Introduction

Many different pipe materials have been used as overflow conduits through embankment dams. As aging dams are rebuilt and new dams are constructed, corrugated HDPE pipe is becoming an increasingly popular choice due to its light weight, joint performance, and structural performance. Corrugated HDPE pipe is suitable for use in many low hazard embankment dam applications, however, as with any pipe material, it is necessary to ensure the dam, overflow structure, and pipe-soil envelope is properly designed and installed for the specific project conditions. Embankment dams, regardless of their size create a significant hazard potential due to the tremendous amount of stored energy in the water they retain.

Embankment Dam Failure Modes

The majority of embankment dam failures are generally the result of inadequate design, poor construction methods, deteriorated pipe, or significant environmental occurrence. Regardless of the cause of failure, the effects can be devastating. It is extremely important to ensure the design criteria and the construction of an embankment dam is properly established to reduce this failure risk. This document will review common failure modes and associated preventative measures.

There are many potential failure modes for embankment dams and while some common modes will be reviewed in this document, it is impossible to provide an exhaustive review. This technical note focuses on failure modes related to the conduit section of a dam. There are two primary methods of outlet works; pressurized outlet works (Figure 1) and non-pressurized outlet works (Figure 2).

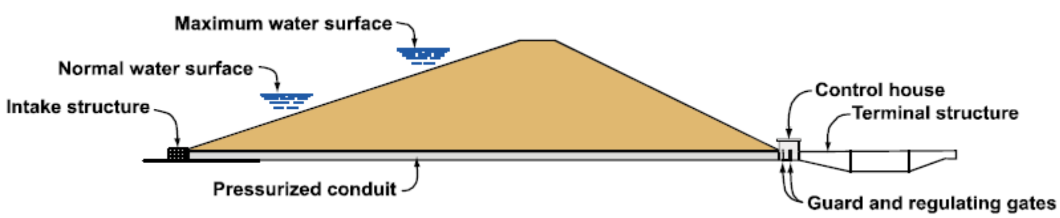

Figure 1. Pressurized Outlet Works

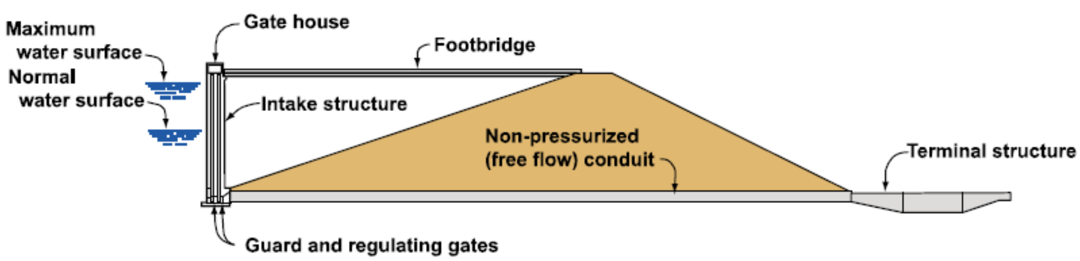

Figure 2. Non-Pressurized Outlet Works

Pressurized outlet works is not an acceptable application for corrugated HDPE pipe because the conduit is typically subjected to constant pressure. These applications typically require specialized pipe material or cast in-place conduit and are engineered specifically for the application. Non-pressurized control methods, however, may be suitable applications for corrugated HDPE pipe, depending on the specific project conditions. While many of the failure modes listed in this document can occur to either of the outlet works methods described above, it is important to note that the pressurized control method is generally much more sensitive to inadequate design, product selection, and construction methods.

1717 16th St NE | Willmar, MN 56201 | Phone: 800-922-1725 | www.prinsco.com

Most embankment dam failures result from "piping erosion" which is a term commonly used to define the erosion processes through soil. This document focuses on failures associated with piping erosion through embankment dams. The first of these failure modes illustrates a hydraulic fracture through an embankment dam occurring above the conduit.

