You Con-du-it; How to Fix a Leaky Pipe

Introduction

A key component in operation and risk management of small to medium sized embankment dams is the outlet conduit(s) that provide the means to control the reservoir level. Maintenance of conduits through embankment dams is essential to the overall reliability of the dam facility. Conduit deterioration such as joint offsets, cracks, and voids behind the conduit develop for a variety of reasons. This deterioration can lead to the inability to operate the conduit or to excessive seepage into, out of, or along the conduit, which could endanger the integrity of the entire dam embankment. This article presents investigation techniques and common methods for in-place outlet pipe repairs that can extend the life of the outlet conduit and possibly provide an alternative to conduit abandonment or replacement.

Outlet Conduit Inspections

Typically, dam safety organizations and embankment dam owners will conduct a variety of inspections throughout the service life of a conduit. Regulatory requirements, dam hazard classification, conduit condition, and access dictate both the scope and frequency of the conduit inspections.

Dam inspections, and therefore outlet conduit inspections, generally fall into four different categories: formal, intermediate, routine, and emergency. For additional detail regarding each type of outlet conduit inspection, refer to Table 1 below.

Table 1: Types of Outlet Conduit Inspections

Type of Inspection	Frequency Interval	Inspection Team	Inspection Scope
Formal[1]	4-6 yrs - High Hazard 10 yrs - Low Hazard Often performed in conjunction with formal inspection of entire dam facility.	Owner Representative Qualified Engineer Regulatory Agency Rep	- Prepare inspection plan & checklist[2] - Review all available data (design reports, drawings, instrumentation data, current and historic operating data) - Check operability of all mechanical equipment associated with the outlet works, through its full range of operation - Perform external conduit inspection - Perform internal conduit inspection - Document findings in inspection log[4] - Develop inspection report[5]
Intermediate[1]	1 yr – High/Sig Hazard 3-5 yrs – Low Hazard	Owner Representative Qualified Engineer Regulatory Agency Rep[6]	- Prepare inspection plan & checklist[2] - Review current operating and instrumentation data - Perform external conduit inspection - Check operability of critical mechanical equipment for outlet works - Perform internal conduit inspection[3] - Document findings in inspection log[4] - Develop inspection report[5]
Routine[1]	Conducted in conjunction with other routine inspections of the dam facility	Owner Representative	- Prepare inspection plan & checklist[2] - Perform external conduit inspection - Perform internal conduit inspection[3] - Document findings in inspection log[4] - Develop inspection report[5]
Emergency[1]	Conducted when an immediate dam safety concern is present or an adverse loading condition has occurred	Owner Representative Qualified Engineer Regulatory Agency Rep[6]	- Perform external conduit inspection - Perform internal conduit inspection[3] - Document findings in inspection log[4] - Develop inspection report[5]

1. More detailed information regarding inspections can be found in *Technical Manual: Conduits through Embankment Dams*, produced by the Federal Emergency Management Agency (FEMA 2005).
2. Develop a detailed inspection plan & checklist to identify the features to be inspected and the objectives of the inspection.
3. Based on the results of the external inspection, state or federal requirements, and general facility maintenance, an internal visual inspection may be warranted.
4. It is good practice to maintain an inspection log documenting the historic inspections and their associated findings for reference during future inspections.
5. After an inspection has been completed, an inspection report should be developed documenting the findings and any recommendations for repairs.
6. As a courtesy, an invitation is typically extended to the regulatory agency but the presence of the regulatory agency is not required.

Conduit inspections are conducted in one of two ways; exterior conduit inspections and interior conduit inspections. Methods for inspecting the various features of a conduit mainly depend on accessibility. Exterior inspections are obviously the most cost-efficient, but rely primarily on secondary indicators of conduit performance and condition. Interior inspections can be difficult to conduct and sometimes require special equipment. For this reason, exterior inspections are typically used as a good screening tool for justifying more costly, but more definitive interior inspections. The following sections describe exterior inspections and interior inspections in more detail.

Photo 1: Sinkhole around a spillway riser[2]

Exterior Inspections

Exterior inspection of the areas above and surrounding the conduit can provide clues about the condition of the conduit. Depressions, sinkholes, or cavities noted along the outlet conduit alignment on the surface of the embankment are indications that internal erosion or backward erosion piping is likely occurring. Seepage areas may also be indicated by changes in vegetative color or excessive vegetative growth on the embankment dam surface. Cloudy discharge or sediment deposits at toe drains or conduit outlets are other external indicators of potential internal erosion issues of the embankment along or into the conduit. Unexplained outlet discharge unrelated to outlet operation or known leakage past the outlet gate is also an indication of potentially deteriorating conditions. If any of these indicators is observed during an exterior inspection, photographs should be taken and the areas monitored for continued changes. These exterior indicators warrant an inspection of the conduit's interior if one has not been recently completed.

