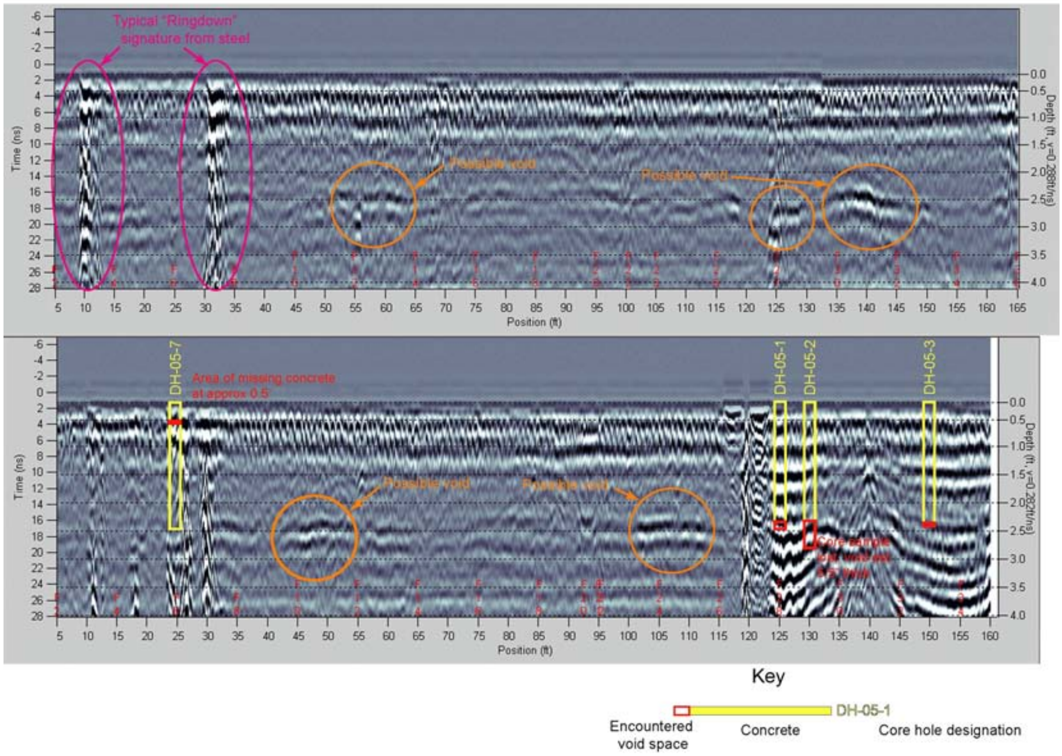

Figure 144.—GPR profiles along a conduit invert. The large amplitude white-black reflection patterns are associated with concrete underlain by voids in drill holes (DH) DH-05-01 through -03.

for generated sonar pulses to return to the transducer (through air or water) are a function of the distance that the pulse travels, it is possible to precisely measure the distance to the conduit surface. When processed by a computer, thousands of these measurements can be used to generate a map (figure 145) of the condition (deflection, joint size, depth of deterioration, etc.) of the conduit. The precision of the system is such that measurements of fractions of an inch can be made. The sonic velocity can vary with temperature and humidity, and calibration is required prior to commencing with the inspection. The accuracy of the measurements depends upon the calibration. The sonar can also be used in navigating the transporting unit within the conduit.

Recent improvements in this technology allowed the USACE to investigate the condition of a conduit without unwatering it. A computer processed signals received from sensors mounted on an ROV to generate three-dimensional images. The user can manipulate the images on the screen in real time to change the observational point of view via graphics software. Thus, the graphics software allows the user to

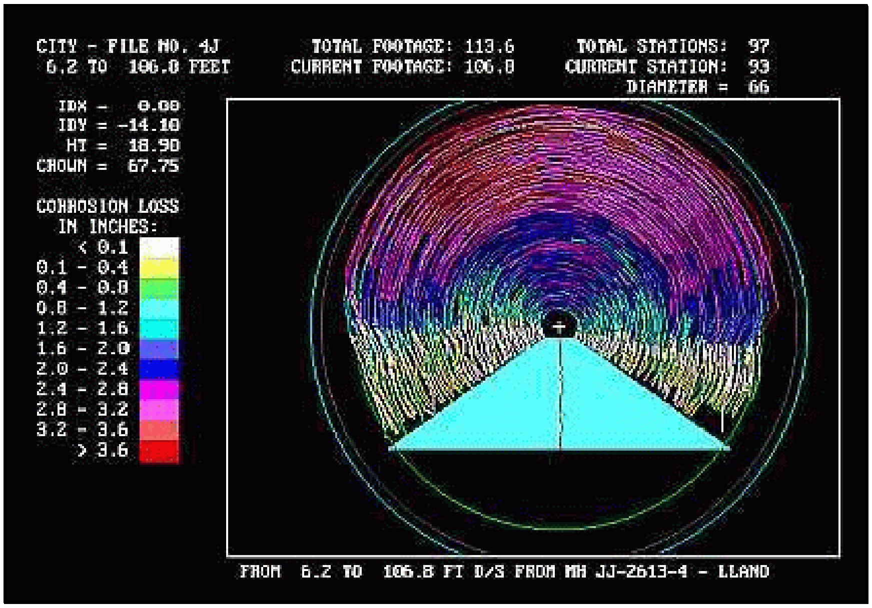

Figure 145.—A rotating sonar transducer mounted on a sled can be pulled through a conduit to measure and record changes in dimensions along the conduit. This can be very useful when determining the size for a proposed slipliner. Here, the measured corrosion loss of the crown of a steel pipe is shown at many locations on one image. The bottom of the conduit was submerged. The sonar device can work in water or air, but requires different settings for each. Thus, both above water and underwater sonar measurements cannot be made at the same time, although a mechanical device on the sonar sled can simultaneously provide information for the bottom of the pipe. Figure courtesy Sonex Corporation.

position the virtual observation point anywhere in space. Features that are not visible from the camera's view angle can become readily apparent (Britzman and Hansen, 2002, p. 3).

10.6 Ultrasonic pulse-echo and ultrasonic pulse-velocity

These methods measure the velocity and frequency content of acoustic pulses of energy through metallic (i.e., CMP) and nonmetallic (e.g., concrete) materials. Piezoelectric transducers are passed through the structure using a "smart pig" device or are attached to the structure to transmit and receive the pulses.

These methods generally use a source with known impulse characteristics, so that a transfer function can be computed between the input and the measured output (receiver) signal. By examining typical and nontypical (anomalous) velocity and frequency information, correlations may be established between sound and poor concrete conditions, and the corresponding acoustic signatures.

Generally, higher pulse velocities indicate good quality material, while decreased velocities or poor return signals (decreased high frequencies) indicate poor quality, such as voids, cracks, or deterioration. A large number of transducers used around the circumference of the conduit will improve the accuracy and the resulting image resolution.

The pulse-velocity method is widely used and has provided reliable in situ delineations of the extent and severity of cracks, areas of deterioration, and general assessments of the condition of concrete structures for many years. The equipment can penetrate thick concrete sections with the aid of amplifiers, is easily portable, and has a high data acquisition-to-cost ratio. Although most applications of the pulse-velocity method have been under dry conditions, the transducers can be waterproofed for underwater surveys. Tests have shown that the pulse-echo system is capable of delineating sound concrete, concrete of questionable quality, and deteriorated concrete, as well as delaminations, voids, reinforcing steel, and other objects within concrete. Also, the system can be used to determine the thickness of a concrete section in which only one surface is accessible. The system will work on vertical or horizontal surfaces. However, the present system is limited to a thickness of about 1.5 feet with only one side accessible. For maximum use of this system, the operator should have had considerable experience using the system and interpreting the results (USACE, 1995b, p. 2-17).

The pulse echo is limited to about a 1 foot thickness. The pulse-echo method is a variation of the pulse-velocity method and is best suited for characterizing voids and cracks parallel to the conduit surface. The pulse-velocity method is suitable for detecting cracks and voids in other directions. The pulse-echo method can be used from a single face of the conduit, whereas the pulse-velocity method requires access to both faces of the conduit. Both methods are commonly used concurrently to get a complete evaluation of the conduit (Promboon, Olson, and Lund, 2002).

Note that recent MASW (section 10.1.1) and GPR (section 10.4) advances have allowed multiple different imaging methods to be used on a given site, allowing greater interpretation confidence in difficult problem areas.

10.6.1 Ultrasonic thickness survey

The thickness of an existing metal or steel pipe can be measured using an ultrasonic thickness survey. The survey is conducted by using a pulse-echo ultrasonic thickness gauge (figure 146). An ultrasonic gauge determines the thickness of metal or steel pipe by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through the thickness of the pipe, reflect from the back or inside surface, and be returned to the transducer. Different types of materials have different acoustic velocities. The advantages of performing an ultrasonic survey are:

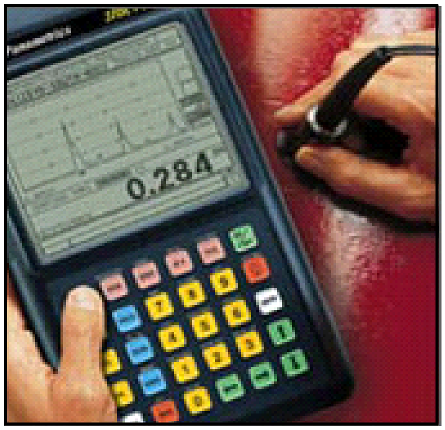

Figure 146.—Ultrasonic thickness gauge for measuring metal thickness.

- Thickness measurements can be taken without removing coating (with the exception of asphalt and concrete linings) on the interior of the pipe.
- Measurements can be taken on the exterior surfaces for exposed pipe while the pipe is in operation (i.e., full of water).
- Thickness measurements taken on the interior of the pipe help determine whether corrosion is occurring on the outside of the pipe shell for buried pipe or pipe encased in concrete.
- Measurements of paint thickness and oxidation/rust thickness can also be taken simultaneously during the plate thickness survey.

However, there are some limitations in performing a survey of this type. Factors that may prevent obtaining readings for specific sections of the metal or steel are:

- Water on the invert.
- Measurements cannot be taken for certain interior coatings, such as asphalt and cement-mortar lining.
- Rough, uneven, corroded surfaces can limit the bond between the transducer and the steel pipe, thus preventing thickness readings.
- Normally, the ultrasonic thickness survey is performed by man-entry into the pipe. However, for inaccessible pipes the thickness survey can be completed using a specially equipped pig that moves through the pipe. In some cases, if the exterior surface of a pipe is accessible, the survey can be completed without requiring man-entry into the pipe. This situation is applicable when the pipe is

located within a larger access conduit. This type of arrangement is discussed in section 3.1.1.1.

- The valleys of the pipe corrugations may be too tight to get a good bond between the transducer and the steel. Transducers vary in size, but 1/8 inch is about the smallest diameter transducer.

In performing an ultrasonic thickness survey, measurements should be taken at intervals sufficient to gather an adequate number of thickness measurement data points to help ascertain the true wall thickness of the pipe. Measurements should be taken circumferentially about the pipe. Particular emphasis should be placed on taking measurements near the invert of the pipe, as this area is more susceptible to wall thinning (metal loss) due to abrasion and corrosion. Factors to consider in determining the amount of measured wall thinning are:

- Pipe manufacturers tend to make the pipe wall slightly larger than the thickness specified to ensure they meet minimum wall thickness requirements.

- Testing accuracies depend upon the test instrument and the transducers. Most ultrasonic thickness equipment has an accuracy of at least 2 percent. Accuracy is also dependent upon proper calibration of the instrument.

If wall thinning is encountered, additional ultrasonic thickness surveys should be considered periodically (i.e., every 5 years, or more frequently, depending upon the severity of the wall thinning, corrosion damage, etc.). A history of these wall thickness surveys may indicate the expected yearly decrease in wall thickness, if uniform corrosion damage is occurring.

A stress analysis of the pipe to determine structural adequacy is recommended, if the ultrasonic thickness survey indicates a wall loss greater than 10 percent of its original specified value (see ASTM A 796 and the USACE's *Culverts, Conduits, and Pipes* [1998a, pp. 4-4 and 4-5] for guidance on performing stress analysis for CMP). A detailed wall thickness survey allows an accurate structural assessment of the pipe to be performed. The results of the thickness surveys can be compared to the minimum acceptable plate thickness specified by design criteria to determine if the pipe has a sufficient safety factor and if corrective action may be required.

Inspection of welds can also be performed by ultrasonic techniques. This process requires the use of an angle beam transducer to detect flaws in the weld metal. Ultrasonic sound waves are transmitted through a transducer, which reflects them into the weld area at an angle of 30 or 45 degrees. The angled reflection of the sound waves allows the flaw area to be detected and accurately sized. The interpretation of the results requires a great deal of experience, and should be performed by someone with a level 2 certification in ultrasonic testing.

10.7 Mechanical and sonic caliper

Calipers can provide information about the internal diameter of the conduit (USACE, 2001c, p. 32). Calipers are used for detecting any changes or defects that cause changes in interior dimensions, such as pits, holes, cracks, deformations, damage, or corrosion. Caliper measurements are made using mechanical, sonic, or ultrasonic methods. For the mechanical method, metal "feeler" instruments contact the inside wall of the conduit. The positions of the feelers are sensed electronically and recorded on a printout. The sonic or ultra sonic calipers use transducers that beam a pulse to the conduit wall. The pulse is reflected by the wall back to the transducer and interpreted based on its time of transit. Typically, calipers are used in conduits with diameters 18 inches or larger. Calipers are deployed using a wire cable or smart pig. Some caliper tools can be used underwater.

10.8 Radiography

The radiography method encompasses any type of penetrating radiation, such as X-rays, gamma rays, beta particles, neutron beams, or proton beams. Radiography is useful for detecting cracks, voids, and defects, or for viewing the internal composition of a conduit. Differences in thickness and density are easily measured and can be seen on a screen or recorded onto film. Although radiography is generally quick, efficient, and accurate, the complex nature of the equipment, costs involved, training, and certification requirements often limit its use.

10.9 Surface hardness

The rebound hammer and penetration resistance methods are quick, simple to use, and inexpensive to perform. These methods can be performed by field personnel with a limited amount of training and instruction. These methods are useful in assessing the general quality of concrete and locating areas of poor quality concrete in a conduit. However, these methods do have a number of limitations, including imprecise measurements of the in-situ strength of concrete. The rebound hammer and penetration resistance methods require man-entry access into the conduit.

10.10 Conduit evaluation by destructive testing

Although not utilized often in conduits, destructive testing can be used to gather more data. Concrete cores can be cut from selected locations to obtain representative samples. Samples are often taken from deteriorated areas and from good quality concrete for comparative purposes. A petrographer can examine the concrete cores, or strength tests can be performed on the cores. By using microscopic analysis and various chemical tests, a petrographer can determine the air content of hardened concrete, estimate the cement content, find evidence of carbonation or other reactions, and detect admixtures or contaminating substances that may have been present during construction. A petrographer can also make general observations about water-cement ratio, degree of cement hydration, early frost damage, excessive bleeding, and similar phenomena. Strength testing on the cores may include tensile and compressive. Drilling of concrete cores in conduits is expensive and should only be used when sampling and testing of the concrete is necessary.

Chapter 11

Appropriate Emergency Actions

Embankment dams are owned and operated by individuals, private and public organizations, and the government. An embankment dam failure resulting in an uncontrolled release of the reservoir can have a devastating effect on persons and property downstream. Even though an embankment dam may be well maintained, the potential for development of conditions that could lead to failure of the embankment dam always exists. Chapter 11 provides guidance on the appropriate actions needed during an emergency situation involving a conduit through an embankment dam. Often emergency situations involving the conduit lead to related problems with the embankment dam. Therefore, this chapter considers not only emergency actions for conduits, but also actions required for the embankment dam.

11.1 Implementation of an Emergency Action Plan

Many types of emergency events could jeopardize the safety and structural integrity of an embankment dam and threaten the safety of the general public downstream of the dam. Whenever people live in areas that could be inundated as a result of a failure of or misoperation at a embankment dam, the potential exists for loss of life and significant damage to downstream property. Developing thorough and consistent Emergency Action Plans (EAPs) in an effort to help save lives and reduce property damage in areas that would be affected by the failure or misoperation of a specific embankment dam and maintaining up-to-date points of contact and phone numbers are important. Copies of the EAP should be provided to emergency management agencies and personnel and periodically discussed with them. If no EAP exists, contact the State dam safety office.

Emergencies involving conduit related issues are only one aspect of potential embankment dam failures. An EAP is a formal document that:

- Identifies potential failure conditions at an embankment dam and specifies preplanned actions to be followed to attempt to prevent a dam failure and to possibly minimize downstream property damage and potential loss of life.

- Specifies actions the embankment dam owner and others should take to mitigate or alleviate a potential dam failure during an emergency.
- Contains procedures and information to assist the embankment dam owner in issuing early warning and notification messages to responsible downstream emergency management authorities of the emergency.
- Includes notification of the State dam safety officials and designates a qualified professional engineer who is experienced in embankment dam design and construction and should also be notified to assist in the emergency response.
- Contains inundation maps to show the emergency management authorities the critical areas for evacuation in case of an emergency.

An EAP is needed for two main reasons:

- To plan the coordination of necessary actions by the embankment dam owner and the responsible local, State and/or federal officials to provide for timely notification, warning and evacuation in the event of an embankment dam failure or release (controlled or uncontrolled).
- To reduce the risk of loss of life and property damage, particularly in the downstream areas, resulting from an emergency.

An effective EAP is generally comprised of six basic elements as follows (FEMA, 2004, pp. 4-5):

1. *Notification flowchart.*—A notification flowchart shows who is to be notified, by whom, and in what priority. The information on the notification flowchart is necessary for the timely notification of persons responsible for taking emergency actions. The flowchart should contain a primary and alternate telephone number (including cell phone numbers) for each person to be contacted. Instructions should state that if the person being contacted does not answer the telephone, a message should be left. But the next person on the list must be called and given the information. The caller must continue the alert process in each alert level until a person has physically been talked to in that level. This person then continues the alert process for the level in the same manner.