Hydraulic Fracture above Conduit

Hydraulic fractures generally occur in embankment dams due to low stress concentrations in the soil of the dam. When a hydraulic fracture occurs above the conduit it is typically the result of poor dam construction, excessive deflection in the pipe (poor backfill compaction around the pipe), differential settlement within the embankment, poor soils, or excessive water levels. Figure 3 illustrates a hydraulic fracture occurring in the embankment dam.

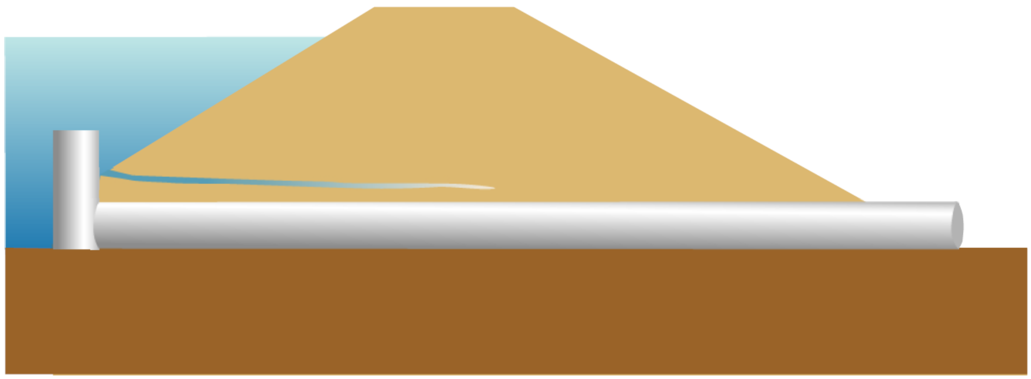

Figure 3.
Step 1 - Onset of hydraulic fracture

The hydraulic fracture eventually extends through the embankment dam due to low stress concentrations in the soil combined with a high enough water level in the reservoir. The progression of this failure mode is illustrated in Figures 3 – 6 as the hydraulic fracture continues through the embankment to cause internal erosion and eventually failure of the conduit and dam.

