservoir.

Hydraulic fracturing is the formation of cracks in the soil caused by the application of hydraulic pressure greater than the accompanying minor principal stress. Hydraulic fracturing of highly erodible soils, such as silts and silty sands that are not protected by filters, can result in the rapid removal of soil particles and subsequent collapse of the embankment. Drilling in embankments for investigations, installing instrumentation, or grouting have been identified as commonly overlooked sources of hydraulic fracturing. If evidence of such drilling is found in the project history, hydraulic fracturing in the embankment may have occurred at the time.

Settlement cracks caused by a compressible material in the embankment or foundation can also provide seepage paths. Shrinkage cracks caused by using highly plastic clays in the embankment can also lead to piping. Other causes of excessive seepage are animal burrows, root systems of large trees, and leakage along or through conduits in an embankment.

The adverse effects of seepage in a zoned earthfill dam are usually controlled by a filter to prevent the piping of embankment or foundation material. However, if the filter is not adequately designed or constructed to handle the volume of seepage occurring and to prevent “piping,” a failure condition could exist.

Biological and chemical action can cause plugging of dam and foundation drains. If the drains remain plugged, the seepage water must seek other exit paths, which can be detrimental to the safety of the dam. Uplift pressures may exist at the base of the dam because of percolation or seepage of water along underlying foundation seams or joint systems after filling the reservoir. Measured values of uplift pressure may also indicate the effectiveness of foundation grouting and of the designed drainage system. If

the uplift values are extreme or exceed the design assumptions, the stability of the dam may be reduced. If extreme or unanticipated uplift pressures or distributions are noted, additional studies may be required.

All surfaces of the embankment should be examined for signs of excessive erosion. Causes of the erosion, such as inadequate slope protection, excessive rainfall, concentrated surface runoff, or the presence of highly erodible silts or dispersive clays, should be identified. The area adjacent to all structures located within the embankment should be examined for erosion that could result in piping through the embankment. Surfaces of the embankment, especially on smaller embankment dams, should be examined for animal burrows and vegetation. Any vegetation that has extensive root systems or prevents a clear view of the embankment or abutment areas should be removed. New vegetation and types of vegetation requiring large amounts of moisture should be suspect, as they may indicate wet spots on the embankment. A color difference noted within an area of the same type of vegetation is a good indication of wet spots on the embankment. Infrared photography can detect wet spots on an embankment. The abutments, downstream face and toe of the dam, and areas downstream of the embankment should be examined for wet spots, boils, depressions, sinkholes, or springs, which may indicate excessive seepage through the dam. Other indicators of seepage are soft spots, evaporates, abnormal growth of vegetation and, in colder climates, ice accumulation areas where rapid snowmelt occurs. Seepage water should he examined for any suspended solids and, if solutioning is suspected, samples of the seepage and reservoir water should be collected for chemical analyses. Seepage water should be tested for taste and temperature to help identify its source. If saturated areas are located, they should be studied to determine if the wet spots are a result of surface moisture, embankment seepage, or other sources. Wet areas, springs, and boils should be accurately located and mapped for comparison with future examinations. Seepage should be measured and monitored on a periodic basis to ensure that an adverse trend does not develop that could lead to an unsafe condition.

Some seepage of water through the embankment and foundation is inevitable for any earthfill structure. However, uncontrolled or excessive

amounts of seepage can affect embankment and foundation stability, and can lead to failure of the structure. Evidence of inadequate seepage control or excessive seepage includes wet spots on the embankment or downstream from the structure; unusually lush vegetation growth on the embankment or downstream from the structure (particularly phreatophytes); saturation patterns, staining, and deposit of precipitates; depressions or sinkholes upstream from the structure; and sand boils or bulges downstream from the structure. Therefore, any inspection for evidence of seepage problems must include not only the structure itself, but also upstream and downstream areas.

As seepage may or may not indicate a serious problem, the dam inspector should note the location of the seepage, give a qualitative estimate of the amount of seepage (i.e., minor, moderate, large, and—if possible—an estimate of the cubic feet per second or gallons per minute), note 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, note whether the seepage seems to be increasing or decreasing in amount, and note whether the seepage appears to be carrying any material (as evidenced by downstream turbidly, sand boils, suspended solids, etc.). Experienced engineering staff must be assigned to take appropriate corrective action.

1. Piping Through Embankment

Piping is the progressive erosion of the embankment caused by concentrated seepage, resulting in the development of channels through the embankment. Severe piping may cause failure of a portion of the embankment. Piping can also occur through the natural foundation of the dam. In this instance, the mode of failure is likely to be downstream blowout and an uncontrollable leak from the reservoir.

Piping through the embankment can begin near the downstream toe, proceeding upstream through the embankment along a pervious stratum, bedding plane, joint, conduit wall, or other weakness (Figure 19). As material is carried outward to the face of the embankment by seepage water, a channel forms. It may eventually penetrate completely through the embankment. If the channel continues to enlarge, or if many channels are formed, the embankment may fail.