2. *Detection, decisionmaking/classification and notification.*—Early detection and evaluation of the situation(s) or triggering event(s) that initiate or require an emergency action are critical. The establishment of procedures for the reliable and timely classification of an emergency situation is imperative to ensure that the appropriate course of action is taken based on the urgency of the situation.

3. *Responsibilities.*—The responsibility for emergency-action-related tasks should be assigned during the development of the plan. Embankment dam owners are responsible for developing, maintaining and implementing the EAP. State and local emergency management officials having statutory obligation are responsible for the warning and evacuation of the general public within the affected areas. The EAP should clearly specify the embankment dam owner's responsibilities, to ensure effective, timely action is taken should an emergency occur at the dam. The EAP must be site specific, because all embankment dams are different.

4. *Preparedness.*—Preparedness actions are taken to mitigate or alleviate the effects of an embankment dam failure or operational reservoir release and to facilitate the appropriate response to emergencies. This section of the EAP identifies actions to be taken before and/or during any emergency.

5. *Inundation maps.*—Inundation maps should delineate the areas that would be flooded as a result of a embankment dam failure for normal and flood conditions or uncontrolled release. Inundation maps are used by both the embankment dam owner and emergency management officials to facilitate timely notification and evacuation of areas affected by an embankment dam failure or flooding. These maps greatly facilitate notification, by graphically displaying flooded areas and showing travel times for wave fronts and flood peaks at critical locations. These maps should be used in advance to develop warning and evacuation plans, but should only be used for guidance.

6. *Appendices.*—The appendices contain information that supports and supplements the material used in the development and maintenance of the EAP.

Once the EAP has been developed, approved and distributed to the proper authorities, the plan still needs to be properly maintained and exercised. Without periodic maintenance, the EAP will become outdated, lose its effectiveness, and no longer be useable. If the plan is not exercised (validated), those involved in its implementation may not be aware of their roles and responsibilities, particularly if emergency response personnel change over time. If the plan is not updated periodically, the information contained in it may become outdated, incorrect, and useless.

An EAP should be developed for site-specific conditions and to the requirements of the agency/organization that owns or regulates the use of the specific embankment dam. The intent of this document is not to provide every detail necessary to develop an effective and useful EAP. The requirements of an EAP vary from State/federal agencies as to the format, level of detail, and information presented in the EAP. For further guidance on developing an effective EAP, see the references from the

Canadian Dam Safety Association (1997); FEMA (1987, 1998, 2004); Colorado Division of Water Resources (1997); FERC (1998); Reclamation (1989a, 1995); and USACE (1996).

Once the EAP has been developed and approved, the appropriate implementation of the EAP is essential and critical to the safety of the general public living downstream of the dam. The EAP should list the proper procedures for the timely and reliable detection, evaluation, and classification of an existing, developing, or potential emergency. The conditions, events or measures for detection of an existing or potential emergency should be listed. Data and information collection systems should be discussed, such as inspection procedures, rule curves, and instrumentation plans. The process that will be used to analyze incoming data should also be discussed. Additionally, procedures, aids, instructions and provisions for evaluation of the collected information and data to assess the severity and magnitude of any existing or potential emergency situation should be discussed.

Emergencies are classified according to their severity and urgency. An emergency classification system is one means of classifying emergency events according to the different times at which they occur and to their varying levels of severity. The classification system should indicate the urgency of the emergency condition or response. Emergency classifications should use terms agreed to by the embankment dam owner and emergency management officials during the planning process, in order for the system to work and to ensure that organizations understand terminology and respond appropriately to the event.

The organizations that will use titles for emergency classifications should choose them carefully, so that everyone will understand what each classification level means when notifications are issued and received. Declaration of an emergency can be a very controversial decision. The issue should not be debated too long. An early decision and declaration are critical to maximize available response time.

Depending on the type of embankment dam, possible emergency events and the potential hazard zone downstream of the particular dam, two or more emergency classifications may be required to ensure the proper and effective response to emergencies at the dam. Coordination is required with State dam safety offices. Three embankment dam failure emergency classifications are suggested:

- Embankment dam failure is imminent or has occurred.
- A potential embankment dam failure situation is developing.
- Nonemergency or unusual condition.

The emergency classification that a failure is imminent or has occurred should convey the impression that the embankment dam is failing, and appropriate evacuation procedures should be employed. This is a situation where a failure has occurred, is occurring, or obviously is just about to occur. Therefore, once an embankment dam owner determines that there is no longer any time available to attempt corrective measures to prevent failure, the "failure is imminent or has occurred" warning should be issued. Emergency management agencies, for evacuation purposes, should conservatively interpret the phrase "failure is imminent" to mean that the embankment dam is failing, and all appropriate parties should be notified to commence emergency operations and evacuation.

The emergency classification that a potential embankment dam failure situation is developing should convey the impression that some time still remains for further analyses/decisions and remedial actions to be made before an embankment dam failure is considered to be imminent. This is a situation where the condition of the embankment dam is deteriorating rapidly and failure may eventually occur; however, preplanned actions taken during certain events could mitigate or alleviate failure of the embankment dam. Even if failure is inevitable, more time is generally available than the "failure is imminent" condition to issue warnings and/or take preparedness actions. All appropriate parties should be on standby-alert status and should be notified to commence their emergency operations and evacuation, if required.

The "nonemergency or unusual condition" classification applies where an unusual problem or condition has occurred, but a failure of the embankment dam is not considered imminent. This is a situation or circumstance that may affect the integrity of the embankment dam but is considered controllable. This condition could lead to a failure of the embankment dam, if appropriate actions or repairs are not employed. All appropriate parties should be notified periodically with regard to the status of the condition of the dam and should be on standby-alert status for emergency actions, should conditions deteriorate.

Table 11.1 provides a guide for determining the level of urgency and the emergency classification associated with emergency conditions attributed to the internal erosion or backward erosion piping of earthfill materials (Colorado Division of Water Resources, 1997, p. 11; FEMA, 1998).

Prompt and effective response to an emergency at a particular damsite could result in the mitigation or avoidance of a embankment dam failure incident, or help reduce the effects of a dam failure or operational spillway release, and facilitate response to the emergency. The preventive actions that an embankment dam owner may take include providing emergency flooding operating instructions, and arranging for equipment, labor, and the stockpiling of materials for use in an emergency situation. An effective EAP should describe preventive actions to be taken during the development of emergency conditions.

Table 11.1.—Assessing emergency classification and urgency

Incident	Level of urgency and response		
	Non emergency condition.—New or increased problem. Change in existing condition.	**Potential dam failure developing**.—Possible embankment dam failure is developing. Condition of embankment dam is deteriorating rapidly.	**Embankment dam failure is imminent**.—Embankment dam failure has occurred, is occurring, or is about to occur.
Response and notification priority	Monitor condition and call for assistance. Contact the State dam safety officials and/or design consultant.	Monitor condition; take appropriate remedial actions; emergency response personnel on standby-alert status; and begin mobilizing for failure, if required. Contact design consultant, general construction contractor, the State dam safety officials, and emergency manager and response personnel.	Commence the appropriate emergency operations and response and evacuation of affected downstream residents. Contact emergency manager and response personnel, design consultant, general construction contractor, and the State dam safety officials.
Problem or condition	Examples of possible observations		
Internal erosion and backward erosion piping	Small amount of sediment in seepage or drains.	New, stable or slowly increasing seepage rates transporting some sediment. Significant amount of sediment in seepage, drains muddy water. Reservoir level is falling without apparent cause (such as outlet works or spillway releases).	Rapidly increasing seepage transporting large amounts of sediments. Sinkholes on embankment dam or abutments, whirlpool in reservoir, significant settlement of embankment dam, significant muddy water. Whirlpool or other signs of the reservoir draining rapidly through the embankment dam or foundation.
Seepage	Downstream slope of embankment dam is wet, soft; minor sloughing; water running down dam face or abutment groins.	Significant new or increasing seepage or sand boils downstream from the embankment dam. Seepage is causing slides, which narrows the embankment dam cross section, or settlement of dam crest and loss of freeboard.	Rapidly increasing seepage and/or transporting large quantities of materials. Sand boils rapidly increasing in size or number and/or rapidly increasing flows. Seepage has caused large slides, which have reduced freeboard to the reservoir level, and/or embankment dam is overtopping due to loss of freeboard.
Sinkholes	Small depressions on embankment dam, abutment or foundation.	Significant new or larger sinkhole(s) or crest settlement. Large sinkhole over outlet works, or on embankment dam, abutment or foundation (larger than 8 in. in diameter). Stable or not increasing in size.	Sinkhole(s) or settlement rapidly increasing in size or number. Unstable or increasing sinkhole over outlet works, or on embankment dam, abutment or foundation. Whirlpool in reservoir.
Settlement	Minor settlement or depressions (less than 1 ft).	Moderate settlement of embankment dam crest or embankment slope (one-half of normal freeboard).	Significant settlement of the embankment dam crest, reservoir is overtopping the dam.
Conduit failure	Broken gate or operator, minor conduit deterioration, seepage adjacent to conduit.	Cracked or perforated conduit, sediment in seepage, deeply scoured or undermined conduit.	Significant, muddy seepage from or adjacent to conduit; sinkholes in embankment over outlet conduit.

Preventive actions involve the installation of equipment or the establishment of procedures for one or more of the following purposes:

- Preventing emergencies from developing, if possible, or warning of the development of an emergency.

- Facilitating the operation of the embankment dam in an emergency through dam operator training.

- Minimizing the extent of damage resulting from emergencies that do develop.

Timely implementation of the EAP and coordination and communication with downstream local authorities are crucial elements in the effectiveness of emergency response. The EAP should contain a discussion of provisions for surveillance and evaluation of an emergency and should clearly indicate that emergency response procedures can be implemented in a timely manner. An important factor in the effectiveness of an EAP is the prompt detection and evaluation of information obtained from instrumentation and/or physical inspection procedures.

Certain planning and organizational measures can help the embankment dam owner and local emergency response personnel manage the emergency more safely and effectively. These measures include stockpiling materials and equipment for emergency use, and coordinating information. Alternative sources of power for spillway or outlet works gate/valve operation and other emergency uses should also be provided. The EAP should list the location of each power source, its mode of operation and, if it is a portable source, the means of transportation and routes to be followed to the damsite.

The EAP should document the following items as they pertain to stockpiling materials, obtaining equipment, and contacting personnel for use in the event of an emergency. Not all embankment dams lend themselves to a need to have stockpiled materials and equipment. The materials and equipment can be stockpiled at the damsite or an accessible site within close proximity to the damsite. Resources needed may include:

- Materials needed for emergency repair and their location, source, and intended use. Materials should be as close to the damsite as possible.

- Equipment to be used, its location, and who will operate the equipment.

- How the equipment operator or construction contractor is to be contacted.

- Any other personnel who may be needed, like laborers and the design engineer, and how they are to be contacted. If there is no designer of record, a list of two to three qualified professional engineers should be available for contact.

The EAP should also document the following items as they pertain to coordination of information and communicating with the emergency response personnel:

- The need for coordination of information on flows based on weather conditions and runoff forecasts and embankment dam failure and other emergency conditions. Describe how the coordination is achieved and the chain of communications, including names and telephone numbers of responsible people.

- Additional actions contemplated to respond to an emergency situation or embankment dam failure at an unattended dam.

- Actions to be taken to lower the reservoir. Describe when and how (maximum drawdown rate) this action should be taken. Also, alternative means of evacuating the reservoir should be specified in the event the outlet works is inoperable, releases through the outlet conduit are not recommended due to a internal erosion situation, or the outlet capacity has been reduced for some reason.

- Actions to be taken to reduce inflow into the reservoir from upstream dams or control structures. The inflows should be stopped or diverted around the reservoir, if possible.

- Actions to be taken to reduce downstream flows, such as increasing or decreasing outflows from downstream dams or control structures on the waterway on which the embankment dam is located or its tributaries.

The EAP should also describe other site-specific or emergency repair actions that can be devised to moderate or alleviate the extent of the potential emergency and possible failure of the embankment dam. The EAP will recommend actions, but serves only as a guide, since there are typically many variables. A trained dam safety official will, in most cases, need to determine the type of action required.

Table 11.2 provides a list of potential problems and immediate response or emergency repair actions that can be undertaken. This is a relatively comprehensive list and includes problems and the associated emergency response as they relate to conduits through embankment dams (FEMA, 1987; Colorado Division of Resources, 2002). Caution is advised in using table 11.2, since many variables are involved, and each damsite is different.

Table 11.2.—Potential problems and immediate response or emergency repair actions

Problem or conditions	Cause	Response or emergency repair actions
Internal erosion and backward erosion piping through the embankment dam, foundation or abutments	Water has created an open pathway, channel or pipe through the embankment dam. The seepage water is eroding and carrying embankment materials. Large amounts of water have accumulated on the downstream slope. Water and embankment materials are exiting at one point. Surface agitation may be causing the muddy water. A break in the conduit could be allowing water to discharge out of the conduit, in the case of a pressurized conduit beneath the embankment dam. A flow path has developed along the outside of the conduit.	• Begin monitoring the outflow quantity and establishing whether water is getting muddier, staying the same, or clearing up. • If the quantity of flow is increasing, the reservoir should be lowered until the flow stabilizes or stops. • Search for a possible opening on the upstream side of the embankment dam and plug, if possible, as noted in the sinkhole section above. • Place a protective filter of sand and gravel over the exit point(s) to prevent further migration of fine embankment materials. • Continue operating the reservoir at a reduced reservoir level until repairs can be made. • Engage a qualified professional engineer to inspect the conditions and recommend further corrective actions to be taken.
Seepage water exiting from a point adjacent to the conduit	Break in the conduit allowing water to discharge out of the conduit, in the case of a pressurized conduit beneath the embankment dam. A flow path has developed along the outside of the conduit or a saturated area on the embankment above the conduit has developed.	• Thoroughly investigate the area by probing and/or shoveling to see if the cause can be determined. Caution should be used when shoveling in the embankment where seepage is occurring, so as to not aggravate the situation. As a precaution, a supply of sand and gravel may be needed to prevent un controlled seepage. • Determine if the leakage is carrying soil particles or sediments. • Construct a measuring device and channel the seepage to the measuring device, to monitor and determine the quantity of flow. • Stake out the saturated area and monitor for growth or shrinkage. • Continue frequent monitoring of the seepage area for signs of slides, cracking or increase or changes in the seepage condition. • If the seepage flow increases or is carrying embankment materials, the reservoir should be lowered until the leakage stops or is stabilized. • Engage a qualified professional engineer to inspect the conditions and recommend further corrective actions to be taken.
Large increase in flow or sediment in seepage	A shortened seepage path or increased storage levels	• Accurately measure outflow quantity and determine amount of increase over previous flow rates. • Collect jar samples of the seepage to compare the turbidity of the water with time. • If either quantity or turbidity has increased by 25%, a qualified professional engineer should be engaged to inspect the conditions and recommend further corrective actions to be taken.
Sinkholes	Backward erosion piping of embankment materials or foundation causes a sinkhole. A sinkhole can develop when a subterranean erosion feature	• Inspect other parts of the dam for seepage or more sinkholes. • Identify actual cause of the sinkhole(s). • Check seepage and leakage outflows for dirty/muddy water.

Problem or conditions	Cause	Response or emergency repair actions
	collapses. A small hole in the wall of a conduit can allow backward erosion piping of materials and develop a sinkhole. Dirty water at the exit portal indicates erosion of the embankment dam materials.	• Carefully inspect and record location and dimensions (depth, width, length) of the sinkhole. Stake out the sinkhole to monitor any growth and development of the sinkhole. Frequent monitoring of sinkholes and seepage. • Lower the reservoir level to a safe level or until the seepage stops. If the sinkhole results from backward erosion piping of embankment materials into the conduit, alternative means to evacuate the reservoir may be required, such as siphoning, pumping, or controlled breach. • Excavate the sinkhole and plug the flow with whatever material is available (e.g., hay bales, bentonite, or plastic sheeting), if the entrance to the internal erosion can be located. • Place a protective filter of sand and gravel over the exit point(s) to prevent further migration of fine embankment materials. • Engage a qualified professional engineer to inspect the conditions and recommend further corrective actions to be taken.
Excessive settlement of the embankment or dam crest	Lack of or loss of strength of embankment materials. Loss of strength can be attributed to infiltration of water into the embankment materials from a crack in the conduit or loss of support by the dam foundation, causing a settlement or collapse of a conduit. Internal erosion or backward erosion piping of the embankment dam materials along the conduit.	• Establish monuments along length of crest and selected locations on the embankment dam to determine exact amount, location, and extent of the settlement. • Engage a qualified professional engineer to determine the cause of the settlement and to supervise all steps necessary to reduce possible threat to the dam and correct the condition. • Re-establish lost freeboard, if required, by placing sandbags or backfilling in the top of the slide with suitable embankment materials. Caution should be exercised not to further increase slide potential. • Re-establish monuments across the crest and selected locations on the embankment dam and monitor monuments on a routine basis to detect possible future settlement. • If continued movement of the settlement of the embankment dam is seen, begin lowering the reservoir at a rate and to an elevation considered safe given the settlement condition. • Continue operating the reservoir at a reduced reservoir level until repairs can be made.
Conduit failure	Cracks, holes or joint offsets in the conduit caused by settlement, rust, erosion, cavitation and poor construction. Broken/bent support block or control stem and broken/missing stem guides due to concrete deterioration, rust, excessive force exerted when operating the outlet gate/valve, and poor maintenance. Damage due to rust, cavitation, erosion, vibration, wear, ice action, or excessive stresses from forcing gate/valve closed when it is jammed.	• If internal erosion or backward erosion piping of the embankment materials through the conduit is the problem, close the outlet gate/valve to protect the embankment dam from further erosional damage. • Lower the reservoir to a safe level. If the outlet works is inoperable or cannot be operable for some reason, alternative means to evacuate the reservoir may be required, such siphoning, pumping, or controlled breach. • Monitor the conduit for settlement, development of sinkholes, and muddy leakage. • Implement temporary measures to protect the damaged structure, such as closing the outlet gate/valve. • Employ experienced professional divers, if necessary to assess the problem and possibly implement repairs. • Engage a qualified professional engineer to inspect the conditions and recommend further corrective actions to be taken.