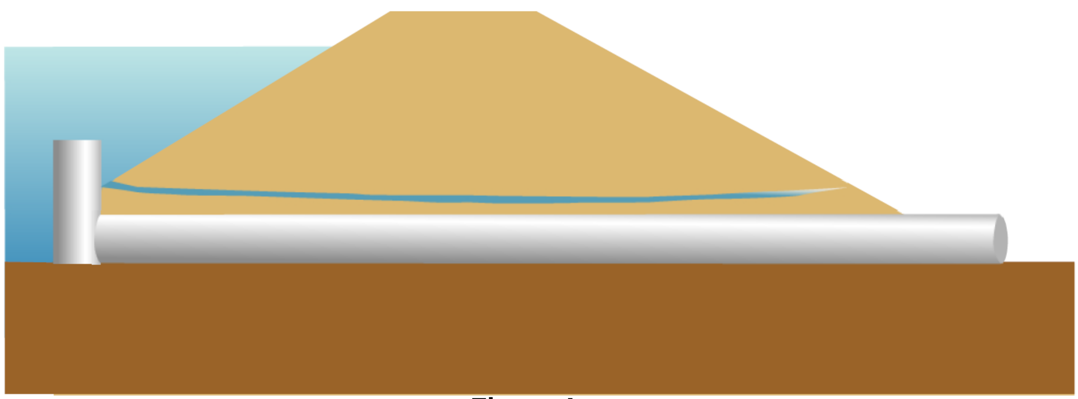

Figure 4.
Step 2 - Hydraulic fracture propagation

1717 16th St NE | Willmar, MN 56201 | Phone: 800-922-1725 | www.prinsco.com

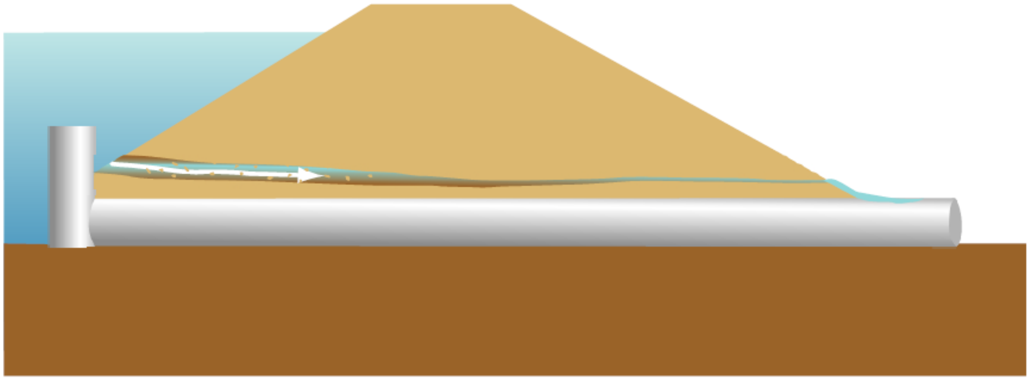

Figure 5.
Step 3 - Onset of internal erosion

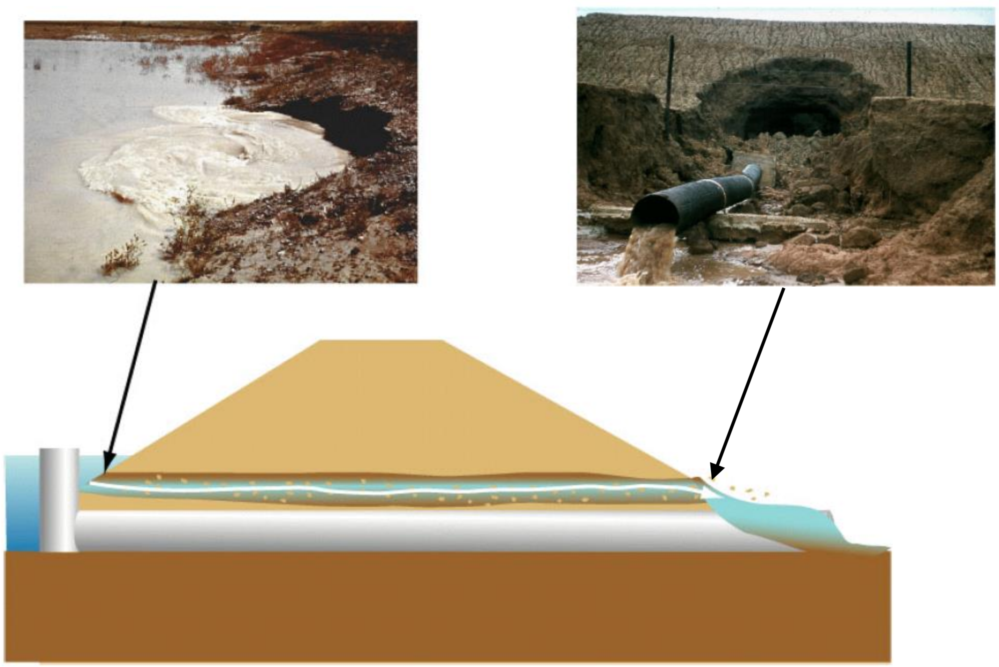

Figure 6.
Step 4 - Complete internal erosion

Hydraulic Fractures beneath Conduit

While Figures 3 - 6 represent hydraulic fractures and ultimate internal erosion above the conduit, hydraulic fractures are not limited to occurring above the conduit. Hydraulic fractures can also occur beneath the conduit as a result of the inadequate or excessive compaction in the haunch area of the conduit. The compaction level of the backfill in the haunch area of a pipe is the most critical area to ensure the pipe has adequate structural support. This can also be the most difficult portion of the backfill envelope to compact if proper compaction methods and equipment are not used. This area of concern is amplified in embankment dam applications due to the hydraulic forces present. While lack of compaction in this area causes low stress concentration areas, excessive compaction causes low stress concentration areas in the bedding directly beneath the pipe invert. The compactive efforts and compaction levels are determined by the type of backfill material, moisture content of the backfill material, the pipe material, and overall embankment dam height. Figures 7 – 11 illustrate hydraulic fracture failures in the area beneath the pipe.

