Training Aids for Dam Safety

MODULE:

IDENTIFICATION OF MATERIAL DEFICIENCIES

TADS

A video presentation accompanies this workbook.

Training
Aids for
Dam
Safety

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IDENTIFICATION OF MATERIAL DEFICIENCIES

TADS

PREFACE

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

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

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

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

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

ACKNOWLEDGMENTS

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MODULE INTRODUCTION

MODULE INTRODUCTION

OVERVIEW OF THE MODULE

In this module, you will learn how to identify deficiencies that affect materials used in dams and appurtenances, and how to explain why these deficiencies present serious dam safety problems. In addition, you will be provided with descriptions of methods and techniques you may use to detect material deficiencies, and guidance about what actions to take when you observe deficiencies.

OBJECTIVES

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

- List major deficiencies affecting concrete, other cement mixture materials, metal and metal coatings, earth and rock materials, and synthetic materials used in dam construction.
- Describe locations and circumstances where certain material deficiencies are most likely to occur.
- Explain the consequences of particular deficiencies on the safety of a dam.
- Recognize material deficiencies that should be referred to an experienced and qualified engineer for immediate evaluation.

MATERIALS TO BE DISCUSSED

The following materials are discussed in this module since they commonly are found in dams and their appurtenances:

- Concrete
- Cement mixture materials other than conventional concrete
  - Mortar
  - Grout
  - Soil cement
  - Roller compacted concrete (RCC)
  - Shotcrete
- Metal and metal coatings
- Earth and rock materials
- Synthetic materials
  - Geotextiles and geomembranes
  - Plastic piping and tubing

While additional materials such as wood and asphalt sometimes are found in dams and appurtenances, use of these materials was not considered sufficiently widespread to warrant inclusion in this module.

MODULE INTRODUCTION

RELATING MATERIAL DEFICIENCIES TO DAM SAFETY

Material deficiencies can threaten the safety of a dam. In some instances, the severity of a problem develops over a long time. In other cases, a threat to the dam can develop quickly. The stresses induced by flooding, for example, might cause the deficient material of some dam components to fail and endanger the dam. This module will help you learn to recognize and report hazardous material deficiencies. To develop such judgment, you will need basic information about the materials and about the relative hazards of different deficiencies commonly found in those materials.

The use of the term "deficiency" in this module does **not** necessarily refer to an intrinsic flaw in the material itself. For example, concrete of excellent quality may develop hazardous cracking due to foundation settlement. The hazardous cracking is a **dam safety deficiency**. Therefore, the term "deficiency" is used to refer to conditions found in certain types of materials that can jeopardize the safety of a dam.

Deficiencies that presently or in the foreseeable future could threaten the safety of a dam are the primary emphasis of this module. Deficiencies without a reasonable potential to affect the safety of a dam are considered maintenance problems. For example, a surface defect in concrete could allow moisture to penetrate, initiating deterioration. Since no hazard exists in the foreseeable future, this deficiency concerns maintenance rather than safety.

This module focuses on the deficiencies that you can detect during inspections, and does not attempt to provide comprehensive, indepth information about materials or detailed descriptions of the causes or mechanics of various deficiencies, unless the information would help you during dam safety inspections. You generally should try to identify causes of the material deficiencies you detect, and to recommend basic corrective actions consistent with your background and experience. For more information about particular materials and their associated deficiencies, refer to the resources listed in Appendix B: References.

HOW TO USE THIS MODULE

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

Before completing this module, you may want to complete all of the inspection modules except Instrumentation For Embankment And Concrete Dams and Evaluation Of Facility Emergency Preparedness.

MODULE INTRODUCTION

CONTENTS OF THIS MODULE

This module is divided into five units followed by two appendixes:

- **Unit I. Deficiencies Of Concrete:** Provides instruction on identifying deficiencies in concrete and determining which deficiencies are hazardous to a dam.
- **Unit II. Deficiencies Of Other Cement Mixture Materials:** Outlines the deficiencies found in cement mixture materials other than conventional concrete and provides guidelines for recognizing hazardous deficiencies in those materials.
- **Unit III. Deficiencies Of Metal And Coatings:** Presents information on deficiencies in metal and how metal deficiencies may affect the safety of the dam, as well as descriptions of deficiencies in metal coatings.
- **Unit IV. Deficiencies Of Earth And Rock Materials:** Provides instruction on how to recognize and report hazardous deficiencies in earth, riprap, and rock.
- **Unit V. Deficiencies Of Synthetic Materials:** Presents information on deficiencies in geotextiles and geomembranes, and plastic piping and tubing, and how to detect hazardous problems with these materials.
- **Appendix A. Glossary:** Defines a number of technical terms used in this module.
- **Appendix B. References:** Lists recommended references that can be used to supplement this module.

DESIGN OF THIS MODULE

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

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

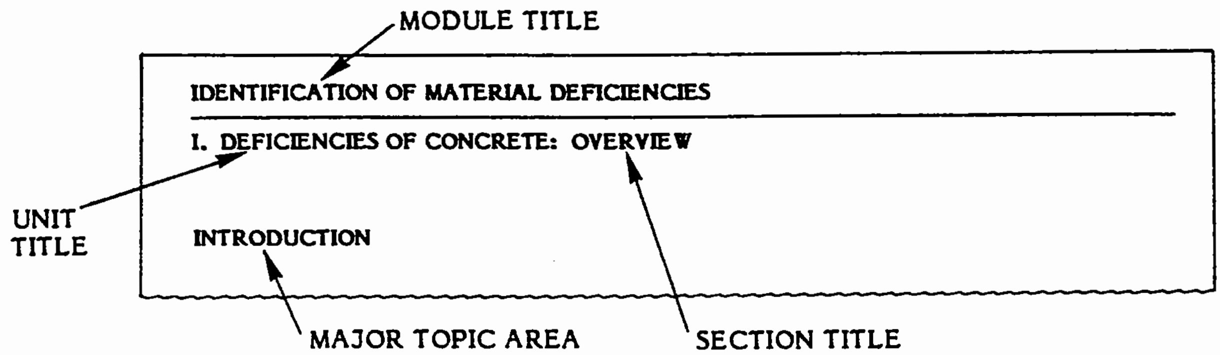
- Text Instruction
- Unit Exercises
- Video Presentations
- Final Review Exercise

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

Text Instruction

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

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



Unit Exercises

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

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

Video Presentations

Two video presentations are included in this module. The text will tell you when to watch each video segment. After viewing each video segment, return to the text. You may watch the video presentations as many times as you find helpful.

> NOTE: The two video segments are contained on one videocassette. Therefore, do not rewind the tape until you have seen both segments.

Final Review Exercise

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

Continued . . .

MODULE INTRODUCTION

Final Review Exercise (Continued)

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

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

REQUIRED MATERIALS

To complete this module, you will need the following materials:

- This workbook and a pencil or pen
- The accompanying videocassette and a videotape player

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

UNIT I

DEFICIENCIES OF CONCRETE

I. DEFICIENCIES OF CONCRETE: OVERVIEW

INTRODUCTION

Concrete is one of the most common materials used in building dams and appurtenances. While performing dam safety inspections, you probably will encounter concrete dams, channels, conduits, walls, and other concrete structures. Since major structural components often are constructed of concrete, concrete deficiencies which threaten these components can also jeopardize the safety of a dam.

UNIT OBJECTIVES

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

- Describe the nature and extent of cracking in concrete.
- Use a crack survey or instrumentation to monitor cracking.
- Identify hazardous individual and pervasive cracking, and recommend possible corrective actions.
- Describe the types and hazards of concrete deterioration, and recommend possible corrective actions for each.
- Distinguish surface defects from other concrete deficiencies.

TYPES OF CONCRETE DEFICIENCIES

Concrete deficiencies fall into the following major categories:

- Cracking
- Deterioration
- Surface defects

Cracking and deterioration are deficiencies that can affect dam safety, while surface defects generally represent maintenance or esthetic problems rather than genuine hazards. Therefore, most of the discussion in this section will focus on concrete cracking and deterioration.

Consider the nature and design of a concrete structure when examining concrete. For example, concrete in an arch dam should be especially assessed for strength, elastic properties, and the condition of boundary concrete, particularly at abutments. Concrete in a gravity dam requires special attention to cracking, leakage, and deeply penetrating deterioration. Concrete in water conveyance structures must be carefully examined for offsets or irregularities that might trigger cavitation damage and for cracks or spalls that may indicate overstressing.

I. DEFICIENCIES OF CONCRETE: CRACKING

WHAT IS CRACKING?

A crack is a separation into one or more major parts, and is usually the first sign of concrete distress. You will encounter two general categories of cracking when you inspect concrete structures.

- **Individual cracks.** A concrete element may have one or a limited number of cracks that can be individually measured and documented within the course of an inspection.

- **Pervasive cracking.** Numerous cracks may be visible within areas of a concrete surface, or may affect the entire surface. Pervasive cracking tends to assume a number of typical appearances produced by specific causes.

  When you inspect concrete with extensively cracked surfaces, the focus of your inspection is the nature and extent of cracking rather than the dimensions of individual cracks. Pervasive cracking usually is a sign of concrete deterioration.

Hazards Of Cracking

Cracks provide openings in the concrete that permit further deterioration of the concrete. By design, a concrete dam and appurtenances must withstand considerable hydrostatic pressure from the reservoir. Hydrostatic pressure acting along cracks through the body of a dam may exert dangerous uplift forces on elements of the dam, possibly leading to lateral propagation of the cracks and eventual overturning or sliding of a portion of the dam.

A crack in a concrete conduit through an embankment dam might allow reservoir water under pressure to enter and erode the embankment along the conduit. A large crack in a concrete spillway discharge channel could allow erosion of underlying material, resulting in loss of support and failure of the spillway. A badly cracked channel wall might fail when subjected to pressure from a large discharge.

Even if a crack itself does not present a serious threat, the mechanism causing the crack may threaten the structure. Cracking in concrete may be a visible manifestation of stress or movement which the concrete cannot accommodate. The underlying cause of cracking can pose an immediate threat to the dam.

I. DEFICIENCIES OF CONCRETE: CRACKING

Characteristics Of Individual Cracks

The American Concrete Institute (ACI) has developed standardized terms to describe the appearance of individual cracks. These terms are . . .

- Direction
  - Longitudinal

    Consistent with terminology used for cracking in embankment dams, some nomenclature for cracks in concrete dams differentiates cracks on and parallel to the crest of a structure - termed longitudinal - from cracks on faces of the structure, which are designated as horizontal. ACI uses the term longitudinal to describe cracks in either location that are parallel to the crest.

  - Transverse
  - Vertical
  - Diagonal
  - Random
- Width
  - Fine: less than 0.5 mm
  - Medium: between 0.5 and 2 mm
  - Wide: over 2 mm
- Depth

Types Of Pervasive Cracking

ACI uses the following classifications to describe extensive cracking of surfaces:

- Pattern cracking
- D-cracking
- Checking

IDENTIFYING HAZARDOUS INDIVIDUAL CRACKS

Of the many cracks you will see in concrete, you must learn to recognize those that may affect the safety of the dam.

Structural Cracks

A structural crack compromises the integrity of a concrete element and therefore may be especially hazardous.

I. DEFICIENCIES OF CONCRETE: CRACKING

Identifying Structural Cracks

In appearance, a structural crack may be . . .

- Diagonal or random with abrupt changes in direction
- Wide, with a tendency to increase in width
- Adjacent to concrete that is noticeably displaced
- Occasionally narrow and diagonal, indicating inadequate design for shear stresses

Causes Of Structural Cracking

Structural cracks often result from movement of portions of a structure or overstressing. External stresses may be caused by . . .

- Extreme or differential loading conditions
- Foundation settlement
- Seismic activity

Structural cracks sometimes reflect design or construction errors or deficiencies in the concrete.

- Flaws in structure design may result in stresses too great for the concrete to withstand.
- Concrete mixtures with deficient strength or elastic properties may crack under design stresses.
- Poor construction techniques may be responsible for deficiencies that promote cracking.

Typical Structural Crack Locations

Look for structural cracks at areas of stress concentrations, such as:

- Corners of openings
- Contraction joints
- Areas of large temperature gradients. Temperature variations between the air and reservoir water in cold weather can cause cracks extending from the structure crest down each face
- Foundation and abutment material or slope changes
- Direction change relative to the section of the structure

I. DEFICIENCIES OF CONCRETE: CRACKING

Using Crack Surveys

A crack survey is an examination of a concrete structure for the purpose of locating, recording, and identifying cracks and of noting the relationship of the cracks with other signs of distress. A design drawing or inspection drawing is often used to record the location and extent of cracks in this type of survey. A grid system established with paint or chalk on a structure's surface can be used as an aid to determine crack locations.

A crack survey should identify . . .

- Characteristics of the cracks (length, width, direction, trend, depth, offset, and location).

  For monitoring purposes, mark measurement points and protect the sharp edges of cracks with a thin coat of clear epoxy. Use a comparator, feeler gauge, or a handheld illuminated microscope to measure width. (A comparator is printed or inscribed with lines of various widths on a transparent background. The user places the device over a crack and matches crack width to a line. Two versions of comparators exist. One is a lighted magnifying glass with an eyepiece scribed with lines. The other is a clear plastic card printed with lines.)

  Try to repeat the survey under varied loading conditions to detect possible changes in crack width or offset.

- Descriptions of crack types.

- Descriptions of other conditions or deficiencies that may be associated with cracking, such as . . .

  - Leakage
  - Deposits from leaching or other sources
  - Spalling of crack edges

Whenever feasible, external cracks should be correlated with internal cracks. Where repairs have been made to the concrete, crack surveys are difficult to perform and may be unreliable because cracks beneath the repairs may indicate deficiencies at greater depths. It is significant, however, to note whether new cracks have developed in the repaired concrete. Such cracks may indicate continuing structural problems.

Figure I-1 presents an example of one portion of a crack survey of a concrete conduit. A separate page is prepared for each section of conduit.

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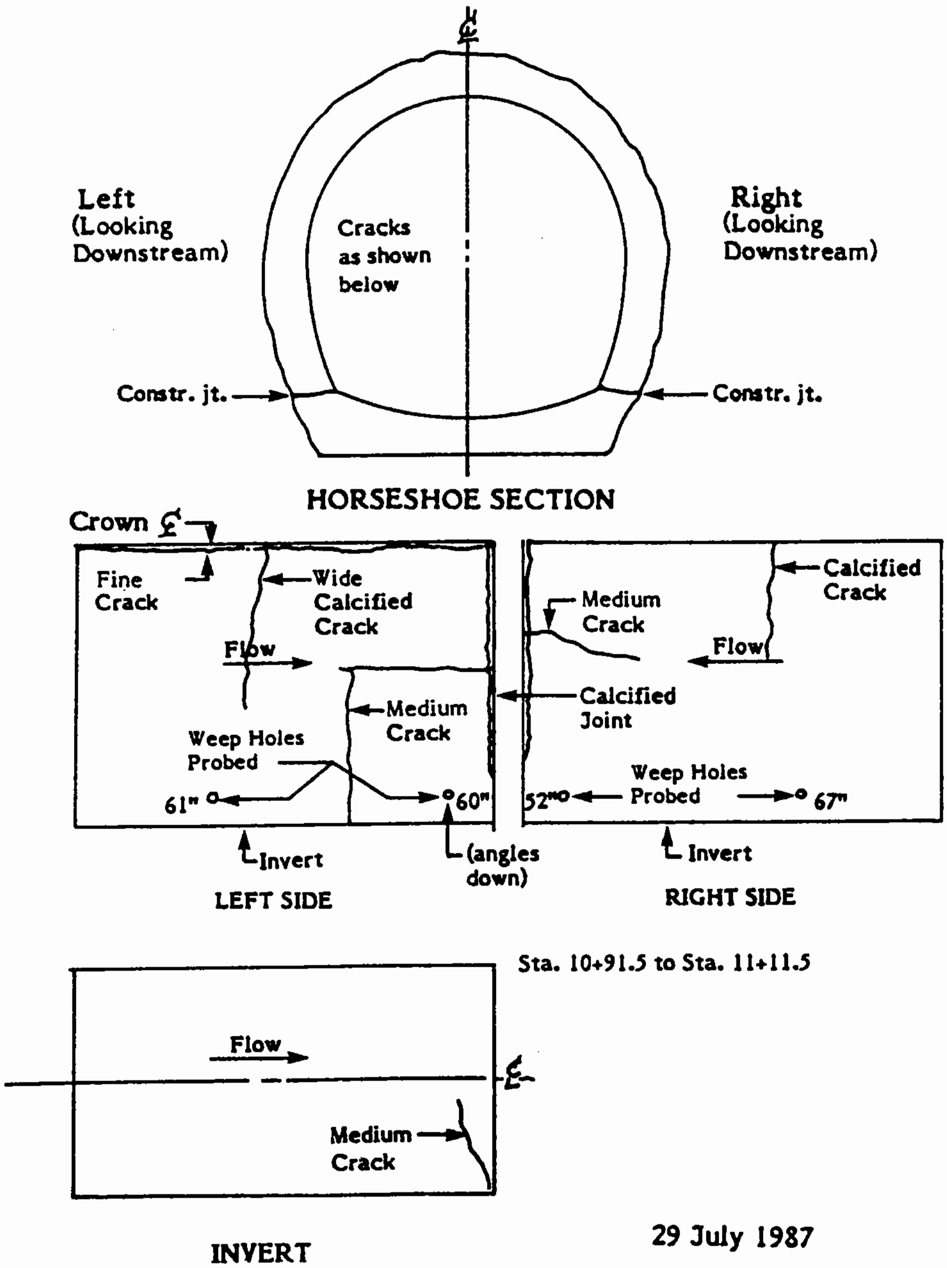
Using Crack Surveys (Continued)

FIGURE I-1. TYPICAL CRACK SURVEY



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Using Crack Surveys (Continued)

Potentially hazardous cracks often are wide, change widths with load changes or temperature cycles, or include significant leakage. Compare your observations with the drawings in past crack surveys, and be alert for new cracks and for changes that depart from past trends.

Monitoring Cracks With Instrumentation

Instrumentation may have been installed to monitor serious cracks, or data from standard dam instrumentation may supply reasons that hazardous cracking has occurred. The module Instrumentation For Embankment And Concrete Dams contains detailed information about using instrumentation. Measurements of leakage and movement are particularly important for evaluating cracks, as well as for evaluating joints, which also are subject to leakage and movement.

Seepage/Leakage Instrumentation

Water from seepage or leakage may . . .

- Result in the development of excessive hydrostatic pressures on portions of the structure.
- Attack concrete chemically.
- Result in freeze-thaw damage to concrete.
- Erode or solution foundation material.
- Result in leaching of the concrete.

Chemical analysis of leakage water and deposits may be advisable.

Sometimes you can determine the leakage source by simple measurements comparing leakage water temperature with ground water and reservoir temperatures.

Dye tests are another means of identifying leakage sources. Approved dyes can be placed in the water upstream of the structure, in drill holes, or in other accessible locations. The location and time the dyes appear downstream can locate the sources and velocity of leakage.

The most common leakage measuring devices include . . .

- Container and stopwatch
- Weir
- Flume
- Flow meter

Continued . . .

I. DEFICIENCIES OF CONCRETE: CRACKING

Seepage/Leakage Instrumentation (Continued)

A container and a stopwatch typically are used to measure the leakage from a crack. But you may first have to use a plate to get the leakage to spring free from the wall and into the container.

Movement Instrumentation

Table I-1, on the following page, lists names and functions of devices that measure movement.

Continued . . .

Movement Instrumentation (Continued)

TABLE I-1. MOVEMENT INSTRUMENTATION

TYPE OF DEVICE	MOVEMENT MEASURED
Survey devices	Absolute movements
Foundation baseplates	Consolidation of foundation materials beneath a dam (separated from total settlement)
Settlement sensors	Settlement values, to identify differential settlement and total settlement
Inclinometers	Lateral movements in abutments, foundations, or in the structure
Extensometers	Internal movements of dams, most often foundations of gravity dams and abutments of arch dams; often installed to monitor specifically identified problems
Tiltmeter	Vertical tilt (rotational movement) of dams, sections of dams, and rock masses
Plumblines	Movement of concrete dams due to temperature changes and applied reservoir pressure
Crack and joint measuring devices, including three general categories: . Measurement points . Calibrated crack monitors . Joint meters	Relative movement between intact masses on either side of a crack or joint, most commonly caused by cyclic temperature changes and reservoir level changes
Embedded strain, stress, joint, and temperature meters	Strain, stress, joint movement, and internal temperature of concrete

You should especially note instances when monitoring equipment reveals enlargement or other changes in a crack. Also, you should examine other instrumentation measurements for evidence of conditions that may have caused changes in the crack.

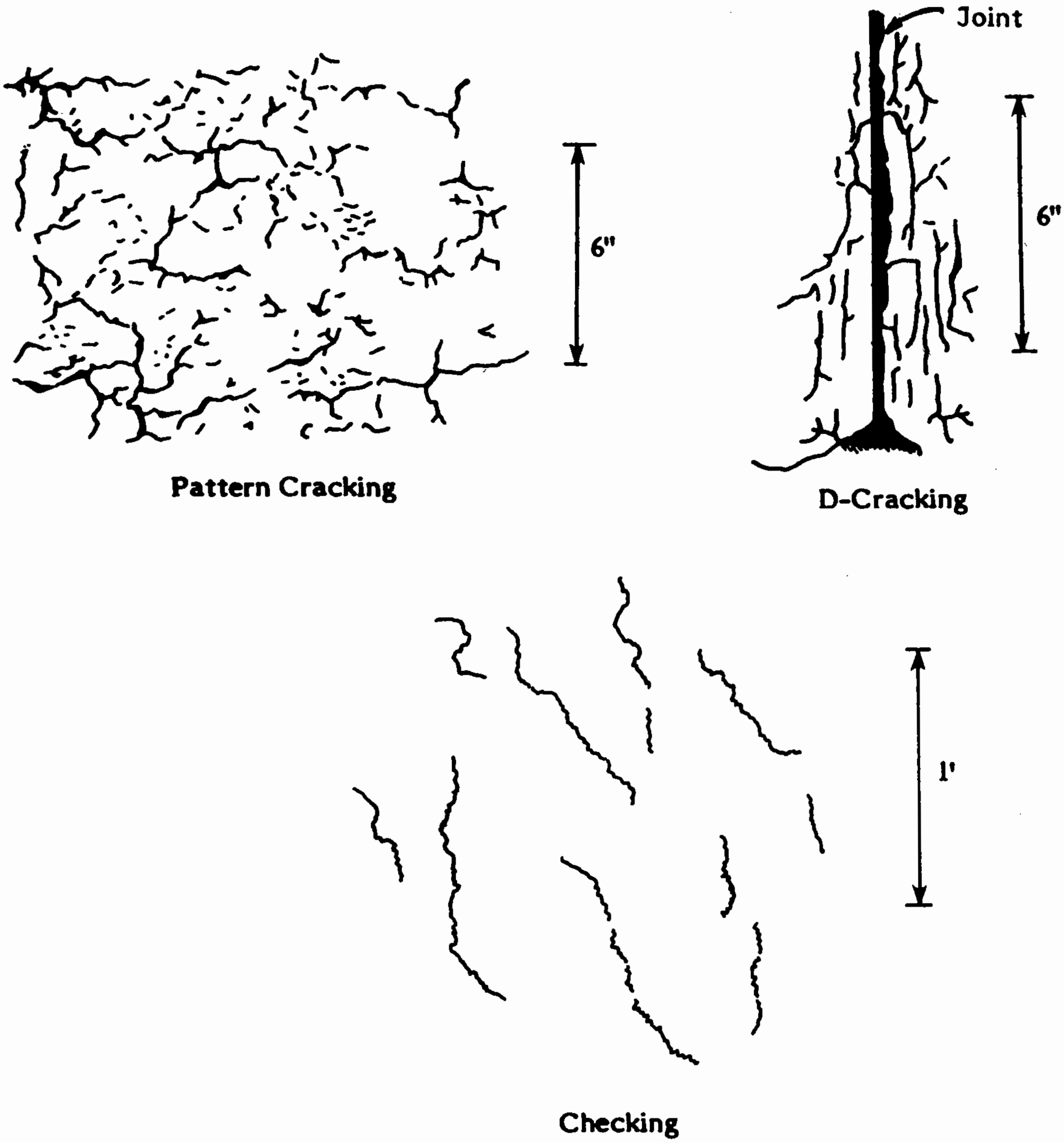
I. DEFICIENCIES OF CONCRETE: CRACKING

IDENTIFYING HAZARDOUS PERVASIVE CRACKING

Pervasive cracking may signal hazardous concrete deterioration.

Figure I-2 illustrates ACI classifications of extensively cracked surfaces.

FIGURE I-2. PERVASIVE CRACKING CONFIGURATIONS



I. DEFICIENCIES OF CONCRETE: CRACKING

Pattern Cracking

Pattern cracking consists of openings on a concrete surface in the form of a pattern, and is caused by either shrinkage of concrete near the surface or a volumetric increase in concrete below the surface layer.

Several mechanisms cause changes in volume.

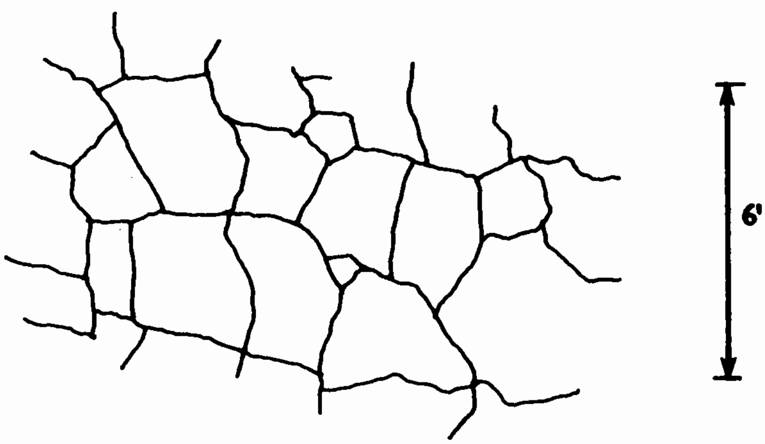
Thermal Stress

Cement hydration in mass concrete causes heat that results in expansion. This is followed by differential cooling and shrinkage of the outer surface that is a major cause of **thermal cracking.** Reactions within massive concrete sections may continue to generate hydration heat for decades. Restraint by rigid foundations or old lifts of concrete also are factors. Thermal cracks are deep, often extending through thin sections.

Be especially alert for thermal cracking in the massive concrete monoliths of concrete dams. A pattern of hairline cracks in an orthogonal, blocky "dried mud puddle" configuration inside of galleries, usually accompanied by considerable leakage, is a sign of thermal cracking.

Figure I-3 illustrates thermal cracking.

FIGURE I-3. THERMAL CRACKING



Thermal Cracking

Continued . . .

I. DEFICIENCIES OF CONCRETE: CRACKING

Thermal Stress (Continued)

Another sign of thermal cracking is the presence of vertical cracks continuous through walls, ceilings, and floors of transverse galleries resulting from cooling of concrete and restraint near the foundation.

If you suspect thermal cracking, installing temperature gauges for temperature studies provides a means to collect relevant data.

Examine the mix designs for the structure. Failure to use low-strength concrete for the interior and high-strength concrete on the exterior of the structure may have promoted thermal cracking.

Check construction records for a lack of such measures as use of thinner lifts, controlling concrete placement temperature, replacement of cement with pozzolan, and a reduced construction rate to deal with hydration heat.

Alkali-Aggregate Reaction

A reaction between soluble alkalis in the cement and the aggregate can cause abnormal expansion and cracking that may continue for many years.

If you observe pattern cracking in areas exposed to wet-dry cycles such as parapets, piers, or the top of a dam, the cause may be alkali-aggregate reaction.

Alkali-aggregate reaction is described more fully in the following section, Concrete Deterioration.

Freeze-Thaw Action

In northern and high elevation areas, freeze-thaw action is a common cause of pattern cracking and D-cracking. Cracking increases geometrically with each freeze-thaw cycle. The freeze-thaw cycle starts when water enters pores, cracks, and joints in the concrete. When temperatures drop, water in the concrete freezes and expands, causing the concrete to crack. Water then enters the new cracks, and when temperatures drop again, the water freezes and expands, forcing the cracks to open wider.