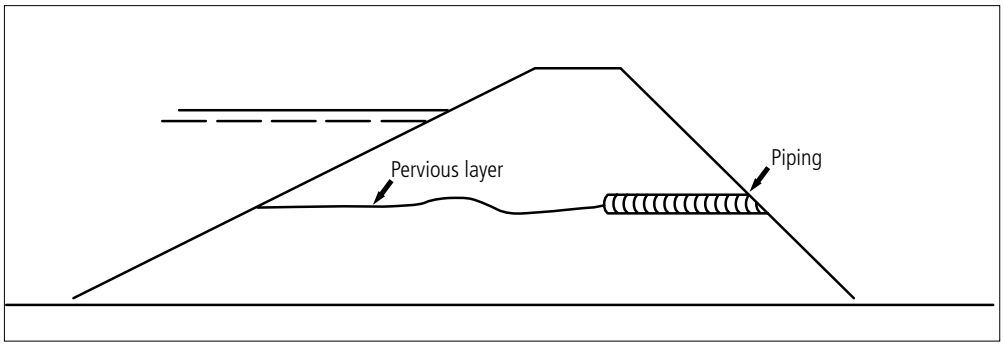

Figure 19. Piping Through Embankment (cross-section)

Embankment piping is indicated by cloudy, turbid flow and signs of seepage (such as wet spots, staining, unusually lush vegetation growth, erosion trails, boils or heaves, or running water) on the downstream face of the embankment. Note the extent of the area affected and give a qualitative estimate of the amount of seepage occurring. Note the level of the reservoir at the time of inspection. If the upstream face of the embankment is exposed, look for and note any evidence that the piping has progressed through the embankment (such as depressions, sloughing, or erosion at joints or bedding planes).

2. Piping Along Outlet Works

The occurrence of preferential seepage paths along pipe conduits in dams is common and well documented. The problem is generally a result of the difficulty in compacting backfill below the springline of the pipe. The result of this can be loose, more permeable zone of soil, which acts as a conduit for seepage. If this seepage is not controlled it can lead to internal erosion of soil particles, or piping. The sides and top of the conduit may also be prone to piping caused by hydraulic fracturing of the embankment soils or stress distributions in the adjacent soils caused by the rigid pipe. Finally, piping along the conduit could be caused by open joints, cracks, and perforations in the conduit, which result in flow, out of the conduit. This could occur under either gravity or pressure flow, and the flow out of the conduit could erode embankment materials from around the conduit.

3. Piping Through the Abutments

Physical examination of the upstream portion of the abutments and foundation is normally not possible because of reservoir storage. Therefore, physical examination is typically limited to the downstream abutments and groins. Indications of harmful seepage may be obvious or subtle. Changes in measured flow from monitored leaks, whether increases or decreases, are immediately suspect. Other indicators may involve the development of new lush vegetation, the presence of suspended particles in seepage water, and new seepage. Experienced engineering staff should assess the degree of seriousness of this condition.

4. Piping Through Foundation

Piping through the natural foundation material under the dam may cause leakage from the reservoir surface at some distance downstream from the dam. If the seepage due to the piping is relatively slow, the result may be the formation of one or more sand boils downstream from the structure (Figure 20). The seepage from the reservoir carries sand and soil particles and deposits them in a conical ring at the downstream exit point. If the seepage occurs underwater downstream of the structure, increased turbidity may be visible at the downstream exit point. Note any evidence of sand boils or increased downstream turbidity; include the location and extent of the affected area. Note the level of the reservoir at the time of observation. If the reservoir is low or empty, look for upstream evidence of piping and leakage, such as depressions or sinkholes. Note the location and extent of such areas. Experienced engineering staff should assess the degree of seriousness of this condition.

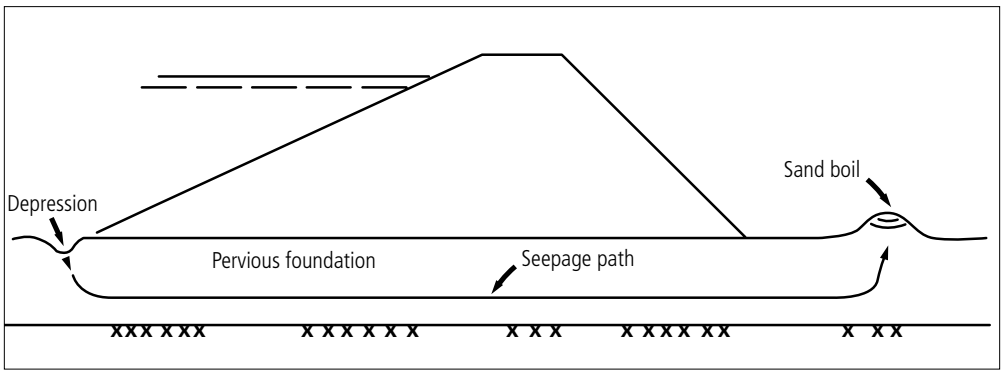

Figure 20. Piping Through Foundation (cross-section)

A sufficient amount of piping and leakage through the foundation may cause a downstream blowout with subsequent uncontrolled leakage from the reservoir. This type of failure can be sudden and can result in the release of large amounts of water if the reservoir is full. Early indications of this type of action include downstream sand boils and upstream depressions, as discussed previously. Any indication of these signs should be noted and described thoroughly at the time of inspection. If a blowout has already occurred, notify the engineering staff immediately. See Figure 21 for an illustration of a blowout.