Interior Inspections

In attempting to inspect the interior of any conduit, accessibility must be considered. Typical accessibility issues include access to the outlet, unwatering the conduit and stilling basin, poor air quality, or small diameter conduits. Confined space permitting, lockout/tagout safety procedures, and stand-by emergency response personnel are all generally required for man-entry into any accessible conduits. If the conduit cannot be unwatered, then special services such as closed circuit television (CCTV), remotely operated vehicles (ROVs), or divers should be used. As a general rule of thumb, dive inspections are 3 to 5 times more expensive than ROV inspections. Should divers be selected to perform an inspection, it is important that they are certified by the Association of Diving Contractors International. Similar to a typical man-entry inspection, a pre-dive inspection plan should be developed and the objectives of the inspection clearly defined prior to the dive, because underwater communication can be difficult with the diver once underwater.

Conduit diameters smaller than 36 inches are generally inaccessible for man-entry and require the use of CCTV or ROVs. An ROV unit typically consists of a video unit, a power source for propulsion, vehicle controllers, and a display monitor. ROVs can be obtained for both dry and underwater conduit inspections. ROVs are capable of providing real-time viewing, continuous video for re-viewing, spot photography, and surveying for spatial reference during re-viewing (typically determined by the length of cable discharged into the conduit with the ROV unit).

Photo 2: ROV entering a conduit for inspection.

If unwatering of the conduit is not possible and the cost of diving is prohibitive, an ROV or CCTV unit can

[2] FEMA *Technical Manual: Conduits Through Embankment Dams*

be used. While ROVs or CCTVs can compensate for the inherent limitations of underwater dive inspections (depth, temperature, altitude, time, etc.) extreme caution is advised when using an ROV for inspection. The ROV operator should be qualified, experienced, and knowledgeable of the potential hazards involved. The primary concern when using an ROV for inspection is that the ROV can become entangled or get stuck in a small-diameter conduit, causing an obstruction. Retrieving ROV units can be difficult and expensive work, so care should be taken prior to the inspection to develop a retrieval plan for the ROV unit. Often, a steel umbilical cable is connected to the unit prior to deployment to assist in retrieval.

In contrast to ROVs, CCTV can be utilized. CCTV units are typically manually operated, mounted onto an external carrier, and pushed into the conduit using a rod to direct the mounted CCTV. Historically, it has been difficult to obtain real time video or images captured by the CCTV but with the advent of mobile technology, cameras that allow for some mobile viewing and control have become commercially available.

In terms of costs, ROV units are typically rented at rates ranging from $1,000/day to $3,000/day, depending on the sophistication of the unit. ROV units can usually be rented directly and the unit shipped or picked up for use. For the reasons previously listed, it is recommended that experienced and certified personnel be used to operate ROV units whenever possible. The cost for a small crew to mobilize, operate the ROV unit, and demobilize depends on the travel required for the crew but usually ranges between $1,500 and $3,000. Most inspections can be conducted in one working day with two days spent traveling to and from the site. In contrast to ROV units, CCTV units are typically purchased by the dam owner and assembled on site. With minimal maintenance, CCTV units can be re-used for future inspections and are a cost-effective solution for many dam owners of small to intermediate sized dams.

One CCTV device that has been used successfully for years by members of the Colorado Dam Safety Branch is a sled-mounted camera attached to a metal push pipe with couplers to extend the sled in 6-foot lengths as necessary. Originally designed by Jim Norfleet in the 1990s and recently modernized by Jason Ward, the sled unit can be constructed for about the cost of a single ROV rental. Details of the sled are provided as an attachment to the PDF of this Tech Note issue and a photo is shown below.

Photo 3: Manually operated CCTV sled.[3]

Common issues with CCTV units include difficulty in obtaining real-time images, lack of spatial reference, and the potential for getting the unit stuck and causing an obstruction. In addition, when inspecting longer conduits or those with bends, CCTV can be problematic and ROV units are typically used instead. Even if man-entry is not an option, the conduits would preferably be unwatered prior to inspection, because particles floating within the water often reflect back during the lighted camera inspection and prevent full view of joints and damage around the conduit.