1717 16th St NE | Willmar, MN 56201 | Phone: 800-922-1725 | www.prinsco.com

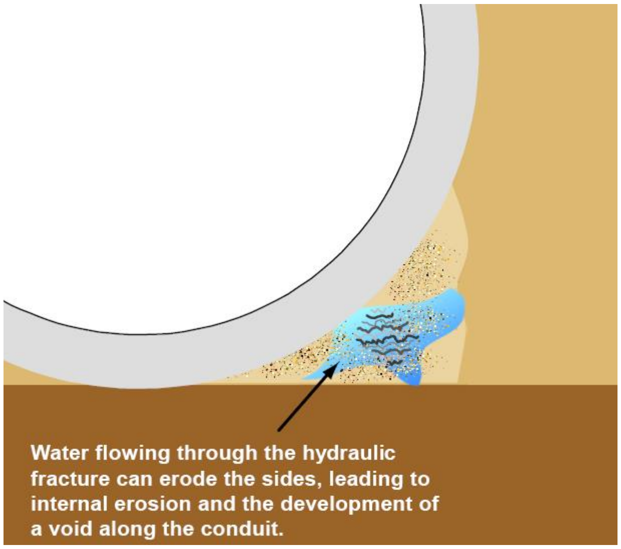

Figure 7.
Hydraulic Fracture due to poor backfill compaction

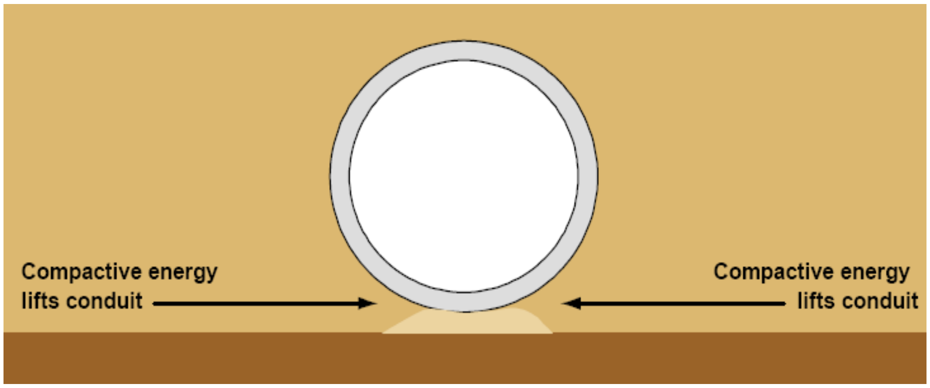

Figure 8.
Hydraulic Fracture due to excessive backfill compaction

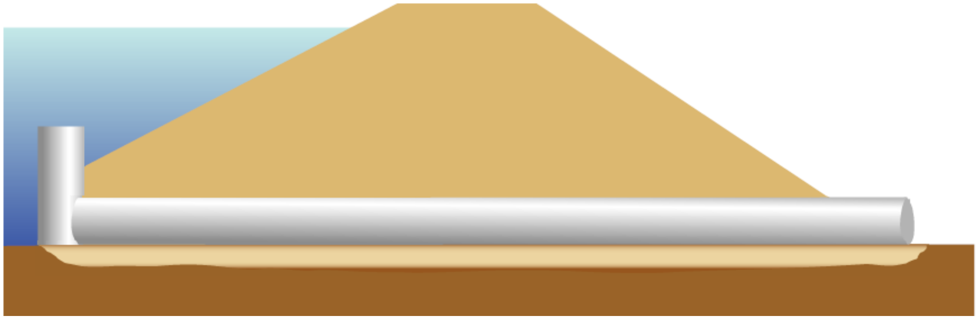

Figure 9.
Step 1 - Hydraulic Fracture propagation causes voids in bedding

1717 16th St NE | Willmar, MN 56201 | Phone: 800-922-1725 | www.prinsco.com

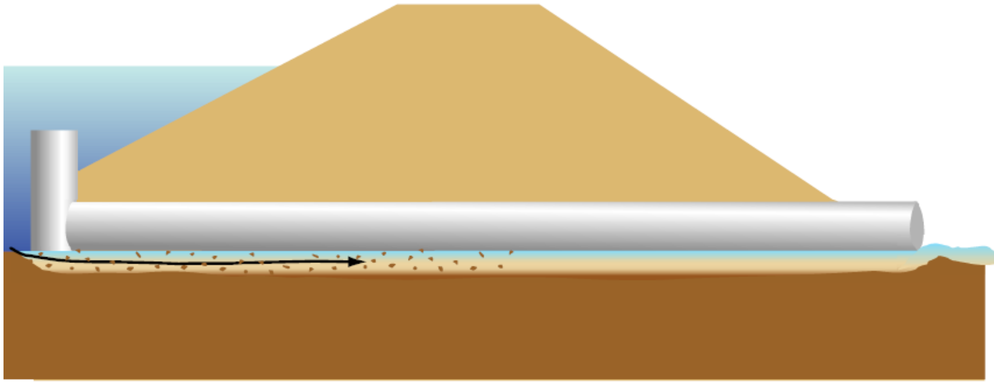

Figure 10.
Step 2 - Internal Erosion occurring through void

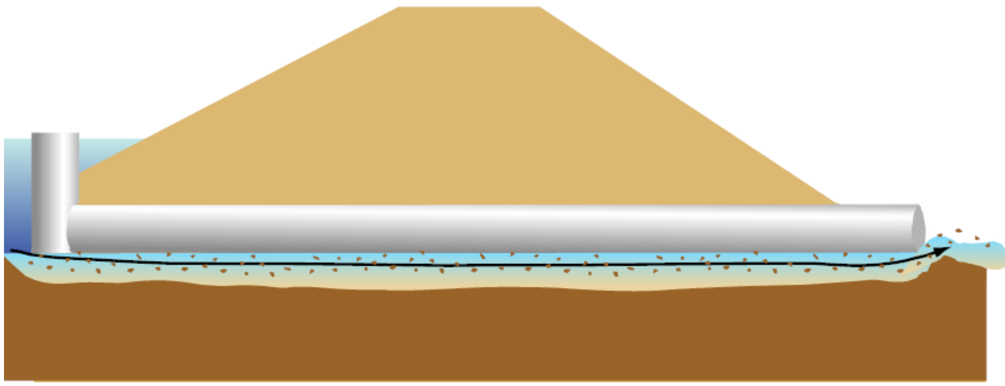

Figure 11.
Step 3 - Complete internal erosion through bedding

Figures 3 – 11 illustrate common occurrences of hydraulic fracture and internal erosion initiating through the face of an embankment dam above and below the conduit. These failure modes and illustrations are not meant to be an exhaustive listing of all potential failure modes. Hydraulic fractures may occur at any point throughout an embankment dam wherever there are low stress concentrations in the soil. While the above descriptions show internal erosion occurring as a result of hydraulic fractures, internal erosion may also occur from leaking pipe joints. Joint leakage may result from improper assembly, inadequate pipe joint performance, excessive operating pressures, improper installation, or poor dam construction methods. These concerns reinforce the need to review the hazard level of an embankment dam prior to product selection.

