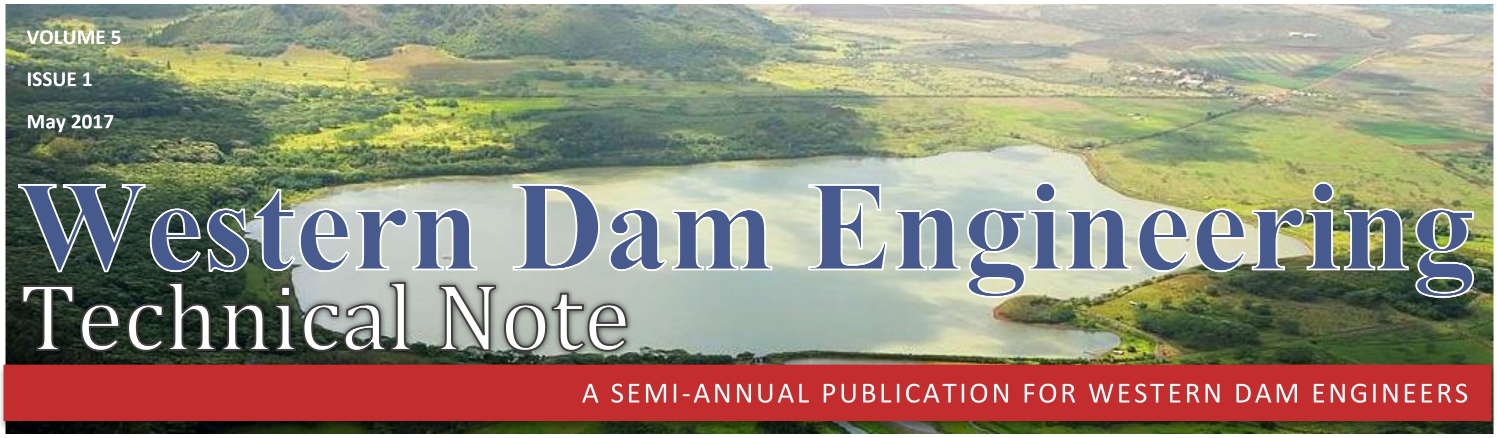

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In this issue of the ***Western Dam Engineering Technical Note***, we present articles on **emergency response to seepage and internal erosion**, **certainty and uncertainty of hydrologic modeling results**, and **inspections of corrugated metal pipes**. This semi-annual newsletter is meant as an educational resource for civil engineers who practice primarily in rural areas of the western United States. This publication focuses on technical articles specific to the design, inspection, safety, and construction of small to medium sized dams. It provides general information. The reader is encouraged to use the references cited and engage other technical experts as appropriate.

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Article Authors:
AECOM: Doug Yadon, PE, Chad Vensel, PE; Hui-Ming "Max" Shih, PhD, PE, CFM; Josh Shackelford, PE; Jennifer Williams, PE; Jason Boomer, PE; John France, PE

Good to Know

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ASDSO National Dam Safety Conference, *Sept 10-14, San Antonio, TX*

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Inspecting Corrugated Metal Pipes in Embankment Dams

Introduction

Until about the 1980s, corrugated metal pipe (CMP) was commonly used for outlet conduits to convey water through earth embankment dams. Typically now used only in low-hazard dams, CMP are not appropriate for use in significant- and high-hazard dams. Many state dam safety regulations now preclude the use of CMP in these higher-hazard structures or they impose rigorous corrosion standards. However, due to hazard creep of low-hazard dams, regulators and dam owners all too often find themselves in a position of having deteriorated CMP's in those critical structures.

CMP also has several serious disadvantages, such as susceptibility to corrosion and abrasion [1]. Due principally to its vulnerability to corrosion, but also because of the potential for other deficiencies (e.g., damage during installation, improper joint connections, etc. described later in this article), the use of CMP as a conduit has been attributed to earth embankment dam failures in the western United States [3].

CMP conduits may be overlooked by dam owners during routine dam inspections because these conduits are often not easily accessible and owners may not be aware of the possibility of failure, or even of their presence. This can lead to a potentially dangerous "out of sight and out of mind" approach. In some cases, CMP conduits were extended during a previous embankment raise with a more durable concrete conduit section, and therefore, only the concrete is visible on the downstream end. Depending on its use, CMP typically has a service life of 25 to 50 years. However, there have been cases when CMP has deteriorated in less than 7 years, given certain soil and water conditions [1]. Most dams, even low hazard dams, have a service life greater than 50 years, meaning that most CMP conduits can be expected to be a potential failure pathway during the service life of every dam where they have been used. It can be reasonably expected that a CMP conduit will need to be repaired or replaced during the life of a dam.