11.2 Obtaining the services of a qualified professional engineer

Tens of thousands of embankment dam owners in the United States have exposure to liability for the water stored behind their dams. The responsibility for maintaining a safe embankment dam rests with the owner. For many owners, the proper operation and maintenance of the embankment dam is only one aspect of their organization's activities. Safely maintaining the embankment dam is a key element in preventing a failure and limiting the liability that an owner could face. An important way to help reduce an owner's exposure to the potential for an embankment dam failure is to have a qualified dam engineer periodically inspect and assess the dam for the development of problems that could lead to the dam's failure. The engineer should provide a written inspection report with recommendations for repairs for any potential problems found.

11.2.1 The need for an engineer

Embankment dams, like any other natural or constructed structures, will deteriorate with time. Failure of a embankment dam, whether due to conduit deterioration, inadequate spillway capacity, seismic inadequacies, or other reasons could leave the dam owner liable for lives lost and property damage that occur downstream as a result of the failure. For these reasons, the owner needs to be sure that the embankment dam and any appurtenant water-retaining structures have been designed, constructed, and maintained to withstand each of the probable loadings that these structures could be subject to during their lifetime. To maintain a safe embankment dam and minimize the possibility of a dam failure, regular periodic inspections, proper maintenance, and occasional repair and rehabilitation of the structures are inevitable. To perform these tasks, an owner needs the expertise of a qualified professional engineer (ADSO, undated), experienced in the design and construction of embankment dams and appurtenant structures. If no design and construction drawings and records exist for the engineer to work with, it may be necessary for the engineer to develop basic plans and calculations. These will help the owner and engineer better understand the structures, evaluate them for stability conditions, and understand the consequences of a embankment dam failure. An engineer can also provide the owner with assistance in selecting a contractor to perform repair or remediation work if necessary and can provide construction quality control if needed.

11.2.2 The type of engineer needed

Choosing a registered professional engineer (P.E.) with a civil and geotechnical engineering background, who is competent and experienced in the field of dam safety is important. Criteria to look for in the prospective dam engineer include:

- A licensed professional engineer, P.E., with a civil engineering degree
- A minimum of 10 years of experience with embankment dam design, construction, and inspections
- A knowledge of the rules and regulations governing embankment dam design and construction in the State where the dam is located
- Specific experience in the problem areas, such as hydrology, hydraulics, structural, or geotechnical engineering

11.2.3 Finding a qualified dam engineer

A good way to locate a qualified professional engineer is to contact your State dam safety office for recommendations. If the State dam safety office is not listed in your local telephone directory, you may find this information on the Internet under the (name of State) dam safety office or on the (name of State) government home page. Another source for obtaining the telephone number of your State dam safety office and/or the names of experienced dam engineers within your State is the Association of State Dam Safety Officials (ASDSO) at 859-257-5140 in Lexington, Kentucky.

11.2.4 Choosing an engineer who is best for your needs

Consultants are typically selected for engineering consulting services using one of three basic processes:

- *Qualification-based.*—Qualification-based selection means that the knowledge, experience, and ingenuity of the engineer are the critical factors in making the selection. This strategy is used when the owner is uncertain about the exact problem or the best solution to the problem. Typically, several engineering firms submit their technical qualifications, experience with similar projects, reputation with existing clients, and any other factors pertaining to the specific project. The owner selects the three most qualified firms to make brief presentations outlining cost-effective and innovative approaches to solve the problem. Based upon these presentations, the owner chooses the most qualified engineer to develop a scope of work. When agreement on the scope of work is achieved, the engineer and the owner negotiate a price that is fair and reasonable to both parties.
- *Fee-based.*—Fee-based selection means that the determining factor in choosing the engineer is the engineer's fee. This approach can be used if the owner knows exactly what work is needed and can clearly define the scope of work. This process has the disadvantage that the engineer best qualified to perform the work may not get the job.

- *Intermediate*.—The intermediate option is a cross between the qualification-based selection and fee-based selection processes. In the intermediate process, the owner prequalifies engineers based on their experience and qualifications, who are then asked to submit a fee-based proposal for a defined scope of work. This process ensures a higher level of certainty that the work will be of superior quality, but requires the owner to clearly define the scope of the work to be done.

11.3 Sinkholes and subsidence

Sinkholes or subsidence of the embankment surface in the immediate area of the conduit are usually the result of erosion of the embankment material. They usually indicate a very serious problem that needs immediate attention. Figure 147 shows an example of a sinkhole that occurred over an spillway conduit.

Seepage from the area around the conduit at the downstream end is also a serious problem, especially if it is a new occurrence. Seepage that is carrying embankment material, viewed as muddy water, is of immediate concern. Seepage of this type in conjunction with active subsidence or sinkholes is cause for immediate alarm and emergency action. Sinkholes can also develop around or adjacent to air shafts constructed to supply air to slide gates within an outlet works conduit.

The following section will discuss sinkholes and subsidence associated with conduits through embankment dams. These types of phenomena may occur on embankment dams for other reasons, but that is outside the scope of this document. For an example of a sinkhole that developed over a conduit, see the Sardis Dam case history in appendix B.

11.3.1 Initial response

The first response to the observance of new sinkholes or areas of subsidence is to initiate appropriate emergency actions. Unless it is determined conclusively that the conditions on the embankment dam are stable and not deteriorating, then it should be assumed that an emergency exists. The emergency action plan should be implemented. The reservoir should be drawn down as soon as possible, but not necessarily through the existing conduit. Section 11.4 discusses alternative means of reservoir evacuation. New seepage or cloudy seepage as discussed in chapter 9 is also of concern.

Figure 147.—Sinkhole over a spillway conduit.

11.3.2 Initial remediation

If the sinkholes are active and it appears that immediate remediation is needed to stabilize the situation, the placement of a well graded sand and gravel mix with nonplastic fines into the sinkhole can be attempted. The concept is that placement of these materials directly into the hole will cause the sand and gravel to be transported directly to the defect in the conduit. A well graded mix will hopefully contain some particles that are larger than the defect and these will thus get trapped. Once this occurs, then other, smaller particles will be trapped. Eventually the process is capable of filtering the embankment dam's core material, causing a seal to form, arresting the erosion completely. This type of solution should only be considered a temporary one, to be followed by a full investigation of the problem.

11.3.3 Investigation

A full investigation should be conducted to determine the root cause of the sinkhole or subsidence area. This is absolutely necessary. No permanent solution can be designed until the problem is pinpointed.

Should a sinkhole become visible on the surface of an embankment dam, it is likely that an erosional failure mode is well underway. Emergency measures should be instituted as described in this chapter. After the emergency conditions have been stabilized, probably by lowering the reservoir level, a forensic investigation of the sinkhole is warranted. A carefully planned and executed investigation can provide important information that will help determine what type of repair is most appropriate.

The surface expression of a sinkhole is most often a small indicator of a much larger cavity beneath the surface. Any investigation of a sinkhole should assume that the subsurface conditions are much worse than they appear to be. Case histories have demonstrated that sinkholes at depth can be much larger than what appears on the surface.

Most often, a sinkhole that was caused by erosion of embankment material into a conduit will be located immediately above the alignment of the conduit, and the following discussions apply to this situation. Figure 148 illustrates a typical sequence of the formation of a sinkhole located above a conduit. Figure 149 shows an example of a sinkhole where the continued removal of soil would have caused the roof of the cavern to migrate to the surface of the embankment dam. Sinkholes that are not associated with a conduit may have different considerations and are not further discussed here.

Investigations of sinkholes above conduits should be preceded by a review of the conduit and embankment design to ensure that the investigation does not increase the amount of damage. Most often, the sinkhole is investigated initially by a backhoe excavation conducted from the surface. This is performed to initially determine the magnitude of the problem and to see if the cause can be readily established. Also, the interior of the conduit below the sinkhole area should be inspected to determine if there are holes or other damaged areas that could be the point where embankment material has entered the conduit.

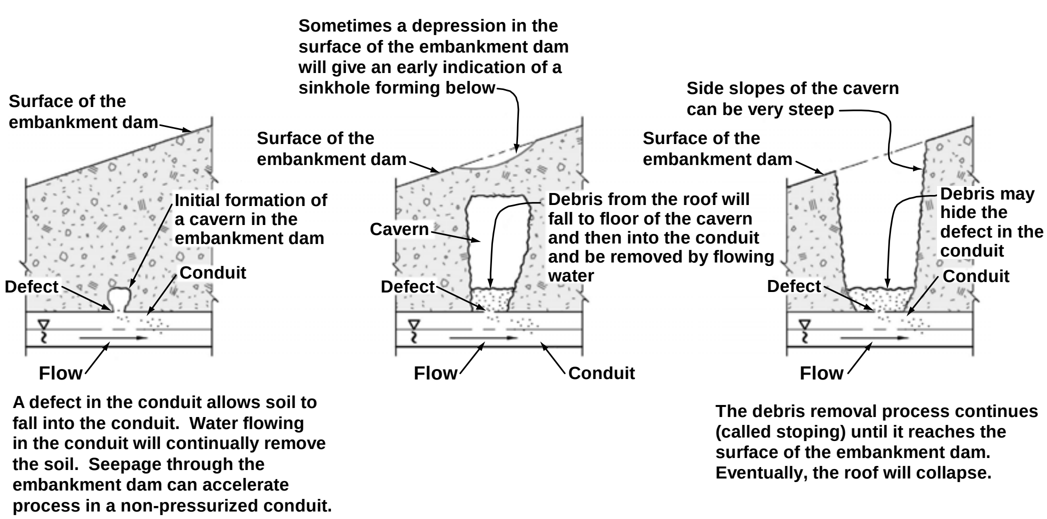

Figure 148.—Typical sequence of the formation of a sinkhole.

Figure 149.—Incipient sinkhole in an embankment dam. Eventually, the continued removal of the soil at the bottom of the cavern would have caused the roof to migrate to the surface of the embankment dam.

If the backhoe investigation results in limited information, it may be necessary to perform a major excavation of the embankment dam to ascertain that the entire sinkhole has been found. This investigation may be combined with the actual repair, as long as the excavation plans are sufficiently flexible to allow for complete removal of the sinkhole wherever it is found.

In-situ testing has been successful at some sites to look for soft areas or voids. A cone penetrometer testing program has been used. A closely spaced series of tests performed on a grid pattern can help discern the limits of any soft areas. At other sites, ground penetrating radar has been somewhat successful to help locate some incipient sinkholes that were near the embankment dam crest, but had not yet broken through to the surface.

11.3.4 Repair

If complete replacement of the conduit is chosen as the repair method, then it is much easier to repair the embankment dam. If the conduit is repaired by some in-situ method, then the repair of the sinkhole is made more difficult. In both cases, the basic concept is to repair the embankment dam with a material that is as good or better than the original material. The material to be used should be selected to perform the same function as the surrounding material. If the repair area is within the impervious core portion of the embankment dam, then similar material should be used. Similarly, shell material should also be used in areas outside of the core. If existing filters and drains were impacted, then these too should be replaced. New filters and drains should be added as needed.

Several factors determine the extent of the excavation required to repair a sinkhole that was caused from embankment soil being eroded into a conduit defect. One factor is the method used to repair the defect in the conduit. In some cases, the conduit will be not be replaced, but will be repaired by one of the sliplining methods. In that case, the embankment does not have to be excavated to gain access to the conduit from the outside for repair operations. The extent and configuration of the required excavation will then depend on how much embankment was damaged by the sinkhole, and how the excavation must be prepared before subsequent replacement of the sinkhole and excavated embankment can proceed.

The configuration for the excavation made to repair the sinkhole must consider differential settlement that will occur between the excavation backfill and adjacent embankment and foundation soils that have already consolidated. The shape of the excavation must also allow efficient operation of compaction equipment used in the reconstruction. Section 5.2 discusses the dangers of arching that can occur in backfilled trenches that are overly steep, particularly when the trench is transverse to the embankment centerline. Recommendations in that section suggest that any excavation made to repair sinkholes should probably be no steeper than 2H:1V for this reason, and only that steep, if the embankment soils have favorable properties. Flatter slopes are recommended for less favorable conditions. The excavation must also be configured for use of appropriate compaction equipment. The slopes of the excavation must be flat enough to operate equipment safely as the backfill of the sinkhole proceeds.

If the repair of the sinkhole involves excavation and replacement of the damaged conduit, consider the recommendations for conduit replacement provided in chapter 13 together with the recommendations above. In most cases, the excavation required to replace the conduit will also remove the portion of the embankment dam that was damaged by the sinkhole.

11.4 Alternative means of reservoir evacuation

Alternative means of evacuating the reservoir should be specified in the event that the outlet works is inoperable, releases through the conduit are not possible/ recommended due to internal erosion or backward erosion piping, or the outlet capacity has been reduced for some reason. The selection of a means that is appropriate depends on the size of the reservoir, the physical features of the particular damsite, the availability of equipment and materials, the volume of water that could be released, and the required rate of release. Care should be employed in determining the means of reservoir evacuation during a specific emergency, to ensure that the reservoir releases do not cause loss of life or significant property damage downstream.

11.4.1 Siphoning

A siphon is a closed conduit system formed in the shape of an inverted U. A siphon (figure 150) can be used to partially drain a small reservoir. A single or a series of siphons can be constructed. Typically, siphons are placed up and over the embankment dam and extended to the toe of the dam. The downstream portion of the siphon can be charged with water and then released to create the siphonic action to start the siphoning of water. The downstream end of the siphon should be equipped with a gate or valve to facilitate creating the siphonic action. Multiple methods should be considered for priming siphons, such as a vacuum pump, water pump, or hand pump. Provisions for breaking the siphon (siphon breaker vent) should be provided at the crest of the embankment dam, should the need arise. At the discharge end of the siphon, the area should be properly protected to ensure that the discharging water does not cause erosional damage. A siphon over an embankment dam is illustrated in figure 151. The siphon in figure 151 is shown extending over the dam crest to avoid excavation into the embankment dam. If the siphon must be excavated through the embankment dam crest, the guidance provided in chapter 5 should be utilized.

Siphons are typically constructed of either PVC, HDPE, steel pipe and typically do not exceed 12 inches in diameter; however, in some instances, siphons as large as 15 to 18 inches in diameter have been successfully utilized for small embankment dams. Because of the negative pressures prevalent in the siphon, the pipe should be sufficiently rigid to withstand the collapsing forces. Pipe joints must be watertight, and the designer must take measures to avoid cracking of the pipe caused by movement or settlement of the embankment dam. In order to prevent absolute pressures within the pipe from approaching cavitation or collapsing presssures, the total drop of the siphon should be limited to a maximum of 20 feet. During emergencies, some cavitation damage may be an acceptable tradeoff.

Embankment dam owners and surrounding property owners should be aware that the use of siphons results in more frequent fluctuation in reservoir level when compared to more traditional pipe-and-riser spillway systems. This is a result of the inherent inefficiency of the siphon prior to priming of the system. Siphons prime with a head between 1 and 1¼ times the diameter of the siphon above the siphon invert. For example, the water surface in the reservoir will need to rise about 12 to 14 inches before a 12-inch diameter siphon becomes most efficient. Once the siphon primes, outflow increases very little with increases in head (reservoir level) (Monroe, Wilson, and Bendel 2002, p. 20). If a series of siphons is used at a site, they must be properly spaced to avoid close proximity. To close of proximity to

Figure 150.—Siphon used to lower the reservoir water surface through the upper entrance of an outlet works intake structure.

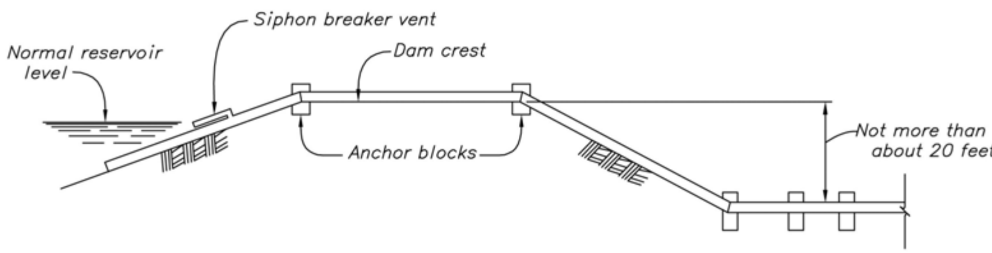

Figure 151.—A simple siphon constructed over the crest of an embankment dam.

each other may cause problems at the intakes of the siphons. Air may be sucked into the siphon pipe, causing the vacuum to be lost.

The advantages of a siphon include:

- The installation of a siphon can be performed in a relatively short amount of time.
- A siphon can be constructed with automatic operation to eliminate the need for frequent manual manipulation.
- The reservoir does not have to be completely drained. Maintaining a partial pool allows for the maintenance of some of the aquatic habitat.
- A siphon allows for the removal of cool water from relatively deep areas within the reservoir to promote cold water fish habitat downstream. In areas where trout populations are threatened by high water temperatures, a siphon can be used to combat the rise in stream temperature.

- Specialty contractors are not required, if quality engineering oversight is available during construction.

