Earth dams

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INTRODUCTION:

- Earth dams is generally built of locally available materials in their natural state with a minimum of processing.
- Earth dams are composed of fragmental materials which derive their strength from their position, friction and cohesion.
- An embankment dam, as defined earlier, is one that is built of natural materials. The embankment dam was constructed with low-permeability soils to a nominally homogeneous profile.

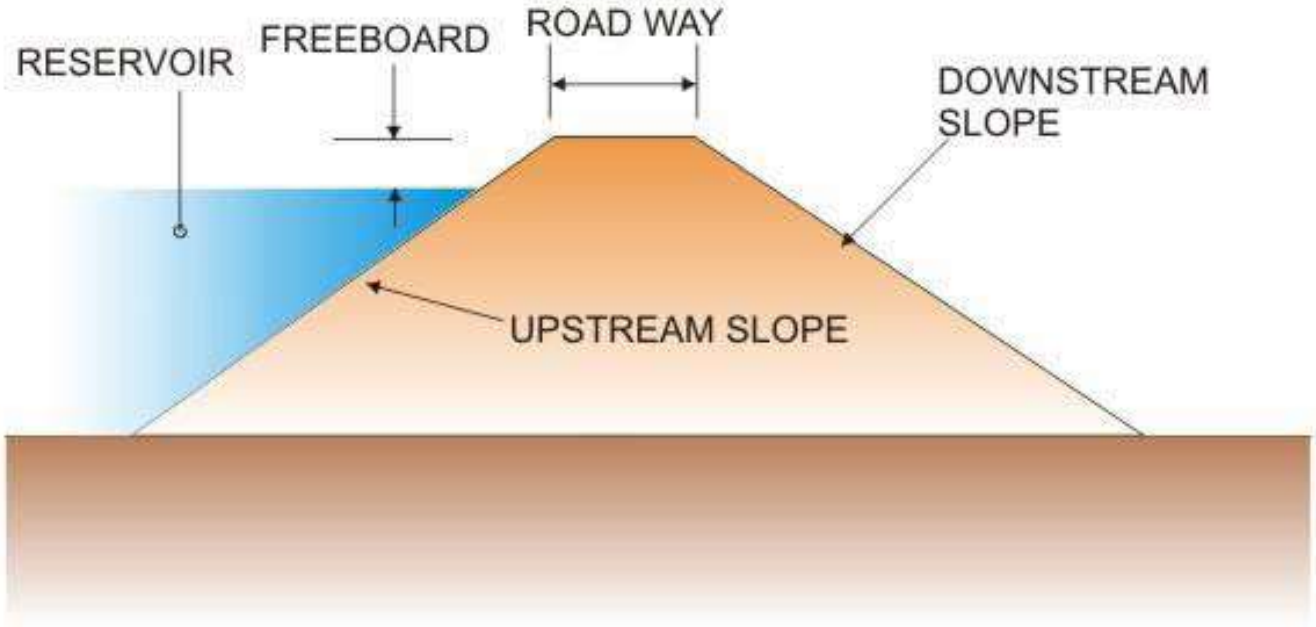


FIGURE 1. General shape of an embankment dam

- Depending on the method of construction the earth dams can be divided into two types:

  a). Rolled fill dam

  b). Hydraulic fill dam

a).Rolled fill dam: The embankment is constructed in successive, mechanically compacted layers.

. The suitable materials are transported from the borrow pits to the construction site by earthmoving machinery, spread by bulldozers.

. Sprinkled to form layers of limited thickness water content and compacted and bonded with the preceding layer by means of rollers of proper design and weight.

b).Hydraulic fill dam:

- The materials are excavated, transported and placed by hydraulic methods.
- Flumes are laid at suitable falling gradient along the outer edge of the embankment.
- The material mixed with water at borrow pits is pumped and washed into these flumes. The slush is discharged through the outlets in flumes, the slush thus flows towards the centre of the bank.
- The coarse materials of the slush settle at the outer edge while the fine materials settle at the centre. No compaction is done.

- Rolled fill earth dams can be further divided into following types

  a. Homogeneous embankment type

  b. Zoned embankment type

  c. Diaphragm embankment type

a) Homogeneous embankment type:

- A purely homogeneous type earth dam is composed of single kind of material. They are used only for low to moderate heights.
- A purely homogeneous section has been replaced by horizontal blanket in which internal drainage system in the form of horizontal filter drain or rock toe is provided.
- This controls the action of seepage so as to permit much steeper slopes.
- The drainage system also keeps the phreatic line well within the body of the dam.

.The phreatic line (that is, the line corresponding to the phreatic surface lying above the saturated zone when seen in a vertical plane) .

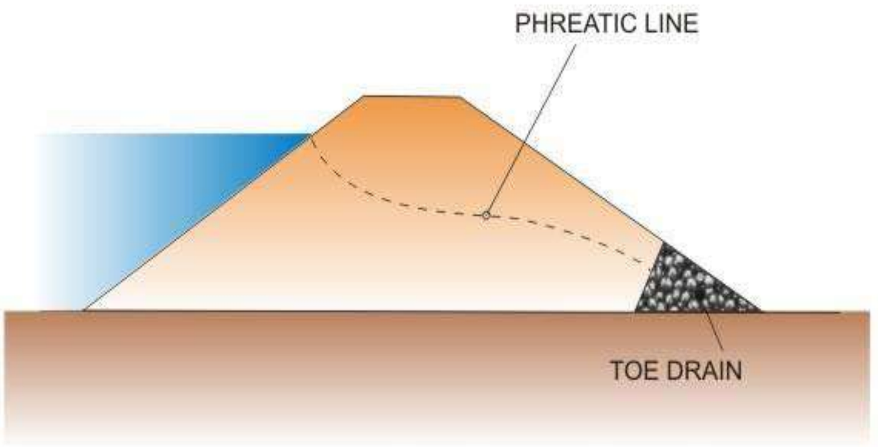


FIGURE 2. Homogeneons earthen embankment dam with toe drain

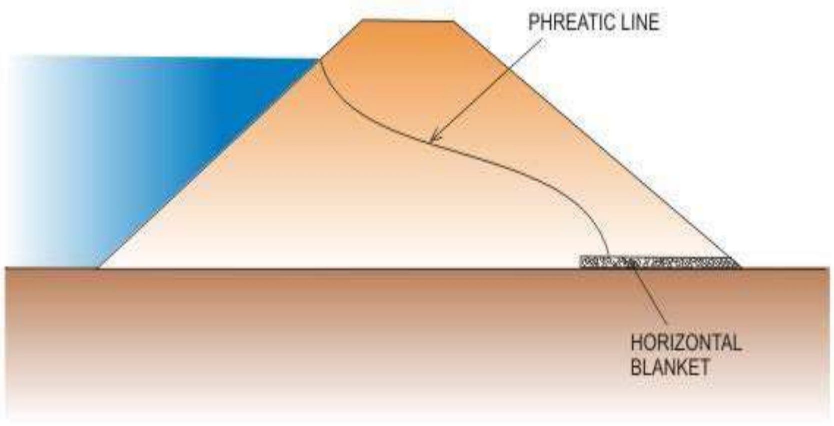


FIGURE 3.Homogeneous dam with horizontal blanket

❖ It may be noticed how the phreatic line is forced to remain within the dam body by providing the clay core (with relatively less permeability) to reduce the amount of seepage water .

.The chimney filter with the horizontal blanket, composed of materials with very high permeability, that is used to drain out the seepage water safely through the body of the dam.

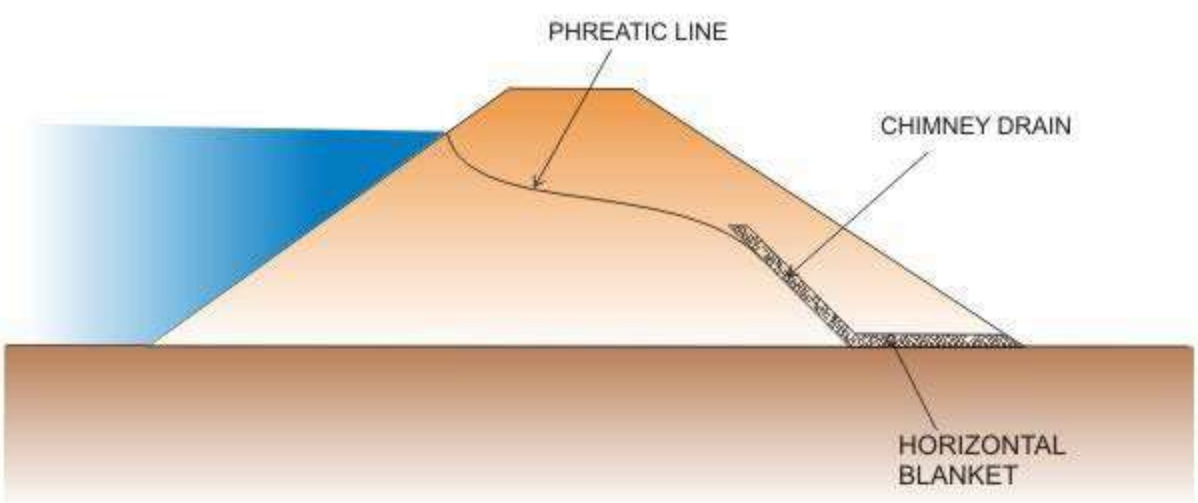


FIGURE 4. Homogeneous dam with inclined chimney drain connected to horizontal blanket

b). Zoned Embankment type:

- It is the type of Earth dam in which the dam is made of more than one materials.
- The most common type of a rolled Earth dam is that in which a central impervious core is flanked by zones of material considerably more pervious.

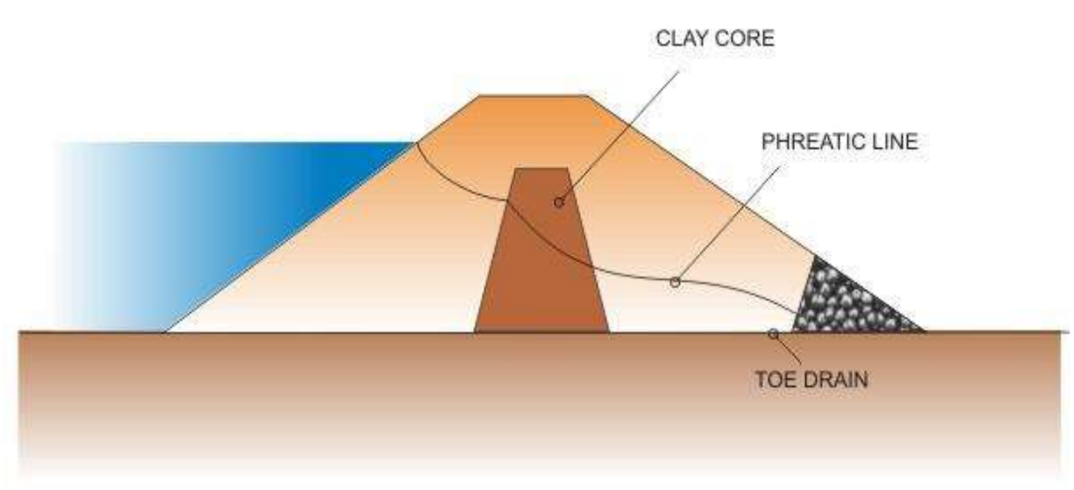


FIGURE 5. Zoned dam with central vertical clay core and toe drain

- A suitable drainage system, in the form of a horizontal drain or a rock toe is also provided.