Figure 1. A CMP Conduit Being Installed [1].

This article will explain:

- How to inspect CMP conduits within earth embankment dams;
- How to recognize common deficiencies associated with CMPs; and
- How to determine whether to monitor, repair, or replace the CMP.

CMP Conduit Inspection Techniques

CMP conduits should be inspected by qualified and trained individuals on a frequency representative of the dam's hazard classification. High- and significant-hazard dams are typically inspected on an annual basis, which would include external inspections along any conduits. Internal inspections of conduits for high- and significant-hazard dams are typically recommended on a 4- to 5-year frequency [1]. For low-hazard dams, external inspection may be as infrequent as every 5-6 years and internal conduit inspections every 10 years [1]. Flood control dams that do not retain a pool under normal operating conditions may have less frequent inspections per some state guidelines. The frequency of inspections may need to be increased if accelerated corrosion of the CMP is observed or there is a change in the operating conditions of the reservoir that make problems apparent (e.g., lower pool level exposing previously submerged portions of the CMP). More detailed information regarding inspections can be found in *Technical Manual: Conduits through*

Embankment Dams, produced by the Federal Emergency Management Agency [1]

It is preferred to seal off all water flow and drain the CMP prior to conducting an inspection. In some cases water shutoff is imperative to allow even remote camera access. Many deficiencies within a CMP conduit can be hidden by just a few inches of water. Shutting off the water supply to a conduit may require preplanning as gates or valves that have not been operated in many years may need to be closed or reservoir water levels may need to be lowered to allow water to be stored instead of released during the inspection.

The CMP conduit should be relatively clean and free from obstructions prior to conducting an inspection. Cleaning of the conduit is a preferred preparatory step, as dirt and debris can hide deficiencies within the conduit. Obstructions should be removed prior to conducting an inspection. Several methods may be used to clean the conduit, such as flushing, using a cleaning pig, or pressure washing. The cleaning and inspection crew must exercise caution when using any of these methods as they may accelerate deterioration of a CMP conduit, especially if the conduit is already partially deteriorated or corroded.

CMP conduits are typically inspected using one of two methods: camera inspections or manned entry. Manned entry should only be used when it is safe to do so, including adequate isolation from water sources, sufficient pipe diameter, and implementation of confined space protocols. Both of these methods are discussed in more detail below.

Camera Inspections

Unmanned camera inspections can include the use of manually or power propelled systems equipped with still, real-time and recorded video, and/or closed-circuit television (CCTV) cameras. Utilizing a CCTV camera mounted on a self-propelled robotic crawler (as shown on Figure 2) is the most common way to effectively inspect a CMP conduit. An operator controls the movement of the crawler and the operation of the CCTV camera. Real-time video is transmitted to an aboveground monitor, which the operator uses to determine where to move the crawler and where to focus the camera.

The CCTV camera should be capable of operating in 100 percent humidity and should have a rotating camera head so that all features and defects of the conduit can be inspected thoroughly. The camera should have a self-leveling head to keep the camera upright through the video inspection. Camera lighting should be sufficient to provide a clear, in-focus picture of the entire periphery of the conduit.

Figure 2. CCTV Camera on a Pipe-Crawler Being Inserted into a Conduit (courtesy Drains Kleen).

The camera should also come to the site equipped with a remote-reading footage counter so that features or deficiencies of the conduit can be specifically located. The location and condition of all features and deficiencies must be logged by the operator. This allows comparison and contrast of the current inspection with all past and future inspections. It is desirable for the operator to provide a voice description of observations within the video recording, if possible. The inspector should provide the dam owner with a copy of the video inspection on a DVD disc or a USB flash drive. The dam owner should provide a written summary of the findings and conclusions of the internal inspection, and the full video record, to the state dam safety regulator.

Typically, the most accessible entry point is at the downstream discharge portal of the pipe. If there is flow within the pipe with reservoir drained, the camera should be moved to the upstream end of the conduit and the inspection should continue towards the downstream end so that any flow within the conduit is moving along with the camera rather than splashing against the camera lens. The operator should be instructed to stop the camera and inspect all features (such as joints, gaskets, gates, etc.) and all deficiencies/damage (no matter how seemingly minor they may be). The camera should focus on the feature or deficiency and pan around as necessary to obtain a complete, unobstructed view. When traveling through the conduit, the camera should proceed at a speed that ensures no features or defects are overlooked. Frequent stopping to pan and zoom to highlight areas of interest should be expected, especially in conduits of suspect condition.

