Technical Manual: Conduits through Embankment Dams

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

September 2005

FEMA

Conduits through Embankment Dams

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

Federal Emergency Management Agency

September 2005

Preface

Tens of thousands of conduits through embankment dams in the United States are aging and deteriorating. These conduits often 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. In an effort to deal with this problem, this document has been prepared to collect and disseminate information and experience that is current and has a technical consensus.

This document 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. Most of the available information on these topics was reviewed in preparing this document. Where detailed documentation existed, it was cited to avoid duplicating available materials. The authors have strived not to reproduce information that is readily accessible in the public domain. This document attempts to condense and summarize the vast body of existing information, provide a clear and concise synopsis of this information, and present a recommended course of action. This document is intended for use by personnel familiar with embankment dams and conduits, such as designers, inspectors, construction oversight personnel, and dam safety engineers.

In preparation of this document, the authors frequently found conflicting procedures and standards in the many references they reviewed. Where conflicts were apparent, the authors focused on what they judged to be the "best practice" and included that judgment in this document. Therefore, this document may be different than some of the various participating agencies' own policies.

Embankment dams, regardless of their size, create a hazard potential from the stored energy of the water they impound. Examples, such as Kelley Barnes Dam, which failed suddenly in 1977, show the destructive power of water when it is released suddenly from behind even a small embankment dam. This embankment dam was less than about 40 feet high and about 400 feet long, but when it failed, it released water downstream at an estimated flow rate of over 24,000 ft^3/s, killing 39 people. The hazard potential of an embankment dam is based on the consequences of failure, rather than its structural integrity.

Embankment dams can be classified according to their hazard potential for causing damages downstream should they fail. Various State and federal agencies have different systems for rating the hazard classes of embankment dams. A single, universally accepted hazard classification system does not exist. All of the hazard classification systems group embankment dams into categories based on the potential impacts of a theoretical release of the stored water during a dam failure. However, the most common problem with all of these classification systems is the lack of clear, concise, and consistent terminology. The Federal Emergency Management Agency (FEMA) has a hazard classification system that is clear and succinct, and this system was adopted for the purposes of this document. The reader is directed to FEMA 333, *Federal Guidelines for Dam Safety: Hazard Potential Classification Systems for Dams* (1998), for a complete version of their system. The FEMA document uses three hazard potential levels to classify embankment dams. These levels are summarized as follows:

- *Low hazard potential.*—Embankment dams assigned the low hazard classification are those where failure or misoperation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

- *Significant hazard potential.*—Embankment dams assigned the significant hazard classification are dams where failure or misoperation results in no probable loss of human life, but can cause economic loss, environmental damage, or disruption of lifeline facilities, or can impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas, but could be located in areas with population and significant infrastructure.

- *High hazard potential.*—Embankment dams assigned the high hazard classification are those where failure or misoperation will probably cause loss of human life.

Hazard potential classification	Loss of human life	Economic, environmental, lifeline losses
Low	None expected	Low and generally limited to owner
Significant	None expected	Yes
High	Probable—one or more expected	Yes (but not necessary for this classification)

Embankment dam hazard classifications are assigned based on their potential for causing downstream damage, but these classifications do not reflect in any way on the likelihood that the dam may fail. An embankment dam might be classified as having a low hazard potential based on the impacts a failure would have on the downstream area, but have a high probability of failure if it were in very poor condition. The hazard classification says nothing about the safety or condition of the structure.

The guidance in this document is considered valid technically without regard to the hazard potential classification of a particular embankment dam. However, some design measures that are commonly used for design of high and significant hazard embankment dams may be considered overly robust for use in low hazard dams. As an example, chimney filters that extend across the entire width of the embankment fill section are recommended for most high hazard embankment dams. Many smaller, low hazard embankment dams are constructed without this feature. This document recommends that even low hazard embankment dams should contain other currently accepted design measures that address seepage and internal erosion along the conduit. Specifically, a filter diaphragm or filter collar around the conduit is recommended for all embankment dams penetrated by a conduit.

Often, low hazard embankment dams are small structures (height or reservoir volume). The term "small embankment dam" does not have a single widely accepted definition. Some designers may consider a 25-foot high embankment dam to be the largest dam in the small dams category, and others may consider this to be the smallest dam in the large dam category. The International Commission on Large Dams defines large embankment dams as being more than about 50 feet high. For this reason, this document will consider only the hazard potential of the embankment dam. The focus of this document is on significant and high hazard embankment dams due to the concern for loss of life and property damage. However, where appropriate, deviation from the guidance is noted for low hazard embankment dams. This deviation is not all inclusive, and the designer may find additional guidance on the design and construction of conduits within low hazard embankment dams in Natural Resources Conservation Service (NRCS) *National Handbook of Conservation Practice Standard Code 378 Pond* (2002). The designer should be aware that future downstream development could require revising the hazard potential classification from low to significant or high. Pressurized conduits are not recommended at low hazard embankment dams, since these structures often lack regular inspections and may not contain the appropriate safety features as discussed in this document.

FEMA's National Dam Safety Program sponsored development of this document 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 primary authors of this document are Chuck Cooper, P.E. (Bureau of Reclamation), John Cyganiewicz, P.E. (Bureau of Reclamation), James Evans, P.E. (Federal Energy Regulatory Commission), Mark Haynes, P.E. (Colorado Division of Water Resources), Danny McCook, P.E. (Natural Resources Conservation Service),

David Pezza, P.E. (U.S. Army Corps of Engineers), and Hal Van Aller, P.E. (Maryland Department of the Environment). The technical editor for this document was Lelon A. Lewis (Bureau of Reclamation). Illustrators for this document were Bonnie Gehringer (Bureau of Reclamation) and Wendy Pierce (Natural Resources Conservation Service). Additional technical assistance was provided by Cindy Gray (Bureau of Reclamation).

Peer review of this document has been provided by Doug Boyer, P.E. (Bureau of Reclamation), Steve Higinbotham, P.E., Brad Iarossi, P.E., William Irwin, P.E. (Natural Resources Conservation Service), Robert McGovern, P.E. (Bureau of Reclamation), Dr. Edward B. Perry, P.E., and Chuck Redlinger, P.E. (Bureau of Reclamation).

The National Dam Safety Review Board (NDSRB) reviewed this document prior to issuance. The NDSRB has responsibility for monitoring the safety and security of dams in the United States, advising the Director of FEMA on national dam safety policy, consulting with the Director of FEMA for the purpose of establishing and maintaining a coordinated National Dam Safety Program, and monitoring of State implementation of the assistance program.

A number of additional engineers and technicians provided input in preparation of this document, and the authors greatly appreciate their efforts and contributions. The authors also extend their appreciation to the following agencies and individuals for graciously providing additional reviews, information, and permission to use their materials in this publication:

ASTM International
American Concrete Institute
American Concrete Pressure Pipe Association
American Society of Agricultural and Biological Engineers
American Society of Civil Engineers
Association of State Dam Safety Officials, Lori Spragens and Sarah Mayfield
BC Hydro, Steve Garner
Bureau of Indian Affairs
Bureau of Reclamation, Richard D. Benik, Rick Frisz, Ernest Hall, Walter
    Heyder, John LaBoon, Rich Markiewicz, William McStraw, Jay Stateler,
    and Chris Veesaert
Canadian Dam Association
Canadian Geotechnical Journal
Colorado Division of Water Resources
Concrete Reinforcing Steel Institute
Federal Energy Regulatory Commission
Keith Ferguson
International Commission on Large Dams

LakeLine Magazine
Maryland Dam Safety Division, Cas Taherian
Mine Safety and Health Administration, John Fredland
Montana Department of Natural Resources and Conservation, Michele Lemieux
National Oceanic and Atmospheric Administration
National Research Council of Canada
Natural Resources Conservation Service, Wade Anderson
Ohio Department of Natural Resources, Jerry Reed
Ed Rossillon
Schnabel Engineering, Mark Dunscomb and Ned Billington
Sonex Corporation, William C. Boyce
Thurber Engineering Ltd., John Sobkowicz
Transportation Research Board
University of New South Wales, Professor Robin Fell
URS Corporation, Sal Todaro
United States Army Corps of Engineers, David Capka, Ed Chisolm, Dan Leavell, Bob Oberle, Michael R. Snyder, and Duane Stagg
Washington State Department of Ecology

If conduits are not designed and constructed correctly, embankment dams will have an increased probability of failure, which endangers the public. The particular design requirements and site conditions of each embankment dam and conduit are unique. No single publication can cover all of the requirements and conditions that can be encountered during design and construction. Therefore, it is critically important that conduits through embankment dams be designed by engineers experienced with all aspects of the design and construction of these structures.

The users of this document are cautioned that sound engineering judgment should always be applied when using references. The authors have strived to avoid referencing any material that is considered outdated for use in modern designs. However, the user should be aware that certain portions of references cited in this document may have become outdated in regards to design and construction aspects and/or philosophies. While these references still may contain valuable information, users should not automatically assume that the entire reference is suitable for design and construction purposes.

Many sources of information were utilized in the development of this document, including:

- Published design standards and technical publications of the various federal and State agencies involved with the preparation of this document.

- Published professional papers and articles from selected authors, technical journals and publications, and organizations.

- Experience of the individuals and the federal and State agencies involved in the preparation of this document.

This document is available in three formats: hard copy, CD-ROM, and DVD. The CD-ROM and DVD formats include built-in Adobe Acrobat Reader software, hyperlinks, and search capabilities. A hyperlink is a highlighted word or image within the document which, when clicked, takes the user to another place within the document or to another location altogether. Hyperlinks are especially useful when the user wants to see the full reprint of a cited reference or the exact location in a reference from which the material was cited. The available document formats and a description of their contents are as follows:

- *Hard copy.*—There may be some users of this document who will not have direct access to a computer and may find hard copies more valuable to them. A hard copy would be especially useful to those users working in the field at construction sites, where direct access to a computer may not be available. Users of the hard copies will lack the hyperlinking and search capabilities available in the other formats.

- *CD-ROM.*—The CD-ROM contains this document and PDF copies of the cited references that were available in the public domain or where permission for reprint was granted. A CD-ROM format is being made available, since there may be a significant number of users who only have CD-ROM drives in their computers. The CD-ROM format will allow these users to take advantage of most of the features built into the digital version of this document. However, there was not enough roomon a single CD-ROM to contain all the features included on the DVD version of the document. Not included on the CD-ROM are the PDF copies of the references in the “additional reading” list. The "additional reading" references have not been specifically cited in this document, but may be of additional interest to the user in furthering their understanding of conduits and embankment dams.

- *DVD.*—The DVD contains this document, PDF copies of the cited references that were available in the public domain or where permission for reprint was granted, plus “additional reading” references in PDF format. As DVD drives become more common, the DVD format will eventually become the preferred format for all users, since it allows the user to utilize all the available features.

This document is intended solely for noncommercial and educational purposes. PDF copies of references available in the public domain have been included whenever possible. For references not readily available in the public domain, efforts were made to obtain copyright permission. Users should be aware that PDF copies for a number of cited references were unavailable due to size constraints, lack of availability in the public domain, or permission for reprint not being granted. These references have been hyperlinked to a PDF file titled "Reference unavailable." For these references, users may want to contact the author or publisher directly for reprint information.

Suggestions for changes, corrections, or updates to this document should be directed to:

Bureau of Reclamation
Denver Federal Center, Bldg. 67
6th Avenue and Kipling
Denver, Colorado 80225-0007
Attention: Chuck Cooper (D-8130)

Please reference specific pages, paragraphs, or figures within this document, together with proposed new material in any convenient format. Sources of proposed new material should be completely cited. Submission of material signifies permission for use in a future revised edition of this document, but credit for such new material will be given where appropriate.

The material presented in this document has been prepared in accordance with recognized engineering practices. The guidance in this document should not be used without first securing competent advice with respect to its suitability for any given application. The publication of the material contained herein is not intended as representation or warranty on the part of individuals or agencies involved, or any other person named herein, that this information is suitable for any general or particular use, or promises freedom from infringement of any patent or patents. Anyone making use of this information assumes all liability from such use.

Any use of trade names and trademarks in this document is for descriptive purposes only and does not constitute endorsement. The information contained herein regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm.

