Diversion Works

Design of Hydraulic Structures (CVL381)

Saumava Dey

Assistant Professor

Department of Civil Engineering

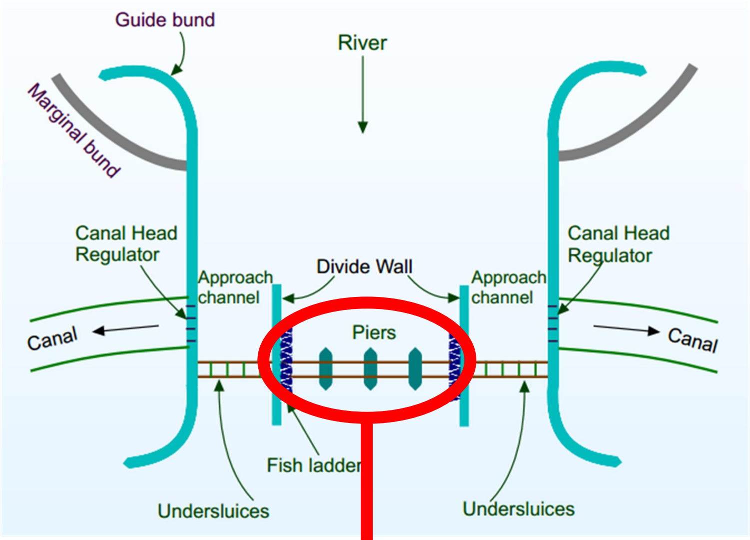
Block V, Room No. 304

Indian Institute of Technology Delhi

Email: saumavadey@civil.iitd.ac.in

Riversluices

- Riversluices are similar to the undersluices without the silt excluders and are separated from the undersluices by means of divide walls.
- They are generally provided in long barrages across wide rivers for simplifying the operation of gates during normal floods and to have better control on the river.

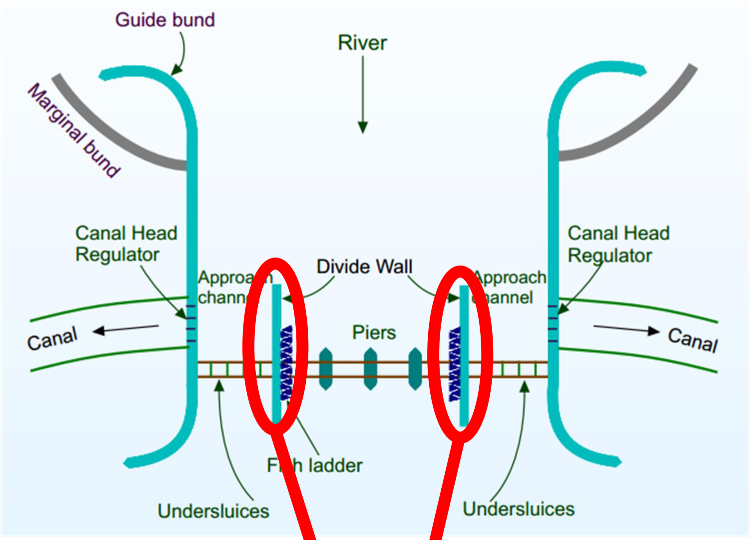


Piers and Abutments

- Piers are provided at an interval of 10-20 m to support bridge decking and the working platform for the operation of gates.
- The piers are high enough to hold the gates clear off the maximum flood level while making clearance for any floating debris under the raised gates.

Tarafeni Barrage at Belpahari, West Bengal

Divide wall or Groyne



- Divide walls are long masonry or concrete walls or groynes much like piers constructed at right angles to the axis of the barrage between the undersluices and the riversluices.
- The main function of a divide wall is to separate the turbulent flow of flood water from the pocket in front of the canal head which helps in restricting sediment entry into the offtaking canal.
- They help in preventing cross currents which can cause damage to the structure.
- The length of the divide wall on the upstream has to be such so as to provide the favorable curvature of flow for feeding the offtaking canal.
- For single head regulator $\frac{2}{3}$rd width covered by divide walls and for twin head regulators full width is covered by divide walls.