The disadvantages of a siphon include:

- Inability to handle flows greater than the designed capacity even though design head exceeds the design level.
- Inefficient flow at heads below 1 to 1¼ times the diameter of the pipe, causing more frequent fluctuation in the water surface when compared to pipe-and-riser spillways.
- Not cost effective (or, in many cases, feasible) for large watersheds. Generally limited to small drainage basins with relatively small peak inflows.
- A siphon designed for automatic operation may require excavation into the embankment dam to locate it below the anticipated reservoir water level.
- If the siphon extends above the reservoir water level, it will require some means of initiating the siphonic action.
- Can be susceptible to vandalism unless protective measures are taken.
- Inability to drain the entire reservoir and limited ability to drain reservoir deeper than about 20 to 25 feet.
- Some underwater work may be required for construction of the siphon.
- A siphon is not recommended in colder climates. Siphons are susceptible to blockage with ice unless special provisions are implemented during design and construction. Siphon piping may require removal from the reservoir during winter to avoid damage from ice loadings. Otherwise, the ice surrounding the siphon may have to be broken up daily.
- The theoretical lift on the upstream side of the siphon is less for sites at higher elevations compared to those at sea level.
- Best suited for low head operations to avoid cavitation potential.
- Storms or snow may prevent site access for personnel to operate the siphon.

For examples of siphons constructed at embankment dams, see the Crossgate and Sugar Mill Dams case histories in appendix B.

11.4.2 Pumping

Pumping of the reservoir water can be used to drain relatively small reservoirs. A single or a series of high capacity (e.g., 3,000-gal/min) portable pumps can be delivered to the damsite to assist in draining of the reservoir. The pumps can be positioned in the spillway entrance or on the embankment dam crest (figure 152) and allowed to discharge into the spillway or outlet works, or the pump can be placed over and down the downstream face of the embankment dam to the downstream toe. At the discharge end of the pumps, the area should be properly protected to ensure that the discharging does not cause erosional damage.

Pumps are usually self-contained and trailer or skid mounted. They can usually be rented in nearby major metropolitan communities, or they can be delivered and set up by the supplier. State or local flood control agencies may be another readily available source for high capacity pumps. Pumps are typically gasoline, diesel, or electrically powered. If electrically powered, a reliable electrical source should be available at the damsite. Purchasing pumps requires continuing maintenance on the pump and has a greater one-time expense compared to renting. Purchase may be justified for remote locations or to fulfill other needs for a high capacity pump by the dam owner, especially if one pump can service multiple dams. See the Balman Reservoir Dam case history in appendix B for an example of using a pump to evacuate a reservoir.

Another consideration with pumps is the limited net positive suction head available, (NPSHA) which essentially is the atmospheric pressure less any suction line friction losses and the height of the lift. To avoid cavitation, all pumps are rated with a net positive suction head required (NPSHR). If the NPSHA does not exceed the NPSHR, the pump will not operate. Also, as the NPSHA approaches the NPSHR, the pump capacity decreases. Placing the pump as close to the reservoir water surface as possible and using large diameter suction lines to minimize friction loss maximizes pump capacity. For reservoirs deeper than about 15 to 20 feet, pumps located on the dam crest or spillway crest may not be able to totally drain the reservoir because the height of the lift from the water surface to the pump by itself exceeds the NPSHA when reservoir levels are down, unless the pump can be moved along with the receding reservoir water surface. Because of the potential for complications caused by terrain and reservoir sediments, the frequent movement of trailer-mounted pumps may not be practical. However, floating pumps are available for these situations but are usually more expensive and probably not as available for rent as trailer-mounted units.

Totally draining the reservoir is usually not necessary to successfully evacuate the reservoir to levels that mitigate embankment dam failure. Usually, only a portion of the total reservoir requires evacuation to stop or control the erosion processes occurring within the embankment dam.

Figure 152.—All available resources may need to be utilized to drain the reservoir in an emergency. Here, the local fire department assists in draining a lake during a thunderstorm after the 45-year old CMP spillway collapsed.

11.4.3 Removal of the inlet structure (tower or riser pipe) of a drop inlet spillway conduit

If the existing spillway conduit can safely accommodate flowing water (e.g., it is in good condition), it may be possible to provide a limited amount of reservoir drawdown by carefully removing a section of the upper portion of the inlet structure and allowing the reservoir to drain out through the existing spillway. This method is best suited for low hazard embankment dams with small diameter riser pipes. To accomplish this method, the riser is removed in stages. For example, a CMP riser pipe can be removed in sections using an abrasive "cutoff saw" or hydraulic shears to cut vertical slots in the upper few inches of the riser followed by bending the metal wall downward. The reservoir should be allowed to drop to a safe level prior to removing additional sections of the riser.

If the riser can be temporarily isolated from the reservoir with a portable cofferdam, a torch can be used to remove the upper portion of the riser. This procedure was used to lower the pool of an embankment dam in Maryland by about 1.5 feet (figure 153). Care must be taken when removing the inlet structure to ensure that the materials being removed do not fall into and plug the spillway conduit, and debris does not enter the conduit (figure 154).

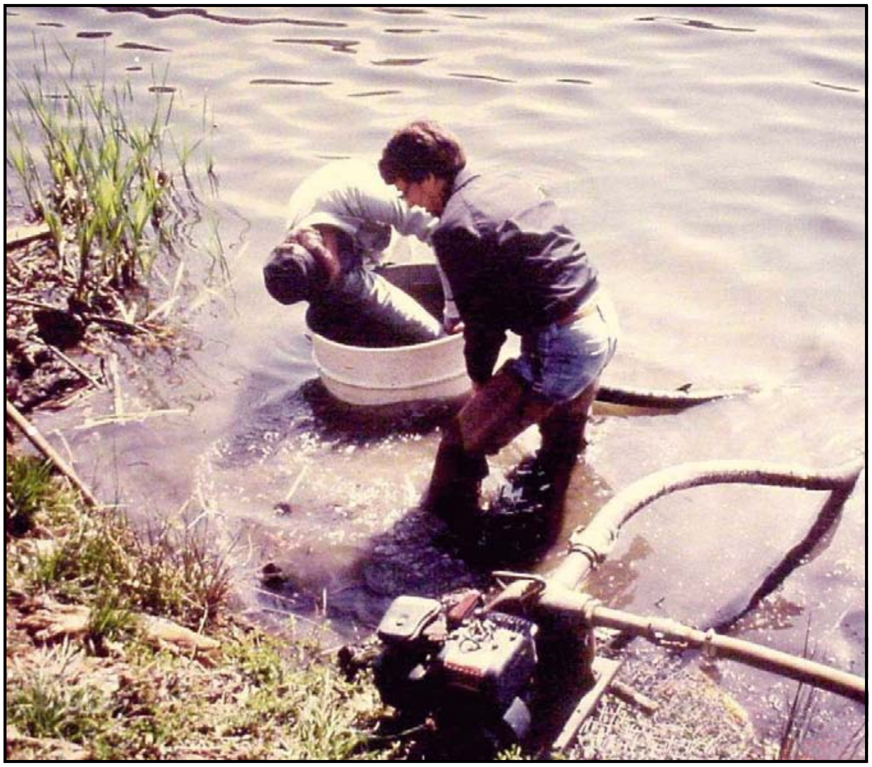

Figure 153.—The upper portion of a small metal pipe riser structure was removed with an acetylene torch. The riser was isolated from the pool by surrounding it with a large drum pressed into the soil. A pump was used to remove the water between the drum and the riser so that the work was completed in the dry.

Figure 154.—Care must be taken to ensure that debris does not clog spillway after removal of the riser.

11.4.4 Removal of the control structure of the spillway (concrete spillway)

The concrete control structure/weir of an existing spillway can be partially or fully removed to facilitate the lowering of the reservoir in the event of an emergency. The concrete control structure is typically used in earth cut spillways as a grade fill. If blasting is employed to remove the concrete, caution should be taken to ensure that the blasting does not cause additional damage to the embankment dam or foundation. Controlled blasting techniques with minimum particle velocities can be used effectively to remove the concrete structure. Figure 155 shows a concrete control structure being partially breached to allow for lowering of the reservoir.

11.4.5 Excavation of a trench through an earthcut spillway

For embankment dams with an earthcut spillway channel or emergency spillway at one of the abutments, a trench can be excavated through the discharge channel to deepen and/or widen the existing spillway discharge channel. Care should be employed to ensure that water being released through the new channel does not cause erosional headcutting of the channel, resulting in an uncontrolled larger-than-planned reservoir release. The trench should be excavated down to or into erosion-resistant materials, if possible. If not, the excavated channel should be protected by placing erosion-resistant materials in the channel, such as rock riprap, concrete rubble (if temporary), sandbagging, plastic sheeting, or geotextiles. The materials should be properly placed in the channel and stabilized to prevent the materials from being washed away. If sandbagging is used in high velocity flows, the sandbags should be placed beginning near the edge of the flow, where the velocities are low, and working toward the high velocity area. The largest sandbag possible should be used, and the ends of the bags should be securely fastened so that material is not washed out.

11.4.6 Excavation of a spillway through the embankment dam abutment

Similarly to excavating a channel through an existing earthcut spillway, a trench can be excavated through the abutment of the embankment dam (figure 156) to provide emergency release of the reservoir, if required. The trench should be properly located to ensure that uncontrolled releases of the reservoir through the channel do not encroach upon the embankment dam and cause an unanticipated breaching of the embankment dam. Care should also be employed to ensure that the excavated channel does not cause larger-than-anticipated flooding downstream of the embankment dam. Construction and cautions similar to those mentioned in the previous section for the excavation of a trench through an existing earthcut spillway should be employed.

Figure 155.—Spillway being partially breached to lower the reservoir.

Figure 156.—The owner of this embankment dam excavated a channel around the dam to prevent its overtopping during a hurricane.

11.4.7 Controlled breach of the embankment dam

A controlled breach of the embankment dam is an alternative means that can be considered to lower the reservoir to a safe level in the event of an emergency at a dam. The embankment dam can be partially or fully breached, depending on the situation or configuration of the dam. The breach location should be carefully selected. Consideration should be made to locate the breach where it can be controlled, the height of the embankment dam is the shortest, and the downstream consequences will be low. Local emergency responders should be involved with all planning for the breach, including any evacuation of the downstream population.

The breaching of the embankment dam should be done in stages and in a controlled manner to ensure that a catastrophic failure of the embankment dam does not occur, causing unanticipated and unwanted downstream property damage or loss of life (figure 157). First, a discharge channel should be excavated down the embankment downstream face or abutment area to convey the discharging water safely to the downstream channel. This channel should be excavated down to or into erosive-resistant materials, if possible. If not, the excavated channel should be protected by lining the channel with erosion-resistant materials, such as rock riprap, concrete rubble (if temporary), sandbagging, plastic sheeting, or geotextiles. The embankment dam can then be breached in a slow and staged operation. The embankment dam is first excavated down to a point that will allow a predetermined maximum amount of water to flow through the breach. The initial flow of water through the breach should be as minimal as possible and allowed to stabilize and diminish before removing another small portion of the embankment dam. The excavation of the embankment material should be kept at a minimal amount to limit the quantity of water discharging through the breach section at any time. This process can then be repeated until the desired breach dimensions have been obtained. If possible, a cofferdam should be upstream of the area to be breached, which serves to prevent a catastrophic failure, if the breached section begins to erode in an un controlled manner. See the Balman Reservoir Dam and Empire Dam case histories in appendix B for examples of controlled dam breaches to draw down reservoirs.

11.5 Gate or valve operational restriction

A gate or valve operational restriction is an emergency action used to lessen the risk associated with potential failure modes resulting from internal erosion or backward erosion piping, as discussed in chapter 7. The restriction is normally kept in force until the entire conduit is restored to a serviceable condition. The gate or valve operational restriction may require that the gate or valve not be operated at all or only be operated to such an opening as to keep the downstream conduit from pressurizing. The restriction typically applies to normal operating conditions. If an emergency arises requiring reservoir evacuation, the restriction could be removed.

Figure 157.—A controlled breach of an embankment dam begins after the 45-year old CMP spillway conduit collapsed and the lake level began to rise.

In addition to the gate or valve operational restriction, other supplemental actions should be considered, such as:

- The reservoir water level may need to be restricted below a certain water level. See section 11.6 for further guidance on implementing a reservoir restriction.
- A periodic monitoring program (i.e., weekly) may need to be implemented, which includes observation and documentation of the seepage outflow from the conduit. The upstream and downstream faces and the embankment dam crest above the conduit alignment should also be visually inspected.
- Periodic man-entry or CCTV inspections (i.e., annual, semi-annual) may need to be implemented to evaluate changing conditions with the conduit.
- The EAP may need to be implemented.
- The EAP may need to be updated to include specific discussion of the operational restriction.

11.6 Reservoir operating restriction

A reservoir operating restriction is not an emergency action, only an interim measure. A reservoir operating restriction requires that the reservoir be operated to maintain a water level below a certain elevation to reduce the risk of internal erosion or backward erosion piping of the embankment dam to an acceptable level of risk. The water level selected is typically lower than the normal water surface. The establishment of a reservoir operating restriction should consider not only the reduction of risk, but also potentially significant adverse impacts, such as:

- Limiting the operational flexibility of the reservoir.
- Reducing or severely curtailing water storage availability for project purposes.
- Severely compromising flood control operations.
- Endangering reservoir habitat.
- Sensitive and significant cultural resource sites may be exposed more frequently, as the reservoir is lowered, and subject to vandalism.
- During droughts, the reservoir could be severely reduced because of a lack of opportunity to store water as a buffer against drought.

A reservoir restriction should remain in place until dam safety modifications have been completed or until a review of additional performance data (i.e., seepage [weir] flows, piezometer data, settlement point data, and visual inspections) leads to other conclusions.

Chapter 12

Renovation of Conduits

The selection of the proper method for renovation, replacement, repair, or abandonment of a conduit is very site specific. Many factors go into the selection of the method to be used. This chapter will address design and construction considerations for the renovation methods. Chapter 13 discusses replacement of conduits, and chapter 14 discusses repairs and abandonment of conduits.

When evaluating older structures for renovation, the designer should proceed with caution. Previous designs may have utilized differing criterion or loadings compared to what is used in modern conduit design. The designer should consider materials available at the time of construction, and changes in material properties, design practices, and construction methods. For example, reinforcing bars used in reinforced concrete have undergone significant changes in the last 100 years. Yield strengths, allowable stresses, bar shapes (e.g., plain round, old-style deformed, twisted square), and splice lengths all have changed, compared to what is used today for modern structures. If original design information is not available, the designer will need to make conservative assumptions. The designer may find it beneficial to consult references that contain information on old design and construction methods. An example of this type of reference would be the ACI Detailing Manuals (available since 1947) (Concrete Reinforcing Steel Institute, 2001, p. 2). The designer could utilize these manuals to determine typical reinforcement details commonly used during the period of design.

The understanding of a historical timeline can often assist the designer with identifying conduits that may remain relatively free of long term deterioration and those that may require actions for renovation, replacement, or repair. Typically, timelines cannot specifically identify exact dates or structures when changes in methods or materials may have occurred because most of the available information is based upon a collective understanding that evolved over a period of time. Available timelines in many cases may be agency specific. An example of a historical timeline developed by Reclamation is illustrated in figure 158. This timeline was developed based on significant events that have occurred in regards to their experience with concrete technology. Using a timeline such as this, if the designer knows the approximate date of construction for a particular conduit, a preliminary assessment of its likely condition can be made.

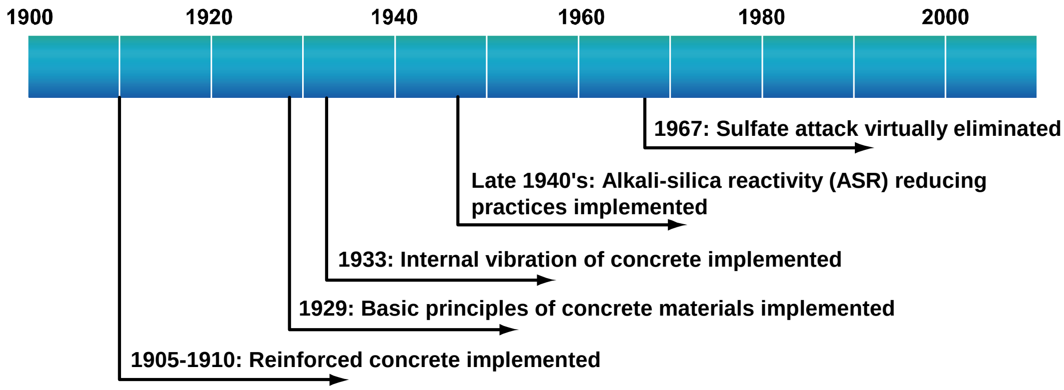

Figure 158.—An example of a historical timeline that can assist the designer in evaluating the condition of a conduit.

The nation's inventory of embankment dams and the conduits within them are aging and deteriorating. Many conduits require renovation to avoid potential embankment dam failures. Many of these conduits are too small to enter for construction activities while renovating them to address this deterioration issue. Traditionally, removal and replacement of the entire conduit has been one of the most frequently pursued alternatives, but one which can be very costly and time consuming. Removing and replacing the entire conduit requires excavation of a large portion of an existing embankment dam. Removal and replacement typically requires draining of the existing reservoir resulting in significant economic impacts. The large excavation of the embankment dam leads to safety concerns for the downstream population while the dam is in the breached condition, and concerns for the development of seepage and erosion within the recompacted earthfill en closure section (Cooper, Hall, and Heyder, 2001, p. 2).

In recent years, renovation has become a popular means of avoiding the traditional removal and replacement method. Methods for renovation include a variety of "trenchless technologies." The term trenchless technology applies to the renovation of existing conduits without requiring complete excavation (open-cut) over the alignment of the conduit. Trenchless technology is rapidly evolving in response to the introduction of new materials, products, and installation systems (USACE, 2001d, p. 3). The users of this document are urged to always refer to the latest manufacturers' recommendations when considering trenchless technology.

The most common renovation method is sliplining. Sliplining involves pulling or pushing a pipe of smaller diameter into the existing conduit and grouting the annulus. Flexible plastic and steel pipe has been successfully utilized for sliplining. Another method that has been used in limited applications is plastic cured-in-place pipe lining. This involves the insertion of a membrane into the existing conduit, which is then cured in place, forming a closely fitting plastic pipe within the existing conduit. See chapter 2 for discussion of materials used in the design and construction of conduits.

