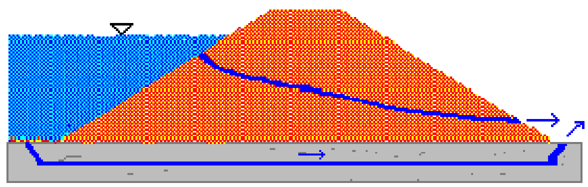
Piping

Internal erosion of the foundation or embankment caused by seepage is known as piping. Generally, erosion starts at the downstream toe and works back toward the reservoir, forming channels or pipes under the dam. The channels or pipes follow paths of maximum permeability and may not develop until many years after construction.



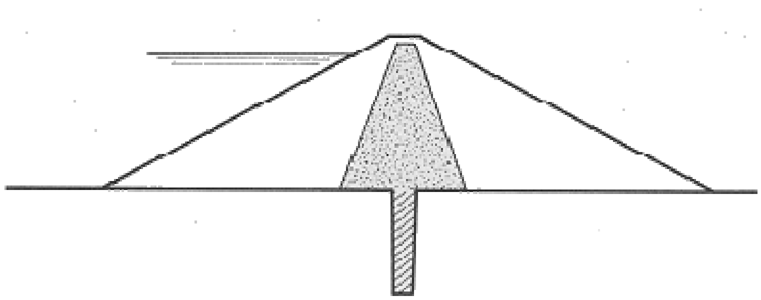
Resistance of the embankment or foundation to piping depends on:

١. plasticity of the soil
٢. the gradation
٣. the degree of compactness

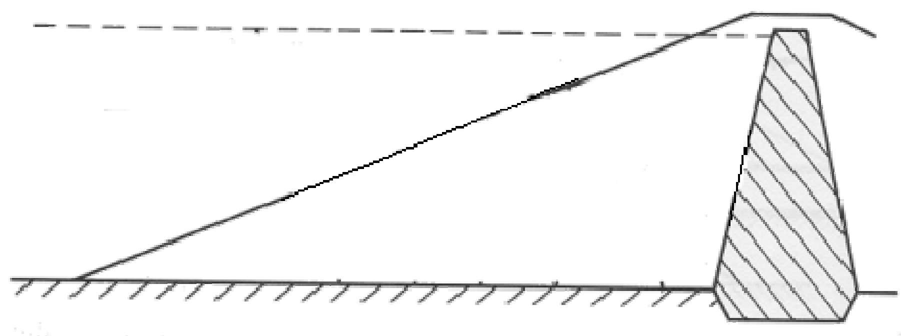
Plastic clays with a plasticity index >١٥, for both well and poorly compacted are the materials which are most resistant to piping. Minimum piping resistance is found in poorly compacted, through to well-graded cohesionless soils with practically no binder. It is also found in uniform, fine, cohesionless sand, even when well compacted. Settlement cracks in resistant materials may also produce piping.

Piping can be avoided by lengthening the flowpaths of water within the dam and its foundations. This decreases the hydraulic gradient of the water flow and hence its velocity. The flowpaths can be increased by:

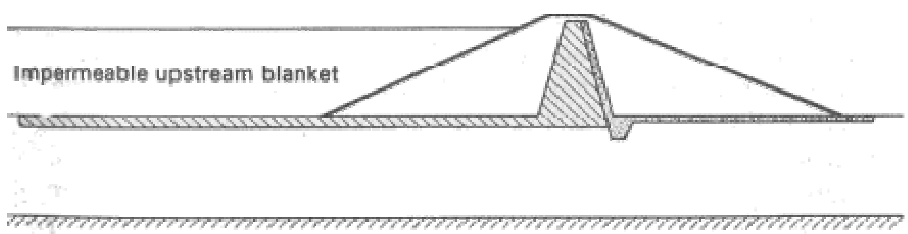
- Cutoff walls



- Impermeable cores

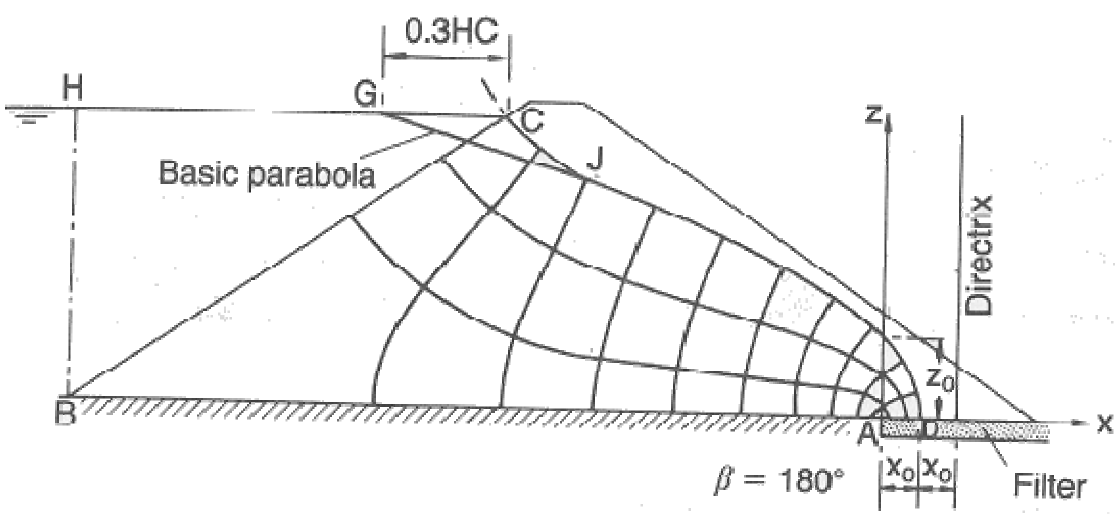


- Impermeable blankets extending upstream from the upstream face



Seepage control

Seepage is the continuous movement of water from the upstream face of the dam toward its downstream face. The upper surface of this stream of percolating water is known as the phreatic surface. The phreatic surface should be kept at or below the downstream toe.



The phreatic surface within a dam can be controlled by properly designed cores or walls.

Internal drain systems

Purpose

A homogeneous dam with a height of more than about ٦ m to ٨ m should have some type of downstream drain. The purpose of a drain is:

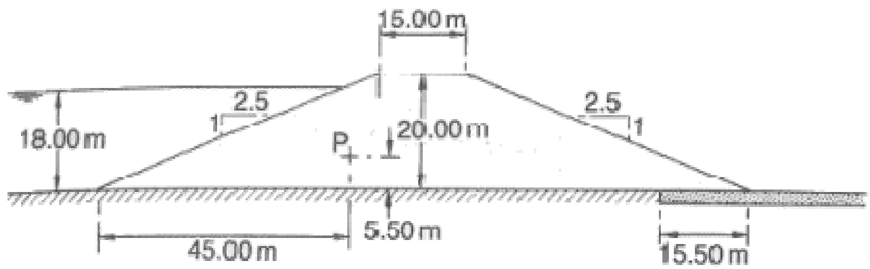
١. to reduce the pore water pressures in the downstream portion of the dam therefore increasing the stability of the downstream slope against sliding.
٢. to control any seepage that exits the downstream portion of the dam and prevent erosion of the downstream slope: i.e. to prevent 'piping'.

The effectiveness of the drain in reducing pore pressures depends on its location and extent. However, piping is controlled by ensuring that the grading of the pervious material from which the drain is constructed meets the filter requirements for the embankment material.

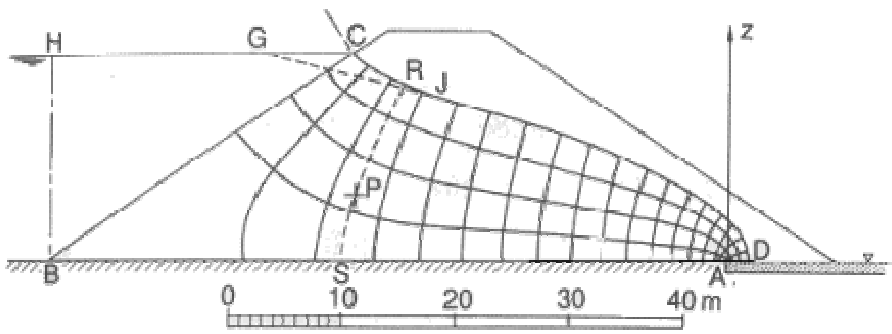
Toe drains

The design of a downstream drainage system is controlled by the height of the dam, the cost and availability of permeable material, and the permeability of the foundation.

