Module 5: Diversion Headworks

Introduction to Diversion Headworks

Diversion headworks are hydraulic structures constructed across rivers to divert a portion of the river flow into an off-taking canal for purposes such as irrigation, domestic water supply, and industrial use. They do not store water like dams but rather raise the water level upstream to facilitate controlled diversion into canals. Diversion headworks must handle issues related to silt entry, varying river discharges, and foundation safety, particularly when built on permeable soils.

Types of Diversion Headworks: Weirs and Barrages

Weirs:

A **weir** is a low-height wall built across a river to raise the water level upstream and enable diversion. Water flows over the crest of the weir at most times. Weirs are simple, robust structures typically made of masonry or concrete. They are economical for small to medium river discharges.

Barrages:

A **barrage** consists of a raised platform equipped with gates installed between piers across the river width. Water level is controlled by operating the gates, allowing greater flexibility in flow regulation. Barrages are suitable for large rivers where river discharge varies significantly throughout the year.

Comparison:

A weir mainly works by passive overflow, whereas a barrage actively regulates flow.

Barrages are more expensive but provide better control over the upstream water level.

Layout of Diversion Headwork – Components

The typical layout of a diversion headwork consists of:

1. **Main Weir or Barrage Structure:**
   To raise and regulate the water level.

2. **Divide Wall:**
   A solid wall extending upstream from the headworks to divide the river into two channels (one leading to the canal and the other allowing river flow).
3. **Under-sluices:**
   Openings with gates located near the riverbed on the side of the canal head regulator to remove sediment-laden water.
4. **Canal Head Regulator:**
   Structure to control and regulate the flow of water from the river into the canal.
5. **Fish Ladder or Fish Pass:**
   A stepped passage to allow migration of fish upstream and downstream of the structure.
6. **Earth Dams (Afflux Bunds):**
   Embankments on either side to prevent water escape from the reservoir area.
7. **Guide Banks (Training Works):**
   Structures designed to guide and stabilise river flow toward the headworks to prevent erosion and uncontrolled flooding.

Each component must be carefully designed to ensure smooth operation, sediment management, and stability.

Causes and Failure of Weirs and Barrages on Permeable Foundations

When constructed on sandy or alluvial riverbeds, weirs and barrages face certain risks due to the pervious nature of the foundation. The primary causes of failure include:

Piping and Undermining:

Seepage beneath the structure can remove foundation soil, leading to the formation of subsurface tunnels or "pipes" that cause collapse.

Uplift Pressure:

Water seepage exerts upward forces on the base of the structure, reducing effective weight and causing structural instability.

Scour:

High-velocity water flows can erode the riverbed near the structure, especially downstream, leading to undermining and settlement.

Excessive Exit Gradient:

If the gradient of seepage lines at the downstream end exceeds the critical value, soil particles start moving, initiating failure.

Preventing these failures requires careful design using seepage control measures and sound foundation treatment.

Silt Ejectors and Silt Excluders

Silt Excluders:

Structures located upstream of the canal head regulator to prevent sediment-laden water from entering the canal. They divert bottom layers rich in silt back to the river while allowing clearer surface water into the canal.

Silt Ejectors (Extractors):

Located within the canal itself, downstream of the head regulator, ejectors remove silt that enters the canal by diverting the heavier sediment-laden bottom layers back to a drain or the river.

Purpose:

- Maintain clear canal water.
- Reduce canal siltation and maintenance costs.
- Protect downstream agricultural lands from sedimentation damage.

Proper design of silt management systems is essential for the long-term efficiency of irrigation projects.

Weirs on Permeable Foundations – Creep Theories

Creep Theories

To analyse seepage and ensure the stability of weirs on pervious foundations, several empirical theories, known as **creep theories**, are used:

1. **Bligh's Creep Theory (1904):**
    - Proposed that water follows the contact between the structure and soil ("creep path").
    - Total length of the seepage path (creep length) is critical.
    - Safe design achieved if the creep length is sufficient to reduce uplift and piping.
    - Assumes horizontal and vertical creeps are equally effective (an oversimplification).
2. **Lane's Weighted Creep Theory (1935):**
    - Improved Bligh's theory by recognising that vertical creeps are more effective in reducing uplift than horizontal creeps.
    - Weighted creep length:

      $$L_w = L_h + 3 \times L_v$$

      where L_h = horizontal creep length and L_v = vertical creep length.
3. **Khosla's Theory (1941):**
    - Based on potential flow theory and experimental observations.
    - Considers pressure distribution underneath the structure.
    - Proposes using intermediate sheet piles and floor thickness to reduce uplift pressures effectively.
    - Provides correction factors for more accurate pressure estimations.

Khosla's theory is considered the most accurate for modern designs.

Determination of Uplift Pressure – Various Correction Factors

Under Khosla's method, theoretical uplift pressures are modified using correction factors:

Correction for Thickness of Floor:

Accounts for pressure loss as seepage passes through a thick floor.

Correction for Mutual Interference of Piles:

When multiple sheet piles are close to each other, interference effects are corrected to ensure correct pressure estimation.

Correction for Entrance and Exit:

Modifies the pressures at the entry and exit points of seepage paths.

These corrections lead to a realistic assessment of pressures and help design safer structures.

Design Principles of Weirs on Permeable Foundations Using Creep Theories

Key design principles include:

Ensuring Adequate Creep Length:

Total creep length must be sufficient to lower exit gradients below critical values.

Use of Intermediate Sheet Piles:

Deep sheet piles at upstream, downstream, and sometimes middle points help in reducing uplift and piping potential.

Adequate Thickness of Impervious Floor:

Thick floors help in resisting uplift pressures by providing additional resistance.

Scour Protection:

Launching aprons, protective pitching, and riprap must be provided to protect against scour both upstream and downstream.

Effective Energy Dissipation:

Hydraulic jump formation and stilling basins should be included to dissipate surplus energy safely.

Design must ensure that exit gradient, uplift pressures, and overall stability are within safe limits under all operating conditions.

Exit Gradient

The **exit gradient** is the hydraulic gradient of the seepage water at the downstream end of the floor. It is critical because:

- If the exit gradient exceeds the critical value for the soil, piping begins, leading to structural failure.
- The permissible exit gradient depends on the type of soil (e.g., for fine sand: 1/7 to 1/6).

Ensuring a low exit gradient by lengthening the floor and providing deep downstream sheet piles is a key design goal.

Upstream and Downstream Sheet Piles

Upstream Sheet Pile:

Prevents uplift pressures by providing a longer seepage path before water reaches beneath the floor.

Downstream Sheet Pile:

Reduces exit gradient, prevents piping, and helps stabilise downstream flow.

Proper depth and placement of sheet piles are crucial for the overall stability and safety of the headworks.

Launching Apron

A **launching apron** is a flexible protective layer of stones or concrete blocks laid on the riverbed downstream of the structure:

- **Purpose:**

  To protect the floor from scour and erosion by distributing flow energy.
- **Working Principle:**

  As scour occurs during floods, the apron settles and adjusts itself naturally to protect the structure.
- **Design:**

  The thickness, width, and material size of the apron are determined based on expected scour depth and flow conditions.

Launching aprons are indispensable for the long-term durability of barrages and weirs on permeable foundations.