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Materials for Embankment Dams

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CHAPTER 1 — INTRODUCTION

This course provides a brief summary of the use of materials in embankment dams. It is not intended to serve as an exhaustive treatise on the characteristics of the various materials that comprise these types of dams. It is, rather, an outline of important points that need to be recognized and understood when selecting materials for use in the embankment dam.

This introduction provides a framework within which materials for use in the dam are selected and evaluated. The basic requirements and functions of embankment dams are described, along with underlying concepts for their design, construction and successful operation.

1.1. HISTORICAL PERSPECTIVE

Embankment dams have served man at least 5,000 years. The remains of ancient structures and civilizations provide clues to the efforts of mankind in the engineering and construction of dams. Jansen (1980) traces the history of dams from the period BC to the 20th century. Of the earth dams built BC, Jansen comments:

> *"Turning to the most available materials, the ancient dam builders made liberal use of soils and gravels. Since they had only the slightest understanding of the mechanics of materials or of flood flow, their methods were haphazard, and their works often failed. Embankment dams were low on the scale of public confidence for many centuries."*

Today, embankment dams exist in excess of 300 meters high with volumes of many millions of cubic meters of fill. Thousands of embankment dams exceeding 20 meters in height have been constructed throughout the world. Currently, China is the leader in embankment dam construction.

The embankment dam is popular because:

- Materials available within short haul distances are used,
- The embankment dam can accommodate a variety of foundation conditions, and
- Often, the embankment dam is least costly when compared to other dam types.

However, before determining whether an existing dam is adequately designed or a proposed embankment dam is suitable for the dam site, the evaluation should investigate such questions as:

- Are the dam and its foundation susceptible to internal or external erosion?
- Is the dam subject to overtopping considering its operational characteristics and various credible loading conditions?
- Is structural sliding of the existing or proposed dam and abutment slopes a possible failure mechanism and, if so, is there an adequate factor of safety?

1.2. BASIC REQUIREMENTS OF THE EMBANKMENT DAM

Satisfactory performance of embankment dams must include the following:

- The embankment, foundation, and abutments must be stable against slumping, sliding and sloughing during construction, during all conditions of reservoir operation and during and following unusual events such as earthquake and flood.
- Seepage through the embankment, foundation, and abutments must be controlled and collected to prevent excessive uplift pressures, piping, sloughing, dissolution and erosion of material into cracks, joints and cavities. Because of low yield within the watershed, some reservoirs require a limitation on the rate of seepage. Foundation cutoffs, select core material, upstream impervious blankets, chimney filter and drain systems, blanket drains, finger drains, toe drains, multiple transition filters between core and rockfill shell material, drainage adits and tunnels, drain holes and relief wells are common measures to control and limit seepage. Redundancy and multiple defenses are often necessary and represent sound engineering practice considering the uncertainties at any given dam site. Existing dams that do not incorporate typical seepage defense measures may require prompt defensive action should a problem develop.
- Freeboard must be sufficient to prevent overtopping by wave action. An allowance for post-construction settlement of the dam and its foundation, and deformation caused by earthquake must be included. In addition, freeboard must be sufficient to pass the maximum design flood, often chosen as the probable maximum flood. Spillways and outlets must be designed with sufficient capacity such that overtopping of the dam does not occur.
- Outer slope protection on both the upstream and downstream slopes must prevent erosion by wave action, reservoir level fluctuations, rainfall and wind. Materials must be durable and resistant to wet/dry and freeze/thaw cycles. Materials must resist weather and erosion over long periods of time.
- The foundations must be properly prepared and treated during construction. Unsuitable material must be removed, water entering the foundation must be controlled, and foundation surfaces must be prepared to receive the first lifts of fill material. If the foundation is a rock surface, the treatment below the core will, at a minimum, include detail cleaning of the rock surface using air and, possibly, water and the application of slush grout and dental concrete, if required. The first few lifts of core material should be as plastic as possible and specially treated to

ensure a good bond with the rock foundation.