In addition, both ROV and CCTV inspections should be monitored by a qualified engineer. When viewed continuously during the inspection, qualified inspectors can spot locations where additional time and video angles are warranted. Modern ROV equipment includes pan and zoom capabilities that can be used to get the most from the inspection. Without adequate oversight, untrained technicians can unknowingly move past areas of interest too quickly and diminish the value of the inspection.

If the conduit is accessible for man-entry, the inspection should be documented using photographs or video equipment and whenever possible, the interior of the conduit should be pressure washed prior to the inspection. Locations of all damaged or questionable areas should be documented using

[3] Photo courtesy of www.water.state.co.us

measuring tape and in concrete conduits, locations of cracks along the conduit should be documented using a crack map, or similar reporting method, to track the development of new cracks during future inspections. The continuity of cracks can be investigated using a geologist's pick to tap on the concrete and listen for variations in pitch that give clues as to the condition of the concrete. In pre-cast conduits, the joints in the conduit should be checked for separation due to settlement along the conduit alignment or issues with construction during assembly of the conduit sections. In conduits accessible for man-entry, joint meters can be installed to monitor the opening and closing of the joints that might be of concern.

Other common defects observed during interior conduit inspections include deterioration or corrosion, obstructions, joint offsets and separations, defective joints, voided encasements, heaving, and cavitation damage. Sediment accumulation within the pipe, especially a concentrated build-up, is usually a sign of a defect along the pipe. Cavitation damage generally occurs immediately downstream of mechanical control equipment, such as gates or valves in the outlet works, where pressure flow changes to free flow. Cavitation damage is usually characterized as an erosion issue that begins with pitting and progresses into large cavities. Proper venting is the best method for preventing cavitation damage. The July 2013 issue of the *Western Dam Engineering* Technical Note can be referenced for information on proper ventilation for outlet works and common indications of cavitation during inspections. Repair methods for some of the defects listed will be covered in more detail in the following sections.

Different Types of Conduits and Common Issues Associated with Them

A variety of materials has been used to construct conduits through embankment dams during the past 100 years. For the purposes of this article, conduits constructed of concrete, plastic, and metal will be reviewed, as they are the most common conduit materials used in small to medium sized dams. This section presents some common defects with each of these materials and a few potential repair alternatives. All repairs presented below require complete unwatering and isolation of the conduit from the reservoir.

Precast Concrete Conduits

Reinforced concrete pressure pipe (RCPP) and reinforced concrete pipe (RCP) are two types of conduits that have historically been used in many small to intermediate sized embankment dams. One of the primary advantages of precast concrete conduits is that they are relatively inexpensive and can be purchased in standard lengths. RCP/RCPP conduits are connected using a bell and spigot type of connection and can be constructed to accommodate some expected settlement along the conduit alignment due to the flexibility provided at each joint location. However, leaks are prone to develop at RCP/RCPP joint locations because the reinforcement is not continuous at the joints and there is potential for exceeding the joint extensibility through poor construction techniques or settlement along the conduit alignment.

Other common issues to look for during inspections of RCP/RCPP conduits are cracks in the conduit and spalled concrete. Cracks in the conduit typically occur at the transition immediately downstream of the control structure due to differential settlement. Spalling often occurs in precast concrete pipe at the joint locations where there is unequal displacement of the joint in the crown and invert or spring line. It should be noted that a well prepared subgrade, continuously positive slope, and good quality control during construction can go a long way toward preventing these joint offsets and other associated issues. Whenever possible, a concrete cradle should be used beneath pre-cast conduits to ensure support underneath the conduit haunches. Unfortunately, however, these more modern practices have not always been followed in the past, leading to long-term degradation of existing precast concrete conduits.

Spalled Concrete

Methods to repair spalled concrete within concrete conduits are similar to that of typical concrete structures. The surface must first be prepared by removing the deteriorated concrete down to sound material. Reinforcing steel exposed for more than one-third of its circumference should be completely exposed to provide clearance around the reinforcement for the repair material.

The final prepared surface should be free of all loose aggregate, spalled concrete, and dirt, leaving the aggregate of the remaining concrete partially exposed to achieve a good bond between the existing and new material. For most small to intermediate sized conduits, the conduit thickness isn't sufficient to develop reinforcement, so dowels typically are not used. All surfaces to be covered with fresh concrete should be moistened to saturated surface dry condition and all standing water removed, leaving the surface damp immediately prior to receiving concrete. A high strength, 3/8-inch concrete mix is usually prescribed for the repairs (pre-mixed Sika product or similar).

