I EARTHEN DAMS

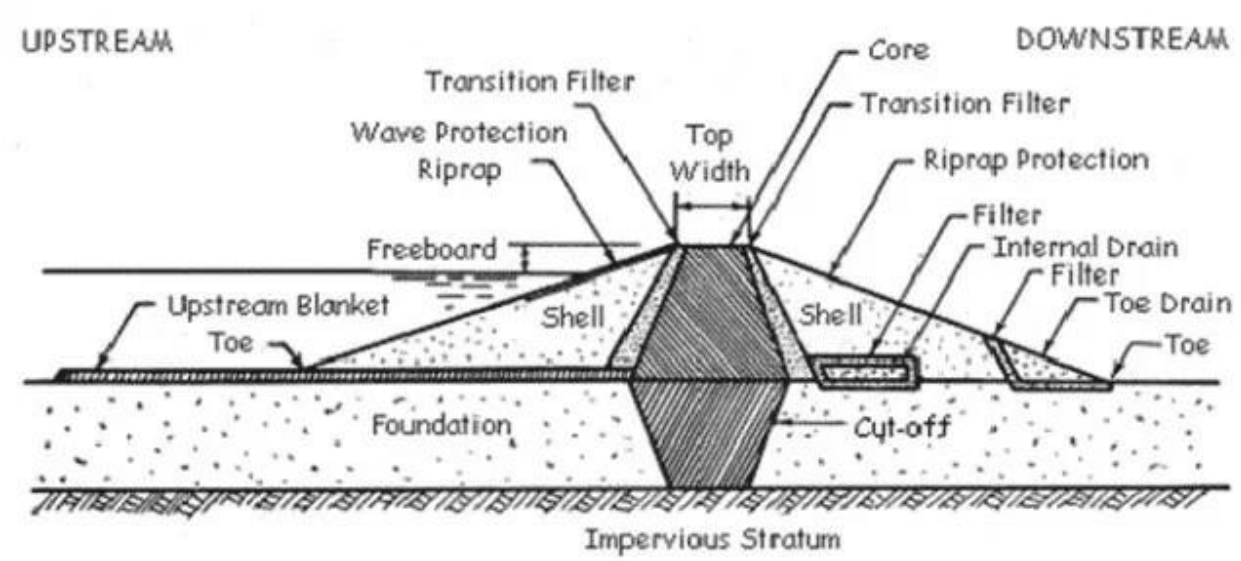
• An earthen embankment is a raised confining structure made from compacted soil.

• The purpose of an earthen embankment is to confine and divert the storm water runoff. Itcan also be used for increasing infiltration, detention and retention facilities.

• Earthen embankments are generally trapezoidal in shape and most simple and economic innature. They are mainly built with clay, sand and gravel, hence they are also known as earthfill dams or earthen dams.

• They are constructed where the foundation or the underlying material or rocks are weak tosupport the masonry dam or where the suitable competent rocks are at greater depth.

• They are relatively smaller in height and broader at the base.



1.1 Components of an Earthen Dam

1. **Shell, Upstream Fill, Downstream Fill or Shoulder:**

2. These components of the earthendam are constructed with pervious or semi-pervious materials upstream or downstream ofthe core. The upstream fill is called the upstream shell and the downstream portion is thedownstream shell.

3. **Upstream Blanket:**

   It is a layer of impervious material laid on the upstream side of anearthen dam where the substratum is pervious, to reduce seepage and increase the path offlow. The blanket decreases both the seepage flow and excess pressure on the downstreamside of the dam. A natural blanket is a cover of naturally occurring soil material of lowpermeability.

3. **Drainage Filter:** It is a blanket of pervious material constructed at the foundation to thedownstream side of an earthen dam, to permit the discharge of seepage and minimize thepossibility of piping failure.

4. **Cutoff Wall or Cutoff:** It is a wall, collar or other structure intended to reduce percolationof water through porous strata. It is provided in or on the foundations.

5. **Riprap:** Broken stones or rock pieces are placed on the slopes of embankment particularlythe upstream side for protecting the slope against the action of water, mainly wave actionand erosion.

6. **Core Wall, Membrane or Core:** It is a centrally provided fairly impervious wall in the

dam. It checks the flow of water through the dam section. It may be of compacted puddledclay, masonry, or concrete built inside the dam.