Contents

page

Tables

Figures

Figures in the Appendices

No. *page*

Appendix A

Appendix B

Common Abbreviations

AAR, alkali-aggregate reaction
AASHTO, American Association of State Highway and Transportation Officials
ACI, American Concrete Institute
ADCI, Association of Diving Contractors International
AISI, American Iron and Steel Institute
ASCE, American Society of Civil Engineers
ASDSO, Association of State Dam Safety Officials
ASTM, ASTM International
ATV, all-terrain vehicle
AWS, American Welding Society
AWWA, American Water Works Association
BIA, Bureau of Indian Affairs
CAT, computerized axial tomography
CCTV, closed circuit television
CD-ROM, compact disc—read-only memory
CFR, comprehensive facility review
CIPP, cured-in-place pipe
CMP, corrugated metal pipe
CPR, cardiopulmonary resuscitation
CPS, cathodic protection system
CSP, corrugated steel pipe
DH, drill hole
DOS, disc operating system
DVD, digital versatile disc
EAP, Emergency Action Plan
FEMA, Federal Emergency Management Agency
FERC, Federal Energy Regulatory Commission
FFP, Fold-and-Formed Pipe
FHWA, Federal Highway Administration
FLAC, Fast Lagrangian Analysis of Continua
GPR, ground penetrating radar
GPS, global positioning system
HDD, horizontal directional drilling
HDPE, high density polyethylene
ICODS, Interagency Committee on Dam Safety
ICOLD, International Commission on Large Dams
IRCI, International Concrete Repair Institute
JHA, job hazard analysis
LL, liquid limit
LMG, limited mobility grout
LOTO, lockout tag-out

MASW, multichannel analysis of surface waves
MCE, maximum credible earthquake
MRI, magnetic resonance imaging
NDL, no decompression limit
NDSRB, National Dam Safety Review Board
NDT, nondestructive testing
NPSHA, net positive suction head available
NPSHR, net positive suction head required
NRCS, Natural Resources Conservation Service
O&M, operation and maintenance
OSHA, Occupational Safety and Health Administration
PCCP, prestressed concrete cylinder pipe
P.E., professional engineer
PE, polyethylene
PDF, portable document format
PFR, Periodic Facility Review
PI, plasticity index
PPI, Plastic Pipe Institute
PVC, polyvinyl chloride
RCCP, reinforced concrete cylinder pipe
RCP, reinforced concrete pipe
Reclamation, Bureau of Reclamation
ROF, report of findings
ROV, remotely operated vehicle
SASW, Spectral Analysis of Surface Waves
SCS, Soil Conservation Service
SD, strength design
SDR, standardized dimension ratio
SNTC, South National Technical Center
SP, self potential
TADS, Training Aids for Dam Safety
UNEP, United Nations Environment Programme
USACE, U.S. Army Corps of Engineers
USDA, United States Department of Agriculture
UV, ultraviolet
VHS, Video Home System
WSD, working stress design

Conversion Factors

To the International System of Units (SI) (Metric)

Pound-foot measurements in this document can be converted to SI measurements by multiplying by the following factors:

Multiply	By	To obtain
acre-feet	1233.489000	cubic meters
cubic feet	0.028317	cubic meters
cubic feet per second	0.028317	cubic meters per second
cubic yards	0.764555	cubic meters
degrees Fahrenheit	(°F-32)/1.8	degrees Celsius
feet	0.304800	meters
feet per second	0.304800	meters per second
gallons	0.003785	cubic meters
gallons	3.785412	liters
gallons per minute	0.000063	cubic meters per second
gallons per minute	0.063090	liters per second
inches	2.540000	centimeters
mils	0.000025	meters
mils	0.025400	millimeters
pounds	0.453592	kilograms
pounds per cubic foot	16.018460	kilograms per cubic meter
pounds per square foot	4.882428	kilograms per square meter
pounds per square inch	6.894757	kilopascals
pounds per square inch	6894.757000	pascals
square miles	2.589988	square kilometers
tons	907.184700	kilograms

Symbols

c, cohesion
E', modulus of soil reaction
f'c, compressive strength of concrete
p, pore pressure
s, shear strength
θ, angle of internal friction
P-, primary. A P-wave is a seismic compression wave.
S-, secondary. An S-wave is a seismic shear wave.

ASTM Standards

ASTM Standard	Title
A 36	Standard Specification for Carbon Structural Steel
A 53	Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless
A 796	Standard Practice for Structural Design of Corrugated Steel Pipe, Pipe-Arches, and Arches for Storm and Sanitary Sewers and Other Buried Applications
C 33	Standard Specification for Concrete Aggregates
C 94	Standard Specification for Ready-Mixed Concrete
C 150	Standard Specification for Portland Cement
C 361	Standard Specification for Reinforced Concrete Low-Head Pressure Pipe
C 397	Standard Practice for Use of Chemically Setting Chemical-Resistant Silicate and Silica Mortars
C 497	Standard Test Methods for Concrete Pipe, Manhole Sections, or Tile
C 822	Standard Terminology Relating to Concrete Pipe and Related Products
C 939	Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)
D 638	Standard Test Method for Tensile Properties of Plastics
D 653	Standard Terminology Relating to Soil, Rock, and Contained Fluids
D 698	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 [600 kN-m/m^3])
D 790	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D 883	Standard Terminology Relating to Plastics
D 1556	Standard Test Method for Density and Unit Weight of Soil in Place by the Sand-Cone Method
D 2216	Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D 2447	Standard Specification for Polyethylene (PE) Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter
D 2657	Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings
D 2922	Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)
D 3017	Standard Test Method for Water Content of Soil and Rock in Place by Nuclear Methods (Shallow Depth)
D 3035	Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D 3261	Standard Specification for Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing

D 3350	Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
D 4221	Standard Test Method for Dispersive Characteristics of Clay Soil by Double Hydrometer
D 4253	Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D 4254	Standard Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
D 4647	Standard Test Method for Identification and Classification of Dispersive Clay Soils by the Pinhole Test
D 5813	Standard Specification for Cured-In-Place Thermosetting Resin Sewer Piping Systems
D 6572	Standard Test Methods for Determining Dispersive Characteristics of Clayey Soils by the Crumb Test
E 165	Standard Test Method for Liquid Penetrant Examination
F 412	Standard Terminology Relating to Plastic Piping Systems
F 585	Standard Practice for Insertion of Flexible Polyethylene Pipe Into Existing Sewers
F 714	Standard Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
F 905	Standard Practice for Qualification of Polyethylene Saddle-Fused Joints
F 1216	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube
F 1743	Standard Practice for Rehabilitation of Existing Pipelines and Conduits by Pulled-in-Place Installation of Cured-in-Place Thermosetting Resin Pipe (CIPP)

Websites

The following websites can provide additional information and publications related to conduits and embankment dams:

American Society of Civil Engineers: www.asce.org
Association of State Dam Safety Officials: www.damsafety.org
Bureau of Reclamation: www.usbr.gov
Bureau of Reclamation Publications:
    www.usbr.gov/pmts/hydraulics_lab/pubs/index.cfm
Canadian Dam Association: www.cda.ca
Federal Emergency Management Agency: www.fema.gov/fima/damsafe/resources
Federal Energy Regulatory Commission: www.ferc.gov/industries/hydropower.asp
International Commission on Large Dams: www.icold-cigb.net
Mine Safety and Health Administration: www.msha.gov
National Performance of Dams Program: npdp.stanford.edu
Natural Resources Conservation Service: www.nrcs.usda.gov/technical/eng
Natural Resources Conservation Service Publications: www.info.usda.gov/ced
U.S. Army Corps of Engineers: www.usace.army.mil
U.S. Army Corps of Engineers Publications:
    www.usace.army.mil/inet/usace-docs/eng-manuals
United States Society on Dams: www.ussdams.org

Introduction

Conduits convey water from a reservoir through, under, or around an embankment dam in a controlled manner. Conduits through embankment dams serve a variety of purposes. Conduits typically convey releases for:

- Releasing stored waters to meet downstream requirements
- Providing emergency reservoir evacuation
- Flood control regulation to release waters temporarily stored in flood control space
- Diverting flow into canals or pipelines
- Providing flows for power generation
- Satisfying a combination of multipurpose requirements
- Stream diversion during construction

Most conduits through embankment dams are part of outlet works systems. 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. Conduits can be classified as either:

- *Nonpressurized flow.*—Open channel flow at atmospheric pressure for part or all of the conduit length (figure 1). This type of flow is also referred to as "free flow."
- *Pressure flow.*—Pressurized flow throughout the conduit length to the point of regulation or control or terminal structure (figure 2)

Many types of materials have been used for conduits over the years, such as reinforced cast-in-place and precast concrete, thermoplastic and thermoset plastic, cast and ductile iron, welded steel, corrugated metal, and aluminum. Some early builders of conduits used whatever materials were readily available, such as wood (figure 3) and hand-placed rubble masonry (figure 4). Regardless of the material use, a conduit represents a discontinuity through an embankment dam and its foundation.

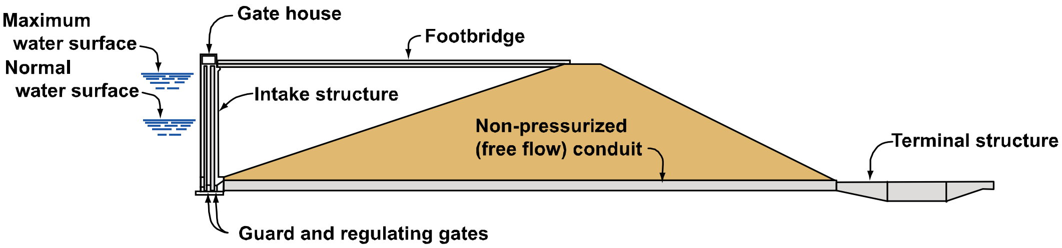


Figure 1.—Nonpressurized outlet works.

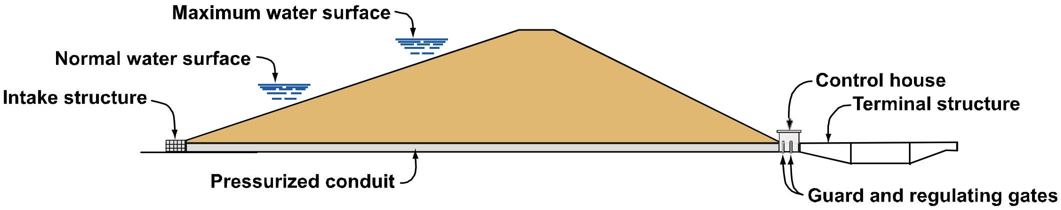


Figure 2.—Pressurized outlet works.

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. The reasons that conduits contribute to these failures are discussed more extensively in several sections of this document.

Historically, a single term, "piping," has been commonly used in literature to describe all erosional processes involved in embankment dam failures. The reason for this is that frequently after a failure, a tunnel-shaped feature resembling a pipe is observed. See figure 5 for an example. In this document, two terms will be used to describe failures of embankment dams associated with uncontrolled flow of water, rather than using a single generic term. The two terms that will be used in this document are:

- Backward erosion piping and
- Internal erosion

Figure 3.—A 15-inch diameter, wire-wrapped wood stave pipe used as an outlet works conduit within a 75-year old embankment dam. The outlet works conduit was removed and replaced due to deterioration and backward erosion piping concerns.

Figure 4.—A 100-year-old, mortar-lined, rubble masonry outlet works conduit.

Figure 5.—Embankment dam failure caused by internal erosion of earthfill near the conduit. Flow was not directly along the contact between earthfill and conduit, but in the earthfill away from conduit. Hydraulic fracture in highly dispersive clay embankment soils caused the failure. The embankment design included antiseep collars, but not a filter diaphragm.

These two terms are more descriptive of the distinctly different mechanisms by which water can damage embankment dams. In this document, the term "backward erosion piping" will be reserved to describe conditions where water flows not through preferential flow paths, such as cracks in the soil, but through the pores of a soil. The flow causing the mechanism of failure termed "backward erosion piping" is solely that from 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. The term "backward erosion piping" is used in an attempt to define this precise condition of failure. The term "internal erosion," discussed in the following paragraph, 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.

The term "internal erosion" will be used in this document to describe all conditions other than "backward erosion piping" by which water flowing through embankment dams or foundations erodes the soils and causes a failure. Internal erosion occurs where water flows through a discontinuity in the embankment dam and/or foundation, and erodes the sides of the crack to enlarge it and cause a failure. The term "internal erosion" is used in lieu of a number of terms that have historically been used to describe variations of this generic process including scour, concentrated leak piping, and others. This term will also be used for another type of condition called suffosion. Suffosion is the type of erosion where the matrix of the soil mass is unstable. When seepage occurs, the finer part of the soil matrix is eroded out, leaving behind a much coarser fraction.

"Backward erosion piping" can develop only in a category of soils susceptible to this mechanism of failures. Certain conditions are required for backward erosion piping to occur, as described by Von Thun (ASDSO, 1996, p. 5), with added conditions suggested by McCook (ASDSO, 2004, p. 8), summarized as follows:

- A flow path/source of water.
- An unprotected exit (open, unfiltered) from which material can escape.
- Erodible material within the flow path that can be carried to the exit.
- The material being piped or the material directly above it must be able to form and support a "roof" or "pipe."
- Water initially flows exclusively within the pore space of soils. This is often termed intergranular seepage. If flow is through macro-features or cracks in the soil or along an interface between the soil and another structure, the term internal erosion is more correct for describing problems that occur.
- The soil through which water is seeping is susceptible to backward erosion piping. The most susceptible soil types are fine sands and silts with little clay and no plasticity. Clays and clayey coarse-grained soils are highly resistant to backward erosion piping. The resistance of clays and clayey coarse-grained soils results from the high interparticle attraction caused by electrochemical forces. Internal erosion mechanisms are responsible for most failures where clayey soils are in the flow path.

Internal erosion may develop any time a discontinuity occurs within an embankment dam that is accessible to water in the reservoir or to water flowing in conduits. Cracks caused by hydraulic fracture of the earthfill, cracks in bedrock that the embankment is in contact with, and other preferential flow paths provide a way that water can erode soils in contact with the feature. Internal erosion is extremely dangerous because of the rapidity in which flow paths can erode, particularly for highly erosive soils, such as low plasticity silts or dispersive clays. Figures 5 and 6 show examples of failure due to internal erosion associated with a conduit through the embankment dam. The terms backward erosion piping and internal erosion are defined in the glossary in this document. To further assist readers in understanding the definition of these two terms in the context of this document, the following illustrations are provided:

Figure 6.—Embankment dam failure caused by internal erosion of earthfill near the conduit. The initial failure was tunnel shaped, but the collapse of the roof of the tunnel resulted in the observed shape of breach. Hydraulic fracture in highly dispersive clay embankment soils caused the failure. The embankment dam design included antiseep collars, but no filter diaphragm.

- Figure 7 illustrates the internal erosion process as a result of a hydraulic fracture through the embankment dam.

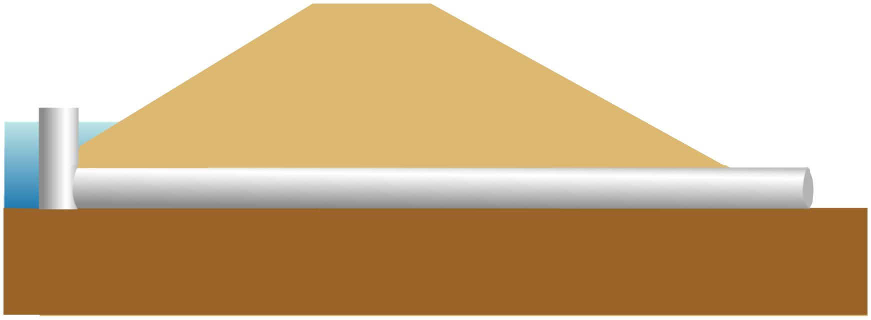
- Figure 8 illustrates the internal erosion process as a result of low density embankment materials under the haunches of a pipe due to poor compaction.