The hazard level of an embankment dam is a function of the volume of the body of water it restrains, the height of the dam, the potential damage of downstream property, the diameter of the outlet pipe, etc. While there is not a definitive hazard rating system, these criteria along with the overall design of the dam should be carefully reviewed prior to the selection of a pipe material. The following information is provided to help determine applications which are suitable for corrugated HDPE pipe.

Application Guidance

Figures 1 and 2 identify the two most common outlet works for an embankment dam. Pressurized outlet works is not an acceptable application for corrugated HDPE pipe as the pipe is under constant pressure. In order for corrugated HDPE pipe to be used in a dam, the water level must be controlled so that the pipe does not operate under pressure.

1717 16th St NE | Willmar, MN 56201 | Phone: 800-922-1725 | www.prinsco.com

Acceptable embankment dam configurations are detailed in Figures 12 – 15. In addition to the figures, the following general guidelines should be referenced when determining the suitability of corrugated HDPE pipe in a dam application.

- Maximum Water level over top of pipe - 5 feet
- Maximum embankment dam height over top of pipe - 10 feet
- Required Joint Performance – Watertight
- Maximum allowable pipe diameter – 24”
- Maximum allowable riser diameter – 24”
- Maximum length of conduit through dam – 60’
- Vertical pond riser shall not be corrugated HDPE pipe