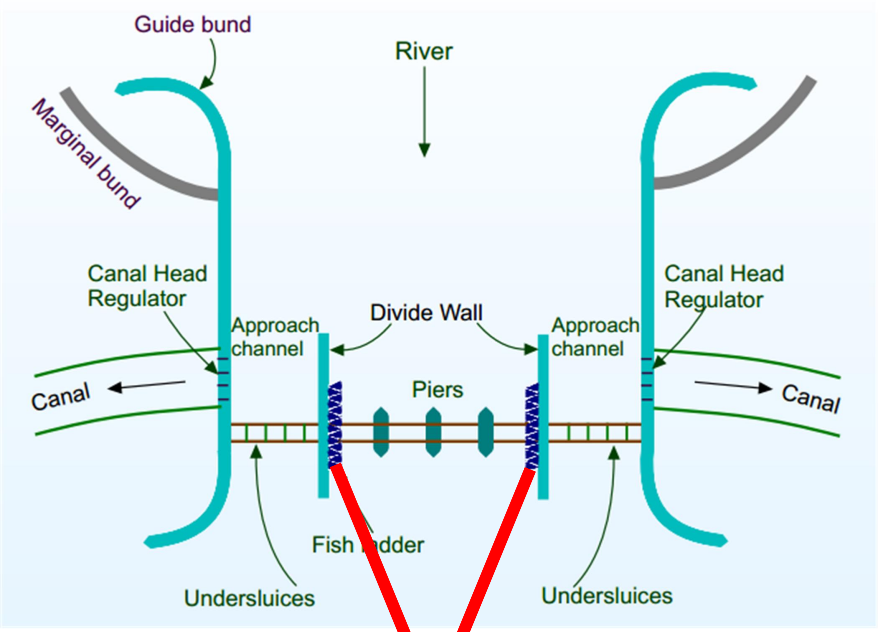
Tilpara Barrage, West Bengal

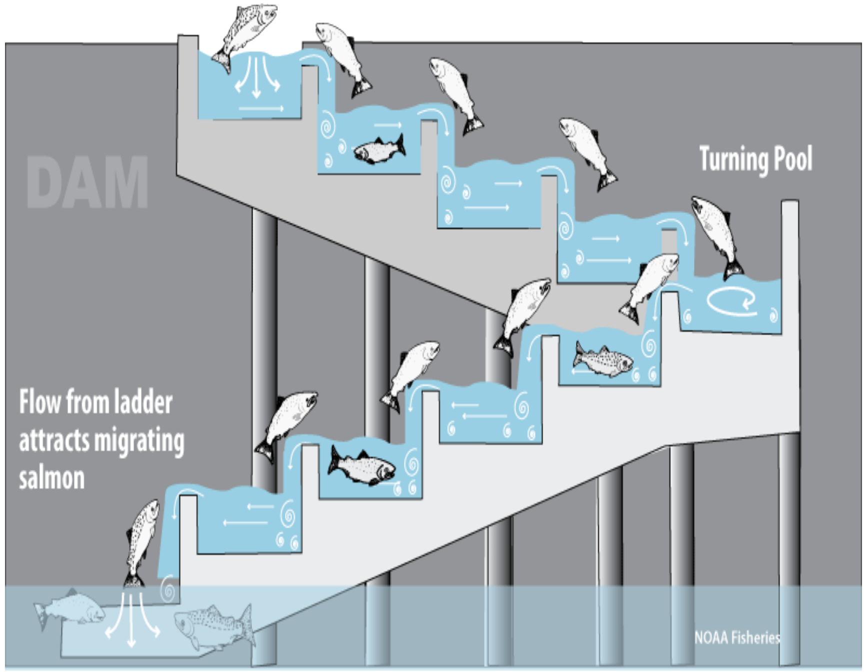
Fish ladder

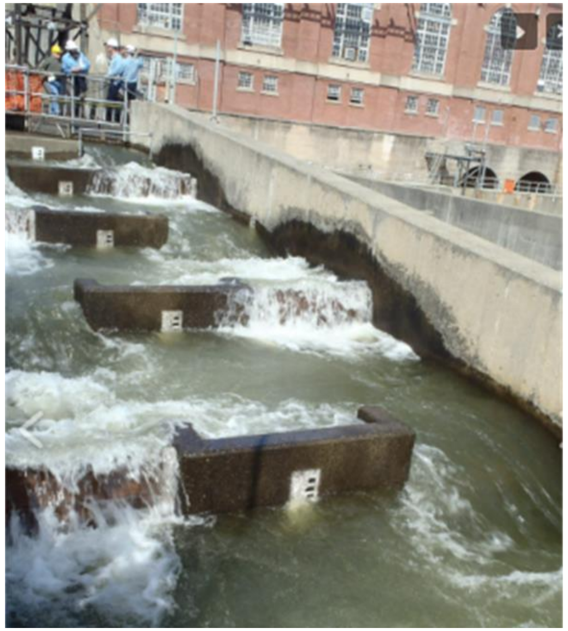
- Fish ladders or fish passes allow migratory fishes to flow up and down the river in search of food.
- The slope of a fish ladder should not be steeper than 1:10 to ensure a current velocity not exceeding 2 m/s at any section of the fish ladder.
- Different types of fish ladders:

➢ For barrages – *pool type, steep channel type*

➢ For high dams – *fish lock type, fish lift or elevator type*





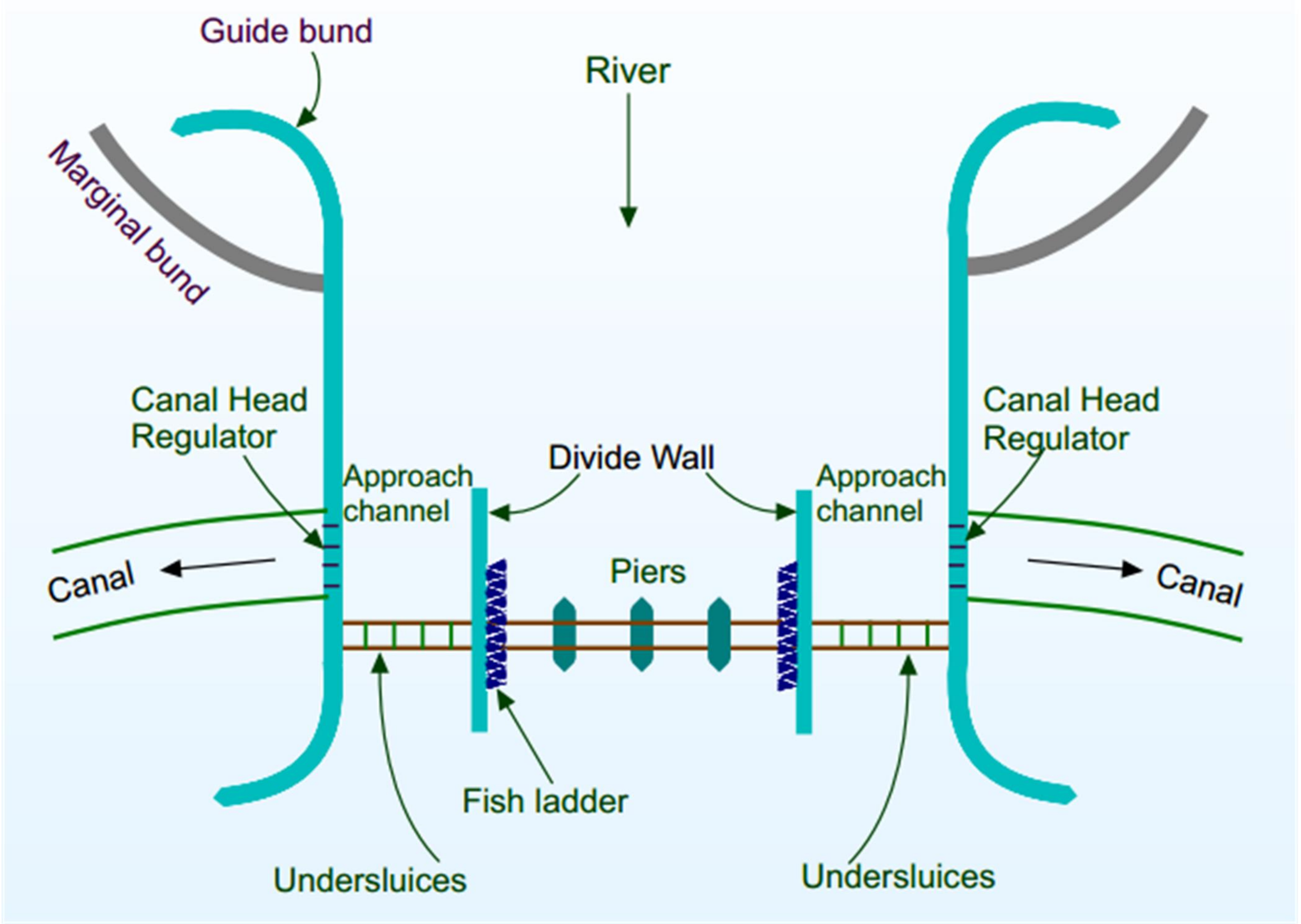


Pool type Fish ladder

Elevator type Fish ladder

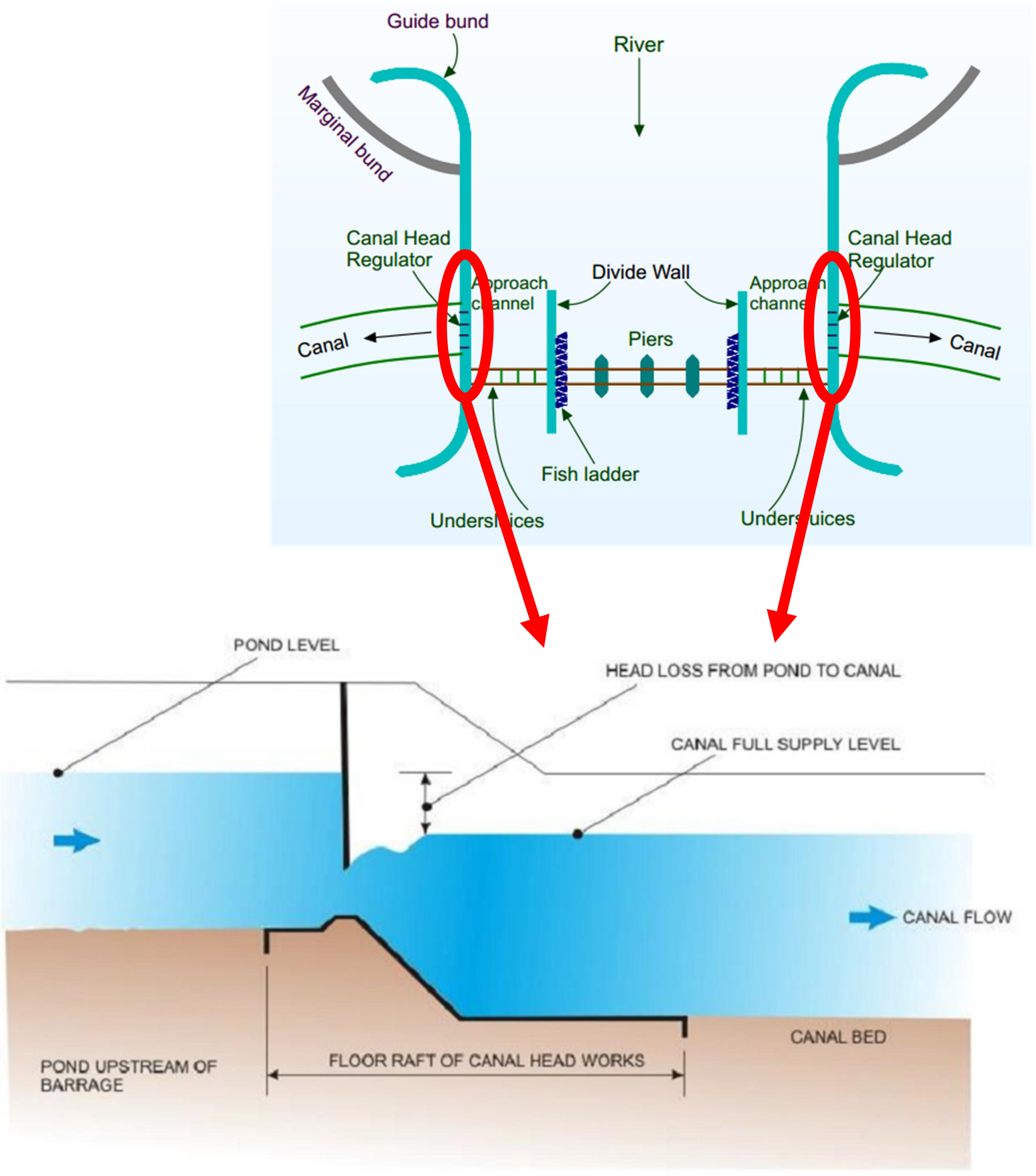
Approach Channel

- The floor level on the upstream side of a barrage is so adjusted that a pocket is formed in front of the canal head regulator.
- This pocket is known as approach channel and is separated from the main river flow by the divide walls.
- The main objective of this pocket formation is to reduce the entry of silt into the canal.
- In this pocket silt settles down and the canal draws water from this still pond of the pocket.



Canal Head Regulator

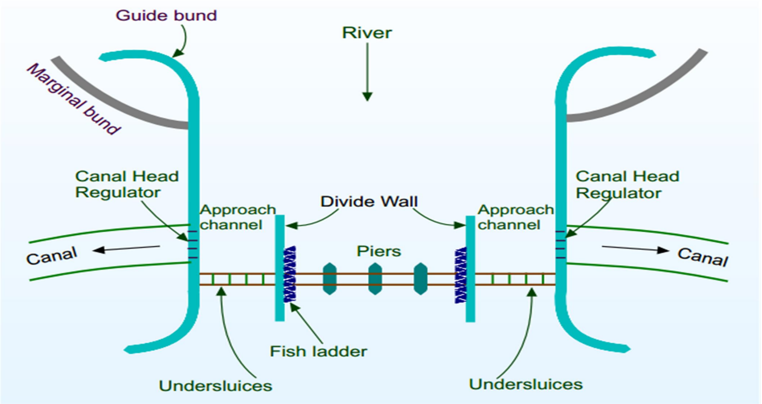
- A Canal Head Regulator regulates the supply of water in the canal and also controls the entry of silt in the canal.
- The regulation of water entry is done by means of gates. In modern days steel gates spanning 6-12 m are used which are operated by electric winches.
- As it is desirable to exclude silt as much as possible from the canal head regulator, the axis of the canal head regulator is laid out at an angle ranging between 90-110° to the barrage axis as recommended in 'IS : 6531(1972) - Criteria for design of canal head regulators.'
- The height of the gates is determined by the differences in the crest level and the pond level plus a little freeboard.



River Training Works

The river training works include:

- **Marginal bunds** – Marginal bunds are provided to protect the land and property against submergence during ponding or high stage of the river.
- **Guide bunds** – Guide bunds are used to narrow down and restrict the wide alluvial river courses to flow axially through the barrage.
- **Spurs** - Spurs are temporary permeable structures that are provided at the curve of a river for protecting the river banks from erosion. Spurs generally project from the river bank at an angle of 60-75° with the bank. They reduce the flow velocity of the river helping in the formation of water pockets at its upstream side where the sediments get accumulated.
- **Groynes** - Groynes are impervious permanent structures which have the same function as the spurs.