Examine areas of concrete exposed to moisture for damage from freeze-thaw action. Exposed horizontal surfaces such as slabs are especially subject to cracking due to improper finishing operations.

Use of entrained air protects concrete from freeze-thaw damage. Lack of entrained air in pre-1940 concrete elements, or an improper percent of entrained air, results in concrete that is vulnerable to damage.

I. DEFICIENCIES OF CONCRETE: CRACKING

D-Cracking

D-cracking consists of fine parallel cracks at close intervals, usually along joints or edges. This pattern of cracking is an early sign of damage from freeze-thaw action. Low-quality limestone aggregates are commonly the cause of D-cracking.

Checking

Checking consists of the development of fine cracks on the surface of concrete that . . .

- Show no evidence of movement
- Are shallow
- Are closely spaced at irregular intervals
- May be several feet long

Checking is usually caused by expansion and contraction or shrinkage of the concrete surface with alternating wet-dry periods. Rapid drying of newly placed concrete may also result in checking of the concrete surface.

Analyzing Cracking

Table I-2 (on the following pages) lists important information you need when inspecting concrete at dams, and will help you: identify cracking that is hazardous, suggest possible causes for cracks, and recommend possible corrective actions. Keep in mind that determining the cause of cracking is far from an exact science.

Continued . . .

I. DEFICIENCIES OF CONCRETE: CRACKING

Analyzing Cracking (Continued)

TABLE I-2. HAZARDOUS CRACKS AT DAMS

CRACK LOCATION	TYPE/ CHARACTERISTICS	POSSIBLE CAUSES	POSSIBLE CORRECTIVE ACTIONS
CONCRETE DAM			
Crest	Transverse, extending from upstream to downstream, 12 inches or more deep	Overloading of dam; earthquake; foundation settlement	
	Transverse with vertical or lateral offsets, opening wider than 1 mm, offset more than 2 mm	Differential settlement of foundation; earthquake; overloading of dam blocks	Lower reservoir and treat foundation
Faces	Vertical and diagonal, more than 5 feet long, 12 inches deep	Excessive stresses; temperature drop in area of restraint	Grout with epoxy to seal cracks and restore strength to the concrete block and possibly bolt waterstop-type membrane over cracks if leakage is occurring
Galleries	Vertical cracks continuous through walls, ceiling, and floor, opening wider than 1 mm, some seepage	Cooling and shrinkage of mass concrete and restraint near foundation	Inject with cement or chemical grout
	Other cracks with noticeable leakage	Thermal gradients between reservoir and upstream galleries	Inject with cement or chemical grout to seal cracks

Continued . . .

I. DEFICIENCIES OF CONCRETE: CRACKING

Analyzing Cracking (Continued)

TABLE I-2. HAZARDOUS CRACKS AT DAMS (Continued)

CRACK LOCATION	TYPE/ CHARACTERISTICS	POSSIBLE CAUSES	POSSIBLE CORRECTIVE ACTIONS
CONCRETE DAM (Continued)			
Buttress dam: buttresses, slab	Vertical, extending up from foundation, noticeable even in summer, more than 10 feet long	Foundation settlement; temperature changes in mass concrete buttresses; earthquake	Grout with epoxy in cooler weather; strengthen and brace buttresses by post tensioning
SPILLWAYS AND CONDUITS			
Channel or stilling basin floor slabs and walls	Opening wider than 1 mm, deeper than 6 inches	Temperature changes; inadequate reinforcement	Clean, chip out loose concrete, inject epoxy into cracks, refinish surface Add reinforcing
Conduits: Inlet and outlet structures	Cracks causing leakage into dam Structural cracks in walls	Uneven settlement Foundation erosion	Seal cracks with epoxy, grout around conduit to improve foundation support Foundation treatment
Terminal sections	Structural cracks		

Continued . . .

I. DEFICIENCIES OF CONCRETE: CRACKING

Analyzing Cracking (Continued)

Use your training and experience to understand, as fully as possible, **why** cracking has occurred. Understanding the cause may identify effective corrective measures and suggest means to prevent additional cracking.

Any recommendations you may make for simple corrective actions should be reviewed by qualified, experienced engineers. Extensive corrective actions that may be taken in response to your findings include . . .

- For cracks that may be leaking but there is not a high hydrostatic head, treatment may consist of grouting the crack by injecting either an elastomeric filler (if crack movement is anticipated) or a rigid epoxy mortar.
- For cracks where leakage is accompanied by high hydrostatic pressure, installation of a drainage system may be necessary.
- If structural analysis shows a crack has affected the structure's stability, post-tensioning between components of the structure or between the structure and foundation rock might be in order.

Repair materials used include epoxy grout, methacrylates, polymerized concrete or mortar, fiber-reinforced concrete, and very low water-cement ratio concrete.

Reporting Hazardous Cracks

If you find new, severe, extensive cracking or sudden changes in cracks, you should take measurements, document changes, and take further action as recommended below.

- Note prominent cracks, cracking over large areas, and the trends for particular cracks. You may wish to decrease the interval between measurements or install appropriate instrumentation.
- If you observe extensive new cracking, consider initiating a crack survey to thoroughly document all cracks in the structure and their characteristics.
- **Contact an experienced and qualified engineer if you are at all unsure about the severity of cracking or if you observe . . .**
    - A major new crack
    - A crack whose characteristics have changed significantly since the last inspection
    - Cracks indicating movement that might be detrimental to the structure or to equipment operation (e.g., misalignment of gates that impedes gate operation and water release)
    - Significant leakage

Continued . . .

I. DEFICIENCIES OF CONCRETE: CRACKING

Reporting Hazardous Cracks (Continued)

- If you find that an excessive amount of water, or water which cannot be handled by the drainage system is flowing through a crack, recommend repairs. **Check with a concrete specialist to identify appropriate repair procedures.**

- Consistent with your training and experience, recommend minor or temporary corrective actions.

I. DEFICIENCIES OF CONCRETE: CONCRETE DETERIORATION

WHAT IS CONCRETE DETERIORATION?

Deterioration is any adverse change on the surface or in the body of concrete that causes the concrete to separate, break apart, or lose strength.

Hazards Of Concrete Deterioration

Deterioration can weaken the design strength of a concrete element, and cause the element to fail. A concrete dam may be susceptible to failure by sliding or overturning due to a reduction in concrete strength.

Concrete deterioration may cause leakage and associated pressures to increase. Deteriorating may also result in distortion of a structure, causing binding of mechanical features such as gates which must operate to ensure the safety of a dam.

Deterioration may be isolated to some concrete elements, or may be due to a serious flaw in all of the concrete used in a structure. When stresses such as hydrostatic pressure or earth load exceed the strength of a weakened element or structure, the dam or appurtenances may fail catastrophically.

Types Of Deterioration

Table I-3 (on the following pages) summarizes information about types of concrete deterioration.

Continued . . .

I. DEFICIENCIES OF CONCRETE: CONCRETE DETERIORATION

Types Of Deterioration (Continued)

TABLE I-3. TYPES OF CONCRETE DETERIORATION

TYPE	DESCRIPTION	RESULTS
Disintegration	Crumbling or deterioration into small particles	Possible failure of a concrete element; one of the most serious forms of concrete deterioration
Spalling	Loss of pieces of concrete (usually flakes or wedge-shaped pieces) from a surface, often at edges, caused by . . . . A blow or external pressure . Weathering . Internal pressure (e.g., corroded rebar near the surface) . Expansion within the concrete mass . Fires built on or against structures	Exposed reinforcing Leakage paths opened around embedded waterstops at joints Offsets on flow surfaces Development of points of structural weakness
Efflorescence	Leaching of calcium compounds from within the concrete and deposition on the surface due to water leaking through joints, cracks, or the concrete itself	Possible widening of openings due to removal of calcium, leading to increased leakage and faster deterioration. (In some cases, openings may be sealed against additional leakage by deposits. The deposits may even stop up drain holes and other leakage control features.)

Continued . . .

Types Of Deterioration (Continued)

TABLE I-3. TYPES OF CONCRETE DETERIORATION
(Continued)

TYPE	DESCRIPTION	RESULTS
Drummy Concrete	Concrete with a void, separation, or other weakness beneath the surface, detected by a hollow sound when struck with a hammer, bonker, or other steel tool	Diminished strength or concrete and susceptibility to further deterioration
Popouts	Small portion of the concrete surface that breaks away due to internal pressure (normally caused by expansion of a deleterious coarse aggregate particle due to wetting/freezing), leaving a shallow, conical depression	Susceptibility to further deterioration
Pitting	Development of relatively small cavities in the concrete surface caused by localized disintegration	Susceptibility to further deterioration
Scaling	Flaking or peeling away of a concrete or mortar surface	Suceptibility to further deterioration

Drying shrinkage, thermal stress, and freeze-thaw action, discussed previously as causes of cracking, also cause concrete deterioration. Table I-4 (on the following pages) summarizes information about additional causes of concrete deterioration.

Continued . . .

Types Of Deterioration (Continued)

TABLE I-4. CAUSES OF CONCRETE DETERIORATION

CAUSE	DEFINITION/FACTORS	RESULTS
Faulty Concrete Mixes	Factors: Improperly graded aggregates Improper cement or water content Lack of or improper percent of entrained air Inadequate mixing, placing, or curing procedures or equipment Improper use of additives	Lack of strength; susceptibility to deterioration
Chemical Attack . Sulfate attack	Definition: Reaction between sulfates (calcium aluminate compounds) in soil and ground water with concrete	Concrete, usually light in color, that falls apart easily when struck with a hammer
	Factors: Pre-1930 mix designs that did not consider sulfate attack Presence of sulfates in local soil or ground water . Natural sources . Manufacturing plant wastes or agricultural runoff contaminating river water	Other signs: . Cracking . Spalling . Scaling . Stains . Total disintegration

Continued . . .

Types Of Deterioration (Continued)

TABLE I-4. CAUSES OF CONCRETE DETERIORATION
(Continued)

CAUSE	DEFINITION/FACTORS	RESULTS
Chemical Attack (Continued) . Acid attack	Definition: Action on calcium hydroxide found in hydrated Portland cement, limestone, or dolomitic aggregates Factors: Sewage Coal mine drainage Cinder storage piles Atmospheric gases from nearby industry Industrial wastes	Leaching away of acid-soluble compounds: . Complete removal of concrete surface . Color change Corrosion and weakening of reinforcing resulting in overstressing of adjacent concrete, which may crack or spall

Continued . . .

Types Of Deterioration (Continued)

TABLE I-4. CAUSES OF CONCRETE DETERIORATION
(Continued)

CAUSE	DEFINITION/FACTORS	RESULTS
Chemical Attack (Continued)		
. Alkali-aggregate reaction	Definition:	
	Reaction between soluble alkalis in the cement and the aggregate	Abnormal expansion and cracking that may continue for many years
	Factor:	
	Use of marine sediments as aggregates, or shale from river gravels containing cherts	Early indicators: . Pattern cracking, usually in areas exposed to wet-dry cycles, such as . . . - Parapets - Piers - Top of a dam . Efflorescence . Incrustation . White rings around aggregate particles . Gel-like substance exuded at pores, cracks, or openings (alkali-silica reactions)

Continued . . .

Types Of Deterioration (Continued)

TABLE I-4. CAUSES OF CONCRETE DETERIORATION (Continued)

CAUSE	DEFINITION/FACTORS	RESULTS
Chemical Attack (Continued) . Alkali-aggregate reaction (Continued)		Signs of severe reaction: . Disbonding of blocks at lift lines . Binding of gates . Severe cracking . Loss of strength and ultimate failure of the structure
Metal Corrosion	<u>Definition</u>: Formation of iron oxide, or rust when water (especially salt water) reaches steel in the concrete Corrosion of the aluminum when water reaches aluminum embedded in or on the concrete	An increase in volume that causes cracking and spalling of overlying concrete (mostly affecting thin structures) Bond broken between steel and concrete, destroying structural strength

Continued . . .

Types Of Deterioration (Continued)

TABLE I-4. CAUSES OF CONCRETE DETERIORATION
(Continued)

CAUSE	DEFINITION/FACTORS	RESULTS
Metal Corrosion (Continued)	Factor:	
	Deicing salts on bridge decks and similar structures that can cause corrosion without initial deterioration of concrete	Signs: . Cracks in straight, uniform lines above reinforcing . Rust stains on the surface . Spalling . Exposed reinforcing . Deterioration of concrete adjacent to unprotected aluminum fish-ladders, hydraulic pumps, gates, and guardrails
Erosion	Factors:	
	Fast-moving water containing abrasive material such as sand and gravel, debris, and ice	Wearing away of softer aggregates, or of matrix material around aggregates Abrasion erosion, especially at points of abrupt change in flow channels or at corners
	Ballmilling: the grinding away of a surface, usually in a circular pattern, especially in stilling basins	Loss of concrete surface; sometimes severe destruction of concrete

Continued . . .

Types Of Deterioration (Continued)

TABLE I-4. CAUSES OF CONCRETE DETERIORATION
(Continued)

CAUSE	DEFINITION/FACTORS	RESULTS
Cavitation	Definition: Formation and subsequent collapse of vapor bubbles, producing shock waves, when water flowing at high velocity makes sudden directional changes that result in creation of areas of low pressure Factor: Offset or irregularity producing turbulence	Pitted or rough surface with aggregate plucked out "Leapfrog" pattern of damage Common sites: . Downstream of gates and valves . Steep spillway chutes, tunnels, or conduits Danger of rapid failure of a spillway or outlet works and potential subsequent failure of the dam during large flows

I. DEFICIENCIES OF CONCRETE: CONCRETE DETERIORATION

DETECTING HAZARDOUS CONCRETE DETERIORATION

You will see many examples of concrete deterioration during the course of your inspections. Some of the deterioration you observe may affect the safety of the dam immediately or in the near future.

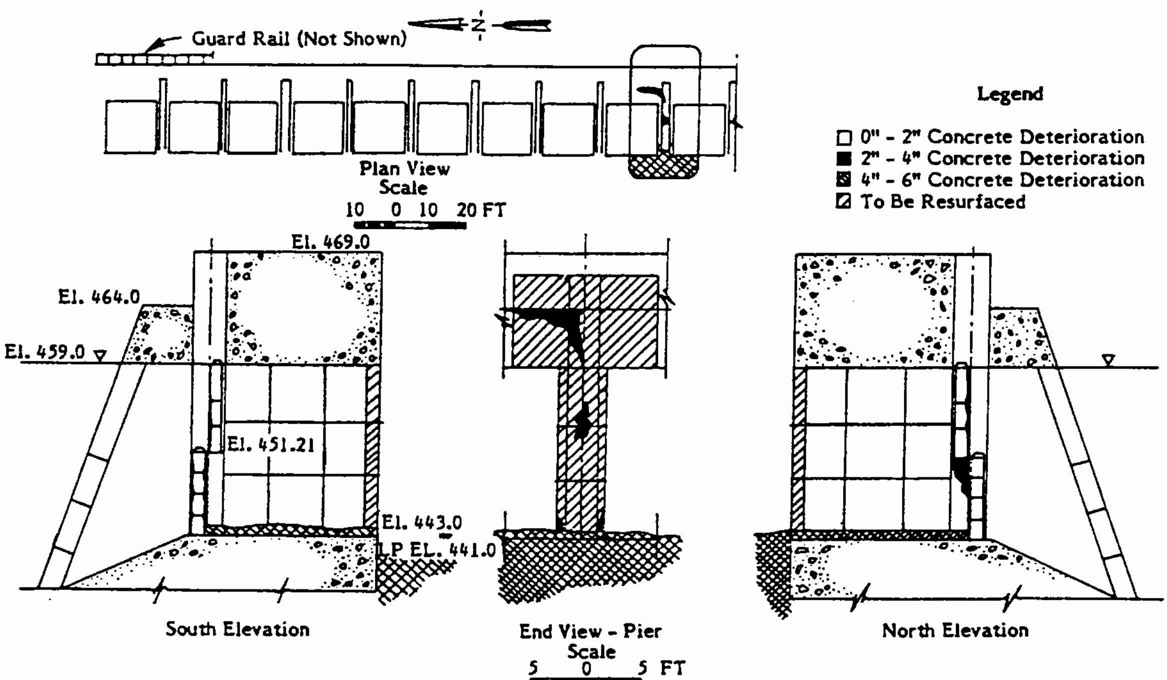
Using Condition Surveys

Condition surveys are detailed engineering studies of concrete conditions that include reviews of engineering data, field investigation, and laboratory testing. If a condition survey was performed on a dam that you are inspecting, the survey should give you a basis for assessing the concrete deficiencies you may encounter.

Using Surface Mapping

Surface mapping involves documenting concrete defects in a systematic manner. All types of deterioration, as discussed in this section of the module, should be included. Surface mapping can be accomplished using detailed drawings, photographs, or videotape. When photographs are used, a ruler or familiar object should be included to indicate scale. A grid is sometimes used to overlay a section of a drawing so the location of cracks and other defects can be shown easily. Figure I-4 shows an example of surface mapping of concrete deterioration.

FIGURE I-4. SURFACE MAPPING



Continued . . .

I. DEFICIENCIES OF CONCRETE: CONCRETE DETERIORATION

Analyzing Concrete Deterioration

Table I-5 will help you to identify hazardous concrete deterioration when you inspect concrete at dams, to look for possible causes of deterioration, and to recommend possible corrective actions.

TABLE I-5. HAZARDOUS CONCRETE DETERIORATION AT DAMS

DETERIORA-TION LOCATION	TYPE OF DETERIORATION	POSSIBLE CAUSES	POSSIBLE CORRECTIVE ACTIONS
CONCRETE DAMS			
Crest and faces	Random open cracks, crumbly concrete along cracks, silica gel	Alkali-aggregate reaction	Fill cracks with grout or other sealants, waterproof exposed surfaces
	Tilting or movement of piers or other portions of structure	Expansion of concrete	For extreme conditions: Lower reservoir level; restrict operation; extensively reconstruct or demolish the dam
Faces	Several spalls over 12 inches in diameter, reinforcing exposed in buttress dams	Freeze-thaw action; differential movement at joints; stress concentrations	Patch concrete; apply new concrete facing or shotcrete for extensive damage
Buttress dam: face slab or arched facing	Exposed, rusted reinforcing, cracked and swollen concrete, excessive pitting or spalling, noticeable leakage	Weathering; sulfate attack; alkali-aggregate reaction; rusted reinforcing	Remove damaged concrete, clean steel, add new reinforcing, patch with epoxy mortar or new concrete; partially reconstruct slab or block

Continued . . .

Analyzing Concrete Deterioration (Continued)

TABLE I-5. HAZARDOUS CONCRETE DETERIORATION AT DAMS
(Continued)

DETERIORATION LOCATION	TYPE OF DETERIORATION	POSSIBLE CAUSES	POSSIBLE CORRECTIVE ACTIONS
CONCRETE DAMS (Continued)			
Buttress dam: buttresses	Exposed, rusted reinforcing, cracked and swollen concrete, large spalls	Weathering; sulfate attack; alkali-aggregate reaction	Remove damaged concrete, clean steel, add new reinforcing, patch with epoxy mortar; partially reconstruct or strengthen and brace buttresses
OUTLET WORKS			
Conduit: inside surface of concrete lining	Pattern cracking, pitting, spalling	Chemical attack; erosion; cavitation; deformation due to high loads from earth embankments	Repair and reconstruct damaged lining, patch with concrete or epoxy mortar
SPILLWAYS			
Entrance channel floor and walls	Lining lost; scour undermining crest structure	Initial construction with poor concrete; high erosive forces; unbalanced hydraulic pressure against slope lining; vortexing	Repair and reconstruct damaged lining, patch with epoxy mortar; anchor slope lining; provide drainage; use anti-vortexing structures to induce laminar flow

Continued . . .

Analyzing Concrete Deterioration (Continued)

TABLE I-5. HAZARDOUS CONCRETE DETERIORATION AT DAMS
(Continued)

DETERIORATION LOCATION	TYPE OF DETERIORATION	POSSIBLE CAUSES	POSSIBLE CORRECTIVE ACTIONS
SPILLWAYS (Continued)			
Control section: Floor	Broken slabs, undermining with foundation exposed	Initial construction with poor concrete; high erosive forces; unbalanced hydraulic pressure against slab	Remove and replace damaged concrete, patch cracks and eroded areas with epoxy mortar; anchor lining; provide drainage
Control section: Pier and walls; overflow crest	Cracking and spalling, exposed reinforcing	Poor concrete; alkali-aggregate reaction; cavitation	Chip out or remove poor concrete, patch with epoxy mortar, add air vents
Control section: Pier nose or tail, contact with floor slab or overflow crest	Pitting, scour, exposed aggregate and reinforcing	Cavitation; attack by chemicals in water; ice erosion or erosion from debris	Clean or chip out concrete surface, patch with epoxy mortar and finish to design surface
Discharge channel	Rough patches, loss of concrete, exposed reinforcing	Cavitation due to irregularities or rough surface or erosion from carried debris	Chip out damaged concrete, patch with concrete or epoxy mortar, grind smooth to gradually varying surface

Continued . . .

Analyzing Concrete Deterioration (Continued)

TABLE I-5. HAZARDOUS CONCRETE DETERIORATION AT DAMS
(Continued)

DETERIORATION LOCATION	TYPE OF DETERIORATION	POSSIBLE CAUSES	POSSIBLE CORRECTIVE ACTIONS
SPILLWAYS (Continued)			
Flip bucket (non-submerged)	Visible scour holes (over 12 inches in diameter), blocks of broken concrete, exposed reinforcing	Heavy debris not swept out of bucket during operation	Remove damaged concrete and all structures located in bucket, rebuild bucket concrete to specified finish; prevent damaging objects from entering bucket
Stilling basin and submerged roller bucket	Scour holes more than 6 inches deep in floor; loss of floor slabs; exposed and damaged reinforcing; boulders in basin	Inadequate hydraulic jump formation; gravel and boulders rolling into basin or bucket	Adjust gate operation to improve jump; remove boulders rolling into basin or bucket; increase tailwater; raise floor or lip of basin or bucket. Replace concrete, or repair with silicon fume fibrous cement, steel lining, form liners, or high strength concrete with abrasion resistant aggregate
Chute blocks or baffle blocks	Damaged or displaced blocks, exposed reinforcing	Cavitation; large rocks or other hard debris in basin or bucket	Rebuild blocks; change block shape; adjust gate operation for better jump; prevent debris from entering basin; use higher quality aggregate and concrete in repairs

Continued . . .

I. DEFICIENCIES OF CONCRETE: CONCRETE DETERIORATION

Analyzing Concrete Deterioration (Continued)

Be sure to use your training and experience to understand as fully as possible **why** deterioration has occurred. Understanding the cause may reveal a solution, or measures that would prevent further damage.

For example, if you see a large spall adjacent to a joint, especially on a spillway slab, examine the joint. Loss of joint filler and replacement with sand or sediment can make joints too rigid to expand, causing spalling. Cleaning debris from joints and application of new joint filler might prevent further spalling.

If poor concrete is a possible cause for deterioration, examine construction records for information about the concrete. If differential movement at joints or stress concentrations could have been responsible for damage, review instrumentation data for evidence of these conditions, or recommend that additional instrumentation be installed to monitor the affected area.

Watch for failure of repairs. Corrective action for concrete deterioration often includes removal of the deteriorated concrete and replacement with superior concrete or another repair material. Shallow repairs with epoxy materials may fail with large drops in air temperatures. Patched areas tend to shrink and crumble.

Reporting Hazardous Concrete Deterioration

If you observe concrete deterioration that may affect the safety of the dam, you should . . .

- Measure and document damaged areas.
- Compare your observations with condition surveys (if available), surface maps, or other documentation of deterioration.
- Be alert to other types of deterioration in the concrete that may be related to an overall problem.
- Consistent with your training and experience, recommend minor or temporary corrective actions.

☞ **INSPECTION TIP:** Immediately notify an experienced, qualified engineer of any deterioration that is extensive, has changed significantly since the previous inspection, or appears to affect the integrity of the structure.

I. DEFICIENCIES OF CONCRETE: SURFACE DEFECTS

WHAT ARE SURFACE DEFECTS?

Surface defects, as defined here, are other concrete deficiencies that may not be progressive in nature; that is, they do not necessarily become more extensive with time. Such conditions may include . . .

- Shallow deficiencies in the surface of the concrete.
- Textural defects resulting from improper construction techniques.
- Localized damage to the concrete surface.

Types Of Surface Defects

Table I-6 provides basic information about surface defects.

TABLE I-6. SURFACE DEFECTS IN CONCRETE

TYPE	CAUSE	DESCRIPTION
Honeycomb	Poor construction practices: segregation due to improper placement or inadequate vibration	Voids in spaces between coarse aggregate particles
Stratification	Overly wet or overvibrated concrete, poor interlayer consolidation (vibration) or cold joints in placement	Separation into horizontal layers, with smaller material concentrated near the top. Possible results include nonuniform strength, weak areas, and disbonding of lifts.
Form Slippage	Form movement during placement and vibration	Slightly offset blocks, uneven joints and surfaces
Stains	Deposits from runoff water, corrosion of exterior steel, spilled construction materials, or curing water with staining qualities	Discoloration
Impact Damage	Blows from moving trucks, boats, cranes, or debris	Marred or spalled surfaces

I. DEFICIENCIES OF CONCRETE: SURFACE DEFECTS

Surface Defects: Inspection Actions

Unlike cracks, which may penetrate well into the concrete, surface defects usually are shallow and do not normally present an immediate threat to the structure. However, they may make the concrete susceptible to more significant deterioration.

If you observe surface defects in the concrete, you should . . .

- Record their nature and location.
- Note the need for prompt repair of defects that might lead to more extensive deterioration (e.g., by allowing water to enter the concrete mass).

I. DEFICIENCIES OF CONCRETE: UNIT EXERCISE

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

1. During an inspection of a concrete dam, you observe hairline cracking and considerable seepage into the galleries. The nature of cracking indicates that hydration heat and resultant stresses are the causes. In the space below, draw the cracking pattern typical of thermal cracking.

2. Put an "X" in the space next to each factor that would **NOT** directly contribute to or accompany freeze-thaw damage of a concrete structure.

_____ Use of pozzolan additives

_____ Lack of entrained air

_____ Efflorescence

_____ D-cracking

_____ Use of low-quality limestone aggregates

Continued . . .

I. DEFICIENCIES OF CONCRETE: UNIT EXERCISE

3. Tools to measure the width of cracks include:

____

____

4. A structural crack in concrete may be particularly hazardous because __________

____

5. Two types of chemical attack that may cause growth or expansion of concrete are:

____

____

6. List three signs of cavitation damage:

- ____
- ____
- ____

7. Write the letter of each dam or appurtenance location listed in the left-hand column next to the name of a concrete deficiency commonly found in that location. (Some deficiencies may be found in more than one location.)

a.	Concrete dam crest	_______	Scouring by sediment or rocks
b.	Buttress on buttress dam	_______	Cavitation damage
c.	Spillway channel floor	_______	Transverse cracks
d.	Stilling basin	_______	Broken slabs
e.	Baffle blocks	_______	Vertical cracks extending up from foundation

Continued . . .

I. DEFICIENCIES OF CONCRETE: UNIT EXERCISE

8. In the space after each concrete deficiency, write the name of at least one possible cause.

   Vertical cracks in a concrete dam gallery ______________________________

   ____

   A transverse crack on the crest of a concrete dam ______________________

   ____

   Cracks in a concrete conduit ____________________________________

   ____

   Spalls and exposed reinforcing in a concrete surface ___________________

   ____

   Lining lost on spillway entrance channel ___________________________

   ____

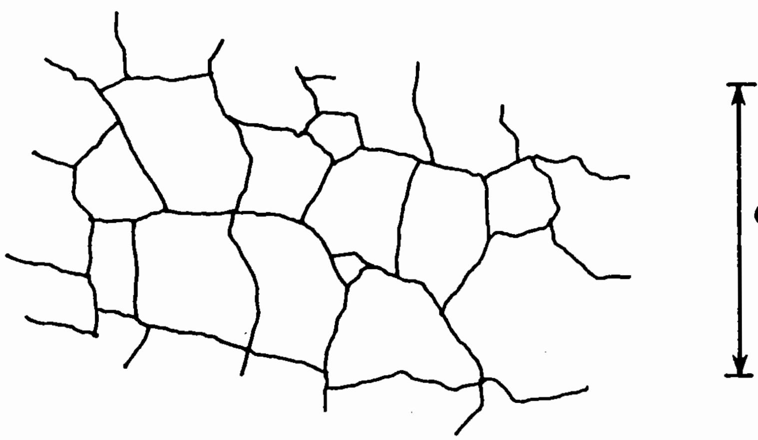
   Pattern cracking of concrete and efflorescence ______________________

   ____

I. DEFICIENCIES OF CONCRETE: UNIT EXERCISE--ANSWER KEY

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

1. During an inspection of a concrete dam, you observe hairline cracking and considerable seepage into the galleries. The nature of cracking indicates that hydration heat and resultant stresses are the causes. In the space below, draw the cracking pattern typical of thermal cracking.



