Filter Diaphragms

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Background

Embankment failures and accidents occur more often in the vicinity of conduits in the embankments than at other locations. These accidents and failures associated with conduits in embankments are of several types:

- Defects in the walls of the conduit may develop over time. Seepage water from the reservoir may percolate through soils with low piping resistance and carry fines into any defects in nonpressurized conduits. In pressurized conduits, the water may escape the conduit and erode soils surrounding the defects. In either case, the surrounding earthfill next to the conduit is damaged, and sinkholes or other problems can develop. Corrugated metal pipe (CMP) is most susceptible to this problem.
- Joints may separate from several causes. Conduits on soft foundations may spread and separate under the loading of the dam if the design does not adequately consider this potential. Joint gaskets may be improperly installed, and bands on corrugated metal pipe may be inadequate. In either case, the surrounding earthfill may erode at the separated joint.
- Water may flow along the contact between the conduit and surrounding soils and erode the soils, leading to partial or full discharge of the reservoir water through the openings. In the case of highly erodible soils, the occurrence may lead to a breaching type failure.
- Water may flow through hydraulic fracture cracks in the earthfill above and to either side of the conduit. Conduits often create differential settlement that is conducive to hydraulic fracture, as discussed later in this chapter.

Guidance on topics related to design of conduits is available in other references. To prevent defects from occurring in the walls of the conduit, materials must be selected that have a design life suitable for the structure being designed. Corrugated metal pipes that do not have adequate corrosion protection are especially susceptible to developing defects in the walls of the conduit. Designing conduits to prevent separation of joints is also covered in other references. This chapter concentrates on problems related to water flowing externally in soils surrounding the conduit.

Water flowing along the contact between conduits and surrounding soil is often attributed to poorly compacted soil next to the conduit. Compacting soils uniformly near conduits is difficult for several reasons. First, hand-held equipment must be used next to the conduit because large equipment cannot be used near conduits to prevent damaging them. The zones of hand-compacted soil next to conduits have different properties than the soils that are compacted with large equipment. Secondly, compacting soils under the haunches of circular pipes that do not rest on a cradle or bedding is difficult. Even hand-held compactors cannot direct their energy uniformly under the haunches of pipes. If too much energy is used to compact soils under the haunches of conduits, the conduit may be lifted, creating voids under the pipe.

These problems are most common where flexible conduits constructed of plastic or corrugated metal are used because they rarely are installed on bedding or cradles. Flexible conduits are not placed on cradles or bedding because these would limit their deflection, and the deflection is important to develop the design strength of these types of conduits.

The other type of problem often associated with conduits occurs when water flows through cracks in the earthfill above and to either side of the conduits. Cracks in earthfills are often associated with conduits because the conduits can cause differential settlement of the earthfill. The soil columns on both sides of a conduit compress more than the soil column over a conduit. This differential settlement can result in cracking of the embankment under some conditions.

Differential settlement may also be associated with trenches that are sometimes used to install conduits. A trench condition can create differential settlement when the compacted soil backfill in the trench has very different properties than the foundation soils in the sides of the trench. This problem is most serious for soft or collapsible foundation soils and for trenches with overly steep side slopes. Side slopes of 3H:1V or flatter are usually specified for trenches transverse to an embankment.

Even if the embankment does not initially develop visible cracks from these differential movements, zones of low stresses may occur in the fill. Hydraulic fracturing may occur in zones of low stresses that can lead to pathways for water flow. Water may flow along hydraulic fracture cracks, as well as flowing along pre-existing cracks in the fill. Problems with hydraulic fracturing often occur when an embankment first impounds water to the full pool depth after construction. Hydraulic fracture is discussed in detail later in this chapter.

For all these reasons, the potential for water to flow directly along the outside of conduits and through cracks in the earthfill surrounding a conduit is a serious problem that must be addressed by suitable design measures. Two design measures have commonly been used to address the concern about water flow through the earthfill surrounding conduits. They are:

- anti-seep collars
- filter diaphragms

Anti-seep collars

For many years, anti-seep collars were the standard design approach used to block the flow of water at the interface of the conduit and the backfill surrounding the conduit for all embankments designed by most design agencies. Based on knowledge gained during the period of intensive embankment construction by NRCS and other agencies in the 1960s through 1980s, the use of anti-seep collars was reconsidered. Beginning in the mid-1980s, anti-seep collars were eliminated in designs of major embankment projects because they were judged to be ineffective in preventing many types of failures observed. All of the major embankment design agencies, such as the U.S. Army Corps of Engineers (USACE), Bureau of Reclamation, and NRCS, as well as private consultants, now specify filter diaphragms rather than anti-seep collars. Filter diaphragms have been recognized as superior to anti-seep collars as a seepage control measure. The NRCS still allows the use of anti-seep collars for seepage control along conduits for low hazard dams that are built according to criteria in Conservation Practice Standard (CPS) 378. Filter diaphragms are required design elements in embankments that are outside of CPS 378.