- The dam must be constructed using appropriate quality control and quality assurance procedures. Appropriate changes to the design must be made during construction should site conditions so indicate. The ultimate performance of the dam depends on careful construction especially regarding foundation treatment, moisture and density control of the fill, and the design and construction of filters and drains.
- During reservoir filling and project operation, routine inspections of the dam and its foundation and the evaluation of instrumentation data to identify abnormal behavior and the necessity for remedial treatment are required. Long-term acceptable performance will be assured by early recognition of problems and prompt remedial treatment. Danger signs include:

  - Erosion of the outer slopes, or of the abutments
  - Wet or saturated areas along the downstream slope
  - Seepage emerging on the downstream slope or from abutments and foundations
  - Changes in seepage rate or in the pore pressure distribution within the dam
  - Clogged drains, or seepage by-passing the drainage system
  - Seepage carrying fines
  - Cracks on the crest, the outer slopes, or within the abutments
  - Sink-holes or unexplained depressions
  - Increased settlement with time

1.3. EMBANKMENT DAM FAILURES

A variety of texts and publications discuss dam safety, the reasons for failures and accidents, and lessons to be learned. A review of the data from the 1975 and 1988 ASCE/USCOLD studies indicates that about 40 percent of failures and accidents to embankment dams are the result of leakage and piping through the dam, foundation, and/or the abutments. Flood discharge and/or overtopping and washout of the dam are a second major cause of failures and accidents. Slides within the abutments or the embankment slopes caused by a high phreatic surface within the downstream slope, drawdown of the reservoir, or earthquake are another major cause of failures and accidents to embankment dams.

Ralph Peck, in his Laurits Bjerrum Memorial Lecture, 1980, commented on the above. The following excerpts are from this lecture.

> *"We can infer ... that a failure is seldom the consequence of a single shortcoming. Usually there is at least one other defect or deficiency, and the failure occurs where two or more coincide. This inference supports the principle of designing to provide defense in depth, the 'belt and suspenders' principle long advocated by Arthur Casagrande. It postulates that if any defensive element in the dam or its foundation should fail to serve its function, there must be one or more additional defensive measures to take its place…*

"The bedrock treatment appropriate to the geological conditions is a matter of design. It is not an aspect of design susceptible, however, to numerical analysis. Instead, it requires the exercise of judgment, a sense of proportion. When a jointed bedrock foundation is being treated and covered with the first layers of fill - a crucial time with respect to the future performance of the dam - engineers fully acquainted with the design requirement should be present, should have the authority to make decisions on the spot, and should not delegate their authority unless and until they are satisfied that their judgment concerning the particular project has been fully appreciated by their subordinates.

"I doubt if guidelines, regulations, or even the best of specifications can take the place of personal interaction between designers and field forces at this stage...

"The literature already has much to say about cracking of earth dams. The emphasis, however, is on the mechanics of producing the initial cracks, an aspect that has recently become at least partly amenable to analysis. The analytical results serve a useful purpose: reduction of cracking can undoubtedly be achieved most successfully if the causes of cracking are understood and avoided. Nevertheless, to accord with the principle of defense in depth, every dam should be designed on the assumption that the core may crack and that the dam should be safe even if it does.

"So we must reckon with the conclusion that modern dams seldom if ever fail because of incorrect or inadequate numerical analyses. They fail because inadequate judgment is brought to bear on the problems that, whether anticipated or not, arise in such places as the foundation or the interface between embankment and foundation."

1.4. UNDERLYING CONCEPTS

The theme of this chapter and of this report is the satisfactory performance of the embankment dam through appropriate selection and understanding of materials. This satisfactory performance must be achieved throughout the useful life of the dam and reservoir, a period of time that could span hundreds of years. To achieve this, the following guiding principles are suggested:

1. **Design defensively, using redundant systems.** For example, a well designed and constructed core, facing or internal membrane backed up by appropriate filters, drains and transitions with sufficient capacity to safely accept flow from cracks or other defects. The many failures and accidents caused directly or indirectly by leakage and piping within the dam, the foundation or the abutments point to the necessity of multiple lines of defense.
2. **Use experience and conservative judgment in selecting foundation preparation and treatment procedures**. The only appropriate opportunity to treat the foundation is when it is exposed during construction. It is difficult, expensive, and sometimes impossible to further treat the foundation after much of the embankment has been placed or after the reservoir has filled.
3. **Continually review and change, if necessary, the "design" of the dam**. This