7. **Toe Drain:** It is a drain constructed at the downstream slope of an earthen dam to collectand drain away the seepage water collected by the drain filters.

8. **Transition Filter:** It is a component of an earthen dam section which is provided with coreand consists of an intermediate grade of material placed

between the core and the shells toserve as a filter and prevent lateral movement of fine material from the core.

1.2 Advantages

1. Design procedures are straightforward and easy.

2. Local natural materials are used.

3. Comparatively small establishment and equipment are required.

4. Earth fill dams resist settlement and movement better than more rigid structures and can bemore suitable for areas where earth movements are common.

1.3 Disadvantages

1. An earthen embankment is easily damaged or destroyed by water flowing on, over or againstit. Thus, a spillway and adequate upstream protection are essential for any earthen dam.

2. Designing and constructing adequate spillways is usually the most technically difficult partof any dam building work. Any site with a poor quality spillway should not be used.

3. If it is not adequately compacted during construction, the dam will have weak structureprone to seepage.

4. Earthen dams require continual maintenance to prevent erosion, tree growth, subsidence,animal and insect damage and seepage.

1.4 Types of Earthen Dam

1. Based on the method of construction:

(a) Rolled Fill Earthen Dams:

• In this type of dams, successive layers of moistened or damp soils are placed one above theother.

• Each layer not exceeding 20 cm in thickness is properly consolidated at optimum moisturecontent maintained by sprinkling water.

• It is compacted by a mechanical roller and only then the next layer is laid.

(b) Hydraulic Fill Earthen Dam:

In this type of dams, the construction, excavation and transportation of the earth are done byhydraulic methods .Outer edges of the embankments are kept slightly higher than the middle portion of each layer.During construction, a mixture of excavated materials in slurry condition is pumped and discharge at the edges.

This slurry of excavated materials and water consists of coarse and fine materials. When it isdischarged near the outer edges, the coarser materials settle first at the edges, while the finermaterials move to the middle and settle there.

Fine particles are deposited in the central portion to form a water tight central core. In this method,compaction is not required.

2. Based on the mechanical characteristics of earth materials used in making the section of

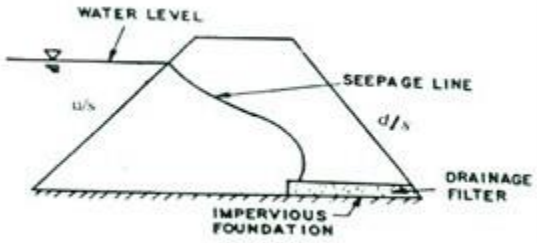
dam:

(a) Homogeneous Earthen Dams:

• It is composed of one kind of material (excluding slope protection).

• The material used must be sufficiently impervious to provide an adequate water barrier, and

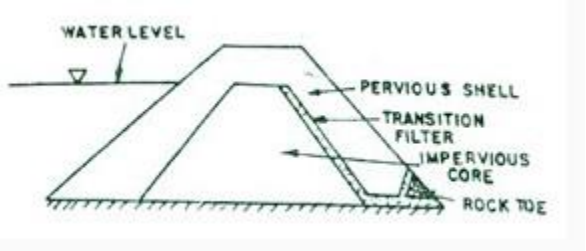
the slopes must be moderately flat for stability and ease of maintenance



(b) Zoned Earthen Dams:

• It contains a central impervious core, surrounded by zones of more pervious material, calledshells.

• These pervious zones or shells support and protect the impervious core.



(c) Diaphragm Earthen Dam:

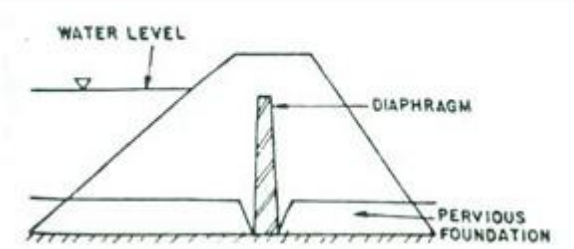
• This type of dam is a modified form of homogenous dam which is constructed with

pervious materials, with a thin impervious diaphragm in the central part to prevent seepage of water.

• The thin impervious diaphragm may be made of impervious clayey soil, cement concrete ormasonry or any impervious material.

