



Figure 187.—Cofferdam constructed around the construction area for a new outlet works.

facilitate construction. For guidance on the design and construction of entrance and terminal structures see section 3.4.

13.9 Microtunneling

Microtunneling (also called “pipe jacking” or “boring and jacking”) is a remotely controlled process for installing conduits underground without the need for excavation of a trench.

Microtunneling techniques should not be used for installation of conduits through embankment dams. Difficulties exist with obtaining a watertight seal along the conduit and potentially with disturbing the embankment dam during installation. Until emerging technology and procedures are significantly improved and shown to be reliable, it is recommended that this renovation method be restricted to installation of conduits in abutments and foundations. Installation of conduits in the abutments and foundations of embankment dams has been successfully performed. The discussion in this section only applies to conduit installation in abutments or foundations.

A successful microtunneling project requires detailed site investigation, appropriate consideration of design criteria, preparation of comprehensive bid documents, accurate contractor submittal information, careful execution by a highly skilled operator and crew, and a knowledgeable, experienced contractor (USACE, 1995d, p. xviii).



Figure 188.—During the removal of this outlet works conduit a flood occurred. No stream diversion or cofferdam was used at this site.

Microtunneling utilizes a two-step process. The first step is installation of and grouting around a liner pipe, also called a carrier pipe or shield. The second step involves installation of the permanent conduit and grouting of the annular space between the two pipes.

Microtunneling has been used to construct conduits up to about 84 inches in diameter. The tunneling technique uses a tunnel boring machine with the tunnel lining being jacked into place as the boring machine advances. The tunneling procedure is remotely controlled and operated and requires limited entry into the tunnel by construction personnel. Tunnel boring machines use laser guidance control systems. Machines are available to drive 300 feet or more in length in soft ground.

Microtunneling consists of a tunnel boring machine that is equipped with a cutting head slightly larger than the tunnel liner. The cutting head has to be carefully selected to deal with the expected ground conditions. Sections of the tunnel liner are assembled outside of the tunnel, and as the boring machine excavates ahead of the conduit liner, the tunnel liner is jacked into place. The cuttings from the tunneling machine are ground into small particles and removed with a bentonite slurry pumped to a location outside of the tunnel. A lubricating fluid is generally pumped into the annular space between the excavation and the tunnel liner to help facilitate the jacking of the liner. At the high slurry flow rates and velocities typically used in

microtunneling, only a very short time is required to erode soil at the face and cause large settlements. The operator must vigilantly control slurry circulation and machine torque to avoid such unacceptable events (USACE, 1995d, p. 4-44). Figure 189 shows a microtunneling installation when an operator stopped advancement.

The selection of the microtunnel liner material is critical. The liner material must be strong enough to withstand the jacking forces and other anticipated loads that the liner could be subjected to during the installation and life of the liner. The liner should be watertight and able to withstand internal and external water pressures. The liner should also be able to withstand any external earth and grouting pressures exerted on it. Once installed, the liner should be strong and durable enough to provide dependable service for the life of the project. Liner material considerations consist of welded steel pipe, reinforced concrete steel cylinder pipe, plain reinforced concrete pipe, HOBAS pipe (a composite fiberglass pipe) and HDPE pipe. Welded steel pipe is the liner material used on most projects. Steel pipe is very suitable for jacking and generally requires a relatively thin-walled section compared to concrete pipe, which reduces the required tunnel excavation to install the steel pipe liner. Welding can be used to repair any damage to the steel pipe and for attaching fittings. The steel pipe has a relatively smooth exterior, which helps reduce the friction between the excavation and the liner as it is being jacked into place. The steel can also be designed to withstand all anticipated internal and external loads. If the tunnel boring bends slightly, the steel liner could buckle as it is forced around the bend. If the liner does buckle, it will be very difficult to repair.

Another consideration of the microtunneling technique is the selection of the liner joints. The joints should have adequate compressive, bending and tensile strength to withstand the forces required to jack the liner into place. Once installed, the joints between each section of microtunneled liner need to be able withstand both internal and external water pressures without leakage. The joints need to be perpendicular to the centerline of the pipe, square, and snugly fit, so the conduit will be straight and easy to steer with the tunnel boring machine. Once installed, the joints of the liner are generally exposed to very minor additional stresses.

Because the pipe can “set” or “freeze” in a location if jacking operations are stopped for any length of time, a continuous installation process may be necessary. Common practice dictates the use of hydraulic jacks with a capacity greater than anticipated in order to avoid this situation.

Once the liner is installed, the annular space between the excavation and the tunnel liner is generally grouted in a continuous operation. As the grouting procedure takes place, the lubricating fluid is forced out of the annular space. The grouting is intended to reduce or eliminate potential seepage along the tunnel liner. The designer should explicitly specify the requirements for the liner installation and grouting. In addition, the contractor should be required to submit for approval by



Figure 189.—A very large surface void appeared directly above a test microtunneling installation when the operator stopped advancement of the machine and briefly allowed the slurry pump to continue to circulate the drilling mud. The void appeared in backfill surrounding some test instruments, some of which appeared to support the adjacent soils.

the design engineer, the proposed procedure and materials prior to implementation. Worster, et al. (2002, p. 9) state:

Many of the contractors doing this work may be accustomed to applications where seepage along the outside of the carrier pipe, or between the carrier and liner pipe, is not as significant of a concern. The focus on grouting and pipe placement requirements may be unusual for these contractors. For this reason, requirements for grouting the carrier pipe/embankment contact, placement of the liner pipe, and grouting the liner pipe/carrier pipe annulus should be specified in detail. A contractor submittal on the means and methods to accomplish these items should be required for approval, to ensure that all specification requirements are met and proper procedures are followed during construction.

Microtunneling with wet recovery of the tunnel boring machine is a relatively new and rapidly developing method of installing conduits into a reservoir partially or fully filled with water. For a wet recovery of the tunnel boring machine, a recovery pit is excavated into the reservoir bottom. The tunnel is advanced from the downstream side of the embankment dam in the direction of the pit. Once the tunnel has advanced to a point near the pit and where the advancing face of the tunnel is still stable, the tunneling is stopped and the hydraulic lines are disconnected from the tunneling machine. A temporary bulkhead is placed inside of the tunnel downstream of the boring machine. The boring machine and tunnel liner are then jacked for the final length of the tunnel, until the boring machine is pushed into the recovery pit.

The tunnel boring machine can then be recovered by a barge in the reservoir. An intake structure can also be installed by prefabricating it in the dry, floating it out to the required location, and sinking it into place.

If the upstream end of the pipe will be located below the reservoir elevation, then a cofferdam will be required. In one case, a jacking pit was excavated in one abutment of an embankment dam, from which pipes were extended to upstream and downstream cofferdams (Wooten, Fortin, and Walker, 1997, p. 518).

A properly designed filter diaphragm or collar should be constructed near the downstream end of the pipe to intercept and control potential seepage along the outside of the conduit. For guidance on the design and construction of the filter, see chapter 6.

13.10 Horizontal directional drilling

Horizontal directional drilling (HDD) was developed in the 1970s to install underground pipelines for the oil and gas industry without the need for trench excavation along the entire length of the pipe (USACE, 1998b, p. 1). This method is generally used on pipes smaller than about 12 inches in diameter.

Horizontal directional drilling techniques should not be used for installation of conduits through embankment dams. Difficulties exist with obtaining a watertight seal along the conduit and potentially with disturbing the embankment dam during installation. Until emerging technology and procedures are significantly improved and shown to be reliable, it is recommended that this renovation method be restricted to installation of conduits in abutments and foundations. Installation of conduits in the abutments and foundations of embankment dams has been successfully performed. The discussion in this section only applies to conduit installation in abutments or foundations.

HDD should be restricted to installation of conduits in embankment dam foundations, with the entrance and exit points located at least 300 feet from the dam (USACE, 2003a, p. 2). In controlled tests conducted by the USACE, hydraulic fracture of the embankment dam, ground subsidence, heave of the ground surface, and significant collapses have all occurred with HDD.

HDD consists of drilling a pilot hole through the soil with a fluid-powered cutting tool attached to a hollow drill stem. Drilling fluid under pressure is pumped through the drill stem to power the drill tool. The drill can be steered, both vertically and horizontally, so that HDD installations need not be straight. After the pilot hole is completed, it is often enlarged with a reamer. Then, a permanent pipeline is attached to the cutting end of the drill stem and “pulled back” through the hole as the drill

Conduits through Embankment Dams

stem is retrieved. The most common pipe material is HDPE, although PVC and steel can be used.

Legitimate concerns are associated with the fluid pressures used for excavation during the horizontal directional drilling process, and the potential for hydraulic fracturing of the embankment dam. Reasonable limits must be placed on maximum fluid pressures in the annular space of the bore to prevent inadvertent drilling fluid “returns” to the ground surface. However, it is equally important that drilling pressures remain sufficiently high to maintain borehole stability, since the ease with which the pipe will be inserted into the borehole depends upon borehole stability.

The drilling pressures should be measured in the borehole, not at the pump. The in-situ pressures should be compared with theoretical criteria that would cause hydraulic fracturing of the adjacent soils. In a test study by the U.S. Army Corps of Engineers, it was found that the pressure in an HDD hole drilled through a levee embankment was nearly independent of the drill rig pump pressure. Monitoring of piezometers in the embankment levee showed that while significant increases in pore pressures in the embankment occurred as drilling operations progressed, the pressures quickly dissipated to their original levels. Studies on plastic behavior showed that fluid pressure may cause hydrofracture (figure 190) when the pressure exceeds twice the value of undrained cohesion of the soil, that is, the unconfined compressive strength of the soil. Therefore, a pressure of 100 lb/in² would be expected to cause hydrofracture in a clay with an unconfined compressive strength less than 7.2 t/ft², a very stiff clay. According to these assumptions, for a compacted saturated clay with a soil unit weight of approximately 125 lb/ft³, 8.7 lb/ft² for each 10 feet of depth would be required to cause hydrofracture. However, these studies did not address the propagation of hydrofracture through the soil but focused solely on the pressures required to initiate hydrofracture. Studies on the elastic behavior compared the stresses on the boundary of the hole and compared these stresses with the tensile strength of the soil. The coefficient of lateral earth pressure was varied to determine its effect on hydrofracture potential. As the ratio of horizontal soil stress to vertical soil stress approached unity, the stresses required to produce hydrofracture were comparable to those computed for the plastic deformation analysis. The fact that hydraulic fracture has not been observed in many HDD projects where the theoretical criteria have been exceeded makes it clear that important factors have been ignored (USACE, 1998b, p. 6).

A properly designed filter diaphragm or collar should be constructed near the downstream end of the pipe to intercept and control potential seepage along the outside of the conduit. For guidance on the design and construction of the filter, see chapter 6.

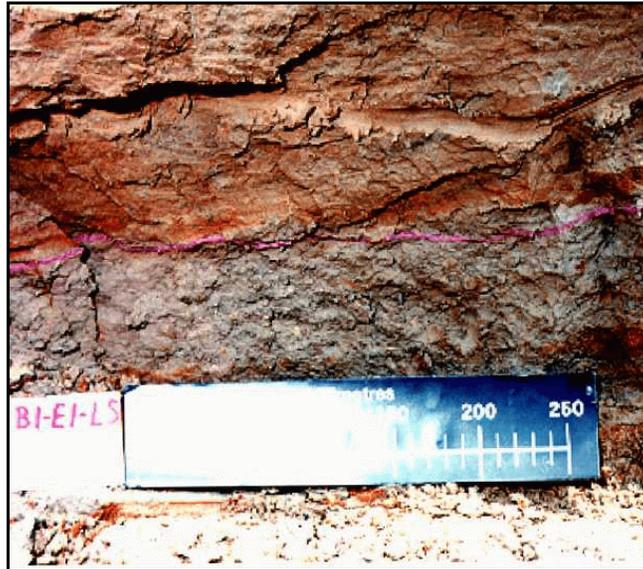


Figure 190.—Hydraulic fracture of embankment levee during HDD installation is visible in this photograph. The drilling mud, which was dyed pink, so that such fractures could be observed, followed an interface along a clay seam (USACE, 1998b, p. 29).

Chapter 14

Repair and Abandonment of Conduits

When water is flowing in an uncontrolled way through the embankment materials surrounding a conduit, some designers have attempted to grout these defects to reduce the water flow. This chapter discusses important considerations for grouting around conduits.

The chapter also discusses methods used to repair damaged conduits when complete replacement is not necessary. Finally, the factors that are important to consider if a decision is made to leave a conduit in place, but abandon it for use are discussed. Recommendations for filling the abandoned conduit and ways to protect against potential pathways for water to flow through the abandoned conduit are discussed.

Previous chapters have discussed methods for renovation and for replacement of conduits. This chapter discusses various other methods available for repairing or abandoning damaged and deteriorated conduits.

14.1 Grouting along the exterior of the conduit

Grouting around conduits is not recommended as a sole solution for prevention of internal erosion or backward erosion piping. Grouting will not likely provide 100-percent encapsulation of the conduit, and seepage gradients in the 'windows' in the grout may actually be higher than the initial gradients before grouting and should always be combined with a downstream filter diaphragm or collar. Grouting can be used to fill or partially fill voids created by internal erosion or backward erosion piping, to reduce future settlements, but filter diaphragms or collars or other positive means must be used to prevent internal erosion. Water can penetrate cracks that cannot be grouted closed.

Generally, grouting along the exterior of an existing conduit consists of injecting cement or chemical grouts into voids. Grouting can also be used to seal leaking joints in the existing conduit. Grouting can be performed from the interior of the existing conduit, if man-entry is possible. If man-entry is not possible, grouting must be performed from the surface of the embankment dam.

Conduits through Embankment Dams

The advantages of grouting along an existing conduit through an embankment dam include:

- *Impacts.*—Construction impacts to downstream users are minimized.
- *Costs.*—Construction costs are generally lower (initially) than for other renovation or replacement methods. However, grouting along conduits is not always fully successful and should not be considered a permanent repair. This method does allow for additional grouting attempts to be made in the future.

The disadvantages of grouting along a conduit through an embankment dam include:

- *Not permanent.*—This method should not be considered a permanent renovation method. This method will have limited effect on corrosion prevention or improvement of structural integrity of the conduit.
- *Voids.*—The filling of all voids surrounding the existing conduit cannot be verified.

Grouting from the interior of man-entry accessible existing conduits generally provides a higher degree of success in filling voids outside the existing conduit and sealing joints. Geophysical methods can be used to identify areas of suspected voids. See chapter 10 for guidance on geophysical methods. These areas can be drilled and a small video camera inserted to determine the extent of the void. Accommodations will need to be made for removal and control of water leaking into the existing conduit as the grout injection work is performed. Partial lowering of the reservoir will reduce leakage into the existing conduit. While work is going on within the existing conduit, a pumping system to discharge reservoir inflows may be required to keep the reservoir at the desired elevation or to meet downstream requirements.

Existing conduits that are not accessible to man-entry generally have limited success in filling voids outside the conduit and sealing joints. Drilling is usually accomplished from the surface of the embankment dam. As the height of the embankment dam increases, so does the degree of difficulty for injecting grout at the desired location along the existing conduit. Grout is advanced from the surface through the drill hole to the void using pressure. The designer is cautioned that this method, unless carefully controlled, has the potential for causing hydraulic fracture within the embankment dam. Drilling from the surface of the embankment dam is not advisable for situations where the reservoir water surface cannot be lowered. If the reservoir cannot be lowered, grouting along the upstream portion of the conduit is not practicable. See section 14.3 for additional guidance on drilling in embankment dams.

In the repair of voids along the outside of the conduit at Lake Tansi Dam (Heckel and Sowers, 1995), grout was placed through borings drilled from the top of the embankment dam using only the pressure from gravity (no pump). Holes with large grout “takes” should be redrilled and grouted again to ensure that the voids are filled. The designer should strategically select the location of any additional holes to maximize the filling of voids.

In order to minimize the potential for accidentally filling the conduit with grout, any cracks or open joints in the conduit should be first repaired. For guidance on repair techniques, see section 14.2.

Any cracks or other defects should be plugged prior to grouting operations. Unless conditions indicate otherwise, grout holes should be drilled and grouted in an appropriate pattern beginning at the downstream end of the conduit at the pipe invert progressing up and around the pipe and from the downstream to the upstream end of the conduit. Figure 191 shows the drilling of a grout hole from the interior of an existing conduit.