12.1 Sliplining

Sliplining an existing conduit through an embankment dam generally consists of installing a new, smaller-diameter pipe into the conduit. The annulus between the new pipe and the existing conduit is grouted. New entrance and terminal structures are sometimes constructed if the existing structures were deteriorated or were required for removal to facilitate installation of the slipliner. Also, a filter diaphragm or collar is constructed around the downstream portion of the existing conduit.

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

- *Excavation.*—Excavation of the embankment dam is minimized. However, some excavation may still be required on the upstream and/or downstream face of the embankment dam for removal and replacement of the entrance and terminal structures and for installation of the filter diaphragm or collar.

- *Maintain reservoir level.*—In some situations (i.e., conduit has upstream control), the reservoir can be maintained at its normal water surface, if the slipliner can be installed from the downstream end of the conduit.

- *Construction.*—The construction time is usually less, reducing impacts to downstream users.

- *Costs.*—Construction costs for sliplining are generally less than for other conduit renovation or replacement methods.

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

- *Deteriorated conditions.*—Sliplining is not appropriate for existing conduits in a significantly deteriorated condition or where the surrounding embankment has been damaged by internal erosion or backward erosion piping.

- *Alignment limitations.*—For inaccessible conduits, sliplining is generally limited to straight conduits. However, in certain situations, sliplining may be applicable for conduits with minor changes in alignment. If the conduit is accessible by man-entry, bends can usually be accommodated by using short sections of pipe.

- *Specialized contractors.*—Specialized contractors are needed sometimes for installation of the sliplining and grouting of the annular space.

- *Loss of reservoir.*—The reservoir is typically drained to provide upstream and downstream access to the conduit.

If the existing conduit has experienced significant deterioration or damage, further consideration is required before proceeding with sliplining. Further consideration should include:

- *Collapse.*—If the existing conduit appears to be on the verge of collapse, this may be an indication of considerable disturbance or movement of material outside of the conduit.

- *Seepage.*—The greater the seepage flow, the more concern that the flow regime could change considerably after sliplining, which could affect safety of the embankment dam. A change in the flow regime could force seepage to flow along the exterior of the conduit. Any evidence that the seepage is under pressure from the reservoir head should be a consideration for replacement of the existing conduit in lieu of sliplining.

- *Location.*—The location of any deterioration or damage within the existing conduit should be evaluated. Seepage upstream of a filter or impervious core may not be as much of a concern as seepage downstream of these features.

- *Void.*—If a void exists behind an opening in the existing conduit, the conduit should probably be considered for removal and replacement. However, some consideration should be given to where the void is located (near the intake structure is less problematic than near the embankment dam centerline). If the void does not seem to be associated with much seepage flow, this could be more of an indication that the void could be the result of erosive forces from the discharges through the existing conduit and that sliplining may be an option. In some cases, it may be possible to fill the voids with grout. Sliplining of the existing conduit may not be economical, if extensive grouting of large voids along the outside of the conduit will be required prior to inserting the HDPE slipliner. The costs involved should be compared to those required for removal and replacement of the conduit.

- *Deterioration process.*—If deterioration of the existing conduit is caused by a corrosive process, then the useful life expectancy of the existing conduit should be evaluated based on the knowledge that deterioration will continue. Generally, the slipliner should be designed to accommodate all internal and external loadings without any support provided from the deteriorating conduit. If the existing conduit is expected to provide support for the new slipliner, and the life expectancy of the existing conduit is less than the life of the project, then removal and replacement should be considered (figure 159).

Figure 159.—The holes in this CMP conduit were clearly visible after removal. The conduit was considered to be so severely corroded that sliplining was not an option and it was removed and replaced. Photo courtesy of Maryland Dam Safety Division.

12.1.1 Thermoplastics

The guidance provided in section 12.1.1 mainly pertains to sliplining of inaccessible conduits. The reader should understand that if the conduit is accessible by man-entry, variance from this guidance will be required.

The most commonly used thermoplastic for sliplining is smooth walled HDPE pipe. PVC pipe has been used in limited applications for sliplining, but has a number of disadvantages as discussed in section 2.2.1. For this reason, only HDPE pipe will be discussed in this chapter. HDPE pipe used for sliplining should meet the requirements of ASTM D 2447, D 3035, and F 714.

Additional design and construction guidance is available from other sources, such as CPChem's *The Performance Pipe Engineering Manual* (2003), NRCS's *Structural Design of Flexible Conduits* (2005), Plastic Pipe Institute (PPI) *Handbook of Polyethylene Pipe*, and the upcoming FEMA-sponsored "best practices" guidance document for plastic pipe used in dams (expected publication date, 2006).

12.1.1.1 Design considerations

The designer must evaluate a number of design parameters when considering HDPE pipe for use in sliplining. A few of the most significant design parameters include:

- Seepage paths

- Service life
- Initial inspection of the existing conduit
- Selection of the diameter and thickness
- Thermal expansion/contraction
- Stress cracking
- Joints
- Flotation
- Entrance and terminal structures

These parameters are further discussed in the following paragraphs. On a case-by-case basis, the designer may need to consider additional parameters depending on the performance criteria and design requirements of the specific application.

Seepage paths.—When an HDPE slipliner installation eliminates seepage into the conduit, the flow patterns within the surrounding embankment are changed and other undesirable seepage paths may develop. Any existing seepage paths may experience an increase in flow. For instance, if an existing deteriorated conduit has acted as a drain and reduced the phreatic surface within the embankment dam, the phreatic surface may increase and force flow through the dam, (along the exterior of the existing conduit) after slipliner installation. This seepage and the potential for internal erosion or backward erosion piping along the conduit must be addressed by installing a filter diaphragm or collar at the downstream end of the existing conduit. The filter diaphragm or collar should be designed to prevent migration of the fines in the embankment dam and should be placed around the entire circumference of the existing conduit. For guidance on the design and construction of the filters, see chapter 6.

Service life.—The service life for HDPE pipe is a function of the stress history of the pipe. A typical design calls for a 50- to 100-year service life.

Initial inspection of the existing conduit.—A thorough inspection of the existing conduit is required prior to selecting the diameter of the HDPE slipliner. Depending on the diameter of the existing conduit, man-entry or CCTV inspection methods should be used; see section 9.5.2 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 movement of embankment materials should be determined. The existence of any deflections, protrusions, or irregularities in the existing conduit will control the selection of the slipliner diameter. The pulling or pushing of a template (figures 160 and 161), inflatable pipeline sphere, or soft (typically open cell polyurethane foam) pig (figure 162) through the existing conduit is recommended. This will also ensure that sliplining can be done without difficulty.

Selection of the diameter and thickness.—The selection of the diameter and thickness of the HDPE slipliner should consider the following factors:

- *Size and condition of the existing conduit*.—The size of the existing conduit limits the diameter of the HDPE slipliner. Further, if the existing conduit has any protrusions or obstructions (i.e., deflection, joint offsets), the diameter of the HDPE slipliner may need to be made smaller to accommodate these restrictions.

- *Discharge requirements*.—At maximum full open operation, the HDPE slipliner should not flow greater than 75 percent full (i.e., 75 percent of the inside diameter) at the downstream end, to minimize the risk of surging or pressure flow developing in the conduit. Pressurized HDPE slipliners are not recommended for significant and high hazard embankment dams. However, an alternative to single wall HDPE pipe is available. This involves the use of a dual wall containment pipe; see the discussion later in this section for further information.

  HDPE pipe is very smooth. While the insertion of a new HDPE slipliner results in a smaller flow area, the reduced friction of the water passing through the slipliner results in only minimal losses of hydraulic capacity, if any. Typically, a new, smaller diameter HDPE slipliner has a hydraulic capacity equal to or greater than the original conduit. For example, the Manning's "n" value for smooth walled HDPE pipe is 0.009, compared to 0.010 for steel, 0.013 for concrete, and 0.022 for CMP.

- *Clearance requirements for grouting of the annulus between the existing conduit and the HDPE slipliner*.—To maintain sufficient clearance during the sliplining process, the outside diameter of the slipliner should be at least 10 percent smaller than the inside diameter of the existing conduit (ASTM F 585). This clear dimension between the interior surface of the existing conduit and outside surface of the slipliner allows for problem-free installation and grouting of the annular space. The designer needs to verify that the clear dimension will accommodate grout and vent pipes, when selecting the outside diameter of the HDPE slipliner.

- *Internal and external loadings*.—Conservatively, the HDPE slipliner should be designed with the assumption that the existing pipe continues to deteriorate after renovation is completed and will provide no support. For this reason, the

Figure 160.—Crossbar template attached to a CCTV camera-crawler to check for irregularities in the CMP conduit.

Figure 161.—A horseshoe shaped template used for checking irregularities in a conduit. The template is attached to the CCTV camera-crawler.

Figure 162.—A styrofoam pig used for checking irregularities in a conduit.

HDPE slipliner should resist all internal and external loadings. Internal loadings consist of water pressure and vacuum. If calculations show that the HDPE slipliner is susceptible to internal vacuum pressures, provisions should be made in the design to provide a means of letting air (i.e., air vent or an air valve) into the HDPE slipliner just downstream of the gate or valve. If the HDPE slipliner will have a downstream control gate or valve and is designed to be pressurized, the designer should consider the possibility that the gate or valve can be closed rapidly and cause water hammer. Good practice requires a properly designed gate or valve to have a closure rate that prevents the development of surge pressures within the HDPE slipliner. External loadings consist of soil and hydrostatic. In some situations, construction loadings from construction traffic and grouting may need to be analyzed. The designer should evaluate potential modes of failure consisting of wall crushing, buckling, and deflection.

Thermal expansion/contraction.—HDPE pipe has a relatively high linear coefficient of thermal expansion. For the temperature range between 22 and 86 °F, the linear coefficient of thermal expansion for HDPE pipe (9.0×10^{-5} in/in x °F) is high compared to steel (6.7×10^{-6} in/in x °F). In designing an HDPE slipliner, means of addressing thermal expansion/contraction should be considered. In a buried application, such as a conduit, the temperature variation is usually small due to the insulating effect of the surrounding embankment on the conduit.

After the HDPE slipliner is placed within the existing conduit, time should be provided for its temperature to equalize prior to grouting. Typically, 24 to 48 hours should be adequate. However, the designer should use their own judgement and allow for additional equalizing time when installations occur during periods of extreme temperatures. Circulating water in the slipliner can assist with the temperature equalization process. Nighttime installation may be another option to consider to reduce the effects of extreme temperature.

The use of upstream and downstream end restraints on the HDPE slipliner will limit expansion/contraction. Once the HDPE slipliner is grouted in place, it should undergo little expansion/contraction. This is largely due to the low modulus of elasticity of the HDPE pipe. The HDPE slipliner may try to expand, but in a restrained condition it cannot mobilize forces of the magnitudes required to cause expansion movement. Since HDPE pipe does not bond with the grout, the resistive forces are largely from the friction along the HDPE pipe/grout interface. Therefore, thrust-accommodating end structures are generally not required for HDPE sliplined conduits.

Stress cracking.—HDPE pipe failures are often attributed to the effects of environmental stress cracking (also called slow crack growth). This phenomenon can occur during the handling or installation of HDPE pipe. The HDPE pipe could be gouged, scratched, or kinked, resulting in a weak spot on the pipe wall. Subsequent operations of grouting the HDPE pipe or pressurizing the conduit result cracking of the weakened section. Specifying HDPE pipe made with ASTM D 3350 cell classification 345464C grade resin provides the highest level of resistance to slow growth cracking and can negate the possibility of this type of failure. This ensures a virgin, high-grade, very stiff resin which has been found highly resistant to environmental stress cracking. Other grades of resin often contain some percentage of low-grade recycled resins.

Joints.—The most common method used to join HDPE pipe is heat fusion (ASTM D 2657). This method is also known as butt fusion. The butt fusion technique is a widely used and industry-accepted heat fusion method for joining sections of smooth solid walled HDPE pipe. This method produces a joint that is watertight and is as strong or stronger than the HDPE pipe material itself, if performed correctly. A special machine (figure 163) is used to trim the ends of the pipes (facing or squaring off), align the ends of the pipe, heat both ends of the pipes to about 400 to 450 °F, and force the ends together under pressure. The melt bead size required for the thickness and diameter of the HDPE pipe determines how much pressure and time is needed for fusion of the joint. About 1 hour should be allowed for the joint to adequately cool after completion of the fusion process (figure 164). Trial fusions should be considered at the beginning of the day, so the fusion procedure and equipment settings can be verified for the actual jobsite conditions. Manufacturer's recommended procedures should always be observed for heat fusion.

Figure 163.—HDPE pipe joint being fusion welded.

Figure 164.—Finished fusion welded joint.

A small bead (figure 165) is formed where the melted material is extruded from the joint. Beads appear on both the inside and the outside of the HDPE pipe. The need for bead removal is uncommon, but can be accomplished using special tools after the joint has throughly cooled to ambient temperature. If removal is necessary, the personnel using the debeading tool should be properly trained, so the HDPE pipe is not needlessly gouged. The existence of the interior bead has a negligible impact on the hydraulic performance of the slipliner. A bead exists on the exterior surface of the joint. If proper annulus clearance is provided by the designer, this should not affect slipliner insertion or the grouting process. The beads should be throughly inspected for uniformity and proper size around the entire joint. Visual inspection is usually adequate; however other methods, such as radiographic or ultrasonic methods, can be used. The use of fusion machine operators who are skilled, knowledgeable, and certified by the manufacturer will produce a good quality joint. Improperly heat fused joints cannot be repaired and must be cut out, and the ends

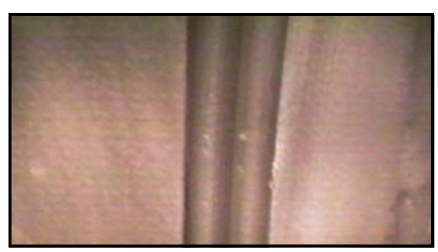

Figure 165.—Interior view of finished joint bead.

must be properly joined (ASTM D 2657). Upon completion of the repair, the HDPE slipliner should be retested for leaks.

Unlike bell and spigot pipe, such as PVC, heat fusion creates a continuous joint-free pipe of nearly constant outside diameter. Bell and spigot joints are susceptible to separation as the embankment dam settles. Because the HDPE slipliner joint does not take up a large part of the original conduit, a larger inside diameter slipliner can be used. This is an advantage when compared to flanged joints.

During cold weather, additional time is required to warm up the fusion machine and to heat the ends of the HDPE pipe. A shelter (figure 166) may need to be constructed for joining the sections of HDPE pipe in case of inclement weather. For additional cold weather procedures, see ASTM D 2657.

Other joining methods for HDPE pipe include:

- *Joints made by extrusion welding.*—Many prefabricated fittings (i.e., elbows, bends, and tees) can be joined to the HDPE slipliner with heat fusion (ASTM D 3261) in the field using an extrusion gun. The extrusion gun (figure 167) is a hand held extruder that preheats the surface of the HDPE pipe and feeds a molten bead of polyethylene into the joint. Extrusion-welded joints are not as strong as butt fusion joints. Proper training is required for using the extrusion gun. Extrusion welding has been successfully used for connecting HDPE grout

Figure 166.—Cold weather shelter constructed for joining sections of HDPE pipe.

Figure 167.—Hand held extrusion gun.

Figure 168.—HDPE grout pipe attached to HDPE slipliner.

and air vent pipes to the slipliner (figure 168). Extrusion welding cannot be used to repair damaged HDPE pipe.

- *Mechanical joints*.—The most common mechanical joint is the flange adapter. Flanged connections are often used to connect HDPE pipe to steel pipe. The flange adaptor consists of a stub end, which is typically butt fused to the HDPE pipe, and a flanged end, which is joined with bolts and nuts to the flanged end of another pipe. Flanged connections allow for easy assembly and disassembly of the joint. Flange joints tend to require more annular space than butt fusion joints.

- *Other joints*.—Some HDPE pipe products have integral threads or snap joints that allow sections to be easily joined without special equipment. However, these should only be used for nonpressurized applications in low hazard embankment dams due to the potential for pullout. Some types of plastic pipe use gasketed or glued bell and spigot joints. HDPE pipe cannot be joined by threading or solvent bonding.

Flotation.—When grouting an HDPE slipliner within an existing conduit, it is likely that the slipliner will "float" or be displaced upward by the fluid pressure of the grout in the annulus between the existing conduit and slipliner. Due to the relatively light weight of HDPE pipe, floatation can be more pronounced with this material. Floating of the slipliner may not allow for grout to completely encase the HDPE pipe and therefore reduce the overall strength of the structure. Floatation can also result in vertical misalignments, which may alter the hydraulics of a conduit, especially one that would flow under open channel conditions.

Steps should be taken to address this floating potential, such as using spacers or blocking between the existing conduit and the slipliner. Figure 169 shows an example of spacers being attached to the HDPE slipliner by extrusion welding. Some manufacturers have recommended that the HDPE pipe be filled with water to reduce flotation of the pipe during grouting. However, this does not always prevent flotation, because water is not as dense as the surrounding grout, and blocking is still necessary. Other manufacturers strongly advise against filling the HDPE pipe with water and instead recommend properly installed blocking and staged grouting.

HDPE pipe is flexible and can conform to alignment changes; therefore, a larger HDPE section is more applicable than a rigid slipliner section, such as steel. This tends to greatly minimize the potential distance an HDPE slipliner can float (i.e., by reducing the size of the annulus) and reduces the potential adverse effects of any displacement. One caution is that since the HDPE slipliner is more flexible, it may require more spacers than a rigid liner for the same span lengths, to control floatation, and provide sufficient room to fully encase the liner. However, if the alignment in the existing conduit varies, then the flexible liner will adapt more easily to the alignment, but will still require sufficient spacers to ensure adequate encasement. Spacers extending the full length of the HDPE slipliner are not recommended. Spacers should be designed to allow grout to fill the annulus between the existing conduit and the HDPE slipliner. The type and spacing of spacers will vary depending on the standard dimension ratio (SDR) of the HDPE slipliner and should be based on the recommendations of the HDPE pipe manufacturer.