Photo 4: Spalled concrete inside a conduit.[2]

Joint Offsets and Cracked Concrete

Since RCPP conduits are typically made up of short sections of pipe connected by gasketed bell and spigot type connections, the joint locations are a common place for deterioration or poor construction practices to manifest. First, the cracks or joint offsets should be thoroughly cleaned of any embankment material and cleared of all loose or spalled concrete. For larger cracks, offsets, or failed joints, grout injection helps to fill any voids that may have developed behind the conduit due to localized erosion at the crack or joint locations.

Photo 5: Crack in precast concrete conduit.

For this method of repair, the opening should be temporarily sealed, creating a bulkhead, so that grout can be injected behind the conduit. Non-shrink grout can be applied from the interior of the conduit to develop the bulkhead and grout injection ports can be installed through the grout, around the circumference of the crack, at a spacing that will allow the grout to fill any voids that may have developed. Generally, grout injection behind the conduit should be completed so that the injection pressures do not exceed about half the lateral earth pressure of the embankment at the location of the crack.

Photo 6: Grouted joint offset with grout port installed for injection grouting behind conduit.

For large cracks, redundancy may be desired and a mechanical repair can be implemented by installing a seal around the inside of the conduit after injection grouting has been completed. A mechanical seal should span the original crack to overlap sound concrete (typically 6-9 inches on either side of the crack). Various products are available to create this seal (Link-Pipe Grouting Sleeve™, EPDM rubber seal, etc.). Many common mechanical repairs consist of a rubber seal with a stainless steel band that helps to compress the rubber seal against the conduit by expanding the band once in place. It is important that any mechanical repairs implemented within the conduit be tapered at the ends to minimize flow obstruction. Because seepage can sometimes extend away from the conduit, it is important that repairs like these are monitored by regular exterior and interior inspections to ensure no new signs of internal erosion, backwards piping, or seepage into or along the conduit develop.

Photo 7: Link-Pipe Grouting Sleeve after installation over cracked conduit.

Metal Conduits

The most common metal pipe used today in constructing conduits through embankment dams is steel. Steel pipes are typically used as liners in RCIP conduits. These conduits are typically delivered to the job site with the interior painted from the factory and the exterior bare steel. The pipe is typically set into place and the joints welded together. The factory-applied coating along the interior of the conduit stops about six inches short on either side of the joints (to allow space for welding) and has to be painted in the field after assembly. A reinforced concrete encasement is cast-in-place after the conduit has been water tested and accepted for use.

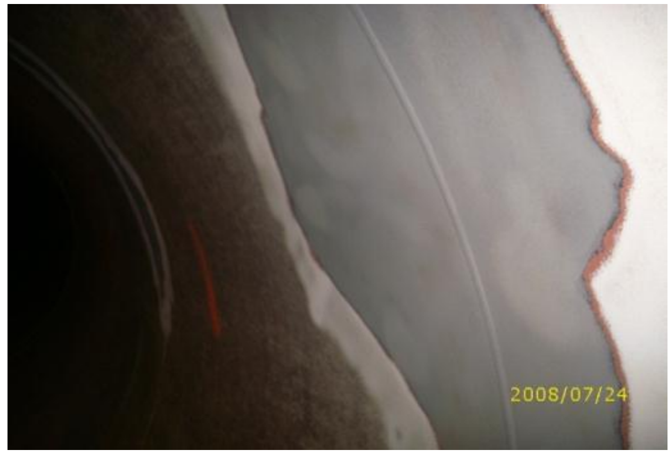

Photo 8: Sandblasted steel surface in preparation for applying new epoxy coating at joints.

Corrosion

A common maintenance issue for steel liner encased conduits is deterioration of the coating system and corrosion of the conduit. Because the joints are painted in the field, the coating at joint locations often deteriorates faster than other portions of the pipe. For that reason, proper care and quality control is critical during construction. Remediation of the liner coating system typically includes sandblasting the interior of the liner to expose the bare steel and applying two coats of high solids epoxy paint (typically ~7 mils per coat).

Voided Encasements

Another common issue in steel liner encased conduits is voids within the concrete encasement due to poor consolidation of the concrete. This issue is most prevalent in encasements that are constructed monolithically (no horizontal construction joints). In these cases, consolidation beneath the steel liner can be difficult during construction. Voids behind the steel liner are usually detected during a conduit inspection from visual confirmation of seepage at the downstream end of the encasement or the sound of water moving behind the conduit.