Grouting should progress so that grout is pushed in the direction of increasing water pressures and up around the conduit to maximize grout penetration and filling of voids, and to minimize the potential for erosion of grout by flowing seepage waters. If suitably safe conditions exist, several rows of grout holes in advance of the

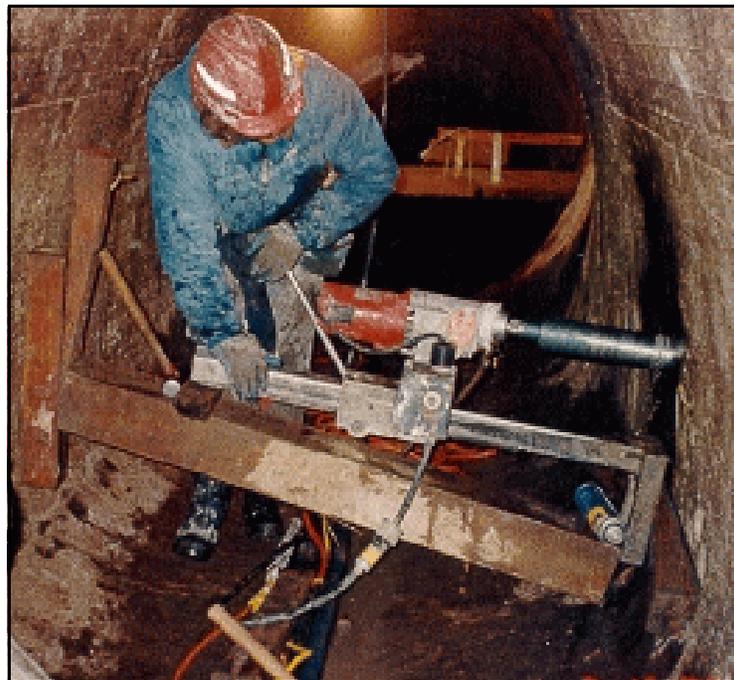


Figure 191.—Drilling a grout hole from the interior of a conduit.

Conduits through Embankment Dams

grouting operations should be opened to monitor the progress of grouting and observe any connections between grout holes due to existing voids around the conduit. This will assist in the assessment of areas where notable erosion and embankment damage has occurred and the need for secondary and tertiary grout holes.

Prior to any grouting or other conduit remediation work, consideration should be given to the installation of appropriate instrumentation in the vicinity of the conduit in order to (1) establish baseline water pressure and seepage gradient conditions prior to repair work, and (2) detect any changes to embankment and foundation water pressures that may result from corrective actions. Depending on the nature of the problem and the corrective actions, such instrumentation will indicate whether the repairs are successful in lowering embankment water pressures, or when repairs may cause undesirable changes that require further corrective actions.

Grouts used for injection into defects or joints and along conduits are usually cementitious or chemical.

- *Cementitious*.—For guidance on cementitious grout, see section 14.2.2.
- *Chemical*.—For guidance on chemical grout, see section 14.2.2. Figure 192 shows grouting operations within a conduit. Chemical grouts have also been used for grouting voids using drill holes from the surface of the embankment dam. For additional guidance on chemical grouts, see USACE's *Chemical Grouting* (1995a).

See the Lake Darling case history in appendix B, for an example of grouting of voids existing along a conduit.

14.2 Repair techniques

Repairs to conduits are typically performed to prevent further deterioration or prior to more extensive renovation methods. Repairs often are done to stop the inflow of water into the conduit through cracks or joints. The following sections mainly pertain to the repair of concrete conduits. For repair guidance for plastic pipe, see sections 12.1.1 and 12.2; for repair guidance on steel pipe, see section 12.1.2.

14.2.1 Concrete repairs

Concrete used in modern conduits is very durable and if properly proportioned and placed will provide a very long service life under normal operating conditions (Reclamation, 1997, p. 1). However, many existing conduits were constructed years ago using early concrete technology. Neglecting to perform periodic maintenance and



Figure 192.—Injection of urethane grout to stop leakage.

repairs could result in continued deterioration and/or failure. A successful concrete repair depends on quality of workmanship, procedures followed, and materials used. A systematic approach to repair should be followed. Sources, such as the Bureau of Reclamation, U.S. Army Corps of Engineers, American Concrete Institute, Portland Cement Association, the International Concrete Repair Institute, and private authors have developed good systems and methodologies. A summary of Reclamation's concrete repair system is presented here as an example (see Reclamation's *Guide to Concrete Repair* [1997] for a detailed discussion on concrete repair):

- *Determine the cause(s) of damage.*—The cause of damage or deterioration (e.g., abrasion, cavitation, poor design and construction, etc.) to the original concrete must be assessed (figure 193), or else the repair of concrete may also become subject to the same damage or deterioration. A determination must be made as to whether the damage is the result of a one-time or a recurring event. The damage could also be the result of multiple causes, such as improper design, low quality materials, or poor construction technique.
- *Evaluate the extent of the damage.*—The extent and severity of the damage and the effects on the serviceability of the existing conduit must



Figure 193.—Determine the cause of the damage to determine the proper repair method.

be understood (figure 194). This evaluation will need to determine how quickly the damage is occurring and what the likely progression will be. The simplest and most common evaluation technique is by the use of sounding (hammer blows applied to the concrete surface). Experienced personnel using sounding and visual observation can assess indications of the extent of damage. In smaller conduits, CCTV inspection techniques may be required.

Sounding can provide an indication of delaminated or disbonded concrete by listening for drummy or hollow sounds. For deeper delaminations or for delaminations with minute separation, placing a hand close to the location of hammer blows or watching sand particles on the surface can provide information. If vibrations are felt or if the sand particles bounce on the surface this can be an indication of delamination.

Sounding can indicate concrete strength by the sounds created as the hammer hits the surface or by the rebound of the hammer. High strength concrete has a distinct ring as the hammer hits the surface, and the hammer rebounds sharply. Low strength concrete has a dull thud as the hammer hits the surface, and the hammer rebounds only slightly.

Concrete cores can be taken from damaged areas to assist with the detection of subsurface deterioration. Laboratory testing and petrographic analysis are needed to confirm the causes of deterioration.

Non destructive testing methods can also be used to assist with the detection of damage. These include the Schmidt Rebound Hammer, ultrasonic pulse velocity, and acoustic pulse echo devices.

The extent of damage determined by the above methods should be mapped and the volume of repair concrete computed for preparation of the repair specifications. In existing conduits that are too small for man entry, CCTV should be utilized to evaluate the extent of damage.

- *Evaluate the need for repair.*—The need for immediate repair should be closely evaluated. If the safe operation of the conduit is affected, immediate repair may be necessary. However, most concrete damage progresses at a slow rate, and early detection and action may be able to slow the rate of deterioration. Early detection may also mean the difference between a repair and complete replacement. Not all deterioration will require repair if it is non safety related. Small hairline cracking on the concrete surface caused by drying and shrinkage usually does not require repair.

An important consideration in determining the need for repair is the scheduling. Except in emergencies, many conduits cannot be removed from

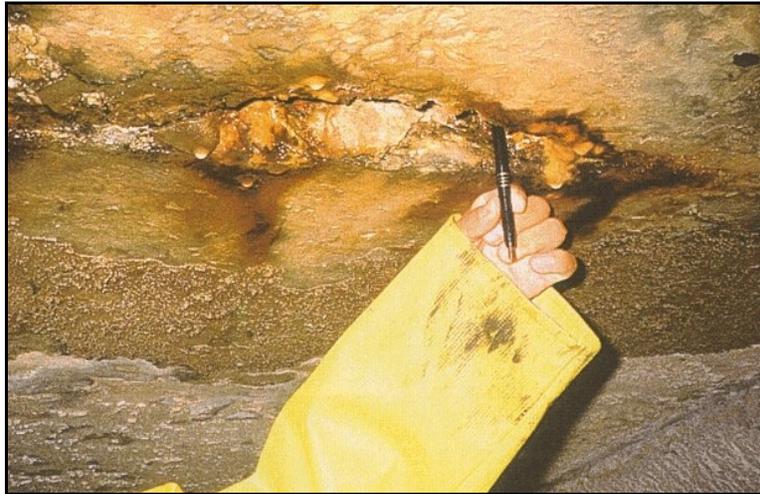


Figure 194.—Evaluate the extent of the damage.

service for repair at certain times of the year without causing significant losses of water.

- *Select the repair.*—Once sufficient information has been obtained, the proper repair method can be determined. Fifteen standard repair materials can be used. If the standard repair materials cannot be utilized, consideration of nonstandard materials will be required. A detailed discussion of standard repair materials can be found in Reclamation’s *Guide to Concrete Repair* (1997).
- *Prepare the old concrete for repair.*—Preparation of the old concrete is required to obtain a durable repair. Even the best repair materials depend upon proper preparation of the existing concrete. All unsound or deteriorated concrete must be removed before new repair materials are applied. The steps involved in preparation consist of:
 1. *Sawcut the perimeters.*—Sawcut the perimeter of the area of existing concrete to be repaired using a depth of 1 to 1.5 inches. Deeper sawcuts should be avoided to reduce the risk of cutting the reinforcement. The sawcuts can be tilted inward 2 to 3 degrees to act as a retaining keyway that lock in the repair to the existing surrounding concrete. The shape of the area to be sawcut should not have any sharp angles, since these are difficult to compact the repair material into. Rounded corners are preferable, but require the use of a bush hammer or jackhammer held vertically.
 2. *Concrete removal.*—Remove all deteriorated concrete to provide a sound surface for the repair materials to bond. The preferred methods of concrete removal are high pressure hydroblasting or hydrodemolition.

Conduits through Embankment Dams

These methods leave a high quality concrete surface in place without leaving any microfractures in the remaining concrete. Impact concrete removal methods with jack hammers and bush hammers result in microfractures that will require subsequent removal by hydroblasting.

Shallow deterioration (less than 1/2 inch) can be removed with shot blasting or with dry/wet sandblasting. Some environmental precautions are required with dry blasting.

3. *Reinforcement preparation.*—All scale, rust, corrosion, and bonded concrete must be removed from the reinforcement. Methods for removal include wire brushing, high water pressure, or sand blasting. In areas where corrosion has reduced the diameter of the reinforcement to less than 75 percent of the original diameter, the reinforcement will need to be removed and replaced.
 4. *Maintenance of prepared area.*—The prepared area must be maintained in a clean and protected manner until the repair materials are placed and cured. Seasonal precautions may be needed for temperature and moisture.
- *Apply the repair method.*—Each of the 15 standard repair materials has unique application requirements. The methods differ for repair of cracks and repair of damaged areas. Cracks need to be evaluated to determine if they are live (opening and closing) or dead (static). Different resins are applied or injected depending on the objective (structural bond, water leakage sealing). Figure 195 shows an example of a repair being made to a damaged area using epoxy bonded replacement concrete. A detailed discussion of application requirements for the different repair materials can be found in Reclamation's *Guide to Concrete Repair* (1997).
 - *Cure the repair properly.*—Proper curing is required for all standard repair materials, with the exception of a few resinous systems. Inadequate or improper curing can reduce the service life of the concrete repair and result in significant costs for replacement of the repair. A detailed discussion of curing requirements for repair materials can be found in Reclamation's *Guide to Concrete Repair* (1997).

Limited repairs of concrete underwater are possible. However, these types of repairs are difficult and require special products and repair methods. Only highly qualified and experienced contractors should attempt this type of work (ACI, 1998b).



Figure 195.—A repair being made using epoxy-bonded replacement concrete. The use of epoxy resin ensures a strong, durable bond between the old concrete and the replacement concrete.

14.2.2 Repairs using grouts

Joint and defect repair in an existing conduit is an important part of the preparation process for many renovation methods. Leakage from joints or cracks in an existing conduit may severely hamper grouting of the annular space between a slipliner and the conduit, and every effort should be made to stop the leakage before grouting (Bendel and Basinger, 2002, p. 6). Two types of grout can be used:

- *Cement grouts.*—The traditional “neat cement” grout (cement mixed with water to make a pumpable slurry) is relatively inexpensive and can be used to fill large and small voids. Some additives are available to adjust the set time and also to reduce the tendency for “bleeding” (which occurs when the cement settles out, leaving water-filled voids.) However, cement grouts are not flexible, so if additional movement occurs, the grouted area may again develop a leak at a later date. Typically, cement grouts may be used to inexpensively fill large voids prior to injection of chemical grouts.

The grout mix design may require adjustment in the field. Plasticizers may be used to facilitate cementitious grout injection. The amount of plasticizer may also require field adjustment.

- *Chemical grouts.*—These types of grout include sodium silicate, acrylates, polyurethanes, lignins, and resins. Of these, the polyurethanes are the most

common for repair of leaking joints and cracks in conduits. Polyurethane grouts are generally viscous liquids which react with water to form a solid or semisolid material. The properties of common chemical grouts are described in the USACE's *Chemical Grouting* (1995a).

Chemical grouts are classified as hydrophobic or hydrophilic depending on how reactive they are when mixed with water. Hydrophilic grouts can incorporate a large amount of water into the cured products, and may shrink substantially if allowed to dry out completely. Therefore, hydrophilic grouts should be used in locations which are not kept wet at all times. Hydrophilic grouts cure with lower strengths than epoxy types of grout and are not considered to produce a structural bond in the area being grouted. Hydrophilic grouts form a closed-cell flexible foam barrier to stop the seepage of water through the joint. These grouts are usually injected when the ambient air temperatures in the existing conduit is above 32 °F. Figure 196 shows an example of resin injection equipment used for small repair projects.

For examples of grout cracks in an existing conduit see the case histories for Pablo and Ridgway Dams in appendix B.

14.3 Conduit abandonment

When the existing conduit deteriorates to a point where it can no longer serve its intended design purpose, a decision must be made to renovate, remove/replace, or to abandon it. In some cases, the designer may find it technically and economically more feasible to abandon the conduit by grouting it closed and leaving it in place. For instance, abandonment has some advantages over removing the conduit because a large trench is not required to be excavated transverse to the embankment dam. Backfilled excavations in an existing embankment are a source of differential settlement and potential hydraulic fracture. If abandonment is selected, a filter diaphragm or collar should be part of a design to intercept any flow that could potentially occur through defects in the grouted conduit or along the interface between the existing conduit and earthfill. For guidance on the design of filter diaphragms and collars, see sections 6.4 and 6.5, respectively. At embankment dams with small reservoirs, abandonment of a conduit may be done in conjunction with the installation of a siphon. See section 11.4.1 for guidance on the design and construction of siphons. For an example of a conduit abandonment, see the case history for St. Louis Recreation Lake Dam in appendix B.



Figure 196.—An example of resin injection equipment used for small repair projects. Components are pumped independently and mixed at the nozzle for injection.

The advantages of abandoning an existing conduit through an embankment dam include:

- *Reservoir operation.*—Abandonment can in some cases be done while the reservoir is full. See section 14.3.1 for precautions involving drilling from the surface of the embankment dam.
- *Costs.*—Costs are generally less than other renovation and replacement methods.

The disadvantages of abandoning an existing conduit through an embankment dam include:

- *Grouting.*—Difficulties may exist trying to grout the existing conduit full.

Conduits through Embankment Dams

- *Loss of use.*—A replacement means of providing downstream flow requirements reservoir evaluation comparability, and flood discharge capacity will be required.

The most common way to abandon an existing conduit is by the injection of grout or concrete. Two methods are usually considered for grout injection:

- *From upstream or downstream access.*—If conduit access is available from either an upstream or downstream location, this typically provides the simplest method for grout or concrete injection. Removal of a portion of the entrance or terminal structures may be required to attain sufficient access. Concrete (with a slump of about 6 or 7 inches) injection is typically more economical, since a larger diameter (about 5 inches) pump line can be used. This type of concrete is often called “backfill” concrete placed with a “slick” line. Injection of grout typically uses a pump line diameter of about 1 to 1½ inches. Also, when using concrete, a pump truck can be used. Grout injection normally requires a mixer, which will deliver grout at a slower capacity and will require more time to fill the existing conduit.
- *Through holes drilled from the surface of the embankment dam.*— When the upstream and downstream ends of the existing conduit are inaccessible, it may be possible to fill the conduit with grout or concrete through holes drilled from the surface of the embankment dam (figure 197). In order to be successful, the precise location of the existing conduit must be determined, and the driller must be experienced and proceed with caution. For an example of this type of conduit abandonment, see the Clair Peake Dam case history in appendix B.

While completely filling the existing conduit is recommended, the need for completely or partially filling the entire conduit will need to be evaluated based on safety concerns and costs. The indicated grouting and backfill procedures in this section may require modification to adapt to given site conditions. The designer is cautioned that grout injection from the surface, unless carefully controlled, has the potential for causing hydraulic fracture within the embankment dam. Drilling from the surface of the embankment dam is not advisable for situations where the reservoir water surface cannot be lowered.

Another possible reason for abandoning an existing conduit would be when a proposed embankment dam raise would result in much higher embankment loads over portions of the conduit. Structural analysis may determine that the higher embankment loads would fail the existing conduit and measures to strengthen it are not feasible. To prevent failure and to reduce the potential for internal erosion and backward piping erosion of embankment materials, the existing conduit would need to be abandoned and a new conduit constructed. The abandonment of the existing conduit may best be postponed until after the replacement conduit has been



Figure 197.—Abandonment of a conduit by injection of cement grout through holes drilled from the surface of the embankment dam to depths of up to 60 feet.

constructed and is fully operational. The existing conduit is used for diversion while the new conduit is constructed.

Any abandonment activities should also evaluate the need for partial or full demolition of the entrance and terminal structures, gate houses, plugging of gate chambers and shafts, and removal of certain mechanical equipment. Blasting for demolition should not be permitted. Shaft structures can be backfilled with compacted sand instead of concrete or grout.