For low dams, a simple toe drain can be used successfully. Toe drains have been installed in some of the oldest homogeneous dams in an effort to prevent softening and erosion of the downstream toe.



(a)



For reservoir depths greater than ١٥ m, most engineers would place a drainage system further inside the embankment where it will be more effective in reducing pore pressures and controlling seepage.

Horizontal drainage blanket

Horizontal drainage blankets are often used for dams of moderate height.

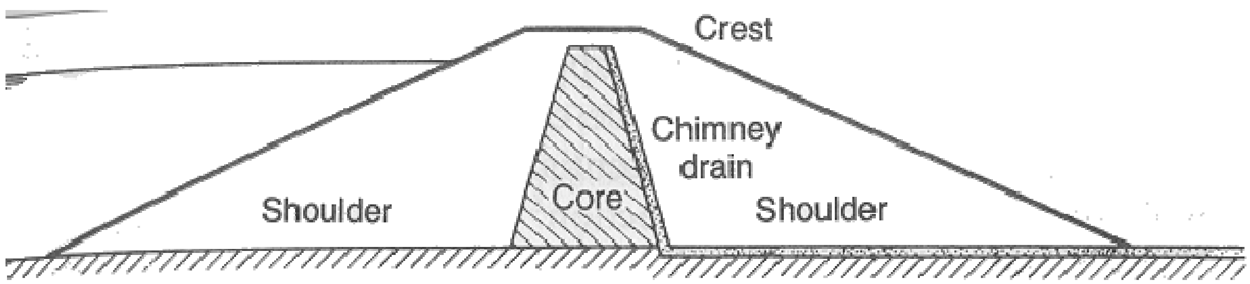
Drainage blankets are frequently used over the downstream one-half or one-third of the foundation area. The Bureau of Reclamation's ٤٥ m Vega Dam is a homogeneous dam which has been constructed with a horizontal downstream drain. Where pervious material is scarce, the internal strip drains can be placed instead since these give the same general effect.

Disadvantages of horizontal drainage blankets

An earth dam embankment tends to be more pervious in the horizontal direction than in the vertical. Occasionally, horizontal layers tend to be much more impervious than the average material constructed into the embankment, so the water will flow horizontally on a relatively impervious layer and discharge on the downstream face despite the horizontal drain.,p> Where this has occurred the downstream slope is prone to slipping and piping. Repairs can be made by installing pervious blankets on the downstream slopes or constructing vertical drains to connect with the horizontal blanket. Such vertical drains are normally composed of sand and gravel.

Chimney drains

Chimney drains are an attempt to prevent horizontal flow along relatively impervious stratified layers, and to intercept seepage water before it reaches the downstream slope. Chimney drains are often incorporated in high homogeneous dams which have been constructed with inclined or vertical chimney drains.



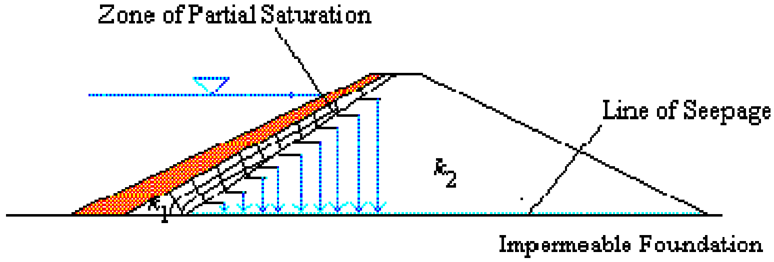
In some major dam projects, chimney drains have been inclined at a considerable slope, both upstream and sometimes downstream. An upstream inclined drain can act as a relatively thin core. In addition to controlling seepage through the dam and increasing the stability of the downstream slope, the chimney drain is also useful in reducing pore water pressures both during construction and following rapid reservoir drawdown.