Thermal Cracking

2. Put an "X" in the space next to each factor that would **NOT** directly contribute to or accompany freeze-thaw damage of a concrete structure.

__X__ Use of pozzolan additives

_____ Lack of entrained air

__X__ Efflorescence

_____ D-cracking

_____ Use of low-quality limestone aggregates

Continued . . .

I. DEFICIENCIES OF CONCRETE: UNIT EXERCISE—ANSWER KEY

3. Tools to measure the width of cracks include:

- **Comparator**
- **Hand-held, illuminated microscope**
- **Feeler gauge**

4. A structural crack in concrete may be particularly hazardous because **the structural integrity of the element may be affected, making failure of the element possible.**

5. Two types of chemical attack that may cause growth or expansion of concrete are:

- **Sulfate attack**
- **Alkali-aggregate reaction**

6. List three signs of cavitation damage:

- **Damage in an area subject to high velocity flows**
- **Rough, ragged holes with aggregate plucked out**
- **Damage shows "leapfrog" pattern**

7. Write the letter of each dam or appurtenance location listed in the left-hand column next to the name of a concrete deficiency commonly found in that location. (Some deficiencies may be found in more than one location.)

a.	Concrete dam crest	**c,d,e**	Scouring by sediment or rocks
b.	Buttress on buttress dam	**c,d,e**	Cavitation damage
c.	Spillway channel floor	**a,b,c,d,e**	Transverse cracks
d.	Stilling basin	**b,c,d**	Broken slabs
e.	Baffle blocks	**b**	Vertical cracks extending up from foundation

Continued . . .

I. DEFICIENCIES OF CONCRETE: UNIT EXERCISE—ANSWER KEY

8. In the space after each concrete deficiency, write the name of at least one possible cause.

   Vertical cracks in a concrete dam gallery: **Cooling of mass concrete and restraint of foundation**

   A transverse crack on the crest of a concrete dam: **Overloading of dam, earthquake, foundation settlement**

   Cracks in a concrete conduit: **Differential or excessive settlement**

   Spalls and exposed reinforcing in a concrete surface: **Freeze-thaw action, differential movement at joints, stress concentrations**

   Lining lost on spillway entrance channel: **Poor concrete, high erosive forces, unbalanced hydraulic pressure against slope lining**

   Pattern cracking of concrete and efflorescence: **Alkali-aggregate reaction**

I. DEFICIENCIES OF CONCRETE: SUMMARY

SUMMARY

The following table summarizes information presented on concrete deficiencies.

DEFICIENCY	TYPES	ESPECIALLY WATCH FOR . . .
Cracking	Structural cracks Pervasive cracking	Any new, severe, or extensive cracking Instrument measurements showing movement or excessive stresses Vertical and lateral offsets along cracks Seepage through cracks
Concrete Deterioration	Disintegration	Abnormal concrete expansion Light-colored concrete that falls apart easily when struck
	Spalling	Signs of corroded reinforcing steel Damage in areas of high velocity flow that may indicate cavitation as the cause Any new, severe, or extensive disintegration or spalling
	Efflorescence	Large affected areas
	Drummy concrete	Large affected areas
	Popouts	Large affected areas
	Pitting	Large affected areas
	Scaling	Large affected areas
Surface Defects	Honeycomb Stratification Form slippage Stains Impact damage	Defects that might lead to significant concrete deterioration in the near future

I. DEFICIENCIES OF CONCRETE: SUMMARY

REMEMBER TO "SMPL"

If deficiencies are observed, remember to . . .

- **S** **Sketch** what you have observed if a photograph would not capture important aspects of the deficiency.
- **M** **Measure** and record the dimensions of the deficiency in your notes.
- **P** **Photograph** the deficiency and describe its characteristics in your notes.
- **L** **Locate** the deficiency in relation to some standard reference point (e.g., a feature of the dam or permanent monument) and record the location in your notes.

UNIT II

DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: OVERVIEW

INTRODUCTION

Other cement mixture materials aside from conventional concrete often are used in dams and appurtenances. Each material has distinctly different uses, properties, and deficiencies associated with it.

UNIT OBJECTIVES

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

- Describe the types of problems with cement mixture materials other than concrete.
- Identify which deficiencies are hazardous to a dam.
- Document vital information about observed deficiencies, and consult an experienced, qualified engineer when warranted.

TYPES OF CEMENT MIXTURE MATERIALS

Materials other than conventional concrete which contain cement include:

- Mortar
- Grout
- Soil cement
- Roller compacted concrete (RCC)
- Shotcrete

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: MORTAR

MORTAR COMPOSITION AND USES

Mortar is composed of cement and sand mixed with water to a plastic consistency. Masonry dams are constructed mainly of stone, brick, rock, or concrete blocks joined with mortar. Therefore, you need to evaluate the condition of mortar if you inspect a masonry dam. Masonry dams are no longer built in the United States because of recent advances in concrete technology and their relatively high cost of construction. As a result, most of the masonry dams you encounter will be older and the mortar will have been subjected to many years of weathering and possibly leaching.

HAZARDS OF MORTAR DEFICIENCIES FOR MASONRY DAMS

Failure of the mortar binding a masonry dam together can lead to failure of the entire structure. The most common consequence of deficient mortar is creation of cracks and openings that allow reservoir water to leak through spaces between masonry blocks, causing disbonding between the blocks. Erosion and freeze-thaw action can damage and remove mortar at the faces of the dam. When the blocks are no longer joined, hydrostatic pressure from the reservoir water leaking through the dam can then lift blocks of the dam and carry them downstream, breaching the dam. Many masonry dams were designed to pass floods over the crest, and for others, newly revised design floods show the dams will be overtopped. If the masonry blocks of these dams are not held together by mortar, upper blocks may be washed away during overtopping and the dam could be breached.

TYPES OF MORTAR DEFICIENCIES

Mortar is subject to deterioration, inadequate compressive strength, and failure to bond.

Deterioration And Cracking

The principal cause of deterioration and cracking in mortar is from water saturating the masonry blocks and mortar and then freezing. Modern high-compressive-strength mortars and air-entrained mortar can withstand many freeze-thaw cycles, but most masonry dams were built with mortar that is susceptible to freeze-thaw damage.

Other causes of deterioration include wet-dry cycles, leaching, and erosion. Mortar is very susceptible to erosion from water, and in some cases to leaching, particularly old lime mortar.

Inadequate Compressive Strength

A mortar without sufficient compressive strength cannot support the weight of the masonry blocks, so that the structure can become destabilized as the mortar is compressed.

Failure To Bond

Quality control may not have been particularly good during construction of older masonry dams, so that mix composition, water content, temperatures, and other factors were not correct. The mortar may have failed to bond to the blocks, resulting in gaps and cracks between the mortar and the blocks. These openings allow water under pressure to enter and possibly lift the blocks.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: MORTAR

IDENTIFYING HAZARDOUS MORTAR DEFICIENCIES

Since you are unlikely to inspect a masonry dam that does not show some deficiencies in the mortar, you need to know which conditions are potentially hazardous.

Signs Of Hazardous Mortar Deficiencies

Look at the mortar joints on the upstream and downstream faces of the dam at and above the water level of the reservoir for signs of deterioration. This location is the most likely spot for freeze-thaw damage. Estimate the extent to which mortar is missing or deteriorated. Look for signs of movement of the masonry blocks or stones near the waterline.

Water may be leaking or even spurting from between blocks on the downstream face of the dam through gaps or cracks in the mortar. Refer to previous inspection reports to determine if the leaks are new, or if the volume of leaking water has increased.

General deterioration of the mortar can weaken bonds between blocks to the point that the masonry blocks shift positions and become unstable. Higher reservoir loading during flooding or even normal stresses then may cause failure. If a considerable portion of the mortar in the dam is missing or crumbling, the dam is in danger of failing, especially if it was constructed of irregularly shaped stones rather than shaped blocks.

Reporting Hazardous Mortar Deficiencies

If you observe mortar deficiencies that may affect the safety of the dam, you should . . .

- Document the location and extent of leaks and of seriously deteriorated mortar that may threaten the stability of the dam.
- Notify an experienced, qualified engineer if you suspect movement or shifting of blocks due to failed mortar.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: GROUT

GROUT COMPOSITION AND USES

Conventional cement grout is composed of neat cement or cement and sand mixed with water to the consistency of a viscous liquid which is poured or injected into joints, cracks, cavities, or other spaces to preclude or retard the movement of water through these spaces. Chemical grout is made with epoxy, polymerized mortar, or methacrylates instead of cement.

Grout is used at dams for . . .

- Consolidating rock masses
- Forming barriers to seepage in dam foundations called "grout curtains"
- Bonding layers of RCC
- Holding bolts, anchors, or other devices in rock and concrete
- Repairing cracks or deteriorated areas in concrete
- Filling the annular space around lined tunnels and conduits

HAZARDS OF GROUT DEFICIENCIES

Deficient grout may result in . . .

- Excessive seepage through rock, concrete, or RCC
- Excessive seepage underneath a dam, resulting in high uplift pressures or piping and subsequent inoperability of equipment such as spillway or outlet works gates
- Failure of rock or concrete fasteners or anchors, causing possible slides

TYPES OF GROUT DEFICIENCIES

Grout is subject to deterioration and cracking, shrinkage, and failure to bond.

Deterioration And Cracking

Freeze-thaw cycles cause near-surface grout deterioration and cracking. Seepage can progressively solution grout. Expansion and contraction or corrosion of embedded anchors can cause cracking and spalling.

Shrinkage

Grout made with epoxy shrinks with large drops in air temperature. Shallow repairs are particularly likely to shrink and crumble.

Failure To Bond

Mix composition, water content, or other factors may have been incorrect when grout was placed, resulting in a failure to bond to the concrete, rock, or other materials. Gaps in grout placement provide openings for deterioration and seepage.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: GROUT

IDENTIFYING HAZARDOUS GROUT DEFICIENCIES

You will inspect most grout in conjunction with inspection of other materials such as concrete, RCC, metal, or rock. The most serious deficiencies in grout are those that permit seepage which the grout was intended to limit or prevent, or which lead to instability because of failed anchoring systems.

Signs Of Hazardous Grout Deficiencies

Most grout injected into cracks and cavities cannot be visually inspected, except for small surface areas. The following conditions indicate deficient grout:

- Seepage through cracks in the grout or at grout boundaries
- Increasing seepage or uplift pressure in the foundation of a dam with a grout curtain
- Shrinkage and a crumbly, dusty appearance in exposed grout
- Cracking and deterioration
- Loose or corroded bolts, anchors, or other embedded items

Reporting Hazardous Grout Deficiencies

If you observe grout deficiencies that may affect the safety of the dam, you should . . .

- Document the location and rate of seepage through grouted areas. Notify an experienced, qualified engineer if instrumentation data or seepage rates indicate that a grout curtain may not be functioning as intended.
- Take samples of seepage water for laboratory analysis.
- Document the location of failed repairs and cracked, deteriorated grout.
- Note loose or corroded embedded items.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SOIL CEMENT

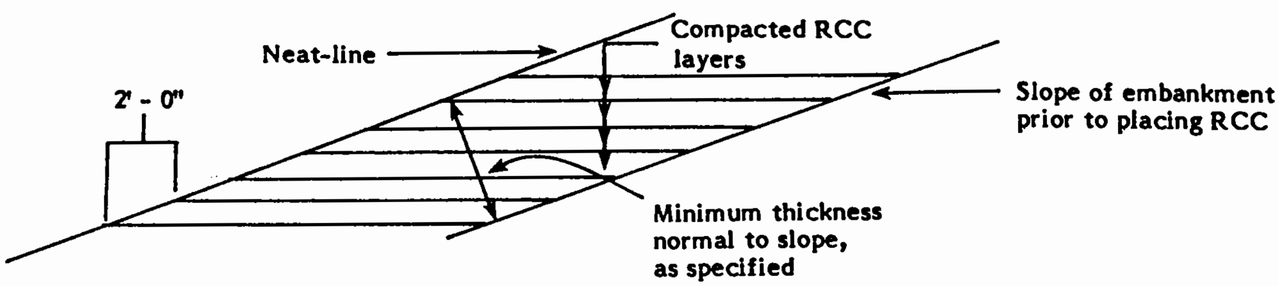
SOIL CEMENT COMPOSITION AND USES

Soil cement is a well-compacted, fairly dry mixture of Portland cement, soil, and water. In dam construction, it is primarily used as an alternative to riprap for slope protection.

Soil cement is usually placed in horizontal layers that are 8 to 10 feet wide and 6 to 12 inches in compacted thickness. Layers of the correct width are added (each layer compacted before the next is added) until the proper depth is achieved.

For slope protection, soil cement is laid in stairstep fashion up the face of an embankment or channel slope. Understanding this method of construction is one key to identifying soil cement deficiencies. Figure II-1 illustrates the placement of soil cement layers, or lifts.

FIGURE II-1. SOIL CEMENT SLOPE PROTECTION
(Elevation View)



II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SOIL CEMENT

HAZARDS OF SOIL CEMENT DEFICIENCIES

Failure of soil cement used as slope protection exposes embankment material or channel slopes to erosion from wave action, surface runoff, and high velocity flows. When the protection fails on the upstream slope of an embankment dam or on the sides of a spillway channel on or adjacent to the embankment, the dam may suffer erosion, breaching, and even eventual failure.

TYPES OF SOIL CEMENT DEFICIENCIES

Soil cement is subject to breaking and disbonding of lifts, cracking, and deterioration.

Breaking And Disbonding Of Lifts

The bond between lifts is the weakest point in soil cement slope protection. Since each lift is compacted separately, the lifts are essentially separate slabs stacked upon one another, each with an exposed offset edge of 1 to 3 feet. Wave action creates a lifting force, tending to separate the slabs.

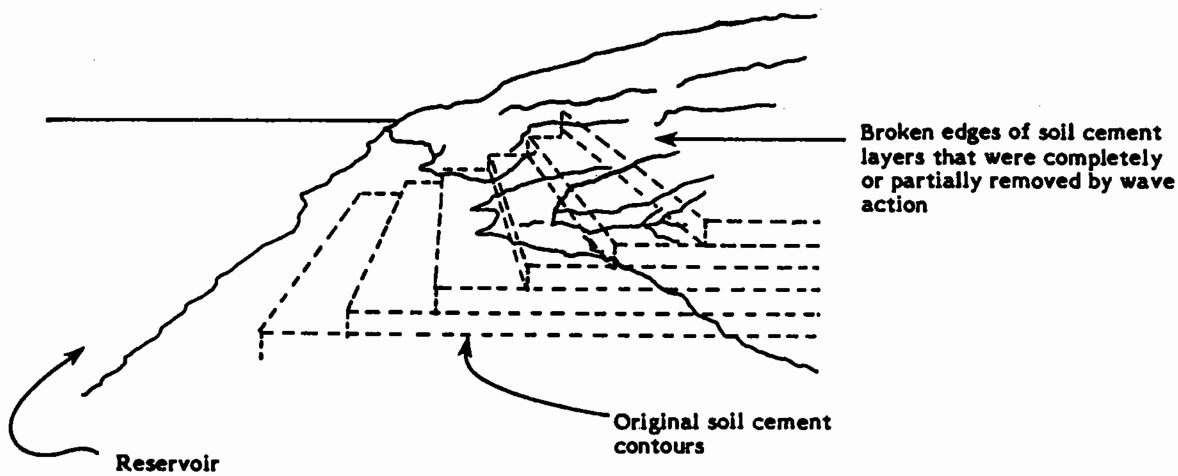
Freezing temperatures also may cause damage to the exposed facing. When ice forms between lifts that are not well bonded, soil cement may crack. Freezing water also can infiltrate and enlarge existing cracks within a lift. Wave action washes away the broken pieces.

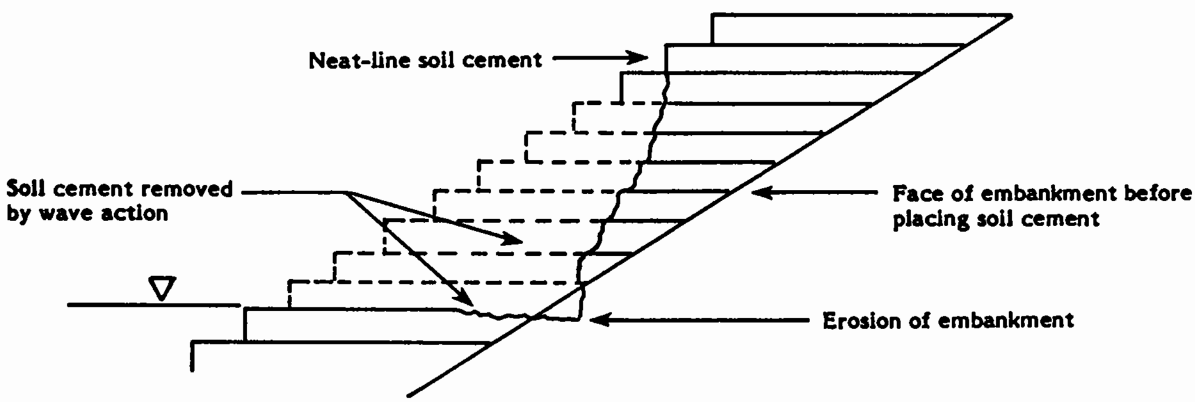
Figure II-2 illustrates a typical pattern of damage to soil cement used as slope protection.

Continued . . .

Breaking And Disbonding Of Lifts (Continued)

FIGURE II-2. DAMAGE TO SOIL CEMENT SLOPE PROTECTION





II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SOIL CEMENT

Cracking

Other than cracking by freeze-thaw action, soil cement may crack because of shrinkage, settlement, and backfill or foundation problems. All soil cement contains cracks, and not all cracks are serious. However, if water penetrates soil cement and saturates the underlying backfill or embankment, and there is insufficient drainage during reservoir drawdown, excessive pressure may result behind the soil cement. (Abruptly lowered reservoir water no longer balances the pressure in the embankment, if the embankment cannot drain quickly enough.) The imbalanced hydrostatic pressures can pop out, or force sections of the soil cement cover away from the embankment.

Deterioration

Deterioration of soil cement is any adverse change on the surface or in the body of soil cement that is caused by separation of soil cement components. Deterioration can be caused by improper mixes or mixing, poor placement, improper compaction, or inadequate curing.

Deteriorating soil cement may crumble or become pitted. Cracking and separation of lifts often may occur along with deterioration.

IDENTIFYING HAZARDOUS SOIL CEMENT DEFICIENCIES

Soil cement used as slope protection normally has a ragged appearance because of the inability to compact the outside edge of each layer. This irregularity does not affect performance of the soil cement. You will need to be able to recognize soil cement which is deficient and is affecting the safety of the dam or could in the foreseeable future.

Signs Of Soil Cement Deficiencies

Failure of soil cement used as slope protection can lead to problems for an embankment dam when the underlying embankment becomes exposed to erosion because the soil cement has failed.

Unless a filter was installed between fine-grained non-cohesive embankment soil and the soil cement cover, embankment particles may migrate through cracks and create voids behind the soil cement. Look for sinkholes, and sound the soil cement for hollow areas, especially if the design did not provide a filter.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SOIL CEMENT

Reporting Hazardous Soil Cement Deficiencies

If you observe soil cement deficiencies that may affect the safety of the dam, you should . . .

- Note the location and dimensions of cracked and missing soil cement and cracking, and the extent of widespread deterioration, including signs of insufficient drainage and erosion.
- Notify an experienced, qualified engineer if you observe extensive areas of failed soil cement that leave the underlying embankment susceptible to wave erosion.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: RCC

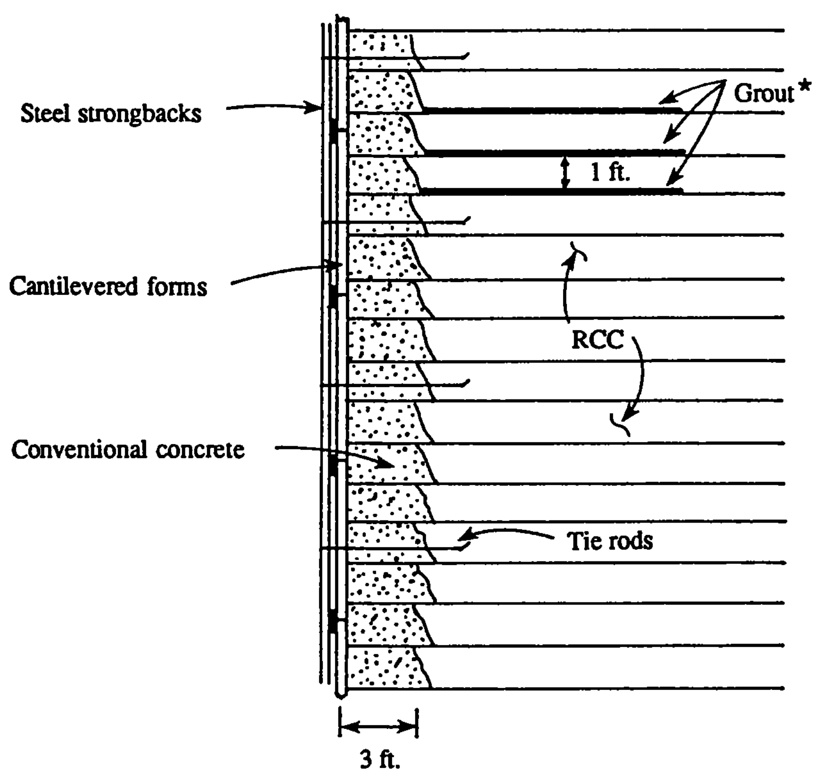
RCC COMPOSITION AND USES

RCC is a type of concrete construction using methods and equipment similar to earthfill construction in which a low water content concrete is laid in layers and compacted. Among the cement mixture materials discussed in this section, RCC most resembles conventional concrete.

Dams and spillways may be constructed of RCC. In dams, RCC often is used in combination with conventional concrete facings.

Figure II-3 illustrates construction of the upstream face of an RCC dam using a conventional concrete facing.

FIGURE II-3. RCC DAM: UPSTREAM FACE CONSTRUCTION (Section)



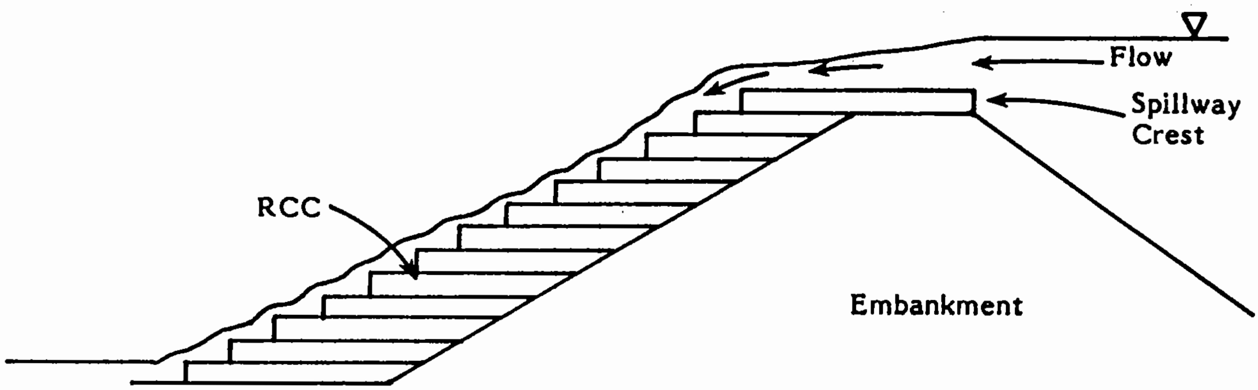
* Grout is usually placed between all layers, extending at least 12 feet from RCC/concrete interface to bond layers and resist tensile forces in the upstream potion of the dam.

Continued . . .

RCC COMPOSITION AND USES (Continued)

Figure II-4 shows an elevation view of a spillway on an embankment that is constructed of RCC.

FIGURE II-4. RCC SPILLWAY
(Elevation View)



HAZARDS OF RCC DEFICIENCIES

Since entire dams or major components of dams may be constructed of RCC, serious deficiencies can cause dam failures.

TYPES OF RCC DEFICIENCIES

RCC is subject to cracking, seepage, and deterioration.

Cracking

RCC cracks can be caused by:

- Abrupt changes in foundation geometry caused by material or alignment changes or by differential movement in foundation or abutments
- Volumetric changes
- Thermal contraction of material laid too slowly or laid during hot weather without measures to prevent buildup of excessive hydration heat
- Surface drying

Continued . . .

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: RCC

Cracking (Continued)

Serious cracking may weaken the structural integrity of an element, leading to failure. RCC used in dams and appurtenances that hold water should be as watertight as possible. Serious cracks in RCC create possible paths for seepage and deterioration of the bonds between RCC layers.

Seepage

Seepage in RCC can be caused by:

- Cracking
- Inadequate or malfunctioning drainage systems
- Inadequate upstream facing
- Improper mixtures or construction practices
  - Failure to bond between lifts
  - Inadequate mixes
  - Poor compaction
  - Segregation of RCC materials
  - Faulty tie-ins to foundations or abutments
- Ruptures in watertight membranes

Deterioration

Deterioration of RCC is any adverse change on the surface or in the body of RCC that is caused by separation of its components. In general, RCC deterioration has the same causes as deterioration of conventional concrete.

Chemical attack, including sulfate attack, acid attack, and alkali-aggregate reaction, may cause serious deterioration that threatens the integrity of an element constructed of RCC.

Erosion or freeze-thaw action may damage the surface of RCC and leave openings for cracking and further deterioration.

Improper construction procedures or mixture ingredients also can cause deterioration.

IDENTIFYING HAZARDOUS RCC DEFICIENCIES

When you inspect RCC, some of the cracking, seepage, or deterioration that you observe can be hazardous to the safety of a dam.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: RCC

Signs Of Hazardous RCC Deficiencies

If crack surveys, surface maps, or other descriptions of cracking and deterioration were performed prior to your inspection, compare your observations with past records. Look for cracking or deterioration that is new, severe, or extensive, or that shows sudden changes.

Sudden increases in the amount of seepage recorded at drainage exits or seepage from other points in the structure may indicate a serious problem. Look for evidence of seepage . . .

- Between lift layers
- At interfaces with conventional concrete
- Through or around watertight membranes
- Around misaligned waterstops
- Through construction or expansion joints

Reporting Hazardous RCC Deficiencies

If you observe RCC deficiencies that could affect the safety of the dam, you should . . .

- Document the extent and location of potentially hazardous cracks, deterioration, or seepage.

- Consult an experienced, qualified engineer if you observe seepage that has increased greatly since prior inspections, or if you find major transverse cracks that show a vertical or lateral offset.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SHOTCRETE

SHOTCRETE COMPOSITION AND USES

Shotcrete is mortar or concrete conveyed through a hose and pneumatically projected at high velocity onto a backup surface. Other names for shotcrete include pneumatically applied mortar (PAM), air-blown mortar, gunned concrete, sprayed mortar, and Gunite, a proprietary term.

Shotcrete is used for . . .

- Tunnel linings (both as a primary support and as a final lining)
- Repair of broken or deteriorated concrete in stilling basins and other locations
- Stabilizing and protecting rock slopes
- Overlay on concrete, masonry, or steel
- Embedding gate guides
- Construction of spillway crests
- Construction of structural shapes that are difficult to form
- Many types of repairs

HAZARDS OF SHOTCRETE DEFICIENCIES

Failure of shotcrete serving as the primary support for a tunnel can lead to collapse of the tunnel. In dams, tunnels may serve as spillways, and failure of a spillway puts a dam in danger of overtopping and possible failure by allowing the reservoir to rise above safe levels.