• The diaphragm can be constructed in the central portion or on the upstream face of the dam.

• The main difference in zoned and diaphragm type of dams depends on the thickness of theimpervious core or diaphragm. The thickness of the diaphragm is not more than 10 m.



3. Design Criteria

Following main design criteria may be laid down for the safety of an earth dam:

1. To prevent hydraulic failures the dam must be so designed that erosion of the embankment isprevented. For this purpose, the following steps should be followed:

a) Spillway capacity is sufficient to pass the peak flow.

b) Overtopping by wave action at maximum water level is prevented.

c) The original height of structure is sufficient to maintain the minimum safe freeboard

after settlement has occurred.

d) Erosion of the embankment due to wave action and surface runoff does not occur.

e) The crest should be wide enough to withstand wave action and earthquake shock.

2. To prevent the failures due to seepage:

a) Quantity of seepage water through the dam section and foundation should be limited.

b) The seepage line should be well within the downstream face of the dam to prevent

sloughing.

c) Seepage water through the dam or foundation should not remove any particle or in otherwords cause piping.

d) There should not be any leakage of water from the upstream to the downstream face.

Such leakage may occur through conduits, at joints between earth and concrete sectionsor through holes made by aquatic animals.

3. To prevent structural failures:

• The upstream and downstream slopes of the embankment should be stable under all loadingconditions to which they may be subjected including earthquake.

• The foundation shear stresses should be within the permissible limits of shear strength of thematerial.

Design of Earthen Dam

The preliminary design of earthen dam is done on the basis of past experiences. For designingpurpose several parameters, given below should be considered.

1. Top Width
2. Free Board
3. Settlement Allowance
4. Casing or Outer Shell
5. Cut-off Trench
6. Downstream Drainage System

1. Top Width:

• Minimum top width (W) should be such that it can enhance the practicability and protect itagainst the wave action and earth wave shocks.

• Sometimes it is also used for transportation purposes.

• It depends upon the height of the earthen dam and can be calculated as follows

$$W = \frac{H}{5} + 3 \quad \text{(for very low dam)}$$

$$W = 0.55\sqrt{H} + 0.2H \quad (H \le 30)$$

$$W = 1.65\sqrt[3]{H + 1.5} \quad (H \ge 30)$$

where H = the height of the dam (m), for Indian conditions it should not be less than 6 m.

2. Free board:

• It is the vertical distance between the top of the dam and the full supply level of the reservoiror the added height.

• It acts as a safety measure for the dam against high flow condition that is waves and runofffrom storms greater than the design frequency from overtopping the embankment.

• The Recommended values of free board for different heights of earthen dams, given byU.S.B.R., are given in Table.

Recommended Values of Free Board given by U.S.B.R.

Nature of spillway	Height of dam	Free board
Free	Any	Minimum 2 m and maximum 3 m over the maximum flood level
Controlled	< 60 m	2.5 m above the top of the gate
Controlled	> 60 m	3 m above the top of the gate

If fetch length or exposure is given then the free board can also be calculated by Hawksley's

formula: hw=0.014 Dm

0.5 where, = wave height (m); Dm = fetch or exposure (m).

2. Settlement Allowance:

• It is the result of the settlement of the fill and foundation material resulting in the decrease of

dam storage.

• It depends upon the type of fill material and the method and speed of construction.

• It varies from 10% of design height for hand compacted to 5% for machine compacted

earthfill.

3. Casing or Outer Shell:

• Its main function is to provide stability and protection to the core.

• Depending upon the upstream and downstream slopes, a recommendation for the casing and

outer shell slopes for different types of soils given by Terzaghi is presented in Table

Recommended Slopes of Earthen Dam (Sources: S.K. Garg, 2008)

Sl. No.	Types of material	u/s slope	d/s slope
1.	Homogenous well graded material	$2\frac{1}{2}:1$	2:1
2.	Homogenous coarse silt	3:1	$2\frac{1}{2}:1$
3.	Homogenous silty clay or clay a) Height less than15 m b) Height more than 15 m	$2\frac{1}{2}:1$ 3:1	2:1 $2\frac{1}{2}:1$
4.	Sand or sand and gravel with clay core	3:1	$2\frac{1}{2}:1$
5.	Sand or sand and gravel with R.C. core wall	$2\frac{1}{2}:1$	2:1

Cutoff Trench:

• It is provided to reduce the seepage through the foundation and also to reduce the piping inthe dam.