Dimensions and permeability of drains

The dimensions and permeability of permeable drains must be adequate to carry away the anticipated flow with an ample margin of safety for unexpected leaks. If the dam and the foundations are relatively impermeable, then the expected leakage would be low. A drain should be constructed of material with a coefficient of permeability of at least ١٠ to ١٠٠ times greater than the average embankment material.

Thin upstream sloping core

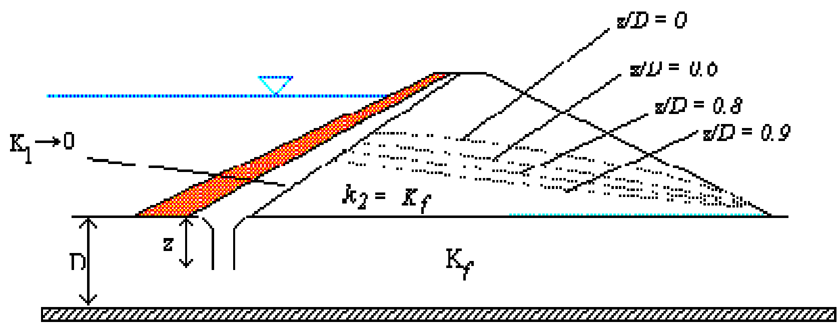
In an earth dam with an upstream sloping core of low permeability, the foundation is assumed to be impermeable and in a steady state. Under steady state conditions the small amount of water that seeps through the core flows vertically downward in a partially saturated zone and then more or less horizontally in a thin saturated layer along the impermeable foundation. For this type of dam the downstream shell must be several hundred times more permeable than the core.



Seepage through an Upstream Sloping Core Dam

Partial cutoffs

An earth dam constructed without a cutoff on permeable or semi-permeable foundations of earth or rock may lead to seepage beneath the dam creating unacceptable uplift pressures and causing instability. If an impermeable cutoff is installed to ٦٠ % of the depth of the permeable foundation, the flow net and downstream slope gradient is only slightly modified to a lower level. A theoretical line of seepage for several depths is given here.



Effects of Partial Cutoff on Position of Line of Seepage

For an effective cutoff the positioning and depth of cutoff must be essentially 'perfect'. Since this is impossible to achieve, other methods of seepage control should be used in conjunction with cutoffs.

(C) Thomas, Henry H. The Engineering of Large Dams
(C) Wahlstrom, Ernest Dams, Dam Foundations and Reservoir Sites
(C) Craig R, F Soil Mechanics

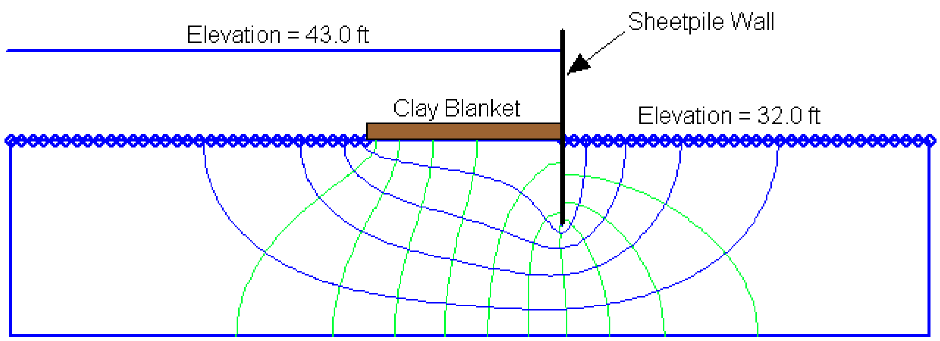
Sample SEEP۲D Problem

SEEP۲D can be used for either confined or unconfined steady-state flow models. For unconfined models, there are two options for determining the phreatic surface. With the first option, the mesh is automatically truncated as the iterative solution process proceeds and when the model converges, the upper boundary of the mesh corresponds to the phreatic surface. With the second option, both saturated and unsaturated flow is simulated and the mesh is not modified. The phreatic surface can be displayed by plotting the contour line at where pressure head equals zero.

