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## Filter Diaphragms

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## Module 45: Filter Diaphragms

### Learning Objectives

By the end of this section, you will be able to:

- **Identify** the primary causes of embankment failures associated with conduits.
- **Evaluate** the technical reasons for the industry transition from anti-seep collars to filter diaphragms.
- **Analyze** the mechanics of hydraulic fracture and implement preventative design strategies.

*Executive Summary:* The potential for water to flow along the outside of conduits or through cracks in the surrounding fill is a critical risk that must be addressed through modern design measures, primarily the transition to filter diaphragms.

### Background (Design Fundamentals)

Embankment failures and accidents occur more frequently in the vicinity of conduits than at any other location. These failures are generally categorized into four primary types:

- **Conduit Wall Defects:** Over time, wall defects may allow seepage to carry fines into non-pressurized conduits or allow water to escape and erode soil in pressurized systems. Corrugated metal pipe (CMP) is most susceptible to this.
- **Joint Separation:** Conduits on soft foundations may spread under the loading of the dam. Improperly installed gaskets or inadequate bands on CMP also lead to erosion at separated joints.
- **Interface Seepage:** Water may flow along the contact between the conduit and surrounding soils, potentially leading to a breaching failure in erodible soils.
- **Hydraulic Fracture:** Differential settlement often creates cracks in the earthfill above and to the sides of conduits, providing flow paths for internal erosion.

### Compaction and Foundation Challenges

Uniformly compacting soil near conduits is difficult due to several factors:

- **Equipment Limitations:** Hand-held equipment must be used near conduits to prevent damage, resulting in soil properties that differ from machine-compacted zones.
- **Haunch Compaction:** It is difficult to direct energy uniformly under the haunches of circular pipes; excessive energy can lift the pipe and create voids.
- **Flexible Conduits:** Materials like plastic or corrugated metal are rarely installed on bedding or cradles because restricted deflection would limit their design strength.

## Differential Settlement and Trench Conditions

Cracks in earthfills are often caused by differential settlement, where soil columns on the sides of a conduit compress more than the soil directly over it.

- **Trench Side Slopes:** Trenches with overly steep side slopes or those backfilled with soil significantly different from the foundation are prone to settlement issues.
- **Standard Practice:** Side slopes of **3H:1V** or flatter are usually specified for trenches transverse to an embankment.
- **Stress Zones:** Even without visible cracks, zones of low stress can develop, leading to hydraulic fracturing when the reservoir first impounds water to full depth.

## Anti-Seep Collars

For many years, anti-seep collars were the standard approach to blocking flow at the conduit-backfill interface. However, based on NRCS, USACE, and Bureau of Reclamation construction knowledge gained between the 1960s and 1980s, their use was reconsidered.

## The Move to Filter Diaphragms

Beginning in the mid-1980s, anti-seep collars were eliminated from major projects because they were judged ineffective in preventing failures.

- **Superiority:** Filter diaphragms are recognized as superior seepage control measures.
- **Current NRCS Policy:** Collars are still permitted for low-hazard dams under Conservation Practice Standard (CPS) 378, but filter diaphragms are required for embankments outside of that standard.

## Historical Failure Analysis

Anti-seep collars were discontinued on TR-60 size embankments for the following reasons:

- **Ineffectiveness:** NRCS embankments failed even with properly installed collars and adequate backfill compaction.
- **Flow Path:** Studies showed the tunnel erosion pathway was typically in the earthfill above or beside the conduit, not along the conduit-backfill contact.
- **Timing:** Failures often occurred during initial rapid pool filling, indicating that traditional seepage path length (the theory behind collars) was not the germane problem.



Figure 45–1: Failed embankments

## Hydraulic Fracture

Hydraulic fracture is the most common cause of cracks in earthen embankments that have failed from internal erosion.

## Mechanics and Causes

Fracture occurs when water pressure exceeds the lateral effective stress on a soil element.

- **Arching:** Occurs when stresses in trench soil are transferred by friction to trench sides, creating a low-stress condition.
- **Foundation Sharpness:** Sharp changes in bedrock profile can cause differential settlement (even as low as 1.0 foot per 100 feet).
- **Desiccation:** Interruptions in fill placement during hot weather can cause drying cracks, which should be removed to avoid planes of weakness.

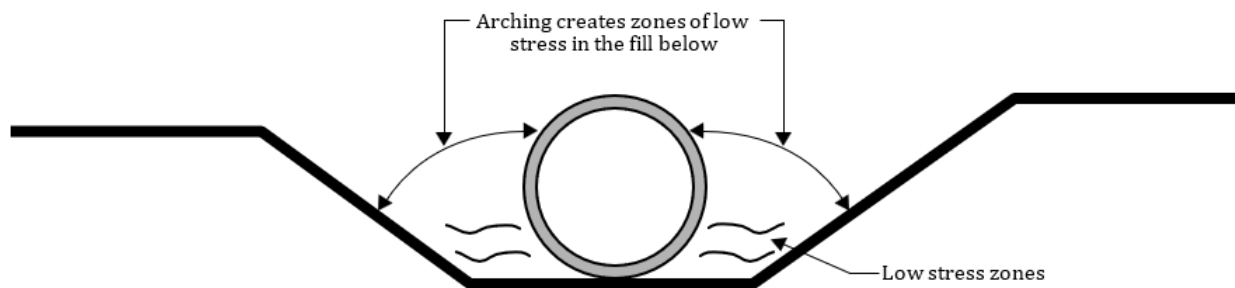


Figure 45–2: Arching in earthfill

## Soil Susceptibility

- **Plasticity:** Soils with a plasticity index (PI) **greater than 15** are more flexible and reduce cracking hazards.