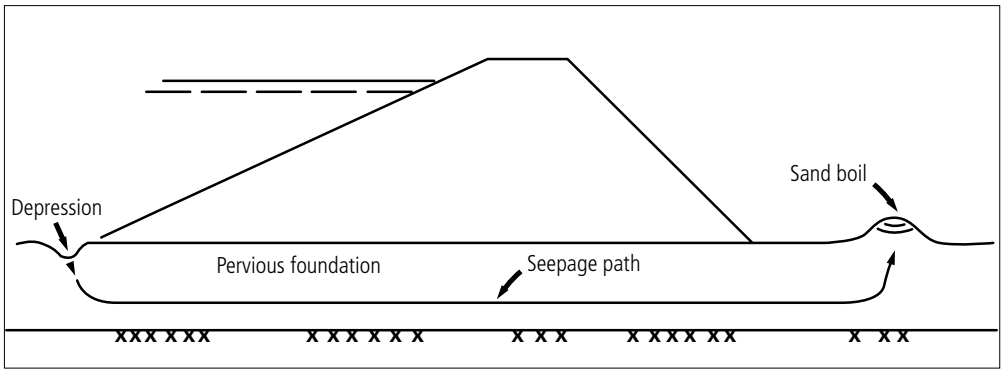

Figure 21. Blowout Through Foundation (cross-section)

5. Seepage Through Embankment

Seepage through the embankment may cause sloughing of the downstream slope. This process begins with a small slough or slide near the toe of the downstream face of the embankment, in the saturated zone below the phreatic line (Figure 22). The steeper face of the remaining embankment face is saturated and slumps again. This unraveling action can progress until the remaining portion of the embankment is insufficient to contain the reservoir waters, and the structure fails completely. Note any evidence of sliding or slumping on the downstream face of the structure. Note the level of the reservoir at the time of inspection and estimate the level of the reservoir (if possible) when the slumping or sliding occurred. Describe the extent of the slide, including measurements of the dimensions of the slide or an estimate of the amount of material in the slide area, or both.

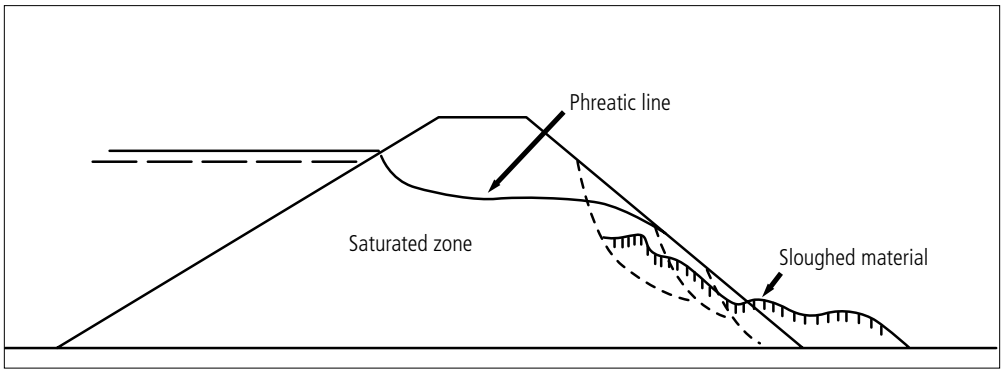

Figure 22. Sloughing of Saturated Embankment (cross-section)

6. Seepage Due to Water-Soluble Materials

Water-soluble material may gradually leach from abutments, embankments, and foundations, causing leakage and instability. Minerals such as gypsum are gradually dissolved and carried away by seepage water, creating cavities and channels within the structure and plugging filters and pervious drains. Note any evidence of leaching, such as staining or formation of precipitates or efflorescence on the dam face, spillways, outlets, or abutments. Piping or seepage channels caused by leaching are similar to those caused by other seepage. Look for and note any signs of seepage (such as upstream erosion and depressions, downstream springs, leaks or vegetation growth, and sand boils) as discussed above. If the materials composing the dam or its natural abutments and foundations contain water-soluble minerals, be especially alert for signs of leaching and seepage leaks.

7. Seepage and Vegetation Growth

The presence of trees, shrubs, or other deep-rooted vegetative species on or adjacent to a dam embankment may cause piping and leakage along root channels. The presence of vegetation on or in the vicinity of the dam may also encourage muskrats or other burrowing animals, which can also damage the structure. In addition, the presence of unusually lush vegetation or of phreatophytes (water-seekers, such as willows or saltcedars) may indicate chronic seepage or leakage. Note the amount and type of vegetation present on the embankment, abutments, and upstream and downstream from the structure. Indicate the location

of and describe any vegetation that appears to be usually green or lush (as compared to vegetation in surrounding area). Note especially the presence of phreatophytes such as willow. Check the soil at the base of any unusually lush vegetation. Compare the soil moisture content with other soils in the area, and note any signs of elevated moisture content. Note the presence of large vegetation (such as trees, shrubs, and brush) on the dam face so that corrective action and removal can be taken as appropriate.