- If a variety of soils are readily available, the choice type of earth- fill dam should always be zoned embankment type because its advantages will lead to economy in the cost of construction.

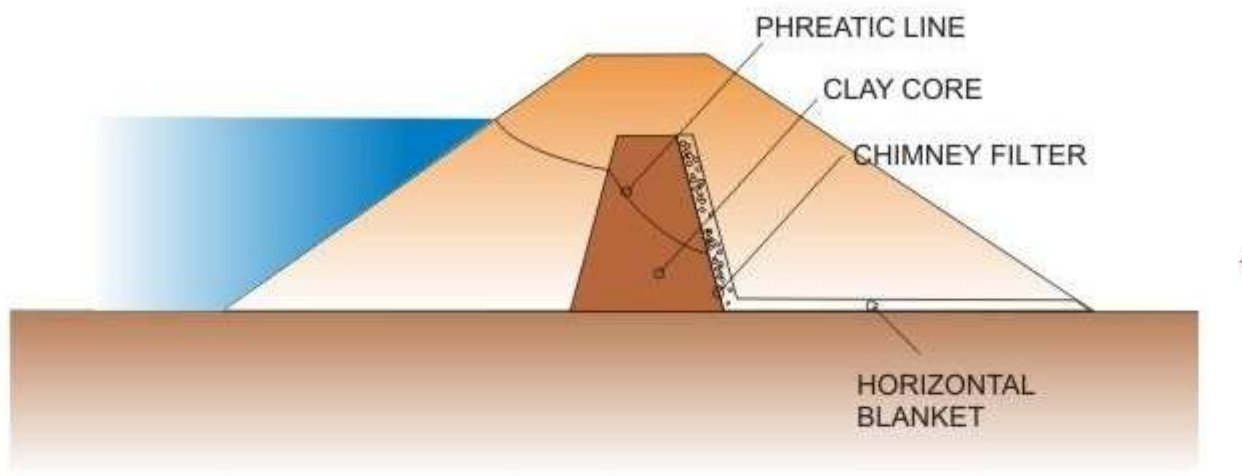


Figure 6. Clay core zoned dam with central vertical core and chimney filter with horizontal blanket

➢ In this type ,outer shells are made of pervious, freely draining material. The shells give stability to the impervious fill, and distribute the load over a large area in the foundation.

* The u/s pervious zone affords stability against rapid draw down while the d/s pervious zone acts as a drain to control the line of seepage. The central impervious core checks the seepage.

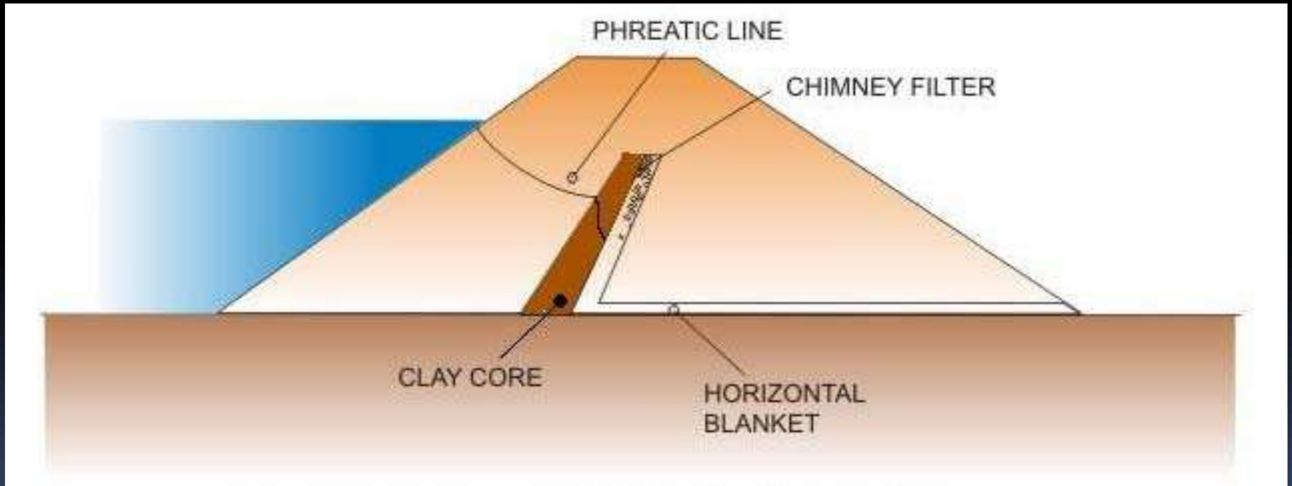


FIGURE 7. Inclined Clay core zoned dam with chimney filter and horizontal blanket.

c). Diaphragm embankment type:

- This is a modification over the homogeneous embankment type, in which the bulk of the embankment is constructed of pervious material and a thin diaphragm of impermeable materials is provided to check the seepage.

- The diaphragm may be of impervious soils, cement concrete ,bituminous concrete or any other material, and may be placed either at the centre of the section as a central vertical core.

- If the thickness of the diaphragm at any elevation is less than 10m or less than the ht. of the embankment ,then the dam is considered to be Diaphragm type embankment.

Causes of failure of earth dams :

The various modes of failures of earth dams may be grouped under three categories:

1. Hydraulic failures – 40%
2. Seepage failures --30%
3. Structural failures – 30%

Hydraulic failures :

- Over topping:
- Overtopping of the dam might have been caused by a flood that exceeded the design flood for the spillway. Sometimes faulty operation of the spillway gates may also lead to overtopping since the flood could not be let out in time through the spillway.

* It is caused due to insufficient freeboard (the difference between the maximum reservoir level and the minimum crest level of the dam) has been provided.

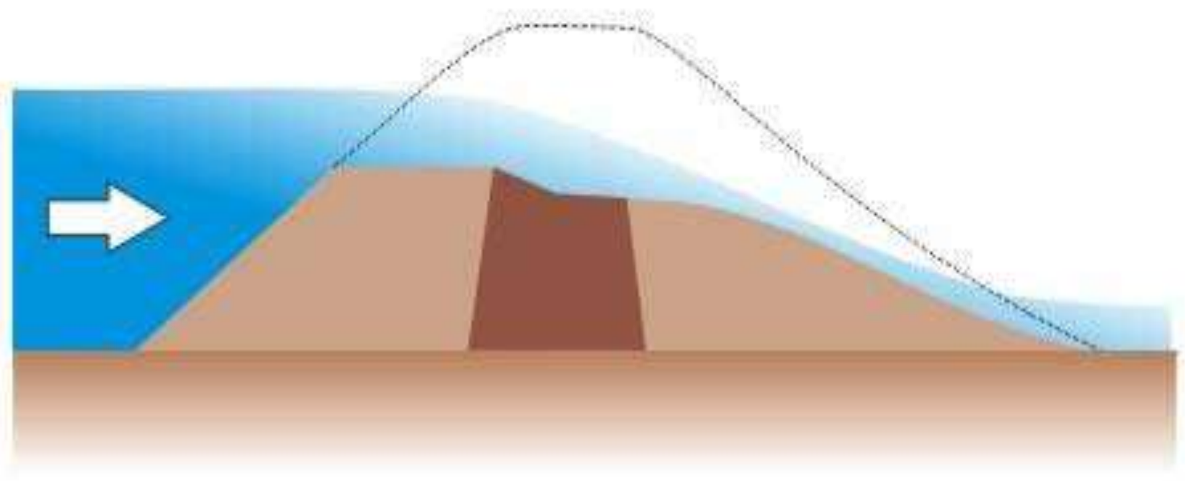


FIGURE 22. Overtopping of dam resulting in washout

❖ Due to Wave Erosion:

* Erosion of upstream face and shoulder by the action of continuous wave action may cause erosion of the surface unless it is adequately protected by stone riprap and filter beneath (Figure 23).

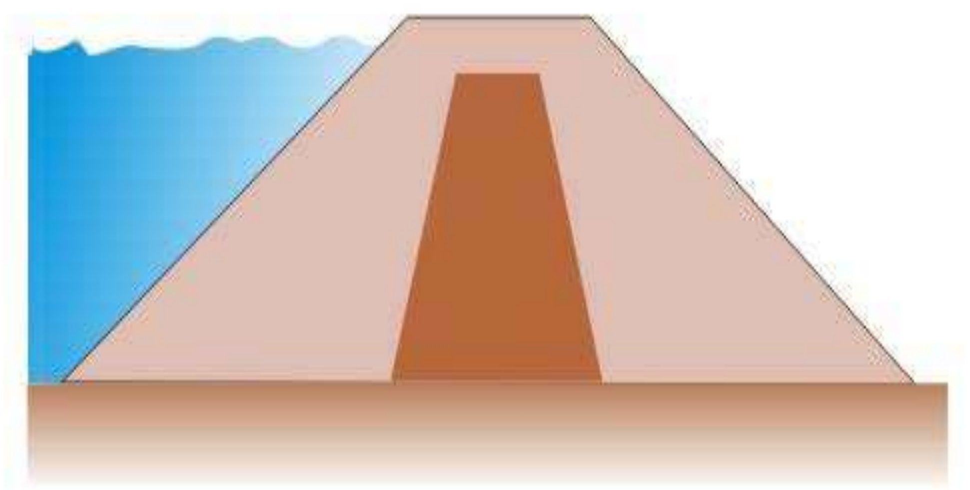


FIGURE 23. Erosion of upstream face by waves breaking on the surface

❖ Cuts due to Rain wash:

- Erosion of downstream slope by rain wash. Though the downstream face of an embankment is not affected by the reservoir water, it may get eroded by heavy rain water flowing down the face, which may lead to the formation of gullies and finally collapse of the whole dam (Figure 24).

CUTS DUE TO RAIN WASH

Figure 24. Scour of downstream face by impact of rain and resulting sheet flow

❖ Due to Toe erosion:

* Erosion of downstream toe of dam by tail water. This may happen if the river water on the downstream side of the dam (which may have come from the releases of a power house during normal operation or out of a spillway or sluice during flood flows) causes severe erosion of the dam base.

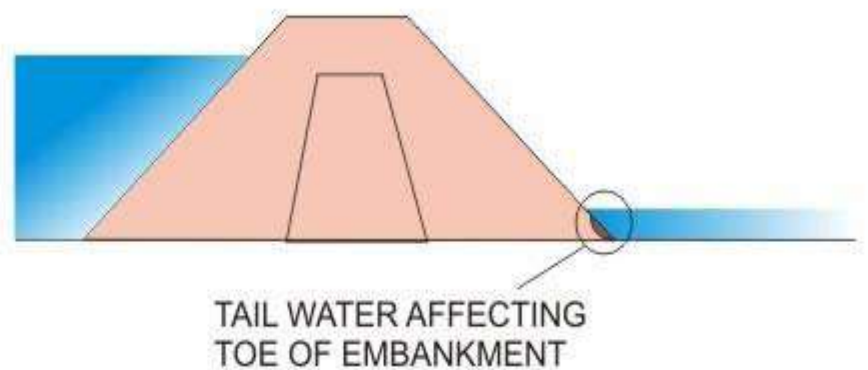


Figure 25. Scour on the downstream toe by tailwater

Seepage failures

* The water on the reservoir side continuously seeps through an embankment dam and its foundation to the downstream side.