## Filter Diaphragms

- **Desiccation Risk:** Soils with PIs **greater than 20** are prone to desiccation; exposed layers must be inspected if left more than a day in hot weather.
- **Dispersive Clays:** These are extremely erodible and highly likely to fail if a hydraulic fracture occurs.

### Risk Reduction Strategies

- **Moisture Control:** Compact cohesive soils at water contents at least **2 percent above** Standard Proctor optimum.
- **The Thread Test:** Cohesive soils should never be compacted at a water content less than that at which a **1/8-inch thread** will roll out without cracking.
- **Slope Flattening:** Flatten transverse excavations to at least **3H:1V** (or **4H:1V** for unfavorable soils like dispersive clays).

## Filter Diaphragm

### Introduction


- **Definition:** A designed zone of filter material (usually well-graded clean sand) constructed around a conduit.
- **Mechanism:** Water flowing through cracks reaches the diaphragm, where soil particles lodge on the upstream face, creating a "filter cake" that seals the crack.
- **Primary Intent:** To act as a **crack intercepting and sealing zone**, not primarily as a drainage zone.

### Design Considerations

If an embankment includes a **chimney filter**, it serves the combined purpose of a filter diaphragm. Chimney filters are standard for high-hazard embankments and dispersive clay designs.

### Dimensions and Outlets

- **Thickness Requirement:** The diaphragm must have a minimum overlying soil thickness equal to at least **half the difference** in elevation between the top of the diaphragm and the top of the dam.
- **Outlet Design:** Outlets must be provided at the downstream toe, often using a drain backfill envelope.

 **Safety Constraint:** Geotextile should **not** be used as a critical element in the outlet system, such as a wrapping for perforated collector pipe, due to clogging risks in inaccessible locations.

- **Collector Pipes:** If perforated or slotted pipe is used, the gravel envelope must be filter-compatible with the sand.

- **Slot Width:** Slotted pipe used with ASTM C 33 sand should have a slot width of **0.5 mm (0.02 in)** or smaller.

### Gradation and Self-Healing

- **ASTM C 33 Sand:** Frequently meets criteria for Category 2 base soils (40 to 85 percent finer than #200 sieve), but design checks in NEH633.26 are mandatory.
- **Self-Healing Property:** This describes a sand's ability to deform and fill cracks. The **Vaughan test** is used to evaluate this property.

### Specifications and Quality Control for Filter Sands

Compacting filter sand is critical to prevent settling upon saturation.

### The Risk of Bulking

Fine moist sand can develop capillary forces that resist compaction, resulting in a loose state.

- **Saturation:** Flooding the trench or compacting sand when dry effectively eliminates bulking.

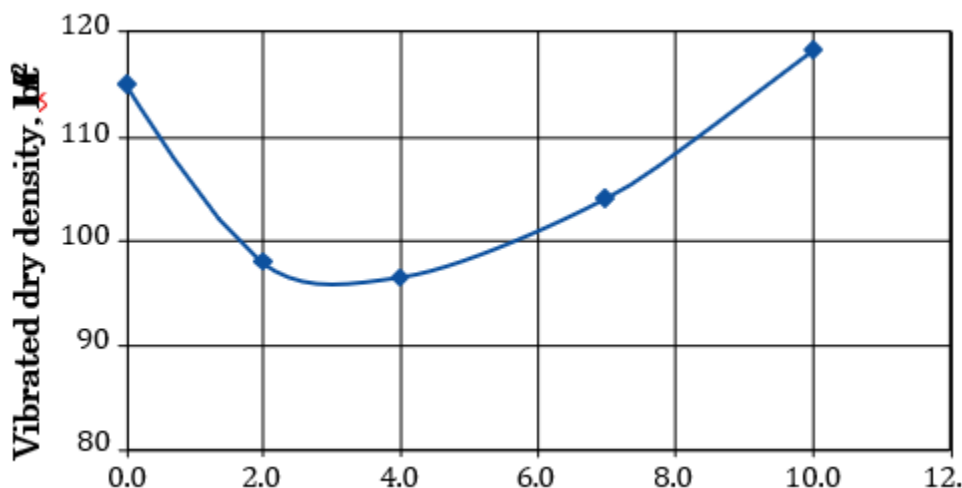


Figure 45–3: Effect of placement water content on vibrated density

### Method Placement Specification

This specifies the manner of compaction rather than a measured density.

- **Lift Thickness:** Layers must not exceed **8 inches** before compaction.
- **Compactor Weight:** Vibratory plate compactors must weigh at least **160 pounds** with a centrifugal force of 2,450 lbs.
- **Maintenance:** Diaphragm surfaces built concurrently with adjacent earthfill must be kept **1 foot above** the adjacent fill elevation.



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