Guide bund, Chandil Dam, Jharkhand

River groynes

Failure of Hydraulic structures on Permeable Foundations

- Hydraulic structures like barrages, weirs, canal head regulators are mostly constructed on permeable foundations comprising of alluvial soils.
- Alluvial soils varies in particle sizes from fine clay to coarse sand.
- Subsurface flow underneath the hydraulic structures directly affect their stability.
- The various causes of failure of hydraulic structures on permeable foundations may be classified into two broad categories:

1. Failure due to seepage or subsurface flow.
   - ***Piping or undermining failure***
   - ***Uplift failure***
2. Failure due to surface flow.

Piping or Undermining Failure

- If the water percolating through the foundation has sufficient energy while emerging at the downstream end of the impervious floor, soil particles may get dislodged at the downstream end.
- With the removal of surface soil particles, there is further concentration of flow into the resulting depression and more soil particles get removed.
- The process of erosion progressively extends backwards towards the upstream side resulting in a hollow pipe-like formation beneath the structure.
- The structure floor may subside in the formed hollows causing piping or undermining failure of the structure.

Remedial measures

- *Provide sufficient length of the impervious floor of the hydraulic structure so that the path of percolation of the seepage water increases and subsequently the hydraulic gradient at the exit decreases.*
- *Provide sheet piles at the upstream and downstream ends of the impervious floor.*

Piping or Undermining Failure

Uplift Failure

- The water percolating through the foundation of the hydraulic structure exerts an upward pressure on the impervious floor.
- If the uplift pressure is not counterbalanced by the weight of the impervious floor, it may fail due to rupture.

Remedial measures

- *Provide sufficient thickness of the impervious floor.*
- *Provide sheet pile at the upstream end of the impervious floor to reduce the uplift pressure.*

Bligh’s Creep Theory

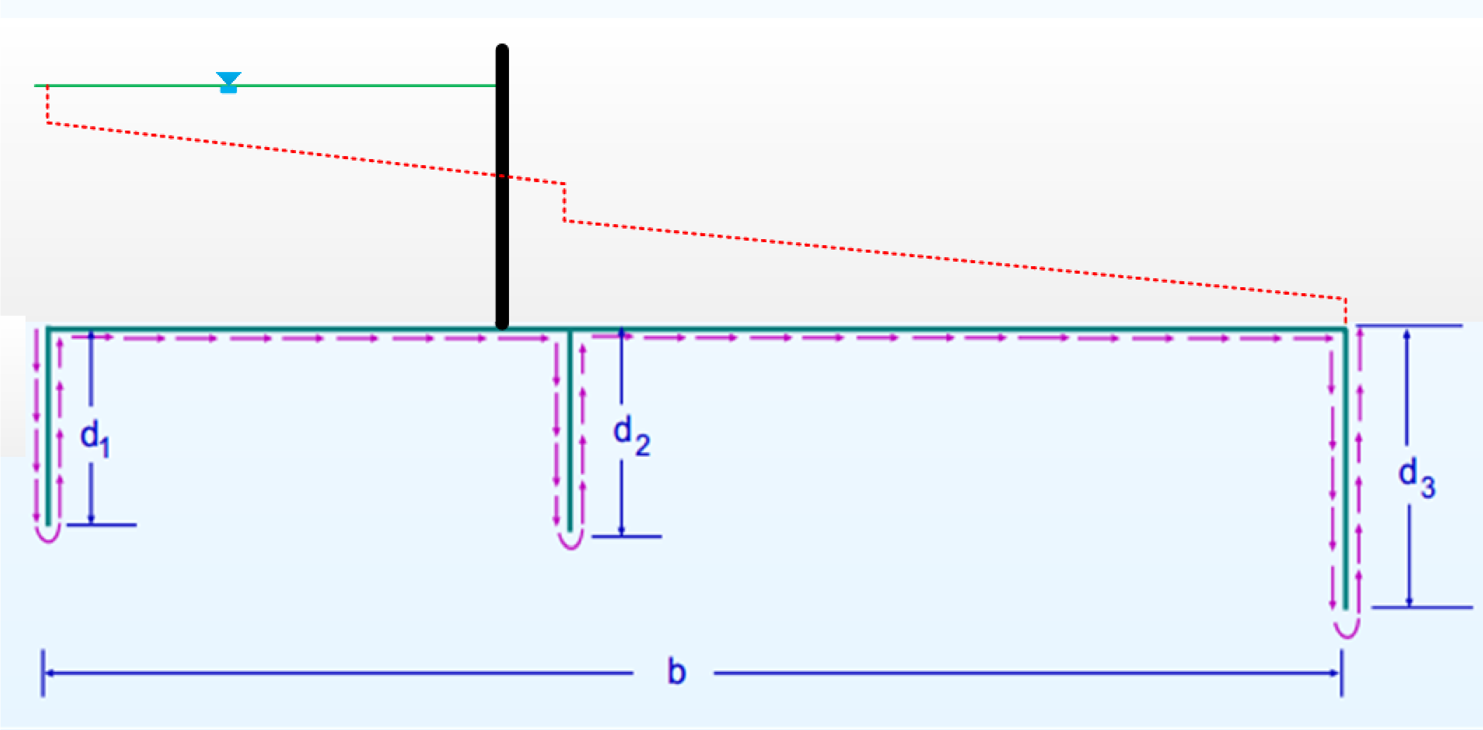
W. G. Bligh presented a theory of subsurface flow underneath hydraulic structures in 1910.

