

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 than the 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 also cause the overtopping problem in earthen dam.

ii. Wave Erosion:

- Wave action removes the soil particles from the unprotected part of upstream face of the dam, 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 the outlet, 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 failures can be eliminated by providing a proper size of berm, turf or good drainage system towards down-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 the main reason of piping. It causes catastrophic failures in the earth fill dams.

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

- a) The flow of seepage water generates an erosive force, which tends to dislodge the soil particles from the dam section. The dislodged particles are migrated into the voids of the filter materials, down-stream side; and thus clogged them, as result the drainage system gets failed.
- 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 the earth dam.
- d) The pore pressure developed in the soil reduces the soil strength, which makes the soil mass weak, 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 is also observed that, the piping type failure is most prominent in those dams, which are poorly

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 is failure 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 critical condition.
- During this stage, the hydrostatic pressure acting along the upstream slope is suddenly removed, as result the face of the dam gets slide.
- In this failure the upstream side slope did not get complete failure, because when slide takes

sliding surface is reduced to a large extent. In this way, the tendency to continue the process of 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/seepage loss through the dam section.
- This results into reduction of stability of the dam, which causes the downstream slope gets collapse.
- In this case, the failure of downstream slope generally takes place in-following two types of slide:

(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 tends to 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 to the 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 to get 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, which ultimately causes to failure the dam.
2. It compresses the foundation and embankment, both, thereby the total free board provided to the 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 the problem 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 shear slide of dam slope.

5. Earthquake is also responsible for sliding the top of dam, which may cause overtopping; and thus 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 the reservoir 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. This causes 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 the forces generated from water waves.

vii. Failure due to Damage Caused by Burrowing:

- Burrowing develops piping type failure in earthen dam. Generally, the animals like muskats burrow the embankment section, either to make shelter for their living or to make a direct passage 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 found that the leaching of natural water soluble materials such as zypsum etc. from the dam tends to create water leakage problem through the dam section.
- In this condition, the foundation also gets settle down, and thus creates the problem of overtopping and ultimately the dam reaches to the point of its failure.