• It should be aligned in a way that its central line should be within the upstream face of theimpervious core.

• Its depth should be more than 1 m. Bottom width of cutoff trench (B) is calculated as:

$B=h-d$ where

h = reservoir head above the ground surface (m); and

d = depth of cutofftrench below the ground surface (m).

4. Downstream Drainage System:

• It is performed by providing the filter material in the earthen dam which is more perviousthan the rest of the fill material.

• It reduces the pore water pressure thus adding stability to the dam.

• Three types of drains used for this purpose are:

1. Toe Drains

2. Horizontal Blanket

3. Chimney Drains.

Causes of Failure

1.Hydraulic Failures 40%

2. Seepage Failures 30%

3. Structural Failures 30%

a) Piping

b) Sloughing

a) Overtopping

b) Wave Erosion

c) Toe Erosion

d) Gullying

a) Upstream slope failure due to sudden drawdown

b) Failure by excessive pore pressure

c) Downstream slope failure by sliding

d) Failure due to settlement of foundation

e) Failure by sliding of foundation

f) Failure by spreading

i. Overtopping:

• The dam is overtopped when the volume of incoming flow into the reservoir is more thanthe actual storage capacity of the reservoir, or the capacity of spillway is not sufficient.

• Sometimes, the faulty operation of spillway also leads to the overtopping problem.

• Similarly, insufficient free board or settlement of foundation as well as embankment alsocause the overtopping problem in earthen dam.

ii. Wave Erosion:

• Wave action removes the soil particles from the unprotected part of upstream face of theclam, continuously.

• This is one of the effective factors to cause the hydraulic type failure in earthen dam.

Toe erosion in the earth fill dam, mainly occurs due to following reasons:

1. **Erosion caused by the tail water**; and

• (ii) Erosion due to cross-currents produced by the storage water, spillway bucket or from theoutlet, create the problem of hydraulic failure.

• This type of failure can be overcome by providing a thick layer of stone riprap on the

downstream face upto the height of tail water level.

iv. Gullying:

• Development of gully in earthen dam is the result of heavy down pour. Such type of failurescan be eliminated by providing a proper size of berm, turf or good drainage system towardsdown-stream side of the dam.

2. Seepage Type Failures:

Failure of earthen dam due to seepage phenomena may be due to following two reasons:

i. Piping; and

ii. Sloughing.

i. Piping:

The continuous flow of seepage water through the body as well as foundation of the dam is themain reason of piping. It causes catastrophic failures in the earth fill dams.

The flow of seepage water through the body of earth dam develops following four effects:

a) The flow of seepage water generates an erosive force, which tends to dislodge the soilparticles from the dam section. The dislodged particles are migrated into the voids of thefilter materials, down-stream side; and thus clogged them, as result the drainage system getsfailed.

b) The seepage flow develops differential pore pressure which tends to lift up the soil mass,causing boiling effect in the dam.

c) Piping is also the result of internal erosion of the soil mass due to seepage flow through theearth dam.

d) The pore pressure developed in the soil reduces the soil strength, which makes the soil massweak, as result there is failure of dam due to shear force.

Sometimes, the leakage from earthen dam also generates the piping type failure. Furthermore, it isalso observed that, the piping type failure is most prominent in those dams, which are poorlyconstructed. Generally, this is due to poor compaction surrounding the concrete outlets or otherparts of the structure etc.

ii. Sloughing:

• Failure of earthen dam due to sloughing is closely related to the water level in the reservoir.

• In full reservoir condition the downstream toe of the dam becomes fully saturated, which isfailure by producing a small slump or miniature slide.

• Under miniature slide the saturated steep face of the dam is dislodged.

• This process is continued till the remaining portion of the dam is being very weak to

withstand against pore water pressure.

3. Structural Failures:

i. Structural failure mainly caused by the following reasons:

ii. Upstream and downstream slope failures due to formation of excessive pore pressure.

iii. Upstream failure due to sudden drawdown in the reservoir water level.

iv. Downstream failure at the time of full reservoir.

v. Foundation slide.

vi. Failure of dam due to earthquake.

vii.Failure of dam due to unprotected side slope.

viii. Failure due to damage caused by burrowing animals.

ix. Failure due to damage caused by water soluble materials.

i. Upstream and Downstream Slope Failure due to Pore Pressure:

• Development of pore pressure in the body of earthen dam, is mainly due to poor compressibility of the soil.