8. Burrowing Animals

Burrowing animals, such as muskrats and ground squirrels, can cause or contribute to embankment failure of small dams. Note any evidence of the presence of burrowing animals.

The muskrat builds burrows in both natural and human-constructed embankments. Muskrat burrows are usually on the upstream slope of the dam, as the animals prefer the burrow entrance below the water line. However, if there is water consistently available at both faces of the dam, the animals may burrow from both faces of the dam, or may burrow all the way through the dam embankment (Figure 23). A colony of muskrats can honeycomb a dam embankment, threatening its existence. Note any evidence of burrowing by muskrats; include

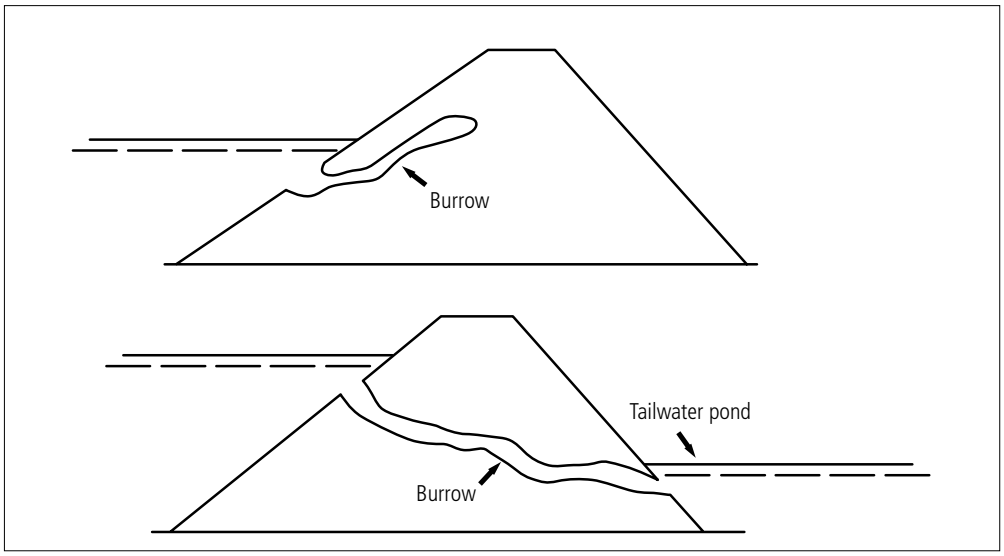

Figure 23. Muskrat Burrows (cross-section)

an estimate of the extent of burrowing damage and the numbers of animals present. If the animals are numerous and are causing extensive damage to the structure, they may have to be removed or eliminated. Consult with the appropriate biological staff to formulate an acceptable method of removal or elimination.

Unlike muskrats, ground squirrels usually prefer to build their burrows in dry soils; they will stop burrowing if they encounter seepage water of moist soils. The burrows are 3 to 4 inches in diameter, but may be enlarged to as much as 12 inches in diameter by badgers seeking the squirrels. If a reservoir has been low or dry for a number of months or years, the ground squirrels may build extensive burrows that penetrate all the way through the embankment, causing embankment failure when the reservoir level again rises. Note the presence of ground squirrel activity, including an estimate of the extent of damage to the embankment and of the numbers of animals present. Consult with the appropriate biological science personnel to formulate an acceptable method of control, elimination, or removal as needed to prevent further damage to the structure.

E. Erosion Problems

Proper erosion control measures are necessary for preventing loss, displacement, or deterioration of upstream embankment facing; crest damage and breaching; and erosion of the downstream face.

Wave erosion may cause failure of dams constructed without adequate freeboard or with extremely steep upstream slopes. However, the probability of a failure of a dam because of wave erosion (even a dam without adequate slope erosion protection) is remote. Wave erosion can contribute to maintenance problems; note evidence of it at time of inspection. Evidence includes signs of erosion at upstream face and crest, overtopping, or erosion trails on the downstream face of the dam. Describe the type and extent of such damage. Most wave erosion problems can be forestalled if satisfactory angle of slope, slope protection or cladding, and adequate freeboard are included in the design and construction of the dam embankment. Note any evidence that these factors may be inadequate; request that experienced engineering

staff assess the seriousness of the condition and take appropriate corrective measures. If significant amounts of erosion are noted, also inspect the borrow pits used during the construction of the dam. Compare the rate of erosion noted in borrow pits with that of the structure itself. Excessive erosion may be due to the characteristics of the borrow as well as to the design and construction of the structure.

F. Foundation Problems

Reaction of structures often reflects foundation changes. Visual surface displacements in the crest, backslope, or foreslope of the dam should be noted. Depressions or sags in the crest or slopes of an embankment dam might reflect embankment or foundation consolidation, solutioning, or piping. Appurtenant structures that have settled or are out of plumb may indicate foundation yielding or compression.

