# MODULE 4: EARTH DAMS AND SPILLWAYS

## Earth Dams

### Types of Earth Dams

An **earth dam** is an embankment made mainly of compacted earth materials such as soil, sand, gravel, or clay, constructed to hold back water across a valley, river, or depression. Earth dams are preferred for low to medium height structures, particularly where suitable natural materials are available locally at low cost. They are flexible structures, able to accommodate minor settlement without significant damage.

The types of earth dams include:

- **Homogeneous Earth Dam:**

  This dam is made entirely of one type of material, usually a well-graded impermeable soil like clay. It is the simplest form but requires careful construction to ensure stability and seepage control.

- **Zoned Earth Dam:**

  In a zoned dam, different materials are used in different zones of the dam body. Typically, an impervious core is surrounded by shells of more pervious material (like sand or gravel) to provide strength and prevent seepage.

- **Diaphragm Earth Dam:**

  In this type, an impermeable diaphragm (thin core) made of clay, asphalt, or concrete is placed either vertically or inclined within the embankment to control seepage.

- **Composite Earth Dam:**

  It combines features of earth and rockfill dams, often having an impervious core of earth and shells made of rock or gravel. This type offers better stability and economy in certain geological conditions.

- **Rockfill Dam with Impervious Membrane:**

  The embankment mainly consists of rock fragments with an impermeable membrane (such as asphalt or reinforced concrete slab) on the upstream face to prevent water seepage.

## Causes of Failure of Earth Dams

Despite their flexibility, earth dams are susceptible to certain types of failures if not properly designed, constructed, or maintained. The common causes of failure are:

- **Overtopping:**
  Water flowing over the crest during floods can erode and wash away the dam materials rapidly, leading to catastrophic failure.

- **Seepage Failure (Piping and Sloughing):**

  Uncontrolled seepage through or beneath the dam can carry soil particles, forming tunnels (piping) that enlarge over time, ultimately breaching the dam.

- **Structural Failure:**

  Weak or improper compaction, differential settlement, poor material selection, or earthquake forces can lead to cracking and sliding of the dam body.

- **Foundation Failure:**

  Weak, compressible, or permeable foundation soils can cause settlement, seepage, and sliding problems, leading to failure.

- **Slip Failure (Slope Instability):**

  Instability of upstream or downstream slopes due to saturation, rapid drawdown of water level, or excessive pore water pressures can cause large-scale landslides.

## Criteria for Safe Design of Earth Dams

To ensure the long-term safety and serviceability of an earth dam, certain critical design criteria must be met:

- **Stability of Slopes:**

  Both upstream and downstream slopes must be designed with adequate factors of safety against sliding under all operating conditions, including rapid drawdown, steady seepage, and earthquake forces.

- **Seepage Control:**

The design should incorporate features like impervious cores, filters, drains, and cut-offs to ensure that seepage is controlled, and internal erosion (piping) is prevented.

- **Adequate Freeboard:**

  Sufficient height above the maximum water level must be provided to account for wave action, settlement, and flood surcharge.

- **Control of Settlement:**

  Proper material selection, placement, and compaction must minimise differential settlement, avoiding cracking and seepage paths.

- **Seismic Safety:**

  In earthquake-prone areas, the dam must be capable of withstanding dynamic forces without significant loss of strength or integrity.

- **Hydraulic Design:**

  Spillways and outlet works must be capable of handling design floods safely to prevent overtopping.

**Seepage Through Earth Dams – Graphical Method**

**Seepage** through an earth dam can be visualised and analysed using the graphical method known as **flow net analysis**:

- **Flow Net:**

  A flow net consists of two families of curves:

  - **Flow Lines:** Indicate the paths along which water flows.
  - **Equipotential Lines:** Represent points at the same hydraulic head.

- **Graphical Procedure:**

  - Draw a rough dam section to scale.
  - Sketch flow lines starting from the upstream face to the downstream exit point.
  - Draw equipotential lines perpendicular to flow lines.
  - Try to make curvilinear squares (equal-sized figures).

- **Uses of Flow Net:**

    - Estimate quantity of seepage.
    - Determine seepage pressure and pore water pressures at any point.
    - Help in locating critical seepage points for design of drainage systems.
- **Seepage Quantity Formula:**

$$q = k \times H \times \frac{N_f}{N_d}$$

where:

$q$ = seepage discharge per unit length,

$k$ = permeability of material,

$H$ = total head,

$N_f$ = number of flow channels,

$N_d$ = number of potential drops.