- Figure 9 illustrates the internal erosion process associated with the creation of a void caused by excessive compactive energy used to compact embankment materials against the conduit.

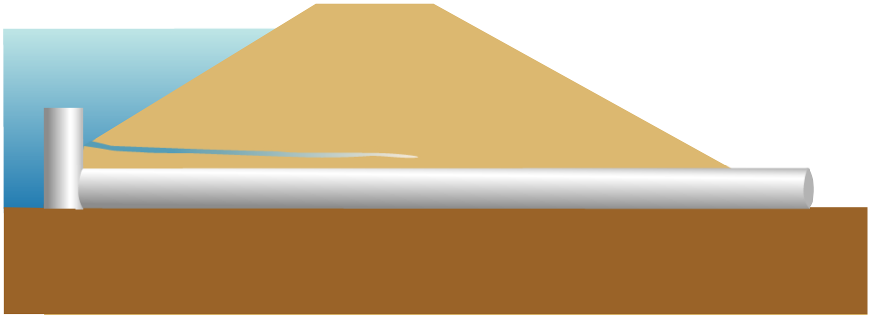
- Figure 10 shows the backward erosion piping process associated with intergranular seepage and the subsequent backward erosion of soil particles.

All four of these mechanisms can lead to partial or full failures of the embankment dam.

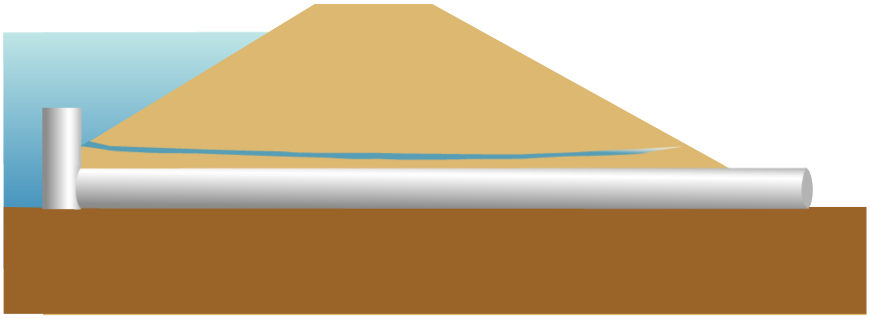
Internal erosion and backward erosion piping can occur suddenly and with little warning. In these cases, little may be done to address the problem quickly enough to avert a failure. Recognizing conditions likely to result in these failure mechanisms is essential to design of conduits and embankment dams that are resistant to failures. In other cases, the failure mechanisms may develop slowly and go unrecognized until the subterranean erosion develops cavities in the embankment dam large enough to



An embankment dam with a low reservoir water level.

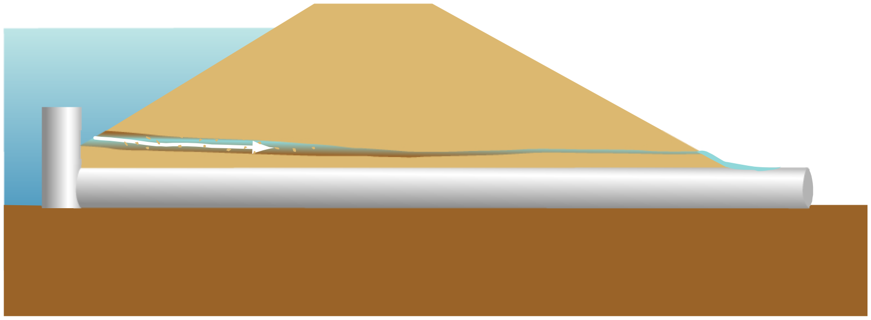


The reservoir water level rises, inducing a hydraulic fracture within the embankment dam due to poor construction or defective soils.

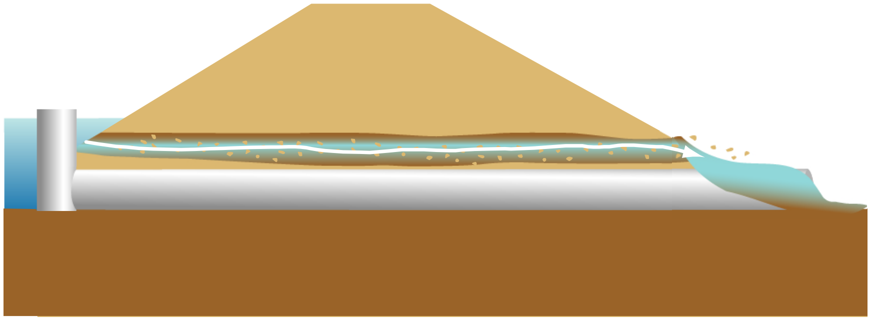


The hydraulic fracture extends through the embankment dam as a result of arching of the overlying embankment, resulting in low stress concentrations in the soil and a reservoir level high enough to cause the fracture. Conduits often create differential settlement and arching of the earthfill, because settlement of the embankment dam is less above the conduit than on either side of it.

Figure 7.—The internal erosion process as a result of a hydraulic fracture.

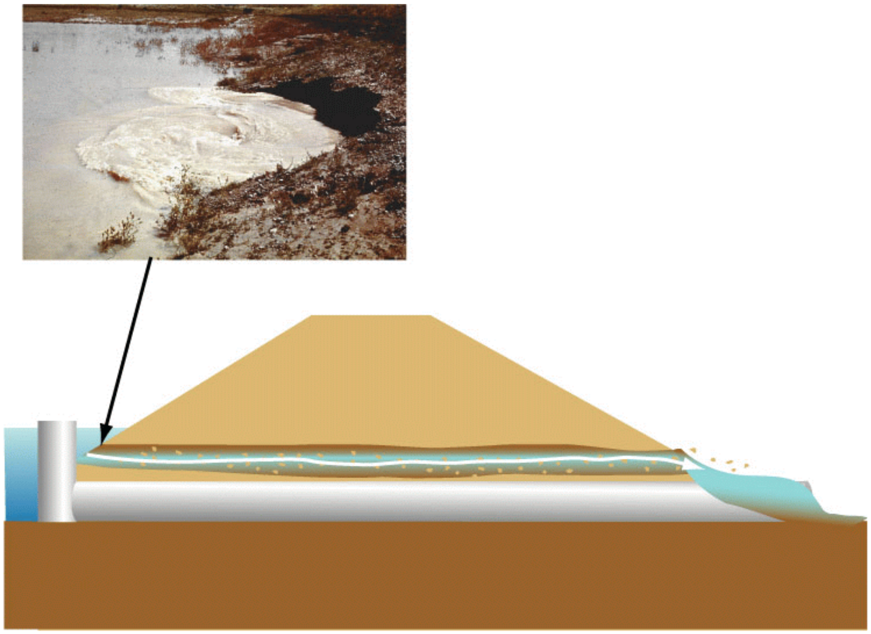


Water from the reservoir penetrates the hydraulic fracture, initiating internal erosion of the side walls of the fracture.

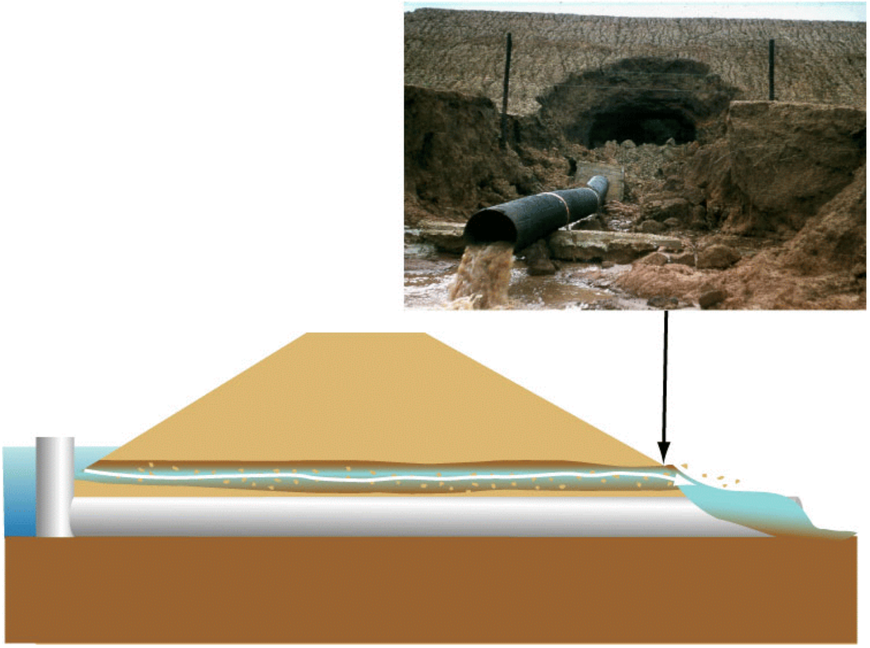


The internal erosion process continues as water flowing in the hydraulic fracture widens the walls of the fracture. Intergranular seepage is not involved in the process, and the soils surrounding the fracture are unsaturated. Intergranular seepage rarely has time to develop, since this type of failure occurs most frequently on first filling of the reservoir.

Figure 7 (cont'd).—The internal erosion process as a result of a hydraulic fracture.

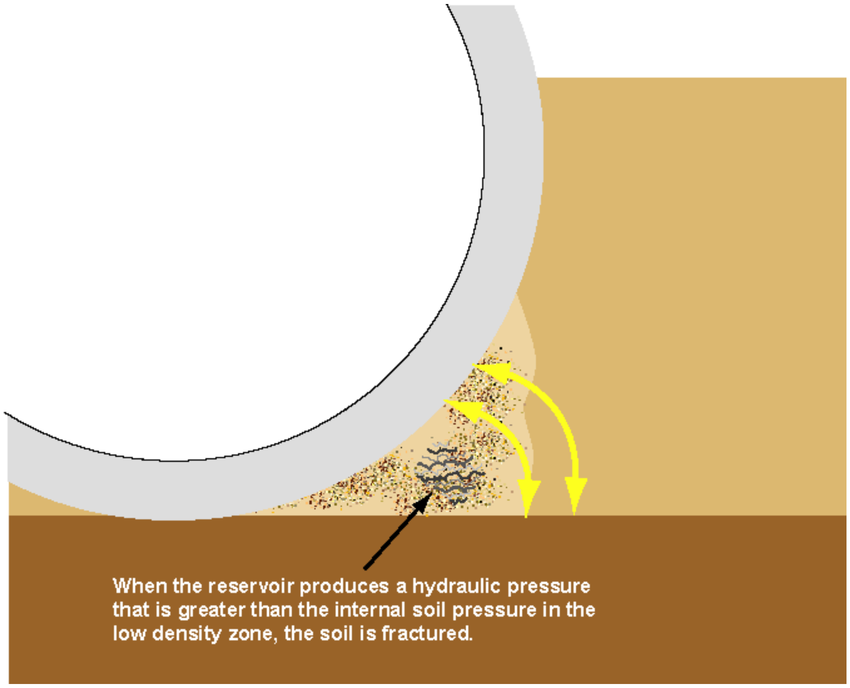


A vortex may form at the location where water in the reservoir enters the upstream end of the hydraulic fracture.

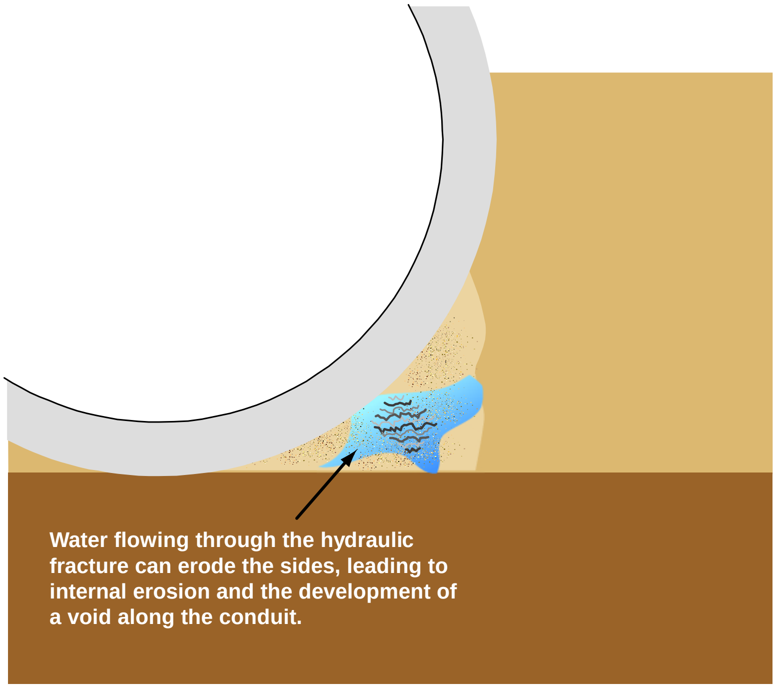


Often, the end result of internal erosion along the hydraulic fracture is a tunnel-shaped void (see figure 5). Loss of the reservoir contents can occur by water flowing through the tunnel-shaped void. Where the tunnel-shaped void enlarges sufficiently (see figure 5), the roof of the tunnel collapses, leaving a v-shaped notch in the embankment dam like that shown in figure 6. If the reservoir had contained a little more storage and the flow had continued a little longer through the tunnel-shaped void, the embankment dam shown in figure 5 would have collapsed and looked similar to the embankment dam in figure 6.

Figure 7 (cont'd).—The internal erosion process as a result of a hydraulic fracture.

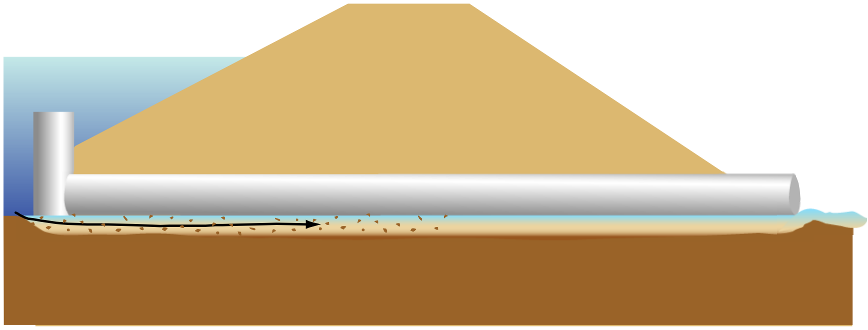


Poor compaction causes arching to occur in the area of the conduit's haunches. This creates a low density zone subject to hydraulic fracture.