14.3.1 Drilling into the existing embankment dam

Historically, drilling into an existing embankment dam has been performed for many reasons. Some of these included the perceived need to extract samples for laboratory sampling or to install instrumentation. However, as discussed in the following paragraphs, drilling into an embankment dam can cause serious damage. The need to drill into an embankment dam should therefore be carefully considered. Many properties of the soils comprising an embankment dam can be reasonably estimated from existing, published data, such as Reclamation's *Design of Small Dams* (1987a). In other cases, general conditions within the embankment dam, such as the phreatic water level, can be reasonably estimated without the need to install a piezometer. Installing an instrument within the embankment dam to develop data on a developing failure mode involving internal erosion or backward erosion piping

Conduits through Embankment Dams

is rarely successful. The installation of an instrument in exactly the proper place would be very fortuitous.

If drilling into an embankment dam has been determined to be necessary, drilling through any portion of an embankment dam should be performed with extreme caution. Improper drilling procedures increase the potential for hydraulic fracture. Drilling fluids, such as water or bentonite, are commonly used during drilling to enhance removal of drill cuttings, but these fluids should be avoided whenever possible when drilling in the fine grained embankment zones. Drilling fluids are typically pumped to the bottom of the hole through the drill stem, exiting through the drill bit. For many reasons, such as a small annulus space around the bit or clogging of the hole by cuttings, the fluids can be quickly pressurized by the pumping action. The drilling equipment can produce pressures in the hole that can rapidly exceed the surrounding earth pressure, causing direct hydraulic fracture of the embankment material. Hydraulic fracture has been known to occur even when extreme caution was being exercised and pressures were being constantly monitored.

Auguring is the preferred method for drilling in the core of embankment dams. Auguring uses no drilling fluid and is inherently benign with respect to hydraulic fracturing. A hollow-stem auger permits sampling in the embankment dam and allows sampling/testing of the foundation through the auger's hollow stem, which acts as casing. If fluids must be used, the risks must be understood and specific procedures should be employed to minimize the chance for hydraulic fracturing. Figure 198 shows an example of an auger being used.

With the exception of auguring, any drilling method has the potential to hydraulically fracture an embankment, if care is not taken and attention is not paid to detail. Various agencies have developed specific regulations regarding drilling with fluids in dams. For instance, Reclamation (1998b, pp. 222-223) indicates that the drilling methods that may be approved for drilling in embankment dams, if auguring is not practical (i.e., cobbly fill) are:

- Cable tool
- Direct rotary with mud (bentonite or biodegradable)
- Direct rotary with water
- Direct rotary with air-foam
- Down-hole hammer with reverse circulation



Figure 198.—An auger is being used to drill within an embankment dam.

Selection of any one of the above methods should be based on site-specific conditions, hole utilization, economic considerations, and availability of equipment and trained personnel.

Once drilling has commenced, drilling personnel are responsible for controlling and monitoring drill pressure, drill media circulation loss, and penetration rate to ensure that the drilling operation minimizes the possibility for hydraulic fracture. All aspects of the drilling operation should be closely monitored, including drill fluid pressures, drill fluid return volume, drill bit pressures, and occurrence of surface seeps (breakouts) of drill fluid. If a sudden loss of drill fluid occurs during embankment drilling within the core, drilling should be stopped immediately. Action should be taken to stop the loss of drill fluid. The personnel operating the drill and the designer should carefully evaluate the reason for the fluid loss.

Other agencies, such as the Corps of Engineers, may not allow drilling with any fluids. See USACE's *Procedures for Drilling in Earth Embankments* (1997) and *Geotechnical Investigations* (2001a).

14.3.2 Inspection

A thorough inspection of the existing conduit is required prior to beginning any abandonment activities. Depending on the diameter of the conduit, man-entry or CCTV inspection methods should be used; see section 9.5 for guidance on inspection of conduits. The condition of the existing conduit, existence of any protrusions or obstructions, joint offsets, amount of deflection, and evidence of leakage or internal erosion should be determined.

14.3.3 Preparations

The existing conduit surfaces against which grout will be placed should be free of roots, sediments, mineral deposits, dust, latence, loose or defective concrete, curing compound, coatings, and other foreign materials. See section 9.6 for guidance on cleaning conduits. Any sediments or debris should be removed from the invert of the existing conduit. Any bolts or other projections should be cut off flush and/or ground smooth with the interior surface of the existing conduit.

If water is entering the existing conduit and cannot be stopped, an inflatable bladder may be required. The pressure required to inflate the bladder and seal off inflow must be closely evaluated to avoid rupturing the conduit. This is usually a concern when high head is present in the reservoir. Also, some pipe materials, such as corroding CMP, are more susceptible to rupture. Abandonment of the existing conduit may need to be scheduled to allow grouting operations when the reservoir is at its lowest annual elevation. Siphons or pumps can be used to further reduce reservoir elevations. In some cases, the construction of a cofferdam may be more applicable, if the reservoir water level needs to remain at a constant elevation. If a new conduit is being constructed, grouting of the existing conduit can be delayed until the new conduit can be used for diversion.

For accessible existing conduits, any open or leaking joints or holes should be patched to minimize grout leakage. A bulkhead should be installed at the downstream end of the existing conduit to resist the loadings from the grout or concrete. An air return (vent) pipe or a series of pipes should be installed at the crown of the conduit and extend from the upstream end of the conduit to the bulkhead.

Grout pipes should be installed at the crown of the conduit. The longest pipes should be attached directly to the crown and the other pipes as closely to the crown as possible. Vent pipes can be used as grout pipes after grout return occurs. Grout pipes typically are Schedule 40 PVC, HDPE, or electrical mechanical tubing. Generally, grout pipes less than 100 feet in length can be $\frac{3}{4}$ inch diameter. Grout pipes longer than 100 feet should be $1\frac{1}{2}$ -inch diameter. The grout and vent pipes installed at the crown should be water tested.

Grouting equipment should be capable of continuously pumping grout at any pressure up to 50 lb/in². Injection pipes for concrete should be about 5 inches in diameter.

The abandoning of an inaccessible existing conduit is much more problematic due to the lack of access into the interior of the conduit. Stopping the flow of water into the existing conduit may be difficult, if there is an opening through the conduit. Abandonment may be possible by drilling into the conduit from the surface of the

embankment dam at several locations and injecting a thick sand and grout mix (sometimes referred to as compaction grout, limited mobility grout, or LMG) to form a bulkhead (Cadden, Bruce, and Traylor, 2000, p. 8). This technique was successfully used to stop leakage in a deteriorating conduit through a 65-foot high embankment dam in southern Maryland (Traylor and Rehwoldt, 1999). In this case, the approximate location of the conduit was first established by use of several geophysical methods (magnetometer, resistivity, and self-potential). An experienced driller can detect when the drill bit enters the existing conduit, advance it to the middle of the conduit, and then pump the grout to form the bulkhead (Traylor and Rehwoldt, 1999, p. 6). Grout was tremied into the existing conduit through additional holes drilled from the surface of the embankment dam.

14.3.4 Grouting

The following paragraphs discuss the grout plan, mix design, and procedure:

- *Grouting plan.*—A grouting plan detailing the contractor’s grout mix equipment, setup, procedures, sequencing, plan for handling waste, method for communication, and method for sealing and bulkheading upstream and downstream should be submitted for review and approval prior to initiation of grouting operations.
- *Grout and concrete mixes.*—Use a grout mix with a water (ASTM C 94) to cement (ASTM C 150) ratio of approximately 0.7:1 to 0.5:1. A grout fluidifier (ASTM C 937) may be needed to promote flowability, reduce water requirements, reduce bleeding, reduce segregation, increase strength, and eliminate grout shrinkage during setting of the grout mix. Trial mixes should be mixed at the job site prior to grouting to confirm the expected performance of the mix. For concrete injection, 3/4-inch aggregate should be used. A 28-day compressive strength of 3,000 lb/in² is generally acceptable.
- *Procedure.*—The pressure at the crown of the conduit as measured at the vent pipe should not exceed 5 lb/in². Grouting is stopped when the air return pipe in the crown flows full with grout. Cap the grout and air return pipes. Remove the bulkhead upon completion of grouting operations. For grouting or backfilling of long existing conduits, the use of sections is recommended. Long grout or backfill placements could result in sufficient expansion and/or contraction to induce cracking of the existing conduit (concrete). The use of sections is also conducive to ensuring an acceptable seal. Figures 199 and 200 show grouting operations involved with the abandonment of an outlet works conduit.

Conduits through Embankment Dams



Figure 199.—Grout is delivered to the site and is pumped into the conduit being abandoned.



Figure 200.—Grout being delivered to the pumping truck.

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Glossary

The terms defined in this glossary use industry-accepted definitions whenever possible. The source of the definition is indicated in parentheses.

Abandonment: Discontinuation of the use of a structure without intent to resume.

Abrasion (ASTM D 653, 2002): A rubbing and wearing away.

Abutment (FEMA, 2004): That part of the valley side against which an embankment dam is constructed. The left and right abutments of embankment dams are defined with the observer viewing the dam looking in the downstream direction, unless otherwise indicated.

Accident (ICOLD, 1974): A significant problem with an embankment dam that has been prevented from becoming a failure by remedial measures.

Acidity: A measure of how acid water or soil may be. Water or soil with a pH of less than 7.0 is considered acidic.

Acre-foot (FEMA, 2004): A unit of volumetric measure that would cover 1 acre to a depth of 1 foot. An acre-foot is equal to 43,560 ft³.

Admixture (ASTM C 822, 2002): A material other than water, aggregates, cement, and reinforcement used as an ingredient of concrete and added to the batch immediately before or during its mixture.

Aggregate (ACI, 2000): Granular material, such as sand, gravel, crushed stone, and iron blast furnace slag, used with a cementing medium to form a hydraulic cement, concrete, or mortar.

Aging: The process of changing properties over time.

Air vent: A system used to permit air to enter the conduit to prevent collapse or to prevent the formation of low pressures within flowing water that could lead to cavitation and its possible attendant damage.

Alkali-aggregate reaction (ACI, 2000): Chemical reaction in concrete or mortar between alkalis (sodium and potassium) from Portland cement or other sources and certain constituents of some aggregates; under certain conditions, deleterious expansion of the concrete or mortar may result.

Alternate design method: See **Working stress design method**.

Conduits through Embankment Dams

Anaerobic: An environment or a condition which is free of oxygen or a organism which can grow in the absence of oxygen.

Anchor: To fasten to prevent movement.

Annulus: The space between an existing conduit and a newly installed slipliner.

Antiseep collar: An impermeable diaphragm, usually of sheet metal or concrete, constructed at intervals within the zone of saturation along the conduit that passes through an embankment dam. In theory, antiseep collars were designed to increase the seepage length along the conduit and thereby prevent backward erosion piping by lowering the hydraulic gradient along the conduit.

Approach channel: The channel upstream from an entrance structure. This channel is generally unlined, excavated in rock or soil, and with or without riprap, soil cement or other types of erosion protection.

Appurtenant structure (FEMA, 2004): An ancillary feature of an embankment dam, such as an outlet, spillway, powerplant, or tunnel.

Auguring: A drilling technique that advances a hole into a soil material. The drill bit used can be one of a wide variety of helical style bits.

Autogenous growth (ASCE, 2000): Self-generating growth produced without external influence.

Auxiliary spillway: See **Spillway, auxiliary**.

Backfill: Soil or concrete used to fill excavations.

Backward erosion piping (piping): The term “piping” has often been used generically in literature to describe various erosional processes, not all of which hold to the classic definition of the term piping. Piping in the classic sense is characterized by the formation of an open tunnel that starts at a downstream seepage exit point and progresses back upstream toward the reservoir. This classic type of piping is often termed “backward erosion piping,” and this term is used in this document. Blowout (also known as heave or blowup) is another term used to describe the condition where hydraulic head loosens a uniform body of cohesionless sand to the point where the permeability of the sand increases and flow concentrates in that zone that is blown out. Failures by blowout may not be exactly the same as “backward erosion piping,” but for the purposes of this document, are grouped under this blanket term. Backward erosion piping involves the following essential conditions:

- Backward erosion piping is associated with intergranular seepage through saturated soil zones, not along concentrated flow paths (such as cracks).
- Backward erosion piping begins at a seepage discharge face where soil particles can escape because of the lack of a filter or an improperly designed filter at the exit face. As particles are removed, erosion progresses backward toward the source of seepage.
- The material being piped must be able to support a “pipe” or “roof,” or must be adjacent to a feature such as an overlying clay layer or concrete structure that would provide a roof.
- For backward erosion piping to progress to the point where a failure occurs, soils susceptible to backward erosion piping must occur along the entire flow path.
- Backward erosion piping requires a hydraulic gradient high enough to initiate particle movement in soils that are susceptible to this phenomenon. Piping can begin with relatively low gradients for horizontal flow. For flow exiting a deposit vertically, if gradients are very high, the soil may be loosened, creating a condition sometimes termed heave.
- The term blowout is used to describe backward erosion piping that results when a sand horizon is overlain by a clay horizon with a defect in it, and an excessive hydraulic gradient causes backward erosion piping through that defect in the blanket. Defects in the blanket may consist of crayfish holes, fence post holes, animal burrows, and drying cracks. The transported sand forms a conical deposit on top of the surface clay horizon that itself is resistant to backward erosion piping.

In this document, the term “backward erosion piping” is used to describe the condition where piping occurs as defined above. The term “internal erosion” is used to describe all other erosional processes where water moves internally through the soil zones of embankment dams and foundations.

Bedding: Concrete used to provide transverse and lateral support under precast concrete conduits. Bedding generally comes up to about 25 percent of the conduit height.

Bedrock (FEMA, 2004): Any sedimentary, igneous, or metamorphic material represented as a unit in geology; being a sound and solid mass, layer, or ledge of mineral matter; and with shear wave threshold velocities greater than 2,500 ft/s.

Bentonite: A type of clay derived from weathered volcanic ash that expands when wet; commonly used as well drilling mud and annular seal.

Conduits through Embankment Dams

Bond (ACI, 2000): Adhesion and grip of concrete or mortar to reinforcement or to other surfaces against which it is placed, including friction due to shrinkage and longitudinal shear in concrete engaged by the bar deformations.

Borehole: Any exploratory hole drilled into an embankment dam or its foundation to gather geophysical data.

Breach (FEMA, 2004): An opening through an embankment dam that allows the uncontrolled draining of a reservoir. A controlled breach is a constructed opening. An uncontrolled breach is an unintentional opening caused by discharge from the reservoir. A breach is generally associated with the partial or total failure of the embankment dam.

Buckling: Failure by lateral or torsional instability of a conduit, occurring with stresses below the yield strength.

Bulkhead gate: See **Gate, bulkhead**.

Bulking: The low density condition in a fine sand that occurs when negative capillary stresses develop when the sands are placed at intermediate water contents. Sands placed at a bulking water content have a much lower density than those placed very dry or saturated. Sands that may have been placed at a bulking water content may be densified by flooding and vibratory compaction.

Calibration hose (ASTM F 1743, 1996): An impermeable bladder, which is inverted within the resin-impregnated fabric tube by hydrostatic head or air pressure and may optionally be removed or remain in place as a permanent part of the installed cured-in-place pipe.

Caliper: An instrument used to measure the diameter of a conduit.

Caliper measurements: Measurement of the internal dimensions of a conduit, either by a physical device or by reflection of acoustic waves from a sled or cart. This method can be used to locate areas of conduit corrosion or excessive deformation.

Camera-crawler: A video camera attached to a self-propelled transport vehicle (crawler). Typically, the camera-crawler is used for closed circuit television inspection of inaccessible conduits.

Canal: A channel that conveys water by gravity to downstream users.

Cast-iron pipe: See **Pipe, cast-iron**.

Cathodic protection system (CPS): A system used to supplement protective coatings used for corrosion control.

Cavitation (ACI, 2000): Pitting of a material caused by implosion, i.e., the collapse of vapor bubbles in flowing water that form in areas of low pressure and collapse as they enter areas of higher pressure.

Cement (Portland) (ACI, 2000): A hydraulic cement produced by pulverizing clinker, consisting essentially of hydraulic calcium silicates, and usually containing one or more of the forms of calcium sulfate as an interground addition.

Chemical grout: Grout used for the repair of leaking joints and cracks within conduits or for the treatment of embankment materials surrounding a conduit.

Chimney drain: A drainage element located (typically) immediately downstream of a chimney filter. A chimney drain parallels the embankment dam's core and is either vertical or near vertical and placed from one abutment completely to the other abutment.

Chimney filter: See **Filter, chimney**.

Clay (ASTM D 653, 2002): Fine-grained soil or the fine-grained portion of soil that can be made to exhibit plasticity (putty-like properties) within a range of water contents, and that exhibits considerable strength when dry.

Closed circuit television (CCTV): A method of inspection utilizing a closed circuit television camera system and appropriate transport and lighting equipment to view the interior surface of conduits.

Closure section: The portion of a permanent embankment dam placed to fill a gap that has been left in the dam to pass diversion flows.