**Measures for Control of Seepage**

Controlling seepage through and beneath earth dams is critical for ensuring their stability and longevity. Common measures include:

- **Impervious Cores:**

  Central or inclined clay cores provide a barrier to seepage through the dam body.

- **Upstream Blankets:**

  Horizontal layers of low-permeability material placed on the reservoir side to reduce seepage gradient.

- **Cut-off Trenches or Walls:**

  Excavated trenches or concrete cut-off walls extend down into impervious strata to block seepage paths.

- **Drainage Filters and Toe Drains:**

  Filter zones of sand and gravel intercept and safely drain seepage water, preventing erosion and piping.

- **Relief Wells:**

Vertical wells that relieve excess pore pressures beneath the dam foundation.

- **Proper Compaction:**

  Good compaction during construction reduces permeability and enhances shear strength.

**Spillways**

**Types of Spillways**

Spillways are hydraulic structures designed to safely release surplus water from reservoirs to downstream areas without causing damage to the dam or the environment. Different types of spillways include:

- **Ogee Spillway:**

  Shaped like an "S" curve (ogee profile), matching the natural trajectory of flowing water. Commonly used with concrete gravity dams.

- **Chute or Trough Spillway:**

  A steep-sloped channel carrying water from the reservoir to the riverbed, used when dam sites are in narrow valleys.

- **Shaft (Morning Glory) Spillway:**

  A vertical shaft leading to a horizontal conduit. Suitable where space is limited.

- **Side Channel Spillway:**

  Water flows parallel to the crest before turning downstream through a channel; useful where topography restricts direct discharge.

- **Saddle Spillway:**

  Constructed at a saddle or low point in the surrounding topography, away from the main dam.

- **Drop Spillway:**

  Water drops suddenly from a height. Suitable for small dams with low heads.

Each type is selected based on site topography, dam type, expected flood discharges, and operational requirements.

**Design Principles of Ogee Spillways**

The **Ogee spillway** is the most widely used type for high dams. Key design principles include:

- **Profile Shape:**

  The downstream face is shaped to match the lower surface of a free-falling jet (called the "nappe") from an ideal sharp-crested weir.

- **Crest Design:**
  - The crest must ensure maximum discharge efficiency.
  - The shape depends on the head of water (design head).

- **Discharge Formula**

  The discharge over an ogee crest is given by:

$$Q = CLH^{1.5}$$

  where: $Q$ = discharge ($m^3/s$),
  $C$ = coefficient of discharge,
  $L$ = effective length of the crest,
  $H$ = head over the spillway.

- **Energy Dissipation:**

  Spillway design includes energy dissipation arrangements like stilling basins or flip buckets to control high-velocity flow downstream.

**Spillway Gates**

Spillway gates are movable structures installed at the crest of a spillway to control reservoir water levels:

- **Types of Gates:**
  - Radial (Tainter) gates
  - Vertical lift gates
  - Drum gates
  - Rolling gates

- **Functions:**
  - Regulate flood releases.
  - Increase storage during normal periods.
  - Provide controlled releases for downstream needs.

Proper gate design ensures operational reliability during flood events and regular reservoir operations.

**Energy Dissipaters and Stilling Basins**

**Significance of Jump Height Curve and Tail Water Rating Curve**

When high-velocity water flows from a spillway, it needs to be slowed down to prevent erosion of the downstream riverbed:

- **Jump Height Curve:**

  Shows the relationship between upstream supercritical flow and the sequent downstream subcritical flow (hydraulic jump). Important for determining the length and depth of the stilling basin.

- **Tail Water Rating Curve:**

  Represents the depth of water available downstream under different flow conditions.
  Design must ensure that the tail water depth is sufficient to form and maintain the hydraulic jump within the basin.

Proper matching of the jump height and tailwater conditions is critical for effective energy dissipation.

**USBR and Indian Types of Stilling Basins**

**Stilling basins** are specially designed concrete basins constructed at the toe of the spillway to dissipate energy:

- **USBR (United States Bureau of Reclamation) Types:**
  - **Type I Basin:** Used for low heads and moderate discharges.
  - **Type II and III Basins:** Used for medium heads and large flows, incorporating chute blocks, baffle piers, and end sills.

    - **Type IV Basin:** Suitable for very high heads, requiring special energy dissipation arrangements.

- **Indian Standard Stilling Basins (As per IS Codes):**

  Designs are similar to USBR types but adapted for Indian river conditions and hydraulic parameters. Indian basins emphasise economical construction, site-specific adjustments, and robustness against sediment loads.

Design of stilling basins ensures effective control over velocity, turbulence, and protection of downstream channels.