*USSD's Committee on Materials for Embankment Dams is preparing a report entitled "**Materials for Embankment Dams**". The stated objectives of the document are as follows:*

- *Present the essence of ICOLD and USSD (USCOLD) Bulletins pertinent to materials for embankment dams.*
- *Tie together the ICOLD Bulletins, which are primarily on singular topics to demonstrate their application to design and construction of embankment dams. Therefore, the USSD document would be a comprehensive document tying together the ICOLD documents, which are specific.*
- *Enhance the ICOLD Bulletins' information with new information, experiences and technology changes (state-of-the-practice).*
- *Prepare a document for USSD membership, practitioners, and possibly the basis for University courses.*
- *Reference publications that provide good background and that will direct the reader/researcher towards more in-depth works.*

The report includes an introduction chapter, and ten technical chapters on the following topics: soil materials, rock materials, granular filters and drains, bituminous concrete facings and cores, concrete facing for rockfill dams, geosynthetics, reinforced fill, slope protection, materials for watertight cutoffs, and construction issues. Each chapter was authored by a member of the committee with expertise on the topic, and was subjected to two rounds of peer review by experts within USSD, ICOLD and others who had relevant expertise on the various topics. The following is an excerpt from the Introduction chapter of the report.

MATERIALS FOR EMBANKMENT DAMS

Introduction
by David E. Kleiner

This document provides an introduction to the important points that need to be recognized and understood when selecting materials for use in an 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.

Historical Perspective

Embankment dams have served man at least 5000 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:

- Is 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?

Basic Requirements of the Embankment Dam

Satisfactory performance of embankment dams must include the following:

1. 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.

2. 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.

3. 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.

4. 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.

5. 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.

6. 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.

7. 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, and
    - Increased settlement with time.

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% 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.

Guiding Principles

The subject of this summary 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, e.g., 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 process starts when the first reconnaissance of the site occurs and it continues through detailed site investigations, through design and analysis of the dam and its foundation treatment, through construction, and during reservoir filling and project operation. The owner of the dam must understand that it is not possible to eliminate all uncertainties that could affect construction and the final cost. The design of the dam is modified as the design process proceeds through site investigations and the analysis of data, and evolves as a better understanding of material and foundation properties is obtained. During construction, foundations are exposed and treated, and borrow areas are opened, yielding data which was not available earlier. The design is challenged and changes are made as needed.

4. Seek peer review throughout the planning, design and analysis, construction, and operation of the dam and reservoir. In the United States, for major dams and/or unusual site conditions, it is common practice to engage an independent board of consultants to advise the owner with respect to the hydrologic and structural safety of the dam and reservoir from the start of planning studies to project start-up and operation. The Federal Energy Regulatory Commission and U.S. Bureau of Reclamation require this. State dam safety agencies require compliance with specific standards for design and construction. Commonly, on major international projects, an independent panel of experts meets periodically to provide experience and judgment concerning critical design and construction issues regarding foundation treatment, materials, and lines of defense.

5. Throughout the life of the project, evaluate the performance of the dam and reservoir using visual observations and instruments. Detailed inspections, conducted regularly by walking the crest, slopes, toe, and abutments of the dam, provide a visual record of performance. Evaluation of instruments that measure water pressure, seepage rate, and deformation provides additional insights concerning performance. Frequent inspections and data evaluation provide the means to judge the performance and structural health of the dam and its foundation.

6. Undertake remedial treatment promptly and in advance of a serious incident. Any abnormal performance of the dam, the foundation, or the abutments, as observed during the visual inspections or as a result of data analysis, must be evaluated to determine the potential impact to the safety of the dam. If it is determined that the safety of the dam may be compromised, the design and construction of remedial repairs should be undertaken immediately.

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