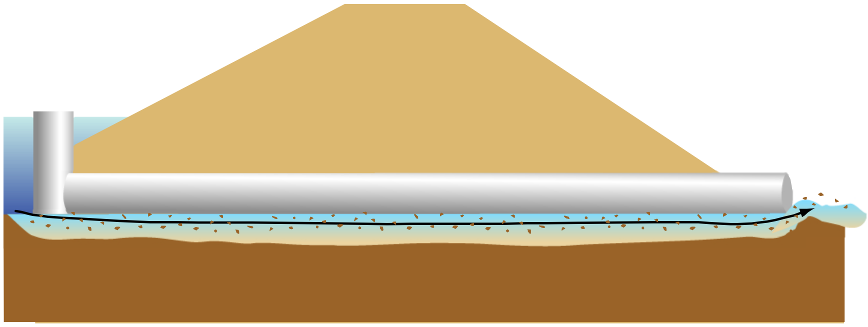


The hydraulic fracture can propagate in a downstream direction and initiate flowing water from the reservoir.

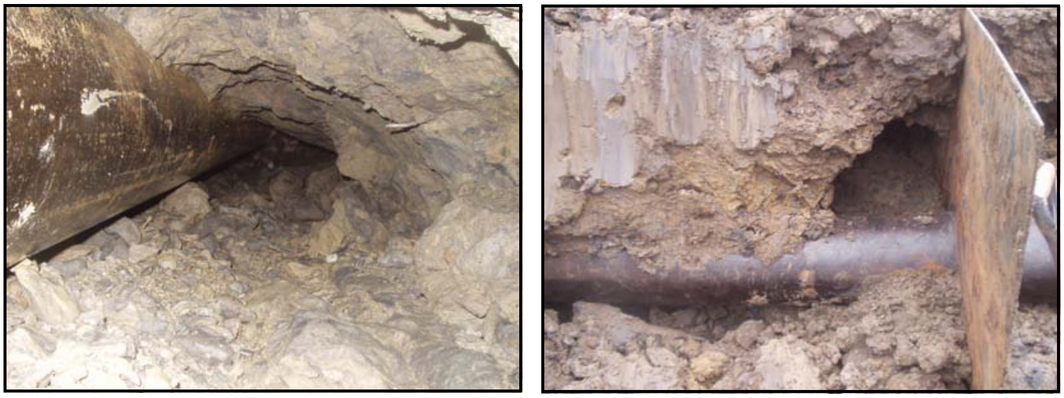
Figure 8.—The internal erosion process as a result of low density embankment materials under the haunches of a pipe due to poor compaction.



Water from the reservoir penetrates the hydraulic fracture, initiating internal erosion of the side walls.

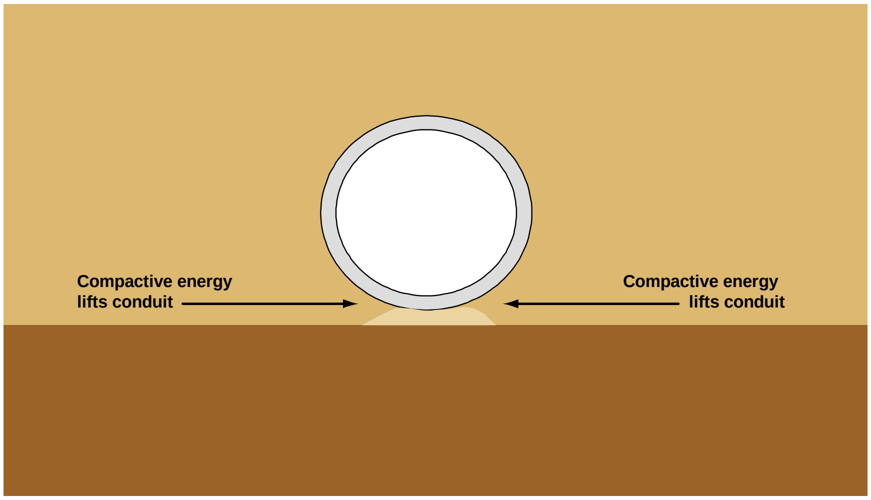


Flowing water from the reservoir continues the internal erosion process within the hydraulic fracture. Intergranular seepage is not necessarily involved in this process, and the embankment materials surrounding the void may be unsaturated.

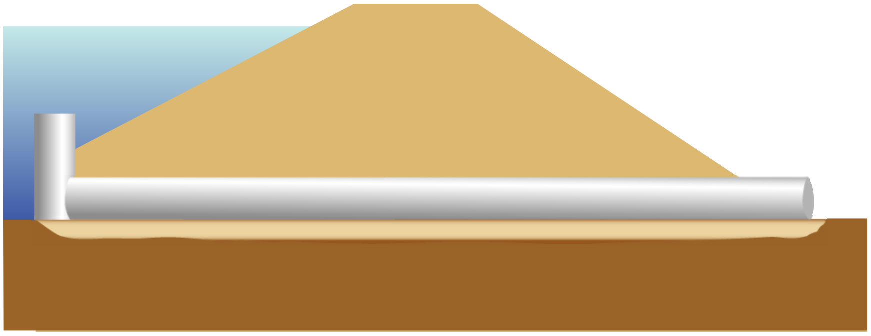


A void was formed along the conduit due to water flowing through a hydraulic fracture.

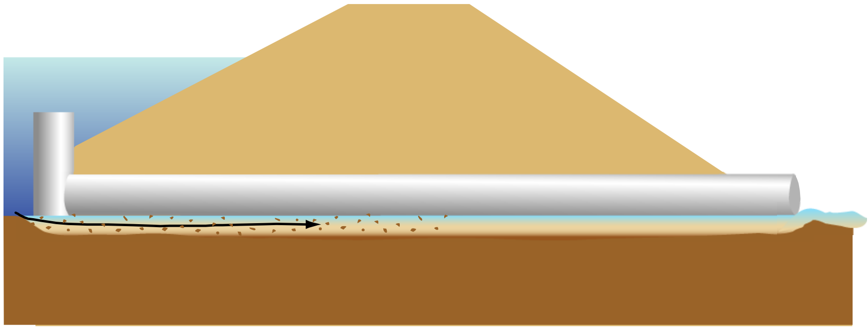
Figure 8 (cont'd).—The internal erosion process as a result of low density embankment materials under the haunches of a pipe due to poor compaction.



If too much compactive energy is applied while attempting to compact the embankment materials under the haunches of the conduit, a void can occur beneath the conduit.

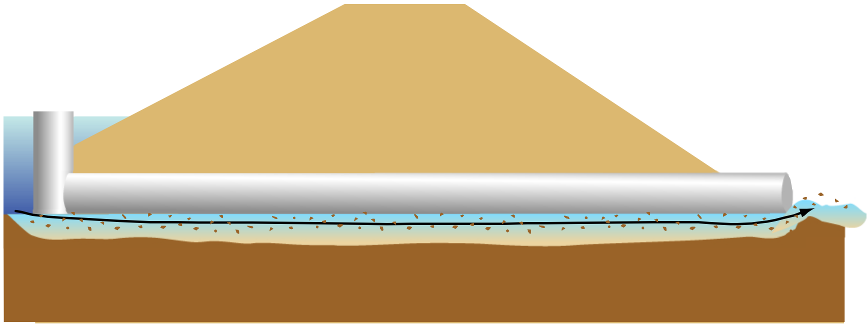


The void can extend beneath the entire length of the conduit.



Water from the reservoir can penetrate the void, initiating internal erosion of the side walls.

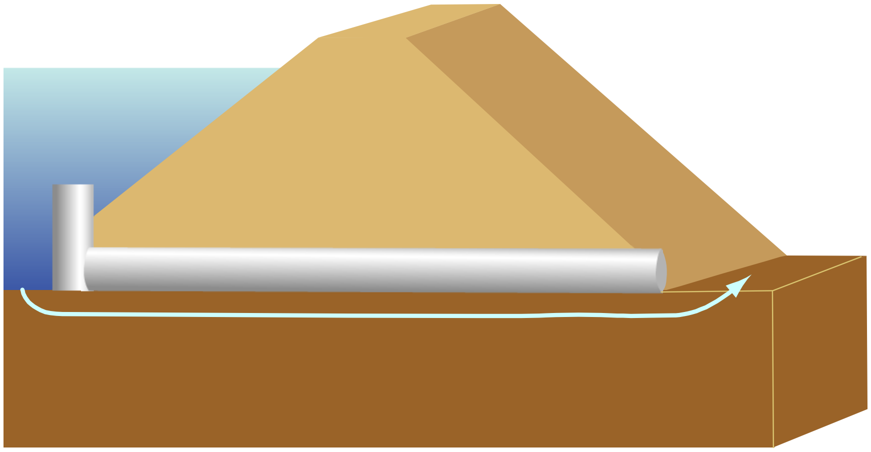
Figure 9.—The internal erosion process associated with the creation of a void caused by excessive compactive energy used to compact embankment materials against the conduit.



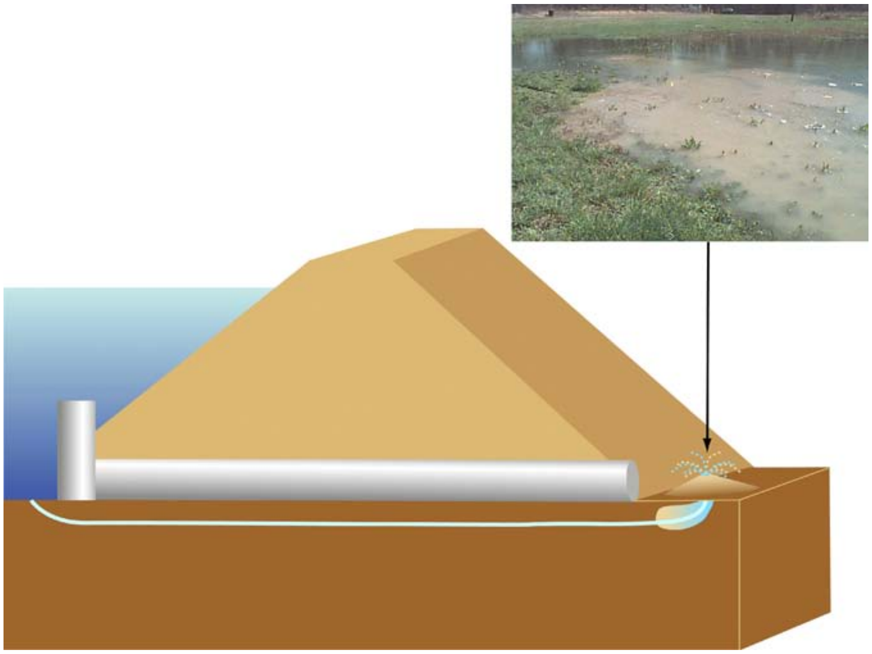
Flowing water from the reservoir continues the internal erosion process within the void. Intergranular seepage is not necessarily involved in this process, and the soils surrounding the void may be unsaturated.

The resulting failure often leaves a tunnel-shaped void along the conduit.

Figure 9 (cont'd).—The internal erosion process associated with the creation of a void caused by excessive compactive energy used to compact embankment materials against the conduit.

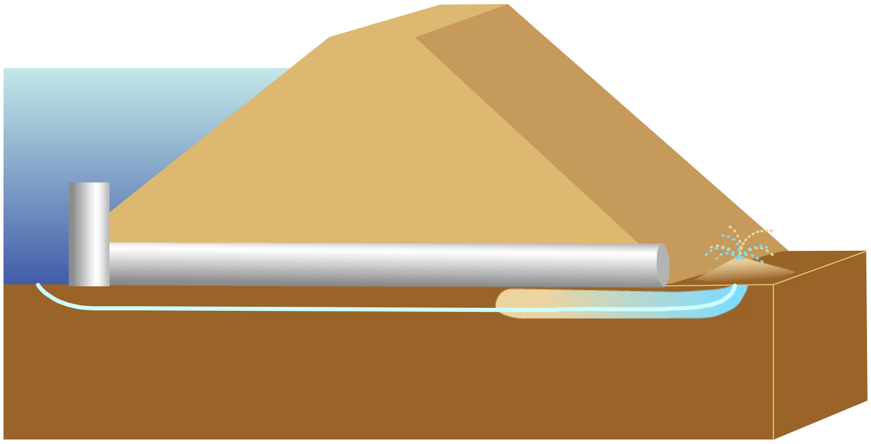


Backward erosion piping begins in fine sand foundation materials at the toe of an embankment dam. The foundation is assumed to be a soil susceptible to piping such as fine, poorly graded sand. A filter zone is not provided at the seepage discharge face (or the filter has been improperly designed), allowing backward erosion piping to begin.

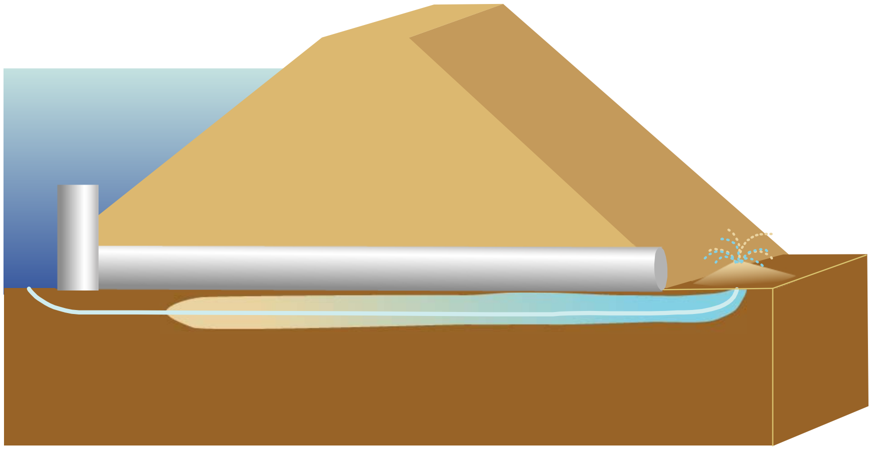


Intergranular seepage flow conditions exist within the foundation under the embankment dam, and soil particles are removed. The particles are deposited (sand boils) on the ground surface at the downstream toe, or washed away if flow is higher.