When shotcrete is used to protect, repair, or stabilize another material, failure of the shotcrete may lead to failure of the underlying material. A concrete structural element may fail, a rockslide may block a tunnel or channel spillway, or deterioration of the exposed material may endanger the dam. A rockfall in a tunnel or from an abutment slope can destabilize the abutment and endanger the dam.

TYPES OF SHOTCRETE DEFICIENCIES

Shotcrete suffers from the same general problems as conventional concrete, including cracking, deterioration, and surface defects. Particular problems with shotcrete include drying shrinkage cracks, voids, delamination (disbonding), and defective surfaces. Improper application is the primary cause of shotcrete deficiencies. Construction records may indicate whether crews applying shotcrete were sufficiently skilled, trained, and conscientious.

Drying Shrinkage Cracks

Because shotcrete has a large surface-volume ratio, lack of proper curing often allows rapid drying and subsequent shrinkage and cracking.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SHOTCRETE

Voids

Voids form in shotcrete when rebounded aggregate accumulates or air pockets are left unfilled behind obstacles to the jet.

Improper procedures, equipment, and materials contribute to produce a poor grade of shotcrete that may contain voids or other defects, such as uneven thickness or inadequate cover.

Delamination

Delamination is the separation of the shotcrete from the underlying surface, and often occurs with shrinkage cracking. Improper application is the primary cause with lack of proper surface preparation (failure to remove unsound material) also a common factor. Inadequate curing can also cause problems.

Defective Surfaces

If a layer of shotcrete lacks sufficient thickness or fails to provide a complete cover, the underlaying material may be exposed to deterioration.

IDENTIFYING HAZARDOUS SHOTCRETE DEFICIENCIES

Some of the shrinkage cracking, voids, delamination, and defective surfaces that you observe when inspecting shotcrete can be hazardous to the dam immediately or in the near future.

Signs of Hazardous Shotcrete Deficiencies

When shotcrete forms a structural element, such as a primary support for a tunnel, deficiencies become particularly hazardous.

Use a hammer, bonker, or similar impact tool to sound for voids in shotcrete. Check the following locations:

- Inside corners
- At wall bases
- Over reinforcement and embedded items
- On horizontal surfaces

Sounding also may reveal if extensive delamination has occurred.

You may observe failed shotcrete exposing damaged or deteriorated concrete, or leaving a steep rock slope susceptible to slides.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SHOTCRETE

Reporting Hazardous Shotcrete Deficiencies

If you observe shotcrete deficiencies that may affect the safety of the dam, you should . . .

- Record the extent and location of cracks, voids, deterioration, or surface defects in shotcrete used to repair, stabilize, or protect other materials.
- Consult an experienced, qualified engineer if you find extensive drying shrinkage cracking, delamination, or general deterioration of a shotcrete tunnel support or lining.

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: UNIT EXERCISE

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

1. You are inspecting a masonry dam. Water is spurting from several locations through gaps where mortar is missing. List below three items you should determine to assess the hazard to the dam from mortar deficiencies.

   - ____________________
   - ____________________
   - ____________________

2. The steps in the breaking and disbonding of soil cement lifts are listed below. Put the steps in order by writing the step number next to each item.

STEP #	DESCRIPTION
_____	Soil cement cracks and breaks
_____	Wave action creates a lifting force
_____	Soil cement slabs begin to separate
_____	Moisture penetrates openings between soil cement slabs
_____	Wave action washes away broken pieces
_____	Ice forms between soil cement lifts

3. List below three locations to check for seepage through RCC structures.

   - ____________________
   - ____________________
   - ____________________

4. Because of a large surface-volume ratio, shotcrete may dry too rapidly, causing

   ____

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: UNIT EXERCISE—ANSWER KEY

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

1. You are inspecting a masonry dam. Water is spurting from several locations through gaps where mortar is missing. List below three items you should determine to assess the hazard to the dam from mortar deficiencies.

   Any three of the following:

   - **Whether leaks are new**
   - **Whether volume of leaking water has increased**
   - **If masonry blocks have shifted or become destabilized**
   - **Whether a significant portion of mortar is in poor condition**

2. The steps in the breaking and disbonding of soil cement lifts are listed below. Put the steps in order by writing the step number next to each item.

STEP #	DESCRIPTION
5	Soil cement cracks and breaks
1	Wave action creates a lifting force
2	Soil cement slabs begin to separate
3	Moisture penetrates openings between soil cement slabs
6	Wave action washes away broken pieces
4	Ice forms between soil cement lifts

3. List below three locations to check for seepage through RCC structures.

   Any three of the following:

   - **Between lift layers**
   - **At interfaces with conventional concrete**
   - **Through or around watertight membranes**
   - **Around misaligned waterstops**
   - **Through construction or expansion joints**
   - **At abutment contacts**
   - **At drains**

4. Because of a large surface-volume ratio, shotcrete may dry too rapidly, causing **drying shrinkage cracks.**

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SUMMARY

SUMMARY

The following table summarizes the information presented in this unit about deficiencies of cement mixture materials other than conventional concrete. All of the materials listed suffer from most of the same general deficiencies as conventional concrete; the most common or hazardous deficienies are included below.

MATERIAL	IMPORTANT DEFICIENCIES	ESPECIALLY WATCH FOR . . .
Mortar and Grout	Deterioration and cracking	Mortar: Deterioration of joints on upstream and downstream faces at or above the reservoir water level New or greatly increased leakage Shifting masonry blocks A significant portion of mortar badly deteriorated
	Inadequate comprehensive strength	Grout: Loose bolts, anchors, or other embedded items Seepage through cracks or at boundaries Corrosion of embedded metal
	Failure to bond	Increasing seepage or hydrostatic pressure in the foundation of a dam with a grout curtain
	Shrinkage	Dusty, crumbly appearance of grout
Soil Cement	Breaking and disbonding at lifts	Embankment exposed to wave action
	Cracking	Deep, wide cracks with exposed embankment
	Deterioration	
RCC	Cracking	Cracks that serve as seepage paths
	Seepage	Seepage between lift layers
	Deterioration	

Continued . . .

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: SUMMARY

SUMMARY (Continued)

MATERIAL	IMPORTANT DEFICIENCIES	ESPECIALLY WATCH FOR . . .
Shotcrete	Drying shrinkage cracks	Potential failure of a primary tunnel support or tunnel lining
	Voids	Widespread voids or delamination
	Delamination	
	Defective surfaces	Exposure of underlying material whose failure would endanger the dam

II. DEFICIENCIES OF OTHER CEMENT MIXTURE MATERIALS: VIDEO SEGMENT #1

VIDEO PRESENTATION

At this point you should watch the first video presentation on deficiencies of concrete and other cement mixture materials. To watch the video presentation . . .

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

After watching video segment #1, return to the next unit on deficiencies of metal and coatings. **Do not rewind the videocassette.**

UNIT III

DEFICIENCIES OF METAL AND COATINGS

III. DEFICIENCIES OF METAL AND COATINGS: OVERVIEW

INTRODUCTION

A number of metal structures serve functions in dams and appurtenances. You probably will encounter metal gates and valves, conduits, cranes and hoists, and operating and access bridges during many of your inspections. Some of these structures must maintain their operability to ensure the safety of the dam. Metal structures often serve as part of the apparatus that controls reservoir levels and releases excess flows, and so are especially crucial to dam safety. The failure of other metal structures might form obstructions that would endanger the dam.

UNIT OBJECTIVES

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

- Recognize the types and hazards of metal corrosion.
- Distinguish hazardous metal corrosion from corrosion that is a maintenance problem.
- Apply the proper procedures for inspecting metal for pitting.
- Recognize the types and hazards of metal cracking and deformation.
- Document cracks and deformations, and notify an experienced, qualified engineer when warranted.
- Describe the types and hazards of metal coating deficiencies.
- Record coating deficiencies and their possible causes, and recommend possible corrective actions.

RELATION BETWEEN DEFICIENCIES IN METAL AND METAL COATINGS

Metal suffers more damage from corrosion than from any other deficiency. Most metal deficiencies are types of corrosion, are related to corrosion, or eventually will involve corrosion. Coatings prevent corrosion in metal. Failure of a coating, therefore, may result in failure of the metal structure due to corrosion.

III. DEFICIENCIES OF METAL AND COATINGS: CORROSION

WHAT IS CORROSION?

Corrosion is an electrochemical reaction and has been defined by the National Association of Corrosion Engineers as "the deterioration of a material, usually a metal, by reaction with its environment."

Destruction of metal parts obviously occurs by processes other than corrosion (e.g., abrasion); however, these processes are often accompanied by corrosion of varying intensity.

Corrosion may be widespread over the surface of a structure resulting in relatively uniform loss of metal, or it may be highly localized, resulting in pitting of the surface and possible penetration of the metal. Either form may be destructive, depending upon the requirements of the structure.

Hazards Of Corrosion

Some corrosion of the metal structures in a dam and its appurtenances is inevitable. This corrosion may pose only a maintenance or aesthetic problem to be controlled by minor replacement or repainting. However, corrosion, once allowed to start, may progress rapidly, becoming a serious, disabling problem if not controlled. Valves or gates may be rendered inoperable because of accumulations of corrosion products (rust) or destruction of critical parts. These, or other metallic structures, may be weakened to the point of failure if measures are not taken to reduce the corrosion rate or stop the corrosion entirely.

The Corrosion Cell

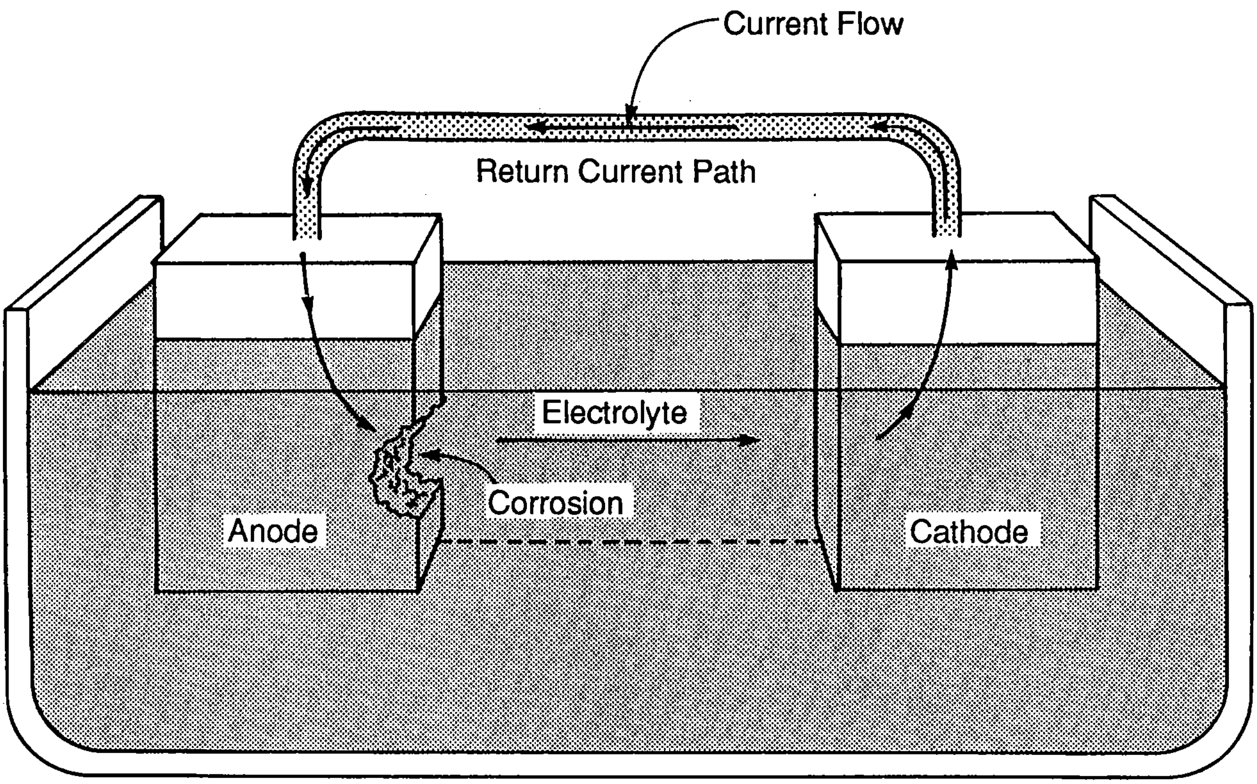
The corrosion cell (Figure III-1) contains four critical elements that are required for its operation. These elements are:

- An anode (the site where corrosion occurs),
- A cathode (where no corrosion occurs--indeed, the cathode is protected from corrosion, as we shall see later),
- An electrolyte (usually water which may be either free water, as in a reservoir, or moisture trapped in the soil), and
- An electrically conductive path between the anode and cathode (welds, bolted or screwed joints, etc.).

Continued . . .

The Corrosion Cell (Continued)

FIGURE III-1. FOUR ELEMENTS OF A GALVANIC CORROSION CELL: ANODE, CATHODE, ELECTROLYTE, AND RETURN CURRENT PATH

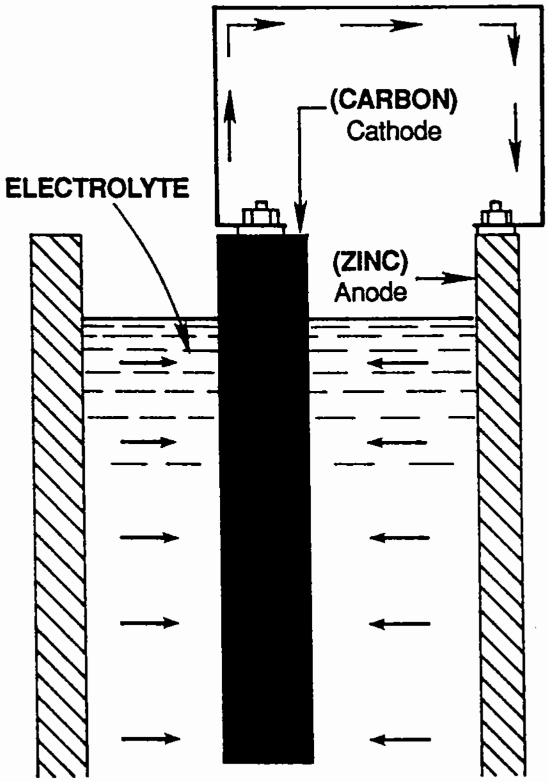


The corrosion cell can be compared to a dry cell battery in a flashlight (Figure III-2). In the battery, the anode is the zinc cup, the cathode is the carbon post, the electrolyte is the paste within the cup, and the electrical connection between the anode and cathode is through the switch and flashlight bulb. As direct current electrical power is produced to light the bulb, the current travels through the electrolyte from the zinc (anode) to the carbon post (cathode). When the current transfers from the zinc to the electrolyte, the zinc corrodes. This corrosion eventually ends the useful life of the battery. In identical fashion, direct electrical current, produced by the corrosion cell, will cause the metallic structure to fail by corrosion when it transfers from the anodic portion of the structure to the electrolyte (water). This process may end the useful life of the structure if not stopped or controlled.

Continued . . .

The Corrosion Cell (Continued)

FIGURE III-2. ELEMENTS OF A DRY CELL BATTERY



The most basic corrosion cell is the galvanic cell, which, as previously described, consists of differing materials as the anode and cathode. A galvanic cell often seen in structures results when brass fittings (e.g., valves) are used in steel pipes. This unfortunate mixture of materials is all too common. When submerged in water (the electrolyte), this mixture results in accelerated corrosion of the steel (the anode in this cell).

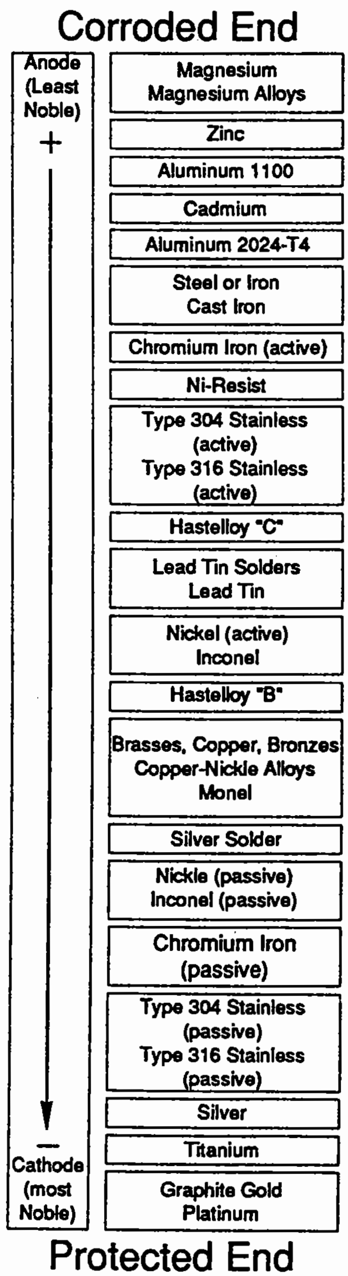
Corrosion due to galvanic action can be predicted from the **galvanic series** (shown in Figure III-3), a table of materials arranged according to their relative susceptibility to corrosion. If any two materials selected from this series are electrically coupled and placed within an electrolyte, the material nearest to the anodic end of the series will corrode.

The galvanic series gives no information as to the rate of corrosion, but only which material may be expected to suffer corrosion when coupled with another material from the series. Corrosion rates are controlled by other factors.

Continued . . .

The Corrosion Cell (Continued)

FIGURE III-3. GALVANIC SERIES



Continued . . .

The Corrosion Cell (Continued)

Corrosion cells may be formed for reasons other than coupling of different metals. One of these reasons arises from differences in the electrolyte. For example, a steel structure submerged in water where the concentration of oxygen is not consistent over the surface of the structure may suffer serious corrosion. A common cause of this "differential aeration" effect in submerged structures is the covering of portions of the surface by mud or other debris, thus denying areas of the surface free access to the dissolved oxygen in the water. Similar corrosion cells may be formed where the concentration of dissolved salts in the electrolyte are not uniform over the surface of the structure. A common example of this is a pipeline that passes through several different types of soils.

Corrosion cells are also created by other conditions including thermal effects and stress concentrations.

Corrosion cells may vary in size from those cells in which the anode and cathode are adjacent crystals in the surface of a metallic plate to those cells on pipelines where the anodic area of the pipe may be separated from the cathodic area of the pipe by several hundred feet.

Types Of Corrosion

While the basic corrosion theory is common to most corrosion cells, corrosion may manifest itself in a number of different ways. For discussion, it is convenient to use the "eight forms of corrosion" as described by Fontana and Greene in Corrosion Engineering (see Appendix B). These eight forms are listed in Table III-1.

TABLE III-1. EIGHT FORMS OF CORROSION

CORROSION FORM	CHARACTERISTICS
Uniform Attack	The most common form of corrosion. Proceeds uniformly over a large area. Results in uniform thinning of the surface and eventual failure if not controlled.
Galvanic Or Bimetal Attack	Formed when different metals from the galvanic series are coupled. Corrosion is predictable according to the galvanic series.
Crevice Corrosion	Often intense and localized. May occur under gaskets, within lap joints, under surface deposits, mud, or other detritus.

Continued . . .

Types Of Corrosion (Continued)

TABLE III-1. EIGHT FORMS OF CORROSION
(Continued)

CORROSION FORM	CHARACTERISTICS
Pitting Corrosion	Intense, highly localized corrosion resulting in holes of relatively small diameter and large depth. May result in penetrations and leaks.
Intergranular Corrosion	Most often noted in or near improperly executed welds in stainless steels. May appear as "knife line" corrosion (as if the metal has been slit) or as thinning of the material in the heat-affected zone adjacent to the weld.
Selective Leaching	The removal of one material from a solid alloy by corrosion. In cast iron, the removal of iron from the alloy, leaving only the carbon matrix (graphitization). In brasses, the removal of aluminum or zinc from the alloy (dealumification or dezincification). In either case, the remaining material has little strength.
Erosion Corrosion And Cavitation	Deterioration of metals because of high velocity impingement on the surface. Results in directional pits and grooves.
Stress Corrosion	Often results in cracking of highly stressed materials (bolts, for example) in corrosive or mildly corrosive environments. Failure can be unanticipated and catastrophic.

PROTECTION OF METALS FROM CORROSION

Common methods of protecting metals from corrosion include protective coatings (paint) and cathodic protection. A third method is used in the design process by incorporating, in the construction, materials that are immune from corrosion in the particular environment expected. Unfortunately, except for occasional replacement of parts, this method is unavailable to the operator of an existing structure.

Cathodic Protection

If we reexamine the basic corrosion cell, we note that corrosion occurs at the anode where the electric current produced by the corrosion process discharges to the electrolyte from the structure, while no corrosion occurs at the cathode, where this current collects on the structure. If these anodic currents can be reversed, that is, if the structure can be forced to collect cathodic current at all points, then the corrosion will be stopped. This principle is the basis for cathodic protection.

Cathodic protection of structures can be accomplished in several ways, the most common of which are by using sacrificial anodes and by using impressed current.

Cathodic Protection Using Sacrificial Anodes

This process of cathodic protection involves attaching a sacrificial anode to the structure. These anodes are often either magnesium or zinc. These materials are both very near the anodic (corroding) end of the galvanic series. In operation, these materials freely corrode, becoming the anode in a newly formed corrosion cell that includes the entire structure as a cathode, thus providing cathodic protection to the structure.

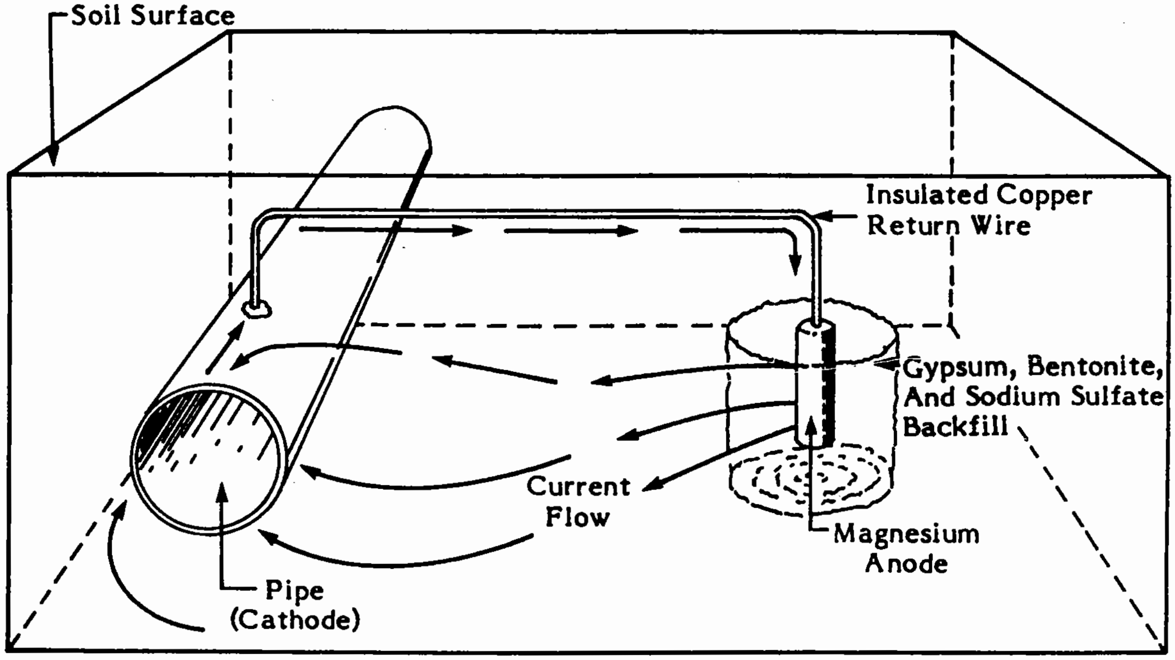
While these anodes are self-regulating and require only periodic examination to ensure that they are still functioning (corroding) and have not completely disintegrated, they have the disadvantage of requiring large numbers of anodes to protect a significant area of the structure. They also have the disadvantage of providing limited protection in more pure waters (e.g., snowmelt waters in higher elevations).

Figure III-4 shows how sacrificial cathodic protection works in an underground situation on a pipeline. Figure III-5 shows typical single and multiple sacrificial anode systems for pipelines. A similar system, where the anodes are attached directly to the structure (without the backfill material), may be used for submerged metalwork.

Continued . . .

Cathodic Protection Using Sacrificial Anodes (Continued)

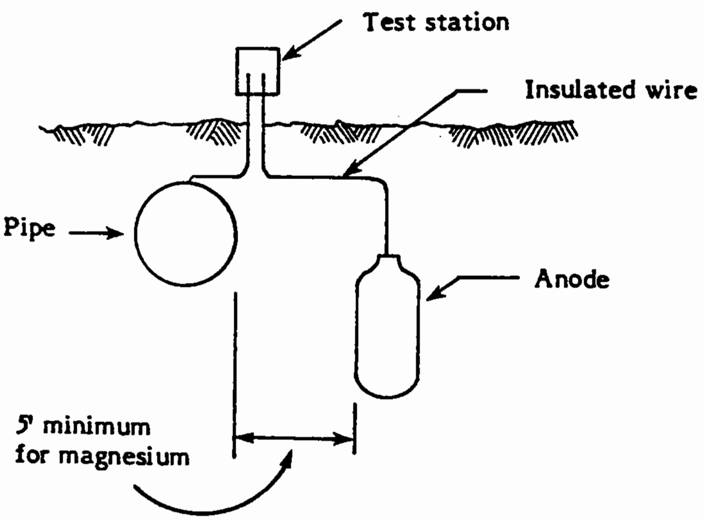
FIGURE III-4. CATHODIC PROTECTION

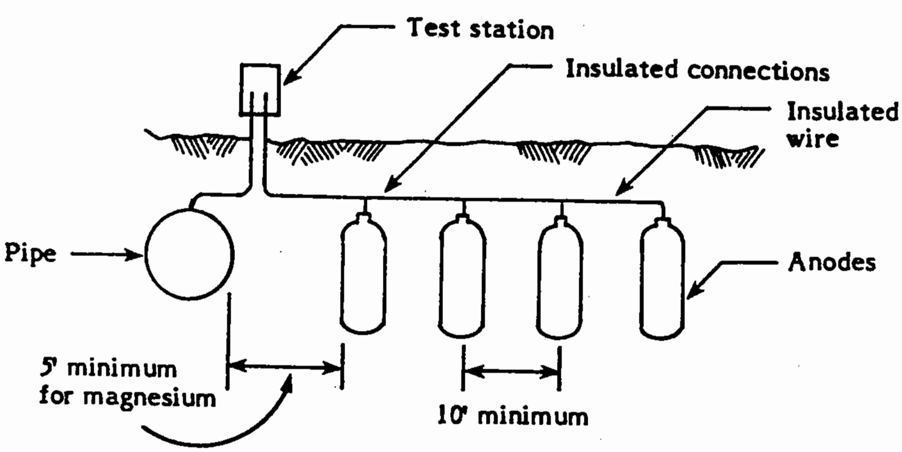


Continued . . .