Bligh’s Creep Theory states:

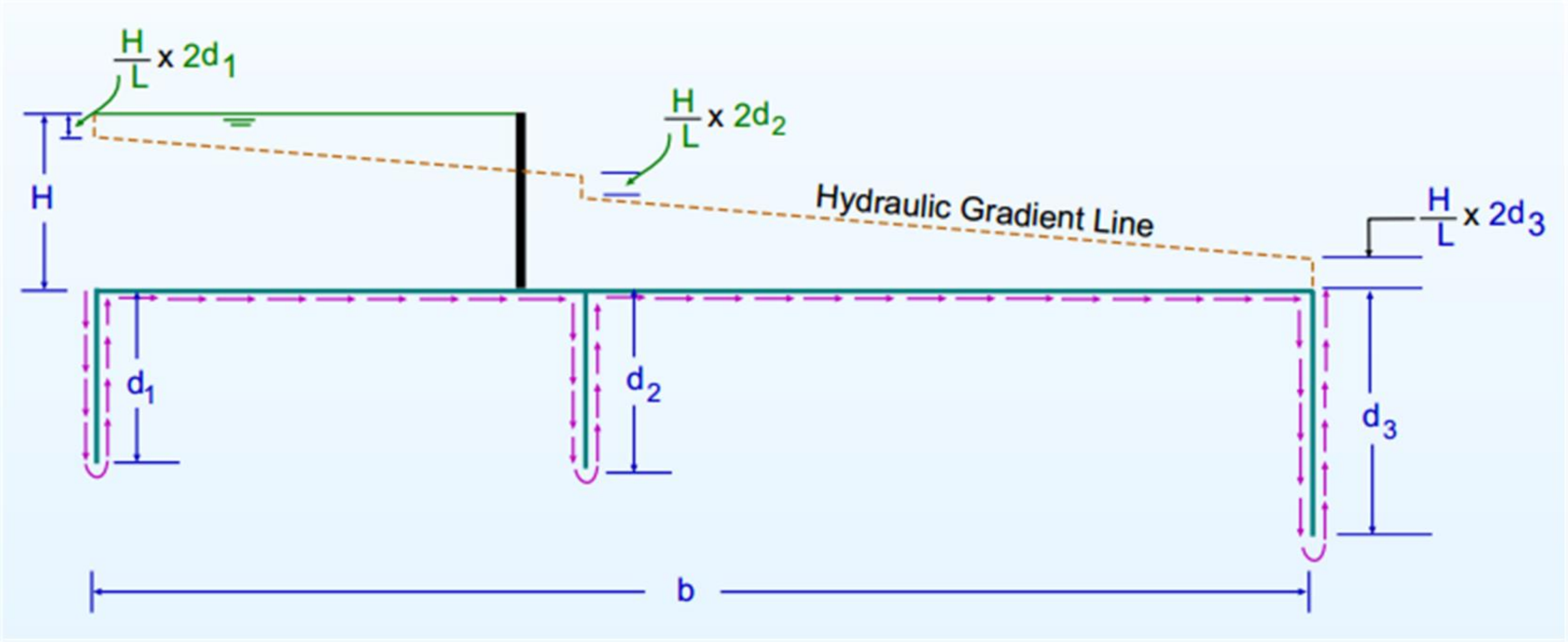
“Water creeps along the base profile of the hydraulic structure which is in contact with the subsoil”

Assumptions:

1. *Head loss per unit length of the creep i.e., the hydraulic gradient is constant throughout the percolating length.*
2. *There is no distinction between horizontal creep and vertical creep.*



Bligh's Creep Theory



Creep Length: $L = b + 2(d_1 + d_2 + d_3)$

Hydraulic Gradient: $i = \frac{H}{L} = \frac{H}{b+2(d_1+d_2+d_3)}$

Bligh's coefficient of creep: $C = \frac{1}{i} = \frac{b+2(d_1+d_2+d_3)}{H}$

Bligh's Creep Theory – Safety against piping

To ensure safety of the impervious floor against piping failure –

The length of creep should be sufficient to provide a safe hydraulic gradient according to the type of the soil.

$$L > CH$$

Soil Type	C	Safe Hydraulic Gradient
Light sand and mud (River Nile)	**18**	1/18
Fine micaceous sand (North Indian Rivers)	**15**	1/15
Coarse grained sand (Central and South Indian Rivers)	**12**	1/12
Sand mixed with boulders and shingle	**5-9**	1/9 to 1/5

The seepage head is measured from the u/s water level to the lowest d/s water level. For worst case scenario, it is calculated considering the maximum u/s water level and no discharge at the d/s end.