It is strongly recommended, but not absolutely necessary to have an engineer present during routine inspection. However, if an engineer is not present, the inspection should be recorded and conducted by an experienced operator. It is recommended that the inspection video be reviewed by an engineer so that they may evaluate the results. We recommend the CCTV operator be Pipeline Assessment Certification Program (PACP) certified, as these operators will have specific training to determine the overall condition of the conduit and the severity of any deficiencies.

Advantages of CCTV camera inspections include:

- No manned entry of confined spaces is required.
- The CCTV camera is able to fit into conduits as small as 6 inches in diameter.
- The CCTV camera provides a recording that is easy to compare to past or future recordings to determine how the condition of the conduit has changed over time.
- The CCTV recording can be shared with the dam owner's engineer for off-site evaluation.

Disadvantages of CCTV camera inspections include:

- It can be difficult to navigate the CCTV camera around gates or valves within the conduit (especially in smaller diameter conduits).
- Inexperienced CCTV camera operators can overlook deficiencies within the CMP conduit.

Some CCTV contractors may promote the use of "push" style CCTV systems. As their name implies, these cameras are pushed into the conduit using a stout cable or rod. Using a push style CCTV camera is less desirable as there is no way for the operator to control the angle of the camera and the dam owner will not be able to see any features or deficiencies clearly. An additional inspection with a camera mounted on a robotic crawler may be required as a follow up to a push style CCTV inspection, which can add time and expense to the inspection process.

Using a mobile video camera, such as a GoPro®, mounted on a sled (as shown in Figure 3) is a cost efficient method to inspect straight (without bends or undulations) conduits, especially conduits at remote dam sites given its small size and ease of transport. The sled can be easily manufactured and attached to a metal push pipe with couplers to extend the sled in 6-foot lengths, as necessary. This style of system will allow the conduit to be inspected by providing video and pictures, but has limitations associated with the lack of panning capabilities and maneuverability of the camera. See our previous Western Dam article You Con-du-it; How to Fix a Leaky Pipe for more information on the mobile-camera sled system used commonly by the Montana and Colorado Dam Safety branches.

Dam owners should expect to pay somewhere between $3 and $6 per linear foot of conduit inspected, plus mobilization costs, for a CCTV camera mounted on a crawler system. The above described manually-propelled sled system can be constructed for about the cost of one or two CCTV crawler inspections.

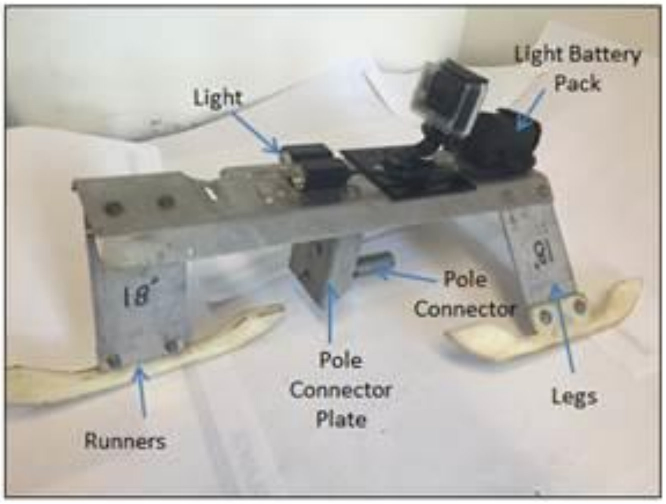

Figure 3. Camera Mounted on Inspection Sled.

Manned Entry

In some instances, it may be possible to inspect CMP conduits via manned entry. The conduit should be at least 36 inches in diameter to safely conduct a manned entry inspection.

Safety is an important consideration with a manned entry inspection. Per OSHA regulations, a confined space is defined as a place with "…limited or restricted means for entry or exit and is not designed for continuous occupancy" [4]. At a minimum, all CMP conduits through dams meet the OSHA definition of a confined space. Furthermore, most CMP conduits through dams will meet the OSHA definition of a permit-required confined space, meaning that special regulations and procedures apply and specialized safety equipment (such as hoisting winches, atmospheric monitors, mechanical ventilators, etc.) will be required to enter the conduit. OSHA regulations for confined spaces must be reviewed and a proper safety planning must be carried out prior to conducting any manned entry inspection.

Advantages of manned entry inspections include:

- Manned entry allows for a set of eyes to focus on the problem, instead of just a camera lens.