Cathodic Protection Using Sacrificial Anodes (Continued)

FIGURE III-5. TYPICAL ANODE INSTALLATIONS





Cathodic Protection Using Impressed Current

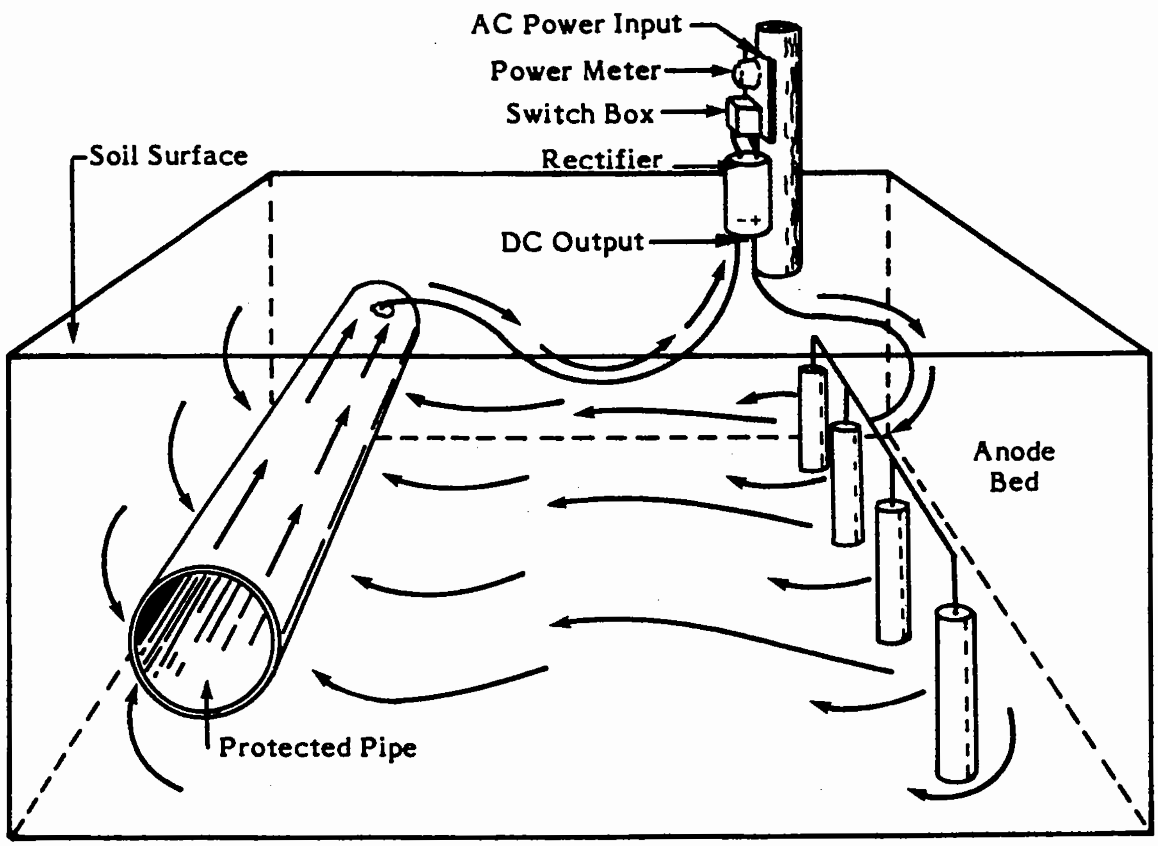
This process involves using inert anodes (anodes fabricated from materials that will not corrode) and providing electric current from some direct current source. The anodes used may be carbon, high silicon steel, or occasionally platinum-coated wire, depending upon the type of environment to which they will be exposed. The power source is usually a rectifier (a device that changes Alternating Current to Direct Current electricity), although solar cells, wind generators, and other DC power sources have been used.

In operation, these systems provide cathodic current to all portions of the structure, eliminating the anodic current discharge which resulted in corrosion.

These systems can protect large structures because the cathodic current available is limited only by the available power. Cathodic protection systems that utilize impressed current must, however, be very carefully designed and require frequent monitoring and adjustment.

Figure III-6 shows one scheme for an impressed current cathodic protection system for pipelines. A similar system in which the anodes are submerged directly in the water with the structure to be protected may be used for submerged metalwork.

FIGURE III-6. IMPRESSED CURRENT FOR CATHODIC PROTECTION



III. DEFICIENCIES OF METAL AND COATINGS: CORROSION

Design And Operation Of Cathodic Protection Systems

Careful design of cathodic protection systems is necessary, especially with impressed current systems, because stray DC electrical currents in the soil (or water in the case of submerged systems) which emanate from the cathodic protection system may cause corrosion on adjacent, unprotected structures.

Cathodic protection systems may fail from several causes, including:

- Interrupted circuits or circuit breakers
- Power failures
- Failed lightning arresters
- Failed rectifiers
- Expended anodes

Adequacy of cathodic protection may be determined (among other ways) by measuring structure-to-electrolyte potentials and by conducting visual inspections (where possible).

Troubleshooting of cathodic protection systems and determination of the adequacy of cathodic protection should be referred to knowledgeable personnel, since improper adjustment of these systems can result in severe corrosion damage to adjacent structures.

IDENTIFYING HAZARDOUS METAL CORROSION

Most of the metal corrosion that you are likely to observe during an inspection will probably only be a maintenance concern. You must learn to recognize when corrosion threatens the safety of the dam.

Metal Structures: Relative Hazards From Corrosion

Some structures are especially crucial to dam safety. Corrosion becomes hazardous when it renders critical metal structures inoperable. Inoperable gates, valves, or cranes and hoists endanger a dam when the ability to release flood flows is hindered and the dam is in jeopardy of being overtopped. Even corrosion that is not particularly severe or extensive may interfere with operation or bind moving mechanical parts.

Metal conduits through embankment dams need to be examined with special care for signs of corrosion, since perforations could allow water into the surrounding embankment, eroding it from within.

Metal girders used as supports for an operating or access bridge might buckle if weakened by extensive corrosion and preclude access to gate or valve controls. Inability to operate spillway gates during a flood could cause the dam to overtop.

III. DEFICIENCIES OF METAL AND COATINGS: CORROSION

Likely Sites For Corrosion

The following conditions foster corrosion:

- Missing or damaged protective coatings

- Areas where metal has been rolled to shape rather than cast, or has been bent or distorted, including:

  - Angle supports
  - Rolled plates
  - Distortions from riveting
  - Welded areas
  - Parts misaligned during assembly

- Contacts between dissimilar metals causing galvanic corrosion, including:

  - Gate arms, connections, and chains of incompatible metals
  - Steel screws in brass
  - Lead solder around copper wire
  - Steel shaft rotating in bronze bearings
  - Broken rust or mill scale (iron oxide) allowing galvanic reaction with exposed steel
  - Dissimilar metals embedded in concrete, such as aluminum conduit and steel reinforcing (aluminum should not be embedded in concrete)

- Sites where moisture and a limited oxygen supply on the metal surface create conditions for galvanic corrosion, including:

  - Under accumulations of dirt or other surface contaminations

  - In crevices (crevice corrosion) such as joints and cracks, rivet holes, gaskets, and valve seats

  - Under coatings (underfilm corrosion destroys coating integrity, allowing corrosion to accelerate)

- Areas of high velocity flows, such as in pressurized sections of conduit, downstream from gates and valves, on needle and tube valves, on outlet pipes in the vicinity of gates, and in locations of sudden changes of direction or flow cross-section

- Locations where metal is cracked due to tensile or dynamic stress, such as in gates, gate seal bars, gate and bridge supports, metal flashboards and stoplogs, valves, valve stems, gate and valve operators, and moving parts on cranes and hoists such as rods and connecting pins

Continued . . .

Likely Sites For Corrosion (Continued)

- Buried conduits, including joints where new sections of conduit were inserted adjacent to older sections

Reporting Hazardous Metal Corrosion

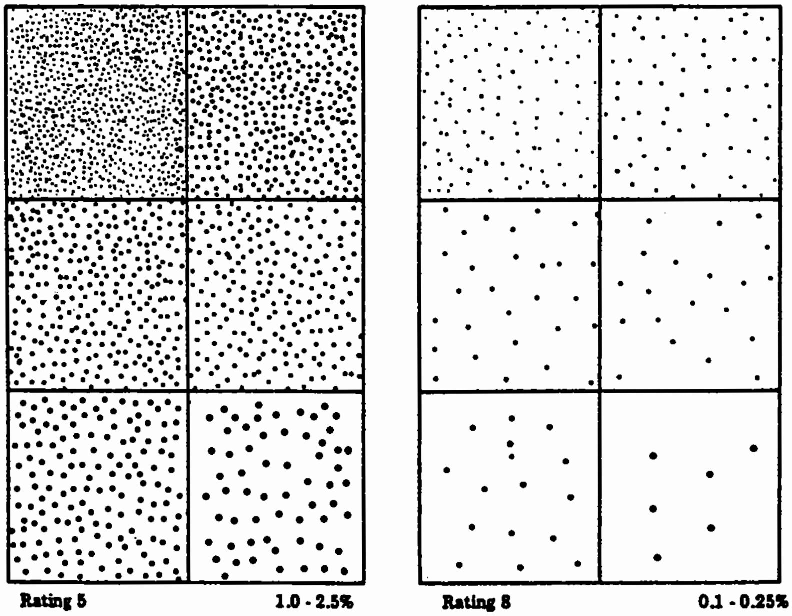
Most instances of routine corrosion that you encounter during inspections will be maintenance problems rather than safety issues, and usually will result in recommendations to repair or replace protective coatings. If you observe hazardous metal corrosion, you should . . .

- Consult a corrosion specialist if:
  - Hazardous metal corrosion may endanger the dam either because the corrosion site is sensitive to relatively small degrees of corrosion (as in a mechanical device such as a gate) or because the corrosion is severe and extensive enough to cause a metal structure to fail.
  - You suspect that metal might have been lost to corrosion on an inaccessible surface, such as the outside of buried metal conduit. Ultrasonic thickness measuring equipment operated from the opposite side can estimate metal thickness, but the extent of pitting corrosion is difficult to determine because damage tends to be highly localized. The conduit may need to be excavated for thorough examination.
- Evaluate pitting, a common form of corrosion, by counting the number of pits (if sites are few) or by using a system of rating charts. Figure III-7 shows an example of rating charts used to note the extent of pitting. Two sample ratings are shown, each with six variations in pit size and number of pits in a standard area. In the system illustrated, a rating of 5 indicates that corrosion is ten times as severe as a rating of 8.

Continued . . .

Reporting Hazardous Metal Corrosion (Continued)

FIGURE III-7. RATING CHARTS FOR EVALUATING PITTING



Pitting can perforate a metal conduit and allow water to erode an embankment dam from within. Pay careful attention to areas where coating is missing or defective. A very small opening in a coating can result in severe, concentrated corrosion at that spot.

Test the operation of gates and valves if operation is included in inspections. Test operation is the best way to determine if corrosion is hindering operation. If those gates and valves are not tested, report extensive, severe corrosion at the junction of gates and gate guides, or deposits on needle and tube valves that might interfere with operation.

III. DEFICIENCIES OF METAL AND COATINGS: CRACKING AND DEFORMATION

WHAT IS METAL CRACKING AND DEFORMATION?

Cracking in metal is a separation into two or more parts, while deformation is the bending or twisting of a metal object into other than its design shape.

Hazards Of Metal Cracking And Deformation

Metal cracking and deformation tend to afflict mechanical devices, such as cranes and hoists, or structures subjected to static and dynamic stress, such as gates and valves.

Deep or extensive cracking indicates that failure due to tearing and rupture may be imminent, while deformations may interfere with mechanical operations. During flooding or other emergencies, inoperable equipment could endanger a dam by being unable to release flood flows.

Types Of Metal Cracking And Deformation

The types of metal cracking and deformation include:

Cracking And Stress Corrosion Cracking

Cracking and corrosion in metals may be closely related; stress corrosion cracking and corrosion fatigue involve both corrosion and mechanical forces. Stress corrosion cracking results from a combination of tensile stress and a mildly corrosive environment.

Fatigue And Corrosion Fatigue

Fatigue is loss of metal strength from repetitive bending, known as corrosion fatigue when combined with corrosion. The affected area weakens, cracks, and then tears or ruptures. Sharp notches and reentrant corners without fillets are often points (called "stress risers") where a crack starts.

Overload Failure

An overload failure results from a single stressing beyond the tensile, shear, or compression strength of a metal part. An example is a conduit or liner buckling due to an internal vacuum or external pressure.

IDENTIFYING HAZARDOUS METAL CRACKING AND DEFORMATION

During your inspections, you probably will observe far more corrosion than cracking and deformation of metals. Cracking and deformation usually affect the integrity of a metal part, and therefore are liable to be hazardous to the safety of a dam.

III. DEFICIENCIES OF METAL AND COATINGS: CRACKING AND DEFORMATION

Likely Sites For Metal Cracking And Deformation

Check gates and conduits for signs of metal cracking and deformation.

Gates

Look for cracked or broken . . .

- Gate connections
- Gate side guides
- Lifting lugs or attachments
- Lifting chain or wire rope
  - Kinks in wire rope (kinked rope should be replaced)
  - Failure at bends in wire rope
  - Defective plastic coating on wire rope
  - Failure at connections
- Roller train components (tractor gates)
- Vanes supporting hollow-cone valves

Look for distorted . . .

- Gates
- Lifting beams

Uneven hoist pull is a possible cause for gate frame and lifting beam distortion, broken gate connections, and broken lifting chain or wire rope.

Conduits

Examine welded joints or fittings for signs of cracking and deformation.

Measure conduit height and width to detect "egg-shaped" or oval conduit flattened by heavy loads. Look for cracks in the conduit, the lining, and the coating caused by stress concentrations.

Reporting Hazardous Metal Cracking And Deformation

If you observe metal cracking or deformation that may affect the safety of the dam, you should . . .

✓ Note the extent, locations, and possible causes of cracks and deformations.

✓ Compare your observations with prior inspection reports.

✓ Notify an experienced, qualified engineer so that further evaluation can be made.

III. DEFICIENCIES OF METAL AND COATINGS: COATING DEFICIENCIES

WHAT ARE METAL COATINGS?

Metal coatings are coating systems that have been specifically formulated to adhere to metal and protect it from corrosion. This does not necessarily mean that these coating systems, as is, or with an appropriate primer (i.e., first or "priming" coat), cannot be used on other surfaces, such as concrete, as well. Metal coating systems for hydraulic structures are divided into two general categories: those suitable for service in water immersion or buried in the ground, and those suitable for atmospheric exposure only. However, some high performance coating systems are suitable for both categories of exposure.

HOW DO METAL COATING SYSTEMS CONTROL CORROSION?

Coating systems control corrosion in one or more of the following ways:

1. Creating a barrier between the metal and corrosive agents in the environment. It is important to realize that there is no such thing as a completely and indefinitely impervious coating system.

2. Gradually releasing corrosion-inhibiting chemicals.

3. Sacrificial action in which the sole or major component of the coating, such as zinc, sacrifices itself to protect the metal underneath. The coating in effect provides a kind of cathodic protection.

HAZARDS OF METAL COATING DEFICIENCIES

Defective or missing protective coatings expose metal parts and structures to corrosion and, therefore, to ultimate failure. Failure of metal structures such as gates, bridges, and conduits can result in dam failures.

Principal Causes Of Coating Deficiencies

All coatings systems, not just those applied on metal, fail prematurely for one or more of the following reasons:

- Poor surface preparation (very frequent cause)

- Poor application procedures (frequent cause)

- Improper specification of a coating system for the underlying metal or exposure conditions it will be facing in the field (infrequent cause)

- Defective or off-standard coating system materials as a result of mistakes or contamination during their manufacture (infrequent cause)

III. DEFICIENCIES OF METAL AND COATINGS: COATING DEFICIENCIES

Avoiding Premature Failure

Premature failures may be avoided by:

- Good organization of the coating project, including preparing or adopting good specifications. The degree of surface preparation must be specified and an appropriate type of coating system must be chosen. All specifications must require adherence to environmental and safety regulations and must take into account the protection of surrounding areas from overspray, etc. A pre-job conference with the contractor and/or coating crew is very helpful in eliminating misunderstandings and resolving inspection and other uncertainties before they become problems.

- Inspection during the entire coating process. Studies have shown that inspection usually extends the life of a coating system approximately 50 percent. Inspection by a specially trained inspector, such as a National Association of Corrosion Engineers (NACE) certified inspector, can usually extend the life of a coating system by approximately 75 percent.

- Good surface preparation and application. These are the keys to a successful coating project and the only way to get the full benefits of a high quality coating system.

- The use of high quality coating system materials purchased from reliable manufacturers. Although at least rudimentary inspection and documentation of the coating system materials to be used in the field is required, the integrity and quality-consciousness of the manufacturer is still one of the better assurances of receiving quality materials. Coating system materials account for only a fraction of the total cost of any but the very smallest coating projects. Consequently, skimping on the quality of the coatings purchased is false economy.

DIFFERENCES BETWEEN NEW-SURFACE COATING PROCEDURES AND RECOATING PROCEDURES

Coating new surfaces is less difficult than recoating previously coated existing ones. A new surface is relatively clean, whereas a previously coated surface has collected contaminants during long exposure. These contaminants (oil, grease, dirt, salts, etc.) must be removed before media blasting or recoating begins. If there is an intact coating that is to be touched up and recoated, the intact and the freshly applied coatings must be compatible with one another. Adequate recordkeeping is an important part of a coating system maintenance program and can reduce the chances of applying an incompatible coating over an existing one.

TYPES OF METAL COATING SYSTEMS

Metal coating systems for dams and associated structures (penstocks, powerplants, administrative and maintenance structures, etc.) can be divided into roughly four subcategories:

1. Coating systems that will be fully immersed in water or covered with backfill (buried)

2. Coating systems that will be both immersed in water and subjected to atmospheric exposure

3. Coating systems that will receive exterior atmospheric exposure only

4. Coating systems that will receive interior atmospheric exposure only

Some coating systems overlap one or more of the above subcategories. Although it is possible that exposure to severe chemicals, saltwater, severe chemical fumes, or salt spray could be encountered, and a coating system that would resist these types of exposure would be required, it is not likely that such exposure conditions would be experienced with freshwater dams and dam-related structures.

III. DEFICIENCIES OF METAL AND COATINGS: COATING DEFICIENCIES

COATING DEFICIENCIES FOUND IN ALL TYPES OF METAL COATING SYSTEMS

The following deficiencies can be experienced with all types of metal coating systems:

	Deficiency	Cause	Remedy
(1)	Sagging	Application of too much coating material too quickly	During application, brush out excess coating and adjust to eliminate improper application techniques. After application, use proper tools to remove sags and apply another coat.
(2)	Orange Peel	Improper thinning and application techniques	Same as (1)
(3)	Blistering	Metal or coated surface contaminated by oil, moisture, or salt; solvent entrapment	Remove blistered coating, thoroughly clean surface, and recoat.
(4)	Pinholing	Improper application conditions or techniques; solvent "popping" through partially dried or cured coating	Detect on dry coating as soon as possible before (5) occurs.
(5)	Pinpoint Rusting	A result of (4), or, when priming, a steel surface profile that is too high for the thickness of the coating	Remove rust and existing coating material in rusted areas; clean and prepare surface properly before recoating.
(6)	Delamination	Poorly bonded undercoat, chalky substrate, incompatible coating(s), and exceeding the recoating times for the coatings being applied	Remove all delaminating coatings; properly clean and prepare surface of well-bonded coating or metal before recoating.
(7)	Deterioration of Coating Systems at Edges, Corners, Channels, etc.	Surfaces that are difficult to coat; construction designs that permit the collection of moisture, salts, dirt, etc.	Round edges; fillet weld seams and crevices; provide drainage.

Continued . . .

III. DEFICIENCIES OF METAL AND COATINGS: COATING DEFICIENCIES

COATING DEFICIENCIES FOUND IN ALL TYPES OF METAL COATING SYSTEMS (Continued)

	Deficiency	Cause	Remedy
(8)	Abrasion and Impact Damage	Damage from physical wear in the form of impact and abrasion	Repair damage; when recoating use more abrasion- or impact-resistant coatings; if feasible, control or eliminate the passage of materials that abrade and/or impact the coated surface.
(9)	Incompatibility	Coatings are not suitable for applications where they are in contact with one another. A strong solvent coating may attack a coating that requires only weak solvents (example: a vinyl over an alkyd). Other types of incompatibilities are physical and/or chemical in nature. Incompatibility manifests itself in one or more of the following ways: 1. Wrinkling and lifting 2. Delamination 3. "Fish eyes" (Also caused by surface contamination with silicon, dirt, or oil) 4. Cratering	Keep good records so that compatible coating systems are chosen when additional coats are applied. If existing coating system is unknown, compatibility tests should be conducted.

III. DEFICIENCIES OF METAL AND COATINGS: COATING DEFICIENCIES

COATING DEFICIENCIES FOUND IN PARTICULAR COATING SYSTEMS

The following deficiencies are more likely to be experienced with particular types and kinds of coating systems:

Deficiency	Types And Kinds Of Coating Systems	Cause	Remedy
(1) Cobwebbing	Lacquers (coatings that dry by solvent evaporation only), such as vinyls or chlorinated rubbers	Too rapid solvent evaporation	Apply under cooler conditions; add retarder (slower evaporating solvent.)
(2) Blushing (Milky appearance on film)	Same as (1)	Same as (1)	Same as (1), except blushed area must be removed by sanding or blasting.
(3) Fading	Coating systems that are subject to exterior exposure or interior exposure in sunlight	Ultraviolet light action on the coating film or moisture behind coating film	Recoat with more light-stable coating, if practical, and avoid sources of moisture.
(4) Wrinkling	Most common with oil-base and alkyd coatings	Surface drying over uncured coating material because of a too thick wet-film having been applied	Remove wrinkles and avoid too thick wet-film thickness when recoating. Avoid strong sunlight on warm days.
(5) Cathodic Disbondment	Coating systems that are immersed or buried and applied on structures that are cathodically protected	Incorrect level of cathodic protection, or a coating system that has not passed a recognized cathodic disbondment test	Correct the level of cathodic protection. If the level of cathodic protection is correct, remove existing coating system and apply one that resists cathodic disbondment.

Continued . . .

COATING DEFICIENCIES FOUND IN PARTICULAR COATING SYSTEMS (Continued)

Deficiency	Types And Kinds Of Coating Systems	Cause	Remedy
(6) Mud Cracking	Inorganic zinc-rich primers, emulsion metal primers, some alkyd primers	Excessive thickness, application or curing at too high temperatures, limited flexibility of the coating	Remove coating, prepare the metal surface, and reapply the coating at a lesser thickness.
(7) Moisture Damage	Oil-based, alkyd, and "non-breathing" coating systems	Buildup of moisture vapor behind coating system	Provide vents, etc., to permit the moisture vapors to escape without passing through the coating. Use a "breathing" coating system, such as an emulsion-type coating system.
(8) Peeling	Although peeling can occur with all coating systems, it is especially common with oil-based and alkyd systems that have been recoated a number of times. Peeling is often preceded by cracking.	Weathering which causes stresses to develop in the film and overcome the adhesion of the base coating to the substrate. In addition, the force of gravity on overly numerous coats of paint applied during recoating operations can also overcome the adhesion of the base coat to the substrate.	Remove coating system and prepare surface before recoating. Spot repair is possible by removing loose coating materials and spot recoating with a flexible coating, such as a flexible emulsion coating.

Continued . . .

COATING DEFICIENCIES FOUND IN PARTICULAR COATING SYSTEMS (Continued)

Deficiency	Types And Kinds Of Coating Systems	Cause	Remedy
(9) Chalking (gradual erosion of a coating film in exterior exposure leading to the collection of white powder on the surface)	Occurs in all coating systems to a greater or lesser degree. It is especially severe with epoxy and aromatic polyurethane systems, as well as bituminous systems. Bituminous systems are very susceptible to degradation by sunlight.	Sunlight attacks and degrades the exposed surface layer of the coating leaving a residue of "chalk." This residue can be washed away by rain exposing a new surface layer, which in turn chalks. Eventually, the entire coating will erode away. If this occurs at a slow rate, it is the most "desirable" form of coating degradation. "Self-cleaning" house paints are based on controlled chalking.	Remove loose chalk, prepare surface, and apply an additional coat or coats. If appearance is important, where epoxies or aromatic polyurethanes are being, or have been, applied, a compatible chalk-resistant coating may be applied as a weathering topcoat. The topcoat must withstand the same type of environments that the epoxy or aromatic polyurethane withstands.
(10) Cavitation Damage	Occurs with metals, other materials, and high-performance coatings that are subject to cavitation. Architectural coating systems, such as oil-based or alkyd coating systems, are not used in immersion application where cavitation occurs.	Cavitation is caused by the formation of vacuum bubbles in the water when there is high-velocity flow and cavitation-inducing flow patterns. When these bubbles implode, tremendous amounts of energy are released. This energy is great enough to remove solid material from a surface, even stainless steel, and can literally disintegrate and/or "blow off" organic coating materials.	Retrofit structures, if possible, to reduce cavitation. Control cavitation in the design stages for new structures. Remove remaining coating, properly prepare surface, and recoat with a more cavitation-resistant coating system.

SUMMARY OF GENERIC COATING SYSTEM FEATURES

Although there is considerable variation within the same generic classes of coating systems, the generic class of a coating class does give some information about its probable properties. Generic classes of coating systems can be a starting point in searching for the right specific coating system for a particular application. Table III-2 gives some of the salient characteristics of some common generic coating systems.

TABLE III-2. GENERIC COATING SYSTEMS

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(1) Oil Based	Oxidation	AO, AI	L	L	Cracking, peeling, fading, moisture damage, pinpoint rusting, mildew.
(2) Alkyds, Epoxy Esters, Oil-Modified Polyurethanes	Oxidation	AO, AI, C	L-M	L	Similar to (1), although overall properties are superior to plain drying oil-based coating systems. (These coating systems are modified with drying oils.)
(3) Vinyls, Chlorinated Rubber	Solvent Evaporation	FWI, AO, AI, C	M-H	M	Abrasion and impact, pinpoint rusting, blistering, deterioration at surfaces that are difficult to coat, cavitation damage, peeling.

Explanation Of Symbols

FWI - Freshwater immersion
AO - Atmospheric, outdoor
AI - Atmospheric, indoor
B - Buried service
C - Condensation of water vapor
L - Low
M - Medium
H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(4) Epoxies (2-component) Some Subgroups: Epoxy-Polyamide Epoxy-Amine Epoxy-Cycloaliphatic Amine Epoxy-Amido-Amine Phenolic Epoxy Water-Borne Epoxy (not yet widely used in immersion exposure)	Chemical Curing	FWI, AO, AI, C	M-H	M-H	Similar to (3), plus heavy chalking in exterior exposure.

Explanation Of Symbols

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Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(5) Aromatic Polyurethanes (2-component) Some Subgroups: Nonelastomeric Elastomeric (rubberlike) Moisture-Cured (Curing component is moisture from air) Aromatic-Aliphatic	Chemical Curing	FWI, AO, AI, C	M-H	M-H	Similar to (4), plus significant color shift and possibly cracking in sunlight. Aromatic-Aliphatic systems are more resistant to sunlight. Elastomeric and some nonelastomeric polyurethanes are more resistant to abrasion, impact, and mild cavitation damage than some other systems.

Explanation Of Symbols

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L - Low
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H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(6) Aliphatic Polyurethanes (2-component) Some Subgroups: Nonelastomeric; Elastomeric (rubberlike); Moisture-Cured (Curing component is moisture from air)	Chemical Curing	FWI, AO, AI, C	M-H	M-H	Pinpoint rusting, blistering, delamination, deterioration at surfaces that are difficult to coat, cavitation damage. Note: Aliphatic polyurethanes are among the most weather-resistant coating systems known. They are less abrasion and water resistant than aromatic polyurethanes. They are frequently used as weathering topcoats over epoxies and aromatic polyurethanes.

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B - Buried service
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L - Low
M - Medium
H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(7) Coal-Tar Enamel	Hot Melt Coating System (with special chlorinated rubber primer)	FWI, C, B	H	H	Cracking, erosion, cavitation damage. When properly applied and maintained, coal-tar enamel is one of the most long-lived organic coatings (50 years +). Will degrade in sunlight. Will exhibit cracking on the top interiors of penstocks if the exteriors of the penstocks are exposed to strong sunlight. Light reflective colored coatings on the exteriors of exposed penstocks will sometimes prevent this.

Explanation Of Symbols

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H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(8) Coal-Tar Cutback (Coal-tar dissolved in a solvent)	Solvent Evaporation	FWI, C	M	L	Delamination, cracking, peeling, cavitation damage, abrasion and erosion, pinpoint rusting. Will degrade in sunlight.
(9) Coal-Tar Epoxy	Chemical Curing	FWI, C, B	M-H	M	Similar to (4). Good freshwater resistance, cannot be exposed to sunlight.
(10) Polyester	Chemical Curing	FWI, AO, AI, C	M-H	M-H	Similar to (4).
(11) Cement Mortar	Hydration	FWI, B	M	M-H	Cracking, abrasion, and erosion. (Small cracks will tend to "heal" themselves when water swells the mortar.)