* Unless a proper design is made to prevent excessive seepage, it may drive down fine particles along with its flow causing gaps to form within the dam body leading to its collapse.

Seepage failures may be due to

a). Piping

b). Conduit leakage

C). Sloughing

- Piping:

  The seepage of water through the body and foundation of the earth dam lead to piping.

- Seeping of water generates erosive forces which dislodge particles from the soil structures and migration of the fines to voids between the larger grains.
- The flow with its differential pore pressure can lift portion of soil mass causing boiling.

- Internal erosion of the soil mass leads to the formation of an open conduit through the soil.
- The internal pressures in the soil water can reduce that part of the soil strength due to that weakening of soil mass and failures by shear.
- This will happen due to inadequate compaction or pervious layers in the embankment and poor bond between the embankment and foundation.

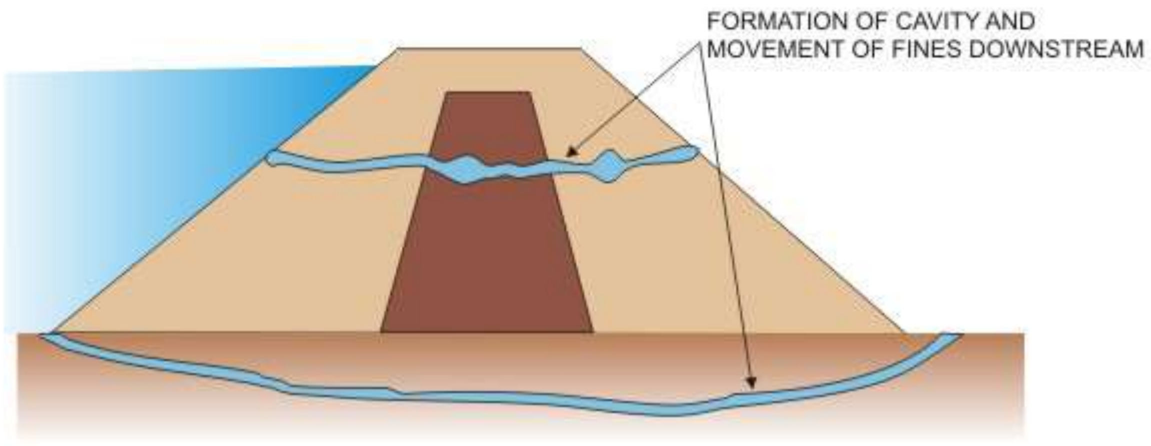


FIGURE 26. Internal erosion and piping through dam body and foundation

Conduit leakage:

- The seepage of water may be from the reservoir to the downstream or due to the water leaking out of the conduit through cracks that might have developed due to unequal settlement of dam or by overloading from the dam.

- The cracking of a conduit may also be caused when the soil mass lying below it settles and the conduit is not sufficiently strong to support the soil mass lying above.

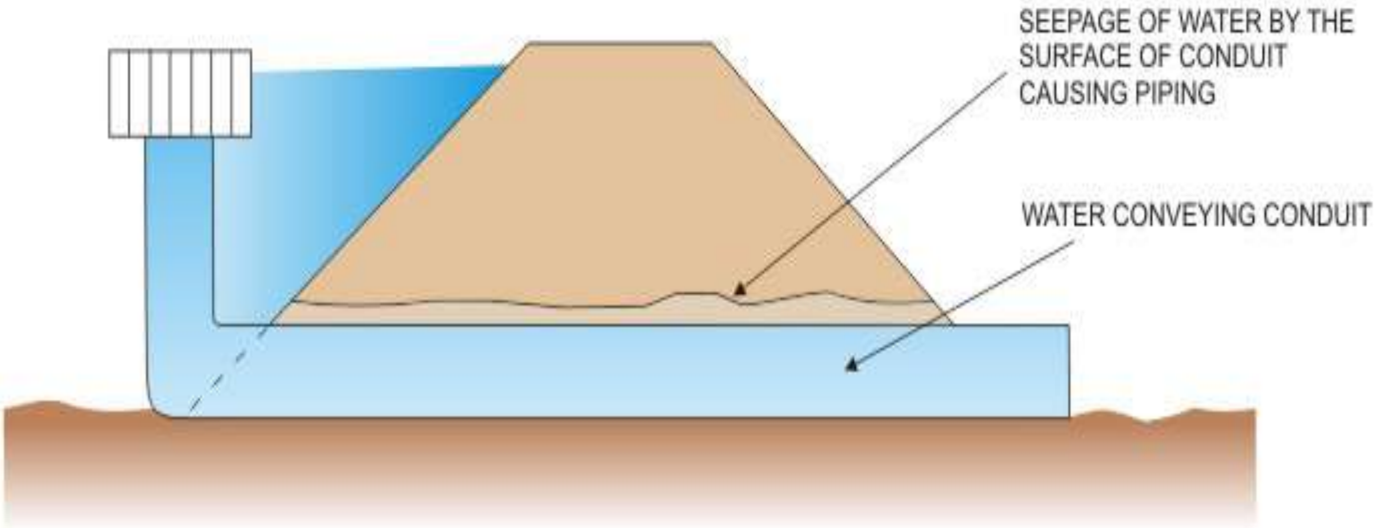


FIGURE 27. Seepage by the outer surface of conduit; may lead to progressive piping

Sloughing of downstream face:

- This phenomena take place due to the dam becoming saturated due to the presence of highly pervious layer in the body of the dam.

- This causes the soil mass to get softened and a slide of the downstream face takes place .

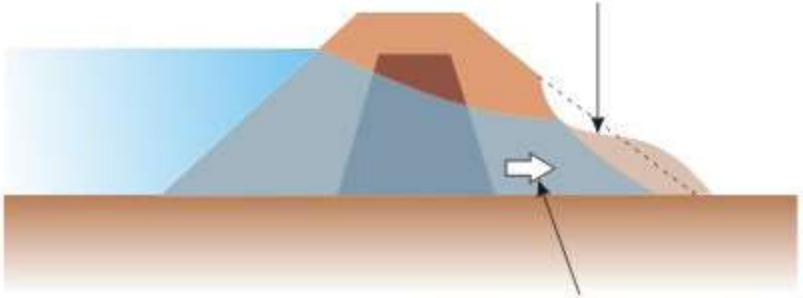


FIGURE 28. Sloughing of downstream face due to high pore water pressure

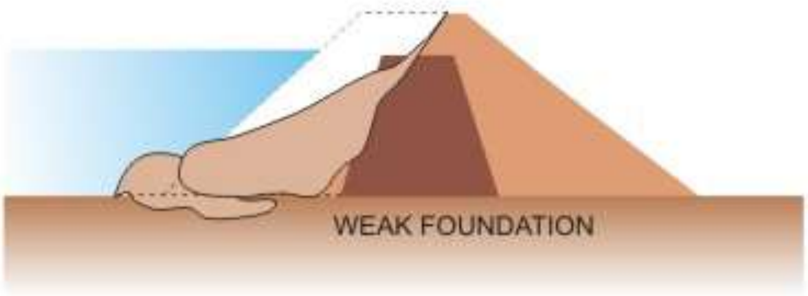
Structural failures **:**

These failures are related to the instability of the dam and its foundation, caused by reasons other than surface flow (hydraulic failures) or sub-surface flow (seepage-failures). These failures can be grouped in the following categories:

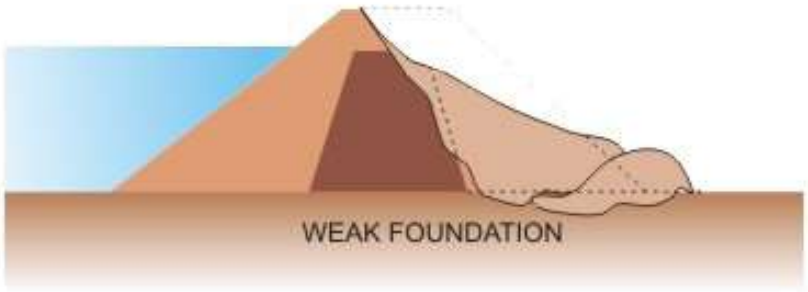
I). Sliding due to weak foundation:

- Due to the presence of faults and seams of weathered rocks, shale's, soft clay strata, the foundation may not be able to withstand the pressure of the embankment dam.

- The lower slope moves outwards along with a part of the foundation and the top of the embankment subsides causing large mud waves to form beyond the toe.



FAILURE OF UPSTREAM SLOPE



FAILURE OF UPSTREAM SLOPE

FIGURE 29. Instability of upstream or downstream slopes caused by failure of weak foundations

II).Sliding of upstream face due to sudden drawdown:

- An embankment dam, under filled up condition develops pore water pressure within the body of the dam. If the reservoir water is suddenly depleted, say due to the need of emptying the reservoir in expectation of an incoming flood, then the pore pressure cannot get released, which causes the upstream face of the dam to slump .

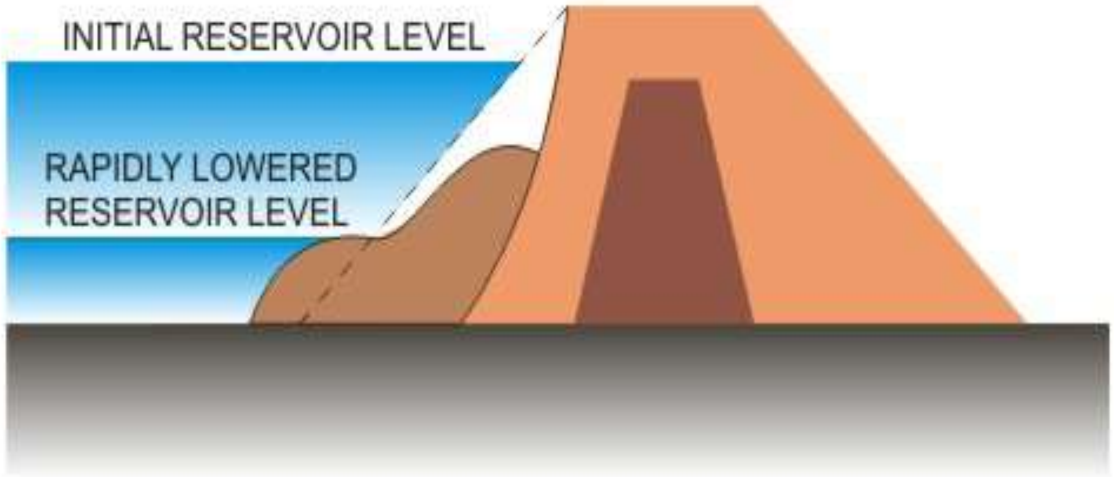


FIGURE 30. Upstream slope failure due to rapid drawdown

III). Sliding of the downstream face due to slopes being too steep:

- Instability may be caused to the downstream slope of an embankment dam due to the slope being too high and too steep in relation to the shear strength of the shoulder material. This causes a sliding failure of the downstream face of the dam .