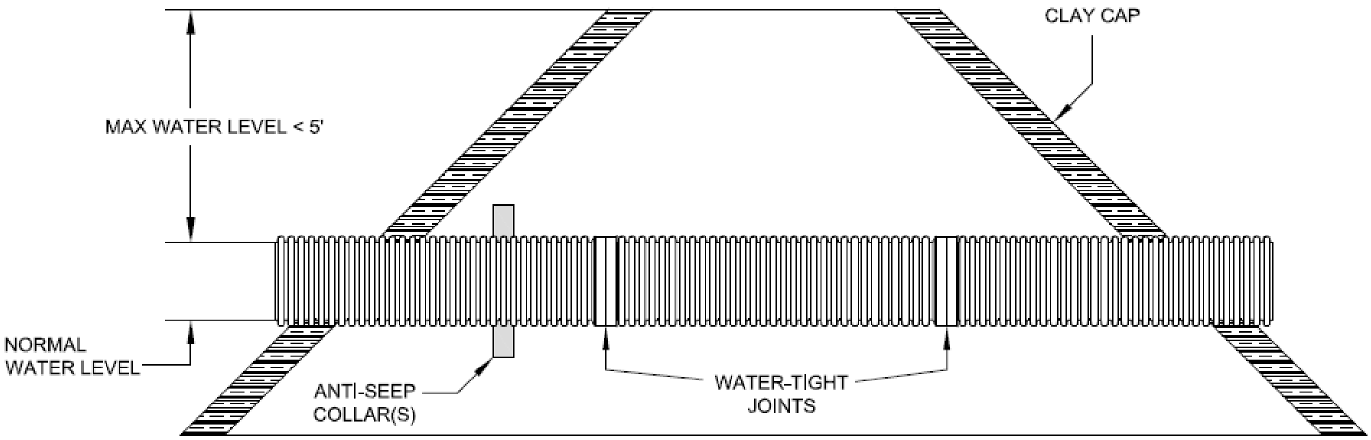

Figure 12.
Horizontal Gravity Flow Outlet
Conditionally Acceptable Application

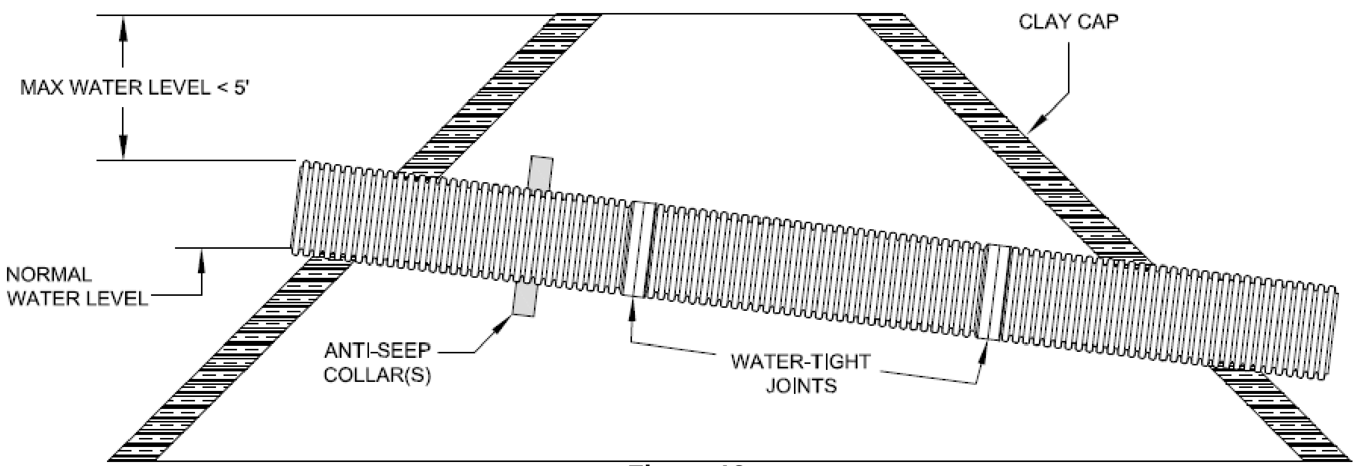

Figure 13.
Sloped Gravity Flow Outlet
Conditionally Acceptable Application

Figures 12 and 13 represent similar gravity flow outlet systems; Figure 12 represents a horizontal outlet, whereas Figure 13 is a sloped outlet drain. Both outlet designs function similarly as the water elevation is controlled by the elevation of the inlet side of the culvert. These types of applications are the least common methods of control due to their operational limitations. These are acceptable applications for corrugated HDPE, provided the system meets the criteria established above.

A more common method of pond level control is the use of a riser structure with a horizontal pipe through the embankment dam. These types of applications are more sensitive to design and installation inadequacies and generally require more care. The following figures illustrate the two main configurations of a pond riser application.