Disadvantages of manned entry inspections include:

- Safety precautions must be taken prior to manned entry of CMP conduits. Injury or death could result from an improper effort.
- Only conduits larger than 36 inches in diameter can be inspected via manned entry.

Common Deficiencies in CMP Conduits

Deficiencies within CMP conduits are generally due to either corrosion or construction defects. The presence of either of these types of deficiencies, when not detected and remedied, has the potential to progress to a dam safety incident and even dam failure.

Corrosion Leading to Internal Erosion of Soils

CMP conduits are especially susceptible to corrosion. The metal within the CMP conduits corrodes due to an oxidative process that involves the formation and release of metallic ions. CMP conduits often corrode from the inside out, due to the presence of water and oxygen within the conduit. If water flowing through conduit contains high sediment it can also abrade the CMP, which reduces the life of any protective coatings. However, corrosion can initiate from the exterior of the pipe depending on site specific factors such as soil composition and moisture. Therefore, upon the first signs of corrosion during interior inspections, it should be considered whether the corrosion may have initiated from the exterior, in which case the deterioration may be more progressed than readily visible from the interior inspection.

The process of corrosion can progress either uniformly or in pitting of the surface. Uniform corrosion is where corrosion occurs evenly over a surface, resulting in a lower rate of corrosion. Pitting corrosion is not uniform and is focused only on a small surface area, resulting in a high rate of corrosion, until a perforation (or pit) eventually develops. Pitting can begin on surface imperfections, scratches, or surface deposits. [1]

The pipe invert is particularly susceptible to corrosion since it is exposed to the flow of water for the longest length of time. CMPs that have inverts with sags could trap water and further increase the potential for and rate of corrosion. Other likely susceptible locations include pipe connections and areas of pipe deformation. Once the corrosion process extends through the wall thickness, a hole or void develops within the conduit, which can allow embankment soils to erode into the conduit. If not detected early, this defect can lead to an internal erosion failure and potentially a breach of the embankment. **Figure** shows a 48-inch CMP internal erosion failure in progress as the result of corrosion.

Figure 4. 48-inch CMP Failure Due to Corrosion

Construction Defects

Construction defects can include joint settlements or slippage and conduit deformations. CMP is flexible and is designed to deform. The surrounding soil provides stiffness and load carrying capacity for the conduit. If the surrounding backfill soil is not adequately compacted or if large equipment is used over the pipe during construction without adequate backfill, deformations are likely to occur. Further, if the foundation is subject to large differential settlements (and therefore spreading), joint slippage may occur. Joint settlements (as shown on Figure 5) provide an immediate path for embankment soils to erode into the conduit. Deformations (as shown on Figure 6) can weaken the pipe and/or introduce strain causing the pipes protective coating to weaken leading to accelerated deterioration.

Figure 5. Joint Settlement in a CMP Conduit [2].

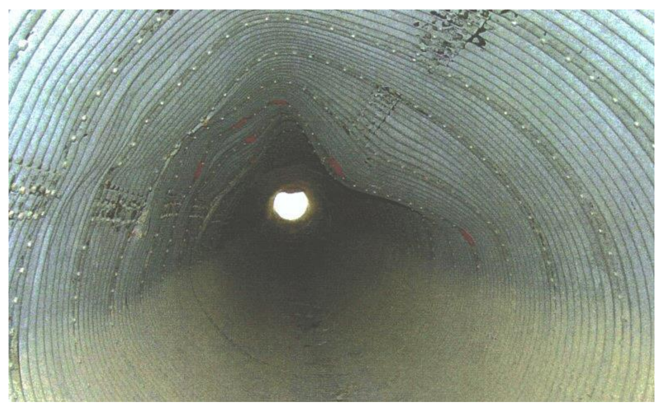

Figure 6. Deformation in a CMP Conduit [1].

Monitor, Repair, or Replace?

The decision to monitor, repair, or replace the CMP conduit can be complex and it involves several factors. This decision is often based on the consequences of potential failure, severity of the defect, the resources available to the owner, and the requirements of the appropriate state dam safety program. Some general guidelines are provided below, but dam owners should make these important decisions in consultation with a qualified engineer.

Continue Monitoring

The dam owner may decide to continue monitoring the following deficiencies without compromising immediate dam safety:

- Minor corrosion, where water is not yet flowing through the walls of the CMP conduit (as shown on Figure 7) – Dam owners should consider inspecting minor corrosion on a more frequent basis to ensure that the deterioration does not worsen to a point where failure is imminent.
- Minor abrasion, where flow through the conduit has removed or damaged the protective coating of the CMP conduit – Similarly, dam owners should consider inspecting minor abrasion defects more frequently to ensure the abrasion does not worsen.