A variety of options are provided in GMS for displaying SEEP۲D results. Contours of total head (equipotential lines) and flow vectors can be plotted. An option is also available for computing flow potential values at the nodes. These values can be used to plot flow lines. Together with the equipotential lines (lines of constant total head), the flow lines can be used to plot a flow net.

A more complete description of the SEEP۲D model, including a discussion of boundary conditions and guidelines for model conceptualization is contained in the SEEP۲D Primer. The SEEP۲D Primer should be reviewed before consulting this help file. The user is also encouraged to complete the SEEP۲D tutorials in the GMS Tutorials document.

Sample Confined Seepage Problem



Dam Safety: Seepage Through Earth Dams

Contrary to popular opinion, wet areas downstream from dams are not usually natural springs but seepage areas. Even if natural springs exist, they should be treated with suspicion and carefully observed. Flows from groundwater springs in existence prior to the reservoir would probably increase due to the pressure caused by a pool of water behind the dam.

All dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Seepage must, however, be controlled in both velocity and quantity.

Seepage can emerge anywhere on the downstream face, beyond the toe, or on the downstream abutments at elevations below normal pool. Seepage may vary in appearance from a "soft", wet area to a flowing "spring". It may show up first as an area where the vegetation is lush and darker green. Cattails, reeds, mosses, and other marsh vegetation may grow in a seepage area. Downstream groin areas (the areas where the downstream face contacts the abutments) should always be inspected closely for signs of seepage. Seepage can also occur along the contact between the embankment and a conduit spillway, drain, or other appurtenance. Slides in the embankment or an abutment may be the result of seepage causing soil saturation or pressures in the soil pores.

At most dams, some water will seep from the reservoir through the foundation. Where it is not intercepted by a subsurface drain, the seepage will emerge downstream from or at the toe of the embankment. If the seepage forces are large enough, soil will be eroded from the foundation and be deposited in the shape of a cone around the outlet. If these "boils" appear, professional advice should be sought immediately. Seepage flow which is muddy and carrying soil particles may be evidence of "piping" and complete failure of the dam could occur within hours. Piping can occur along a spillway and other conduits through the embankment, and these areas should be closely inspected. Sinkholes that develop on the embankment are signs that piping has begun. A whirlpool in the lake surface may soon follow and then likely a rapid and complete failure of the dam. Emergency procedures, including downstream evacuation, must be implemented if this condition is noted.

A continuous or sudden drop in the normal lake level may be an indication that seepage is occurring. In this case, one or more locations of flowing water are usually noted downstream from the dam. This condition, in itself, may not be a serious problem, but will require frequent and close monitoring and professional assistance.

The need for seepage control will depend on the quantity, content, and/or location of the seepage. Controlling the quantity of seepage that occurs after construction is difficult and quite expensive. It is not usually attempted unless drawdown of the pool level has occurred or the seepage is endangering the embankment or appurtenant structures. Typical methods used to control the quantity of seepage are grouting, installation of an upstream blanket, or installation of relief wells. Of these methods, grouting is probably the least effective and it is most applicable to leakage zones in bedrock, abutments, and foundations. All of these methods must be designed and constructed under the supervision of a professional engineer experienced with dams.

Controlling the content of the seepage or preventing seepage flow from removing soil particles is extremely important. Modern design practice incorporates this control into the embankment through the use of cutoffs, internal filters, and adequate drainage provisions. Control at points of seepage exit can be accomplished after construction by using weighted filters and providing proper drainage. The filter and drainage system should be designed to prevent migration of soil particles and still provide for passage of the seepage flow. The bottom layer of the weighted filter should be ٦ to ١٢ inches of sand placed over the seepage area. The sand layer should be covered with a gravel layer of similar thickness. Larger rock should be placed next to complete the berm. This methods will permit the seepage to drain freely, but prevent piping (removal) of soil particles. The weight of the berm will hold the filter in place and may also provide additional stability to the embankment and/or foundation.