Coating (ACI, 2000): Material applied to a surface by brushing, dipping, mopping, spraying, troweling, etc. to preserve, protect, decorate, seal, or smooth the substrate.

Coefficient of thermal expansion (ACI, 2000): Change in linear dimension per unit length or change in volume per unit volume per degree of temperature change.

Cofferdam (FEMA, 2004): A temporary structure enclosing all or part of a construction area, so that construction can proceed in the dry. A diversion cofferdam diverts a stream into a conduit, channel, tunnel, or other watercourse.

Cohesion (ASTM D 653, 2002): The portion of the shear strength of a soil indicated by the term c , in Coulomb's equation, $s = c + p \tan \theta$.

Conduits through Embankment Dams

Cohesionless soil (ASTM D 653, 2002): A soil that, when unconfined, has little or no strength when air dried and that has little or no cohesion when submerged.

Cohesive soil (ASTM D 653, 2002): A soil that, when unconfined, has considerable strength when air dried and that has significant cohesion when submerged.

Collapse: The movement or damage of a structural member that makes it unable to support loads.

Compaction (FEMA, 2004): Mechanical action that increases density by reducing the voids in a material.

Controlled: A compaction process that includes requirements for maximum lift thickness and other criteria to ensure that the compacted soil has the intended properties.

Method: A compaction process that only specifies the equipment and its operation in compacting the soil.

Compressible foundation: Foundation materials that will compress significantly when loaded.

Compressive strength (ASTM C 822, 2002): The maximum resistance of a concrete specimen to axial compressive loading; or the specified resistance used in design calculations.

Concrete (ACI, 2000): A composite material that consists of a binding medium (Portland cement and water, with or without admixtures) within which are embedded particles or fragments of fine and coarse aggregate.

Precast (ACI, 2000): Concrete that is cast somewhere other than its final location.

Reinforced cast-in-place (ACI, 2000): Structural concrete containing reinforcement that is placed and allowed to cure in the location where it is required to be when completed.

Condition assessment rating: A method for evaluating the condition of a conduit based on inspection.

Conduit (FEMA, 2004): A closed channel to convey water through, around, or under an embankment dam.

Consequences (FEMA, 2004): Potential loss of life or property damage downstream of a dam caused by floodwater released at the embankment dam or by water released by partial or complete failure of the dam.

Consolidation (ASCE, 2000): The process of densifying a material both naturally and mechanically.

Construction joint: See **Joint, construction**.

Contamination: The introduction of undesirable or unsuitable materials.

Contraction (ACI, 2000): Decrease in either length or volume.

Contraction joint: See **Joint, contraction**.

Control: The location within a conduit where regulation of flow occurs.

Control features: Typically gates or valves located in the entrance structure, conduit, gate chamber, or a terminal structure.

Control joint: See **Joint, control**.

Control testing: Laboratory tests performed on embankment material during construction to check if the specified material properties are being achieved.

Controlled breach (or wet breach): Excavation of a channel through an embankment dam to lower the reservoir to a safe level in the event of an emergency at the dam.

Controlled compaction: See **Compaction, controlled**.

Controlled low-strength material (CLSM): A self-compacting, cementitious material typically used as a replacement for compacted backfill around a conduit.

Core (FEMA, 2004): A zone of low permeability material in an embankment dam. The core is sometimes referred to as central core, inclined core, puddle clay core, rolled clay core, or impervious zone.

Corrosion (ACI, 2000): Disintegration or deterioration of a material by electrolysis or chemical attack.

Corrugated metal pipe (CMP): See **Pipe, corrugated metal**.

Crack: A narrow discontinuity.

Conduits through Embankment Dams

Cradle: Reinforced, formed concrete that provides both longitudinal and lateral structural support to a circular conduit. A cradle extends for the full length of the conduit and encases the lower half of the conduit up to the springline.

Creep ratio: The ratio of the seepage path through an embankment dam divided by the head differential between the upstream and downstream toes of the dam. Weighted creep ratio includes proportioned vertical distances added to the horizontal seepage path length. The proportions are weighted based on the ratio of horizontal to vertical permeabilities in layered embankment and foundation soils. “Creep ratio” is no longer in common use as a design tool.

Cross section (FEMA, 2004): An elevation view of an embankment dam formed by passing a plane through the dam perpendicular to the axis.

Cured-in-place pipe (CIPP) (ASTM F 1743, 1996): A hollow cylinder consisting of a fabric tube with cured (cross-linked) thermosetting resin. Interior or exterior plastic coatings, or both, may be included. The CIPP is formed within an existing conduit and takes the shape of and fits tightly to the conduit.

Cutoff trench (FEMA, 2004): A foundation excavation later to be filled with impervious material to limit seepage beneath an embankment dam.

Dam (FEMA, 2004): An artificial barrier that has the ability to impound water, wastewater, or any liquid-borne material, for the purpose of storage or control of water.

Earthfill (FEMA, 2004): An embankment dam in which more than 50 percent of the total volume is formed of compacted earth layers comprised of material generally smaller than 3 inches.

Embankment (FEMA, 2004): Any dam constructed of excavated natural materials, such as both earthfill and rockfill dams, or of industrial waste materials, such as a tailings dams.

Rockfill (FEMA, 2004): An embankment dam in which more than 50 percent of the total volume is comprised of compacted or dumped cobbles, boulders, rock fragments, or quarried rock generally larger than 3 inches.

Tailings (FEMA, 2004): An industrial waste dam in which the waste materials come from mining operations or mineral processing.

Dam failure (FEMA, 2004): A catastrophic type of failure characterized by the sudden, rapid, and uncontrolled release of impounded water or the likelihood of such an uncontrolled release. There are lesser degrees of failure, and any

malfunction or abnormality outside the design assumptions and parameters that adversely affect an embankment dam's primary function of impounding water is properly considered a failure. These lesser degrees of failure can progressively lead to or heighten the risk of a catastrophic failure. They are, however, normally amenable to corrective action.

Dam safety (FEMA, 2004): Dam safety is the art and science of ensuring the integrity and viability of dams, such that they do not present unacceptable risks to the public, property, and the environment. Dam safety requires the collective application of engineering principles and experience, and a philosophy of risk management that recognizes that an embankment dam is a structure whose safe function is not explicitly determined by its original design and construction. Dam safety also includes all actions taken to identify or predict deficiencies and consequences related to failure, and to document and publicize any unacceptable risks, and reduce, eliminate, or remediate them to the extent reasonably possible.

Decant: To draw off the upper layer of liquid after the heaviest material (a solid or another liquid) has settled.

Defect: A discontinuity whose size, shape, orientation, location, or properties make it detrimental to the useful service of the structure in which it occurs.

Deflection: The decrease in the vertical diameter of a conduit due to loading.

Deformation (ACI, 2000): A change in dimension or shape due to stress.

Delamination: A separation of layers.

Desiccation: The process for evaporating water or removing water vapor from a material.

Design: An iterative decisionmaking process that produces plans by which resources are converted into products or systems that meet human needs or solve problems.

Designer: A registered engineer representing a firm, association, partnership, corporation, agency, or any combination of these who is responsible for the supervision or preparation of plans and specifications associated with an embankments dam and its appurtenances.

Destructive testing: Testing of a physical specimen or structure to determine its material properties. This may require the removal of a portion of a structure (such as a core sample of concrete removed from a conduit) for testing in a laboratory or for petrographic analysis.

Conduits through Embankment Dams

Deterioration (ACI, 2000): Disintegration or chemical decomposition of a material during a test or service exposure.

Differential settlement (ASTM D 653, 2002): Settlement that varies in rate or amount, or both, from place to place across a structure.

Discharge channel: The channel downstream from a terminal structure. This channel conveys releases back to the “natural” stream or river. This channel may be excavated in rock or soil, with or without riprap, soil cement or other types of erosion protection.

Disking: Mechanical mixing (deep disking to blend materials) or scarifying (shallow disking to roughen the surface).

Dispersive clays: Dispersive clays differ from “normal” clays because of their electrochemical properties. Dispersive clays usually have a preponderance of sodium cations on the clay particles compared to a preponderance of calcium and magnesium on “normal” clays. The imbalance of electrical charges that result from this makeup causes dispersive clays to deflocculate in the presence of water. This deflocculation occurs because the interparticle forces of repulsion exceed the attractive forces. The clay particles go into suspension even in slowly moving or standing water. This means that dispersive clays are extremely erosive, and flow through cracks in dispersive clays can quickly erode the cracks and lead to rapid enlargement of the cracks. Failures caused by internal erosion in dispersive clay dams are common. Dispersive clays are also subject to severe rilling and jugging on exposed natural and constructed slopes because they are so erosive. Dispersive clays are not detectable with normal soil tests, such as mechanical analyses and Atterberg limit tests, and special tests, such as the crumb test, double hydrometer, and pinhole test, are required to detect the presence of dispersive clays.

Diver: A specially trained person who performs underwater inspection of structures or other underwater activities.

Dowel (ACI, 2000): A steel pin, commonly a plain or coated round steel bar that extends into adjoining portions of a concrete construction, as at an expansion or contraction joint; to transfer shear loads.

Downstream access: Entry through a terminal structure or exit portal of a conduit.

Downstream control: Regulation of flow within a conduit located near or at the terminal structure or exit portal.

Drain: A pipe that collects and directs water to a specified location.

Drawdown (FEMA, 2004): The difference between a water level and a lower water level in a reservoir within a particular time. Used as a verb, it is the lowering of the water surface.

Drilling: The process of penetrating earth and/or rock formations.

Dry density (ASTM D 653, 2002): The mass of solid particles per the total volume of soil or rock.

Dry spot (ASTM F 1743, 1996): An area of fabric of finished CIPP that is deficient or devoid of resin.

Dry unit weight (ASTM D 653, 2002): The weight of soil or rock solids per unit of total volume of soil or rock mass.

Durability (ACI, 2000): The ability of a material to resist weathering, chemical attack, abrasion, and other conditions of service.

Ductile iron pipe: See **Pipe, ductile iron.**

Earthfill dam: See **Dam, earthfill.**

Earthquake (FEMA, 2004): A sudden motion or trembling in the earth caused by the abrupt release of accumulated stress along a fault.

Electrical resistivity: A geophysical mapping method based on the principle that the distribution of an applied electrical potential (voltage) in the ground depends on the composition and density of surrounding soils and rocks.

Embankment dam: See **Dam, embankment.**

Emergency (FEMA, 2004): A condition that develops unexpectedly, which endangers the structural integrity of an embankment dam and/or downstream human life or property, and requires immediate action.

Emergency Action Plan (EAP) (FEMA, 2004): A plan of action to be taken to reduce the potential for property damage and loss of life in an area affected by an embankment dam failure or large flood.

Emergency classification: The act of classifying an emergency at an embankment dam, to determine the severity of the emergency condition and the proper response to prevent a dam failure, and to reduce loss of life and property damage, should the dam fail.

Conduits through Embankment Dams

Emergency gate: See **Gate, emergency**.

Emergency spillway: See **Spillway, emergency**.

Engineer: A person trained and experienced in the profession of engineering; a person licensed to practice the profession by the appropriate authority.

Entrance structure: A structure located at the upstream end of a conduit. Entrance structures often include gates or valves, bulkheads, trashracks, and/or fish screens. Entrance structures are often referred to as intake structures for outlet works and inlet structures for spillways.

Epoxy: Any of various resins capable of forming tight, cross-linked polymer structures characterized by toughness, strong adhesion, and corrosion resistance. Commonly used as a two-part adhesive.

Erosion (FEMA, 2004): The wearing away of a surface (bank, streambed, embankment, or other surface) by floods, waves, wind, or any other natural process.

Evacuation: The act of removing water from a reservoir.

Event tree: A graphical representation of a series of events.

Excavation: Any manmade cut, trench, or depression in a surface, formed by earth and/or rock removal.

Expansion (ACI, 2000): Increase in either length or volume.

Expansion joint: See **Joint, expansion**.

Extensometer (ASCE, 2000): An instrument that measures the change in distance between two anchored points.

Fabric tube (ASTM F 1743, 1996): Flexible needled felt, or equivalent, woven or nonwoven material(s), or both, formed into a tubular shape, which, during installation, is saturated with resin and holds the resin in place during installation and curing process.

Failure (ICOLD, 1974): Collapse or movement of a part of an embankment dam or its foundation, so that the dam cannot retain water. In general, a failure results in the release of large quantities of water, imposing risks on the people or property downstream from the embankment dam.

Failure mode (FEMA, 2004): A physically plausible process for an embankment dam failure, resulting from an existing inadequacy or defect related to a natural foundation condition, the dam or appurtenant structure's design, the construction, the materials incorporated, the operation and maintenance, or aging process, which can lead to an uncontrolled release of the reservoir.

Filter cake: A thin layer of soil particles that accumulate at the face of a filter when water flowing through a crack carries eroding particles to the face. The filter cake forms when eroded particles embed themselves into the surface voids of the filter. The filter cake is effective in reducing further water flow to that which would occur through a layer of soil with the permeability of the eroded soil particles.

Filter collar: See **Filter, collar**.

Filter diaphragm: See **Filter, diaphragm**.

Filter: A zone of material designed and installed to provide drainage, yet prevent the movement of soil particles due to flowing water.

Chimney: A chimney filter is a vertical or near vertical element in an embankment dam that is placed immediately downstream of the dam's core. In the case of a homogenous embankment dam, the chimney filter is typically placed in the central portion of the dam.

Collar: A limited placement of filter material that completely surrounds a conduit for a specified length within the embankment dam. The filter collar is located near the conduit's downstream end. The filter collar is usually included in embankment dam rehabilitation only when a filter diaphragm cannot be constructed. A filter collar is different from a filter diaphragm, in that a filter diaphragm is usually located within the interior of the embankment dam.

Diaphragm: A filter diaphragm is a zone of filter material constructed as a diaphragm surrounding a conduit through an embankment. The filter diaphragm protects the embankment near the conduit from internal erosion by intercepting potential cracks in the earthfill near and surrounding the conduit. A filter diaphragm is intermediate in size between a chimney filter and a filter collar. The filter diaphragm is placed on all sides of the conduit and extends a specified distance into the embankment.

First filling: Usually refers to the initial filling of a reservoir or conduit.

Flood (FEMA, 2004): A temporary rise in water surface elevation resulting in inundation of areas not normally covered by water. Hypothetical floods may be expressed in terms of average probability of exceedance per year, such as

Conduits through Embankment Dams

1-percent-chance flood, or expressed as a fraction of the probable maximum flood or other reference flood.

Flood control: The regulation of flood inflows to reduce flood damage downstream.

Flotation: The act or state of floating.

Fly ash (ACI, 2000): The finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system.

Footbridge: A structure that allows for pedestrian travel.

Forensics: The branch of science that employs scientific technology to assist in the determination of facts.

Foundation (FEMA, 2004): The portion of a valley floor that underlies and supports an embankment dam.

Frost heave (ASTM D 653, 2002): The raising of a structure due to the accumulation of ice in the underlying soil or rock.

Fully deteriorated conduit (ASTM D 5813, 2004): The existing conduit is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the design life of the rehabilitated pipe.

Gate: A movable water barrier for the control of water.

Bulkhead (FEMA, 2004): A gate used either for temporary closure of a channel or conduit before unwatering it for inspection or maintenance, or for closure against flowing water when the head difference is small, as in a diversion tunnel.

Emergency (FEMA, 2004): A standby or reserve gate used only when the normal means of water control is not available for use.

Guard (FEMA, 2004): A standby or auxiliary gate used when the normal means of water control is not available. Sometimes referred to as an emergency gate.

Regulating (regulating valve) (FEMA, 2004): A gate or valve that operates under full pressure flow conditions to regulate the rate of discharge.

Gate chamber: An outlet works structure containing gates or valves located between the upstream and downstream conduits.

Gauge (ASCE, 2000): A device that measures something with a graduated scale.

Geophysical techniques: Methods used to study the physical characteristics and properties of embankment dams. Geophysical techniques are based on the detection of contrasts in different physical properties of materials.

Geotextiles (FEMA, 2004): Any fabric or textile (natural or synthetic) when used as an engineering material in conjunction with soil, foundations, or rock. Geotextiles have the following uses: drainage, filtration, separation of materials, reinforcement, moisture barriers, and erosion protection.

Gradation (ASTM C 822, 2002): The distribution of particles of granular material among standard sizes, usually expressed in terms of cumulative percentages larger or smaller than each of a series of sieve openings.

Gravel (ASTM D 653, 2002): Rounded or semirounded particles of rock that will pass a 3-inch (76.2)-mm and be retained on a No. 4 (4.75- μ m) U.S. standard sieve.

Ground-penetrating radar: A geophysical method which uses high-frequency radio waves to locate voids at shallow depths, less than about 15 to 20 feet (the effective depth is very limited in clayey soils).

Grout (FEMA, 2004): A fluidized material that is injected into soil, rock, concrete, or other construction material to seal openings and to lower the permeability and/or provide additional structural strength. There are four major types of grouting materials: chemical, cement, clay, and bitumen.

Grout mix (ASTM D 653, 2002): The proportions or amounts of the various materials used in the grout, expressed by weight or volume (The words “by volume” or “by weight” should be used to specify the mix).