Entrance and terminal structures.—The sliplining of an existing conduit may require partial or full removal and replacement of certain structures to improve release capabilities or to facilitate construction. Figure 170 shows an intake structure

Figure 169.—Spacers being attached to an HDPE slipliner using an extrusion gun.

Figure 170.—The intake structure has been removed as part of a conduit renovation.

that has been removed as part of outlet works renovation involving sliplining. For guidance on the design and construction of entrance and terminal structures, see section 3.4. Specially fabricated steel transitions are sometimes used at the critical upstream end of a conduit being sliplined with HDPE pipe. The transition and HDPE pipe are connected using a flanged joint.

12.1.1.2 Construction considerations

The designer must evaluate a number of construction parameters when considering HDPE pipe for use in sliplining. A few of the most significant parameters include:

- Sample testing and certification
- Handling and storage
- Installation
- Repairs to the HDPE slipliner prior to or during the insertion process
- Grouting
- Postinspection and acceptance
- Maintenance and repair of the completed HDPE slipliner
- Alternatives to sliplining existing conduits with solid walled HDPE pipe

These parameters are further discussed in the following paragraphs. On a case-by-case basis, the designer may need to consider additional parameters, depending on the construction requirements of the specific application.

Sample testing and certification.— Manufacturer's certification should be furnished prior to any shipment of HDPE pipe to the worksite. The certification provides proof that the HDPE pipe was manufactured, sampled, tested, and inspected in accordance with ASTM F 714 and meets the requirements. More details can be obtained by requesting the actual test data from the manufacturer. Not all HDPE pipe is tested; manufacturers may only test certain lots of pipe or perform testing at regular, scheduled intervals.

Handling and storage.—HDPE pipe is much lighter than steel or concrete pipe and generally does not require heavy lifting equipment. HDPE pipe is shipped in longer lengths than steel or reinforced concrete pipe due to its lighter weight.

HDPE pipe should be carefully handled and stored according to all of the manufacturer's recommendations. The manufacturer often ships handling instructions with the HDPE pipe. Cold weather handling precautions should be used to eliminate any impacts on HDPE pipe when temperatures are at or below freezing to avoid fracturing of the pipe. Handling of HDPE pipe when the temperature is below -10 °F is not recommended. The pipe should not be dropped or allowed to be dumped when off-loading. Strap slings should be utilized for straight HDPE pipe and the use of chains and hooks should be avoided. Lifting points should be well spread and evenly spaced. The HDPE pipe should be fully inspected at the time of delivery, with any defects noted. The HDPE pipe should be stacked on firm, flat ground, adequately supported, kept away from heat sources, and kept in original protective packaging until used. Pipes should not be stacked higher than five units or 10 feet, whichever is less. Stacking pipe with differing wall thicknesses and pressure ratings should be avoided. Testing has shown that unlike PVC, HDPE pipe does not become brittle under exposure to ultraviolet (UV) radiation. This resistance to UV radiation is the result of the small percentage of carbon-black which is added to the HDPE pipe material during the manufacturing process. Since virtually all conduits are buried, such exposure is generally minimal.

Installation.—HDPE pipe is a flexible material and, as such, can easily accommodate minor changes in vertical and horizontal alignment of the existing conduit being lined. Guidance on sliplining installation includes:

- *Preparation of existing surfaces*.—The existing conduit surfaces that grout will be placed against need to be free of roots, sediments, mineral deposits, dust, latence, loose or defective concrete, curing compound, coatings, and other foreign materials. 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. See section 9.6 for guidance on cleaning conduits.

  A thorough inspection of the existing conduit is required prior to installing the HDPE slipliner to ensure that no obstructions remain that may hinder slipliner insertion. Prior to slipliner insertion, a soft pig or inflatable pipeline sphere of the same diameter as the HDPE pipe should be pulled through the existing conduit to check for proper clearance. Consideration should be given for adequate spacers and grout pipes to be attached to the HDPE slipliner.

- *Leak testing of joints*.—Hydrostatic testing of the joints is required and should be done prior to installation, using a sustained pressure test to find leaks in the HDPE slipliner. Prior to performing the hydrostatic test, the slipliner should be properly restrained from movement. Depending on the limits of the testing equipment, the entire length of HDPE slipliner can be tested at one time or the test can be separated into shorter sections. If a leaking joint is found, it will need to be cut out and a new section of HDPE pipe installed and the ends of the pipe heat fused together. Further guidance on leak testing is provided in CPChem's Performance Pipe Technical Note 802 (2002) and ASTM F 905.

- *Access and insertion*.—HDPE pipe is light in weight relative to more traditional pipe materials, and as such is easier to insert into existing conduits. Pulling, pushing, or a combination of both are the typical methods for slipliner insertion. Backhoes, bulldozers, and winches have been used to assist with the slipliner insertion (figure 171).

  The HDPE slipliner should be inserted following an approved installation plan, manufacturer's recommendations, and ASTM F 585. Sufficient work area must be available at the downstream toe of the embankment dam for insertion of the slipliner. For small embankment dams, smooth walled HDPE pipe sections can be fused into one long section on the crest of the dam and transported to the downstream toe. The HDPE slipliner is then inserted into the downstream end of the conduit and simply pushed upstream. For larger embankment dams, access to both the upstream and downstream portals should be obtained, so the fused sections of HDPE pipe can be pulled through the existing conduit with the use of a special pulling head attached to the slipliner.

  The pulling head design is based upon the axial pulling (tensile) stress. The axial pulling stress can be estimated by dividing the force of the pull load by the

Figure 171.—Insertion of an HDPE slipliner into an existing concrete conduit. A backhoe is being used to assist with slipliner insertion.

cross-sectional area of the pipe wall thickness. The pulling load is a function of many variables, such as the weight of the slipliner and frictional drag. A variety of pulling head configurations are possible, depending upon the application. Approved manufacturer pulling head recommendations should be followed.

The nose cone pulling head (also known as the banana nose or soft nose) is a simple and cost effective configuration to use where the pulling stress on the HDPE slipliner is less than 700 lb/in^2. The nose cone pulling head is made from a few extra feet of HDPE pipe that has been fused onto the slipliner. Evenly spaced wedges are cut into the leading edge of the pulling head. A couple of alternatives exist for the nose cone configuration: (1) the wedges are collapsed towards the center to form a cone and fastened together with bolts. A pulling cable is attached to secondary bolts that extend across the collapsed nose (figure 172) and (2) holes are drilled through the wedges and cables or narrow plates are attached to the wedges. The cables or plates are attached to a pull ring (figure 173).

If the sliplining application requires higher pulling stresses, the manufacturer should be consulted for specialty pulling head configurations. Fabricated mechanical pulling heads are available.

Blocks of wood or other material (called blocking or bridging) should be attached to the top of the HDPE slipliner, so that the slipliner will not contact the top of the existing conduit. Once the slipliner insertion (figure 174) begins, it should continue without any stoppage until completion. The pulling method will result in some stretching of the HDPE slipliner (1 percent of the total length). The slipliner will also experience differential temperatures before and

Figure 172.—Nose of HDPE slipliner modified for pulling into an existing conduit.

Figure 173.—A nose cone configuration utilizing a pull ring.

Figure 174.—Insertion of an HDPE slipliner into an existing CMP outlet works conduit.

after insertion, which will affect the length of the slipliner (1 in./100 ft/10 °F). Allowances for these changes in HDPE slipliner length need to be considered during insertion (figure 175). A 24-hour relaxation period is recommended to allow the slipliner to recover its length.

In some instances, a vertical riser pipe that is connected to the horizontal conduit may be required (typically associated with service or auxiliary spillways). The connection of the HDPE slipliner to a riser pipe can be somewhat difficult. A custom transition piece may need to be fabricated. Sometimes the riser can be removed and replaced with a new structure that facilitates a mechanical connection to the conduit slipliner.

<u>Repairs to the HDPE slipliner prior to or during the insertion process</u>.—Damage to the HDPE slipliner may occur from improper shipping and handling or from poor insertion technique. Damage can be in the form of kinks, punctures, breaks, or abrasion. HDPE pipe that undergoes this type of damage cannot be repaired, and the damaged section of pipe should be removed and replaced. The damaged section of HDPE slipliner should be cut out and a new section of pipe installed. The HDPE slipliner should be cut one pipe diameter on each side of the damaged area. The ends of the existing pipe and replacement pipe should be heat fused together.

Figure 175.—This gap shows that the designer did not adequately consider the potential for thermal expansion/contraction during installation of this HDPE slipliner. To avoid this problem, the HDPE slipliner should have been designed to extend beyond the end of the existing conduit.

Grouting.—Careful grouting of the annular space between the existing conduit and the HDPE slipliner is essential. This can be a complex process, requiring the experience of a qualified contractor. Full encapsulation for the entire length of the annulus rarely is achievable, and the HDPE slipliner is typically designed to withstand all internal and external loadings independently from exterior conditions. A lightweight, low density grout containing no aggregate will ensure the best result. The following guidance discusses the grout plan, mix design, sequencing, and injection:

- *Grout 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 the upstream and downstream ends should be submitted for review and approval prior to initiation of grouting operations.

- *Grout mix*.—The grout mix, consisting of water, cement, flyash, and chemical admixture must remain fluid and not thicken for at least 2 hours. Premature thickening of the grout will result in high injection pressures, and inadequate support of the HDPE slipliner.

  Cement meeting ASTM C 150, type II is generally considered acceptable for use in grout mixes for injection. Other types may be considered based on particular applications. The chemical admixture used will depend upon the type of injection application. High-range, water-reducing, shrinkage-compensating, plasticizing admixtures may be beneficial.

The grout should be tested in accordance with ASTM C 939. The design should specify mix design, density, viscosity, maximum injection pressure, initial set time, 24-hour and 28-day compressive strength, shrinkage, stability, and "bleed" or fluid loss. A minimum design compressive strength of 4,000 lb/in^2 at 28 days is generally acceptable.

The grouting contractor must have dependable equipment of a size that will allow the grouting to be done quickly. The contractor must also have backup equipment available and ready at the site. Any grout not used after 20 minutes should be wasted. Grouts are susceptible to degradation by excessive water infiltration before the grout sets. Extensive use of flyash aggravates this problem. Therefore, flyash-based lightweight grouts are not recommended.

- *Sequencing and injection.*—The grouting equipment should be capable of mixing and delivering the grout at a rate that will allow the annular space to be entirely filled in a continuous operation, unless staged grouting is being used. The contractor should monitor the grout pressure. If the existing conduit has deflected vertically from a straight alignment, trapped air could result in a void in the grout.

  Grout injection can be accomplished by a number of methods, including gravity and pressure:

  1. *Gravity.*—Injection of grout into the annular space starts at the upstream end of the HDPE slipliner and progresses toward the downstream end, so as to more easily displace water and debris. Suitable injection tubes must be inserted at the upstream end. Vent pipes installed at the downstream end should be 150 percent larger than injection tubes, to minimize the potential for clogging. Dirty water and excess grout discharged from the downstream vent tube should be collected and disposed of properly. Grouting should continue until heavy grout exits from the downstream vent tube.

  2. *Pressure.*—HDPE grout pipes (typically 1 to 1½-inch diameter) are extrusion welded to the crown of the slipliner prior to installation. The designer will need to determine the required number and length of each individual grout pipe. The number of grout pipes required for a particular sliplining application is a function of the diameter of the pipe and the expected length of grout travel, once it leaves the end of the grout pipe. A rule of thumb used by Reclamation assumes about 25 to 30 feet of grout travel from the end of the grout pipe. For example, if a deteriorated outlet

works conduit (150 feet in length) is to be sliplined, 4 grout pipes (120, 90, 60 and 30 feet in length) would be needed to grout the annulus.

Bulkheads are placed around the annulus of the slipliner at both ends of the conduit to contain the grout. The bulkheads must be secured in place and sealed, so no leakage of grout will occur during grouting operations. Air vent bleeder systems are installed through the bulkheads, near the crown of the existing conduit at both ends of the conduit to prevent air and bleed water from being trapped within the annular space.

Injection of grout into the annular space starts at the downstream end of the HDPE slipliner and progresses upstream through the longest grout pipe first, while low pressure air (5 lb/in^2) is pumped through the downstream air vent. The air pressure assists in holding the grout in the annulus space. Grout pressures should be kept as low as possible to avoid collapsing the HDPE slipliner. As grouting begins, the upstream air vent through the bulkhead remains open until grout begins to flow from the vent, and then the vent is closed.

Grouting continues in the longest pipe until no air returns from the next longest pipe, or grout no longer flows through the longest pipe. The longest pipe is plugged and grouting is initiated on the next longest grout pipe and the sequence is repeated for this pipe. Pumping of air in the air vent is discontinued when the shortest grout pipe on the conduit is being grouted. Grouting of the last grout pipe is continued until the annular space is fully grouted. When the annular space is fully grouted and heavy grout returns from the downstream air vent, a grout pressure of 10 lb/in^2 is maintained for 10 minutes to ensure all voids are filled.

Postinspection and acceptance.—The completed HDPE slipliner (figure 176) should be visually inspected by trained personnel to evaluate the conditions within the renovated conduit. If the sliplined conduit is too small for man-entry inspection, CCTV inspection methods should be used. Some designers may want to consider the use of white or gray HDPE pipe to reduce glare using CCTV equipment, figure 177 shows an example of this type of pipe. See section 9.5.2 for guidance on inspection of conduits. No localized dimpling or distortion of the HDPE slipliner wall or infiltration of groundwater or grout should be present.

Maintenance and repair of the completed HDPE slipliner.—No maintenance is typically required for the HDPE sliplined conduit, unless the conduit requires some type of cleaning. Periodic operation of the conduit usually is sufficient to flush sediments through the system. HDPE pipe is smooth and generally resists the adherence of sediment deposits. See section 9.6 for guidance on cleaning of conduits.

Figure 176.—Completed HDPE slipliner in existing CMP spillway conduit. Photo courtesy of Maryland Dam Safety Division.

If the HDPE slipliner experiences some type of damage over the long term, the damage should be assessed by trained personnel using man-entry or CCTV inspection methods as discussed in section 9.5. Repair of HDPE pipe after installation and grouting is completed is not practicable for the buried sections of pipe. Very little can be done to effectively repair the existing HDPE slipliner in buried sections of pipe within the embankment dam. However, another HDPE slipliner of smaller diameter can usually be inserted and grouted in place. Sections of HDPE pipe that are exposed and accessible may be repaired by cutting out the damaged section and replacing the entire section of pipe. Further guidance on replacement and methods available for joining pipe are provided in CPChem's *The Performance Pipe Engineering Manual* (2003).

For examples of projects that have utilized HDPE sliplining, see the case histories in appendix B for Round Rock and Twin (Turtle) Dams.

Alternatives to sliplining existing conduits with solid walled HDPE pipe.—A newer application of HDPE pipe for sliplining existing conduits involves the use of dual containment HDPE pipe. This application is recommended, if the HDPE slipliner is to be pressurized. Dual containment HDPE pipe is manufactured as two separate HDPE pipes and assembled by placing one inside the other. The inside pipe (containment pipe) is centered within the outer pipe (carrier pipe) with end spacers (centralizers) located at each end of a section of pipe. The end spacers are fabricated for a tight fit and are extrusion welded to the dual wall containment pipe.

Figure 177.—White HDPE pipe can reduce glare when using CCTV inspection equipment.

Intermediate spacers (known as spiders) are placed at intermediate points between the end spacers to provide additional support. The distance between the spiders is a function of the pipe diameter and wall thickness. Large diameter, thick walled pipe does not require the spiders to be as close as small diameter, thin walled pipe. The joints of the dual containment pipe are joined using the same heat fusion method, as used for joining single walled HDPE pipe.

The annulus between the existing conduit and the outside pipe is grouted. However, the annulus between the inside and outside pipe of the dual containment pipe remains open, even after installation of the end spacers and spiders, and upon completion of the heat fusion of the joints. This is one of the most desirable aspects of this type of pipe. The open annulus allows downstream detection of any leakage from the inside pipe, while still having full containment protection provided by the outside pipe. The end spacers and spiders are designed with openings to allow any leakage to pass through the annulus between the two pipes and exit at a downstream location. The dual containment pipe provides a redundancy and additional safety factors to the system. The inside pipe is rated at 75 percent of the normal bursting pressure due only to the inability to inspect the outside surface of the heat fusion joints. For this reason, the inside pipe is typically designed for a 33 percent higher pressure than the outside pipe.

When sliplining an existing CMP, the CMP is typically assumed to be corroded to the point that it cannot be relied upon to provide any strength. With the dual containment HDPE pipe, both pipes can be designed for the full expected loading. This allows a factor of safety of at least 2 without relying on exterior conditions, such as the existing CMP or the annulus grouting.

An additional benefit of the dual containment pipe is that the inside pipe is not subjected to any outside protrusions within the existing conduit that could possibly damage the pipe. The inside pipe is protected by the outside pipe, so if there is any damage the outside pipe will protect the inside pipe. Figure 178 shows an example of dual containment pipe.

Dual containment HDPE pipe weighs approximately twice as much as a solid walled pipe with a diameter equal to the outside pipe. The cost for materials and installation of the dual containment pipe is typically slightly more than twice what a solid walled pipe might cost. The higher cost is mainly due to increased labor required for heat fusion and installation of the dual containment pipe.

When sliplining an existing conduit with a solid walled HDPE pipe, the discharge capacity is normally not reduced because any loss in flow area is compensated by the smoother surface of the HDPE pipe in comparison to CMP, concrete, etc. This is due to the extremely low hydraulic friction in the HDPE pipe. With the dual containment pipe, the cross sectional area is further reduced by the smaller diameter of the inside pipe. The smaller cross sectional flow area may result in a net loss in discharge capacity compared to the original capacity of the existing conduit. The loss in capacity is dependent on the diameter of the inside pipe of the dual containment pipe. The loss in discharge capacity will be a smaller percentage of the original capacity as the existing conduit diameter gets larger.

Figure 178.—A 14-inch diameter interior HDPE pipe is being inserted into a 20-inch diameter outside pipe. Intermediate spacers are used to keep the interior HDPE pipe centered and supported. The annulus grouting between the existing CMP and exterior HDPE pipe has been completed.