The location of the seepage or wet area on the embankment or abutment is often a primary concern. Excessive seepage pressure or soil saturation can threaten the stability of the downstream slope of the dam or the abutment slopes. An abutment slide may block or damage the spillway outlet or other appurtenances. In these cases, not only must the seepage be controlled but the area must be dried out. This is sometimes accomplished by installing finger drains (lateral drains for specific locations). Seepage control systems must always be free-draining to be effective.

Monitoring

Regular monitoring is essential to detect seepage and prevent failure. Without knowledge of the dam's history, the owner or the inspector has no idea whether the seepage condition is in a steady or changing state. It is important to keep written records of points of seepage exit, quantity and content of flow, size of wet area, and type of vegetation for later comparison. Photographs provide invaluable records of seepage. The inspector should always look for increases in flow and evidence of flow carrying soil particles. The control methods described previously are often designed to facilitate observation of flows. At some locations, v-notch weirs can be used to measure flow rates.

Regular surveillance and maintenance of internal embankment and foundation drainage outlets is also required. Normal maintenance consists of removing any soil or other material that obstructs flow. Internal repair is complicated and often impractical and should not be attempted without professional advice. The rate and content of flow emerging from these outlets should be monitored regularly.

Detection

Seepage can emerge anywhere on the downstream face, beyond the toe, or on the downstream abutments at elevations below normal pool. Seepage may vary in appearance from a "soft" wet area to a flowing "spring." It may show up first as an area where the vegetation is lush and darker green. Cattails, reeds, mosses, and other marsh vegetation often become established in a seepage area. Another indication of seepage is the presence of rust-colored iron bacteria. Due to their nature, the bacteria are found more often where water is discharging from the ground than in surface water. Seepage can make inspection and maintenance difficult. It can also saturate and weaken portions of the embankment and foundation, making the embankment susceptible to earth slides.

If the seepage forces are large enough, soil will be eroded from the foundation and be deposited in the shape of a cone around the outlet. If these "boils" appear, professional advice should be sought immediately. Seepage flow which is muddy and carrying sediment (soil particles) is evidence of "piping," and is a serious condition that if left untreated can cause failure of the dam. Piping can most often occur along a spillway or other conduit through the embankment, and these areas should be closely inspected. Sinkholes may develop on the surface of the embankment as internal erosion takes place. A whirlpool in the lake surface may follow and then likely a rapid and complete failure of the dam. Emergency procedures, including downstream evacuation, should be implemented immediately if any of these conditions are noted.

Seepage can also develop behind or beneath concrete structures such as chute spillways or headwalls. If the concrete structure does not have a means such as weep holes or relief drains to relieve the water pressure, the concrete structure may heave, rotate, or crack. The effects of the freezing and thawing can amplify these problems. It should be noted that the water pressure behind or beneath structures may also be due to infiltration of surface water or spillway discharge, but should still be addressed.

A continuous or sudden drop in the normal lake level is another indication that seepage is occurring. In this case, one or more locations of flowing water are usually noted downstream from the dam. This condition, in itself, may not be a serious dam safety problem, but will require frequent and close monitoring and professional assistance.

Control

The need for seepage control will depend on the quantity, content, and location of the seepage. Reducing the quantity of seepage that occurs after construction is difficult and expensive. It is not usually attempted unless the seepage has lowered the pool level or is endangering the dam or appurtenant structures. Typical methods used to control the quantity of seepage are grouting or installation of an upstream blanket. Of these methods, grouting is probably the least effective and is most applicable to leakage zones in bedrock, abutments, and foundations. These methods must be designed and constructed under the supervision of a professional engineer experienced with dams.

Controlling the content of the seepage or preventing seepage flow from removing soil particles is extremely important. Modern design practice incorporates this control into the dam design through the use of cutoffs, internal filters, and adequate drainage provisions. Control at points of seepage exit can be accomplished after construction by installation of toe drains, relief wells, or inverted filters.

Weep holes and relief drains can be installed to relieve water pressure or drain seepage from behind or beneath concrete structures. These systems must be designed to prevent migration of soil particles but still allow the seepage to drain freely. The owner must retain a professional engineer to design toe drains, relief wells, inverted filters, weep holes, or relief holes, and regular monitoring of these features is critical.