Grout pipe: The pipe used to transport grout to a certain location. The grout may be transported through this pipe by either gravity flow or pressure injection.

Guard gate: See **Gate, guard**.

Hazard (FEMA, 2004): A situation that creates the potential for adverse consequences, such as loss of life, or property damage.

Hazard potential classification: A system that categorizes embankment dams according to the degree of adverse incremental consequences of a failure or

Conduits through Embankment Dams

misoperation of a dam. The hazard potential classification does not reflect in any way on the current condition of the embankment dam (i.e., safety, structural integrity, flood routing capacity).

Heat fused joint: See **Joint, heat fused**.

Height (above ground): The maximum height from natural ground surface to the top of an embankment dam.

High density polyethylene (HDPE): A polymer prepared by the polymerization of ethylene as the sole monomer.

Holiday: A discontinuity in a coating, such as a pinhole, crack, gap, or other flaw, that allows an area of the base metal to be exposed to any corrosive environment that contacts the coating surface.

Homogeneous: Constructed of only one type of material.

Horizontal directional drilling (HDD): A trenchless construction method that uses guided drilling. The method involves three main stages: drilling of a pilot hole, pilot hole enlargement, and pullback installation of the carrier pipe.

Hydraulic fracture: A separation in a soil or rock mass that occurs if the applied water pressure exceeds the lateral effective stress on the soil element. Hydraulic fracture may occur if differential foundation movement is allowed. Soils compacted dry of optimum water content are more susceptible to hydraulic fracture.

Hydraulic gradient: The slope of the hydraulic grade line. The hydraulic gradient is the slope of the water surface in an open channel.

Hydrophilic: Having a strong affinity for water.

Hydrophobic: Having a strong aversion for water.

Hydrostatic head (ASTM D 653, 2002): The fluid pressure of water produced by the height of the water above a given point.

Hydrostatic pressure: The pressure exerted by water at rest.

Ice lens: A mass of ice formed during the construction of an embankment dam, when a moist soil is exposed to freezing temperatures. In certain types of soils (silts and silty soils) the size of the ice mass will increase as it draws unfrozen capillary water from the adjacent soil. A void in the soil may remain after the ice lens melts.

Impervious: Not permeable; not allowing liquid to pass through.

Incident (ICOLD, 1974): Either a failure or accident, requiring major repair.

Inclinometer (ASCE, 2000): An instrument for measuring the angle of deflection between a reference axis and casing axis.

Infiltration: The flow of water through a soil surface or the flow of water into a conduit through a joint or defect.

Inspection: The review and assessment of the operation, maintenance, and condition of a structure.

Inspector: The designated on-site representative responsible for inspection and acceptance, approval, or rejection of work performed as set forth in the contract specifications. The authorized person charged with the task of performing a physical examination and preparing documentation for inspection of the embankment dam and appurtenant structures.

Instrumentation (FEMA, 2004): An arrangement of devices installed into or near embankment dams that provide for measurements that can be used to evaluate the structural behavior and performance parameters of the structure.

Intake structure (FEMA, 2004): Placed at the beginning of an outlet works waterway (power conduit, water supply conduit), the intake establishes the ultimate drawdown level of the reservoir by the position and size of its opening(s) to the outlet works. The intake may be vertical or inclined towers, drop inlets, or submerged, box-shaped structures. Intake elevations are determined by the head needed for discharge capacity, storage reservation to allow for siltation, the required amount and rate of withdrawal, and the desired extreme drawdown level.

Internal erosion: A general term used to describe all of the various erosional processes where water moves internally through or adjacent to the soil zones of embankment dams and foundation, except for the specific process referred to as “backward erosion piping.” The term “internal erosion” is used in this document in place of a variety of terms that have been used to describe various erosional processes, such as scour, suffosion, concentrated leak piping, and others.

Inundation map (FEMA, 2004): A map showing areas that would be affected by flooding from releases from a dam’s reservoir. The flooding may be from either controlled or uncontrolled releases or as a result of a dam failure. A series of maps for a dam could show the incremental areas flooded by larger flood releases.

Conduits through Embankment Dams

Inversion (ASTM F 1743, 1996): The process of turning the calibration hose inside out by the use of water pressure or air pressure.

Invert: The bottom or lowest point of the internal surface of the transverse cross section of a conduit.

Job Hazard Analysis (JHA): A procedure which helps integrate accepted safety and health principles and practices into a particular operation.

Joint (ASTM F 412, 2001): The location at which two sections of conduit or pipe are connected together.

Construction (ACI, 2000): The surface where two successive placements of concrete meet, across which it is desirable to develop and maintain bond between the two concrete placements, and through which any reinforcement that may be present is not interrupted.

Contraction (ACI, 2000): Formed, sawed, or tooled groove in a concrete structure to create a weakened plane and regulate the location of cracking resulting from the dimensional change of different parts of the structure. The concrete surface is unbonded. No reinforcement extends across the joint. Smooth dowels may be provided to maintain proper alignment of monolithic units.

Control: Joints placed in concrete to provide for control of initial shrinkage stresses and cracks of monolithic units. The concrete surface is unbonded. Control joints are constructed as described for contraction joints, except that reinforcement is always continuous across the joint. The reinforcement prevents the longitudinal forces from opening the joints.

Expansion (ACI, 2000): A separation provided between adjoining parts of a structure to allow movement where expansion is likely to exceed contraction or an isolation joint intended to allow independent movement between adjoining parts.

Heat fused (fusion) (ASTM F 412, 2001): A joint using heat and pressure only.

Mechanical (ASTM F 412, 2001): A connection between piping components employing physical force to develop a seal or produce alignment.

Joint meter (ASCE, 2000): A device used to measure the movement of a joint in concrete or any other material.

Leakage (FEMA, 2004): Uncontrolled loss of water by flow through a hole or crack.

Linear coefficient of thermal expansion: The change in length with temperature for a solid material relative to its original length.

Lining: A material applied to the inside surface of a conduit to provide a protective covering.

Lubricant (ASTM F 412, 2001): A material used to reduce friction between two mating surfaces that are being joined by sliding contact.

Maintenance: All routine and extraordinary work necessary to keep the facility in good repair and reliable working order to fulfill the intended designed project purposes. This includes maintaining structures and equipment in the intended operating condition, and performing necessary equipment and minor structure repairs.

Man-entry: A conduit size large enough for personnel to access and perform the required actions.

Mastic: A permanently flexible waterproofing material used for sealing water-vulnerable joints.

Maximum water surface: The highest acceptable water surface elevation considering all factors affecting the dam.

Mechanical caliper: An instrument used for measuring the distance between two points.

Mechanical joint: See **Joint, mechanical**.

Method compaction: See **Compaction, method**.

Microtunneling: A trenchless construction method that uses a tunnel boring machine normally controlled from the surface. The method simultaneously installs pipe as the spoil is excavated and removed.

Modulus of soil reaction (E'): An empirical value used to express the stiffness of the embedment soil in predicting flexible pipe deflection.

Moisture content: The water content in a soil.

Conduits through Embankment Dams

Monitoring: The process of measuring, observing, or keeping track of something for a specific period of time or at specified intervals.

Mortar (ACI, 2000): A mixture of cement paste and fine aggregate. In fresh concrete, this is the material occupying the interstices among particles of coarse aggregate.

Mud slab (ACI, 2000): A 2- to 6-inch layer of concrete below a structural concrete floor or footing over soft, wet soil; also called mud mat. Mud slabs are used to protect foundations during construction.

Multichannel Analysis of Surface Waves (MASW): An extension of Spectral Analysis of Surface Waves, MASW uses multiple geophones (usually 24 or more) to simultaneously acquire surface wave data on many points from a single seismic source.

Nondestructive testing (NDT): Geophysical methods for assessing the condition of a conduit, embankment dam, or other structure, which do not require that a physical sample be removed from the structure. These methods include seismic tomography, electromagnetic tomography, ground penetrating radar, and ultrasonic pulse-echo. When combined with modern computer processing software, the data obtained from the testing can be used to create detailed images of the structure.

Nonpressurized flow: Open channel discharge at atmospheric pressure for part or all of the conduit length. This type of flow is also referred to as “free flow.”

Normal water surface (FEMA, 2004): For a reservoir with a fixed overflow sill, this is the lowest crest level of that sill. For a reservoir whose outflow is controlled wholly or partly by moveable gates, siphons, or other means, it is the maximum level to which water may rise under normal operating conditions, exclusive of any provision for flood surcharge.

Nuclear gauge: An instrument used to measure the density and water content of both natural and compacted soil, rock, and concrete masses. The gauge obtains density and water contents from measurements of gamma rays and neutrons that are emitted from the meter. Gamma rays are emitted from a probe inserted into the mass being measured. Measurement of the gamma rays transmitted through the mass, when calibrated properly, reflects the density of the mass. Neutrons are emitted from the base of the gauge. Measuring the return of reflected neutrons when the gauge is calibrated properly can be related to the water content of the mass.

Offset (ACI, 2000): An abrupt change in alignment or dimension, either horizontally or vertically.

Open cut: An excavation through rock or soil made through topographic features to facilitate the passage of a conduit.

Optimum moisture content (optimum water content) (ASTM D 653, 2002): The water content at which a soil can be compacted to a maximum dry unit weight by a given compactive effort.

Outlet works (FEMA, 2004): An embankment dam appurtenance that provides release of water (generally controlled) from a reservoir.

Overburden (ASTM D 653, 2002): The loose soil, sand, silt, or clay that overlies bedrock. All materials overlying a conduit.

Oxygen content: The amount of dissolved oxygen.

Partially deteriorated conduit (ASTM D 5813, 2004): An existing conduit that can support the soil and live loads throughout the design life of the rehabilitated conduit. The soil adjacent to the existing pipe must provide adequate side support. The pipe may have longitudinal cracks and some distortion of the diameter.

Penetrometer: A device used to determine the resistance to penetration (bearing capacity) of a soil.

Penstock (FEMA, 2004): A pressurized pipeline or shaft between the reservoir and hydraulic machinery.

Permeability: A measure of the rate at which water can percolate through soil.

Pervious: Permeable, having openings that allow water to pass through.

Pervious zone (FEMA, 2004): A part of the cross section of an embankment dam comprising material of high permeability.

Phreatic line (ASCE, 2000): Water surface boundary. Below this line, soils are assumed to be saturated. Above this line, soils contain both gas and water within the pore spaces.

Phreatic surface (ASCE, 2000): The planar surface between the zone of saturation and the zone of aeration. Also known as free-water surface, free-water elevation, groundwater surface, and groundwater table.

Piezometer (ASCE, 2000): An instrument for measuring fluid pressure (air or water) within soil, rock, or concrete.

Conduits through Embankment Dams

Pig: A cylindrical device inserted into a conduit to perform cleaning or internal inspection.

Pipe jacking (ASCE, 2001): A system of directly installing pipes behind a shield machine by hydraulic jacking from a drive shaft, such that the pipes form a continuous string in the ground.

Pipe: A hollow cylinder of concrete, plastic, or metal used for the conveyance of water.

Cast iron: A type of iron-based metallic alloy pipe made by casting in a mold.

Corrugated metal: A galvanized light gauge metal pipe that is ribbed to improve its strength.

Ductile iron: A type of iron-based metallic alloy pipe that is wrought into shape.

Plastic (ASTM F 412, 2001): A hollow cylinder of plastic material in which the wall thicknesses are usually small when compared to the diameter and in which the inside and outside walls are essentially concentric.

Precast concrete: Concrete pipe that is manufactured at a plant.

Steel: A type of iron-based metallic alloy pipe having less carbon content than cast iron, but more than ductile iron.

Piping: See **Backward erosion piping**.

Pitting: A form of localized corrosive attack characterized by holes in metal. Depending on the environment and the material, a pit may take months, or even years, to become visible.

Plastic pipe (ASTM F 412, 2001): A hollow cylinder of plastic material in which the wall thicknesses are usually small when compared to the diameter and in which the inside and outside walls are essentially concentric.

Polyester (ASTM D 883, 2000): A polymer in which the repeated structural unit in the chain is of the ester type.

Polyethylene: A polymer prepared by the polymerization of ethylene as the sole monomer.

Polyvinyl chloride (PVC): A polymer prepared by the polymerization of vinyl acetate as the sole monomer.

Pore pressure (ASCE, 2000): The interstitial pressure of a fluid (air or water) within a mass of soil, rock, or concrete.

Power conduit: A conduit used to convey water under pressure to the turbines of a hydroelectric plant.

Precast concrete pipe: See **Pipe, precast concrete.**

Pressure flow: Pressurized flow throughout the conduit length to the point of regulation or control or terminal structure.

Principal spillway: The primary outlet device through an embankment dam for flood regulation. Typically, consists of riser structure in combination with an outlet conduit.

Pumping: The release or draining of a reservoir by means of a machine or device that creates pressure and water flow.

Quality assurance: A planned system of activities that provides the owner and permitting agency assurance that the facility was constructed as specified in the design. Construction quality assurance includes inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. Quality assurance refers to measures taken by the construction quality assurance organization to assess if the installer or contractor is in compliance with the plans and specifications for a project. An example of quality assurance activity is verifications of quality control tests performed by the contractor using independent equipment and methods.

Quality control: A planned system of inspections that is used to directly monitor and control the quality of a construction project. Construction quality control is normally performed by the contractor and is necessary to achieve quality in the constructed system. Construction quality control refers to measures taken by the contractor to determine compliance with the requirements for materials and workmanship as stated in the plans and specifications for the project. An example of quality control activity is the testing performed on compacted earthfill to measure the dry density and water content. By comparing measured values to the specifications for these values based on the design, the quality of the earthfill is controlled.

Radiography: A nondestructive testing method that provides an internal examination of a metallic structure or component by exposing it to a beam of X-ray or gamma radiation. Internal defects can be seen on a screen or recorded on film.

Regulating gate: See **Gate, regulating**.

Reinforced cast-in-place concrete: See **Concrete, reinforced cast-in-place**.

Reinforcement (ASTM C 822, 2002): Steel in the form of continuous wire, welded wire fabric, or bars embedded in concrete in such a manner that the concrete and steel act together to resist stresses.

Relative density: A numerical expression that defines the relative denseness of a cohesionless soil. The expression is based on comparing the density of a soil mass at a given condition to extreme values of density determined by standard tests that describe the minimum and maximum index densities of the soil. Relative density is the ratio, expressed as a percentage, of the difference between the maximum index void ratio and any given void ratio of a cohesionless, free-draining soil; to the difference between its maximum and minimum index void ratios.

Remotely operated vehicle (ROV): An unoccupied, highly maneuverable underwater robot controlled by a remote operator usually located in a ship or on the shore. Most vehicles are equipped with a video camera and lights. Additional equipment can be added to expand the vehicle's capabilities.

Renovation: The repair or restoration of an existing structure, so it can serve its intended purpose.

Repair: The reconstruction or restoration of any part of an existing structure for the purpose of its maintenance.

Replacement: The removal of existing materials that can no longer perform their intended function and installation of a suitable substitute.

Reservoir (FEMA, 2004): A body of water impounded by an embankment dam and in which water can be stored.

Reservoir evacuation: The release or draining of a reservoir through an outlet works, spillway, or other feature at an embankment dam.

Resin (ASTM F 412, 2001): A solid or pseudosolid organic material, often with high molecular weight, which exhibits a tendency to flow when subjected to stress, usually has a softening or melting range, and usually fractures conchoidally (shell-like fracture).

Resistivity: A measure of the resistance to current flow in a material.

Resolution (ASCE, 2000): The smallest increment in measurement that can be distinguished.

Riprap (FEMA, 2004): A layer of large, uncoursed stone, precast blocks, bags of cement, or other suitable material, generally placed on the slope of an embankment or along a watercourse as protection against wave action, erosion, or scour. Riprap is usually placed by dumping or other mechanical methods and in some cases, is hand placed. It consists of pieces of relatively large size, as distinguished from a gravel blanket.

Riser pipe: A vertical pipe section at the upstream end of a spillway that allows water to drop into the conduit and be discharged downstream.

Risk (FEMA, 2004): A measure of the likelihood and severity of adverse consequences (National Research Council, 1983). Risk is estimated by the mathematical expectation of the consequences of an adverse event occurring, that is, the product of the probability of occurrence and the consequence, or alternatively, by the triplet of scenario, probability of occurrence, and the consequence.

Risk reduction analysis: An analysis that examines alternatives for their impact on the baseline risk. This type of analysis is begun once the baseline risk indicates risks are considered too high and that some steps are necessary to reduce risk.

Rockfill dam: See **Dam, rockfill**.

Rutting: The tire or equipment impressions in the surface of a compacted fill that result from repeated passes of the equipment over the compacted fill when the soil is at a moisture and density condition that allows the rutting to occur. Rutting usually occurs when soils are not well compacted and/or are at a water content too high for effective compaction.

Sand (ASTM D 653, 2002): Particles of rock that will pass the No. 4 (4.75- μm) sieve and be retained on the No. 200 (0.075-mm) U.S. standard sieve.