Figure 10.—The backward erosion piping process associated with intergranular seepage and the subsequent backward erosion of soil particles.

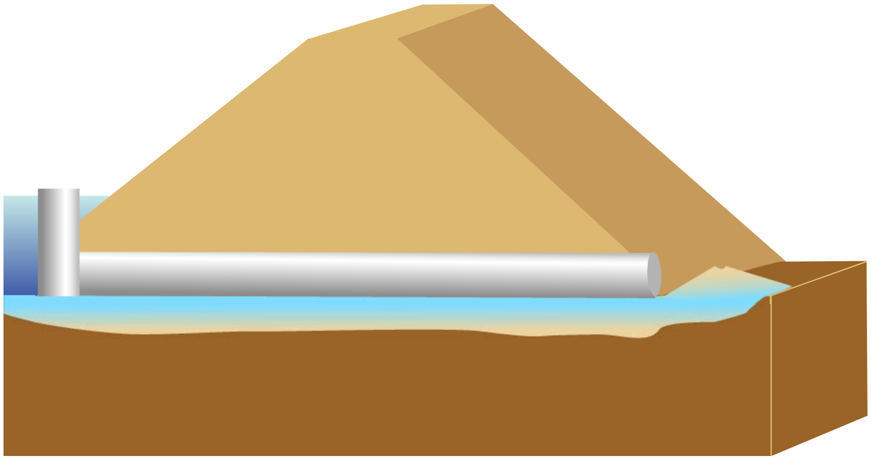


The process of dislodging soil particles continues at an escalating rate because of the hydraulic gradient increase. As the backward erosion piping gets closer to the reservoir, seepage quantity also increases.



A tunnel develops due to the continued erosion of the soils in the foundation. This assumes the overlying embankment dam, foundation layer, or conduit is able to support the tunnel that is forming. The soil exposed to flow in the developing tunnel is erodible, and the walls of the tunnel can grow larger at the same time that the discharge face moves upstream.

Figure 10 (cont'd).—The backward erosion piping process associated with intergranular seepage and the subsequent backward erosion of soil particles.



Eventually, the tunnel erosion feature reaches the reservoir. Outflow will then increase substantially, leading to direct erosion of the embankment dam and complete breach or draining of the reservoir through the tunnel that develops.

The resulting failure often completely destroys the embankment dam, leaving few traces of the original piping tunnel. The failure of this embankment dam was attributed to piping of foundation sands. Photo courtesy of National Oceanic and Atmospheric Administration.

Figure 10 (cont'd).—The backward erosion piping process associated with intergranular seepage and the subsequent backward erosion of soil particles.

be observable at the surface of the embankment or foundation. Visual inspection, seepage and turbidity measurements, and pore pressure readings are useful in detecting whether problems like these may be developing in an embankment dam. Chapter 9 discusses inspection techniques in detail.

Design and construction inadequacies are often to blame for internal erosion and backward erosion piping incidents. Designers must understand which design measures are effective in preventing these mechanisms of failure.

In nonpressurized conduits, water seeping through the embankment dam can enter the conduit through defects. If the surrounding soils are susceptible to backward erosion piping, cavities can develop in the embankment and foundation of the conduit. This problem is discussed in more detail in section 7.1.

In pressure flow conduits, water under pressure can escape through defects and damage the surrounding embankment and foundation. This problem is discussed in more detail in section 7.2.

In nonpressurized or pressurized conduits, water seeping along the interface between the conduit and surrounding soil may be concentrated enough to result in backward erosion piping, if the soils are susceptible. If the soils are resistant to backward erosion piping, but a crack or potential flow path develops near the conduit, internal erosion can result. This problem is discussed in more detail in section 7.3.

If the soils surrounding the conduit are resistant to backward erosion piping, hydraulic fracture may occur. The hydraulic fracture created can then erode and lead to a failure tunnel that is similar to that which develops in soils that are susceptible to backward erosion piping. This problem is discussed in more detail in section 7.4.

Internal erosion and backward erosion piping incidents are often associated with conduits through embankment dams. The following factors increase the likelihood of these problems developing at a given site:

- 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. See section 1.2 for more discussion on factors in locating conduits in the most favorable conditions.

- Circular conduits constructed without concrete bedding or cradles are more likely to experience problems than conduits in more favorable shapes (i.e., horseshoe). See section 4.1 for more discussion on conduit shapes.

- Conduits with an excessive number of joints are more likely to develop defects that can lead to problems. See section 4.3 for discussion on joints in conduits.

- Excavations made to replace unsuitable foundation materials for conduits increase the potential for differential settlement problems. Section 5.1 also discusses this factor.

- 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. Section 5.1.2 discusses soil foundations for conduits. Locating conduits on bedrock is desirable, but not always practical. See section 1.2 for more discussion on factors in locating conduits in the most favorable conditions.

- Conduits located in closure sections in embankment dams contribute to differential settlement problems. Section 5.2 discusses this factor in detail.

- Embankment dams constructed with materials susceptible to internal erosion or backward erosion piping. Sections 5.2 and 5.3 discuss this factor in detail.

- Conduits constructed without adequate compaction around the conduit are more likely to experience erosional problems. Section 5.3 discusses this factor in detail.

- Embankment dams constructed without a chimney filter or conduits constructed without a filter collar or filter diaphragm. See chapter 6 for more discussion on the design and construction of filters.

- Conduits constructed of materials susceptible to deterioration, such as corrugated metal pipe. See chapter 8 for discussion of defects in conduits.

Understanding the steps involved in a failure mode as the result of internal erosion or backward piping erosion is important in designing defensive measures to prevent these failures. An event tree can be used to understand the series of events that can lead to embankment dam failure by internal erosion or backward erosion piping. An event tree used by the Bureau of Reclamation (Reclamation, 2000, p. 15) for internal erosion of an existing embankment dam is shown in figure 11. The steps or "nodes" of the event tree shown on figure 11 are generally described as follows:

1. The reservoir rises, causing a water load on the embankment dam. The information is generally derived from the statistical historic record of reservoir operations. Normally, it is the probability of a reservoir to rise onto a portion of the embankment dam that might contain a flaw and not usually the time that the reservoir exists at a specific elevation.

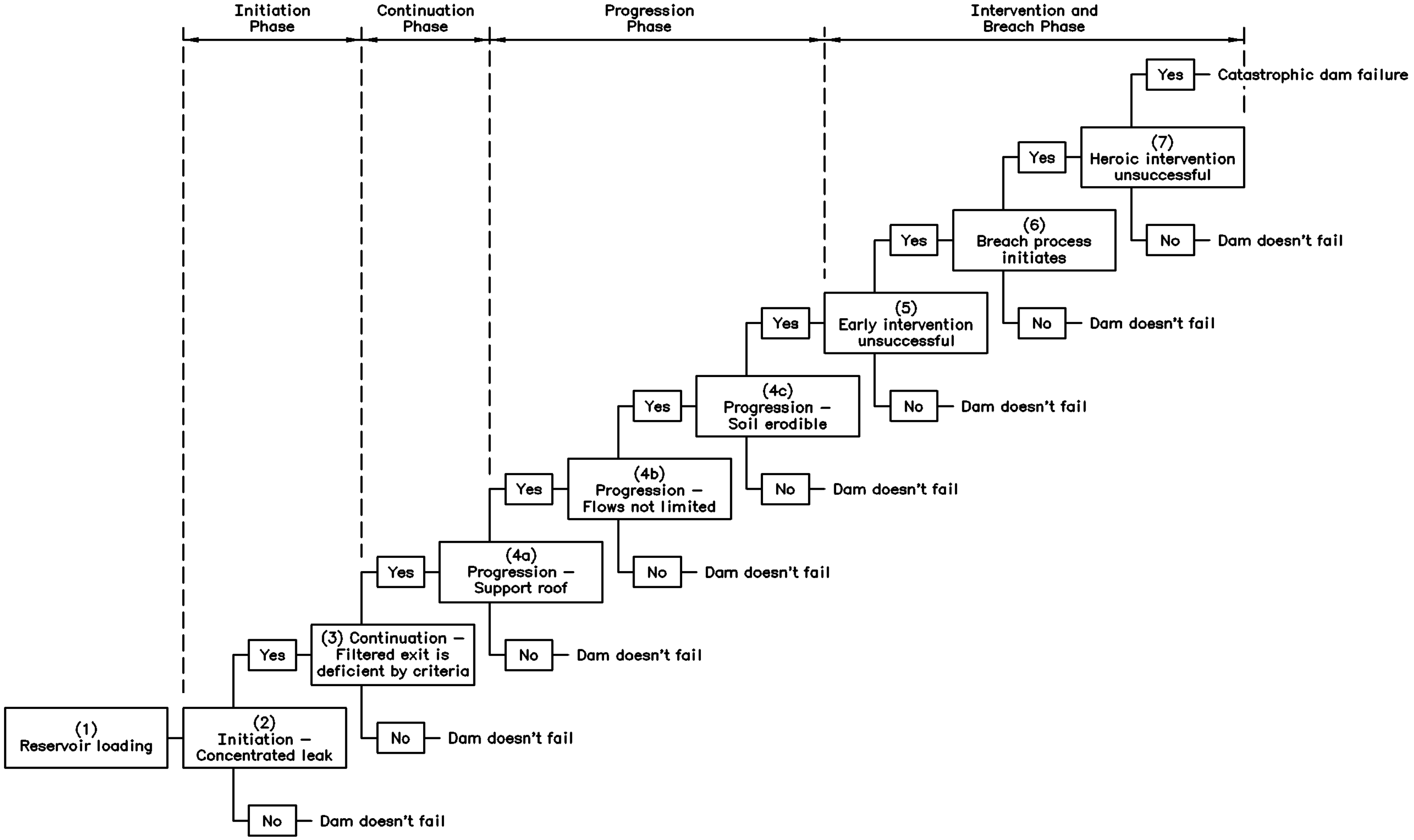


Figure 11.—Example of an event tree used to illustrate the internal erosion process.

2. The next node of the event tree considers the potential for a concentrated leak to exist or newly occur. The leak must be of sufficient size to reasonably expect the soil erosion process to begin.

3. The next node then considers if the erosion process continues. This is usually done by assessing the potential for an adequate filter to exist at the downstream end of the leak.

4. If there is no reasonable expectation of a filter, the potential for the erosion process to progress is examined in the next three nodes by considering (a) the potential for a roof to form over the pipe channel, (b) the potential for an element at the upstream end of the leak to limit flow, and (c) the erosion characteristics of the embankment material.

5. If the erosion process will fully reach the progression stage, the potential to successfully intervene to prevent failure soon after detection of the erosion is considered.

6. If such early intervention will not likely be successful, the potential for the embankment dam to fully breach is considered.

7. If the embankment dam is of a type that can actually breach, the potential to heroically intervene to save the dam is examined (e.g., the potential to quickly lower the reservoir). The culmination of a negative outcome of all the events in the event tree is the catastrophic release of the reservoir.

This event tree is usually used by Reclamation to assess the potential for the failure of an existing embankment dam in a risk context. In a risk assessment of an internal erosion failure mode, a probability of the event tree would be estimated and this would be multiplied by some consequence of the embankment dam failure, usually life loss. The event tree was developed for the internal erosion failure mode only. An event tree for a failure mode of backward erosion piping might be slightly different than this one. For instance, instead of the potential for a concentrated leak, the initiation node might evaluate the potential for a high exit gradient to begin the erosion process.

For a new embankment dam being designed, understanding the events that can lead to failure by internal erosion or backward erosion piping can lead to improvements in the design. As most of the steps of the process are considered, opportunities for multiple lines of defense in the design can be developed.

Compilations of case histories of embankment dam failures and accidents show that frequently, conduits were considered a factor in the failures or accidents. Case histories such as those shown in appendix B are examples of embankment dams where conduits were associated with failures and accidents. The case histories in appendix B include a variety of situations where defects in the conduit and poor design or construction decisions contributed to the failures. Several modes of failure are discussed in this document related to conduits, which include both the backward erosion piping and internal erosion modes of failure. Appendix B includes very few case histories that involve backward erosion piping associated with conduits. This is because soils that are highly susceptible to backward erosion piping have seldom been used to backfill around conduits. Most case histories of failures and accidents involving conduits are related to one of the internal erosion modes of failure. Both this *Introduction* and chapter 7 provide more discussion on modes of failure.

In 1998, a survey of State dam safety programs was conducted for the Interagency Committee on Dam Safety (ICODS) Seminar No. 6 on piping associated with conduits through embankment dams (Evans, 1999, p. 1). Fourteen states provided responses to the survey. The respondents indicated that 1,115 embankment dams with conduits would likely need repair within the next 10 years. Of these 1,115 embankment dams, 53 percent had conduits constructed with corrugated metal pipe (CMP), 23 percent were constructed with steel pipe, and 20 percent were constructed with concrete pipe.

Conduits within embankment dams are often designed using standards not specifically intended for penetrations through dams. For example, certain pressure pipe standards (e.g., those from the American Water Works Association) may not be applicable (without design and construction modifications) for use in pressurized conduits through embankment dams. The purpose and performance characteristics of conduits through embankment dams differ from those required for water supply pipelines. The use of certain types of manufactured pipe for conduits through embankment dams is a concern, since these materials were developed and standardized for applications other than embankment dams. The unique performance requirements for conduits in embankment dams include:

- *Service life.*—Most embankment dams are designed assuming a minimum 100-year service life with minimal maintenance. Manufactured pipe needs to be durable in the expected wet, dry, and freeze/thaw environments found within a conduit.

- *Accessibility.*—As the height of the embankment dam increases, the practicality of accessing the conduit for repairs decreases. Manufacturing and installation quality control needs to be high to ensure dependable installations.