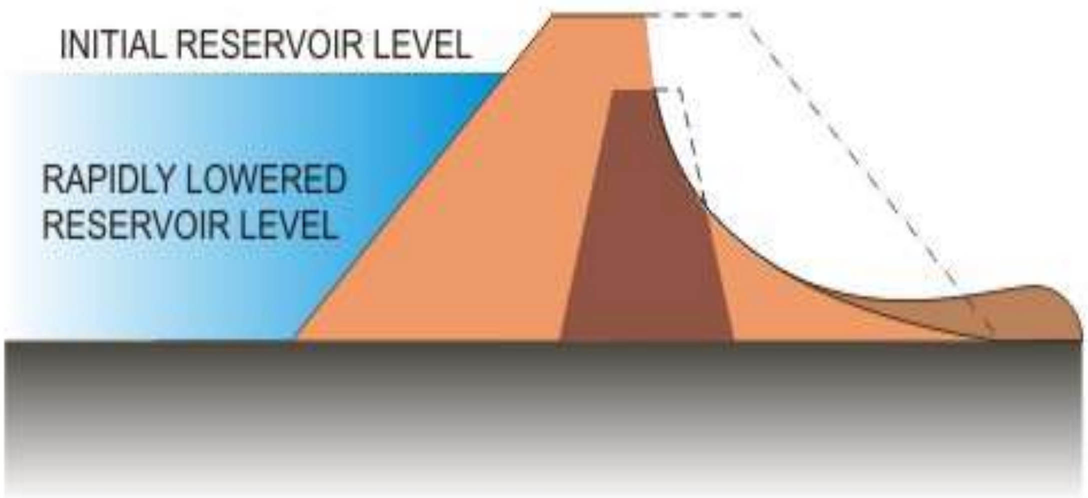


FIGURE 31. Downstream face too steep unable to be resisted by soil shear strength

IV).Flow slides due to liquefaction:

- During an earthquake, some portion of the dam or foundation may destabilize due to the phenomena called liquefaction.
- Even cohesion less soil cannot drain quickly enough as the movements are so sudden that the rate of extra loading on the soil becomes greater than the rate of drainage of the seepage water out of the soil.
- This causes excess pore water pressure to develop, where both the effective stress and the strength decrease. Under circumstances when the effective stress drops to zero.
- which means the soil loses all its shear strength, it behaves like a dense liquid and slides down, and the dam slumps.

V).Damage caused by burrowing animals or water soluble materials:

- Embankment dams get damaged by the burrows of animals which causes the seepage water to flow out more quickly, carrying fine material along with.
- water soluble materials within the body of the dam gets leached out along with the seepage flow causing piping and consequent failure.

VI). Embankment and foundation settlement:

- Excess settlement of the embankment and/or the foundation causes loss of free board. The settlement may be more in the deeper portion of the valley, where the embankment height is more.

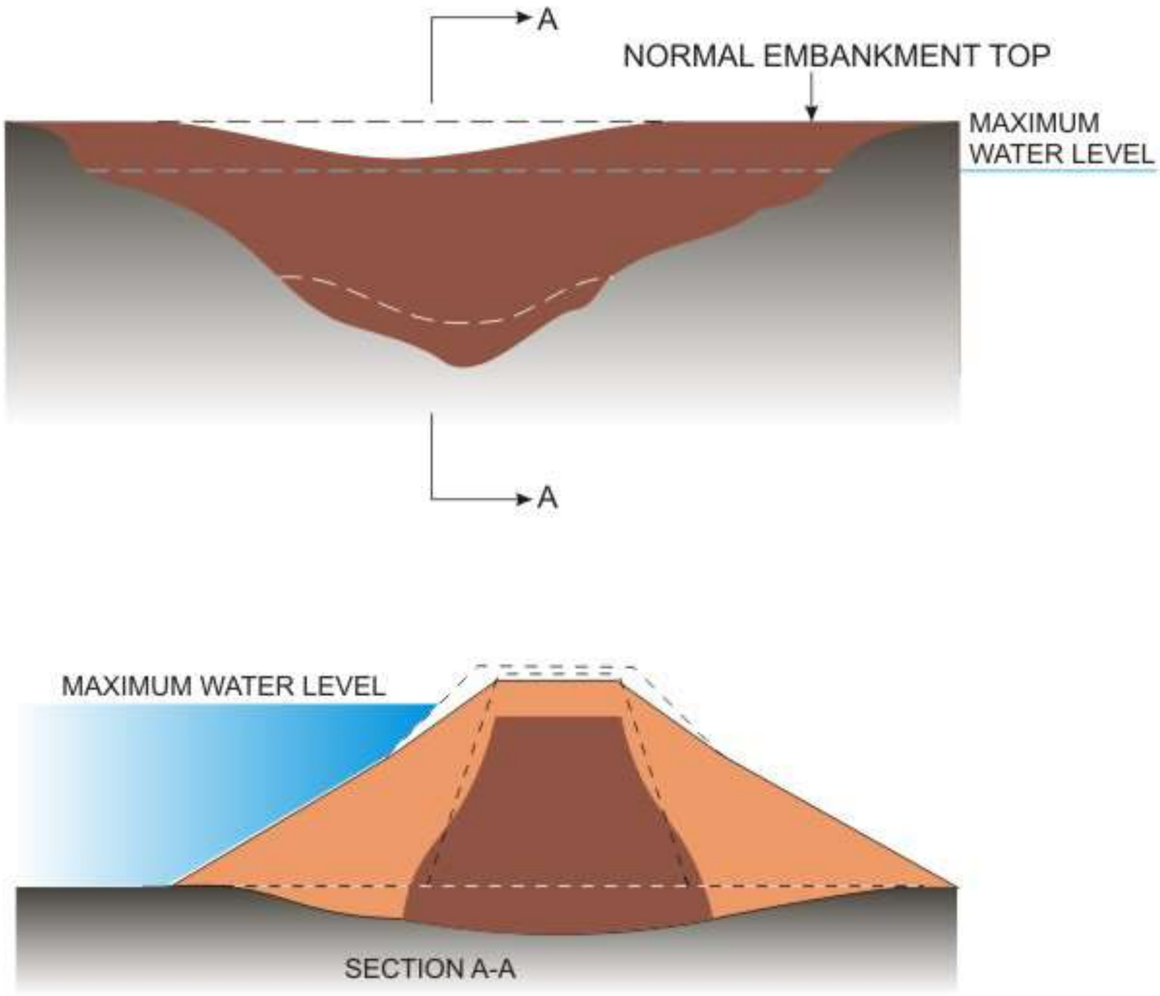


FIGURE 32. Excessive settlement of dam and foundation

Criteria for safe design of Earth Dams:

- An Earth dam must be safe and stable during the phases of construction and operation of the reservoir.
- The embankment must be safe against overtopping during the occurrence of inflow design flood by provision of sufficient spillway and outlet works.
- The dam must have sufficient free board so that it is not overtopped by wave action.
- Seepage flow through embankment , foundation and abutments must be controlled by suitable design provisions so that no internal pressure takes place.

Contd…

- There should be no opportunity for the free passage of water from upstream to the downstream either through the dam (or) through the foundations.
- The portion of the d/s of the impervious core should be properly drained.

- The u/s and d/s slopes should be so designed that they are safe during and immediately after the construction.
- The d/s slope should be so designed that it is safe during steady seepage case under full reservoir condition.

- The u/s slope should be stable during rapid draw down condition.

- The u/s and d/s slopes of the dam should be flat enough so that the shear stress induced in the foundation is enough less than the shear strength of the material in the foundation to ensure a suitable factor of safety.

- The u/s slope must be protected against erosion by wave action and the crest and downstream slope must be protected against erosion due to wind and rain.

Section of an Earth Dam:

- The preliminary design of an earth dam is done on the basis of past experience and on the basis of performance of dams built in the past.
- We shall discuss here the preliminary selection of these terms:
  - Top width
  - Free board
  - Casing or outer shells
  - Central impervious core
  - Cut-off trench
  - Downstream drainage system

1). Top width:

- It is based on the following considerations
  - Nature of embankment materials
  - Height of the structure
  - Importance of the structure
  - Width of Highway on the top of the dam
  - Practicability of construction
  - Protection against Earthquake forces

Following are the emperical equations for Top width 'b':

$b = (Z/5)+3$ - applicable for low dams

$b = 0.55Z^{(1/2)} + 0.2$ - for lower than 30 m

$b = 1.65(Z+1.5)^{(1/3)}$ - higher than 30 m

2) Free board:

- It is the vertical distance between the horizontal crest of the embankment and the reservoir level.
- It is based on the inflow design flood occur and should the outlet works and spillway function as planned.
- Sufficient free board must be provided so that there is no overtopping takes place.

3).Casing or outer shells:

- The function of casing or outer shells is to impart stability and protect the core.
- The relatively pervious materials which are not subjected to cracking on direct exposure to atmosphere are suitable for casing.

- The design slopes of the u/s and d/s embankments may vary widely depends on the character of the materials available ,foundation conditions and the ht. of the dam.
- The u/s slope may vary from 2:1 to as flat as 4:1 for stability. The usual d/s slopes are 2:1, where d/s pervious zone is provided.

4) Central impervious core:

- The min. safe thickness of the core depends on these factors:
  - Tolerable seepage loss
  - Max. width that will permit for construction
  - Types of the materials available for the core and the shells
  - Design of the proposed filter layers

- The shear strength of the core material is always less than that of the embankment. Hence a thinner shell is preferable in view of stability.

- However, a thick core has more resistance to piping which may develop differential settlement.

- The thickness of the core at any elevation is not less than that elevation . The width of the crest should not less than 3m to permit the compaction.

- The top level of the core should be at least 1m above the max. water level to prevent seepage .

5). Cut-off Trench:

- Reduces loss of stored water through foundation and abutments and prevent sub-surface erosion by piping.
- The alignment of the cutoff trench should be fixed in such a way that its central line should be within the u/s base of the impervious core and it should be keyed into rock.
- The bottom width of cutoff trench may be 4m is recommended.

6).Downstream drainage system:

- Filter zones are invariably provided in all earth dams. They are constructed of material of more pervious than embankment soil.

- Provision of filters at d/s serves two purposes
  - It reduces the pore water pressure in d/s of dam so the stability of dam increases.
  - It checks piping by checking the migration of the particles.

- Generally three types of drains are provided in earth dams
  - Toe drain
  - Horizontal blanket
  - Chimney drain’s
- Toe drains are installed in some of oldest Homogeneous dams to prevent softening at d/s toe.
- Horizontal blankets are widely used for dams of moderate height.
- In order to prevent seepage water before it reaches the d/s slope, many of high homogeneous dams have been constructed with inclined chimney drains.

Design to suit available materials:

- The section of a Earth dam should be o selected that the available materials are utilized maximum and limited qty. of other required materials are imported to site.

- The available materials can be classified into three types:
  - Gravel (or) Coarse sand is available with Clayey silt.
  - Only Fine Gravel (or) Coarse sand is available.
  - Only Silty clay is available.

- In addition to these ,three general foundation conditions may be there.
  - Foundations Impervious to a large depth,
  - Foundations pervious to moderate depths, after which impervious strata is available
  - Foundations pervious to large depth.