Sand boil: Sand or silt grains deposited by seepage discharging at the ground surface without a filter to block the soil movement. The sand boil may have the shape of a volcano cone with flat to steeper slopes, depending on the size and gradation of particles being piped. Sand boils are evidence of piping occurring in the foundation of embankments or levees from excessive hydraulic gradient at the point of discharge.

Conduits through Embankment Dams

Scaling: The deposition and adherence of insoluble products on the surface of a material.

Scarification: The process of roughening the surface of a previously compacted lift of soil before placement of the next lift. Scarification is accomplished with discs, harrows, and similar equipment. The purpose of scarification is to promote bonding of lifts and reduce interlift permeability. Scarification is usually required in construction specifications written by designers concerned over stratification of earthfills.

Scour: The loss of material occurring at an erosional surface, where a concentrated flow is located, such as a crack through a dam or the dam/foundation contact. Continued flow causes the erosion to progress, creating a larger and larger eroded area.

Seepage (ASTM D 653, 2002): The infiltration or percolation of water through rock or soil or from the surface.

Seepage paths (ASCE, 2000): The general path along which seepage follows.

Segregation: The tendency of particles of the same size in a given mass of aggregate to gather together whenever the material is being loaded, transported, or otherwise disturbed. Segregation of filters can cause pockets of coarse and fine zones that may not be filter compatible with the material being protected.

Seismic activity: The result of the earth's tectonic movement.

Seismic tomography: A geophysical method that measures refraction and reflection of small, manmade seismic waves and high-level imaging software to create cross-sectional views of the internal portions of a structure, similar to computerized axial tomography (CAT) scans used in medicine.

Self potential (or streaming potential): A geophysical method that maps fields of electrical potential (voltage) generated by water flowing through a porous material to locate seepage areas in a dam or foundation.

Self-healing: The property of a sand filter that reflects its ability to deform and fill a crack that is transmitted to the filter.

Service life: Expected useful life of a project, structure, or material.

Service spillway: See **Spillway, service**

Settlement (FEMA, 2004): The vertical downward movement of a structure or its foundation.

Shear strength (ASCE, 2000): The ability of a material to resist forces tending to cause movement along an interior planer surface.

Shear stress: Stress acting parallel to the surface of the plane being considered.

Shore (ACI, 2000): A temporary support for formwork and fresh concrete.

Silt (ASTM D 653, 2002): Material passing the No. 200 (75- μm) U.S. standard sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air-dried.

Sinkhole: A depression, indicating subsurface settlement or particle movement, typically having clearly defined boundaries with a sharp offset.

Siphon: An inverted u-shaped pipe or conduit, filled until atmospheric pressure is sufficient to force water from a reservoir over an embankment dam and out of the other end.

Slaking: Degradation of excavated foundation caused by exposure to air and moisture.

Sliplining: The process of inserting a new, smaller-diameter lining or pipe into an existing larger-diameter conduit.

Slope (FEMA, 2004): Inclination from the horizontal. Sometimes referred to as batter when measured from vertical.

Slurry: A mixture of solids and liquids.

Soil (ASTM D 653, 2002): Sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, and which may or may not contain organic matter.

Soil resistivity: The measure of the resistance to current flow in a soil.

Soluble salt: A salt that can be dissolved in water.

Sonar: A geophysical method which measures the reflection of acoustic waves to map underwater structures. Often refers to side-scan radar.

Conduits through Embankment Dams

Sonic caliper: An instrument that utilizes pulses to measure the distance between two points.

Spacer: A specially fabricated material used during the sliplining of conduits to keep a smaller diameter pipe centered within the larger diameter pipe.

Spall (ACI, 2000): A fragment, usually in the shape of a flake, detached from a larger mass by a blow, by action of weather, pressure, or expansion within the larger mass.

Specifications: The written requirements for materials, equipment, construction systems, and standards.

Spectral Analysis of Surface Waves (SASW): A nondestructive, geophysical procedure for characterizing in-situ materials based on the principle that different materials have varying surface (Rayleigh) wave velocities. Surface wave data from geophones and small seismic sources are processed with specialized computer software to evaluate material properties, such as density, stratification, and location of voids.

Spigot: The plain end of a bell and spigot pipe. The spigot is inserted into the bell end of the next pipe.

Spillway (FEMA, 2004): A structure, over or through which water is discharged from a reservoir. If the rate of flow is controlled by mechanical means, such as gates, it is considered a controlled spillway. If the geometry of the spillway is the only control, it is considered an uncontrolled spillway.

Auxiliary (FEMA, 2004): Any secondary spillway that is designed to be operated infrequently, possibly in anticipation of some degree of structural damage or erosion to the spillway that would occur during operation.

Emergency (FEMA, 2004): See **Spillway, auxiliary**.

Service (FEMA, 2004): A spillway that is designed to provide continuous or frequent regulated or unregulated releases from a reservoir, without significant damage to either the dam or its appurtenant structures. This is also referred to as principal spillway.

Spray lining: The application of cement mortar or epoxy resin against the inside walls of an existing conduit, using a revolving spray head moved through the conduit.

Stability (ASCE, 2000): The resistance to sliding, overturning, or collapsing.

Standard Proctor compaction test: A standard laboratory or field test procedure performed on soil to measure the maximum dry density and optimum water content of the soil. The test uses standard energy and methods specified in ASTM Standard Test Method D 698.

Standardized dimension ratio (SDR): Ratio of the average specified outside diameter to the minimum specified wall thickness for outside diameter controlled plastic pipe.

Standards (ASCE, 2000): Commonly used and accepted as an authority.

Steel pipe: See **Pipe, steel**.

Stoping: The sequence of soil removal at the bottom of hole followed by roof collapse. This bottom-up erosion process forms a cavern in the embankment material, typically with steep sides.

Stoplogs (FEMA, 2004): Large logs, timbers, or steel beams placed on top of each other with their ends held in guides on each side of a channel or conduit so as to provide a cheaper or more easily handled means of temporary closure than a bulkhead gate.

Storage (FEMA, 2004): The retention of water or delay of runoff either by planned operation, as in a reservoir, or by temporary filling of overflow areas, as in the progression of a flood wave through a natural stream channel.

Strain gauge (ASCE, 2000): A device that measures the change in distance between closely spaced points.

Strength design method (ACI, 2000): A design method that requires service loads to be increased by specified load factors and computed theoretical strengths to be reduced by the specified phi factors. Also, known as ultimate strength design method.

Subsidence: A depression, indicating subsurface settlement or particle movement, typically not having clearly defined boundaries.

Suffosion: Seepage flow through a material that causes part of the finer grained portions of the soil matrix to be carried through the coarser grained portion of the matrix. This type of internal erosion is specifically relegated only to gap graded soils (internally unstable soils) or to soils with an overall smooth gradation curve, but with an overabundance of the finer portions of the curve represented by a “flat tail” to the gradation curve. While a crack is not needed to initiate this type of internal erosion, a concentration of flow in a portion of the soil is needed.

Conduits through Embankment Dams

Sulfate attack (ACI, 2000): Either a chemical reaction, physical reaction, or both between sulfates usually in soil or ground water and concrete or mortar; the chemical reaction is primarily with calcium aluminate hydrates in the cement-paste matrix, often causing deterioration.

Surface air voids (ACI, 2000): Small regular or irregular cavities, usually not exceeding about 0.5 inch in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation. Commonly referred to as bugholes.

Surface hardness: The surface hardness of concrete can be measured to provide a relative indication of the strength of in-situ concrete. Surface hardness can be measured by rebound hammer (also called Schmidt Hammer or Swiss Hammer, ASTM C 805) or by the penetration resistance test (also called Windsor Probe, ASTM C 803). Surface hardness is affected by the condition of the surface, composition of concrete, type of coarse aggregate, and degree of carbonation of the concrete surface. To improve accuracy of the inferred strength, the test methods must be calibrated with laboratory strength tests performed on samples of the concrete.

Tailings: The fine-grained waste materials from an ore-processing operation.

Tailings dam: See **Dam, tailings**.

Tailwater (ASCE, 2000): The elevation of the free water surface (if any) on the downstream side of an embankment dam.

Terminal structure: A structure located at the downstream end of the conduit. Terminal structures often include gates or valves and may include some type of structure to dissipate the energy of rapidly flowing water and to protect the riverbed from erosion.

Tether: A cable that attaches two things together.

Thermocouple (ACI, 2000): Two conductors of different metals joined together at both ends, producing a loop in which an electric current will flow when there is a difference in temperature between two junctions.

Thermoplastic (ASTM F 412, 2001): A plastic that can be repeatedly softened by heating and hardened by cooling through a temperature range characteristic of the plastic, and that in the softened state can be shaped by flow into articles by molding or extrusion.

Thermoset (ASTM F 412, 2001): A plastic that, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble product.

Toe of the embankment dam (FEMA, 2004): The junction of the downstream slope or face of a dam with the ground surface; also referred to as the downstream toe. The junction of the upstream slope with ground surface is called the heel or the upstream toe.

Transducer (ASCE, 2000): Any device or element that converts an input signal into an output signal of a different form.

Transverse crack: A crack that extends in an upstream and downstream direction within an embankment dam.

Trashrack (FEMA, 2004): A device located at an intake structure to prevent floating or submerged debris from entering the entrance of the structure.

Tremie concrete (ACI, 2000): Concrete which is deposited through a pipe or tube, having at its upper end a hopper for filling and a bail for moving the assemblage.

Trench: A narrow excavation (in relation to its length) made below the surface of the ground.

Trenchless technology (ASCE, 2001): Techniques for conduit renovation with minimum excavation of the embankment dam or ground surface.

Tunnel (FEMA, 2004): An long underground excavation with two or more openings to the surface, usually having a uniform cross section, used for access, conveying flows, etc.

Turbidity meter (ASCE, 2000): A device that measures the loss of a light beam as it passes through a solution with particles large enough to scatter the light.

Ultimate strength design method: See **Strength design method**.

Ultrasonic pulse-echo: A nondestructive testing method that measures the time for an ultrasonic (acoustic) wave generated by a transducer to travel through a structure and return to a sensor.

Ultrasonic pulse-velocity: A nondestructive testing method that measures the speed of an ultrasonic (acoustic) wave generated by a transducer to travel through a structure to a remotely located sensor.

Unwater: Removal of surface water; removal of water from within a conduit.

Conduits through Embankment Dams

Uplift (ASCE, 2000): The pressure in the upward direction against the bottom of a structure, such as an embankment dam or conduit.

Upstream access: Entry through an entrance structure or inlet portal of a conduit.

Upstream control: Regulation of flow within a conduit located near or at the entrance structure or inlet portal.

Utility conduit: A conduit utilized for electricity, gas, telecommunications, water, or sewer service.

Valve (FEMA, 2004): A device fitted to a pipeline or orifice in which the closure member is either rotated or moved transversely or longitudinally in the waterway so as to control or stop the flow.

Void: A hole or cavity within the foundation or within the embankment materials surrounding a conduit.

Water content (ASTM D 653, 2002): The ratio of the mass of water contained in the pore spaces of soil or rock material, to the solid mass of particles in that material, expressed as a percentage.

Water quality: The condition of water as it relates to impurities.

Waterstop (ACI, 2000): A thin sheet of metal, rubber, plastic, or other material inserted across a joint to obstruct the seepage of water through the joint.

Watertight (ASTM C 822, 2002): Will restrain the passage of water to not exceed a specified limit.

Weir (ASCE, 2000): A barrier in a waterway, over which water flows, serving to regulate the water level or measure flow.

Working stress design method (ACI, 2000): A method of proportioning structures or members for prescribed working loads at stresses well below the ultimate, and assuming linear distribution of flexural stresses. Also known as the alternate design method.

Zone: An area or portion of an embankment dam constructed using similar materials and similar construction and compaction methods throughout.

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Index

A

Abandonment of conduits, 225, 289, 333, 345, 354-362
Abrasion, 55, 177, 178, 181, 184, 211, 259, 308, 321, 323, 328, 349
Abutment, 34, 37, 127, 134, 266, 269, 284-286, 337, 341
Accident, 20, 21, 31, 164
Acidity, 24, 25, 183
Admixture, 42, 261, 309, 310
Aggregate, 41, 42, 103, 108, 145, 147, 178, 180, 189, 309, 321, 361
Aging, 178-180, 193, 198, 201, 230, 242, 290, 333
Air vent, 60, 61, 68, 297, 301, 311, 322, 326, 328
Alkali-aggregate reaction, 180, 182, 248
Alternate design method, 89, 90
Alternative means of reservoir evacuation, 273, 277-286
Anaerobic, 185, 229
Annulus, 49, 164, 167, 290, 291, 295, 299, 302, 309, 311, 313, 314, 318, 319, 322, 325, 340, 358
Antiseep collar, 4, 6, 27, 32-35, 138, 170, 233
Approach channel, 57
Appropriate emergency actions, 261-288
Appurtenant structure, 90, 239, 271
Arrangement of control features, 59-67
Assessment of conduit-related problems, 193-244
Auguring, 358
Autogenous growth, 236

B

Backfill, 120-128, 334-335
 selection and compaction, 120-127
Backward erosion piping, 2-6, 14-18, 20, 21, 28, 30, 31, 32, 34, 35, 59, 75, 77, 99, 116, 135-138, 158-174, 192, 206, 208, 231, 235-239, 241, 265, 266, 269, 270, 277, 286, 288, 291, 294, 331, 345, 357
 failure modes, 22, 34, 157, 159-172, 177, 190, 227, 238, 286
Barrier within joints, 107-112
Bedding, 17, 30, 81, 83-86, 95, 336
Bedrock, 5, 17, 18, 37, 39, 73, 101, 121, 126, 135, 137, 141, 143, 170, 175
Bentonite, 270, 338, 358

Conduits through Embankment Dams

Bond, 84, 92, 102-104, 114, 115, 118, 120, 123, 124, 149, 185, 258, 259, 298, 302, 335, 351-354
Borehole, 247, 342
Breach, 2, 6, 16, 20, 28, 116, 124, 163, 164, 166, 168, 169, 172, 174, 270, 284-287, 290
Buckling, 52, 85, 297, 318, 323, 339

C

Calibration hose, 328, 330
Caliper, 245, 246, 260
Caliper measurements, 260
Camera-crawler, 222, 224, 225, 254, 328
Canal, 1
Cathodic protection system, 51, 54, 185, 317
Cavitation, 60, 68, 75, 90, 178, 180-182, 211, 270, 278, 280, 281, 323, 349
Cement, 41, 42, 51, 57, 58, 114, 127, 178, 180, 184, 261, 309, 330, 345, 349, 353, 357, 361
Chemical grout, 345, 348, 353, 354
Chimney drain, 18, 33, 82, 126-128, 131, 133-138, 140-144, 147, 174, 175, 333
Clay, *see* Dispersive clay backfill
Cleaning of conduits, 73, 103, 104, 111, 114, 145, 147, 152, 219, 228-231, 305, 311, 323, 327, 329, 330, 336, 352, 360
 methods, 229, 230
 reasons, 228
Climb inspection, 217
Closed circuit television, 47, 60, 76, 147, 177, 205, 209, 212, 213, 217, 221-230, 241, 287, 294, 296, 311-313, 323, 329, 330, 350, 359
Closure section, 18, 105, 119, 120, 124, 137, 174, 290, 332, 335
CMP, *see* Pipe, corrugated metal
Coating, 25, 48, 51-55, 89, 91, 103, 104, 111, 178, 184, 185, 211, 230, 258, 305, 317-320, 323, 325, 360
Coefficient of thermal expansion, 46, 294, 297, 309, 316, 318, 324, 326
Cofferdam, 282, 286, 331, 332, 336-338, 341, 360
Cohesion, 342
Cohesionless soil, 158
Collapse, 6, 9, 60, 61, 73, 113, 144, 145, 165, 167, 172, 174, 180, 181, 185, 191, 212, 235, 270, 278, 282, 287, 292, 307, 311, 326, 341
Collars, *see* Filters, collars