- *Strength.*—The structural loading on manufactured pipes can be very high due to positive projecting, rather than trench loading conditions, and very high embankments. The pipe needs to be structurally designed for all possible loading conditions for applications within embankment dams.

- *Risk.*—The development of small defects within the conduit can lead to serious failure modes threatening the entire embankment dam. Designs needs to be robust and conservative.

- *Movement.*—Conduits within high embankments dams, built on compressible foundations, may experience significant displacement as the dam settles. The conduit joints need to be capable of absorbing such movements while remaining watertight. The conduit placement needs to anticipate subsequent settlement in order to remain positively sloping for gravity drainage.

Inexperienced designers may inadvertently apply inappropriate design standards or misuse design standards to save on time and provide cost savings. Examples of the misapplication of design standards include:

- *Inappropriate design references.*—State highway department standard plans for culverts and culvert structures are sometimes simply referred to in construction specifications and drawings to save the designer from actually designing the conduit. Culvert designs are not intended for use within embankment dams.

- *Inappropriate application of standards.*—The NRCS has developed several standardized conduit and joint detail drawings for use in embankment dams. Such drawings have been used to successfully build thousands of small embankment dams. Such drawings have also been misused. In one known case, the standard detail drawings were used to unsuccessfully install a pressurized conduit on a high hazard embankment dam on a soft foundation. As with all standardized designs and drawings, the design and construction assumptions made in preparing the drawings need to be satisfied for the specific application and site.

- *Inappropriate use of materials.*—Reinforced concrete pressure pipe has been used for pressurized conduits within embankment dams. Reinforced concrete pressure pipe utilizes gasketed joints, which could be subject to leakage, if improperly constructed. In a typical 100-foot high embankment dam there could be over 80 gasketed joints, all with the potential for leakage.

Conduits often penetrate other types of embankment structures or are used for utility purposes. These types of penetrations are not addressed in detail in this document. Some of the guidance presented in this document may apply to these types of penetrations and should be carefully evaluated by designers for implementation. Users of this document will need to evaluate the applicability of the proper guidance to their project. Conduit penetrations not specifically addressed within this document include:

- *Conduits within levees.*—Guidance on conduits through levees is available from other sources, such as the USACE's *Design and Construction of Levees* (2000).

- *Utility conduits.*—Utility conduits are utilized for various functions, such as water, wastewater, sewer, electrical, telecommunications, and gas lines. As urbanization pushes farther out into previously undeveloped or agricultural areas, more utility conduit crossings of embankment dams are being required. While many of the new utility conduits installations are made through low hazard dams, the continued urbanization may make previously low hazard structures become significant or high hazard dams.

  Typically, requests for utility crossings are made to local and State agencies. These agencies provide the necessary review and right-of-way permitting. If at all possible, these conduit crossings should be located outside the limits of the embankment dam, so as not to provide a discontinuity within the dam or a transverse seepage path through the dam.

  Inexperienced designers associated with utility conduits may utilize designs that trench through the embankment dam for new installations or to repair or replace existing conduits and not use proper excavation, backfill, and compaction practices around the conduit. This can lead to failure of the embankment dam. Any utility conduit installation should be designed by a professional engineer experienced in the design and construction of embankment dams. If these conduits must be located within the embankment dam, they should be positioned in the upper crest of the dam, well above the design flood elevation. Typically, this is not a problem, as the utility owner requires permanent access to the conduit. If the utility conduit is for a water line, special precautions should be employed, so that a rupture of the conduit will not continue unchecked and cause erosion of the embankment dam. Such precautions should consider applicable guidance contained within this document, automatic shutoff mechanisms, frequent testing and inspection of the system, and visual monitoring.

  Another concern with utility conduit crossings are unauthorized installations. Embankment dam failures have occurred as the result of unauthorized utility conduit installations where no notice was given to the responsible agency for proper review and right-of-way permitting. All embankment dams should be marked with "no trespassing" signs. Unfortunately, these signs are often ignored during unauthorized utility conduit installations.

  One alternative to burying the utility conduit crossing within an embankment dam is to construct the crossing over the crest of the dam. This alternative has been successfully used by USACE for conduit crossings over levees and is best suited for small diameter pipes. To accomplish this alternative, additional earthfill is added on the crest of the dam, so a ramp is constructed over the utility conduit to allow for the crossing of vehicular traffic. Typically, a minimum of 2 feet of cover is provided over the conduit and a 6-percent grade is utilized on the ramps. Additional earthfill is ramped around the utility conduit on both the upstream and downstream faces of the embankment dam as needed to provide protective cover. The grade on these ramps is usually about 10 percent. This alternative eliminates any concerns associated with excavation into the embankment dam.

- *Conduits within tailings and slurry impoundment dams.*—This document is intended to apply to traditional embankment type dams. The design and construction of conduits through tailings and slurry impoundments often utilize different guidelines than those presented in this document.

  Tailings and slurry dams are an integral and vital component of mining operations. Tailings dams permanently retain mining, chemical, and industrial waste products (e.g., ground-up rock that remains after the mineral value has been removed from the ore). Figure 12 shows an example of a tailings dam. A slurry dam permanently retains waste created by the processing and washing of coal. These structures retain the waste products and allow them to settle out, enabling reclamation (recycling) of the slurry water, and permanent retention and eventual restoration of the site.

  The coarser fraction of the waste material is commonly used to construct the dam, with the finer waste being pumped as slurry behind the dam. Typically, tailings and slurry dams are constructed over the life of the mine, with the dam being raised as needed to provide additional disposal capacity. The dams may be raised by downstream, upstream, or centerline construction. In many cases, the dams reach several hundred feet in height.

  As with any dam, an important aspect of these impoundments is handling water, in this case both storm runoff and water pumped in with the slurry. Some of the dams are totally diked structures while others have contributing watersheds. Often the impoundment water is reclaimed for use in processing or in other mining activities. The seepage from these impoundments can cause chemical deterioration due to its acidity or alkalinity. In some cases, the nature of the leachate requires that the impoundment be provided with an impervious liner. A "decanting system" typically removes free water from behind the dam. Designers use a variety of methods and materials to decant water from slurry and tailings dams. Decanting systems often consist of an extendable intake structure (e.g., tower or sloping chute) and a conduit to convey discharge away from the tailings dam. Figure 13 shows an example of an intake structure for a decanting system. The intake structure is normally constructed progressively as the deposition level rises to avoid the costs of a high, unsupported structure

Figure 12.—An example of a tailings dam.

before the impoundment is constructed. Reinforced cast-in-place concrete, precast concrete, steel, and plastic conduits have all been used. Some designers prefer to avoid having a conduit pass through the dam and use either floating pump installations or siphons to decant the water. Use of these options is especially favored in areas where the impoundment can be located high in the watershed to minimize runoff inflow, and in areas, such as portions of the western United States, where rainfall is low. Designers also cite the advantage in this approach of eliminating potential problems with decant conduit risers, such as structural stability and debris clogging.

Some tailings dams are required to be provided with impervious liners due to the acidity of the leachate. In these cases, if a decant conduit is used, a watertight connection must be achieved between the liner and the conduit. The presence of the liner affects these installations by limiting the potential for seepage along the conduit.

Some tailings dam failures and problems have been attributed to problems with compaction of the backfill around the decant conduit. A notable occurrence was a failure at a phosphate tailings dam in Florida in 1994. While this case involved CMP, it highlighted the difficulty in obtaining adequate compaction in the haunch area under the pipe. Postfailure investigation of two other decants that had been installed at the same facility indicated gaps or loose areas in the haunch area backfill. Interestingly, although plastic and steel pipes have been used extensively in slurry impoundments, no failures are known to have occurred, and only a few problems have been attributed to inadequate haunch area compaction in these applications.

In the past, decant pipes were constructed of CMP. However, in many cases the acidity of the refuse caused corrosion problems. Protective coatings were

Figure 13.—An example of a decant intake structure.

employed to combat this problem, but there also were problems with the watertightness of the joints. This problem became particularly apparent when dam safety regulators began to require pressure testing of the pipes.

As a result of problems with corrosion and joint watertightness, and to deal with increasing fill heights over the pipes, designers turned to two other types of decant pipes: thick-walled welded steel pipe, and high density polyethylene pipe (HDPE). Pipes were often designed to withstand the fill height loading from several stages of construction, and the pipe would be replaced by installing another pipe at a higher elevation, with the original pipe being filled with grout.

Designers considered corrosion-protected welded steel and HDPE pipes to be beneficial for the type of foundation conditions and construction practices found at these dams. The locations of these dams are limited to areas near the processing plants, meaning that designers need to deal with varied, and often less than ideal, foundation conditions. Furthermore, as these pipes may be extended up- or downstream, their length can become relatively long, sometimes exceeding 1,000 feet. Over such lengths, a flexible pipe could tolerate some differential movement due to varying foundation conditions. Additionally, many of these dams have underground mining in their vicinity and the possibility of mining-induced ground movement needs to be considered.

The pipes used for the decanting systems have typically been installed without being encased in concrete. In most cases, the pipes have been installed with hand compaction of the backfill in the haunch area. Hand held compaction equipment has often been used. Flowable fill has been used in a few cases. A more recent practiced has been to place the pipe high in the dam cross section, so that it is above the normal phreatic level; then the pipe is grouted and replaced by another pipe when the next stage is constructed. A concern for a pipe placed high in the dam is that a large storm could result in a raised phreatic level which may subject the pipe to a situation analogous to "first filling" of the dam. That is, a problem with seepage along the pipe may only become evident at a critical time with respect to the amount of water stored in the impoundment.

In an attempt to address potential problems with seepage along a conduit, older installations made use of antiseep collars. In more recent years, filter diaphragms have been installed. In spite of installing the pipes with hand compaction of the haunch area, a practice that has led to problems in other applications, no significant problems have been attributed over the last 25 years to piping or excessive seepage through the backfill of a decant conduit for slurry impoundments.

The International Commission on Large Dams (ICOLD) has prepared a number of technical publications (Bulletins Nos. 44, 74, 97, 98, 101, 103, 104, 106, and 121 [1989a, 1989b, 1994b, 1995a, 1995b, 1996a, 1996b, 1996c, and 2001]) related to the design, construction, and operation of these types of dams (many of these have been developed in partnership with the United Nations Environment Programme [UNEP]).

Tailings and slurry dams have inherent differences compared to embankment dams used for the storage and control of water. The reasons that tailings and slurry dams do not fit within the normal context of "embankment" dams include (see ICOLD publications for further information):

1. They are designed to be abandoned and not operated.

2. Construction is usually simultaneous with its operation.

3. Generally constructed with mill tailings, mine waste, and earth- or rockfill.

4. The primary use is the disposal of waste and slurry from the processing operations. They usually impound water only for sedimentation, reclamation, and mill operation. Water retention is considered to be incidental to their intended operation of waste disposal.

5. The waste is typically discharged along the upstream slope of the dam, forming a delta of settled fines, with the water pushed back away from the dam.

6. The hydraulic gradient existing within the dam is typically less than that existing within in a traditional embankment dam.

7. These dams often are required to impound and release water with a low pH, which can cause corrosion and deterioration of the conduit.

8. Typically, the free water that is impounded is a small percentage of the total stored volume. The majority of the stored volume is hydraulically deposited fine waste.

9. These dams typically cannot be breached at the end of their useful service life and the reservoir area returned to its original condition. These dams must retain their waste products for hundreds of years.

10. These dams are often raised many times to stay ahead of the rising impoundment water.

11. These dams are normally subjected to only a nominal amount of drawdown of free water.

12. The settled fines typically provide a low permeability zone, which acts to restrict seepage.

13. Due to the much larger mass of these dams, decant conduits are generally much longer than conduits in traditional water storage dams. Some dams have conduits over 1,000 feet in length.

As a result of these factors, the performance experience indicates that the combination of hydraulic gradient and backfill material characteristics may have been sufficient to prevent internal erosion and backward erosion piping problems. Also, it may be possible that particles of fine waste carried with the seepage act to choke off potential seepage paths. Experience has shown, for example, that moving the discharge point of the slurry to a point upstream of a localized seepage area is often effective in eliminating the seepage.

Since these types of dams are raised concurrent with disposal, and construction occurs over the life of the mine, which could be a few years to over 30 years, these dams provide a unique opportunity to monitor the structural performance of decant conduits. In applications where the height of fill proposed over the conduit creates concerns about pipe deflection, deflection is typically monitored at various intervals of fill height. Based on these measurements, parameters affecting deflection, such as the modulus of soil reaction (E') can be back-analyzed, and future pipe deflection, and the point at which remedial actions may be required, can be better modeled and estimated.

The "best practices" provided in this document should be applied to the decant conduits installed in tailings and slurry dams. However, these best practices creates a dilemma in the case of tailings and slurry dams. As previously discussed, there are benefits to having a conduit that can tolerate some deformation in these dams. Furthermore, these impoundments do not typically have an "impervious core," and the added cost of reinforced cast-in-place conduits concrete is not as suitable for the shorter life of impoundment conduits, as compared to conduits through traditional embankment type dams. While the absence of significant problems does not rule out future problems, the existing record does provide some indication that alternatives to concrete encasement may be reasonable in tailings and slurry impoundment applications. The following recommendations are provided for installing conduits in these types of dams:

1. Although extensive problems have not been encountered with decant pipes through these dams, good conduit design and installation practices need to be followed. A primary recommendation is that designers recognize the large body of evidence that indicates that adequate compaction cannot be achieved in the haunch area by conventional hand held compaction methods. Using these methods, full contact between the pipe and the backfill cannot be ensured. For guidance on compaction, see section 5.3.

2. Decant conduits should be provided with an adequately designed filter. The filter should extend far enough out from the conduit to intercept areas where cracks may occur due to hydraulic fracturing or differential movement of backfill/embankment materials. For guidance on filters, see chapter 6.

3. The filter should not be considered as an adequate defense, by itself, against problems with seepage along the conduit. The permeability of the backfill material and its level of compaction need to be sufficient to restrict seepage and reduce the hydraulic gradient along the conduit. The filter is intended to collect the limited seepage that occurs through well compacted and suitable backfill. The filter could be overwhelmed and rendered ineffective by excessive seepage.