Case I: Gravel or Coarse Sand available along with clayey silt:

a). Foundation Impervious to large depth:

- In this case the Impervious stratum is exposed to the surface and the foundations are impervious to a large depth.

- The outer shells are made of the pervious material available at the near by site. The central core of clay silt may its axis either vertical or inclined.

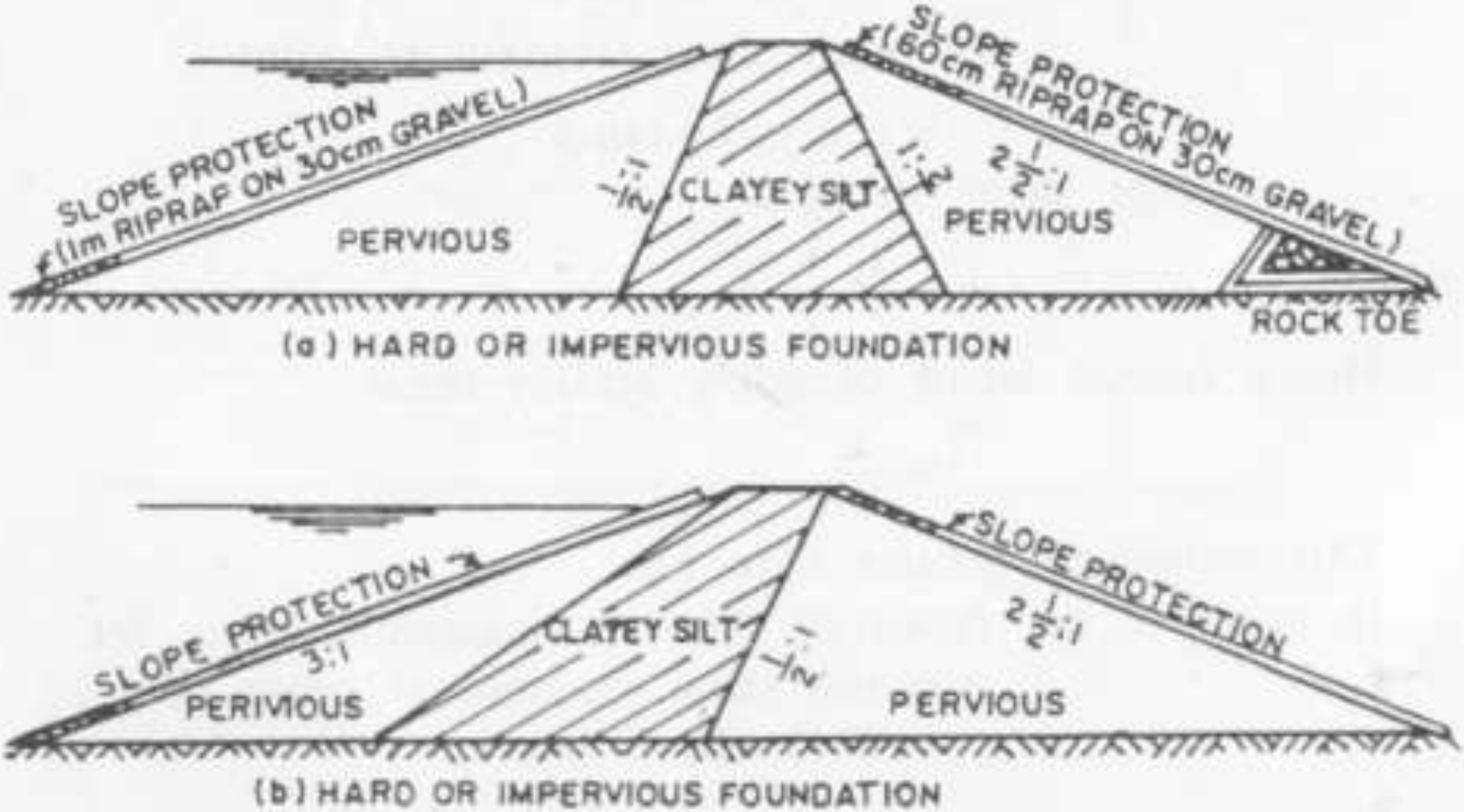
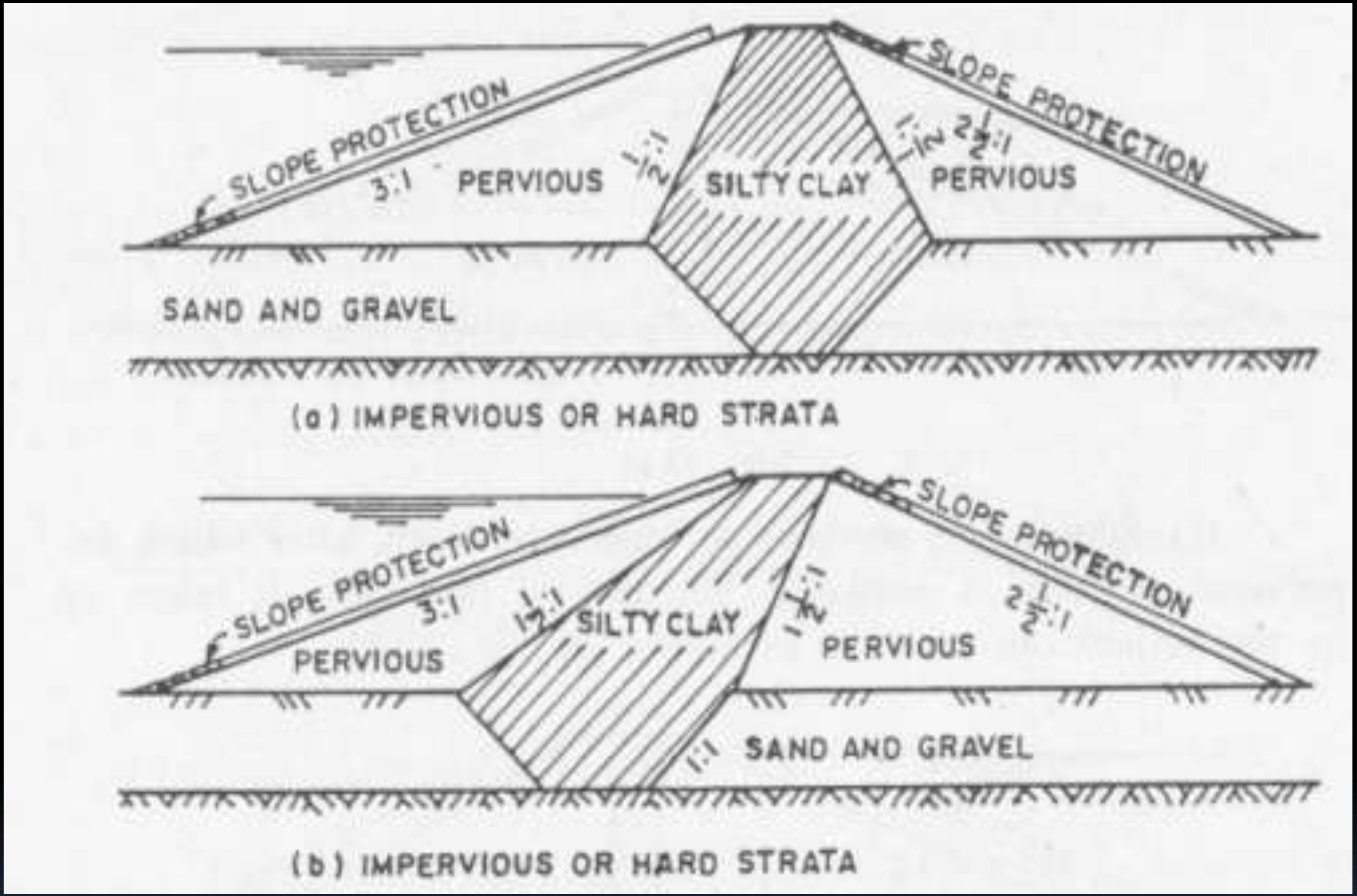

SLOPE PROTECTION
(1m RIPRAP ON 30cm GRAVEL)
PERVIOUS
CLAYEY SILT
PERVIOUS
SLOPE PROTECTION
(60cm RIPRAP ON 30cm GRAVEL)
2 1/2 :1
ROCK TOE
(a) HARD OR IMPERVIOUS FOUNDATION
SLOPE PROTECTION
3:1
PERIVIOUS
CLAYEY SILT
PERVIOUS
SLOPE PROTECTION
2 1/2 :1
(b) HARD OR IMPERVIOUS FOUNDATION

FIG. 10.37

b). Foundation pervious to a moderate depth, after which impervious stratum is available:

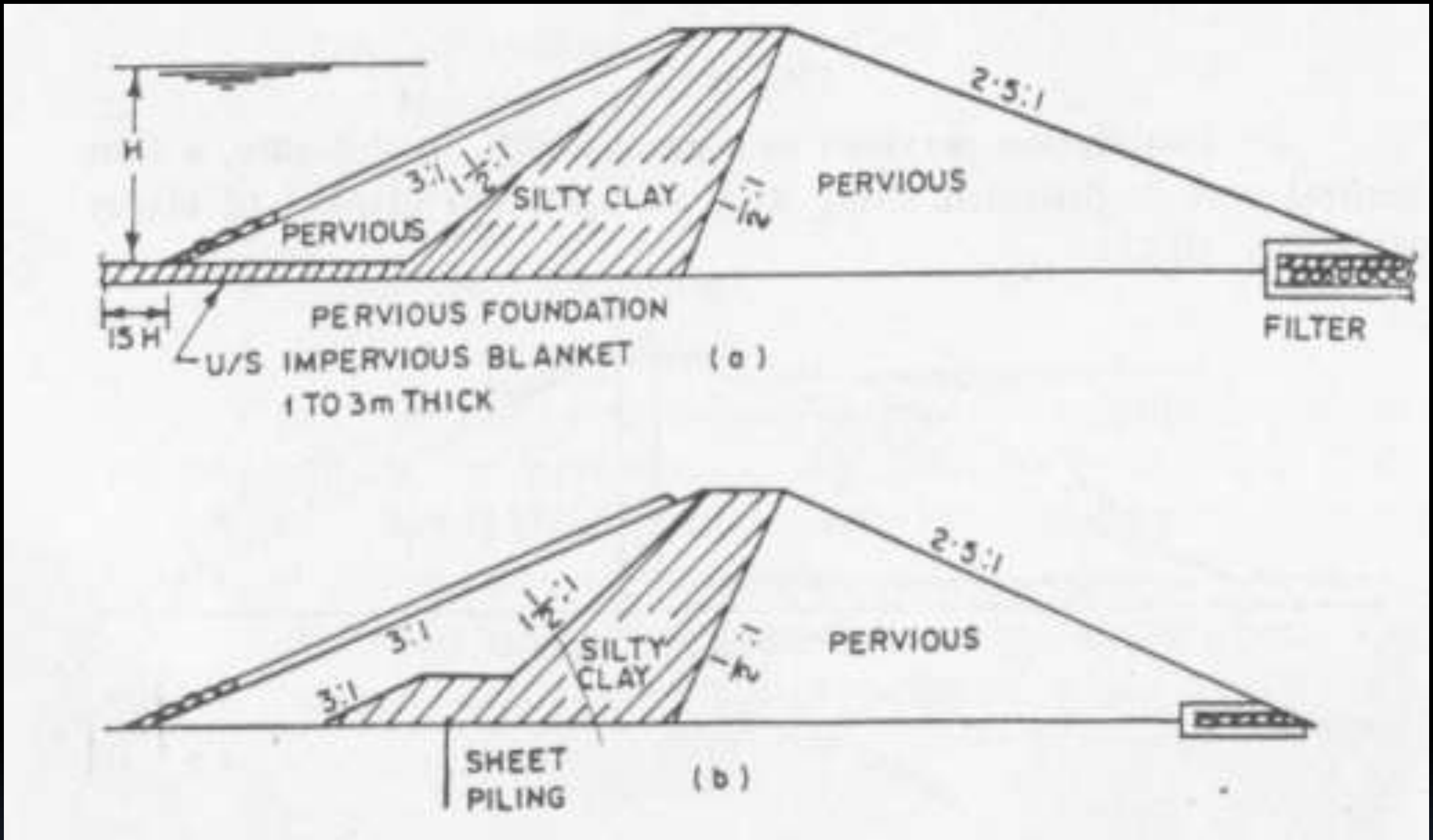
- The construction is similar to pervious case, except that the central core is taken up to impervious foundation level as shown in fig .



