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Materials for Embankment Dams

Course Number: CE-02-208

PDH: 10

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Module 1: Introduction

Learning Objectives

By the end of this section, you will be able to:

- **Evaluate** the primary performance requirements and common failure mechanisms of embankment dams.
- **Identify** key "defense in depth" design concepts and material selection frameworks.
- **Select** appropriate monitoring and remedial strategies based on observed "danger signs" in existing structures.


Executive Summary: Successful embankment dam engineering relies less on exhaustive numerical analysis and more on expert judgment, the application of "defense in depth" redundancy, and the continuous evaluation of materials and foundation interfaces throughout the project life cycle.

Historical Perspective and Modern Popularity

Embankment dams have been utilized for at least 5,000 years. Early structures often relied on haphazard methods with a limited understanding of soil mechanics and flood flow, leading to frequent failures and low public confidence. Today, modern engineering allows for structures exceeding **300 meters** in height and involving millions of cubic meters of fill.

Key Drivers for Embankment Selection

- **Material Proximity:** These dams utilize materials typically available within short haul distances.
- **Foundation Versatility:** The design accommodates a wider variety of foundation conditions compared to other dam types.
- **Cost-Efficiency:** They are often the least costly option for large-scale water storage.

 **Design Tip:** Before finalizing a site, PEs must rigorously investigate susceptibility to internal or external erosion, potential for overtopping under credible loading, and the factor of safety against structural sliding.

Basic Requirements for Satisfactory Performance

For an embankment dam to perform reliably over a service life spanning century, it must meet several non-negotiable criteria:



Stability and Seepage Control

- **Structural Stability:** Foundations and abutments must remain stable against slumping, sliding, and sloughing during construction, operation, and extreme events like earthquakes or floods.
- **Controlled Seepage:** Seepage must be collected to prevent **pipng**, excessive uplift, dissolution, or erosion of material into cracks and joints.
- **Redundancy:** Utilize **multiple defenses**, including foundation cutoffs, select core material, chimney filters, blanket drains, and relief wells.

Hydraulic and Environmental Resilience

- **Freeboard and Capacity:** Freeboard must account for wave action, post-construction settlement, and seismic deformation. Spillways and outlets must be designed with sufficient capacity to prevent overtopping.
- **Slope Protection:** Upstream and downstream slopes require protection against wave action, reservoir fluctuations, rainfall, and wind.

Construction Integrity

- **Foundation Preparation:** PEs must ensure the removal of unsuitable material and the treatment of rock surfaces using air/water cleaning, slush grout, and dental concrete.
- **Bonding:** The initial lifts of core material should be as **plastic as possible** to ensure a high-integrity bond with the rock foundation.

If the following conditions are observed, PEs must evaluate the safety impact immediately:

Table 1-1: Operational Danger Signs

Category	Specific Danger Signs
Seepage	Emerging seepage on slopes, seepage carrying fines, or clogged drains
Surface	Erosion of outer slopes, sink-holes, or unexplained depressions
Structural	Cracks on the crest or abutments, or increased settlement rates over time

Analysis of Embankment Dam Failures

Historical data indicates that approximately **40 percent** of failures and accidents in embankment dams are the result of leakage and piping through the dam, foundation, or abutments. Other primary causes include overtopping and washout during floods, and slides caused by a high phreatic surface or seismic activity.



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⚠ **Safety Constraint:** Failure is seldom the consequence of a single shortcoming; it typically occurs where two or more defects or deficiencies coincide. Engineers must adopt the "**belt and suspenders**" principle: if one defensive element fails, there must be additional measures to take its place.

Underlying Concepts for Engineering Practice

To ensure long-term performance, PEs should adhere to the following guiding principles:

- **Design Defensively:** Assume the core **may crack** and ensure the dam remains safe via redundant filters, drains, and transitions.
- **Foundation Judgment:** Use experience and conservative judgment for foundation treatment; the only appropriate opportunity to treat the foundation is when it is exposed during construction.
- **Continuous Review:** The "design" is not static; it must be continually reviewed and modified as site conditions are revealed during detailed investigations and construction.
- **Peer Review:** Major projects or unusual site conditions should seek independent boards of consultants or panels of experts from planning through operation.
- **Remedial Urgency:** Evaluating performance through instrumentation (water pressure, seepage rate, deformation) is critical; undertake remedial treatment **promptly** if safety is compromised.

Checkpoint Quiz

1. According to the "belt and suspenders" principle advocated by Arthur Casagrande, what is the primary design assumption for the dam core?

Answer: (b). This concept is known as "defense in depth." It acknowledges that while engineers attempt to prevent cracking through analysis and material selection, real-world conditions (such as differential settlement or seismic activity) may still cause a core to breach. Therefore, the overall design must include redundant defensive measures—such as internal filters and drains—that can safely handle concentrated seepage even if the primary barrier (the core) fails.

2. What percentage of embankment dam failures and accidents are historically attributed to leakage and piping?

Answer: (c). A review of data from the 1975 and 1988 ASCE/USCOLD studies confirms that approximately 40 percent of failures and accidents are the result of leakage and piping through the dam, its foundation, or its abutments. This high percentage underscores why seepage control and internal drainage are the most critical technical aspects of embankment dam design.



3. When is the most critical and often only appropriate time to perform foundation treatment procedures?

Answer: (b). As emphasized in Section 1.4, once the embankment fill is placed or the reservoir begins to fill, access to the foundation becomes impossible or prohibitively expensive. The "window of opportunity" occurs during excavation and initial fill placement, where engineers can observe actual geological conditions and apply treatments like dental concrete or slush grouting to ensure a watertight bond between the earth and the rock.



Module 2: Soil Materials

Learning Objectives

By the end of this section, you will be able to:

- **Classify** fine-grained and coarse-grained soils using USCS index properties and engineering behavior.
- **Calculate** hydraulic conductivity and relative density using standard empirical formulas for dam design.
- **Evaluate** the risks of dispersive clays and soil liquefaction and select appropriate mitigation strategies.

Executive Summary: Soil selection for embankment dams is driven by economic availability and engineering behavior. While index properties like plasticity and gradation serve as primary classification tools, final design must account for specific characteristics—such as clay mineralogy and particle density—to ensure stability against internal erosion and seismic loading.

Introduction

Embankment dams are constructed of all types of geologic materials, with the exception of organic soils and peats. Most embankments are designed to utilize the economically available on-site materials for the bulk of construction. Special zones such as filters, drains, and riprap may come from off-site sources. Soil materials are commonly obtained from local borrow pits and required excavations.

Inorganic soils are divided into two broad categories: **fine-grained soils** and **coarse-grained soils**. Many embankments are constructed of **broadly graded soils** (e.g., moraine deposits) which exhibit characteristics of both.

Fine Grained Soils (Silts and Clays)

Fine-grained soils are frequently used in homogeneous dams and in the impervious core sections of zoned embankment dams.

General Characteristics and Index Properties

Fine-grained soils are defined by the Unified Soil Classification System (USCS) as materials having at least 50 percent by weight of particles finer than 0.074 mm (U.S. Standard No. 200 sieve).

- **Clays:** Particles smaller than 2 microns (0.002 mm).
- **Silts:** Particles between 2 microns and the No. 200 sieve.



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