Explanation Of Symbols

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L - Low
M - Medium
H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(12) Emulsion Coatings: Acrylics, Polyvinyl Chlorides, Polyvinylidene Chlorides, Bitadiene-Styrenes	Water Evaporation and Film Coalescence	AO, AI	L-M	L	Cracking, peeling, pinpoint rusting, deterioration at surfaces that are difficult to coat. Note: Most emulsions are "breathing" type coatings.
(13) Galvanizing	Hot Dipping	FWI, AO, AI, C	H	H	Reaction with strongly acidic or basic materials, abrasion and impact, erosion. Performance has been spotty in freshwater immersion service.
(13a) Organic Coatings over Galvanizing	- - -	FWI, AO, AI, C	M-H	- - -	Peeling, delamination. Failures are caused by improper surface preparation and/or the use of an improper coating system.

Explanation Of Symbols

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L - Low
M - Medium
H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(14) Inorganic Zinc Rich	Chemical Curing	FWI, AO, AI, C	M-H	H	Reaction with strongly acidic or basic materials, abrasion and impact. Note: Use in fresh-water immersion is controversial. This is a sacrificial coating that reacts to protect the steel. It is often overcoated with organic coatings. An example is an epoxy intermediate and an aliphatic polyurethane topcoat. Overcoating must be skillfully carried out to prevent delamination of the organic coatings from the organic zinc-rich primer.

Explanation Of Symbols

FWI - Freshwater immersion
AO - Atmospheric, outdoor
AI - Atmospheric, indoor
B - Buried service
C - Condensation of water vapor
L - Low
M - Medium
H - High

Continued . . .

TABLE III-2. GENERIC COATING SYSTEMS
(Continued)

Coating System	Types Of Drying Or Curing	Exposures Many (Not All) Listed Systems Are Suitable For	Relative Degree Of Clean Surface Preparation Required	Relative Difficulty Of Application	Typical Mechanisms Of Deterioration
(15) Metallizing	Hot Melt Using Flame or Electric Arc Spaying	FWI, AO, AI, C	H	H	Similar to (14), but forms a denser and thicker film. Relatively easy to overcoat with selected organic coating systems. Organic seal and topcoats are required for freshwater immersion.
(16) Tape Coatings: Coal-Tar, Polyethylene, etc.	Pre-made and then applied by hand, machine, or extrusion depending on type of tape system	B, AO, AI, C	H	H	Mechanical damage to the tape system. Tape systems are usually applied to the exterior of pipes and pipe joints that are to be backfilled.

Explanation Of Symbols

FWI - Freshwater immersion
AO - Atmospheric, outdoor
AI - Atmospheric, indoor
B - Buried service
C - Condensation of water vapor
L - Low
M - Medium
H - High

IDENTIFYING AND QUANTIFYING HAZARDOUS METAL COATING SYSTEM DEFICIENCIES

Identifying and quantifying hazardous metal coating system deficiencies is accomplished by periodic inspection of the applied coatings. This inspection is relatively easily accomplished on the coating systems that are exposed to the atmosphere, either indoors or outdoors, and are reasonably accessible. Inspections of immersed coating systems on gates, the interiors of penstocks, etc., can be accomplished only when those structures have been dewatered. Buried coating systems on the exteriors of pipe or other structures cannot be directly inspected unless they have been uncovered for some reason. If there is a corrosion monitoring system in place, the coating systems can be indirectly inspected for their general conditions. Among the tools required for the periodic inspections are: a knife, a magnifying glass, and a thickness gauge. A pit gauge or other means of measuring, or at least reasonably estimating, the depth of pits is also necessary.

The first areas to exhibit coating failure are usually welds, boltheads, edges, and areas where access is difficult. The thickness gauge is used to measure decreases in coating system thickness from erosion, chalking, and abrasion. Thicknesses are usually measured in thousandths of an inch (mils). As a point of comparison, a dollar bill is about 4 mils thick. Pitting is often the most serious defect and can cause rapid failure of piping or other structures while a major portion of the remaining metal is intact. This defect can be very serious in a metal conduit running through an embankment dam, for example, because the escaping water can erode the dam from within. Measuring the depth of pits enables a calculation to be made of the pit depth versus the thickness of the steel.

A knife is one of the best and most important inspection instruments. It is necessary for removing corrosion so that pitting can be measured, and for removing loose coating system material so that corrosion undercutting of the coating system film can be discovered. A knife is a good instrument for checking adhesion to see how much adequately bonded coating is left if there is local peeling or other signs of removal of the coating system. It can also be used to check flexibility and discover embrittlement of coating system films, and to break blisters to check the condition of the metal underneath.

Cavitation damage can be detected visually in areas where cavitation is likely to occur. It is distinguished by the loss of material in a pitting pattern which appears as though the lost material was "sucked" off or, in some instances, by removal of the coating system and evidence of attack on the metal underneath.

Continued . . .

IDENTIFYING AND QUANTIFYING HAZARDOUS METAL COATING SYSTEM DEFICIENCIES (Continued)

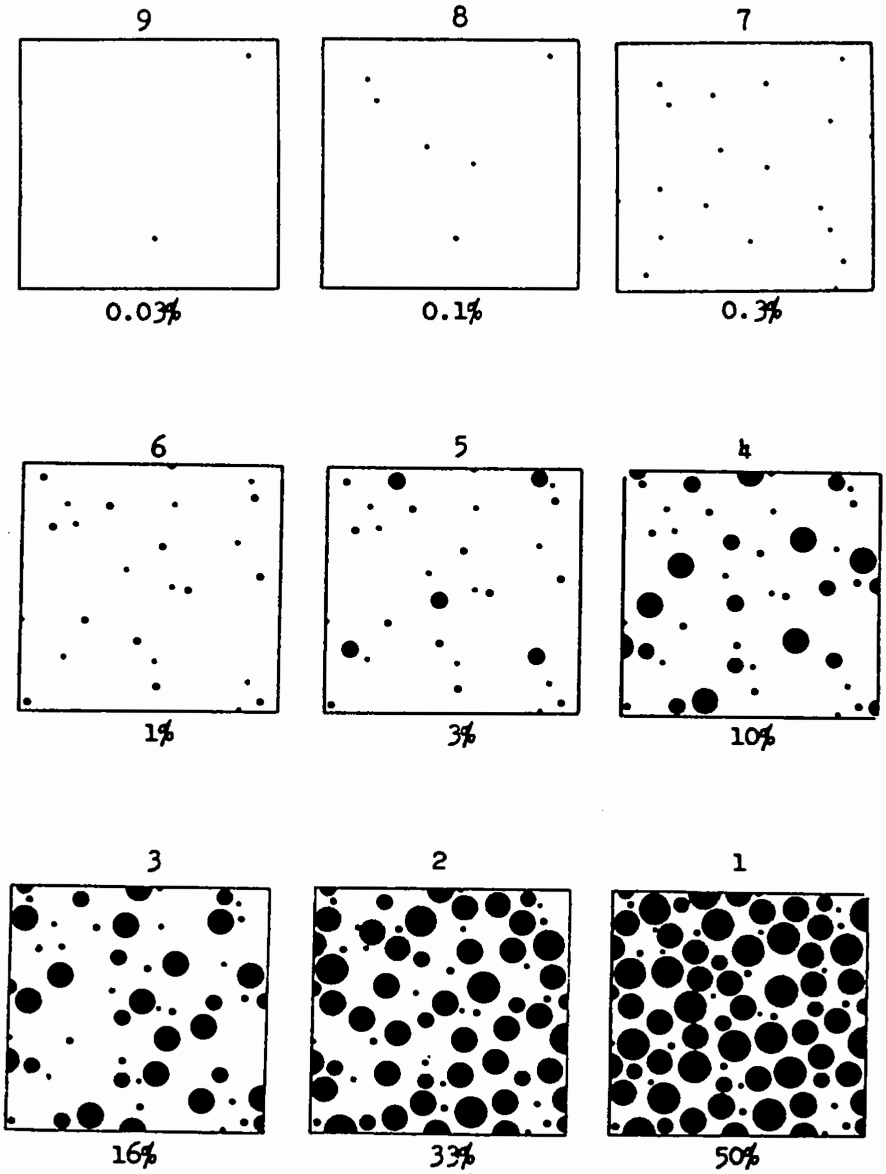
Quantification of coating system defects can be accomplished by using ASTM pictorial methods. These methods with good photographs and drawings as pictorial standards are available in Pictorial Standards of Coating Defects published by the Federation of Societies for Coatings Technology (FSCT) (see Appendix B). Pictorial standards are available for blistering, chalking, checking, cracking, erosion, filiform corrosion, flaking, mildew, and rusting. Both a number and a description are given, such as No. 4 medium dense blisters. Through the use of these standards it is possible to convey the appearance of a coating system defect to people who have not witnessed it personally. It is very important to accurately record the locations of defects. An imaginary grid system can be used as long as the location of the grids is recorded. Another method is verbal description, such as upper left or center left of a gate whose dimensions are given. In pipes the distance and direction from reference points, such as manholes, can be given. A line drawing that quantifies rusting is shown in Figure III-8.

Continued . . .

IDENTIFYING AND QUANTIFYING HAZARDOUS METAL COATING SYSTEM DEFICIENCIES (Continued)

FIGURE III-8. RATING OF PAINTED STEEL SURFACES AS A FUNCTION OF PERCENT AREA RUSTED

Proposed: ASTM-D610
SSPC-Vis 2



Continued . . .

IDENTIFYING AND QUANTIFYING HAZARDOUS METAL COATING SYSTEM DEFICIENCIES (Continued)

Recording the results of both scheduled and unscheduled coating system inspections is extremely important. The records of the coating systems on all structures must begin with the coating systems that were originally applied. A complete history must be kept of all the coating systems that have been applied to the structures, including records of touchups. An existing system must be overcoated or touched up with a compatible coating. The records can track the rate of deterioration of coating systems and make pre-planned maintenance and recoating possible. Also, the records, with or without an additional inspection, can supply the information required for decisions on whether to touch up, repair and overcoat, or remove the existing coating system to metal, prepare the surface, and completely recoat with the same or a different coating system.

III. DEFICIENCIES OF METAL AND COATINGS: UNIT EXERCISE

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

1. List below two locations you should check when examining a gate for hazardous metal corrosion.

   - ____________________________________
   - ____________________________________

2. A perforation in a metal conduit running through an embankment dam is especially dangerous because ____________________________

   ____

3. Put an "X" in each space next to a condition that is a possible hazard to a dam.

   _____ Badly peeling paint on a bridge handrail

   _____ A pitted area inside a metal outlet works conduit through an embankment dam

   _____ Faded enamel finish paint

   _____ Corrosion in a crevice where two bridge support beams are joined

   _____ Bits of coating missing downstream from a gate

4. List below two metal parts in gate mechanisms that are especially susceptible to breakage, cracking, or distortion.

   - ____________________________________
   - ____________________________________

III. DEFICIENCIES OF METAL AND COATINGS: UNIT EXERCISE

5. The corrosion cell requires four critical elements for its operation. These elements are:

   - The ______________________ (site where corrosion occurs)
   - The ___________________________ (site protected from corrosion, where no corrosion occurs)
   - The ______________________ (usually water)
   - An electrically conductive path

6. List below two causes of failure in cathodic protection systems.

   - ____
   - ____

7. What is the single most frequent cause of premature coating system failure?

   ____

III. DEFICIENCIES OF METAL AND COATINGS: UNIT EXERCISE—ANSWER KEY

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

1. List below two locations you should check when examining a gate for hazardous metal corrosion.

   Any two of the following:

   - **Spots where coating is damaged or missing**
   - **Welded areas**
   - **Crevices between gate parts**
   - **At rivets and bolts**

2. A perforation in a metal conduit running through an embankment dam is especially dangerous because **water can escape into the embankment and erode the dam from within, causing it to fail.**

3. Put an "X" in each space next to a condition that is a possible hazard to a dam.

   _____ Badly peeling paint on a bridge handrail

   __X__ A pitted area inside a metal outlet works conduit through an embankment dam

   _____ Faded enamel finish paint

   __X__ Corrosion in a crevice where two bridge support beams are joined

   __X__ Bits of coating missing downstream from a gate

4. List below two metal parts in gate mechanisms that are especially susceptible to breakage, cracking, or distortion.

   Any two of the following:

   - **Gate connections**
   - **Lifting lugs or attachments**
   - **Lifting chain or wire rope**
   - **Lifting beams**

III. DEFICIENCIES OF METAL AND COATINGS: UNIT EXERCISE — ANSWER KEY

5. The corrosion cell requires four critical elements for its operation. These elements are:

- The **anode** (site where corrosion occurs)
- The **cathode** (site protected from corrosion, where no corrosion occurs)
- The **electrolyte** (usually water)
- An electrically conductive path

6. List below two causes of failure in cathodic protection systems.

Any two of the following:

- **Interrupted circuits or circuit breakers**
- **Power failures**
- **Failed lightning arresters**
- **Failed rectifiers**
- **Expended anodes**

7. What is the single most frequent cause of premature coating system failure?

Poor surface preparation

III. DEFICIENCIES OF METAL AND COATINGS: SUMMARY

SUMMARY

The following table summarizes information presented on deficiencies of metals and metal coatings.

METAL DEFICIENCY	MOST COMMON TYPES	ESPECIALLY WATCH FOR . . .
Corrosion	Pitting	Deep pitting in pipes and conduits
	Galvanic corrosion	Broken mill scale, contacts between dissimilar metals
	Stress corrosion cracking	Cracking in metal parts subject to stress
	Erosion corrosion and cavitation	Directional pits and grooves on metal exposed to high velocity flows
	Uniform attack	Corrosion proceeding uniformly over a large area, resulting in uniform thinning of the surface
	Crevice corrosion	Intense, localized corrosion under gaskets, within lap joints, under surface deposits, mud, or other detritus
	Intergranular corrosion	"Knife-line" corrosion in the heat-affected zone adjacent to an improperly executed weld in stainless steel
	Selective leaching	Corrosion resulting in the removal of one material from a solid alloy

Continued . . .

III. DEFICIENCIES OF METAL AND COATINGS: SUMMARY

SUMMARY (Continued)

METAL DEFICIENCY	MOST COMMON TYPES	ESPECIALLY WATCH FOR . . .
Cracking and Deformation	Cracking and stress corrosion cracking	Cracking in metal parts subject to static stress
	Fatigue and corrosion fatigue	Cracking and tearing of mechanical parts subject to dynamic stress
	Overload failure	Buckling and shearing of metal parts resulting from single stresses beyond the strength of the parts
Coating Deficiencies	Rust spots or nodules; pinpoint rusting	Deep pits, active pitting
	Blistering; poor coating adhesion and/or poorly bonded undercoat	Corrosion under coating
	Cracking	Cracks penetrating to metal
	Erosion	Eroded coatings on pipe and conduit inverts
	Cavitation	Tiny particles plucked from coating surfaces in areas of high velocity flow
	Sagging	Areas where too much coating was applied
	Orange peel	Areas where improper thinning and application techniques were used
	Pinholing	Solvent "popping" through partially dried or cured coating
	Abrasion and impact damage	Corrosion on metal at points where impact and abrasion result in physical wear on the metal

UNIT IV

DEFICIENCIES OF EARTH AND ROCK MATERIALS

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: OVERVIEW

INTRODUCTION

Earth and rock materials often are used to construct dams and appurtenances. Earthfill dams comprise the majority of existing dams, and many spillways have earthen linings. Rock materials are used in the body of rockfill dams and to provide slope protection for embankment dams. Also many unlined spillways are situated in rock.

UNIT OBJECTIVES

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

- Describe dispersive soils, the problems associated with them, and recommend corrective measures to mitigate such problems.
- Perform simple tests to detect dispersive soils.
- Describe the types and hazards of riprap deficiencies and recommend corrective measures as appropriate.
- Identify hazardous rock deficiencies, including movement, deterioration, seepage, and deficient reinforcements.
- Describe the types and hazards of gabion deficiencies, and recommend corrective measures.

EVALUATING EARTH MATERIALS

Deficiencies in dams and appurtenances comprised of earth and rock are usually attributable to a lack of understanding of the characteristics and behavior of particular earthen materials, and the subsequent misuse or failure to properly treat or compensate for any adverse material characteristics or behavior that may exist.

For further information about problems related to earthen materials in dams, their appurtenances, and foundations, see the modules Inspection Of Embankment Dams, Inspection Of The Foundation, Abutments, And Reservoir Rim, Evaluation Of Embankment Dam Stability And Deformation, and Evaluation of Seepage Conditions.

Dispersive soils are not discussed in those modules because such soils are not widely encountered (despite being common in some geographic areas). However, because dispersive soils have a propensity toward severe erosion which can lead to rapid failure of a dam, recognition of them is important. Therefore, dispersive soils are addressed in this module.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: OVERVIEW

TYPES OF ROCK MATERIALS

The types of rock materials used in dams and appurtenances include:

- Riprap
- Rock
- Gabions

This module will address deficiencies in each of these rock materials.

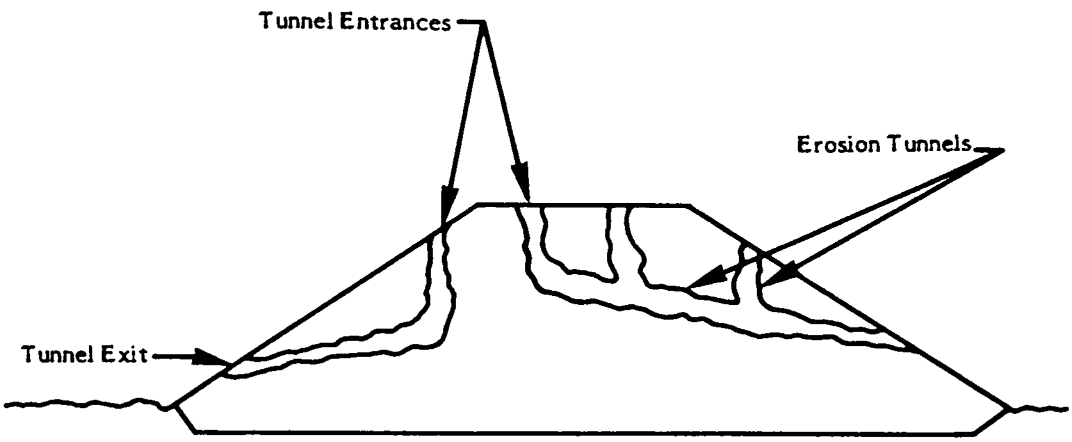
IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: EARTH MATERIALS

DEFICIENCIES IN EARTH MATERIALS: DISPERSIVE SOILS

Dispersive soils are a hazardous type of earth material because of their propensity toward deflocculation in water, making these soils very susceptible to erosion. Such erosion may start in a desiccation crack, settlement crack, animal burrow, or other discontinuity in the surface of the dam that concentrates surface runoff on or near the crest that may emerge farther down the slope. Dispersive soils have a very characteristic erosion pattern consisting of vertical tunnels or sinkholes.

Figure IV-1 shows a section of a dam comprised of dispersive soil with the typical erosion tunnels that form.

FIGURE IV-1. EROSION TUNNELS IN DISPERSIVE SOIL



While embankment dams can be constructed of dispersive soils, measures must be incorporated in the structures which mitigate the erodible nature of the soils.

Problems with dispersive soils can be corrected or avoided by the following measures:

- Using properly graded filters in the embankment or on slopes to stop migration of soil particles with seepage or surface runoff
- Covering slopes with chemically treated (lime-modified) soil
- Chemically treating (lime-modifying) dispersive soils placed in critical areas

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: EARTH MATERIALS

HAZARDS OF DISPERSIVE SOILS

The failure rate for dams built of dispersive soils is high. Embankment dams comprised of dispersive soils often fail upon the first reservoir filling. Rainfall erosion also causes damage severe enough to result in failure. Too often, failure of the dam is the first indication of dispersive soils in the area. Early recognition and identification of dispersive soils are crucial in preventing sudden, irreversible, and catastrophic events leading to failure.

IDENTIFYING DISPERSIVE SOILS

Dispersive soils are found in various locations in the United States and other countries. Records of dam failures show geographic patterns that engineers have used to identify areas with problem soils. For example, in the U.S. the southwestern states, Oklahoma, Nebraska, Mississippi, and Kansas contain regions where dispersive soils are found. However, undiscovered problem soils may exist in many areas.

A number of tests have been developed for effective detection of dispersive soils. One test, the crumb test, is a simple procedure that you might use in the field. A soil sample is placed in distilled water, and grades of reaction interpreted at timed intervals. The test procedure is fully described in USBR 5400, Procedure for Determining Dispersibility of Clayey Soils by the Crumb Test Method (listed in Appendix B: References). The Crumb Test provides a good indication of potential erodibility, although some dispersive soils escape detection using this method.

Other laboratory tests include . . .

- Laboratory Dispersion Test (SCS Double Hydrometer Test)
- Pinhole Test
- Chemical Tests

These tests are described in the chapter "Dispersive Clays" in Advanced Dam Engineering For Design, Construction, And Rehabilitation (listed in Appendix B: References).

Signs Of Dispersive Soils

Dispersive soils display a number of easily recognizable erosion patterns, which include . . .

- Vertical rainfall erosion tunnels occurring in spite of good protective grass cover.
- Damage in areas of high crack potential such as along conduits, in areas with large differences in foundation compressibility, or desiccated areas.
- A pattern of deep, narrow gullies.
- Excessive turbidity of storage water.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: EARTH MATERIALS

Reporting Dispersive Soils

If you see evidence that a dam or appurtenance may have been constructed of dispersive soils, you should . . .

- Record the location and extent of erosion gullies and tunnels.
- Photograph the area.
- Perform a preliminary test for dispersive soils, using the Crumb Test, and record the results.
- Take soil samples for laboratory testing.
- Recommend temporary corrective and diagnostic actions, such as . . .
  - Restricting the reservoir.
  - Conducting more frequent inspections.
  - Making observations during and after heavy rains.
- Contact an experienced, qualified engineer to make further evaluations.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: RIPRAP

RIPRAP INSTALLATION AND USES

Riprap is broken rock or boulders placed on the upstream and downstream slopes of embankment dams, on spillway channel floors and walls, and as a protective lining for plunge pools located at the ends of spillways and outlet works. Riprap provides protection from erosion caused by wave action, surface runoff erosion, high velocity flow, and wind scour.

Precast concrete shapes and broken concrete also are used in place of rock to form varieties of riprap, but rock riprap is the type that you are most likely to encounter in the dams that you inspect.

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

- **The Inner Layer(s):** The inner layer(s), called the filter layer or bedding, is usually sand (less than 3/8 inch in diameter) and gravel-sized (between 1/4 and 3 inches in diameter). These smaller particles prevent the underlying embankment from being washed out through the voids in the larger rocks found in the outer layer.

- **The Outer Layer:** The outer layer is cobble-size (between 2-1/2 and 10 inches in diameter) and boulder-size (larger than 10 inches in diameter) rock that is large enough not to be displaced by the anticipated wave action turbulence or velocity.

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

The slope upon which the riprap is placed must be flat enough to prevent riprap from dislodging and moving down the slope. Hand-placed riprap, while usually providing good protection, is typically a relatively thin blanket of protection. Hand-placed riprap is susceptible to failure because the dislodging of one large rock may cause displacement of the surrounding rock due to a lack of adequate support. However, most modern riprap is dumped in place, resulting in a much thicker-layered blanket of protection. Figure IV-2 presents a diagram of riprap that is appropriately designed and placed on an upstream slope.

Continued . . .

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: RIPRAP

RIPRAP INSTALLATION AND USES (Continued)

FIGURE IV-2. RIPRAP SLOPE PROTECTION

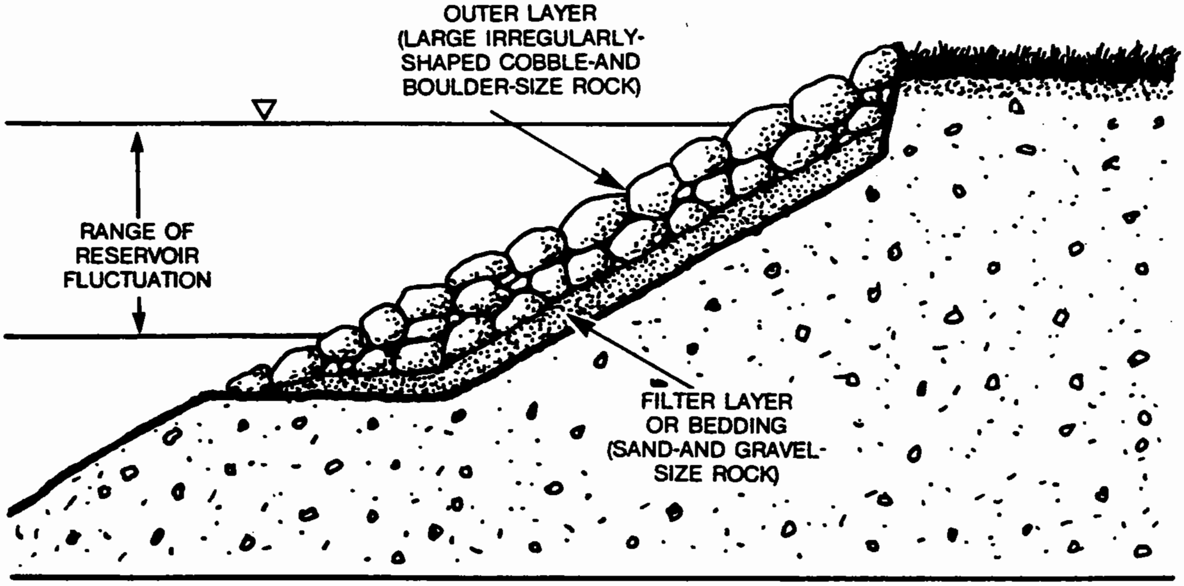
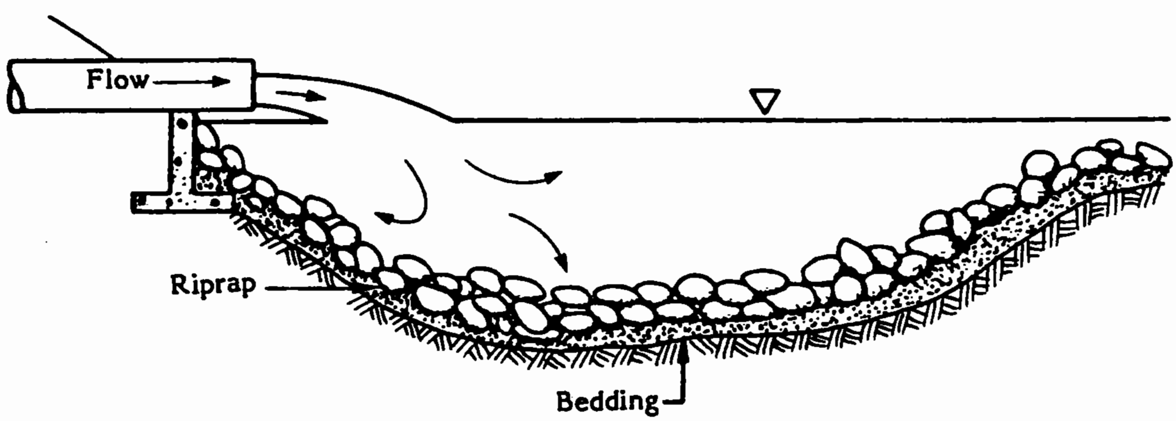


Figure IV-3 illustrates how riprap is used in a plunge pool receiving flow from an outlet works pipe.

FIGURE IV-3. RIPRAP-LINED PLUNGE POOL



IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: RIPRAP

HAZARDS OF RIPRAP DEFICIENCIES

When deficiencies prevent riprap from providing erosion protection, the earth structure beneath the riprap is exposed to erosion damage. Undercutting by wave action, slides, and slope failure can lead to failure of a spillway channel, a plunge pool, or, if erosion continues unchecked, even the breaching of an embankment dam or dike.

TYPES OF RIPRAP DEFICIENCIES

Riprap may suffer from displacement or rock degradation. These deficiencies may be related, with degradation often leading to displacement.

Riprap Displacement

Displacement of riprap or the underlying slope material is the removal of rocks from their as-placed position. Filter or bedding material may become exposed, or the riprap layer may become thinner, providing inadequate protection.