• This occurrence is more susceptible, when dam is constructed with relatively impervious compressible soils, in which drainage of seepage water is extremely low, which causes the development of pore pressure in the soil.

• The compressibility of soil is related to the permeability.

• It has been observed that, when permeability of soil is less than 10–6 cm/s, then there is no substantial drop in pore pressure in the central part of the dam by the end of construction.

• A pore pressure equal to 140% of total weight of soil develops a very crucial situation

regarding dam stability. In this condition the slope of dam is likely to failed.

ii. Failure of Upstream Slope due to Sudden Draw down in the Reservoir Water level:

• Failure of upstream slope due to sudden draw down in reservoir water level is a criticalcondition.

• During this stage, the hydrostatic pressure acting along the upstream slope is suddenlyremoved, as result the face of the dam gets slide.

• In this failure the upstream side slope did not get complete failure, because when slide takesplace due to sudden draw down in reservoir water level, the pore pressure acting along thesliding surface is reduced to a large extent. In this way, the tendency to continue the processof sloughing and sliding of upstream face of the dam, is checked.

iii. Downstream Slope Slide during Full Reservoir Condition:

• When the reservoir is in full condition, then there happens maximum percolation/seepageloss through the dam section.

• This results into reduction of stability of the dam, which causes the downstream slope getscollapse.

• In this case, the failure of downstream slope generally takes place in-following two types ofslide:

(a) Deep Slide:

• Deep slide generally takes place in the clay foundations.

• In deep slide the magnitude of free board given to the dam is reduced due to extending of

upstream face beyond its edge of the crest.

• In this type of slide the pore pressure does not decrease, and the unstable vertical face tendsto slough or slide again and again, until to breach the entire dam.

(b) Shallow Slide:

• The shallow slide extends in the dam section not more than 2 m in the direction normal tothe slope.

iv. Failure due to Foundation Slide:

• This type of failure of earthen dam generally takes place, when foundation is constructed,using fine silt or soft soil materials.

• Sometimes, when soft and weak clayey soil exists under foundation, then dam also tends toget slide.

• Similarly, excess water pressure in confined sand and silt is also developed in the foundation, which causes the failure of dam due to creation of unbalanced condition.

v. Failure of Dam due to Earthquake:

It generally takes place due to following reasons:

1. Earthquake develops cracks in the body of dam; and thus leading to flow of water, whichultimately causes to failure the dam.

2. It compresses the foundation and embankment, both, thereby the total free board provided tothe dam gets reduce and thus, increasing the chances of overtopping problem.

3. It shakes the bottom of the reservoir, as result there develop wave action, which causes theproblem of failure of dam due to overtopping and wave erosion.

4. It generates an additional force on the face of embankment that can lead to develop shearslide of dam slope.

5. Earthquake is also responsible for sliding the top of dam, which may cause overtopping; andthus damaging the structure.

vi. Failure of Earthen Dam due to Slope Protection:

• Generally, slopes are protected by rip-rap or revetment using a layer of gravel or filter

blanket.

• When a heavy storm occurs, then water wave beats the dam slope repeatedly above thereservoir level.

• This action of wave produces the following two effects:

• The wave enters the voids of the rip-rap and washout the filter layer from the dam face. Thiscauses the embankment to get expose to the wave action; and

• If rip-rap is not done by heavy rocks, then there is greater chance of their removal by theforces generated from water waves.

vii. Failure due to Damage Caused by Burrowing:

• Burrowing develops piping type failure in earthen dam. Generally, the animals like muskets

burrow the embankment section, either to make shelter for their living or to make a directpassage for running from one end to another.

• If several muskats involved together to make the hole, then their holes may extremely

weaken the dam section.

viii. Failure due to Water Soluble Materials:

• Based on several observations on this aspect of failure of earthen dams, it has been foundthat the leaching of natural water soluble materials such as zypsum etc. from the dam tendsto create water leakage problem through the dam section.

• In this condition, the foundation also gets settle down, and thus creates the problem ofovertopping and ultimately the dam reaches to the point of its failure.