Sinkholes, depressions, or cavities on the surface of the embankment, along the conduit alignment, can indicate piping and the potential for voids within the encasement. Because of the presence of the welded steel liner, seepage into the conduit is typically not an issue. Repairs to voided encasements are generally made by injecting grout behind the steel liner. Pressure grouting behind the steel liner is done via primary injection ports that are drilled and installed along the invert, spring line, and crown of the voided encasement to ensure that the grout can travel and vent as necessary. Secondary grout ports can be added at intermediate locations if communication between the primary grout ports is not confirmed (air or grout return). Grout pressures should be monitored during injection and each port grouted until project criteria for grout refusal is met or grout return is achieved at the next grout port location. Communication between the voids in the encasement and the surrounding embankment could exist; therefore, pressures should be limited to prevent fracturing the embankment behind the encasement.

In the past, many small and intermediate sized embankment dams were constructed with conduits made of Corrugated Metal Pipe (CMP). CMP has a typical service life of about 25 to 50 years, but depending on the metal's reaction with certain soils and water conditions, cases have been documented where CMP has deteriorated in less than 7 years after construction. The current state of practice is not to repair severely deteriorated CMP but to replace it with another conduit system. Describing methods for replacing CMP conduits is outside of the scope of this article but the March 2013 issue of the Western Dam Engineering Technical Note can be referenced for information on slip lining existing conduits.

Photo 9: Injection grouting voided encasement behind steel liner.

Plastic

Historically, when compared with steel or concrete, plastic pipe has not been commonly used as the primary material in outlet conduits. FEMA (2007) describes the uses of plastic pipe in embankment dams. Plastic pipe is more typically used in small-diameter toe drain systems. Plastic pipe, however, has been used in lining rehabilitation of existing conduits. Plastic conduits are generally considered to have a shorter service life than RCPP conduits (approximately 50 to 100 years). However, in environments where the water or soil may cause premature degradation of concrete and steel, plastic conduits may be a favorable alternative. Lining rehabilitation with plastic pipe is typically accomplished by one of two methods, slip lining (typically using HDPE) or cured-in-place pipe (CIPP) liners. Slip lining is completed by installing a smaller, "carrier pipe" into a larger "host pipe," grouting the annular space between the two pipes, and sealing the ends. Preventing collapse of the interior carrier pipe during grouting of the annulus is critical to the success of a lining rehabilitation project. Pressures should be monitored during grouting and, in some cases, the carrier pipe filled with water to provide additional resistance to collapse.

Photo 10: Grouting HDPE liner pipe.[3]

A CIPP liner is a resin-saturated felt tube made of polyester, which produces a jointless, seamless, pipe-within-a-pipe. A CIPP liner is either inverted or pulled into the host pipe, cured-in-place using pressurized steam or hot water, and serves as the new carrier pipe. Although these rehabilitation methods may also require draining of the reservoir, they are typically lower cost alternatives to cut and cover methods for full replacement. Renovation of existing conduits by installing a liner is outside the scope of this article, but the March 2013 issue of the Western Dam Engineering Technical Note can be referenced for information on slip lining existing conduits.

FEMA's technical manuals provide detailed discussion of parameters that should be considered during the slip lining design process.

FEMA - Conduits through Embankment Dams

FEMA - Plastic Pipe Used in Embankment Dams

Conclusion

For a variety of reasons, joint offsets, cracks, liner deterioration, and voids are common issues that must be addressed during the service life of a conduit. With careful planning, design, and construction quality control, existing outlet pipe repairs can be successfully implemented and the service life of an outlet structure extended. As an alternative to conduit abandonment or rehabilitation, this article presents some repair methods that can be considered for typical localized defects of various types of conduits commonly associated with small dams. The repairs discussed in this article should be carefully considered for each specific project before implementation, and final design should be prepared by an experienced dam engineer.

Useful References

The following is a list of design references that should be used during design:

[1] FEMA (2005), *Technical Manual: Conduits through Embankment Dams*, FEMA 484, Federal Emergency Management Agency, September 2005.

[2] NRCS (2005), *Structural Design of Flexible Conduits*, NRCS, 2005.

[3] FEMA (2007), *Plastic Pipe Used in Embankment Dams*, FEMA, 2007.

[4] AWWA (2004), *Steel Water Pipe: A Guide for Design and Installation*, AWWA, M11, 2004.

[5] *Amstutz (1970), Buckling of Pressure Shafts and Tunnel Linings, Amstutz, Ing. Ernst, 1970.*