Bligh's Creep Theory – Safety against uplift

Let at any point at the bottom of the impervious floor the uplift pressure is given as:

$$U = \gamma_w h'$$

The downward force at that point due to the weight of the floor material is given as:

$$W = \gamma_w G t$$

For force equilibrium at that point:

$$U = W$$

$$\gamma_w h' = \gamma_w G t$$

$$h' = G t$$

$$h' - t = G t - t$$

$$t = \frac{(h' - t)}{(G - 1)} = \frac{h}{(G - 1)}$$

Considering a factor of safety of $\frac{4}{3}$:

$$t = \frac{4}{3} \frac{h}{(G - 1)}$$

γ_w: Specific weight of water

h': Seepage head at that point

G: Specific gravity of the floor material

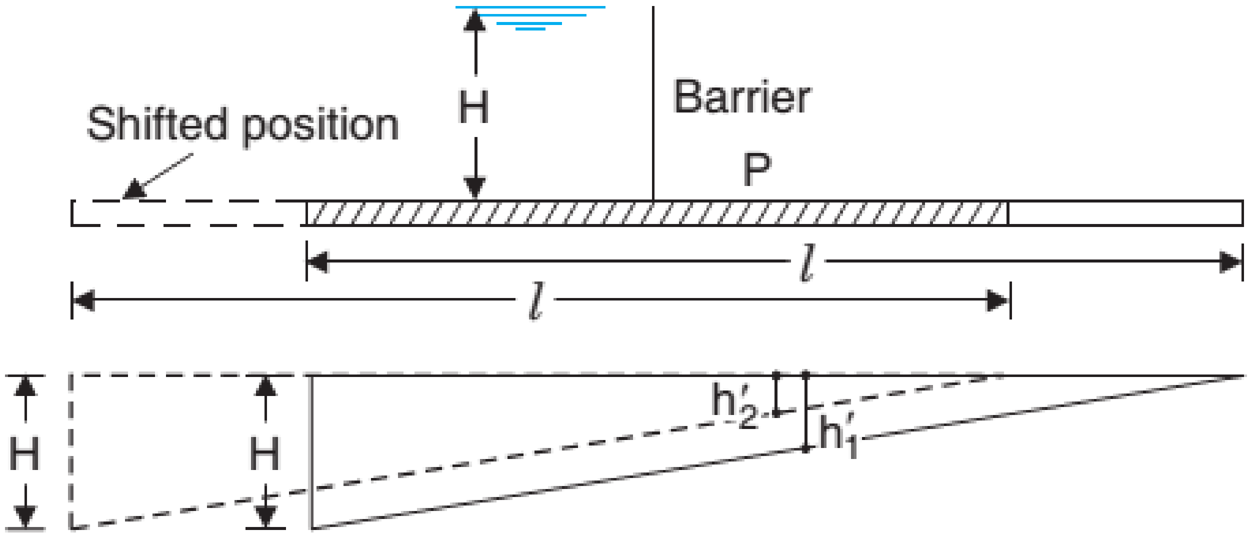
t: Floor thickness

h: The ordinate of the HGL measured above the top of the floor

$(G - 1)$: Submerged unit weight of the floor material

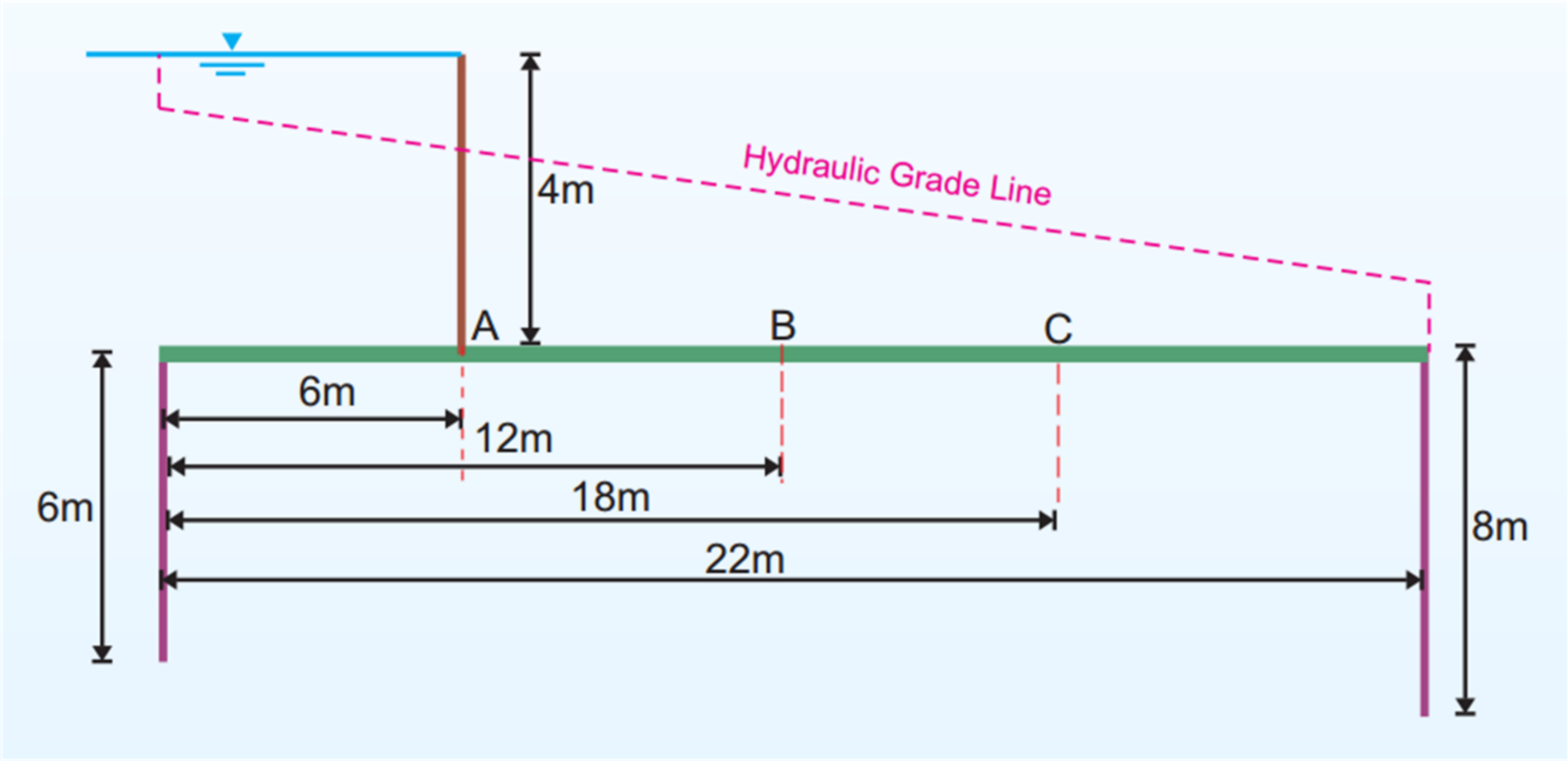
Bligh's Creep Theory – Practical Considerations

- ✓ For the portion u/s of the barrier, only **nominal thickness** is provided for the impervious floor as much of the uplift pressure is counterbalanced by the self weight of water on the u/s side.
- ✓ For the given length of the impervious floor, if a greater proportion is provided on the u/s side of the barrier, the design will be comparatively economical.
- ✓ However, there is a minimum length of impervious floor that has to be provided on the d/s side of the barrier.



Numerical Problem: Example 1

The following figure shows the section of a hydraulic structure founded on sand. Calculate the average hydraulic gradient. Also find the uplift pressures at points A, B, C, and determine the required floor thickness at these points. Assume specific gravity of the floor material: G = 2.24. **(Using Bligh's Creep Theory)**



Limitations of Bligh's Creep Theory

- ✓ Bligh made no distinction between horizontal and vertical creep.