Reasons riprap can become displaced include . . .

- Inadequate thickness of riprap layer
- Improper sizing or gradation of riprap relative to filter or bedding material (inner layer is washed through outer layer)
- Improper anchorage at base of protected slope
- Loss of foundation support
- Missing, inadequate, or improperly sized filter or bedding material
- Wrong shape (too slabby/flat, or too round: most problems are due to stones being too round and easily rolled by waves or flows)
- Rock weight insufficient (due to small size or low specific gravity) for anticipated wave action or flow velocity
- Too much variance in size and weight
- Average weight reduced by rock deterioration
- Nondurable rock
- Damage from reservoir ice thrust or movement
- Bedding not properly installed

Continued . . .

Riprap Displacement (Continued)

- Poor grading of slope
- Improper foundation preparation
- Rock sizes segregated during placement
- Loose placement resulting in large voids

Rock Degradation

Rock is degraded from different causes, which include:

- High abrasion loss
- Structural weakness (cracks, fractures, etc.)
- High absorption rates (freeze-thaw damage from absorbed water)
- Impact damage from debris

Types of rock degradation are:

- Cracking
- Spalling
- Splitting or delaminating along bedding planes and joints
- Deaggregating and disintegrating of poorly cemented sedimentary rock
- Dissolving

IDENTIFYING HAZARDOUS RIPRAP DEFICIENCIES

Riprap is deficient when it fails to protect the underlying earth from erosion. Many riprap deficiencies can be dealt with through routine maintenance, such as adding rock to areas where riprap has started to become displaced. More severe riprap deficiencies may threaten the safety of the dam.

Signs Of Hazardous Riprap Deficiencies

Riprap installations in areas exposed to numerous freeze-thaw cycles or high winds are most likely to experience serious problems. Be especially alert for riprap problems if the dams you inspect are exposed to these conditions.

Riprap exposed to wave action, high velocity flows, or turbulence, such as on the upstream slope of an embankment dam, the lining of a spillway channel, or the lining of a plunge pool, is especially vulnerable. Rock may be displaced, or may degrade by becoming weathered and breaking down, thereby allowing damage to the underlying slope.

Continued . . .

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: RIPRAP

Signs Of Hazardous Riprap Deficiencies (Continued)

If spillway side walls slide and block the spillway entrance or channel, the dam may overtop because of reduced capacity to pass flood flows. Erosion of plunge pools and return channels may expose the toe of the dam to erosion, undercutting, and subsequent slope failure.

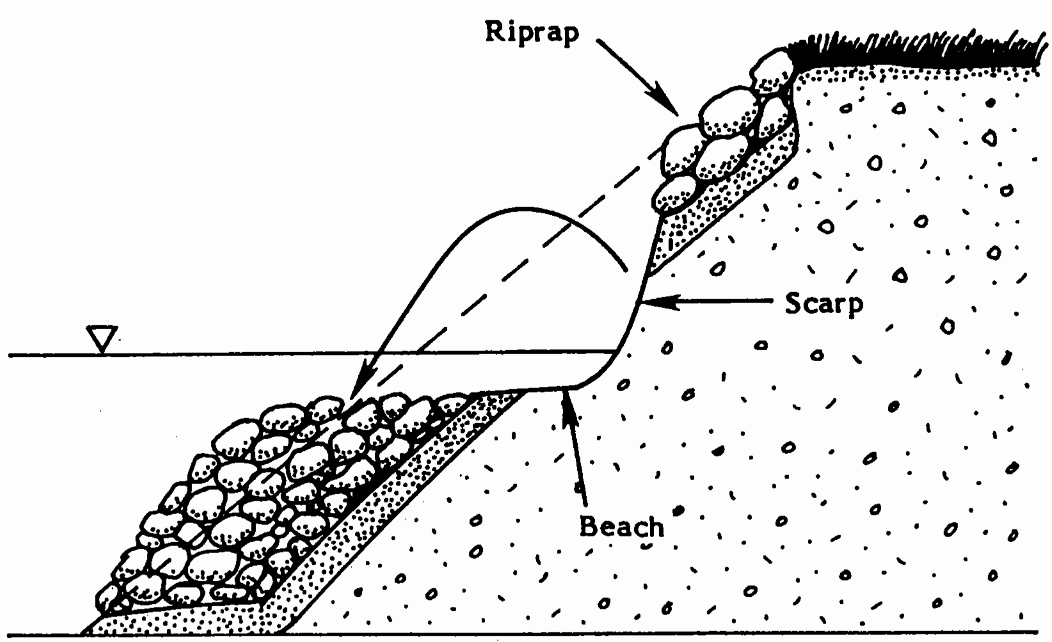
Beaching and scarping are indications of wave-induced displacement that can lead to slope failure.

Beaching

Beaching within a slope occurs when riprap and bedding are removed by wave action and deposited further down the slope. A relatively flat beach area with a steep back slope, or scarp, is formed.

Figure IV-4 illustrates beaching within a riprapped slope.

FIGURE IV-4. FAILED RIPRAP SLOPE PROTECTION



Ice action or local settlement can also cause displacement of riprap and bedding. When beaching and scarps form which lessen the width and possibly the height of an embankment, the result may be instability or overtopping of the dam.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: RIPRAP

Degraded Riprap

All riprap degrades over time, but wave action wetting and drying, and freeze-thaw cycles accelerate degradation. Look for signs that the riprap is smaller near the waterline, that rocks are shattered, or that beaching, thinning of the riprap layer, or gaps in the riprap have developed. The riprap layer may be so degraded and displaced that erosion of the underlying material has begun.

Your agency or organization may have established procedures for assessing the adequacy of a riprap installation. Approximate particle counts can be derived by using techniques such as visual percent estimation charts, and various methods have been developed to estimate particle weights and sizes.

Reporting Hazardous Riprap Deficiencies

If you observe riprap deficiencies that may affect the safety of the dam, you should . . .

- Record the location and areal extent of riprap deficiencies that you observe. Photograph the area.
- Record the approximate dimensions of any beaching that has occurred.
- Recommend temporary corrective actions, such as restricting the reservoir, if the crest of the dam could be breached during a storm.
- Consult an experienced, qualified engineer to evaluate the need for major repair.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: ROCK

ROCK AT DAMS

Dams built in areas where rock is at or near the surface may include outlet works and spillway channels and tunnels constructed in or through the rock; also, dam foundations and abutments often are rock.

HAZARDS OF ROCK DEFICIENCIES

Fallen rock may block discharges through a tunnel or channel, or rock falls into the reservoir immediately upstream from the dam could render outlet works, penstocks, or spillways inoperable. Abutment movement may restrict or prevent operation of appurtenances located in or on the abutment. Loosened rock could block or damage structures in their fall paths. Any of these conditions may cause the dam to be overtopped.

Unstable rock in an abutment or at the toe of a dam may result in slides which could cause the dam to fail.

TYPES OF ROCK DEFICIENCIES

Rock deficiencies can be classified into the following categories:

- Inadequate hardness or strength
- Discontinuities
  - Faults
  - Shears
  - Joints
  - Bedding planes
- Weathering, or deterioration due to . . .
  - Temperature variations (thermal stresses)
  - Freeze-thaw action
  - Erosion
  - Plant and animal activity
  - Chemical action
- Solutioning (Chemical weathering of mineral or rock into solution by seepage flow)

Geologic data in the Dam Safety File or from other sources should contain information on rock hardness and compressive strength, as well as information about faults under or around the dam site.

Excavated rock slopes and tunnel walls are subject to spalling and weathering from freeze-thaw action. Rock contains joints (also termed fractures or discontinuities) along which water can pass, resulting in deterioration. Movement at these joints caused by an earthquake or excess hydrostatic pressure may result in large rock falls.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: ROCK

IDENTIFYING HAZARDOUS ROCK DEFICIENCIES

You should be alert for potentially large rock falls, slides, and obstruction of tunnels and spillway channels.

Signs Of Hazardous Rock Deficiencies

The following conditions may indicate hazardous rock deficiencies.

Instability

Look for signs of rock movement at fractures and joints which might indicate a future rock fall or slide, such as . . .

- Fresh cracks in the rock surface
- Cracks in dam concrete where it joins the rock
- Blocks falling from abutments
- Displacement of vegetation
- Arc-shaped cracks on or above slopes

Slides on slopes adjacent to spillways are especially hazardous because of the potential for blockage, or damage to the structure preventing operation.

In rock abutments adjacent to a concrete dam, look for freshly exposed rock at or near the dam-abutment contact.

Check any instrumentation data that may exist for indications that rock walls or slopes have moved. Movement of abutment rock can be very serious, possibly resulting in loss of support for the dam. If data show progressive movement and increasing seepage pressure, the dam and abutments are in danger of destabilization.

Degradation

Look for evidence of past rock falls, and check the floors of rockcut spillways and unlined rock tunnels for excessive amounts of rock chips and pieces. Examine the walls for general deterioration.

If there is evidence that end blocks of a concrete dam have moved due to thermal or chemically induced expansion or other causes, check rock abutments adjacent to the dam for spalling and possible crushing of rock at joints and fractures caused by pressure from concrete movement.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: ROCK

Seepage

Note the following points about any seepage you observe:

- Rate of seepage
- Correspondence of seepage rates to reservoir levels
- Staining
- Turbidity of seepage

Seepage can create excess hydrostatic pressure, weaken the overall strength of the abutment, and produce increasingly large channels for water flow. Openings can enlarge sufficiently to cause abutment movement or collapse.

Stains from seepage water indicate solutioning of minerals which may reduce the shearing strength of the rock materials and cause rock consolidation. Take samples of the seepage so that the mineral(s) can be identified. Check geologic data for evidence of deposits of limestone or other rock especially subject to solutioning that may underlie competent rock. Turbid flow indicates that internal erosion or piping is occurring.

Check the construction records to see if rock walls and slopes were grouted to control seepage. If grouting was not done in the past, this procedure may control the seepage. If prior grouting proved inadequate to prevent or control seepage, an experienced, qualified engineer should examine possible causes and sources for the seepage and evaluate corrective actions.

Deficient Rock Reinforcements

Rock reinforcements such as bolts, anchors, dowels, and tendons may be installed in the rock tunnels and slopes that you inspect. Be sure to make a record of deficient rock reinforcements, such as:

- Deterioration of the rock around fastening plates
- Loose bolts or plates
- Corroded bolts, fastening plates, or wire grids (especially in the vicinity of seepage)

Reporting Hazardous Rock Deficiencies

If you observe rock deficiencies that may affect the safety of a dam, you should . . .

- Record the location and extent of the deficiencies, and photograph the affected areas.

- Notify an experienced, qualified engineering geologist immediately if you suspect or observe abutment movement or a rockfall in an unlined tunnel.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: GABIONS

GABION INSTALLATION AND USES IN DAMS

A gabion is a prefabricated rectangular wire cage or basket filled in place with rocks. Gabions are free-draining and capable of being stacked for erosion protection in channels. The term "gabion wall" may be used to refer to stacked gabions, and "gabion mattress" to refer to a layer of gabions used to protect a chute or basin floor.

TYPES OF GABION DEFICIENCIES

The following deficiencies may cause deformation and possible toppling of gabion walls.

Inadequate Foundation Support

Settlement and possible displacement of gabions can result from inadequate foundation support or from erosion of the subgrade.

Settlement Of Rock (Consolidation)

Rock within a gabion can shift and consolidate into a smaller space than when the basket was filled, creating unsupported space at the top of the basket.

Rock Degradation

Rocks within gabions may spall, split, disintegrate, or dissolve. Flowing water can then wash pieces of rock through openings in the basket. The loss of rock mass makes the gabions susceptible to being lifted and moved by flows, and consolidation of rock within the basket creates empty, unsupported space at the top of the basket.

Failure Of Wire Baskets

The wires of the baskets may become corroded, broken or cut by vandals, or deformed by rapidly flowing water. Rocks may be washed out of a damaged basket, and the basket can be deformed by the weight of shifting rocks or other gabions, and fail.

IDENTIFYING HAZARDOUS GABION DEFICIENCIES

Failure of gabion channel protection may result in exposure of slopes or channel floors to erosion, undercutting, and subsequent failure. When gabion structures consist of stacks or rows of baskets, the integrity of individual baskets is crucial to the integrity of the structure. Baskets are prone to deformation because basket wires can bend, corrode, and break, and stones can shift, deteriorate, or be dislodged.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: GABIONS

Signs Of Hazardous Gabion Deficiencies

Some settlement of a gabion installation is normal. Gabions are designed to be flexible and allow for some degree of settling. Minor deterioration in a gabion installation generally constitutes a long-term maintenance problem rather than a hazard to the dam.

Hazardous gabion deficiencies are those that destabilize the installation, or cause it to fail entirely, usually because of deficiencies in a limited number of baskets.

The lower baskets in a vertical or battered gabion wall support the greatest weight, and are most likely to become deformed. Because of their position, failure of lower baskets carries great potential to destabilize a gabion installation. Defects such as broken, cut, or deformed wires and missing rock can lead quickly to failure of the individual gabion and subsequent failure of a wall. Look for damaged baskets or baskets crushed by overlying gabions, and for movement and for undermining caused by waves or current.

Reporting Hazardous Gabion Deficiencies

If you observe gabion deficiencies that may affect the safety of the dam, you should . . .

- Record the location and extent of defective areas, and describe the nature of the deficiency; i.e., basket wires broken, degree of deformation or settlement, approximate amount of missing rock, etc.
- If the underlying slope is exposed, record the extent of slope damage, using such measures as the length, width, and height of the affected area.
- Photograph the damaged area.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: UNIT EXERCISE

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

1. You are inspecting a recently constructed embankment dam in an area that may contain dispersive soils. List below two signs of dispersive soils that you may observe.

   - ______________________________
   - ______________________________

2. The steps in the failure of riprap slope protection and consequent failure of a dam are listed below. Put the steps in order by writing the step number next to each item.

STEP #	DESCRIPTION
_____	Oversteepened slopes fail, may lose freeboard, and eventually breach the dam
_____	Wave action or turbulence displaces riprap
_____	Failure of the dam
_____	Portions of the embankment are removed and deposited further down the slope
_____	Exposed filter or bedding material erodes

3. In the space below, explain why a rock slide blocking a rockcut spillway channel or tunnel can be hazardous to the dam.

   ____

   ____

   ____

Continued . . .

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: UNIT EXERCISE

4. While inspecting gabions used for spillway channel slope protection, you notice that vandals have cut a number of basket wires. The cuts are fresh, and the baskets show no signs of deformation or rock loss. Write in the space below whether you should consider the cut wires primarily as a maintenance problem or a safety problem, and explain your decision.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: UNIT EXERCISE—ANSWER KEY

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

1. You are inspecting a recently constructed embankment dam in an area that may contain dispersive soils. List below two signs of dispersive soils that you may observe.

   Any two of the following:

   - **Vertical rainfall erosion tunnels in spite of good grass cover**
   - **A pattern of deep, narrow gullies**
   - **Excessive turbidity of storage water**
   - **Erosion along conduits, in desiccated areas, or in areas with differing foundation compressibility**

2. The steps in the failure of riprap slope protection and consequent failure of a dam are listed below. Put the steps in order by writing the step number next to each item.

STEP #	DESCRIPTION
4	Oversteepended slopes fail, possibly reducing freeboard
1	Wave action or turbulence displaces riprap
5	Possible breaching failure of the dam if incorrected
3	Portions of the embankment are removed and deposited further down the slope
2	Exposed filter or bedding material erodes

3. In the space below, explain why a rock slide blocking a rockcut spillway channel or tunnel can be hazardous to the dam.

   Obstruction of spillway flow can cause the reservoir to rise above safe levels, and possibly result in overtopping of the dam.

Continued . . .

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: UNIT EXERCISE—ANSWER KEY

4. While inspecting gabions used for spillway channel slope protection, you notice that vandals have cut a number of basket wires. The cuts are fresh, and the baskets show no signs of deformation or rock loss. Write in the space below whether you should consider the cut wires primarily as a maintenance problem or a safety problem, and explain your decision.

   Cut wires are a safety problem. Deformation and rock loss may be swift under flood flows, since the structural integrity of the affected wire baskets has been damaged. Flood flows could quickly destabilize the entire gabion installation, leading to collapse and partial blockage of the channel and exposure of the underlying slopes to erosion.

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: SUMMARY

SUMMARY

The following table summarizes information presented on deficiencies of earth and rock materials.

MATERIAL TYPE	DEFICIENCIES	ESPECIALLY WATCH FOR . . .
Earth	Dispersive soils	Vertical rainfall erosion tunnels, especially in grass cover
		Pattern of deep, narrow gullies
		Turbidity in the reservoir
Riprap	Displacement	Bare or thinly covered areas
		Exposure of filter/bedding material or embankment
		Beaching
	Rock degradation	Rock breaking down into pieces too small for effective slope protection
		Erosion visible beneath riprap cover
Rock	Rock degradation	Spalling, chipping, shattering, disintegration
		Excessive deposits of rock chips and pieces on channel and tunnel floors
		Badly degraded rock walls or slopes
	Instability	Signs of movement at rock fractures and joints
		Displacement of vegetation

Continued . . .

IV. DEFICIENCIES OF EARTH AND ROCK MATERIALS: SUMMARY

SUMMARY (Continued)

MATERIAL TYPE	DEFICIENCIES	ESPECIALLY WATCH FOR . . .
Gabions	Settling	Empty space at the top of baskets, basket deformation
	Rock degradation	Breakdown of rock within baskets and loss of rock through basket openings
	Defective wire baskets	Corroded, broken, cut, or deformed wires
	Undermining	Tilting or settlement of gabion wall

UNIT V

DEFICIENCIES OF SYNTHETIC MATERIALS

V. DEFICIENCIES OF SYNTHETIC MATERIALS: OVERVIEW

INTRODUCTION

In general, synthetic materials are not visible for examination during inspection. You will detect most deficiencies in synthetic materials by noting indirect signs, such as changes in drainage amounts.

UNIT OBJECTIVES

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

- Describe the types of geotextile and geomembrane lining deficiencies.
- Identify hazardous geotextile and geomembrane lining deficiencies.
- Document and report hazardous geotextile and geomembrane lining deficiencies.
- Describe the types and hazards of plastic pipe and tubing deficiencies.
- Identify hazardous plastic pipe and tubing deficiencies.
- Report observed deficiencies, and recommend possible corrective actions.

TYPES OF SYNTHETIC MATERIALS

Synthetic materials are discussed in two major categories:

- Geotextiles and geomembrane linings (geosynthetics)
- Plastic piping and tubing

V. DEFICIENCIES OF SYNTHETIC MATERIALS: GEOSYNTHETIC LININGS

INSTALLATION AND USES OF GEOTEXTILES AND GEOMEMBRANE LININGS

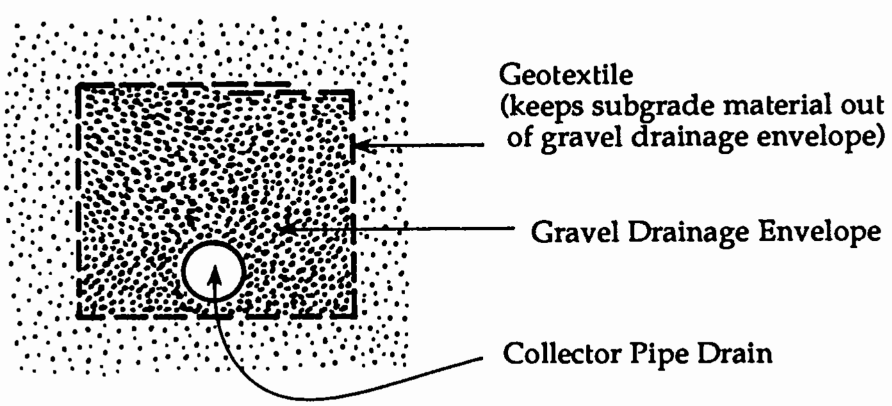
Geotextile filters are water permeable, are generally made from polypropylene or polyester, and can be woven, nonwoven, or a combination of woven and nonwoven segments. Uses for geotextiles include:

- Separation between layers of materials
- Drainage
- Reinforcement
- Filtration

In dams, geotextiles may have temporary construction uses, or become permanent materials. Because long term performance of geotextiles has yet to be proven, approval for permanent use, especially as filters, depends largely on ease of replacement. Some geotextiles (such as filters in drains or bedding for riprap) could be replaced relatively simply. However, geotextiles placed as embankment dam core and foundation filters would be extremely difficult to replace and such uses have generally not been embraced by the profession as accepted applications.

Figure V-1 shows how a geotextile can be installed for drainage, where replacement is practical.

FIGURE V-1. GEOTEXTILE USED FOR DRAINAGE



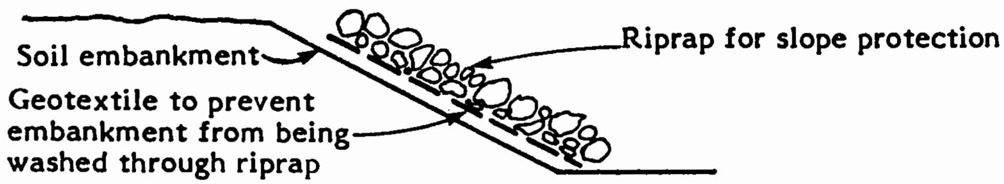
Continued . . .

V. DEFICIENCIES OF SYNTHETIC MATERIALS: GEOSYNTHETIC LININGS

INSTALLATION AND USES OF GEOTEXTILES AND GEOMEMBRANE LININGS (Continued)

Geotextiles are sometimes used in lieu of granular filters beneath other erosion control materials such as riprap. Protected slopes may be on the dam embankment or surfaces in spillways and plunge pools. Figure V-2 shows a section view of a geotextile used for filtration under riprap slope protection.

FIGURE V-2. GEOTEXTILE UNDER RIPRAP



Geomembrane linings are impermeable, and are used as water barriers. Geomembrane linings may be composed of:

- PVC
- CPE
- CSPE (also called Hypalon, a DuPont trade name)
- HDPE
- HDPE-A
- Neoprene

Dams constructed of RCC may incorporate a geomembrane lining on the upstream face of the dam to control seepage.

HAZARDS OF GEOTEXTILE AND GEOMEMBRANE LINING DEFICIENCIES

Geotextiles serve to control or prevent the movement of soil fines. When a geotextile fails, the failure may jeopardize the incorporating structure. If seepage in a protected slope is restricted from entering a collector drain because of a clogged geotextile, excessive hydrostatic pressure could develop in the embankment or slope which could lead to slope failure. A ruptured geotextile could lead to piping of the embankment material because the filtering capacity is lost, at least locally.

A failed geomembrane reservoir liner can permit seepage through porous foundation zones which might cause piping to develop.

V. DEFICIENCIES OF SYNTHETIC MATERIALS: GEOSYNTHETIC LININGS

TYPES OF GEOTEXTILE AND GEOMEMBRANE LINING DEFICIENCIES

Geotextiles and geomembrane linings may have the following deficiencies:

- Punctures, including damage caused by . . .
  - Spreading equipment
  - Installation of anchorage fasteners
  - Construction or maintenance activities
  - Dropping riprap without cushioning
- Seams unbonded or poorly bonded, due to . . .
  - Seams opened under load
  - Poor bond between new and old fabric
- Sections incorrectly positioned or overlapped
- Displacement (usually slippage down slope)
- Soil piping through broken or open seams or punctures
- Clogging with soil particles (geotextiles only)
- Design problems
  - Lack of strength or durability for intended use
  - Incorrect match to soil base (improper filtering)
  - No anchorage provided
  - Inadequate transmission of water (inadequate porosity)
- Defective materials
  - Lack of specified strength or durability
  - Holes or weak areas
- Deterioration caused by . . .
  - Aging
  - Temperature extremes (especially at or below the freezing point)
  - Exposure to ultraviolet light (sunlight)
  - Adverse chemical or biological conditions

IDENTIFYING HAZARDOUS GEOTEXTILE AND GEOMEMBRANE LINING DEFICIENCIES

A hazardous deficiency in a geotextile or geomembrane lining severely affects the integrity of the incorporating structure. In the case of geotextiles within a dam, the deficiency could cause the dam to fail from internal erosion or piping. Deficiencies of geotextiles used for slope protection could result in a slope failure. The deficiency may affect a structure crucial to the safe operation of a dam, such as a spillway or plunge pool.

V. DEFICIENCIES OF SYNTHETIC MATERIALS: GEOSYNTHETIC LININGS

Signs Of Hazardous Geotextile And Geomembrane Lining Deficiencies

You are most likely to detect deficiencies in geotextiles and geomembrane linings installed within a dam when you record the amount and check the clarity of seepage collected at drains. If seepage has decreased and water pressure within the embankment has increased, as measured by a piezometer, geotextiles within the embankment may be clogged. Undrained seepage may be building hydrostatic pressure inside the embankment, weakening soil strength, or eroding the embankment. (Refer to the TADS module Instrumentation For Embankment And Concrete Dams for information about measuring seepage and using piezometers.) Turbid flow indicates piping and loss of material.

Geotextiles under riprap or similar materials used for slope protection and also for lining spillways and plunge pools keep the foundation or bedding material in place. Punctures and other deficiencies may result in loss of bedding material and erosion of foundation material beneath the geotextile, leading to sunken areas and voids under the riprap.

Clogging of geotextiles under riprap will cause a buildup of hydrostatic pressure at the toe, saturate the slope, and may cause a local failure that is seen as bulging at the slope toe until the geotextile breaks. After the geotextile breaks, you will see a washed-out area.

At an RCC dam that incorporates a geomembrane liner, look for increased seepage through the dam. For reservoirs sealed with a geomembrane liner, unaccountable losses from the reservoir may be the first clue that the liner is leaking. Seepage around the reservoir rim is another indicator. You will want to examine the reservoir floor with the reservoir drawn down if possible. Examine the protective layer over the membrane liner for gaps, plant growth, animal burrows, damage from vandalism, and piercing of the liner.

Reporting Hazardous Geotextile And Geomembrane Lining Deficiencies

If you observe deficiencies in geotextiles or geomembrane linings that could affect the safety of the dam, you should . . .

- Record the observations that indicate possible problems with geotextiles or geomembrane linings.
- Refer indications of geotextile failure within an embankment dam or a reservoir geomembrane lining failure to an experienced, qualified engineer.

V. DEFICIENCIES OF SYNTHETIC MATERIALS: PLASTIC PIPING AND TUBING

INSTALLATION AND USES OF PLASTIC PIPING AND TUBING

Plastic piping and tubing may be made of:

- PVC
- ABS
- PE (used primarily for tubing)

Plastic pipe is used for conveying water and other fluids, but the pipe must be protected from mechanical damage. Plastic piping and tubing usually are embedded in concrete or buried underground for protection.

Common uses for plastic piping and tubing include:

- Piezometer tubing used to measure water pressure in earth structures or foundations and abutments
- Tubing in stilling wells
- Electrical conduit
- Seepage collectors in drainage systems
- Outlet works conduits (PE and PVC)

HAZARDS OF PLASTIC PIPING AND TUBING DEFICIENCIES

Deficiencies of plastic pipes that affect the safety of the dam generally involve drainage systems. Malfunction of plastic pipes used as seepage collectors in drainage systems could result in excess or leaking drainage water building hydrostatic pressure inside the embankment, the dam, or in the foundation, causing a loss of strength, reduction of safety against slope failure or sliding, and possible failure at the downstream toe or slope. Seepage also may erode soil from within the dam or foundation into a broken or damaged collector system.

TYPES OF PLASTIC PIPING AND TUBING DEFICIENCIES

Deficiencies of plastic piping and tubing include:

- Mechanical damage such as . . .
  - Cracks
  - Breaks
  - Split seams

Continued . . .

V. DEFICIENCIES OF SYNTHETIC MATERIALS: PLASTIC PIPING AND TUBING

TYPES OF PLASTIC PIPING AND TUBING DEFICIENCIES (Continued)

- Disbonded fitting/joints
- Poorly welded joints
- Shear at wall-backfill interface
- Crushing by stones in backfill or vehicles driven on the embankment
- Burned or deformed when exposed in areas where surface vegetation is controlled by burning

• Deterioration caused by . . .