4. If the pipe is not to be encased in concrete, with sloping sides that allow compaction by heavier equipment, then an alternate construction method, that provides for adequate compaction and full contact in the haunch area, needs to be specified.

5. Use of an alternate construction method should only be considered where it can be shown that the combination of hydraulic gradient and backfill

material characteristics indicate adequate protection against internal erosion and backward erosion piping.

6. Whatever conduit installation method is to be used, the specifications should include a detailed step-by-step procedure for installing the conduit and for achieving full contact with the bedding and backfill. The type of equipment to be used to achieve the specified backfill densities should be specified. Quality control during construction should be the responsibility of a registered professional engineer who is familiar with the project specifications and the potential problems. The specifications should indicate how it will be determined that full contact between the conduit and the backfill has been achieved and the required backfill moisture/density specifications have been met. The engineer should be required to inspect and accept the conduit bedding and backfill before the backfill is placed over the conduit.

Even though these dams differ significantly from embankment type dams, they can experience failure. Regulatory agencies, dam owners, and designers may find application of the guidance provided in this document can improve the overall integrity of their structure. They should fully consider the basis for these best practices and decide on the applicable guidance to use. Where the design and construction of a conduit through these types of dams deviates from these best practices, the designer should ensure that potential problems are otherwise accounted for in the design.

Chapter 1

General

Conduits have been placed through embankments for centuries. However, placing a conduit within an embankment dam increases the potential for seepage and internal erosion or backward erosion piping. Water may seep through the earthfill surrounding the conduit, through cracks in the embankment caused by the conduit, or into or out of defects (e.g., cracks, deterioration, or separated joints) in the conduit. If the conduit is flowing under pressure, and defects exist in the conduit, the water escaping the conduit can erode surrounding soils.

Replacement of a conduit through an embankment dam is difficult, time consuming, and expensive. Designers should adopt a conservative approach for the design of conduits. The purpose of this chapter is to provide guidance for both constructing new conduits and renovating or replacing existing conduits in embankment dams. When evaluating existing conduits, designers should attempt to determine how closely the design of the existing conduit complies with criteria for new conduits. If the existing conduit lacks state-of-the-practice defensive design measures, it may be considered inadequate by modern standards. These design measures should provide both primary and secondary defensive measures to reduce the probability of failures. Inadequate conduit designs, poor construction, and improper maintenance can adversely affect the safety of embankment dams.

1.1 Historical perspective

Most designers of embankment dams have attempted to include defensive design measures to address potential seepage along conduits extending through earthfill or earth- and rockfill embankments. Even so, many observed failures and accidents of embankment dams have occurred, involving conduits or the earthfill near the conduits. For large embankment dams, about one-half of all failures are due to internal erosion or backward erosion piping. In about one-half of these failures, internal erosion or backward erosion piping was known to have initiated around or near a conduit (Foster, Fell, and Spannagle, 2000, p. 1032). This means that about 25 percent of all embankment dam failures are a result of internal erosion or backward erosion piping associated with conduits.

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 gradient 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. In the 1980s, major embankment dam design agencies including the U.S. Army Corps of Engineers (USACE), and the Bureau of Reclamation (Reclamation) discontinued using antiseep collars on conduits for new dams. Reasons why antiseep collars were abandoned include:

- Antiseep collars impeded compaction of soils around the conduit.
- Antiseep collars contributed to differential settlement and created potential hydraulic fracture zones in the fill.
- Designers realized that problems associated with conduits were more likely to be caused from internal erosion mechanisms than from intergranular seepage.
- Designers achieved increased confidence in the capability and reliability of filters to prevent internal erosion failures.
- Antiseep collars can form a foundation discontinuity that could result in differential settlement and cracking of the conduit.

The Natural Resources Conservation Service (formerly Soil Conservation Service, SCS) also discontinued using antiseep collars on new embankment dams, but continues to allow them on small, low hazard dams and only under certain restrictive conditions.

Figures 14 through 16 show examples of the construction difficulties involved with compaction around antiseep collars. Appendix A gives a detailed history of the design rationale used for antiseep collars and reasons for their being discontinued. Figures 17 and 18 show examples of the ineffectiveness of antiseep collars in preventing embankment dam failure resulting from internal erosion near conduits.

Figure 14.—Antiseep collars impeded the compaction of soils around the conduit. Hand tampers were used next to the antiseep collars.

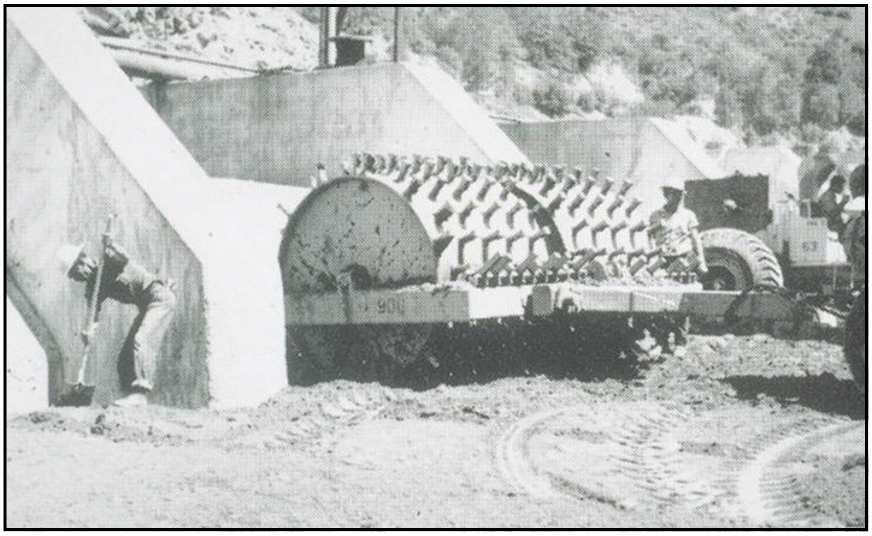


Figure 15.—Compaction around antiseep collars was difficult using large equipment.

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

Figure 16.—Good compaction around antiseep collars was difficult to achieve.

embankment dam design. See chapter 6 for guidance on the design and construction of filters. Since filters have become a standard design element in embankment dam designs, very few failures have occurred that can be attributed to internal erosion or backward erosion piping near conduits.

1.2 Locating the conduit

A number of factors influence the layout of a conduit, such as the type and cross section of the embankment dam, topography, geology, and hydraulics. Conduits through embankment dams are often referred to as "cut-and-cover" conduits. Conduits through embankment dams should be avoided, when safe and cost-effective alternatives are available. An alternative to a conduit through the embankment dam is a tunnel located in the abutment, wherever geology, topography, and economics are favorable. The advantages of a tunnel include:

- *Eliminates potential failure modes.*—The tunnel is not physically associated with the embankment dam. Using a tunnel completely eliminates the potential failure modes normally associated with a penetration through an embankment dam.

- *Facilitates construction*.—A tunnel can often facilitate stream diversion around the damsite during construction.

- *Simplifies embankment placement.*—A tunnel can allow unobstructed embankment placement, since it no longer hinders construction of the earthfill.

Figure 17.—Failure of an embankment dam following first filling. The failure was attributed to internal erosion because the time required for seepage to develop through the compacted embankment and cause failure was very short. Also, the soils are not the type ordinarily considered susceptible to backward erosion piping. Antiseep collars were not effective in preventing the failure.

Figure 18.—Antiseep collars were not adequate to prevent the internal erosion failure of this embankment dam. The internal erosion that occurred on first filling of the reservoir occurred in dispersive clay soils that are not susceptible to backward erosion piping.

- *Eliminates compaction requirements.*—A tunnel eliminates the need for special compaction requirements around the conduit.

- *Allows for independent construction of tunnel.*—Tunnel construction can be performed independently of the embankment dam construction. Typically, the construction of the conduit through an embankment dam is a critical path feature for construction of the dam.

- *Eliminates the need for special filters.*—A tunnel eliminates the need for special filter placement and drainage requirements, which can typically slow the progress of embankment dam construction.

However, there are disadvantages associated with a tunnel, such as:

- *Increased cost.*—A tunnel is often more expensive than a conduit through an embankment dam. This is especially true for smaller diameter conduits. However, for larger diameter conduits or where pressurized systems are required, the relative cost differences can be reduced. The reduction in cost difference is due to a lesser need for redundant safety features, such as steel pipe liners, special filter and drainage requirements, and more efficient embankment dam construction.

- *Soft ground concerns.*—A tunnel may be problematic in soft ground conditions. This could result in higher design and construction costs. Also, the portal conditions must be able to accommodate the entrance and terminal structures.

- *Potential for overruns.*—A tunnel typically involves more risk for cost and schedule overruns than a conduit through an embankment dam.

- *Requires additional engineering experience.*—Fewer engineering firms maintain a qualified staff for planning, design, and construction services for tunnels than for conduits through embankment dams.

- *Construction data lacking.*—Since tunnels are not very often constructed, up-to-date construction cost data are not always readily available for comparison of costs to conduits through embankment dams.

Tunnels are seldom used for small embankment dams and may be a more costly option for some larger dams. In those embankment dams, a conduit penetrating the dam may be preferred. Conduits have typically been located at about the embankment/foundation interface. They are often located so as to align the conduit discharges with the original watercourse, bypassing streamflow during construction, and potentially emptying the reservoir by gravity. This means that for many sites, the conduit is located on alluvial soils that can be deep and compressible. This also means the conduit is often located near the maximum section of the embankment dam, which contributes to greater structural loading on the conduit. The designer should consider the following guidance in locating the conduit (Reclamation, 1987c, p. 3):

- *Avoid differential settlement.*—Whenever possible, the conduit should be located where the profile is entirely on bedrock, or entirely on soil. Differential settlements can occur where the overburden soil thickness is extremely variable or foundation properties differ. The bedrock profile underlying the conduit location should not have abrupt changes in a short horizontal distance.

- *Locate the conduit in a trench.*—Locate the conduit in a trench section in firm rock when the rock is at or near the ground surface (figure 19). For this option, the construction specifications should include provisions for rock excavation to be performed to eliminate or minimize open fractures or other damage to the rock beyond the limits of the excavation. Concrete should extend to an upper limit of the top of the conduit or to the original rock surface, if lower than the top of the conduit.

- *Locate the conduit on a bench.*—Locate the conduit on a bench excavated along the base of an abutment when geological conditions and topography are favorable. Placing concrete on the abutment side or placing the conduit against the excavated rock reduces or eliminates requirements for earthfill compaction against one side of the conduit (figure 20).

- *Consider the potential for nonuniform settlement.*—Foundation conditions along the length of the conduit are often nonuniform, and concentrated settlement is common in some areas. As the height of the embankment dam is raised during the construction of the dam, periodic inspection of the interior of the conduit should be performed. The frequency of such inspections should be determined based on anticipated foundation conditions as well as any uncertainties. Some conduits have experienced distress during and after construction as a result of unidentified foundation conditions. If distress is observed in the form of cracking or separation of joints, prompt remedial action is required. Reclamation has monitored and recorded these concentrated settlements at a number of their embankment dams after construction was completed. The results of monitoring show that nonuniform settlement along the conduit is common after completion of construction.

- *Flatten slopes where conduits span a cutoff trench.*—Where a conduit spans a cutoff trench, the side slopes of the cutoff trench may require flattening to reduce differential settlement between the compacted backfill in the cutoff trench and the foundation soils adjacent to it.

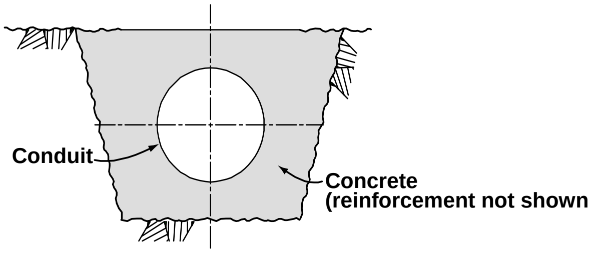


Figure 19.—Conduit constructed in a trench in firm rock.

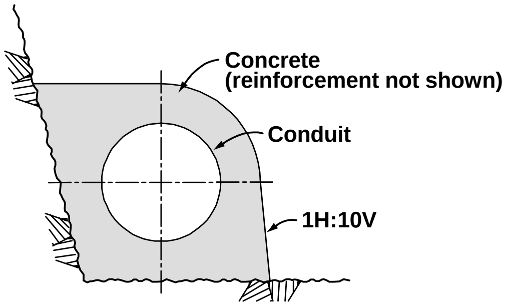


Figure 20.—Conduit cast against excavated rock slope.

- *Limit number of conduit penetrations.*—Designs should use only one conduit, when feasible, to minimize problems associated with penetrations of the embankment dam. Installing several conduits, particularly near one another, compounds the construction difficulties and increases the likelihood of problems associated with conduits through the embankment dam. However, the designer should be aware that with only one conduit, if problems develop that limit the ability to control the release of water, this may result in a dam safety concern. Therefore, the design should be robust using proven methods.

- *Avoid locating conduit joints at discontinuities.*—Locate joints for the conduit where underlying discontinuities do not occur. If the conduit alignment intersects a slurry trench cutoff or vertical drainage zone, the conduit should be designed where these discontinuities are not at a joint, but near the midway point between joints. For guidance on conduit joints, see section 4.3.

- *Consider seismic deformation.*—Seismic activity can result in significant deformation of the embankment dam. Deformations, such as settlement and spreading can open conduit joints and cause cracking and displacement of the conduit.

- *Avoid the use of bends.*—Locate the conduit so that bends in the alignment or profile are not required for the portion under the embankment dam. This will facilitate future inspection and renovation (i.e., sliplining). This will also provide improved compaction near the conduit and eliminate any stress concentrations resulting from the bend.

Some techniques that have been found to be applicable for designing conduits on compressible foundations include:

- *Excavate and replace compressible foundation soils.*—To reduce differential settlement or to reduce total settlement, excavate compressible foundation soils and replace with less compressible compacted soil.