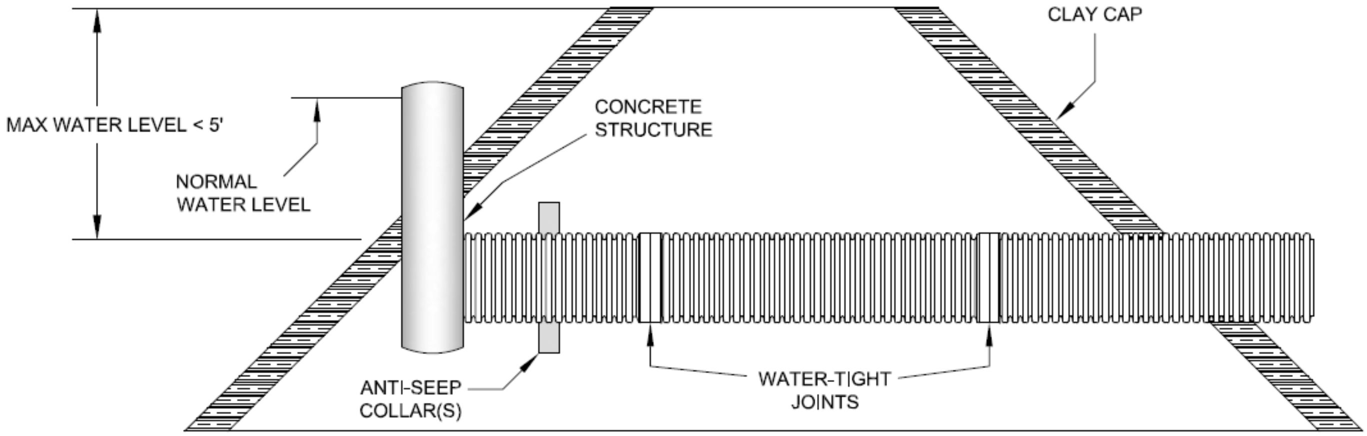

Figure 14.
Vertical Riser Located in Dam
Conditionally Acceptable Application

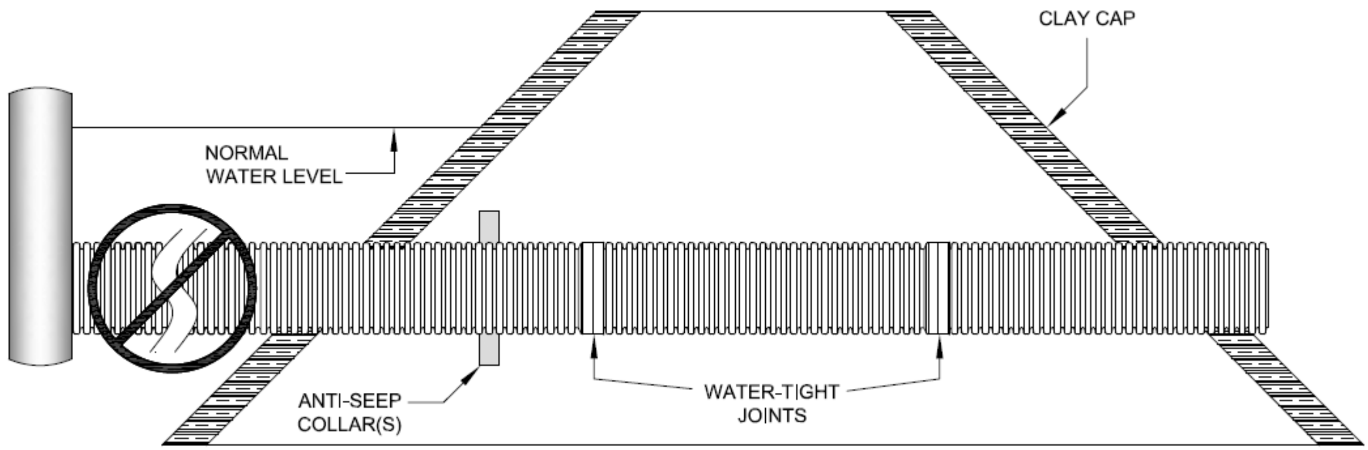

Figure 15.
Vertical Riser Located in Pond
Unacceptable Application

While Figures 14 and 15 represent similar applications with the use of a vertical pond riser, they are significantly different in their associated risk. Figure 14 is an acceptable application for corrugated watertight HDPE pipe provided that the riser is not corrugated HDPE pipe. Also, it is very important to encase the pipe to riser connection in concrete to ensure the connection is adequately sealed and supported. The design engineer shall specify the riser material based on the specific project conditions. Figure 15 represents an application which is unsuitable for corrugated HDPE pipe. Corrugated HDPE pipe shall not be installed into the pond or beneath the pond where it is subjected to constant pressure. It is also very important for the riser structure to be installed in the embankment to reduce damage resulting from wind, frost heave, wave action, constant pressure, etc.

Summary

While it is often overlooked, pipe through embankment dams involve design, construction, and operation concerns which can easily translate into problems. It is important that embankment dams and the associated outlet control devices and conduits be properly designed by a qualified engineering professional to ensure trouble free operation regardless of the size of the dam, method of outlet control, or pipe material used. As with any pipe material, corrugated HDPE pipe is not appropriate for every application but it certainly may be used in certain embankment dam applications where the design, construction, and installation is properly performed.

References

The following reference was used extensively in the creation of this technical note both for the technical content and illustrations:

Federal Emergency Management Agency. *Technical Manual: Conduits through Embankment Dams,* September 2005

1717 16th St NE | Willmar, MN 56201 | Phone: 800-922-1725 | www.prinsco.com