HDPE joint fusion machines require specialized contractors, and mobilizing them to a construction site can add to the cost of a sliplining project, especially for smaller embankment dams. For some nonpressurized projects in low hazard embankment dams, an alternative product, such as "Snap-Tite®" may be used. This proprietary product consists of gasketed joint grooves machined onto lengths of standard HDPE pipe. This alternative is not appropriate for use with pressurized conduits, due the possibility of leakage through the gasketed joints. This type of pipe is lightweight, and sections of the pipe can be easily handled by three or four workers and a backhoe (figure 179). After the first section of the pipe is inserted into the existing conduit, the next section is aligned with the first section and the joint is lubricated and pulled together with "come-along hoists" and chains wrapped around the liner. As in the usual method of installing HDPE slipliner, the first section of the pipe is tapered to allow the leading edge to ride over irregularities in the existing conduit. The joined sections of pipe can be pulled or pushed into the existing conduit. Pulling from the upstream end is preferred, because in some cases, excessive force used to push the liner from the downstream end has damaged some joints. The blocking and grouting procedure would be the same as that for fused HDPE pipe. For further design and installation details, see the manufacture's data.

The primary advantage of using Snap-Tite instead of standard heat-fused HDPE pipe is reduced installation costs, since a fusion machine is not needed. Disadvantages include the high cost of the proprietary pipe (due to the cost of machining of the joint grooves) and that the product has a relatively thin wall, so it may not be suitable under high embankment dams. The product usually consists of

Figure 179.—Sections of proprietary Snap-Tite® pipe can be easily handled with small equipment.

pipe with an SDR of 26 or 32.5, although heavier pipes may be available for custom applications. The designer will need to evaluate the suitability of this type of product for their project. For an example of a conduit renovation at a low hazard embankment dam using Snap-Tite, see the Rolling Green Community Lake Dam case history in appendix B.

12.1.2 Steel pipe

In most applications, steel pipe slipliners are used within accessible conduits. Section 12.1.2 mainly pertains to conduits accessible by man-entry. However, some discussion of steel pipe slipliners used within inaccessible conduits is provided.

Steel pipe slipliners (figure 180) are generally applicable, if the existing conduit is straight and does not have bends or significant invert slope changes. Steel pipe slipliners can be installed in conduits with bends or slope changes, if adequate clearance will allow for the insertion of the fabricated pipe sections.

12.1.2.1 Design considerations

The designer must evaluate a number of design parameters when considering steel pipe for use in sliplining. A few of the most significant design parameters include:

- Seepage paths
- Service life
- Initial inspection of the existing conduit
- Selection of the diameter and thickness
- Thermal expansion/contraction
- Stress cracking
- Fabrication
- Joints
- Flotation
- Entrance and terminal structures

Figure 180.—The Lake Linganore Dam outlet works consists of a 48-in diameter RCP conduit with a sluice gate located at the downstream end, which places the conduit under full reservoir head at all times. Concern about the integrity of the RCP joints led to installation of a steel slipliner when the inoperable sluice gate was replaced.

These parameters are further discussed in the following paragraphs. On a case-by-case basis, the designer may need to consider additional parameters, depending on the performance criteria and design requirements of the specific application.

Seepage paths.—For a discussion of seepage paths refer to section 12.1.1.

Service life.—The service life of a steel pipe slipliner is considered to be indefinite, if the coatings on the interior surface are properly maintained. However, improper maintenance of the interior surface could result in deterioration of a steel pipe slipliner in less than 25 years. Protective coatings are rarely completely effective, because even on application, they contain discontinuities, such as pinholes, flaws, scratches, and connected porosity. The use of a cathodic protection system (CPS) may be applicable in certain situations. A CPS has been used in conjunction with protective coatings, have been effective in controlling corrosion. A CPS consists of anodes that pass a direct current to the steel pipe liner through the electrolyte environment. With a CPS, the whole steel pipe slipliner becomes a cathode and does not corrode. CPSs can be one of two types, galvanic anode or impressed current anode. Hybrid CPSs can contain both types of anodes to provide protective current to all surfaces of the protected steel pipe slipliner (USACE, 1999, p. 1-1).

Initial inspection of the existing conduit.—For a discussion of the initial inspection of an existing conduit refer to section 12.1.1.

Selection of the diameter and thickness.—The selection of the diameter and thickness of the steel pipe slipliner should consider the following factors:

- *Size and condition of the existing conduit*.—Similar size and condition requirements are needed for steel pipe slipliners as are used for the design of HDPE slipliners, see section 12.1.1 for further details.

- *Discharge requirements*.—Similar discharge requirements are needed for steel pipe slipliners as are used for the design of HDPE slipliners, see section 12.1.1 for further details.

- *Clearance requirements for grouting of the annulus between the existing conduit and the steel pipe slipliner*.—Similar clearance requirements are needed for steel pipe slipliners as are used for the design of HDPE slipliners, see section 12.1.1 for further details. However, it should be noted that flanged joints generally require more clearance than heat fused HDPE joints or welded steel joints.

- *Internal and external loadings*.—Similar loadings can be expected on steel pipe slipliners as are used for the design of HDPE slipliners; see section 12.1.1 for further details. Steel pipe slipliner thickness requirements are generally governed by external pressures and the potential for buckling during future unwatering of the slipliner. Steel pipe should be designed in accordance with industry-accepted methods, such as those found in AWWA M11 (AWWA, 2004c), Amstutz (1970), and Jacobsen (1974).

Thermal expansion/contraction.—Thermal expansion/contraction is generally not a concern with steel pipe slipliners, as long as it does not have any portion exposed to the environment.

Stress cracking.—Stress cracking is generally not a concern with steel pipe slipliners.

Fabrication.—Steel pipe used for sliplining should be fabricated in accordance with AWWA C200 (1997) and ASTM A 36 and A 53. The steel pipe slipliner should be hydrostatically tested at the factory based on the design pressures. The steel pipe slipliner should be coated as specified by the designer.

To avoid delays to the construction schedule, the steel pipe slipliner should be shop fabricated while other site preparations for installation of the slipliner are being performed (e.g., construction access, or concrete removal). Depending on the diameter and length of the steel pipe slipliner, it may be advantageous to shop fabricate the slipliner in sections, so finished sections can be installed while other segments are being fabricated. Sometimes a separate procurement contract for the steel pipe slipliner is issued early, so fabrication can begin sooner.

Joints. - Steel pipe slipliner joints should be welded in accordance with AWWA C206 (2005). Flanged steel joint rings should be fabricated in accordance with AWWA C207 (2002). "Full face" rubber gaskets between the flanges are required in order to ensure a watertight joint. Fittings should have a factory-applied coating to protect against corrosion. Bolts should be of stainless steel or low allow steel and should be field coated after installation.

Flotation.—Flotation is a concern for steel pipe slipliners, but not as much as it is for thermoplastic slipliners. The weight of the steel pipe slipliner helps to prevent it from being displaced upward by the fluid pressure of the grout in the annulus between the existing conduit and steel pipe slipliner. Spacers or jack screws are always required to secure the steel pipe slipliner from movement during grout placement.

Entrance and terminal structures.—The steel pipe sliplining of an existing conduit may require partial or full removal and replacement of certain structures to improve release capabilities or to facilitate construction. For guidance on the design and construction of entrance and terminal structures, see section 3.4.

12.1.2.2 Construction considerations

The designer must evaluate a number of construction parameters when considering steel pipe for use in sliplining. A few of the most significant parameters include:

- Handling and storage
- Installation
- Repairs to the steel pipe slipliner prior to or during the insertion process
- Grouting
- Postinspection and acceptance
- Maintenance and repair of the completed steel pipe slipliner

These parameters are further discussed in the following paragraphs. On a case-by-case basis, the designer may need to consider additional parameters, depending on the construction requirements of the specific application.

Handling and storage.—During loading, transportation, unloading, storage, and laying, every precaution should be taken to prevent damage to the steel pipe slipliner sections, linings, coatings, and flanges. Steel pipe slipliner sections should be stored on timber blocking and adequately protected from weather and damage. Any damage to lining or coating will need to be properly repaired. If proper repair cannot be made, the damaged section will need to be replaced.

Installation.—The steel pipe slipliner should be supported and braced to prevent distortion during installation and grouting. Spacers are required to maintain separation between the existing conduit and the steel slipliner during grouting. Figure 181 shows spacers being installed on a steel pipe slipliner. Guidance on installation includes the following. Additional guidance on steel pipe installation is available in AWWA M11 (2004c).

- *Preparation of existing surfaces*.—The existing conduit surfaces, against which grout will be placed, should be free of latence, dirt, dust, grease, oil, loose or defective concrete, curing compound, coatings, and other foreign materials. 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 the existing conduit is full of water, considerations should be made for unwatering. A thorough inspection of the existing conduit is required prior to installing the steel pipe slipliner to ensure no obstructions remain that may hinder slipliner insertion.

- *Leak testing joints* .—Steel pipe slipliner joints should be welded and tested in accordance with AWWA C206 (2005), except testing of field welds should be by the ultrasonic method. Ultrasonic examination of field welds should conform to the requirements of American Welding Society (AWS) D1.1 (2004). Any offsets that could reduce the hydraulic capacity of the steel slipliner should be ground flush and flared into the adjacent surfaces. In lieu of ultrasonic examination, the field welded joints can be tested by the liquid penetrant method in accordance with ASTM E 165. The liquid penetrant method provides an indication of the presence, location, and to a limited extent, the nature and magnitude of any discontinuities. Welds can also be tested using radiographing and magnetic-particle methods.

- *Access and insertion*.—The steel pipe slipliner is typically installed by pulling, pushing, or a combination of both similar to an HDPE pipe as discussed in section 12.1.1.

Repairs to the steel pipe slipliner prior to or during the insertion process.— Damage to the steel pipe slipliner may occur from improper shipping and handling

Figure 181.—Spacers being installed on a steel pipe slipliner.

or from poor insertion technique. Damage can be in the form of kinks, punctures, breaks, or abrasion. Steel pipe slipliners that undergo this type of damage can be easily repaired, if the pipe has not been inserted into the existing conduit. The repair would typically involve cutting out the damaged area of steel pipe slipliner and welding a new piece of steel plate in place. An installed slipliner with a damaged area can only be repaired in place if it is of sufficient diameter to allow man-entry. If the steel pipe slipliner diameter is too small for man-entry, the section of pipe will need to be removed to perform the proper repair.

Grouting.—Careful grouting of the annular space between the existing conduit and the steel pipe slipliner is essential. This can be a complex process, requiring the experience of a qualified contractor. A lightweight, low density grout containing no aggregate will ensure the best result. The following guidance discusses the grout plan, mix design, sequencing, and injection:

- *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 the upstream and downstream should be submitted for review and approval prior to initiation of grouting operations. The contractor should also provide the method to be used to remove trapped air from any high points in the existing conduit during the grouting operation. All welding and inspection of the steel pipe slipliner should be completed before grouting operations commence.

- *Grout mix*.—For guidance on grout mix, see section 12.1.1. The grout mix used for grouting of the annulus for a steel pipe slipliner will be similar to that used for grouting of the annulus of an HDPE slipliner.

- *Sequencing and injection*.—For guidance on sequencing and injection of grout, see section 12.1.1.

  Grout injection can be accomplished by a number of methods, including gravity and pressure:

  1. *Grouting for accessible existing conduits*.— Threaded couplings are installed through the steel pipe slipliner, from which grouting operations can be performed. After grouting operations have been completed, a pipe plug is installed in the threaded coupling, tightened, seal welded, and ground flush with the interior surface of the steel pipe slipliner.

     Grouting is best accomplished in lifts (four lifts are recommended for large diameter steel pipe slipliners). For each lift, grouting should begin at the downstream end of the conduit and proceed upstream.

     Grout injection should begin at the lower ports in the steel pipe slipliner and progress to the next higher ports. Grouting should begin by injecting through the lower ports and continue until grout return is observed at the next higher ports. Recommended port locations are at the invert, 45 degrees each side of the invert, both springlines, 45 degrees each side of the pipe crown, and the pipe crown.

     Grout should be pumped at pressures not exceeding 10 lb/in^2 at the injection ports. Any trapped air along the high points in the annular space should be expelled through air vents located on the crown. Rings of grout ports should be spaced at about 40-foot intervals. The designer should determine the required number and location of all ports and actual grouting pressures to be used. The steel pipe slipliner position, circularity, and shape should be monitored during grouting operations. Upon completion of grouting, grout plugs should be installed and ground flush with the steel liner surface.

  2. *Grouting for inaccessible existing conduits*.— Grouting of steel slipliners will be very similar to that used for grouting of HDPE slipliners. The main difference being the use of steel grout and vent pipe, welded to the steel slipliner. Full encapsulation for the entire length of the annulus rarely is

achievable, and the steel pipe slipliner is typically designed to withstand all internal and external loadings independently from exterior conditions.

Grout injection can be accomplished by a number of methods, including gravity and pressure:

- *Gravity*.—For guidance on gravity grouting, see section 12.1.1.

- *Pressure*.—Steel pipe slipliner grout pipes (typically 1 to 1½-inch diameter) are welded to the crown of the slipliner prior to installation. For guidance on pressure grouting, see section 12.1.1.

Postinspection and acceptance.—Trained personnel should visually inspect the completed steel pipe slipliner installation to evaluate the conditions within the renovated conduit. If the sliplined conduit is too small for man-entry inspection, CCTV inspection methods should be used. See section 9.5.2 for guidance on inspection of conduits. No damage to linings or coatings, or infiltration of groundwater should be present.

Maintenance and repair of the completed steel pipe slipliner.—Maintenance typically performed on steel pipe slipliners involves coatings on the interior of the slipliner. The interior surface of the pipe may require periodic recoating, if it has been subjected to abrasion or corrosion. The only other maintenance required for steel pipe slipliners would involve cleaning of the conduit. Periodic operation of the conduit usually is sufficient to flush sediments through the system. The steel slipliner is smooth and generally resists the adherence of sediment. See section 9.6 for guidance on cleaning of conduits.

If the steel slipliner experiences some type of localized damage (abrasion, buckling, cavitation, corrosion, etc.) over the long term, the damage should be assessed by trained personnel using man-entry or CCTV inspection methods as discussed in section 9.5. Repair of steel pipe slipliners after installation and grouting is completed can be accomplished, if the pipe is of sufficient diameter to allow man-entry. If the damaged area of steel pipe is not extensive, the repair would typically involve cutting out the damaged area and welding a new piece of steel plate in place or applying weld material in the damaged area. The welded material would be ground to a smooth finish. If the steel pipe slipliner diameter is too small for man-entry, a steel pipe slipliner of smaller diameter can usually be inserted and grouted in place.

For examples of projects that utilized steel pipe sliplining, see the case histories for Como and McDonald Dams in appendix B.

12.2 Cured-in-place pipe

Plastic cured-in-place pipe (CIPP) liners are typically used within inaccessible conduits. However, guidance provided in section 12.2 basically applies to lining of accessible or inaccessible conduits. CIPP liners are best suited for existing conduits that are not severely damaged or deformed and have constant diameters and no sharp bends. The designer should consider the method of CIPP liner installation as part of the design process. CIPP liners can be inserted into the existing conduit by either the inversion method (ASTM F 1216) or the pulled-in-place method (ASTM F 1743).

Additional information on CIPP liners used in sewer and pipeline application is available in USACE's *Guidelines for Trenchless Technology: Cured-in-Place Pipe (CIPP), Fold-and-Formed Pipe (FFP), Mini-Horizontal Directional Drilling (Mini-HDD), and Microtunneling* (1995d) and ASTM D 5813.

12.2.1 Design considerations

The designer must evaluate a number of design parameters when considering CIPP lining for conduits. A few of the most significant design parameters include:

- Seepage paths
- Service life
- Initial inspection of the existing conduit
- Selection of the diameter and thickness
- Thermal expansion/contraction
- Stress cracking
- Fabrication
- Joints
- Flotation
- Entrance and terminal structures

These parameters are further discussed in the following paragraphs. On a case-by-case basis, the designer may need to consider additional parameters, depending on the performance criteria and design requirements of the specific application.

Seepage paths.—For a discussion of seepage paths, refer to section 12.1.1.

Service life.—Research conducted by the Trenchless Technology Center at Louisiana Tech University found that the service design life of CIPP liners generally exceeds 50 years. The inversion tube processes, in which a resin-impregnated tube is cured in place, may not be suitable for lining bituminous coated CMP conduits unless they are prelined to prevent contamination of the resin by chemicals present in the asphalt coating (USACE, 1990, p. 3).

Initial inspection of the existing conduit.—For a discussion of the initial inspection of an existing conduit refer to section 12.1.1.

Selection of the diameter and thickness.—The selection of the diameter and thickness of the CIPP liner should consider the following factors:

- *Size and condition of the existing conduit*.—The size of the existing conduit will limit the diameter of the CIPP liner. A determination of the condition of the existing conduit is required to estimate the contributing support. A conservative assumption would be that the existing conduit is "fully deteriorated." For this assumption, the existing conduit provides no contributing support, and the CIPP lining needs to carry the external and internal loads resulting from the embankment dam and hydrostatic water pressures. A less conservative assumption would be an existing conduit in a partially deteriorated condition. For this condition, the existing conduit is assumed to be able to accommodate all internal and external loads for the life of the renovated conduit. If the existing conduit is large enough for man-entry, spot repairs of deteriorated areas may be considered prior to CIPP liner placement.

- *Discharge requirements*.—Similar discharge requirements are needed for CIPP liners as are used for the design of HDPE slipliners; see section 12.1.1 for further details.

- *Clearance requirements*.—Grouting is not normally required, since the CIPP liner fits tightly against the interior surface of the existing conduit. However, the designer needs to closely evaluate the applicability of a CIPP liner used for lining of a CMP conduit. The CIPP liner cannot tightly fit within the corrugations, and the ability to grout this annulus would be difficult.