SLOPE PROTECTION
3:1
PERVIOUS
SILTY CLAY
SLOPE PROTECTION
PERVIOUS
SAND AND GRAVEL
(a) IMPERVIOUS OR HARD STRATA
SLOPE PROTECTION
3:1
SILTY CLAY
PERVIOUS
SLOPE PROTECTION
PERVIOUS
1:1
SAND AND GRAVEL
(b) IMPERVIOUS OR HARD STRATA

c).Foundation pervious to a great depth:

- In this case there is large seepage through foundations. Hence some form of cut-off is to be provided.
- If sufficient impervious material is available, an u/s clay blanket should have to provided.
- Otherwise a sheet cut-off pile may be provided to some reasonable depth.

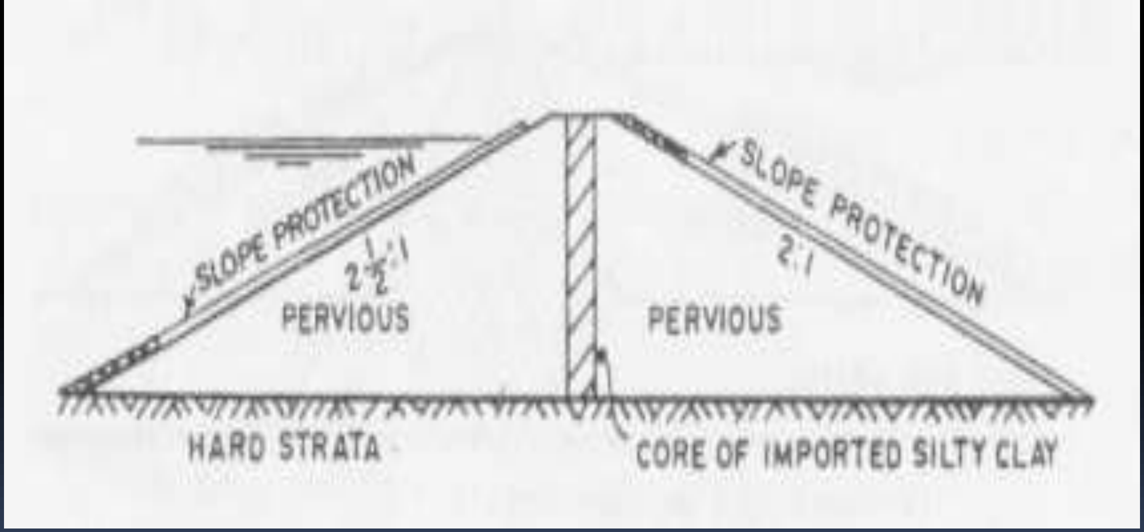


2·5:1
H
3:1
SILTY CLAY
PERVIOUS
PERVIOUS
PERVIOUS FOUNDATION
15 H
U/S IMPERVIOUS BLANKET
1 TO 3m THICK
(a)
FILTER
2·5:1
3:1
SILTY CLAY
PERVIOUS
3:1
SHEET
PILING
(b)

Case II. Only pervious material is available:

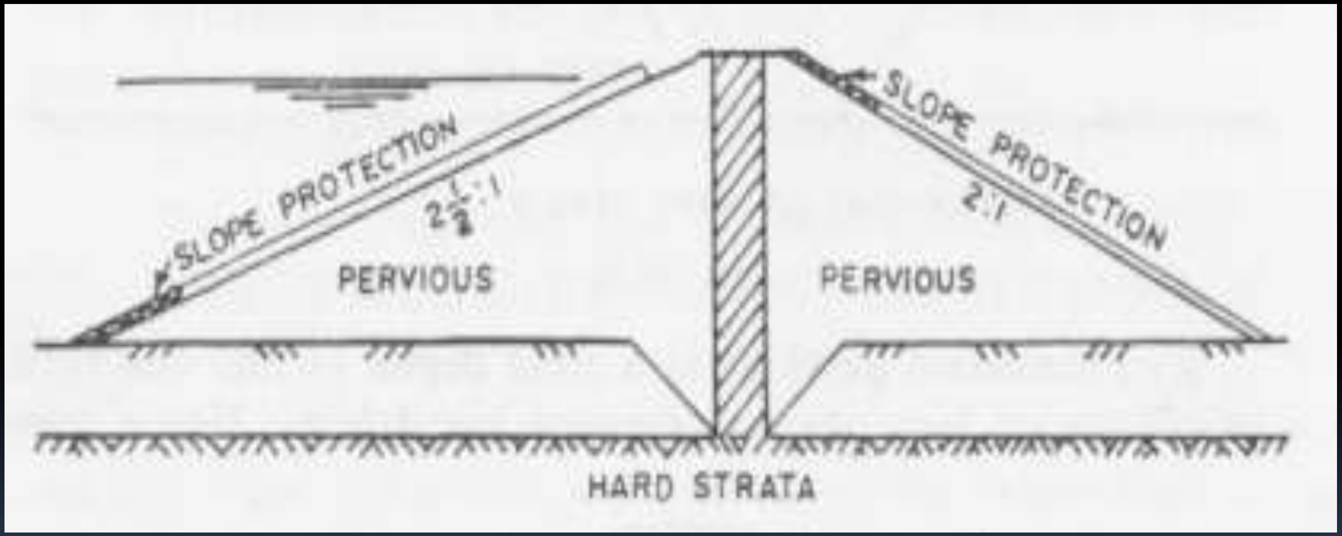
a). Foundation Impervious to large depth:

Since the impervious material to be imported, so thin impervious core is provided as shown in fig.



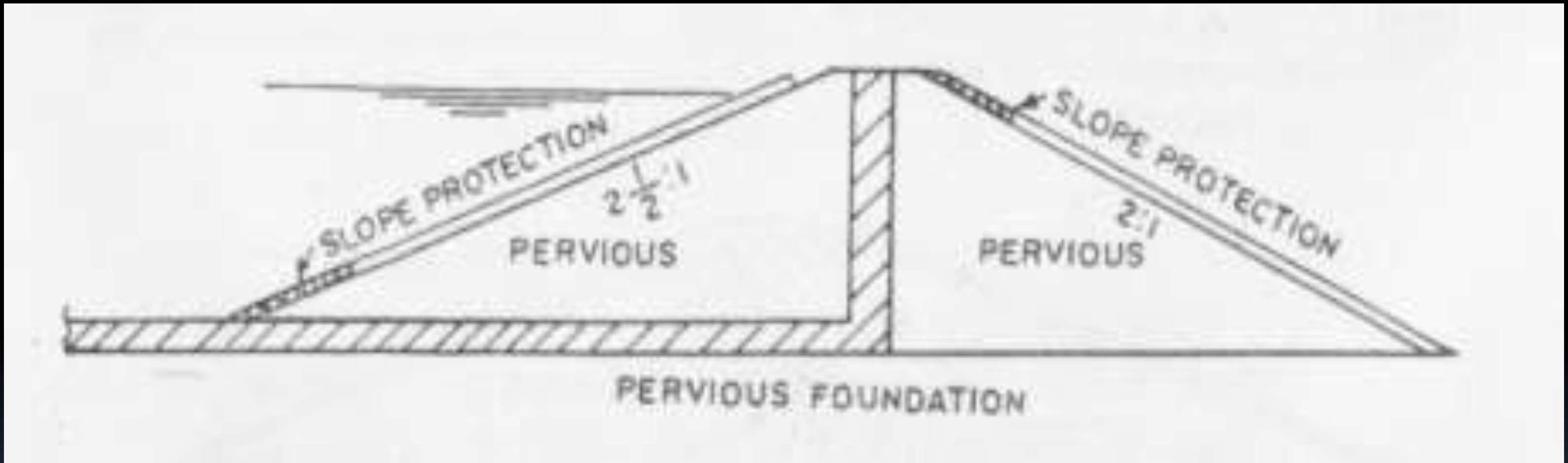
b). Foundation pervious to a moderate depth, after which impervious stratum is available:

- The central core is taken up to the impervious stratum as shown in fig.



c). Foundation pervious to a great depth:

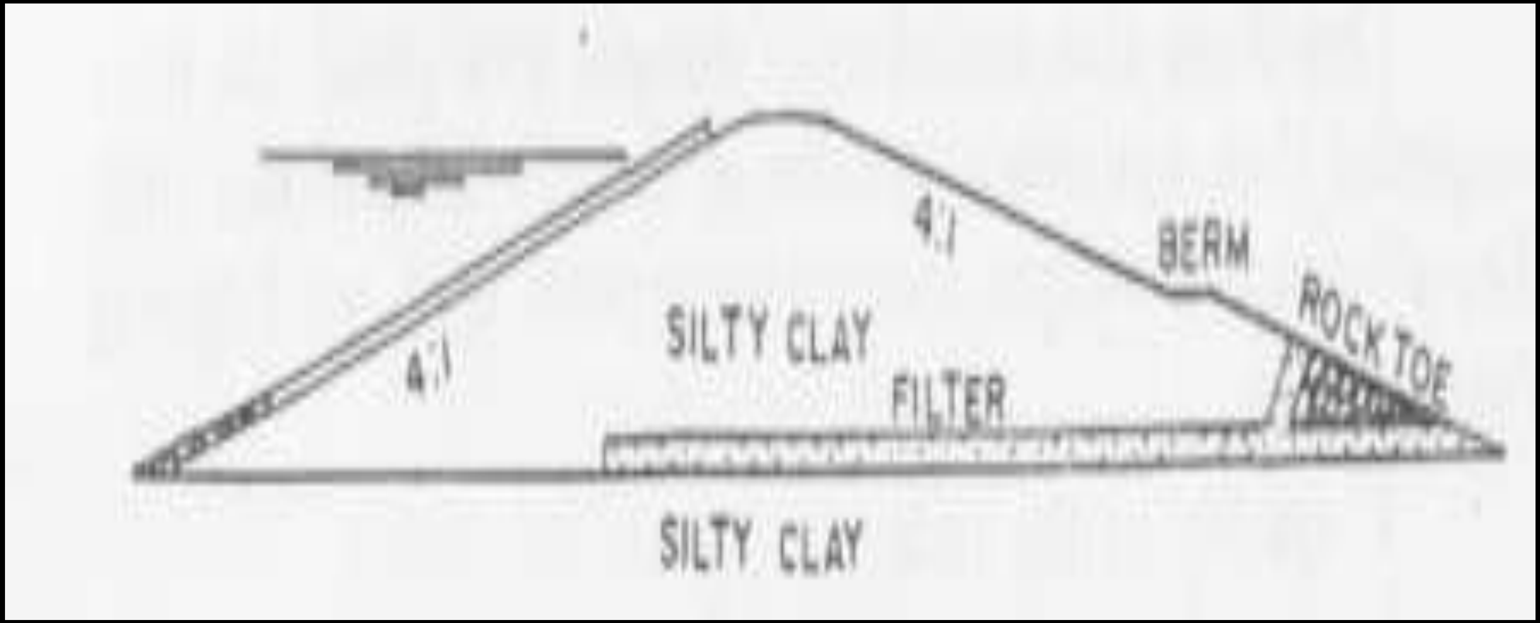
- In this case , a thin central core is provided along with an upstream blanket of clayey silt have to be provided.