Figure 7: Minor Corrosion in a CMP Conduit [5].

Repair

Moderate deficiencies in the CMP conduit, where a substantial amount of embankment material has not eroded into the conduit or the pipe, has limited deformation can generally be repaired; however, this course of action should be evaluated by an engineer. These include:

- Moderate corrosion, where water is flowing through the walls of the CMP conduit (as shown on Figure 8), but little to no embankment material has eroded into the conduit. Some additional remedial efforts (such as low pressure grouting using traditional cement-based grouts or chemical grouts) should be undertaken if a minor amount of embankment material has eroded into the conduit resulting in suspected void(s) along the outside of the conduit.

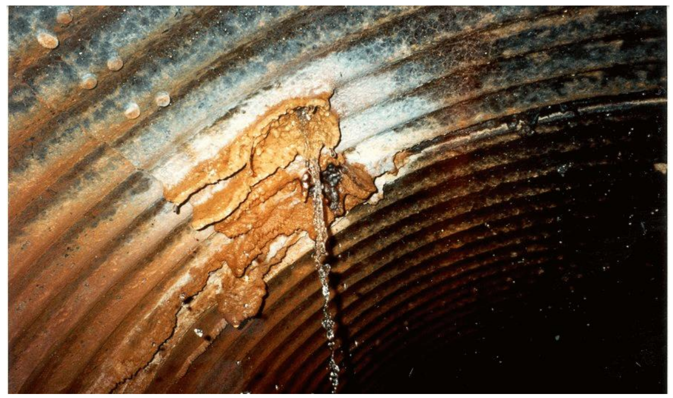

Figure 8. Moderate Corrosion in a CMP Conduit [1].

Replace

It may be necessary to replace the CMP conduit in instances where the conduit is either structurally deficient or a substantial amount of embankment material has eroded into the conduit leading to large voids along the outside of the conduit. Some specific examples include:

- Construction defects, where the CMP conduit has settled or deformed (as shown previously on Figures 5 and 6)
- Major corrosion, where the CMP conduit is no longer structurally sound (as shown on Figure 9)

Repair and Replacement Methods

An in-depth discussion of the repair and replacement methods available for CMP conduits is beyond the scope of this article; however, dam owners should be aware that several effective methods are available. Repair methods include cured-in-place pipe (CIPP), sliplining, spiral-wound liners, and sprayed liners. Some of these methods are discussed in other articles of *Western Dam Engineering Technical Note*, such as:

- Low-Level Conduits – Rehab or Replace (Volume 1, Issue 1, 2013).

- [You Con-Du-It; How to Fix a Leaky Pipe (Volume 2, Issue 2, 2014).]
- [You Down with CIPP? Yeah! You Know Me! (Volume 4, Issue 1, 2016).]

Replacement methods will typically involve an open-cut to ensure that the deficient CMP conduit is removed and a new properly designed and constructed conduit is installed. Replacing the CMP conduit has the potential added benefit of allowing placement of a filter diaphragm or completing improvements that may extend the service life of the dam embankment.

Figure 9. Major Corrosion in a CMP Conduit [2].

Conclusion

CMP conduits can be a major risk concern for dam owners who may not fully understand their design life limitations and how they structurally fail and can lead to dam failure. The pipe generally shows signs of distress before failure. Regular monitoring and inspection of CMP conduits pays off as defects can be detected earlier resulting in less expensive repair options. Eventually; however, if steps are not taken the CMP conduit will corrode enough to allow embankment material to erode into the conduit, and then the only alternative available will be to excavate and replace the pipe. This is a potential emergency situation that may be prevented by early, responsible inspection.

References

[1] Federal Emergency Management Agency (FEMA), *Technical Manual: Conduits through Embankment Dams*, September 2005.
[2] Federal Highway Administration (FHWA), *Culvert Assessment and Decision-Making Procedures Manual*, September 2010.
[3] Great West Engineering, *Manual on Corrugated Metal Pipe in Dams for Montana Dam Owners*, September 2012.
[4] Occupational Safety and Health Administration, 29 CFR Part 1926 (Confined Spaces in Construction – Final Rule), May 2015.
[5] United States Forest Service, Decision Analysis Guide for Corrugated Metal Culvert Rehabilitation and Replacement Using Trenchless Technology, December 2012.