- *Internal and external loadings*.—The CIPP liner design is based on the condition (partially or fully deteriorated) of the existing conduit, the type of application (pressurized or nonpressurized), and the resin and fabric tube material construction. If the existing conduit can support the soil and surcharge loads throughout the design life of the rehabilitated conduit, it is considered to be partially deteriorated for use in computing the required design thickness. Typically, If 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 conduit, it is considered to be fully deteriorated for use in computing the design thickness. Other factors affecting the thickness of the CIPP liner are groundwater, soil types, and loadings on the existing conduit. Guidance for design should be in accordance with the manufacturer's recommendations and ASTM F 1216. Proper precautions are required to provide required venting (i.e., air vent or an air valve) to avoid collapse by internal vacuum pressures.

Thermal expansion/contraction.—Thermal expansion/contraction are generally not a significant concern with CIPP.

Stress cracking.—Stress cracking is generally not a concern with CIPP.

Fabrication.—The CIPP liner should be fabricated in a diameter size which will tightly fit the internal circumference of the existing conduit after installation. Allowance should be made for any circumferential stretching during the inversion process. The volume of resin should be sufficient to fill all voids in the tube material at nominal thickness and diameter. The resin volume may need to be adjusted by adding 5 to 10 percent excess resin to account for the change in volume due to polymerization and to allow for migration of resin into open cracks or joints in the existing conduit.

Joints.—Typically, CIPP liners are installed as one continuous length, and no joints are required.

Flotation.—Flotation is not an issue with CIPP, since the interior of the CIPP liner is filled with water during the curing process, and grouting is typically not required.

Entrance and terminal structures.—The installation of a CIPP liner into a existing conduit may require partial or full removal and replacement of certain structures to improve release capabilities or to facilitate construction. For guidance on the design and construction of entrance and terminal structures, see section 3.4.

12.2.2 Construction considerations

The designer must evaluate a number of construction parameters when considering CIPP lining for conduits. A few of the most significant parameters include:

- Installation
- Repairs to the CIPP liner prior to or during the insertion process
- Curing
- Grouting
- Postinspection, testing, and acceptance
- Maintenance and repair of the completed CIPP-lined conduit

These parameters are further discussed in the following paragraphs. On a case-by-case basis, the designer may need to consider additional parameters, depending on the construction requirements of the specific application.

Installation.—Upstream and downstream access as typically required for installation. Installation should be in accordance with the manufacturer's recommendations and ASTM F 1216 (inversion method) and ASTM F 1743 (pulled-in-place method). The manufacturer should provide the minimum and maximum allowable hydrostatic pressures. The use of a nontoxic lubricant is recommended to reduce friction during inversion. The use of an experienced CIPP liner installer is highly recommended.

- *Preparation of existing surfaces*.—The existing conduit surfaces should be free of roots, sediments, mineral deposits, and loose or defective concrete. 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. See section 9.6 for guidance on cleaning of conduits. If the existing conduit is full of water considerations will be required for unwatering. A thorough inspection of the existing conduit is required prior to installing the CIPP liner to ensure no obstructions remain that may hinder CIPP insertion.

- *Access and insertion*.—Two methods of installation are available for insertion of the CIPP liner:

    1. *Inversion method*.—The inversion method (figures 182 through 184) consists of utilizing air or water (hydrostatic head) to push the CIPP liner inside-

out as it advances along the conduit. The inversion method is used for conduits with diameters ranging from 4 to 108 inches.

2. *Pulled-in-place method*.—The pulled-in-place method consists of a winch attached to a cable, which is attached to the CIPP liner and used to pull the liner into position. The liner is then inflated through the inversion of a calibration hose by the use of hydrostatic head or air pressure. The pulled-in-place method is usually only done where sufficient water pressures are not available or the scaffold towers required for the inversion process are not practical or where a particular lining is required. Insertion by the pulled-in-place method has some limitations due to the size and weight of the liner and possible resulting damage by moving the liner through the existing conduit. The pulled-in-place method is used for conduits with diameters ranging from 4 to 96 inches.

Repairs to the CIPP liner prior to or during the installation process.—Damage to the CIPP liner may occur from improper shipping and handling or from poor installation technique. Damage can be in the form of punctures, breaks, or abrasion to the CIPP liner or improper injection and care of the liquid resin. CIPP liner that experiences this type of damage must be replaced.

Curing.—After the CIPP liner is in place, a suitable heat source, water recirculating equipment, and temperature gauges are required to circulate heated water throughout. Curing of the CIPP must consider the existing conduit, resin system, and the surrounding embankment conditions, including temperatures, moisture levels, and thermal properties. Curing should be in accordance with the manufacturer's recommendations and ASTM F 1216. The cured CIPP liner will take the shape of the existing conduit, including any deformities. CIPP is usually thermally cured by the circulation of heated water (up to 82.2 °C or 180 °F). Alternative resins can be used that require lower curing temperatures, if thermal stresses are a design concern. However, once the curing process is complete, the CIPP liner is stable to heat and cannot be made to flow or melt again. Ultraviolet and ambient cure methods are alternatives to the thermal curing method, but these methods may have installation limitations or properties not equal to those of a thermally cured product. When completed, the CIPP liner acts as a new watertight lining within an existing conduit. After the curing process is completed, the ends of the CIPP liner can be trimmed flush as needed. If a service connection or air vent opening is required, this can be done by personnel using a special cutting device for conduits large enough for man-entry. If the conduit is too small for man-entry, a robotic crawler with a special cutter can be used to cut the required opening in the CIPP liner.

Grouting.—Grouting is not normally required, since the CIPP liner fits tightly against the interior surface of the existing conduit.

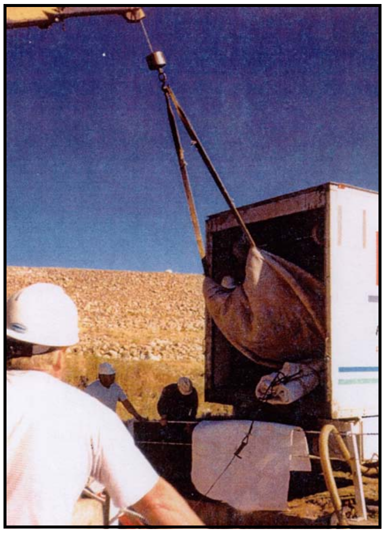

Figure 182.—Unloading the CIPP liner prior to installation.

Figure 183.—CIPP liner being positioned for installation.

Postinspection, testing, and acceptance.— Trained personnel should visually inspect the completed CIPP installation. No dry spots, lifts, delamination, pinholes, or infiltration of groundwater should be present and the CIPP liner should be in a fully expanded condition. Wrinkles (figure 185) that could reduce the hydraulic capacity of the CIPP liner should not be allowed. If the CIPP-lined conduit is too small for man-entry inspection, CCTV inspection methods should be used. See section 9.5.2 for guidance on inspection of conduits.

Figure 184.—The hydrostatic inversion method is being used for CIPP liner installation into an existing conduit.

Two samples (cut from the end of the cured CIPP liner) should be prepared and submitted for the purpose of acceptance testing. The samples should be prepared in accordance with ASTM F 1216 or ASTM F 1743 for flexural and tensile testing. Testing should be used to verify flexural properties in accordance with ASTM D 790 and tensile properties in accordance with ASTM D 638.

Maintenance and repair of the completed CIPP-lined conduit.—No maintenance is typically required for the CIPP-lined conduit, unless the conduit requires some type of cleaning. Periodic operation of the CIPP-lined conduit usually is sufficient to flush sediments through the system. The CIPP lining is smooth and

Figure 185.—The calibration hose of this pulled-in-place CIPP developed "fins." These fins were considered to have an insignificant effect on hydraulic capacity for this particular conduit application and were not removed.

generally resists the adherence of sediment. See section 9.6 for guidance on cleaning of conduits.

If the CIPP liner experiences some type of damage over the long term, the damage should be assessed by trained personnel using man-entry or CCTV inspection methods as discussed in section 9.5. Repair of the CIPP lining after installation and curing are completed is possible. Repair kits are available from the manufacturer.

For an example of a project that utilized a CIPP liner see the case history for Willow Creek in appendix B.

12.3 Spray lining

Spray lining is a conduit renovation method that has been used since the 1920s mainly for small diameter water mains (USACE, 2001d, p. 10). Spray lining typically involves the spraying of a cement mortar mixture or epoxy resin against the inside walls of the existing conduit. Trowels that trail the rotating sprayer head smooth the sprayed cement mortar. Spray lining has been used to retard iron pipe corrosion and reduce the rate of deterioration of the existing walls of water mains.

While this renovation method may have some limited applicability for low hazard embankment dams, it is not recommended for significant or high hazard embankment dams. The spray lining technique cannot ensure a long term watertight barrier and has a limited life expectancy.

Chapter 13

Replacement of Conduits

Generally, removal and replacement of an existing conduit through an embankment dam consists of excavating the dam down to the existing conduit, stockpiling the material, removing the existing conduit, constructing a new conduit and possibly new entrance and terminal structures, installing a filter diaphragm or collar around the downstream portion of the conduit, and replacing the embankment material. A cofferdam may also be required if the reservoir cannot be drained during construction.

Removal and replacement of a deteriorating conduit can be time consuming and expensive compared to other renovation methods. Typically, construction costs for removal and replacement may be 5 to 10 times higher than for sliplining or cured-in-place conduit renovation methods. This cost difference depends upon the height of the embankment dam. However, if the embankment dam is small and the downstream impacts to users are acceptable; this method may be more advantageous than renovation. Often, removal and replacement is the alternative of choice for low hazard embankment dams, since it generally is less expensive. This is especially true on older low hazard embankment dams, where they may have been built without adequate engineering. Few designers will want to try and guess how the embankment dam was built. The safer and more efficient solution would be to remove and replace the conduit and possibly the entire embankment dam..

The advantages of removal and replacement of an existing conduit through an embankment dam include:

- *Evaluation*.—The exposed foundation of the conduit can be fully evaluated.
- *Repairs*.—Areas along the existing conduit that may have been damaged by internal erosion or backward erosion piping can be repaired.
- *Seepage*.—Extensive seepage control measures along the conduit can be installed.

- *Design modifications.*—The new conduit can be designed to provide increased discharge capacity to meet current or future operational and emergency release requirements.

The disadvantages of removal and replacement of an existing conduit through a high embankment dam include:

- *Cofferdam.*—Unless the reservoir can be drained, the construction of a cofferdam is generally required. Inflows into the reservoir will need to be diverted. In some special cases a downstream cofferdam may also be required.

- *Costs.*—Construction costs for removal and replacement are generally higher than for other renovation methods. Construction costs rapidly rise as the height of the embankment dam increases.

- *Reservoir operations.*—Construction may impact reservoir operations and add risk to the downstream community.

- *Seepage paths.*—If proper compaction of the embankment closure section is not obtained, potential seepage paths may exist along the junction of the closure section and existing embankment

13.1 Embankment excavation slopes.

An excavation transverse to an existing embankment dam centerline increases the potential for hydraulic fracture of the replacement embankment material from arching. Because hydraulic fracture poses special hazards when the reservoir is subsequently refilled, special care is required for designs that involve excavation transverse to the existing embankment dam. The excavation should be wide enough to accommodate motorized compaction equipment, and the side slopes should be flat to reduce differential strain.

The guidance for excavation discussed in chapter 5 applies equally to construction involving removal and replacement of existing conduits. Excavations for conduits in soil foundations should be wide enough to allow for backfill compaction parallel to the conduit using heavy rolling compaction equipment. Equipment used to compact along the conduit should be free of framing that prevents its load-transferring wheels or drum from working against the structure (USACE, 2004a, p. 6-6).

13.2 Removal of the existing conduit

The first step in removal and replacement of the existing conduit is usually to excavate the embankment dam to the invert of the conduit and remove it. Removal of the entrance structure (figure 186), terminal structure, or other structures may be required due to age or deterioration, or to ease construction of the replacement structures. Occasionally, where removal of the existing conduit is difficult and expensive, the existing conduit may not be removed, but will be abandoned by backfilling the conduit with grout and installing a new conduit at a separate location. See section 14.3 for guidance on abandonment of conduits. Excavations should be wide enough at the bottom to ensure adequate working room for removal of the existing conduit and replacement with the new conduit, and compaction of earthfill materials.

A qualified professional engineer or engineering geologist should carefully observe and document the excavation required for the removal of the existing conduit to verify that any damaged embankment or foundation materials have been fully removed and/or treated prior to construction of the new conduit and replacement of embankment materials. For an example of the replacement of a conduit, see the Pablo Dam case history in appendix B.

13.3 Design and construction of the conduit

For guidance on design and construction of the conduit, see chapters 3 and 4.

13.4 Design and construction of the filter

For guidance on the design and construction of the filter, see chapter 6. The new filter should be designed to extend upstream into the embankment dam. Frequently, the filter installed in this situation is larger than that used for first time construction of an embankment dam. The filter should extend to both sides of the new conduit and key into the existing embankment dam. If the existing embankment dam has a chimney filter, the filter should be designed to be a part of that system where feasible.

13.5 Design and construction of the replacement embankment dam

The following sections discuss aspects of design and construction that the designer should consider for the replacement portion of the embankment dam.

Figure 186.—Excavator removing the intake structure for an existing outlet works.

13.5.1 Zoning

If the conduit is being replaced in a zoned earthfill embankment dam where a central core is substantially different in properties than the outside embankment shells, backfill for the conduit should coincide with the zoning for the embankment dam. Core zone backfill should only be used around the conduit through the core section, with shell backfill soils used through those sections of the conduit. An exception to this recommendation is where rock shell zones include large angular rocks that could impose point loads on the conduit that exceed its strength. For that condition, cushioning soil with small sand and gravel should encircle the conduit to prevent this problem.

13.5.2 Compaction considerations for backfill used in rebuilding the embankment dam

The soil removed from the embankment dam as the existing conduit is excavated is frequently reused to backfill the notch in the dam. Designers should carefully evaluate the water content of these soils and determine if drying or wetting is required for satisfactory reuse. The excavated slopes in the existing embankment dam may remain exposed for a period of time before they are backfilled. The time over which the excavation made to replace the conduit is left exposed may be hot, dry weather. In this case, the exposed soils on the face of the excavation may desiccate to considerable depths. Before commencing backfilling of the excavation in the embankment dam, any desiccation cracks in the existing dam must be removed, and the earthfill surface disked and moistened. This process will probably have to be delayed until immediately before backfill of an interval of the embankment dam is ready to commence. If backfilling of the excavation is interrupted during hot weather, the surface of the reconstruction backfill also should be closely inspected for desiccation features before placing new fill. Poorly bonded lifts can occur during interruptions of fill placement. They provide an avenue for possible internal erosion.

Designers should consider these important points:

- *Testing*.—Soils used to rebuild the embankment dam should be evaluated by the same tests that would be used to evaluate soils for a new embankment dam. The water content, plasticity, gradation, compaction properties, and dispersivity of clay fines are important evaluations. If the replacement fill is in a zoned embankment dam, similar zoning should be used.

- *Water content*.—Soils used to rebuild the embankment dam should usually be placed wet of Standard Proctor optimum water content to improve their flexibility and resistance to cracking and arching. Compacting soils at water contents that are 1 to 3 percent wet of optimum significantly improves their flexibility. At the same time, the likelihood that pore pressures could be generated in medium to high plasticity clays in fills of significant height should also be evaluated. Designers must weigh the advantages of compacting soils wet of optimum against the disadvantages of this wetter compaction water content. The lower shear strength and potential pore pressures generated by wetter compaction water contents must be considered in the design stability evaluations. Many designers consider excessive pore pressures to be a lesser long term danger to the successful performance of an embankment dam than the danger of arching and hydraulic fracture if the soils are placed dry.

- *Exposed filler*.—Special care to remove desiccation cracks in exposed fill surfaces is important. This applies to the exposed excavation slopes and to layers of fill used in reconstructing the embankment dam.

For additional guidance on hydraulic fracture and closure sections, see section 5.2.

13.6 Construction impacts

Generally, the construction period for a complete removal and replacement of a conduit will require more time than other renovation methods. Mitigating the impacts of a longer construction period may require consideration of the following:

- *Water requirements.*—Providing for diversion and downstream water requirements (irrigation, etc.).
- *Traffic control.*—Traffic control measures (lighting, signs, etc), road closures, construction of detours (such as detouring dam crest traffic).
- *Disturbance.*—Larger disturbance areas and potential environmental issues.
- *Draining or drawing down of the reservoir.*—Caution is required if the reservoir is drained, since the existence of a heavy bed load could move and block the intake structure.

13.7 Construction of a cofferdam or temporary diversion channel.

A cofferdam (figure 187) may be needed to act as a temporary barrier to protect the construction area from flooding (Reclamation, 1987a, pp. 499-500). If construction for the removal and replacement of the existing conduit can be performed during the low water season, the use of a cofferdam may be minimal. However, where the reservoir inflow characteristics are such that construction cannot be done during a low water season, the cofferdam must be designed for safety and for optimal height to accommodate the full range of expected inflows during the construction period. Often the flood selected for sizing diversion requirements is based on the projected length of the construction period. For instance, if the projected length of the construction period is 1 year, the cofferdam would need to be able to accommodate a flood with a return interval of 5 years. If the projected length of the construction period is 2 years, a 10-year diversion flood would be used.

At some sites, a diversion channel in lieu of a cofferdam may be more practical. Diversions or cofferdams may not be justified for smaller embankment dam projects with limited working room for the removal and replacement of conduits. For these projects, certain hydrologic events during construction may impede progress and cause delays resulting in added costs for clean up of debris caused by flooding. For this situation, construction should be scheduled during periods when the lowest rainfall is probable to avoid these problems. Figure 188 shows an embankment dam site where rainfall during construction has partially flooded the exposed excavation and conduit removal. This flooding resulted in a delay and cleanup before construction could resume.

13.8 Design of entrance and terminal structures

The removal and replacement of an existing conduit may require partial or full removal and replacement of certain structures to improve release capabilities or to