-
- Compaction of backfill, 6, 10, 11, 18, 23, 25-27, 29, 32, 75, 76, 80, 81, 83, 84, 89, 113, 115, 116, 118, 120-125, 137, 138, 143, 144, 147, 148, 150-153, 157, 168, 170, 171, 191, 206, 237, 248, 277, 332-335, 361
- by hand, 26, 27, 122, 123
 - controlled, 151
 - method, 29
- Compressible foundation, 18, 22, 39, 52, 75, 84, 99-101
- Compressive strength, 53, 90, 178, 310, 342, 361
- Concrete, 1, 17, 21, 22, 25, 26, 29, 32, 37, 39, 41-48, 51, 52, 54, 70, 74, 76, 77, 79-85, 87, 89-99, 102-111, 114, 115, 118, 121, 129, 133, 145, 147, 158, 177-182, 184-190, 197, 209-211, 213, 221, 224, 229, 235, 246-248, 251, 253-258, 260, 261, 270, 284, 286, 289, 295, 304-306, 314, 318, 320, 327, 339, 348-353, 356, 357, 360, 361
- precast, 1, 25, 41, 44, 45, 76, 80-85, 89, 93-95, 99, 102, 106, 107, 109-111, 190
 - reinforced cast-in-place, 1, 25, 29, 41-43, 45, 51, 52, 69, 76, 81-83, 87, 89-93, 95, 97-99, 102-104, 107, 187, 190
 - repairs, 348
- Conduit
- abandonment, *see* Abandonment of conduits
 - cleaning, *see* Cleaning of conduits
 - evaluation by testing, 57, 58, 74, 75, 100, 187, 200, 201, 203, 209, 223, 227, 228, 234, 235, 242, 245, 247, 251, 257, 260, 262, 264, 267, 331, 335, 349, 350, 356
 - failure modes, 18, 20, 22, 34, 128, 157, 159, 161-175, 177, 190, 227, 238, 241, 274, 286, 357
 - federal agency policy on filters, 131
 - hydraulic design, 57, 58, 74, 116
 - joints, 2, 17, 22, 26, 31, 37-39, 42, 44-48, 50, 52-56, 64, 65, 67, 82-84, 91-93, 96, 98-104, 106-115, 157, 159, 160, 163-165, 167, 177, 183, 186-188, 191, 192, 197, 198, 208-211, 227-233, 235, 236, 255, 270, 278, 294, 295, 298-302, 304, 305, 313, 315-320, 324, 326, 339, 345-348, 353, 354, 359, 360
 - locating, 17, 18, 23, 25, 33, 34, 36-39, 52, 57, 58, 60-66, 69, 75, 79, 80, 84, 93, 101, 113-115, 117, 123, 124, 135, 140, 141, 146, 147, 183, 188, 198, 213, 215, 217, 220, 237, 240, 248, 252, 253, 259, 260, 268, 270, 272, 275, 276, 280, 281, 284, 286, 292, 312, 317, 322, 341
 - materials, 1, 5, 6, 10-14, 18, 20-22, 24, 28-30, 33, 41, 42, 45-47, 49, 50, 52, 55, 65, 77, 80, 84, 87, 89, 91, 94, 95, 98, 102, 107, 109, 111, 113-115, 118-123, 127, 129, 131, 133, 135, 137, 138, 145, 147-150, 152-155, 158, 160, 165, 167, 175, 177, 178, 180-184, 189, 190, 192, 197, 198, 211, 217, 226, 229, 230, 235, 237, 238, 240, 241, 248, 251, 253, 256, 257, 263, 265-267, 269, 270, 273-277, 282, 284, 286, 289-292, 294, 298, 299, 302, 305-307, 314, 320, 323, 326, 331-333, 339, 340, 342, 345, 349, 351, 352, 354, 356, 358, 360
 - multibarrel, 77

Conduits through Embankment Dams

- nonpressurized, 1, 2, 17, 45, 47, 48, 77, 98, 157-159, 161, 162, 238, 302, 315, 326
- potential defects, 177
- power, 1, 69, 70, 178, 198, 218, 224, 267, 281, 341
- pressurized, 1, 2, 17, 21, 22, 36, 39, 45, 56, 59, 65, 69, 84, 98, 157, 158, 165-167, 206, 212, 215, 217, 235, 269, 286, 295, 297, 298, 312, 315, 326, 358
- renovation, 39, 41, 45, 46, 48, 50, 76, 98, 135, 138-140, 145, 146, 157, 164, 177, 187, 188, 229, 289-291, 295, 303, 304, 316, 330-332, 335, 337, 341, 345, 346, 348, 353, 355
- repair and abandonment, 345
- replacement, 31, 41, 114, 154, 157, 164, 177, 179, 180, 195, 276, 277, 289-292, 302, 308, 312, 319, 326, 331-333, 335, 336, 345, 346, 350, 352, 353, 355, 356
- shape, 17, 42, 75-81, 83
- side slopes, 37, 81, 87, 113, 115, 118, 119, 121, 123, 240, 332
- structural design, 57, 58, 74, 75-77, 84, 85, 87, 91, 95, 98, 187, 297
- Consequences, 2, 20, 58, 59, 63, 64, 67, 69, 81, 86, 158, 163, 198, 201, 242, 251, 271, 286
- Consolidation, 42, 86, 100, 118, 188-190
- Construction, 85-98, 148-151, 187-192, 304-315, 319-324, 327-330, 333-336
 - cofferdam or temporary diversion channel, 336
 - impacts, 335, 346
 - poor, 7, 31, 138, 165, 188, 190, 191, 270, 349
- Contamination, 148-150, 325
- Contraction, 102-104, 298, 361
- Control features, 58-61, 76
- Control structure, 67, 268, 284
- Control testing, 123, 153
- Controlled breach, 270, 286, 287
- Controlled low-strength material, 120
- Core, 17, 29, 94, 120, 127, 133, 135, 137, 140, 143, 148, 175, 198, 211, 237, 254, 260, 261, 274, 276, 292, 334, 350, 358, 359
- Corrosion, 25, 26, 28, 46-48, 51, 52, 55, 75, 178, 182-189, 211, 222, 228, 248, 256, 258-260, 317, 319, 323, 330, 346, 352
- Corrugated metal pipe, *see* Pipe, corrugated metal
- Corrugated steel pipe, *see* Pipe, corrugated steel
- Cracks, 2, 4, 5, 17, 29, 31, 32, 37, 38, 54, 64, 65, 67, 75, 82, 89-92, 94, 100, 102, 103, 113-116, 118, 120-122, 124-126, 134, 138-141, 143, 144, 147, 148, 154, 155, 158, 162, 167, 168, 170, 172-175, 177, 180, 185, 187-189, 191, 198, 208, 209, 211, 231, 235, 236, 238-240, 248, 257, 260, 266, 269, 270, 278, 294, 298, 316, 318, 324, 326, 335, 345, 347, 348, 350, 352-354, 361
- Cradle, 17, 39, 44, 81, 83-85, 95, 111, 112, 170
- Cross section, 27, 34, 44, 80, 82, 107, 110, 137, 142, 146, 266, 314
- Cured-in-place pipe, *see* Pipe, cured-in-place
- Cutoff trench, 37, 127, 135, 140

D

Dam

- embankment, 113-130, 333-335, 357-359
- rockfill, 133, 147
- tailings, 24, 25

Dam failure, 2, 4, 6, 18, 20, 23, 25, 31, 32, 55, 59, 67, 116, 127-129, 157, 167, 170, 172, 234, 242, 261-266, 268, 271, 281, 290

Dam safety, 21, 26, 38, 70, 95, 154, 193, 194, 196, 199, 200, 210, 226, 251, 261, 262, 264, 266, 268, 271, 272, 288, 293, 312

Decant, 24-29

Defect, *see* Potential defects

Deflection, 28, 39, 56, 85, 90, 107, 255, 294, 295, 297, 359

Deformation, *see* Structural deformation

Delamination, 185, 246, 329, 350

Density quality control, 151

Desiccation, 124, 138, 335

Design, 57-112, 147-149, 293-304, 316-319, 333-335

- entrance and terminal structures, 36, 58, 70, 74, 103, 179, 211, 213, 218, 226, 291, 294, 302, 304, 316, 319, 324, 326, 331, 336, 337, 357

measures to prevent failure, 164, 167, 171, 174

gradation, *see* Gradation design, filter and drain

hydraulic, *see* Conduits, hydraulic design

poor, 2, 21, 165, 187, 190, 349

structural, *see* Conduits, structural design

Designer, 17, 22-26, 29, 30, 31-33, 37, 38, 40, 59, 73, 75, 79-81, 83-87, 90, 91, 93, 94, 99, 100, 108, 112, 114-116, 123, 128, 140, 141, 143, 147, 148, 150, 151, 154, 165, 187, 202, 231, 235, 237, 268, 278, 289, 290, 293, 294, 297-299, 304, 309-311, 316-319, 322, 324, 325, 327, 331, 333-335, 339, 345-347, 354, 356, 359

Destructive testing, 219, 245, 247, 260, 350

Deterioration, 2, 3, 18, 24, 28, 31, 47, 55, 77, 159, 165, 167, 177-181, 184, 187, 188, 193, 197, 205, 208-211, 213, 227, 228, 245, 248, 255, 257, 266, 270, 271, 289, 290, 292, 317, 330, 333, 348-350, 352

Differential settlement, 7, 17, 18, 32, 37, 39, 55, 76, 77, 80, 100-102, 113-116, 118-120, 124, 125, 138, 140, 143-145, 170, 172-174, 190-192, 198, 277, 354

Discharge channel, 58, 229, 284, 286

Disking, 122

Dispersive clay backfill, 124-128

Dispersive clays, 4-6, 35, 113, 116, 117, 119, 120, 124-128, 136, 140, 145, 161, 170, 174, 175

Diver, 67, 213-217, 219-221, 270

Diversion channel, *see* Temporary diversion channel

Conduits through Embankment Dams

Dowel, 102, 103
Downstream access, 60-64, 77, 292, 327, 356
Downstream control, 59, 61, 62, 66, 67, 167, 297
Drains, 16, 48, 61, 67, 133-135, 137, 139, 143, 146-148, 150-153, 183, 187, 211, 238, 266, 277-282, 290, 292, 294, 331, 332, 336
Drawdown, 28, 39, 71, 212, 240, 268, 282
Drilling, 114, 237, 254, 255, 261, 307, 324, 340-343, 346-348, 355-361
 horizontal directional, 324, 341-343
 into the existing embankment dam, 357
Drop inlet spillway conduit, 68, 282
Dry density, 152, 153
Dry spot, 329
Dry unit weight, 123, 153
Ductile-iron, 1, 39, 41, 53, 54
Durability, 91, 104, 179, 183, 185, 188, 189

E

Earthcut spillway, *see* Spillway, earthcut
Earthfill, 2, 4-7, 18, 24, 31, 32, 34, 37, 42, 44, 45, 47, 52, 54, 56, 59, 75-77, 79-84, 88, 114, 116, 120-124, 127, 128, 138-141, 143, 145, 149, 152, 158, 159, 170-173, 182, 191, 208, 237, 248, 265, 290, 333-335, 354
 ramp, *see* Ramp, earthfill
Earthquake, 86, 196, 201
Electrical resistivity, 182-184, 245, 246, 251-253, 361
Embankment excavation slopes, 118, 141, 332, 335
Embankment load, 85, 88, 121, 190, 356
Emergency Action Plan, 261-265, 267, 268, 273, 287
Emergency Actions, 261, 262, 265, 273
Emergency classification, 264-266
Engineer, obtaining the services of, 271
Entrance structure, 45, 57, 70, 205, 212, 220, 333
Epoxy, 330, 352-354
Erosion
 backward erosion pipe, *see* Backward erosion piping
 internal, *see* Internal erosion
Evaluation by testing, 57, 58, 74, 75, 100, 187, 200, 201, 203, 209, 223, 227, 228, 234, 235, 242, 245, 247, 251, 257, 260, 262, 264, 267, 331, 335, 349, 350, 356
Event tree, 18, 20
Excavation, 18, 23, 24, 37, 83, 87, 113-116, 118, 119, 121, 141, 142, 170, 226, 232, 275-278, 280, 284, 286, 290, 291, 332-339, 341, 342, 354

Existing conduit, 23, 31, 45-51, 89, 98, 180, 187, 188, 195, 226, 229, 273, 290-295, 298, 302, 304-307, 309-316, 318-322, 324-334, 336, 345-350, 353-357, 359-361

Existing embankment dam, 18, 20, 139, 149, 234, 237, 290, 332-334, 357

Expansion, 46, 52, 103, 105, 128, 180, 239, 297, 298, 361

Extensometer, 236

Exterior inspection, 206

F

Fabric tube, 326

Factors influencing scheduling of inspections, 196

Failure modes, *see* Potential failure modes

Federal agency policy, 131

Filter, 4, 6, 14, 18, 20, 27, 29, 32-34, 36, 45, 61, 76, 77, 82, 84, 85, 97, 98, 121, 125-129, 131, 133-155, 157, 165, 167, 168, 170-172, 174, 175, 198, 269, 270, 274, 277, 291, 292, 294, 331, 333, 341, 342, 345, 354

 cake, 126, 131, 133, 134, 140

 chimney, 18, 33, 82, 126, 128, 131, 134-136, 138, 140-144, 147, 174, 175, 333

 collar, 18, 33, 131, 134, 138, 140, 145-147, 150, 175

 diaphragm, 4, 6, 18, 27, 33, 45, 82, 84, 85, 97, 98, 121, 126, 128, 129, 131, 134, 135, 137-145, 147, 150, 153, 167, 168, 171, 175, 291, 294, 331, 341, 342, 345, 354

 zones, 14, 131, 133, 134, 138, 142-145, 149, 150, 153, 172, 175

First filling, 8, 27, 35, 58, 59, 116, 117, 125, 173-175, 194, 242

Flood, 1, 23, 58, 59, 67-69, 73, 86, 93, 195, 199, 263, 265, 281, 284, 288, 336, 338, 356

Flood control, 1, 58, 59, 67, 69, 73, 93, 281, 288

Flotation, 93, 294, 302, 316, 319, 324, 326

Fly ash, 180

Footbridge, 65, 66

Forensics, 231-233, 274

Foundation, 1, 2, 4, 14-18, 22, 26, 32, 37, 39, 40, 42, 45, 52, 59, 75, 79, 80, 83-87, 92, 95, 98-101, 113-115, 118-121, 131, 133, 135, 136, 141, 142, 151, 152, 167, 189-193, 197, 198, 203, 208-210, 213, 228, 234-236, 239-241, 266, 269, 270, 277, 284, 331-333, 337, 341, 348, 358

 investigation, 40

 preparation, 113

 rock, 87, 113, 114, 239

 soil, 18, 114, 115, 118, 133, 332

Fracture, *see* Hydraulic fracture

Conduits through Embankment Dams

Frost, 120, 128, 129, 261

Frost heave, 128

G

Gate, 39, 50, 52, 57-61, 64-67, 73, 75, 90, 167, 181, 182, 198, 205, 216, 220, 230, 266, 273, 278, 286, 287, 297, 317, 357

bulkhead, 57, 60, 63, 65, 67, 70, 205, 212, 311, 340, 360, 361

emergency, 60

guard, 60, 205, 220

regulating, 59-61, 65, 220

Gate chamber, 58, 64, 198, 357

Gauge, 111, 153, 154, 207-209, 214, 236, 243, 257, 258, 328

Geotextiles, 154, 155, 284, 286

Gradation design, filter and drain, 147

Gravel, 120, 129, 133, 134, 137, 143, 145, 147, 148, 151, 167, 177, 269, 270, 274, 334

Ground-penetrating radar, 245, 246, 253-255, 257, 276

Grout, 26, 27, 49, 114, 164, 167, 232, 233, 290-292, 295, 297-302, 304, 305, 309-313, 315, 318-323, 325-328, 333, 338-340, 345-349, 353-357, 360-362

injection, 310, 322, 323, 346, 353, 356

Grout mix, 309, 321, 322, 353, 361

Grout pipe, 301, 305, 310, 311, 323, 360

H

Hazard, 22, 23, 32, 39, 41, 45, 47, 48, 52, 54, 55, 58, 66, 67, 83, 84, 89, 94, 97, 98, 106, 120, 121, 134-138, 145, 148, 153, 154, 175, 194, 196, 199, 200, 203, 204, 214, 220, 225, 241, 264, 282, 295, 302, 315, 316, 330-332

Height, 21, 24, 26, 28, 37, 57, 68, 84, 87, 94, 102, 127, 149, 150, 241, 281, 286, 331, 332, 335, 336, 346

High density polyethylene, 26, 46-48, 50, 84, 164, 167, 178, 180, 278, 292-295, 297-315, 318, 320, 322, 325, 339, 342, 360

Historical perspective, 31

Holiday, 51, 185

Homogeneous, 107, 124, 135, 140, 144

Horizontal directional drilling, *see* Drilling, Horizontal directional

Horizontal movements, 39, 114, 239, 240

Hydraulic forces, 165, 168

Hydraulic design of conduits, *see* Conduits, hydraulic design

Hydraulic fracture, 4-11, 17, 18, 29, 32, 37, 58, 76, 77, 81, 82, 113-119, 124, 125, 138, 140, 142, 145, 157, 161, 162, 166, 168, 170-175, 179, 180, 198, 237, 248, 305, 332, 335, 341-343, 346, 354, 356, 358, 359

Hydraulic gradient, 15, 28, 29, 32, 117

Hydrophilic, 354

Hydrophobic, 354

Hydrostatic head, 98, 108, 112, 327, 328

Hydrostatic pressure, 63-67, 73, 86, 91, 141, 212, 327

I

Ice lens, 128, 129

Implementation of an Emergency Action Plan, 261

Incident, 17, 58, 59, 149, 194, 265, 266

Inclinometer, 240

Infiltration, 206, 228, 270, 310, 311, 323, 329

Initial remediation, 274

Initial response, 273

Inlet structure, 70, 282

Inspection of conduits, 193, 205, 218, 223, 294, 311, 323, 329, 359

- climb, 217
- closed circuit television, 47, 60, 76, 147, 177, 205, 209, 212, 213, 217, 221-230, 241, 287, 294, 296, 311-313, 323, 329, 330, 350, 359
- exterior, 206
- factors influencing scheduling, 196
- interior, 209
- periodic, 37, 76, 177, 193, 194, 199, 201, 271
- remotely operated vehicle, 205, 213, 217
- terminal structures, 212, 213
- types, 194, 196
- underwater, 213, 217, 219

