Conduits through Embankment Dams

Best Practices for Design, Construction, Problem Identification and Evaluation, Inspection, Maintenance, Renovation, and Repair

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FEMA

Introduction

Conduits convey water from a reservoir through, under, or around an embankment dam in a controlled manner. Most conduits are part of an outlet works. However, some conduits act as either primary or service spillways; auxiliary or secondary spillways to assist the primary spillway structure in passing floods; or power conduits (penstocks) used for the generation of power.

Tens of thousands of these conduits through embankment dams in the United States are aging and deteriorating. Many of these conduits were poorly constructed and are not frequently inspected, if at all. Deteriorating conduits pose an increasingly greater risk for developing defects that can lead to embankment dam failure with each passing year.

To address this growing concern, the Federal Emergency Management Agency (FEMA) National Dam Safety Program sponsored development of a technical manual in conjunction with the Association of State Dam Safety Officials, Bureau of Reclamation, Federal Energy Regulatory Commission, Natural Resources Conservation Service, and U.S. Army Corps of Engineers.

The *Technical Manual: Conduits through Embankment Dams* provides procedures and guidance for "best practices" concerning design, construction, problem identification and evaluation, inspection, maintenance, renovation, and repair associated with conduits through embankment dams. The manual is intended for use by personnel familiar with embankment dams and conduits, such as designers, inspectors, construction oversight personnel, and dam safety engineers.

How do conduits affect embankment dams?

A conduit represents a discontinuity through an embankment dam and its foundation. This discontinuity can cause settlement to be different adjacent to the conduit than it is in the rest of the embankment dam. Earthfill may also be compacted differently around a conduit than for the rest of the embankment dam. These factors can cause cracking of the earthfill and lead to other consequences. Failures of embankment dams caused by the uncontrolled flow of water through the dam or foundation are a common problem.

A conduit can develop defects from deterioration, cracking from foundation compressibility, or joint separation due to poor design and construction. Water leaking from defects in conduits can contribute to seepage pressures exceeding those that occur solely from flow through soils in the embankment dam from the reservoir. When preferential flow paths develop in the earthfill through which water can flow and erode the fill, severe problems or breaching type failures often result.

Failure of an embankment dam due to the discontinuity represented by the conduit.

What is internal erosion and backward piping erosion?

Internal erosion and backward piping erosion are used to describe failure mechanisms of embankment dams associated with the uncontrolled flow of water rather than the single term "piping." These terms describe the distinctly different mechanisms by which water can damage embankment dams.

"Backward erosion piping" applies to conditions where water flows through the pores of a soil. "Backward erosion piping" is caused solely by intergranular flow causing excessive seepage forces at an exit face. These seepage forces cause a boil condition or particle detachment at an exit face, if it is not protected by a properly designed filter.

"Internal erosion" describes the more common way that water can damage embankment dams, as it flows through cracks, discontinuities at the interfaces between conduits and earthen embankments or their foundations, or other preferential flow paths. Seepage flow for internal erosion is typically concentrated.

A failure due to internal erosion often leaves a tunnel-shaped void along the conduit.

What factors can lead to embankment dam failure?

Factors that increase the likelihood of internal erosion and backward erosion piping incidents developing at a given site include:

1. Conduits constructed across abruptly changing foundation conditions (i.e., a concrete core wall or bedrock with a quickly changing profile) are more likely to experience differential settlement.

2. Circular conduits constructed without concrete bedding or cradles are more likely to experience problems than conduits in more favorable shapes.

3. Conduits with an excessive number of joints are more likely to develop defects that can lead to problems.

4. Excavations made to replace unsuitable foundation materials for conduits increase the potential for differential settlement problems.

5. Conduits with compressible foundations are more likely to deform excessively, which may damage the conduit. Compressible foundations may also contribute to differential settlement that can result in hydraulic fracture of the earthfill surrounding the conduit.

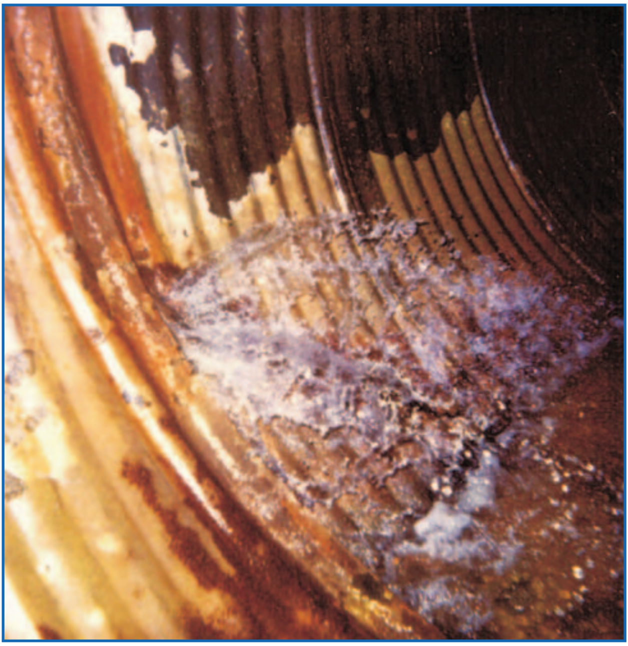
6. Conduits located in closure sections in embankment dams contribute to differential settlement problems.