Consolidation of foundation materials due to the weight of the structure may cause differential settling of the embankment, with subsequent cracking and stability problems. See Section B for a discussion of the significance of various types of cracking.

Seepage and piping through the foundation may also cause or contribute to reservoir leakage and failure. See Section D for a discussion of seepage through the foundation.

Liquefaction of the foundation materials can occur because of seismic acceleration. Certain types of materials are especially prone to liquefaction and shear failure. Liquefaction potential should be assessed for dams that are classified as having “high” or “significant” hazard potential in any area where seismic activity is likely to occur. As this condition is not detectable by visual inspection, identify the need for assessment of liquefaction potential as described previously. The appropriate experts should be consulted to assess liquefaction potential and formulate remedies for the condition.

G. Spillways and Outlets

Spillways or outlet works can be defective because of hydraulic inadequacy, structural inadequacy, or operational malfunctions. Spillways and outlets should be checked to ensure that they are in good condition, free of

obstructions, and capable of carrying the volume of flow for which they were designed. Verify the type, number, location, and dimensions of all spillways and outlets at the time of inspection.

Note any debris or obstructions that reduce spillway or outlet capacity. Inadequate spillway capacity can cause overtopping and failure of the dam during high-flow periods. Also note any debris accumulated along the reservoir shoreline and against the dam embankment that might be carried into the spillway or outlet during high-flow periods. If there appears to be encroachment on the freeboard of the embankment, or if the dam appears to be close to overtopping even during periods of normal or low flow, notify engineering personnel who can calculate adequate spillway capacity and take appropriate corrective actions. Note any other evidence of damage or maintenance needs for the approach channel to the spillway or outlet, such as slides, slumps, and cracks; broken or missing trash racks or barriers; and excessive sediment or siltation.

If there is a log boom to prevent movement of debris into the spillway or outlet channel, note any problems such as submergence of the boom, uncleared debris, parting, loss of anchorage, or inadequate slack for low reservoir stages. If there are trash racks to prevent the movement of debris through outlets or spillways, note any debris clogging or accumulating, damage or breakage, or loss of anchorage.

Discharge conduits or channels are vulnerable to obstruction; excessive sidewall loading (as evidenced by deflections, cracks, and differential deflection at joints); invert anchorage and foundation support deterioration (as evidenced by drummy sounding, buckled linings, or excessive uplift); and dangerous or undesirable flow patterns. Inadequate freeboard, cross waves, wall climb, unwetted surfaces, ride-up on horizontal curves, negative pressures on vertical curves, pressure flow, cavitation, hydraulic jump formation, and erosion of unlined channels all indicate undesirable flow patters.

The foot or toe of spillway structures can deteriorate because of inadequate dissipation of energy, undercutting, retrogressive erosion, and erosion of adjacent structures resulting from impingement by spillway or outlet flow.

Note and describe any evidence of deteriorating spillway or outlet toe or box. Include a description of any damage to adjacent structures or areas due to impingement by spillway or outlet flow.

H. Reservoirs and Impoundments

Note the reservoir stage at time of inspection (high, moderate, or low water; or no water). Note evidence of recent reservoir stages, such as high-water marks, debris or deposition lines, or bank undercutting. Note whether or not any water is moving over spillways or through outlets. If any of the reservoir basin is exposed, describe any evidence of depressions or sinkholes. Note whether or not there is any sedimentation or siltation of the reservoir. If necessary, take a profile through the reservoir, embankment, and downstream channel to determine relative elevations. This will allow a calculation of the amount of sedimentation or siltation within the reservoir basin. Note any evidence of unstable reservoir banks, such as leaning trees, undercutting, slumping, or sliding.

If the reservoir is lined with materials designed to minimize or prevent leakage (such as butyl rubber, polyethylene, or bentonite), inspect the lining for evidence of punctures, tears, seam openings, deterioration, or animal activity that may cause the liner to leak. Note the location, type, and extent of any such damage.

I. Other Appurtenances

If there are any gates or wiers present, check to see that they are operable, free of obstructions, and not visibly deteriorated. Note any inoperable structures or maintenance needs. Note the condition of any dikes, ditches, or conduits. They should be free of cracks, erosion, settlement, or leakage. Note any maintenance needs (such as debris or vegetation removal, or removal or repair of deteriorated linings, or control of burrowing animals), including an estimate of the type and amount of maintenance required.

J. Site and Surrounding Area

Note any changes in land use or cover type that might affect runoff quantity or characteristics. For example, the presence of a large, newly clear-cut area upstream from the dam site may increase the amount of runoff and may contribute to more rapid siltation of the reservoir. Also note any changes in the downstream land uses that may affect the hazard classification of

the dam. Note any evidence of large-scale groundwater or oil and gas extraction, as these activities may cause subsidence at the dam site. Note any evidence of recorded seismic activity, wind damage, or subsidence.

Assess the access to the dam site. Identify roads access routes (preferably on a map). Estimate the suitability of access routes for travel under various conditions (i.e., identify whether or not access is available year-round or under certain climatic conditions only, or other situations). If there are any warning devices or signs at or near the dam site, check to see that they are operable, readable, and accurate.