Case III. Only silt clay is available:

a). Foundation Impervious to large depth:

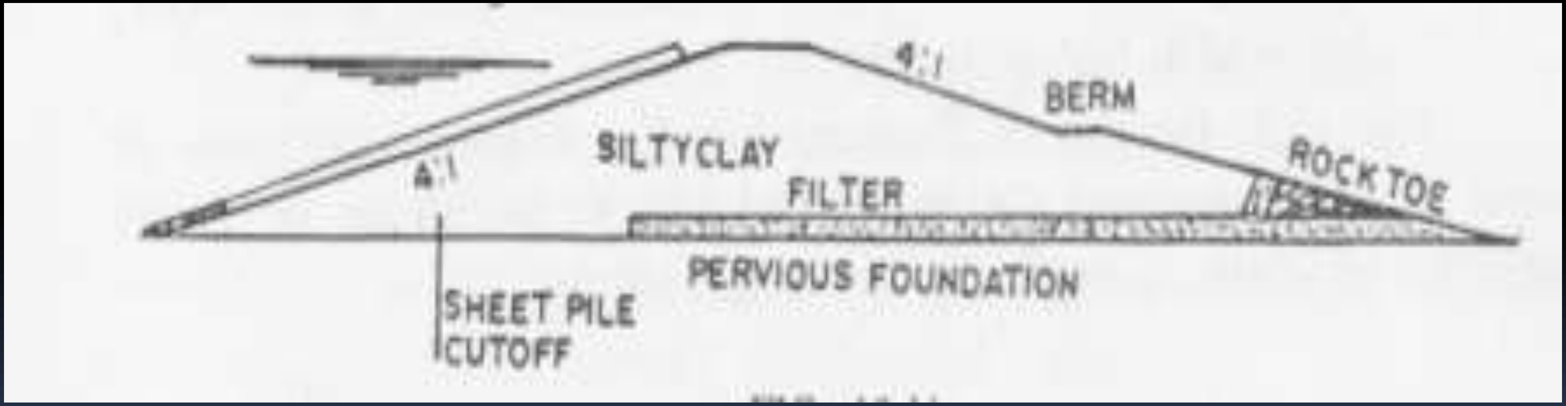
- The whole dam is Homogeneous, made up of silty clay.
- However a Horizontal drainage filter will be provided up to a great distance inside the body of the Dam .



4:1
BERM
SILTY CLAY
4:1
ROCK TOE
FILTER
SILTY CLAY

b). Pervious Foundation:

- If the foundation is pervious and impervious material is available the whole dam may made homogeneous, provide a sheet pile cutoff and a long horizontal filter.



Seepage control measures:

- The seepage control measures are necessary to prevent the percolation of water through the embankment and its foundation.

- The following devices are used for seepage control through earth dam:

  - Embankment seepage control
  - Foundation seepage control

Embankment seepage control:

- Toe control
- Horizontal drainage filter
- Protective filter D/s of the toe
- D/s coarse section
- Chimney drains extending upward to embankments

Foundation seepage control:

- Impervious cut off
- Upstream impervious blanket
- D/s seepage berms
- Drainage trenches
- Relief wells

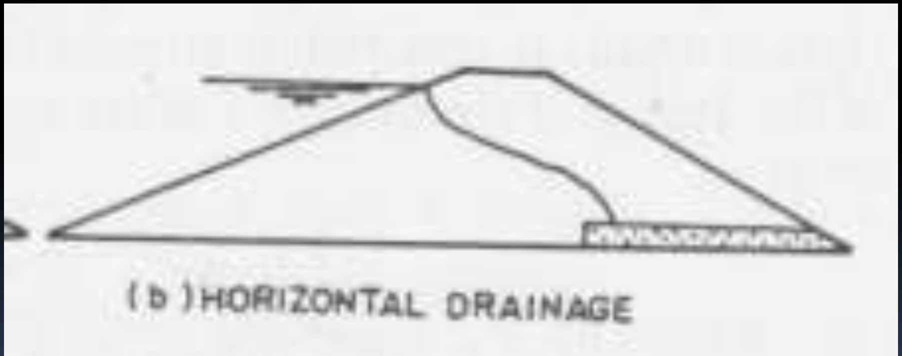
○ Toe filter:

- Rock toe keeps the Phreatic line well within the section and facilitates drainage.
- Its height is generally kept equal to 30 to 40% of reservoir head.

(c) ROCK TOE FILTER

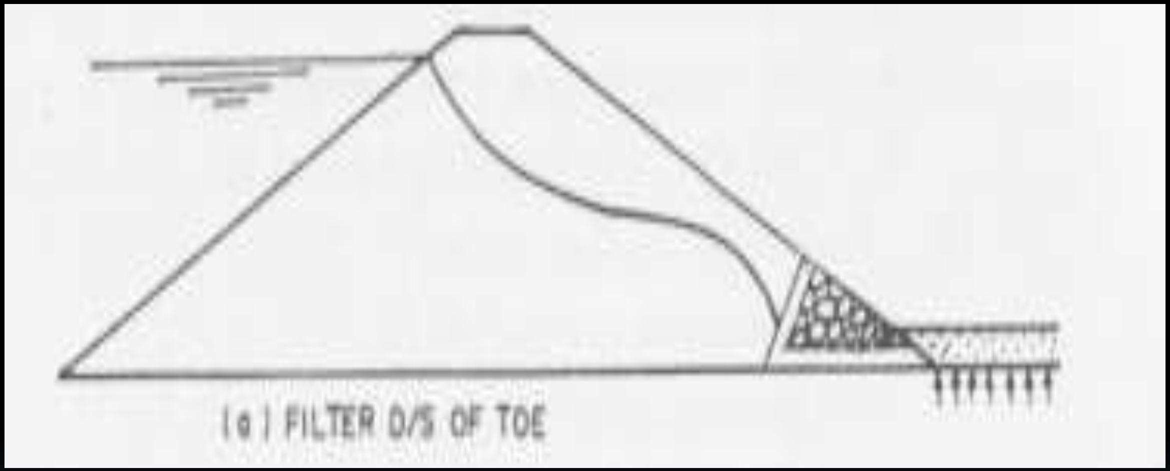
Horizontal drainage filter:

- The horizontal drainage filter may extend from 25 to 100% of the distance from D/s toe to the centre line of the dam.
- This serves for following purposes
  - It keeps the phreatic line within the dam
  - It also provides drainage for foundation
  - It also accelerates the consolidation



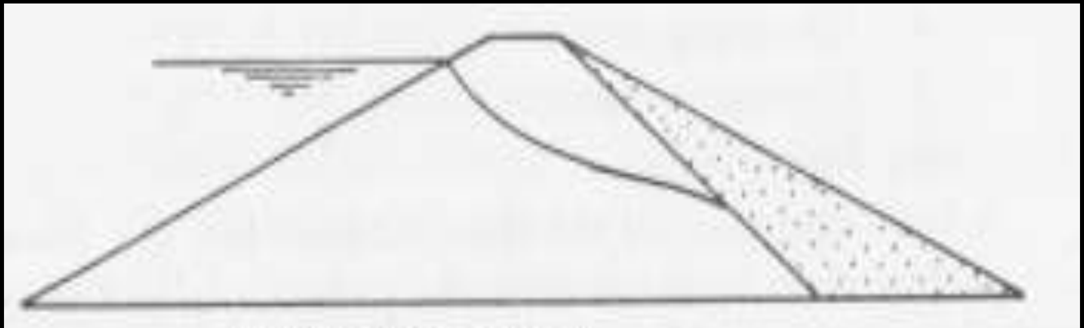
Filter D/s of the Toe:

- The provision of such filter provides additional weight and thus makes the upward flow more safe.



Downstream coarse section:

- This also intercepts the flow through the embankment, and makes the d/s slope safe against piping.
- It is also an Earthquake resistant measure.


(b) D/S COARSE SECTION

Chimney drain:

- When there is high degree of embankment stratification, the horizontal permeability is greater than vertical resulting in greater spread of seepage.

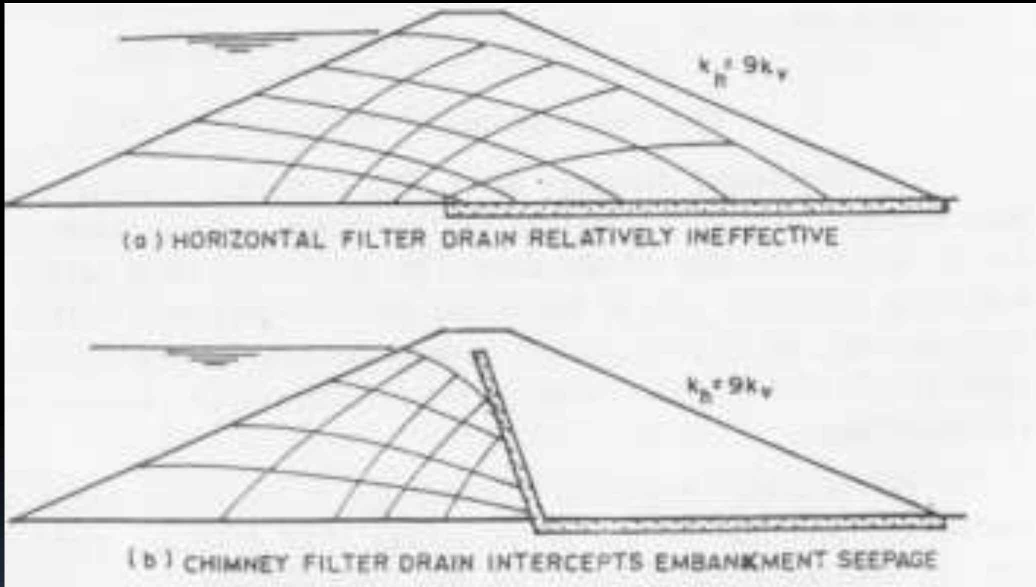


FIG.10.48. EFFECTIVENESS OF CHIMNEY DRAIN.