- Exposure to ultraviolet light (sunlight)
- Chemical attack
- Stress-deformation (creep), buckling
- Localized sources of high heat, including burning

IDENTIFYING HAZARDOUS PLASTIC PIPING AND TUBING DEFICIENCIES

Check for hazardous deficiencies in plastic pipe used in drainage systems. Past inspection reports and other documentation contain drainage measurements to compare with your observations.

Signs Of Hazardous Plastic Piping And Tubing Deficiencies

If you are inspecting exposed plastic piping and tubing, look for:

- Leaking fittings and joints
- Visible impact damage
- Warp or creep
- Silted or obstructed flow area
- Plugged outlets obstructing free flow (lack of flow may be normal; some drains operate only during wet weather)
- Crushed pipe
- Burned surfaces
- Turbidity/sediments in the discharge

If you are inspecting unexposed pipe, reduced flow, turbid flow, or lack of flow are indicators of possible problems with the pipe. You may perform or recommend the following procedures:

- Pull a plug through the pipe to test for obstructions (if open at two ends)
- Inspect the pipe interior using a remotely operated vehicle with video camera (large diameter pipe)
- Use a motorized drain cleaning tool to clear possible obstructions
- For a pipe that should be watertight, pressurize the pipe with air or water, and check the pressure to detect leaks (not recommended unless very low pressures are used, since a sudden break or release could damage the embankment)

V. DEFICIENCIES OF SYNTHETIC MATERIALS: PLASTIC PIPING AND TUBING

Reporting Hazardous Plastic Piping And Tubing Deficiencies

If you observe a deficiency in plastic piping and tubing that may affect the safety of the dam, you should . . .

- Record your observations and the procedures used to investigate changes in drainage patterns.
- Describe any findings about the causes of the deficiency, and possible corrective actions.
- If the apparent volume of leakage into the embankment is sizable, consult an experienced, qualified engineer for further evaluation.

V. DEFICIENCIES OF SYNTHETIC MATERIALS: SUMMARY

SUMMARY

The following table summarizes information presented on deficiencies of synthetic materials.

MATERIAL TYPE	DEFICIENCIES	ESPECIALLY WATCH FOR . . .
Geotextiles And Geomembrane Linings	Punctures Seams unbonded or poorly bonded	Geotextiles used for drainage: Increased seepage, turbid flow
	Deterioration	
	Clogging with soil particles	Reduced drainage
	Sections not correctly positioned or overlapped	Geotextiles used under riprap: Lost bedding material Displaced riprap Bulging of riprap at toe of slope
	Displacement or perforation	Geomembrane linings: Greatly increased seepage
Plastic Piping And Tubing	Mechanical damage	Visible leaks, damage, and deterioration Soil particle transmission or collection
	Deterioration	Reduced flow or lack of flow
	Filter failure or broken pipes	Turbid flow, sediment in the flow

V. DEFICIENCIES OF SYNTHETIC MATERIALS: VIDEO SEGMENT #2

VIDEO PRESENTATION

At this point you should watch the final video presentation. This video segment presents information on deficiencies in metal and coatings, earth and rock materials, and synthetic materials.

To watch the video presentation . . .

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

After watching video segment #2, rewind the videocassette and then return to the text and complete the Final Review Exercise.

FINAL REVIEW EXERCISE

FINAL REVIEW EXERCISE

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

1. In the space below, list four characteristics you can use to describe cracks in the concrete that you observe during inspections.

- ______________________________
- ______________________________
- ______________________________
- ______________________________

2. Structural cracks in concrete tend to occur in areas of stress concentration. In the space below, list three locations where stress concentrations may cause structural cracks.

- ______________________________
- ______________________________
- ______________________________

3. The steps in freeze-thaw damage of concrete are listed below. Put the steps in order by writing the step number next to each item.

STEP #	DESCRIPTION
_____	Cracks open wider
_____	The concrete cracks
_____	Water enters new cracks and freezes
_____	Water freezes and expands
_____	Water enters pores, cracks, and joints in concrete

Continued . . .

FINAL REVIEW EXERCISE

4. You are inspecting concrete that has been patched, and see significant cracks in the repaired concrete. What problem do these cracks indicate?

   ____

5. List below three early indicators of alkali-aggregate reaction.

   - ____
   - ____
   - ____

6. List below two possible results of severe alkali-aggregate reaction.

   - ____
   - ____

7. Write in the missing steps that describe deterioration of concrete by corroded reinforcing bars.

STEP #	DESCRIPTION
1	Cracks or other concrete deterioration allow water to reach steel.
2	____ ____
3	Steel volume increases.
4	____ ____

8. Write the names of the material (RCC or soil cement) next to the most serious immediate result of cracking in that material.

   ____________________ Providing a path for seepage

   ____________________ Deterioration through infiltration of freezing water

Continued . . .

FINAL REVIEW EXERCISE

9. Identify two locations where you should use a hammer or bonker to check for voids in shotcrete.

   - ________________________________
   - ________________________________

10. In the space below, explain why the type of corrosion known as pitting is hazardous in outlet works conduits through embankment dams.

    ____

    ____

    ____

    ____

11. You are examining the interior of an abrupt bend in an uncoated metal conduit. What would you see on the metal surface if erosion or cavitation damage were occurring?

    ____

12. In what type of location in the United States would you be most likely to find serious problems with riprap installations?

    ____

13. In the space below, draw a cross-section of riprap slope protection using a geotextile for filtration, showing locations of geotextile, bedding, and riprap.

Continued . . .

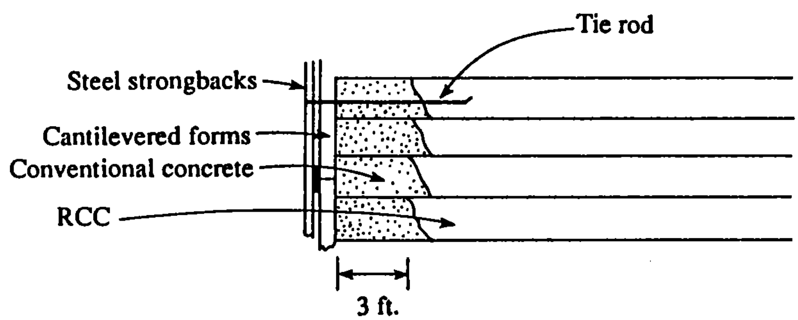
14. What would be a sign of possible problems with an embedded plastic drainage pipe?

____

15. You are most likely to see soil cement used for ____________________

____

16. Draw heavy lines on this diagram of RCC construction to identify likely paths for seepage.



17. List below two examples of sites where contacts between dissimilar metals could result in galvanic corrosion.

- ____
- ____

18. If corrosion made a gate inoperable, what would be the worst possible consequences for the dam?

____

____

____

____

Continued . . .

FINAL REVIEW EXERCISE

19. In the space below, draw a section view of an embankment slope where riprap displacement has created beaching and scarping. Label the beach and the scarp in your drawing.

20. List below two of the possible hazardous conditions that may result from seepage through a rock abutment.

- ____
- ____

FINAL REVIEW EXERCISE

ANSWER KEY

FINAL REVIEW EXERCISE--ANSWER KEY

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

	REFERENCES
1. In the space below, list four characteristics you can use to describe cracks in the concrete that you observe during inspections. **Any four of the following:** • **Length** • **Width** • **Direction** • **Trend** • **Location** • **Depth** • **Offset**	Text Pages: I-2 - I-5 Video Segment #1
2. Structural cracks in concrete tend to occur in areas of stress concentration. In the space below, list three locations where stress concentrations may cause structural cracks. **Any three of the following:** • **Corner of an opening** • **Contraction joint** • **Areas of large temperature gradient** • **Foundation discontinuities**	Text Page: I-4 Video Segment #1

Continued . . .

	REFERENCES
3. The steps in freeze-thaw damage of concrete are listed below. Put the steps in order by writing the step number next to each item.	Text Page: I-12 Video Segment #1
4. You are inspecting concrete that has been patched, and see significant cracks in the repaired concrete. What problem do these cracks indicate?	Text Page: I-5 Video Segment #1
5. List below three early indicators of alkali-aggregate reaction.	Text Page: I-23 Video Segment #1

3. The steps in freeze-thaw damage of concrete are listed below. Put the steps in order by writing the step number next to each item.

STEP #	DESCRIPTION
5	Cracks open wider
3	The concrete cracks
4	Water enters new cracks and freezes
2	Water freezes and expands
1	Water enters pores, cracks, and joints in concrete

4. You are inspecting concrete that has been patched, and see significant cracks in the repaired concrete. What problem do these cracks indicate?

Structural problems in the underlying concrete.

5. List below three early indicators of alkali-aggregate reaction.

Any three of the following:

- **Pattern cracking**
- **Efflorescence**
- **Incrustation**
- **White rings around aggregate particles**
- **Exudation of a gel-like substance**

Continued . . .

FINAL REVIEW EXERCISE—ANSWER KEY

	REFERENCES
6. List below two possible results of severe alkali-aggregate reaction. **Any two of the following:** • **Disbonding of blocks at lift lines** • **Binding of gates** • **Severe cracking** • **Loss of structural strength**	Text Page: I-24 Video Segment #1
7. Write in the missing steps that describe deterioration of concrete by corroded reinforcing bars. **STEP #** — **DESCRIPTION** 1 — Cracks or other concrete deterioration allow water to reach steel. 2 — **Steel corrodes, producing oxide.** 3 — Steel volume increases. 4 — **Overlying concrete cracks and spalls.**	Text Page: I-24 Video Segment #1
8. Write the names of the material (RCC or soil cement) next to the most serious immediate result of cracking in that material. **RCC** — Providing a path for seepage **Soil Cement** — Deterioration through infiltration of freezing water **An RCC dam should be as watertight as possible, with seepage carefully controlled. Soil cement damage usually occurs through wave action separating layers whose bond is already weakened by freeze-thaw damage.**	Text Pages: II-7 and II-13 Video Segment #1

Continued . . .

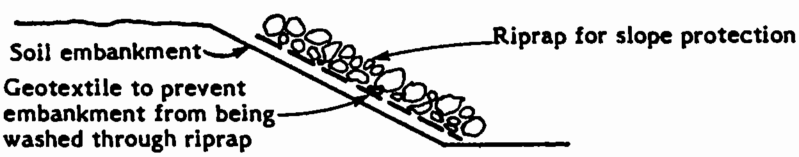
FINAL REVIEW EXERCISE—ANSWER KEY

	REFERENCES
9. Identify two locations where you should use a hammer or bonker to check for voids in shotcrete. **Any two of the following:** • **Inside corners** • **At wall bases** • **Over or near reinforcement or embedded items** • **On horizontal surfaces**	Text Page: II-16 Video Segment #1
10. In the space below, explain why the type of corrosion known as pitting is hazardous in outlet works conduits through embankment dams. **Pitting can weaken and perforate a conduit, allowing water to leak into the embankment and cause internal erosion.**	Text Page: III-15 Video Segment #2
11. You are examining the interior of an abrupt bend in an uncoated metal conduit. What would you see on the metal surface if erosion or cavitation damage were occurring? **Directional pits and grooves.**	Text Page: III-7 Video Segment #2
12. In what type of location in the United States would you be most likely to find serious problems with riprap installations? **Areas subjected to frequent freeze-thaw cycles and high winds**	Text Page: IV-9 Video Segment #2

Continued . . .

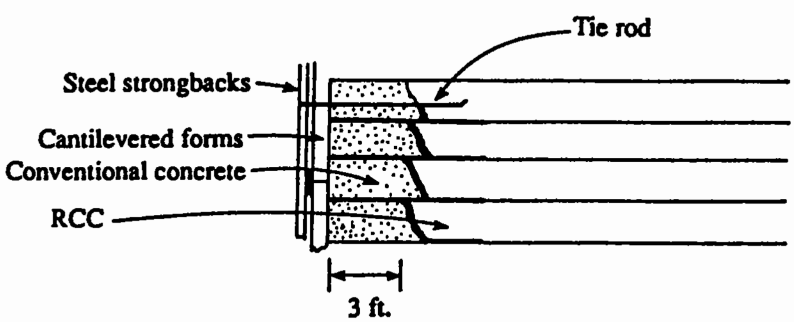
FINAL REVIEW EXERCISE—ANSWER KEY

	REFERENCES
13. In the space below, draw a cross-section of riprap slope protection using a geotextile for filtration, showing locations of geotextile, bedding, and riprap.	Text Page: IV-3 Video Segment #2



If bedding is used, the bedding would be placed above the geotextile. Bedding can protect the geotextile from being punctured by riprap.

14. What would be a sign of possible problems with an embedded plastic drainage pipe? **Reduced flow, lack of flow, or turbid flow**	Text Page: V-7 Video Segment #2
15. You are most likely to see soil cement used for **slope protection, as an alternative to riprap.**	Text Page: II-6 Video Segment #2
16. Draw heavy lines on this diagram of RCC construction to identify likely paths for seepage.	Text Page: II-11 - II-14 Video Segment #2



Continued . . .

	REFERENCES
17. List below two examples of sites where contacts between dissimilar metals could result in galvanic corrosion. **Any two of the following:** • **Broken mill scale on steel (steel and iron oxide)** • **Steel screws in brass** • **Lead solder around copper wire** • **Steel shaft rotating in bronze bearings** • **Aluminum conduit and steel reinforcing embedded in concrete**	Text Page: III-13 Video Segment #2
18. If corrosion made a gate inoperable, what would be the worst possible consequences for the dam? **If flood flows could not be released by opening the gate, the reservoir level might rise until the dam was overtopped and failed.**	Text Page: III-12 Video Segment #2

Continued . . .

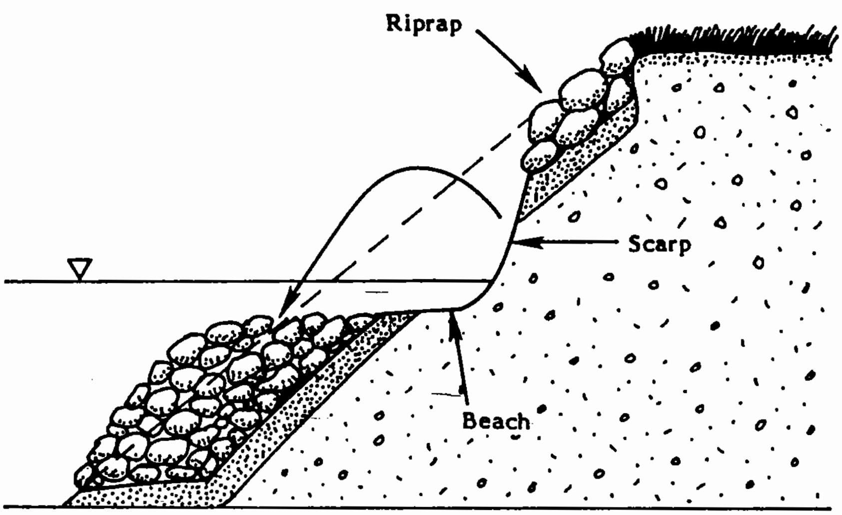
FINAL REVIEW EXERCISE--ANSWER KEY

REFERENCES

19. In the space below, draw a section view of an embankment slope where riprap displacement has created beaching and scarping. Label the beach and the scarp in your drawing.

Text Page: IV-10

Video Segment #2



20. List below two of the possible hazardous conditions that may result from seepage through a rock abutment.

- **Excessive hydrostatic pressure**
- **Enlarged channels for water flow**
- **Solutioning of minerals in rock that reduces shearing strength and causes consolidation**

Text Page: IV-14

Video Segment #2

APPENDIX A

GLOSSARY

GLOSSARY

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

ABS - Acrylonitrile-butadrine-styrene pipe.

ACCESS BRIDGE - A structure that provides access from the crest or reservoir rim to an intake structure.

ALKALI-AGGREGATE REACTION - A chemical reaction between certain aggregate mixtures and the alkalis (sodium and potassium, primarily in the cement) that causes irreversible expansion of concrete, and usually subsequent cracking.

ARCH DAM - A concrete dam that is arched upstream so as to transmit the major part of the water load to the abutments.

BAFFLE - An upright obstruction that slows water flow.

BAFFLE BLOCK - A block of reinforced concrete constructed in a channel or stilling basin to dissipate the energy of the flowing water.

BEACHING - The removal by wave action of a portion of the upstream slope of the embankment, and the depositing of material farther down the slope. Characterized by a resulting flat area or beach.

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

BONKER - A hardwood dowel with a metal tip used to sound for voids under concrete.

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

BUTTRESS DAM - A dam consisting of a watertight element supported at intervals on the downstream side by a series of buttresses. Buttress dams can take many forms, such as a flat slab, massive head buttress, or multiple arch buttress.

CAVITATION - A process that damages concrete or metal by the formation of bubbles in a water flow, created when offsets or irregularities exist on a flow surface exposed to high velocities.

CAVITATION DAMAGE - Damage to a concrete or metal surface caused by shock waves from the collapse of bubbles in a high-velocity water flow.

Continued . . .

GLOSSARY

CHECKING - Development of shallow cracks at closely spaced but irregular intervals on the surface of mortar or concrete.

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

CLOSED-SYSTEM PIEZOMETER - A system to measure water pressure wherein the water is not exposed to atmospheric pressure.

CONDUIT - A pipe or box structure constructed by joining sections of pipe or conduit in an excavated trench, inside a tunnel, on the ground surface, or supported on cradles.

CONSOLIDATION - The change in volume of a soil or rock material (normally considered in the vertical direction) which results from an externally applied load causing the expulsion of fluids contained in the soil or rock pores.

CONSTRUCTION JOINT - The interface between two successive placings of concrete where bond is intended.

CONTRACTION JOINT - Joints between concrete blocks that are designed to prevent the formation of tension cracks as the structure undergoes volumetric shrinkage due to temperature drop. Contraction joints are vertical and run transversely through the dam, from the foundation to the crest.

CONTROL GATE (OR VALVE) - A gate (or valve) that is used to regulate water flows, and therefore can be used fully open, fully closed, or at any setting in between.

CONTROL SECTION - A spillway component that receives the flow of water from the entrance channel and determines the elevation and capacity of discharge.

CPE - Chlorinated polyethylene.

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

CSPE - Chlorosulfonated polyethylene.

DAM - A barrier constructed across a watercourse for the purpose of storage, control, or diversion of water.

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

DAM SAFETY FILE - A compilation of all information pertinent to the safety of a specific dam. A separate Dam Safety File may exist; however, some organizations consider a compilation of existing project files to be the Dam Safety File.

Continued . . .

GLOSSARY

D-CRACKING - Progressive formation of a series of fine cracks at rather close intervals, often of random patterns, and often paralleling a joint or curving across slab corners.

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

DEFLOCCULATION - Loss of cohesion between particles of a mass when exposed to a liquid.

DESICCATION - The process of drying up or dehydrating.

DESIGN WATER LEVEL - The maximum water elevation, including the flood surcharge, that a dam is designed to withstand.

DIFFERENTIAL MOVEMENT - Localized movement of one section of a structure relative to adjacent sections.

DISCHARGE SECTION - A spillway component that conveys flow from the control section to the terminal section, return channel, or natural stream.

DOWNSTREAM CHANNEL - See **RETURN CHANNEL.**

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

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

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

DRUMMY CONCRETE - Concrete that has a void or weakness beneath an intact surface that can be located by tapping on the surface.

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

EFFLORESCENCE - A deposit of salts that is leached from within the concrete and deposited on the surface.

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

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

Continued . . .

EMERGENCY SPILLWAY - See **AUXILIARY SPILLWAY.**

ENERGY DISSIPATOR - An appurtenance at the end of spillways and outlet works that uses turbulence to aid in the dispersal of excess energy in the water. Types include baffles, plunge pools, impact basins, stilling pools, and stilling wells, among others.

ENTRANCE CHANNEL - A structure that conveys water to the control section of the spillway or to the intake structure of the outlet works.

EXPANSION JOINTS - Joints placed in a concrete structure primarily to accommodate volumetric expansion due to temperature rise.

EXTENSOMETER - A device for measuring relative changes in length along the instrument's axis.

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

FILL DAM - See **EMBANKMENT DAM.**

FLIP BUCKET - An upward-curved structure located at the end of a chute, designed to be used when water depth does not permit a hydraulic jump to form.

FLOW METER - A meter capable of measuring the velocity of movement of water through a pipe or channel.

FLUME - A constricted channel of specific dimensions in which water is accelerated for the purpose of measuring water flow.

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

FOUNDATION BASEPLATE - A device for measuring foundation settlement.

FOUNDATION DEFORMATION - Movement in the foundation of a dam resulting from loads placed upon the foundation.

FOUNDATION DRAIN - A drain drilled into the foundation downstream of the grout curtain to collect seepage water and carry it up to the internal drainage system where it can be disposed of.

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

FREE FLOW - Flow that occurs either in an open waterway or in a conduit that flows partly full.

Continued . . .

GLOSSARY

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

FULL CONDUIT FLOW - See **PRESSURE FLOW.**

FULL DESIGN LOAD - The maximum loading condition on a dam from the reservoir, earth, wind, or other factors that can be accommodated.

GABION - A prefabricated, rectangular wire cage or basket filled with rocks.

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

GALVANIC CORROSION - The result of electrical/chemical reactions between two dissimilar metals.

GATE - An adjustable device used to control or stop the flow of water in a waterway. A gate consists of a leaf or member which is moved across the waterway from an external position.

GRADATION - The proportions by mass of a soil or fragmented rock distributed in specified particle-size ranges.

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

GRAVITY DAM - A concrete dam that relies on its weight and internal strength for stability.

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

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

GROUT CURTAIN - A zone, created by drilling a line of holes deep in the foundation near the heel of the dam, into which grout is injected to reduce seepage under or around a dam.

HDPE - High-density polyethylene.

HDPE-A - High-density polyethylene alloy.

HOLIDAY (PAINTER'S HOLIDAY) - A small area on a painted surface left bare when the brush or other applicator skipped over it.

Continued . . .

GLOSSARY

HONEYCOMB - Voids left in concrete when mortar fails to fill the spaces between coarse aggregate particles. Also called rockpocket.

HYDRAULIC JUMP - The abrupt rise in water surface that may occur in an open channel or stilling basin when water flowing at high velocity is suddenly slowed down.

HYDRAULIC JUMP BASIN - See **HYDRAULIC JUMP STILLING BASIN.**

HYDRAULIC JUMP STILLING BASIN - A structure designed to produce a hydraulic jump that will dissipate energy.

INCLINOMETER (INCLOMETER, DEFLECTOMETER) - An instrument usually consisting of a metal or plastic tube inserted in a drill hole and a sensitized monitor either lowered into the tube or fixed within the tube. This monitor measures (at different points) the tube's inclination to the vertical. The device may be used to measure horizontal movement and settlement when equipped with special joints.

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

INTAKE STRUCTURE - Placed at the beginning of an outlet works waterway, the intake structure establishes the ultimate drawdown level of the reservoir by the position of its opening(s) to the outlet works. Intake structures may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

INTERNAL EROSION - See **PIPING.**

JUMP BASIN - See **STILLING/HYDRAULIC JUMP BASIN.**

LATERAL SPREADING - The horizontal spread of embankment materials along the length of the dam.

LEAKAGE - The undesirable flow of water through joints, cracks, and openings in hydraulic structures.

LIFT LINE - Horizontal construction joints that are created when new concrete is placed on a previous lift.

MASONRY DAM - A dam constructed mainly of stone, brick, or concrete joined with mortar.

METHACRYLATE - A component of acrylic plastic.

Continued . . .

GLOSSARY

MISALIGNMENT - The movement of a structure from its design location.

NEOPRENE - A synthetic rubber.

OPEN-CHANNEL FLOW - See **FREE FLOW.**

OPEN-SYSTEM PIEZOMETER - A system to measure water pressure wherein the water is exposed to atmospheric pressures.

ORIFICE - The opening of an inlet structure, or the open end of a pipe, conduit, or tunnel.

OUTFALL - The outlet end of a toe drain.

OUTLET - An opening through which water can be discharged.

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

OVERFLOW CREST - A weir or sill designed for water to spill over when the reservoir level rises above the weir elevation.

PATTERN CRACKING - Fine openings on concrete surfaces in the form of a pattern; resulting from a decrease in volume of the material near the surface, or increase in volume of the material below the surface, or both.

PE - Polyethylene.

PENSTOCK - A pipeline or pressure conduit leading from a headrace or reservoir to power-producing turbines. Because of the possibility of sudden load changes, a penstock is designed to withstand pressure surges.

PIEZOMETER - An instrument used for measuring water pressure within soil, rock, or concrete.

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

PITTING - Development of relatively small cavities in a concrete or metal surface.

POOL - See **RESERVOIR.**

POORLY-GRADED SOIL - Soil with particles that are uniform, most being about the same size; or soil with skip gradation, characterized by the absence of one or more intermediate sizes.

Continued . . .

GLOSSARY

POPOUT - A small portion of concrete surface that breaks away, due to internal pressure, leaving a shallow, conical depression.

PORE PRESSURE - The pressure of water in the voids within a mass of soil, rock, or concrete.

PRESSURE FLOW - The situation that exists when a control gate is placed downstream from the conduit entrance: the portion of conduit above the control gate flows under pressure. An ungated conduit can also flow under pressure, depending on the geometry of the inlet and the conduit.

PVC - Polyvinyl chloride.

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

RESERVOIR - The body of water impounded by a dam.

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

RETURN CHANNEL - A structure that conveys spillway and outlet works discharges to the natural stream channel downstream of the dam structure.

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

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

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

ROLLER COMPACTED CONCRETE (RCC) - A type of concrete construction in which a mixture of well-graded aggregate and cement with a low water content is laid in layers and compacted using heavy equipment.

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

SCALING - Flaking or peeling away of the surface of concrete or mortar.

SCARP - An over-steepened surface on a slope resulting from instability or erosion. A scarp consists of a relatively flat area with a steep back slope.

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

Continued . . .

GLOSSARY

SEEPAGE COLLAR - See **CUTOFF COLLAR.**

SETTLEMENT - The vertical downward movement of a structure.

SHOTCRETE - A sand-cement mixture sprayed on rock, concrete, or compacted earth.

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

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

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

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

SOIL-CEMENT - A well-compacted mixture of soil, Portland cement, and water that produces a hard material similar to concrete.

SOLUTIONING - A chemical dissolving of minerals present in the soil or rock.

SPALLING - The loss of chunks of concrete or rock from a surface, usually because of compression, impact, or abrasion.

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

STRATIFICATION - Separation of concrete into horizontal layers, with increasingly smaller material concentrated toward the top.

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

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

STRUCTURAL CRACK - A crack that calls into question the structural integrity of an element of a dam.

SUBSIDENCE - Flattening out or sinking.

SULFATE ATTACK - Chemical and/or physical reaction between sulfates (usually in soil or ground water) and concrete or mortar. Deterioration of the concrete or mortar may result. Sulfate attack is common in older dams in the western United States where sulfate-resistant cement was not used, or alkali aggregate was used.

Continued . . .

GLOSSARY

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

TERMINAL SECTION - A structure containing one or more energy dissipators.

TERMINAL STRUCTURE - See **ENERGY DISSIPATOR.**

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

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

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

TUNNEL - An enclosed waterway excavated through in situ material, usually away from the dam.

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

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

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

UPSTREAM POOL - See **RESERVOIR.**

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

VALVE - An adjustable device used to control or stop the flow of water in a waterway. A valve is fixed permanently within the waterway, and has a closure member that is either rotated or moved transversely or longitudinally in the waterway in order to control or stop the flow.

WATER COLLECTION SYSTEM - A system, which may be an open channel or pipe system, that is used to collect discharge from the relief wells, drainage blankets, and toe drains, and convey water to a point downstream of the dam. Normally, this water is discharged into the stream below the dam.

WATERSTOP - A continuous strip of waterproof material, usually PVC, metal, or rubber, designed to limit moisture penetration through concrete joints.

Continued . . .

GLOSSARY

WEATHERING - Changes in color, texture, strength, chemical composition, or other properties of a natural or artificial material due to the action of the weather.

WEEPHOLE - A drain embedded in a concrete or masonry structure to pass moisture from the foundation or backfill material to the surface of the structure.

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

WELL-GRADED SOIL - Soil with a continuous distribution of particle sizes from the coarsest to the finest, in such proportions that the successively smaller particles almost completely fill the spaces between the larger particles.

APPENDIX B

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REFERENCES

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