Note any evidence of upstream channel changes such as course changes or the presence of slides or slumps. Note any downstream channel changes; identify any channel obstructions that may cause tailwater backup at the toe of the dam. Note the presence of any human-made channel changes (diversions, straightening, lining, or the impoundment structures or dredging) in the vicinity of the dam site, both upstream and downstream.

Note any evidence that wildlife or stock use the reservoir. If possible, identity the type of wildlife and type of use (feed area for water birds, watering for deer etc.). As discussed previously, note the presence of burrowing animals at the dam site.

K. Safety Considerations

Dam inspectors are exposed to hazards. Caution is required to prevent injury to inspection personnel. Only those with experience or training in their use should operate gates or valves. Controls should be locked or otherwise protected to prevent misuse or vandalism. Note any evidence of tampering with gate or valve controls or mechanisms.

Inspecting and measuring high flow velocity inlets, outlets, and spillway discharges may be dangerous. Even relatively small volumes of water can possess surprising force. Exercise caution when performing inspections, and stay clear of apertures carrying high-velocity flows.

Examine structures such as catwalks, ladders, or footbridges to ensure that they are adequately anchored, with sufficient floorboards, rungs, or treads, and with adequate handholds. Do not attempt to traverse such structures if they do not appear to be in good repair.

Falls may result from poor footing or slippery surfaces. Be particularly careful when traversing embankment slopes or abutments, riprap faces, or areas where there is a growth of moss, algae, or other vegetation. Approach wet areas with caution, particularly when traversing slopes. Be aware of such dangers as snakes, badgers, ticks, bees. Always follow Bureau safety requirements, including the use of protective clothing and devices. Report any accidents to your supervisor, and follow Bureau reporting procedures if a formal report is required (BLM Manual Section 1112).

L. Photographs and Sketches

If possible, take a photograph of each structure and surrounding area during the inspection. At a minimum, try to take photos of the upstream and downstream faces of the structure, the spillways or outlets, and of any conditions requiring extensive or nonroutine maintenance. Overall views of the site can be useful for orientation, identification of vegetation types, and documentation of channel and reservoir changes. Keep a record of the weather conditions and the date the pictures were taken. Attach photos to the condition explaining the view taken (upstream face, downstream face, or other views) and any unusual details (cracks, settling, and vegetation overgrowth).

Make sketches as appropriate to illustrate conditions such as pattern cracking or sliding; include key dimensions. If profiles are taken, sketch the profile and note key elevations (such as reservoir bottom, crest of dam, crest of spillway, downstream channel bottom, and water surface). Attach sketches to the condition survey report.

V. Classification Information for Dams

Dams are classified for seismic acceleration, size, condition, and hazard. A summary of the information needed for classification follows.

A. Seismic Peak Ground Accelerations (applicable to high-hazard dams only)

The peak ground acceleration (PGA) caused by an earthquake is a function of the latitude and longitude of the high-hazard dam. For design purposes, a spectral acceleration of 1.0 seconds is used for a 50-year recurrence interval, as shown in Figure 24. The site-specific PGA may be found at the following U.S. Geological Survey site: *http://www.fema.gov/hazard/earthquake/index/shtm.*

B. Size Classification

The size classification of a dam is determined by either the hydraulic height or the retention–detention capacity—whichever yields the greater size category.

Size Classification	Hydraulic Height	Retention–Detention Capacity
Minor Dam (M)	6 to 25 feet	15 to 50 acre-feet
Small Dam (S)	26 to 40 feet	51 to 1,000 acre-feet
Intermediate Dam (I)	41 to 100 feet	1,001 to 50,000 acre-feet
Large Dam (L)	>100 feet	>50,000 acre-feet

Figure 24. Horizontal Peak Ground Accelerations for 1.0-second spectral response, 5% critical damping, Site Class B (rock). (From Building Safety Council, 1998, NEHRP)

C. Hazard Classification

The hazard classification for a dam is based on the potential for loss of life and property downstream from the dam. A dam may be hazard classified only if it 1) is 25 feet or more in hydraulic height, or 2) impounds 50 acre-feet or more of water. Dams that are smaller than these limits should not be in the dam safety program. If no loss of life is probable as the result of dam failure, the dam is classified as low or significant hazard. Improbable loss of life exists where persons are only temporarily in the potential inundation area. The classification system does not contemplate the improbable loss of life of the casual or occasional recreational user of the river and downstream lands, passer-by, or nonovernight outdoor user of downstream lands. To be classified as a significant hazard, the economic, environmental, and lifeline losses must interrupt vital utilities such as State highways (not County highways unless traffic counts are high), Interstate highways, and high traffic railroads.

Hazard Potential Classification	Loss of Human Life	Economic, Environmental, Lifeline Losses
Low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable. One or more expected	Yes (but not necessary for this classification)

D. Safety Ratings

SAFETY RATING CODES

Principle Spillway or Outlet Works

This section describes the physical conditions associated with the alignment, settlement, joints, structural conditions, scour, and other items associated with outlet works (intake structures, conduits, gates, and stilling basins).

N Not applicable. Use when the dam has no outlet works.