- *Properly locate controls.*—Position the control gates and valves upstream of im pervious zone in the embankment dam.

- *Avoid pressurizing the conduit.*—Avoiding pressurized conduits through impervious embankment dams, unless the pressure conduit is placed within a larger conduit. To prevent pressurizing of the conduit, a free standing welded steel pipe supported by cradles can be placed within a larger reinforced concrete conduit. Access is provided along the side of the steel pipe. The steel pipe is considered to be ductile and will deform and still maintain a watertight conduit. When possible, field weld the steel pipe joints after the initial foundation settlement of the conduit has occurred.

- *Bridge over weak areas.*—Longitudinal reinforcement extending across the joints of the reinforced concrete encasement surrounding the welded steel pipe liner can provide a rigid beam effect and bridge over weak foundation areas to minimize locally concentrated deflections.

- *Utilize longitudinal reinforcement across joints.*—Large horizontal movements often occur at randomly selected conduit joints, rather than uniformly along the conduit length. This type of concentrated movement can open gasketed conduit joints that are not designed for large horizontal movements. The use of longitudinal reinforcement across the joints and continuous welded steel pipe liners are effective in reducing concentrated openings within conduits.

- *Provide camber.*—A conduit that is not located on bedrock must be designed so that the amount of predicted foundation settlement does not damage the conduit or its function. A conduit constructed on a compressible foundation should be cambered to accommodate the predicted foundation settlement, to achieve a proper final grade.

In lieu of constructing tunnels or conduit penetrations through embankment dams, siphons can often provide alternative reservoir drawdown capability for low hazard dams. Siphons are particularly useful for recreation reservoirs that do not make regular releases. However, proper design precautions must be utilized to ensure long term performance. For guidance on the design of siphons, see section 11.4.1.

1.3 Foundation investigations

Thorough foundation investigation and interpretation of the data obtained are required to determine whether a safe and economical conduit can be built at a selected site. The designer should always participate with the planning of the subsurface exploration program. Guidance for planning, conducting, and interpretation is available in Reclamation's *Design of Small Dams* (1987a) and *Engineering Geology Field Manual* (1998b), and the USACE's *Geotechnical Investigations* (2001a). The designer should be aware that final alignment of the conduit may require adjustment after the complete foundation has been exposed.

Chapter 2

Conduit Materials

Various materials have been used in the design and construction of conduits through embankment dams. The reasons for utilizing these different materials have included cost, availability, operations, maintenance, and constructability. The most common materials used in the construction of new and renovated conduits have been:

- *Concrete.*—Reinforced cast-in place and precast
- *Plastic.*—Thermoplastic and thermoset
- *Metal.*—Steel, ductile iron, cast iron, and CMP

The strength and performance characteristics of each conduit material depend on its chemistry and the relationship of its components. For example, concrete is produced using cement, sand, aggregates, and reinforcement, whereas metal is a homogenous, isotropic material.

Certain design and construction advantages and disadvantages are associated with each material. Each material requires specific design and construction considerations. Some of these materials, are not recommended for use in the design and construction of conduits through significant and high hazard embankment dams. For example, CMP is seldom used in any embankment dams other than low hazard dams and needs to be carefully evaluated for the specific dam site. For guidance on the use of specific materials in renovation, replacement, and repair of conduits, see chapters 12, 13, and 14.

2.1 Concrete

Concrete materials used in conduit construction have included:

- Reinforced cast-in-place
- Precast concrete pipe

These materials are discussed in the following sections.

2.1.1 Reinforced cast-in-place concrete

Reinforced cast-in-place concrete is placed and allowed to cure in the location where it is required to be in the completed conduit. Reinforced cast-in-place concrete is made by mixing cement, fine and coarse aggregates, sand, and water. Admixtures are frequently added to the concrete immediately before or during its mixing to increase the workability, strength, or density, or to lower its freezing point. A framework of reinforcing steel is constructed, and forms to contain the wet concrete mix are built around the reinforcement. The wet concrete mix is placed inside the forms and around the reinforcing steel. Typically, consolidation of the concrete mix is obtained by vibration. The final solidified mass becomes reinforced cast-in-place concrete. Reinforced cast-in-place concrete conduits are built at the construction site. Figure 21 shows typical reinforcement used with cast-in-place concrete.

Reinforced cast-in-place concrete conduits (figure 22) have a long history of use by the major dam design agencies. Reinforced cast-in-place concrete conduits are very adaptable in their application and can be designed to fit specific project requirements and site conditions. A variety of design shapes are possible. For guidance on selecting the proper shape see section 4.1. Properly designed and constructed reinforced cast-in-place concrete should have a service life of 100 years or longer.

The advantages of using reinforced cast-in-place concrete for conduits include:

- The longitudinal reinforcement typically extends across the conduit joints. This prevents the joint from separating and developing a leak.

- A variety of conduit shapes are available to provide better distribution of loadings to the foundation.

- Conduit shapes can be designed to provide for good compaction of earthfill against the conduit.

- Allows for redundant seepage barrier protection, since waterstops and reinforcement typically extends across conduit joints. Welded steel liners are often used to provide additional seepage barrier protection.

The disadvantages of using reinforced cast-in-place concrete conduits include:

- Construction costs are often higher than for other conduit materials, particularly for small diameters.

Figure 21.—Reinforcement being unloaded for use in cast-in-place concrete.

Figure 22.—Concrete placement for a reinforced cast-in-place conduit.

- Quality of concrete depends on quality control and construction inspection in the field.

- Aggressive water or soil chemistry can limit service life, unless proper precautions are taken in design.

2.1.2 Precast concrete

Precast concrete refers to concrete pipe that is cast somewhere other than its final location. Precast concrete pipe sections are transported to the location where the conduit is constructed (figure 23). Three types of precast concrete pipe have typically been used in the construction of conduits through embankment dams: reinforced concrete pipe (RCP), reinforced concrete cylinder pipe (RCCP), and prestressed concrete cylinder pipe (PCCP).

Precast concrete pipes are typically circular in cross section. Rectangular precast conduits (also known as precast concrete boxes) are seldom used in embankment dams, because joints cannot be constructed that are reliably watertight.

The advantages of using precast concrete for conduits include:

- Manufactured to tight tolerance in a controlled environment.
- Quality is unaffected by adverse field casting conditions.
- Can be installed quickly, thus minimizing the amount of time required for stream diversion.
- Articulation of joints and the ability to accommodate varying settlement along the entire length of the conduit without high structural stresses.

The disadvantages of using precast concrete for conduits include:

- Longitudinal reinforcement does not extend across the conduit joints. Joints can open as a result of embankment dam settlement or elongation, unless a continuously reinforced concrete cradle is provided along the full length of the conduit.
- Due to shipping and handling limitations, short pipe lengths are required to reduce weight. This will result in many pipe joints for the entire length of the conduit and increase the number of locations for potential leakage.
- Gasketed joints are the only defense against leakage.
- Compaction of earthfill is difficult under the haunches of the pipe, unless a concrete cradle is provided.
- Aggressive water or chemistry can limit service life, unless proper precautions are taken in design.

Figure 23.—Precast concrete pipe being unloaded from delivery truck.

Some design agencies, such as Reclamation, do not permit use of pressurized or nonpressurized precast concrete conduits through embankment dams due to concerns with watertightness, the lack of longitudinal reinforcement extending across conduit joints, and the difficulty of adequately compacting earthfill against the conduit below its springline.

Other design agencies, such as NRCS, use precast concrete pressure pipe (American Water Works Association [AWWA] C300 [2004a], 301 [1999b], and 302 [2004b]) extensively for all embankment dams other than low hazard dams. The typical NRCS application is a pressure rated pipe in a nonpressurized conduit situation where the entrance structure is an ungated riser or tower, and the terminal structure is an ungated plunge pool or stilling basin. *Earth Dams and Reservoirs* (1990) contains NRCS design guidance for conduits in embankment dams.

2.2 Plastic

Plastic pipe is often used in the renovation of conduits (e.g., sliplining or lining of existing conduits). Plastic pipe that is used in the construction of new, significant and high hazard embankment dams should always be encased in reinforced cast-in-place concrete to assure quality compaction against the conduit. Use of plastic pipe in new, low hazard embankment dams is generally limited to small diameters (less than 12 inches). Plastic pipe used in low hazard embankment dams is often not encased in reinforced cast-in-place concrete for economic and construction-related reasons. However, use of a filter diaphragm or collar is a valuable defensive design measure, even for low hazard classification sites with favorable conditions. Some designs may not employ a filter diaphragm around the conduit, but eliminating this valuable feature should be carefully considered and justified, based on extremely favorable soil conditions, good conduit construction materials and methods, reliable construction practices, and favorable foundation conditions. Plastic pipe is generally considered to have a shorter service life (approximately 50 to 100 years) than concrete, but may be preferred in situations where aggressive water or soil chemistry could attack concrete.

Plastic pipe consists of resins composed of polymerized molecules mixed with lubricants, stabilizers, fillers, and pigments. Plastic pipe used in the construction or renovation of conduits has included thermoplastic and thermoset plastic. These materials are discussed in the following sections.

2.2.1 Thermoplastic

Thermoplastics are solid materials that change shape when heated. Thermoplastics commonly include polyethylene (PE) and polyvinyl chloride (PVC). Thermoplastic pipe is produced by the extrusion process. The extrusion process continuously forces molten polymer material through an angular die by a turning screw. The die shapes the molten material into a cylinder. After a number of additional processes, the final product is cut into the specified pipe lengths.

The advantages of using thermoplastic pipe as a new conduit or for the sliplining of an existing conduit include:

- Lightweight material that facilitates installation.
- Resists corrosion and is not affected by naturally occurring soil and water conditions. May be preferable in certain conduit applications where aggressive water or soil chemistry would limit the life of concrete or metal pipe.
- The smooth interior surface reduces friction loss. Also, due to the very smooth surface of thermoplastic pipe, adherence of minerals (e.g., calcium carbonate) is minimized.
- The ability to heat fuse PE pipe joints provides a watertight joint.
- Resists biological attack.

The disadvantages of using thermoplastic pipe as a new conduit or for the sliplining of an existing conduit include:

- High coefficient of thermal expansion relative to concrete can cause movement of the slipliner, requiring the use of end restraints.
- Can easily be damaged or displaced by construction and compaction equipment unless it is encased in concrete.

- Compaction of earthfill is difficult under the haunches of the pipes unless encased in concrete to provide good compaction of earthfill against the conduit.

- Heat fusion of pipe joints requires special equipment and an experienced operator.

- Requires a concrete encasement for significant and high hazard embankment dams to provide a favorable shape for compaction of earthfill against the conduit.

Solid wall, high density polyethylene (HDPE) is the most commonly used thermoplastic material for sliplining of existing conduits. Figure 24 shows an example of HDPE pipe. HDPE pipe is an inert material and as such is not subject to corrosion or deterioration, has a long service life, and requires little maintenance. This is especially important in small conduits that are not easily renovated and cannot be easily inspected. HDPE has been used in sliplining of existing conduits, since the early 1980s. HDPE is typically available in sizes up to 63 inches in diameter. The manufacturer can fabricate HDPE pipe fittings, such as bends, flanges, reducers, and transitions. Specialized fittings can also be custom fabricated. HDPE pipe is typically black. However, HDPE pipe is also available with gray and white pigmentation to reduce glare and improve conduit inspection using closed circuit television (CCTV) equipment. For guidance on the use of HDPE pipe in conduit sliplining applications, see section 12.1.1.

PVC pipe (figure 25) is not as commonly used as HDPE pipe as a conduit or slipliner due to concerns with lack of watertightness and other inherent disadvantages. The major disadvantage with PVC pipe is the bell and spigot joint connections. This type of joint connection has the potential for leakage or can separate as the embankment dam settles. The bell and spigot joint integrity must be tested for leaks to ensure that the gasket has not rolled off during installation. Use of PVC bell and spigot joints should only be considered for nonpressurized, low hazard dam applications. PVC is typically available in sizes up to 48 inches in diameter.

Figure 24.—HDPE pipe to be used for sliplining of an existing conduit.

Figure 25.—PVC pipe has infrequently been used in conduit applications within low hazard embankment dams. The bell and spigot joint connection used for this type of pipe limits its use for most conduits.

2.2.2 Thermoset plastic

Thermoset plastics are rigid after manufacturing or curing and cannot be reformed. The most commonly used thermoset plastic for lining nonpressurized conduits is cured-in-place pipe (CIPP). CIPP is also referred to as an "elastic sock." CIPP consists of a polyester needle-felt or glass fiber/felt reinforcement preimpregnated with polyester resin (USACE, 2001d, p. 11). The preimpregnation process is usually done at the factory for quality control purposes. On the inner surface of the CIPP liner is generally a coating or membrane of polyester, polyethylene, surlyn, or polyurethane, depending on the type of application. The membrane provides a low friction and hydraulically efficient inner surface to the CIPP liner. Figure 26 shows CIPP being used to line an existing conduit. CIPP has been successfully used in renovating deteriorated pipelines, drain pipes, and conduits through levees for over 25 years. CIPP has been used for conduit renovation through embankment dams since about the mid-1990s.

The advantages of using CIPP lining for conduits include:

- Thermoset plastic pipe is corrosion resistant and is not affected by naturally occurring soil and water conditions. Thermoset plastic pipe may be preferable in certain conduit applications where aggressive water or soil chemistry would limit the life of concrete or metal pipe.

Figure 26.—CIPP liner exiting from an existing conduit via the hydrostatic inversion method.

- The smooth interior surface reduces friction loss. Also, due to the very smooth surface of thermoset plastic pipe, adherence of minerals (e.g., calcium carbonate) is minimized.

- Thermoset plastic pipe resists biological attack.

- Typically, the need for grouting of the annulus between the CIPP liner and existing conduit is eliminated, since it is tight fitting.

The disadvantages of using CIPP lining for conduits include:

- High material and installation costs.

- Not suited for conduits with significant bends or changes in diameter.

- Inability to accommodate internal and external loadings when the original conduit is severely damaged.

CIPP liners are generally applicable for lining of existing conduits ranging in diameter from 4 to 132 inches. Maximum lengths of CIPP liners generally range