Impervious cut-off:

- Whenever economically possible the seepage should cutoff. The various cutoff's may consists of
  - cutoff trenches
  - Grout curtains
  - Sheet pile cutoff

- It is impossible to provide cutoffs up to impervious stratum .In such case only partial cutoff's is provided.

- 90% depth of cutoff reduces the discharge by 64% and 50% depth by 25%.

Down stream seepage berms:

- Berms can be used to control seepage efficiently where d/s top stratum is relatively thin and uniform, or where no d/s top stratum is present.
  - To provide additional weight to resist uplift pressure
  - To afford protection against sloughing of the d/s slope of the dam.

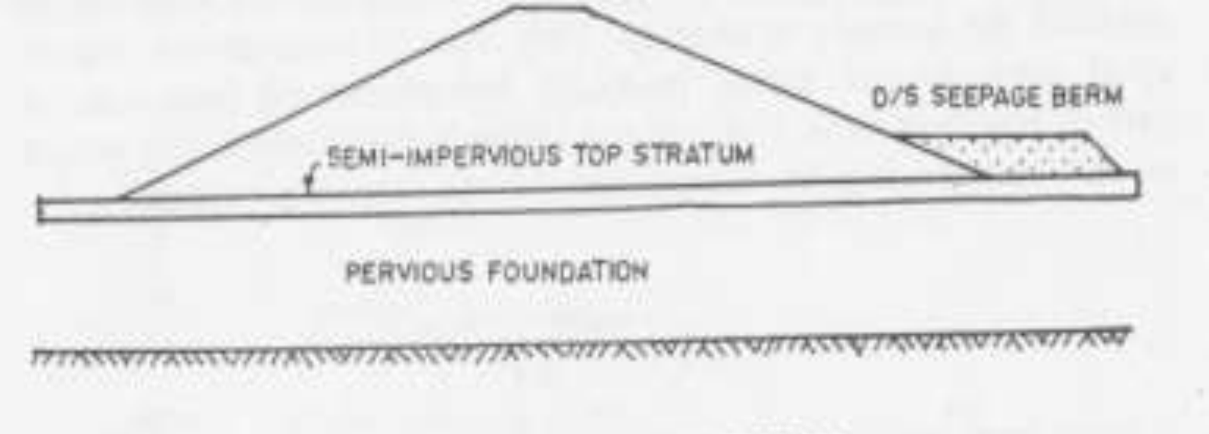


FIG. 10.49. D/S SEEPAGE BERMS.

Drainage trenches:

- They are provided when top stratum is thin and pervious stratum is also shallow.

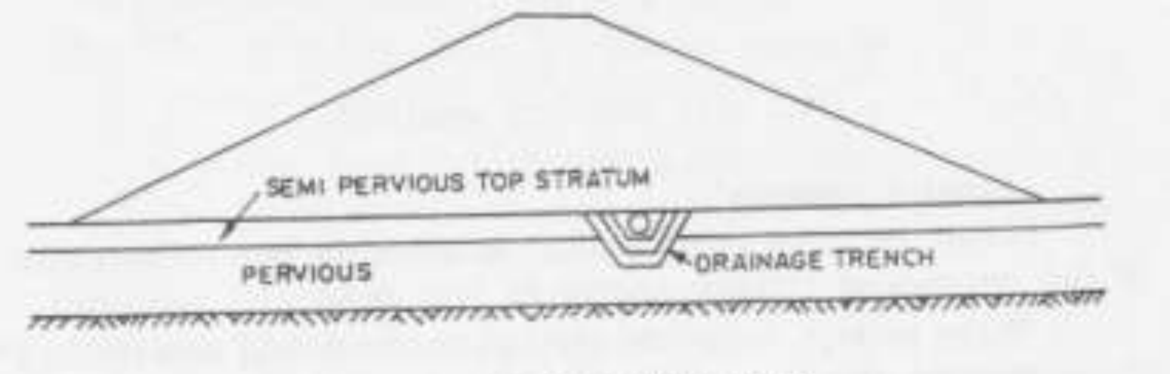


FIG. 10.50 DRAINAGE TRENCH

Relief wells:

- The purpose of this is to reduce the sub-stratum uplift pressure d/s of the dam otherwise would cause piping.
- They intercept the seepage and control the outlet for seepage.

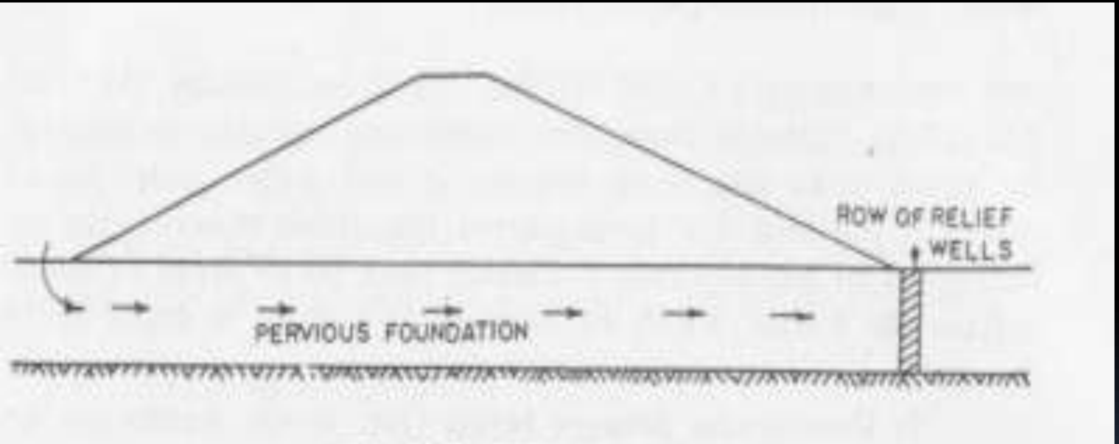
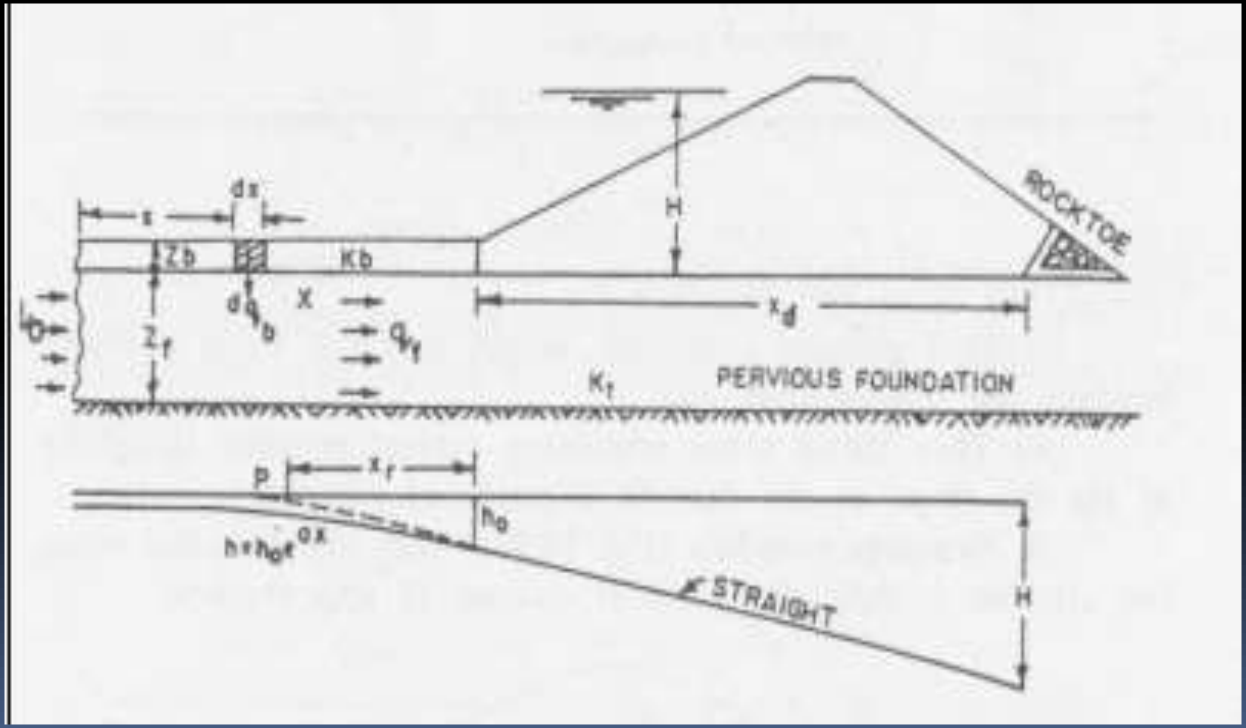


FIG. 10.51. RELIEF WELL.

Upstream impervious blanket:

- Impervious Upstream or riverside blankets overlying pervious foundation are effective in reducing the seepage.

- They also reduce uplift pressure and gradients d/s land side.



Slope protection:

- The u/s slope should be protected against the wave action and the d/s slope should be protected against rain.
- In some instances provision must be made against burrowing animals.
- Following are the materials used for slope protection:
  - Rock Rip rap
  - Concrete pavement
  - steel facing
  - Bituminous pavement
  - Precast concrete blocks

- The efficiency of dumped rock riprap depends on the following characteristics:
  - Quality of the rock
  - Weight or size of the individual pieces
  - Shape of stones & Rock fragments
  - Slope of the embankments
  - Stability and effectiveness of the filter

- The USBR has found a thickness of about 1m of dumped riprap, placed on 30 to 50 cm of gravel filter to be required for the slope protection.

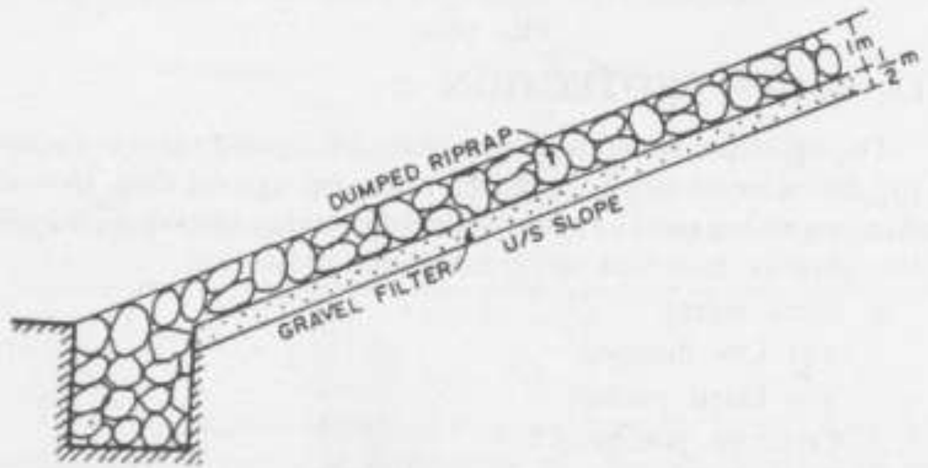


FIG. 10.45. UPSTREAM SLOPE PROTECTION

- A layer of graded gravel should be provided underneath the riprap.
- when the compacted material of earth dam fines may not be washed out through the voids in the riprap by wave action.