9 EXCELLENT—No deficiencies.

8 VERY GOOD—No noticeable or noteworthy deficiencies that affect the operation of the outlet works. Minor debris accumulation on trash racks.

7 GOOD—Concrete surfaces have shrink cracks, light scaling, and insignificant spalling that does not expose reinforcing steel. Insignificant damage has been caused by drift with no alignment change and not requiring corrective action. Some minor scouring has occurred near conduit outlet or basin outlet. Metal conduits have smooth symmetrical curvature with superficial corrosion and no pitting. Gates operate smoothly, but may have superficial corrosion and no pitting.

6 SATISFACTORY—Minor deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalling on concrete. Conduit outlet or stilling basin has local minor scouring. Metal appurtenances have significant corrosion or moderate pitting. Gate operator stems may be leaking lubricant. Significant debris has accumulated at gates and conduit inlets that does not impede flow or operation.

5 FAIR—Moderate deterioration or disintegration, extensive cracking and leaching, or spalling on concrete. Minor settlement or misalignment. Noticeable scouring or erosion at the outlet works or the stilling basin. Metal appurtenances have significant distortion and deflection in one

section, significant corrosion or deep pitting present. Gate operator stems have misalignments that do not affect the full operation of the gate. Major debris has accumulated at gates and conduit inlets that impedes flow or operation.

4 POOR—Major spalling, heavy scaling, wide cracks, or exposed rebar in concrete. Conduits, appurtenances, stilling basins, and intakes have major settlement or misalignment. Considerable scour or erosion is present at the outlet works or stilling basin. Metal appurtenances have significant distortion and deflection throughout, extensive corrosion or pitting. Gate does not have complete range of operation.

3 SERIOUS—Any condition described in code 4 that is excessive in scope. Severe movement or differential settlement of the outlet works including intake, conduit, stilling basin, and gates. Holes may exist in concrete surfaces. Metal conduits or appurtenances have extreme distortion and deflection in one section, extensive corrosion, or deep pitting with scattered perforations. Gate is not operable.

2. CRITICAL—Severe settlement in the outlet works. Conduit can no longer support embankment. Piping or seepage is present along conduit. Corrective action is required to keep dam in service. Metal conduit and appurtenance have extreme distortion and deflection throughout with extensive perforations due to corrosions.

1 "PARTIAL FAILURE"—Dam is out of service because of outlet works failure. Reconstruction of the outlet works would put the dam back in service.

0 FAILED—Dam has failed. Replacement of the entire structure is necessary.

Good (codes 7–9)	Fair (codes 5–6)
Poor (codes 2–4)	Unsatisfactory (codes 0–1)

EMERGENCY SPILLWAY

This section describes the physical conditions associated with flow of water through spillways, such as channel stability and the condition of the spillway, riprap, slope protection, or control devices, including spur dikes.

N Not applicable. Use when a dam has no spillway channel.

9 EXCELLENT—There are no noticeable or noteworthy deficiencies that affect the condition of the spillway channel.

8 VERY GOOD—Spillway channel and banks are protected. Spillway control devices such as spur dikes, weirs, and channel protection are not required or are in a stable condition.

7 GOOD—Concrete surfaces have shrink cracks, light scaling, and insignificant spalling that do not expose reinforcing steel. Spillway channel and bank protection is in need of minor repairs. Spillway control devices and channel side slopes have a little minor damage. Banks or channel have minor amounts of drift or vegetation growth.

6 SATISFACTORY—Minor deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalling on concrete. Spillway banks are beginning to slough. Spillway control devices and channel protection have widespread minor damage. There is minor spillway channel bed movement (erosion) evident. Debris or vegetation (short, less than 1 foot in height) is restricting the waterway slightly.

5 FAIR—Moderate deterioration or disintegration, extensive cracking and leaching, or spalling on concrete. Spillway protection is being eroded. Spillway control devices or channel side slopes have major damage. Trees and brush restrict the channel.

4 POOR—Major spalling, heavy scaling, wide cracks, or exposed rebar in concrete. Spillway and channel side slope protection is severely undermined.

Spillway channel has severe headcutting and widespread erosion. Spillway control devices have severe damage.

3 SERIOUS—Concrete has loss of section, deterioration, or spalling has seriously affected the primary structural components. Shear cracks in concrete may be present. Spillway protection has failed. Spillway control devices have been destroyed. Channel aggradation, degradation, or lateral movement have changed the spillway to now threaten the dam.

2 CRITICAL—The spillway has changed to the extent that the dam or the spillway is near a state of failure. Advanced deterioration of primary structural elements is present. Shear cracks in concrete may be present and leaking water.

1 "PARTIAL FAILURE"—Dam is out of service because of spillway failure. Reconstruction of the spillway would put the dam back in service.

0 FAILED—Dam has failed. Replacement of the entire structure is necessary.

Good (codes 7–9)	Fair (codes 5–6)
Poor (codes 2–4)	Unsatisfactory (codes 0–1)

EMBANKMENT

This section describes the physical conditions associated with the alignment, settlement, joints, structural conditions, scour, and other items associated with concrete and earth fill embankment dams.