Inspector, 109, 123, 193, 199, 200, 203, 209, 221

Instrumentation, 106, 194, 203, 206, 211, 234, 235, 237, 242, 243, 348, 357

Intake structure, 24, 26, 57, 58, 65-67, 69-73, 101, 179, 197, 205, 279, 292, 302, 303, 334, 336, 341

Intermediate control with downstream access, 60-62

Internal erosion, 2, 4-13, 17, 18, 20, 21, 28, 30, 31, 32, 34, 35, 59, 75, 77, 82, 99, 116, 117, 119, 124, 126-129, 134-138, 140, 149, 158, 159, 161-175, 192, 206, 208, 231, 235-239, 241, 265, 266, 268-270, 277, 286, 288, 291, 294, 331, 335, 345, 356, 357, 359

Inundation map, 262, 263

Conduits through Embankment Dams

Inversion, 49, 324-329
Invert, 57, 167, 168, 183, 186, 187, 209, 216, 224, 227, 254, 255, 258, 259, 278, 305, 316, 320, 322, 327, 333, 347, 360
Investigation, 25, 40, 206, 208, 231-233, 242, 246, 248, 251, 274-276, 337, 359
 forensic, 231-233, 274
 foundation, 40

J

Job Hazard Analysis, 196, 203-205, 214, 232
Joint, 2, 17, 22, 26, 31, 37-39, 42, 44-48, 50, 52-56, 64, 65, 67, 82-84, 91-93, 96, 98-104, 106-115, 157, 159, 160, 163-165, 167, 177, 183, 186-188, 191, 192, 197, 198, 208-211, 227-233, 235, 236, 255, 270, 278, 294, 295, 298-302, 304, 305, 313, 315-320, 324, 326, 339, 345-348, 353, 354, 359, 360
 construction, 93, 103, 104, 114
 contraction, 102-104
 control, 92, 99, 103, 104, 109
 expansion, 103
 heat fused, 299, 306, 308, 318
 mechanical, 301
Joint meter, 211, 236

L

Leakage, 2, 4, 20, 42, 47, 67, 99, 116, 131, 133, 134, 154, 159, 186, 208, 215, 217, 231, 232, 300, 305, 306, 320, 345, 346, 353, 354, 360
Linear coefficient of thermal expansion, 297
Locating the conduit, 34, 37
Lubricant, 46, 327

M

Maintenance, 21, 31, 41, 47, 51, 52, 63-65, 67, 75, 85, 90, 95, 193, 196, 200, 202, 203, 229, 263, 270, 271, 279, 281, 304, 311, 317, 319, 323, 327, 329, 348, 352
Man-entry, 112, 172, 196, 203-205, 216, 221, 293, 338, 350
Mastic applied to pipe, 110-112

Mechanical caliper, 246
Metal conduits, 1, 18, 21, 32, 41, 46, 48, 50, 89, 95, 98, 102, 107, 110, 111, 129, 158,
177, 178, 180, 182, 184, 185, 224, 229, 230, 239, 252-254, 257-260, 282,
283
 corrosion, 25, 26, 28, 46-48, 51, 52, 55, 75, 178, 182-189, 211, 222, 228, 248,
256, 258-260, 317, 319, 323, 330, 346, 352
Materials, *see* Conduit, materials
Microtunneling, 324, 337-340
Modes, *see* Failure modes
Modulus of soil reaction, 28
Moisture content, 86, 121, 123, 124, 128, 183, 184
Monitoring, 23, 28, 37, 58, 147, 194, 195, 199, 203, 206, 208, 209, 211, 217-219, 223,
224, 234-236, 238-243, 266, 269, 270, 287, 310, 322, 342, 348, 358, 359
Mortar, 51, 100, 104, 178, 330
Mud slab, 114
Multichannel Analysis of Surface Waves, 248, 257

N

Nondestructive testing, 245, 246
Nonpressurized conduit, *see* Conduit, nonpressurized
Normal water surface, 67, 86, 288, 291
Nuclear gauge, 153, 154

O

Offset, 163, 191, 200, 209, 211, 220, 225, 270, 294, 295, 320, 359
Operating restriction, *see* Reservoir operating restriction
Outlet works, 1-3, 57-60, 63, 67, 70-74, 75, 77, 89, 99, 100, 118, 125, 160, 164, 185,
186, 216, 222, 223, 228, 232, 233, 243, 266-268, 270, 273, 277, 279, 281,
304, 308, 310, 317, 334, 337, 338, 361
Overburden, 37, 87, 226
Oxygen content, 183

P

- Penetrometer, 123, 276
- Penstock, 1, 69, 70, 193
- Periodic inspections, *see* Inspection, periodic
- Permeability, 28, 29, 114, 117, 124, 126, 129, 133, 134, 147, 148, 150, 161, 171, 252
- Pervious zone, 39, 79-81, 83, 84, 120, 133, 198
- Phreatic line, 134, 135, 161
- Phreatic surface, 247, 294
- Piezometer, 227, 288, 357
- Pig, 221, 230, 256, 258, 260, 294, 295, 297, 305
- Pipe
 - cast iron, 41, 50, 55
 - corrugated metal, 1, 18, 21, 25, 41, 50, 54-56, 98, 158, 159, 183-186, 190, 191, 210, 222, 229, 248, 250, 256, 259, 282, 287, 293, 295, 296, 308, 312-314, 325, 360
 - corrugated steel, 185
 - cured-in-place, 48-50, 290, 324-331
 - ductile iron, 1, 39, 41, 53, 54
 - plastic, 1, 25, 41, 45, 46, 48, 49, 89, 95, 97, 98, 102, 107, 118, 120, 149, 158, 177, 178, 180, 187, 229, 270, 284, 286, 290, 297, 298, 302, 324, 342, 348
 - precast concrete, 1, 25, 41, 44, 45, 76, 80-85, 89, 93-95, 99, 102, 106, 107, 109, 111, 112, 190
 - prestressed concrete cylinder, 44, 93-95, 97, 106, 107
 - reinforced concrete, 22, 39, 44, 74, 89, 90, 93-96, 106, 107, 159, 289, 304, 317, 339
 - reinforced concrete cylinder, 44, 93, 94, 96, 106, 107
 - riser, 282, 308
 - steel, 21, 25, 26, 36, 39, 50-52, 63, 67, 69, 79, 80, 98, 101, 185, 228, 246, 256-258, 278, 290, 301, 316-323, 339, 348
- Pipe jacking, 337
- Piping, *see* Backward erosion piping
- Pitting, 181, 183, 232, 260, 340
- Policy, federal agency, *see* Federal agency policy
- Polyester, 48
- Polyethylene, 26, 46-48, 178, 180, 300
- Polyvinyl chloride, 46-48, 107, 109, 224, 278, 293, 300, 305, 342, 360
- Poor design and construction, 2, 165, 187, 190, 349
- Pore pressure, 17, 237, 335, 342
- Potential defects, 177
- Potential failure modes, 34, 159, 177, 190, 227, 286
- Power conduits, *see* Conduits, power
- Precast concrete pipe, *see* Pipe, precast concrete

Pressure flow, *see* Conduit, pressurized
Principal spillway, 67, 69, 94, 95
Pumping, 24, 25, 66, 230, 270, 278, 281, 283, 311, 322, 338, 340-342, 346, 347, 355, 356, 358, 360-362

Q

Quality assurance, 81, 137, 151
Quality control, 21, 30, 43, 48, 151, 153, 271
Quality of water, *see* Water quality

R

Radar, *see* Ground-penetrating radar
Radiography, 245, 246, 260
Ramp, earthfill, 123
Rebuilding the embankment dam, 334
Reinforcement, 39, 41-45, 48, 75, 82-84, 87, 90, 92, 98-100, 102-104, 178, 185, 186, 188, 211, 213, 221, 224, 289, 351, 352
Reinforced cast-in-place concrete, *see* Concrete, reinforced cast-in-place
Relative density, 152, 153
Remotely operated vehicle, 205, 213, 217
Removal of the control structure of the spillway, 284
Removal of the existing conduit, 333
Removal of the inlet structure, 282
Renovation of conduits, 39, 41, 45, 46, 48, 50, 76, 98, 135, 138-140, 145, 146, 157, 164, 177, 187, 188, 229, 289-291, 295, 303, 304, 316, 330-332, 335, 337, 341, 345, 346, 348, 353, 355
Repair of conduits, 41, 164, 177
Replacement of conduits, 195, 277, 289, 331, 336, 345
Reservoir evacuation, 1, 58, 273, 277, 286
Reservoir Operating Restriction, 287, 288
Reservoir water level and flows, 236, 242
Resin, 46, 48, 107, 298, 325, 326, 328, 330, 352-355
Resistivity, *see* Electrical resistivity
Resolution, 217, 218, 246, 257
Riprap, 57, 58, 73, 284, 286
Riser pipe, *see* Pipe, riser
Roadway, 253

Conduits through Embankment Dams

Rock foundation, 87, 113, 114, 239
Roof of an eroded cavern, 5, 6, 9, 20, 165, 172, 275, 276
Rutting, 122

S

Saddles, 79, 80
Sand, 5, 14, 16, 41, 42, 114, 120, 129, 133, 139, 140, 143, 145, 147-149, 151-155, 158, 167, 177, 178, 180, 183, 197, 208, 252, 266, 269, 270, 274, 334, 350, 352, 357, 361
Sand boil, 14, 208, 252, 266
Scaling, 181, 184, 187, 248, 352
Scarification, 122
Scheduling of inspections, *see* Inspections, scheduling
Scour, 4, 178, 266
Seam, soil, 117, 166, 343
Seepage paths, 23, 28, 32, 109, 123, 172, 190, 208, 269, 293, 294, 316, 317, 324, 325, 332
Seepage quantity, 15, 236, 237
Segregation, 91, 148-150, 152, 361
Seismic activity, 38, 65, 151, 190, 193, 199
Seismic tomography, 245-247, 250
Selection of backfill, 120
Self potential, 245, 251, 252
Self-healing, 147
Service life, 21, 28, 42-45, 47, 51, 53, 55, 86, 93, 184, 185, 187, 293, 294, 316, 317, 324, 325, 348, 352
Settlement, 2, 7, 17, 18, 22, 32, 37-39, 44, 52, 55, 75-77, 79-81, 84, 85, 87, 99-102, 107, 113-116, 118-120, 124, 125, 138, 140, 143-145, 151, 170, 172-174, 190-192, 197, 198, 208, 234-236, 239, 266, 270, 277, 278, 288, 339, 345, 354
Shape, *see* Conduit, shape
Shear strength, 85, 91, 99-101, 115, 335
Shear stress, 127, 187
Shore, 189, 212
Side slopes, *see* Conduit, side slopes
Silt, 5, 119, 128, 129, 158, 161, 177, 178
Sinkhole, 126, 158, 161, 163, 164, 167-169, 197, 206-208, 239, 252, 253, 266, 269, 270, 273-277
Siphon, 25, 39, 40, 216, 270, 278-280, 354, 360
Slaking, 114

-
- Sliplining, 39, 45-47, 51, 164, 167, 180, 277, 290-295, 297, 302, 304, 305, 307, 310, 312-316, 318, 319, 323, 331
- Sluice, 317
- Slurry, 24, 25, 27-29, 38, 338-340, 353
- Snap-Tite®, 315, 316
- Soil foundation, 18, 114, 115, 118, 133, 332
- Soil resistivity, *see* Electrical resistivity
- Soluble salt, 183
- Sonar, 218, 245, 246, 254-256
- Sonic caliper, 245, 246, 260
- Spacers, 302, 303, 305, 312-314, 319-321
- Specialized inspection, 205, 212, 213
- Specifications, 22, 30, 37, 94, 95, 98, 105, 123, 150-153, 188, 202, 340, 350
- Spectral Analysis of Surface Waves, 248
- Steel pipe, *see* Pipe, steel
- Spigot, 47, 48, 53, 106, 107, 109-111, 300, 302
- Spillway, 1, 67-73, 89, 91, 94, 95, 115, 159, 160, 181, 183, 184, 207, 243, 248, 250, 253, 265-267, 271, 273, 274, 278, 280-285, 287, 308, 312
- auxiliary, 1, 69, 70, 308
 - earthcut, 284
 - emergency, 69, 284
 - service, 1
- Spliced, 108, 109, 289
- Spray lining, 330
- Stability, 25, 56, 71, 271, 310, 335, 342
- Stave, 3
- Stoplog, 70
- Storage, 9, 27, 28, 59, 67, 134, 269, 288, 304, 319, 320
- Strain gauge, 209, 236
- Strength design method, 90
- Structural deformation, 235-237
- Structural design of conduits, *see* Conduits, structural design
- Styrofoam, 297
- Subsidence, 273, 274, 341
- Suffosion, 4, 126
- Sulfate attack, 180
- Surface air voids, 188
- Surface hardness, 213, 245, 246, 260
- Surface waves, *see* Spectral Analysis of Surface Waves

T

- Tag, 105, 106
- Tailings, 24, 25, 27, 29
- Tailwater, 57, 242
- Tampers, 33, 80, 122
- Template, 295, 296
- Temporary diversion channel, 336
- Tensile, 52, 53, 82, 90, 92, 95, 104, 105, 185, 187, 189, 261, 306, 329, 339, 342
- Terminal structure, 1, 36, 45, 58, 61, 64, 66, 67, 70-74, 103, 179, 197, 208, 211-213, 217, 218, 226, 291, 294, 302, 304, 316, 319, 324, 326, 331, 333, 336, 337, 356, 357
- Testing, 23, 26, 47, 50, 73, 94, 95, 100, 112, 121, 123, 126, 127, 147-149, 151-154, 175, 194, 195, 211, 213, 219, 232, 241, 245, 247, 257, 259-261, 276, 304-306, 310, 318, 320, 327, 329, 335, 340-342, 350, 360
 - conduit, *see* Conduit, evaluation by testing
 - control, *see* control testing
 - destructive, *see* destructive testing
 - geophysical, *see* Geophysical testing
 - nondestructive, *see* Nondestructive testing
- Tether, 221, 224, 226
- Theory of filter seal development, 131
- Thermocouple, 105
- Thermoplastic, 1, 41, 46, 47, 50, 97, 109, 293, 319
- Thermoset plastic, 1, 41, 46, 48, 49, 97
- Toe of the embankment dam, 14, 33, 70, 73, 135, 143, 147, 165, 197, 239, 240, 278, 281, 306
- Tomography, *see* seismic tomography
- Tower pipe, *see* Pipe, tower
- Transducer, 246, 254-260
- Transverse crack, 115, 120, 124, 134, 240
- Trashrack, 216
- Trench, 21, 23, 37, 38, 87, 88, 115, 118, 121, 127, 133, 135, 137, 140, 142, 144, 152, 154, 237, 277, 284, 337, 341, 354
- Trenchless technology, 290, 324, 325
- Tunnel, 6, 9, 15-17, 34, 36, 39, 69, 87, 158, 161, 163, 165-168, 172, 174, 338-341
- Turbidity meter, 236

U

Ultrasonic pulse-echo, 245, 246, 256, 257, 350
Ultrasonic pulse-velocity, 213, 245, 246, 256, 257, 350
Ultrasonic thickness survey, 257-259
Uplift pressures, 91, 236, 237, 239
Underwater inspections, *see* Inspection, underwater
Upstream control, 60, 62, 65, 66, 291
Utility conduit, 23, 24

V

Valve, 39, 50, 52, 57-61, 64-67, 73, 75, 90, 167, 181, 216, 230, 278, 286, 287, 297, 326
Vertical movements, 75, 85, 236, 239, 240
Void, 6, 9, 11-13, 115, 124, 128, 129, 133, 149, 159, 163, 167, 188, 189, 206, 211, 232, 246, 248, 250, 253-255, 257, 260, 276, 292, 310, 311, 326, 340, 345-348, 353

W

Waves, *see* Spectral Analysis of Surface Waves
Water content, 86, 118, 120, 121, 123, 124, 151, 153, 154, 334, 335
Water level, 7, 141, 203, 205, 212, 227, 236, 238, 242, 243, 280, 287, 288, 357, 360
Water quality, 59, 197, 236, 241
Waterstop, 103, 107-110
Watertightness, 26, 45, 47, 52, 53, 64, 83, 98, 99, 106, 112, 192
Weir, 206, 207, 236, 238, 288
Wood stave, 3

Z

Zones, filter, *see* Filter, zones
Zoning of embankment dams, 10, 14, 28, 32, 33, 38, 39, 61, 76, 79-84, 118, 120-124, 126-128, 131, 133-135, 137-140, 142-145, 147-150, 152, 153, 155, 161, 165, 167, 168, 170, 172, 175, 179, 181, 198, 237, 239, 246, 248, 253, 264, 334, 335, 358