7. Embankment dams constructed with materials susceptible to internal erosion or backward erosion piping.

8. Conduits constructed without adequate compaction around the conduit are more likely to experience erosional problems.

9. Embankment dams constructed without a chimney filter or conduits constructed without a filter collar or filter diaphragm.

10. Conduits constructed of materials susceptible to deterioration, such as corrugated metal pipe.



Leakage through a defective joint in a corrugated metal pipe outlet works conduit.

Sinkhole which developed over a spillway conduit.

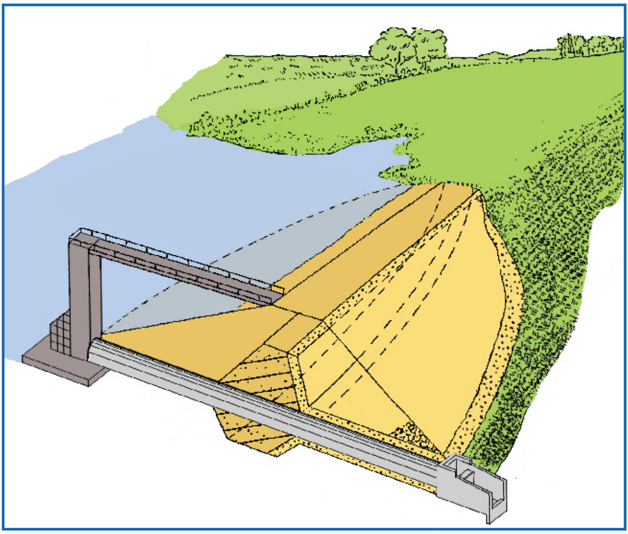
Best practices for conduits through embankment dams

Until about the mid-1980s, the most common approaches for controlling seepage were antiseep collars (also known as cutoff collars) and careful compaction (special compaction using small hand held compaction equipment) of backfill around conduits. Antiseep collars are impermeable diaphragms, usually of sheet metal or concrete, constructed at intervals within the zone of saturation along the conduit. They increase the length of the seepage path along the conduit, which theoretically lowers the hydraulic grdient and reduces the potential for backward erosion piping.

Antiseep collars were designed primarily to address intergranular seepage (flow through the pore spaces of the intact soil). Antiseep collars did not fully address the often more serious mechanism of failure (internal erosion), that occurs when water flows through cracks and erodes the compacted earthfill near the conduit outside the zone of influence of the antiseep collars in the compacted earthfill near the conduits.

Most embankment dam designers, dam regulators, and dam-building agencies now recommend a zone of designed filter material surrounding the penetrating conduit. Some designs use a filter diaphragm located about midway between the centerline of the embankment dam and downstream toe. Other designs use a filter collar around the downstream portion of the conduit. Often, a chimney filter serves as a diaphragm to protect the conduit, as well as satisfying other functions of embankment dam design. Since filters have become a standard design element in

Antiseep collars impeded the compaction of soils around the conduit. Hand tampers were used next to the antiseep collar.



A typical filter design used for an embankment dam with a penetrating conduit.

embankment dam designs, very few failures have occurred that can be attributed to internal erosion or backward erosion piping near conduits.

The technical manual provides guidance for understanding and addressing a wide ranging number of topics, such as:

- Locating the conduit
- Materials used in construction of the conduit
- Hydraulic design
- Structural design
- Watertightness of conduit joints
- Excavation
- Selection and compaction of backfill
- Hydraulic fracture
- Filter zones
- Potential failure modes

Concrete placement for a reinforced cast-in-place conduit.

Insertion of a high density polyethylene (HDPE) slipliner into an existing outlet works conduit.

- Defects associated with conduits
- Inspection and assessment of conduit-related problems
- Evaluation by geophysical and nondestructive testing
- Sinkholes and subsidence
- Alternative means of reservoir evacuation
- Appropriate emergency actions
- Renovation of conduits
- Replacement of conduits
- Repair and abandonment of conduits

In addition, the technical manual contains more than 280 illustrative figures, 34 case histories, and an extensive glossary.

How can you obtain a copy of the technical manual?

The *Technical Manual: Conduits through Embankment Dams* is available in three formats (hard copy, CD-ROM, and DVD) in an attempt to address the interests and needs of a wide variety of users in the dam safety community. The formats are:

1. Hard copy - A hard copy is useful where direct access to a computer is not available, such as at construction sites. However, users of hard copies will lack the hyperlinking and search capabilities available in the CD-ROM and DVD formats.

2. CD-ROM - The CD-ROM and DVD formats include hyperlinking, search capabilities, and PDF copies of all cited references in the technical manual that were available in the public domain or where permission for use was obtained.

3. DVD - The DVD format also includes an extensive collection of “additional reading” references. PDF copies of these references are provided to assist the user with furthering their understanding of topics related to conduits and embankment dams.

For information on how to obtain a hard copy, CD-ROM, DVD version of this technical manual go the FEMA website at:

www.fema.gov/fima/damsafe