N Not applicable. Use when the dam has no outlet works.

9 EXCELLENT—No deficiencies, "like new."

8 VERY GOOD—No noticeable or noteworthy deficiencies that affect the condition of the embankment. Upstream face is protected with riprap or other slope protection.

7 GOOD—Concrete surfaces have shrink cracks, light scaling, and insignificant spalling that does not expose reinforcing steel. Some minor wave action scouring has occurred on the upstream face. Embankment has minor amounts of vegetation growth (trees and brush).

6 SATISFACTORY—Minor deterioration or initial disintegration, minor chloride contamination, cracking with some leaching, or spalling on concrete. Minor amounts of rodent holes, cracking, surface erosion, and seepage present. Embankment has vegetative growth (trees and brush) covering large portions of the embankment. Vegetation is less than 3 feet in height.

5 FAIR—Moderate deterioration or disintegration, extensive cracking and leaching, or spalling on concrete. Minor settlement, depressions, or bulges present in the embankment. Minor differential movement is present at the abutment contacts. Major amount of rodent holes, cracking, and erosion present in the embankment and associated slope protection. Embankment has vegetative growth (trees and brush) covering large portions of the embankment. Vegetation is less than 5 feet in height.

4 POOR—Major spalling, heavy scaling, wide cracks, or exposed rebar in concrete. Major settlement, depressions, or bulges present in the

embankment. Severe amount of rodent holes, cracking, and erosion present in the embankment and associated slope protection. Indication of sinkhole or boils is developing in the embankment. Major differential movement is present at the abutment contacts. Embankment has vegetative growth (trees and brush) covering large portions of the embankment. Vegetation is greater than 5 feet in height.

3 SERIOUS—Any condition described in code 4 that is excessive in scope. Severe movement or differential settlement of the embankment. Major amount of sinkhole or boils is present in the embankment or downstream toe. Piping is evident. Sediment is present in seepage. Rate of seepage has increased from previous monitoring. Concrete has loss of section, deterioration, or spalling has seriously affected the primary structural components. Shear cracks in concrete may be present.

2 CRITICAL—Advanced deterioration of primary structural elements. Shear cracks in concrete may be present and seeping water. Dam embankment is near a state of failure.

1 "IMMINENT FAILURE"—Dam will fail if not taken out of service. Reconstruction of the embankment would put the dam back in service.

0 FAILED—Dam has failed. Replacement of the entire structure is necessary.

Good (codes 7–9)	Fair (codes 5–6)
Poor (codes 2–4)	Unsatisfactory (codes 0–1)

E. Overall Dam Safety Rating

The overall safety rating of the dam is based on the lowest rating code associated with each of the three different elements of the dam (i.e., outlet works, emergency spillway, and embankment); therefore, if the rating code for the outlet works is a 3, the rating code for the emergency spillway is a 6, and the rating code for the embankment is an 8. The overall rating for the dam would be a 3.

Condition	Criteria
1—Good	Structure is in good condition as measured against new condition. No repairs are needed at time of inspection. Structure is serving the purpose for which it was constructed.
2—Fair	Minor repairs or routine maintenance only is needed. Structure is operational and is serving the purpose for which it was constructed.
3—Poor	Major repairs or modifications are required to make the structure operational or to prevent failure of the structure. Structure is only partially operational, and is not adequately serving the purpose for which it was constructed.
4—Unsatisfactory	Structure is breached or flanked. Structure is not operational and is not serving the purpose for which it was constructed.

VI. Selected References

The following references are recommended for officials engaged in the safety inspection and maintenance of dams, reservoirs, or other water control structures:

Coordinating Council for Science, Engineering and Technology. 1979. Federal Guidelines for Dam Safety. Ad Hoc Interagency Committee on Dam Safety, Washington, D.C.

Interagency Committee on Dam Safety. 1998. FEMA 333. Reprinted January 2004.

U.S. Department of Defense, Army Corps of Engineers. n.d. Recommended Guidelines for Safety Inspection of Dam. Office of the Chief of Engineers, Washington, D.C. Reprinted as Appendix D, Recommended Guidelines for Safety Inspection of Non-Federal Dams. Federal Register Vol. 44, No. 188, pp. 55356–55375; September 26, 1979.

U.S. Department of the Interior, Bureau of Reclamation (now Water and Power Resources Service). 1973. Design of Small Dams (2nd ed.), U.S. Government Printing Office, Washington, D.C. [Stock No. 2403-0068]

U.S. Department of Agriculture, Soil Conservation Service. 1972. SCS National Engineering Handbook. U.S. Government Printing Office, Washington, D.C.

U.S. Department of the Interior, Water and Power Resources Service. 1979. Manual for Safety Evaluation of Existing Dams (SEES Manual). Engineering and Research Center, Denver, Colorado.

The following references are sources of useful supplemental information:

American Society of Civil Engineers. 1976. The Evaluation of Dam Safety. Proceedings of the American society of Civil Engineers, November 28–December 3.

Inspection, Maintenance, and Rehabilitation of Old Dam. 1974. *In* Proceedings of the Engineering Foundation Conference.

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