Anti-seep collars originally had two basic purposes. One was to prevent flow along the interface between the conduit and the compacted backfill; the other was to increase the length of the flow path for the seepage water. By forcing water to flow a greater distance, the theory was that more hydraulic head is dissipated. This reduces the energy of the water where it exits the embankment and foundation at the downstream toe of the dam. The theory of increasing the length of the flow path to decrease the potential for piping was based on experience with concrete gravity dams.

Anti-seep collars are typically constructed of metal, concrete, or plastic. Often, the same material is used for the collars as used for the conduit. The CPS for smaller embankments, CPS 378, as amended, requires filter diaphragms to be used for problematic soil types. The NRCS criteria for larger embankments are contained in TR–60, which was revised in October 1985 to require that anti-seep collars no longer be used as a design measure. This amendment required that filter diaphragms be substituted for anti-seep collars in the design of all structures governed by TR–60. Filter diaphragms are discussed in detail in following sections. Anti-seep collars were discontinued on TR–60 size embankments because:

- Several NRCS embankments constructed in the 1960s and 1970s failed the first time the reservoirs filled following construction. The embankments that failed had anti-seep collars that were properly designed and installed, and the surrounding backfill was adequately compacted. It was obvious that the failures were not prevented by the collars. Most of the failures occurred in dams constructed of dispersive clays. Figure 45–1 shows typical embankments that failed even though properly installed anti-seep collars were included in their designs. Failure occurred from hydraulic fracture in dispersive clay embankments. These NRCS embankments failed when the reservoir filled suddenly soon after the dams were completed. Failure was attributed to flow along hydraulic fracture cracks in the embankment. Anti-seep collars were correctly installed and good quality control was used around the anti-seep collars.
- These failures usually occurred shortly after completion of the dam, when the pool filled quickly for the first time. Obviously, not enough time had elapsed for seepage to have caused the failures. One of the purposes of anti-seep collars was to increase the length of the seepage path and, thereby, reduce the hydraulic gradient at the downstream toe. If seepage flow was not responsible for the failures, the function of the collars to increase the length of the seepage flow path was not germane to the problem.
- Studies of the failed embankments showed that the pathway for the water that eroded a tunnel through the dam was most often not directly along the contact between the conduit and backfill, but it was in the earthfill above or to either side of the conduit.
- The Soil Mechanics Laboratory in Lincoln, Nebraska, initiated a testing program on filters for soils in the 1980s. The testing demonstrated the efficacy of a sand filter in intercepting and sealing flow through cracks in an earthfill, thus, preventing subsequent erosion.

Figure 45–1 Failed embankments

In summary, the reasons anti-seep collars were replaced by filter diaphragms in TR–60 were:

- A number of dams failed even though properly designed and installed anti-seep collars were used.
- Sand filters were demonstrated to be successful in controlling erosion by water flowing through cracks in earthfill in laboratory experiments conducted by the NRCS.

Factors that contributed to the failures of the NRCS earthfills are discussed in following sections. The discussion should provide better understanding of the reasons filter diaphragms have become the accepted method for preventing uncontrolled flow of water in earthfill surrounding conduits.

Hydraulic fracture

Cracks in earth dams have many causes. Desiccation, differential settlement, and hydraulic fracture are the most common causes. Cracks parallel to the embankment (longitudinal) are usually less of a problem than cracks transverse (perpendicular) to the alignment of the embankment. Hydraulic fracture is the cause of most cracks in earthen embankments that have failed from internal erosion. The cracks that are opened in an earthfill by hydraulic fracture can extend completely through the earthfill. The cracks can provide flow paths for internal erosion. Hydraulic fracture of an earthfill can occur for several reasons as described in following paragraphs.

Hydraulic fracture can occur in a soil when the water pressure acting on a soil element exceeds the lateral effective stress on the soil. Low lateral stresses are caused by several conditions, most often differential settlement and arching. Arching occurs when soils settle differentially. The presence of a conduit can create conditions favorable for arching. Other factors are also discussed in following paragraphs. Hydraulic fracture usually creates a horizontal plane of weakness in the fill.

Low lateral stresses can occur under the haunches of conduits that are constructed without cradles or bedding concrete because it is difficult to obtain uniform compaction in that area of earthfills. Operating equipment near the conduit must be limited to avoid damaging the pipe, so hand-held equipment is often used to avoid damage by larger compaction equipment. Hand-compacted soil may have different properties than machine-compacted soils.

Desiccation cracks can occur in moderate to high plasticity soils when fill placement is interrupted during hot, dry weather. Cracks can occur even in as short a period as a weekend. Drying cracks should be removed from fill surfaces before placing the next layer of fill. This precaution will avoid a plane of weakness in the fill which could be prone to hydraulic fracture.