- ✓ Bligh's method holds good so long as the horizontal distance between the pile lines is greater than twice their depth.
- ✓ Bligh did not mention the concept of **exit gradient**. The safety against undermining cannot simply be obtained by considering a simple average hydraulic gradient less than a permissible value. Undermining of the floor starts from the tail end. Hence, calculation of the hydraulic gradient at the exit is very important.
- ✓ Bligh makes no distinction between outer and inner faces of sheet piles or the intermediate sheet pile, whereas according to investigations, the outer faces of the end sheet piles are much more effective than inner ones. Also, intermediate sheet piles of shorter length than the outer ones are ineffective except for local redistribution of pressure.
- ✓ In reality, the loss of head is not linearly proportional to the creep length.
- ✓ The uplift pressure distribution is not linear but follows a sine curve.
- ✓ Bligh does not specify the absolute necessity of providing a sheet pile at d/s end whereas it is absolutely essential to have a deep vertical cut off at d/s end to prevent undermining.

Lane's Weighted Creep Theory

- ✓ One of the major limitation of Bligh's Creep Theory was:

"No distinction between vertical and horizontal creep."

- ✓ In 1932, Lane after investigating around 300 dams and weirs across the world found that vertical creep is more effective than the horizontal creep.
- ✓ He suggested a weightage of **3** for **vertical creep** and **1** for **horizontal creep**.
- ✓ For inclined floors the weight is calculated as:

$$1 + \frac{2\theta^{\circ}}{90^{\circ}}$$

Lane's Creep Coefficient

S. N.	*Type of soil*	*Lane's creep coefficient* C_w	*Lane's safe Hydraulic gradient* $(1/C_w)$
1.	Very fine sand or silt	8.5	1/8.5
2.	Fine sand	7.0	1/7.0
3.	Medium sand	6.0	1/6.0
4.	Coarse sand	5.0	1/5.0
5.	Fine Gravel	4.0	1/4.0
6.	Medium Gravel	3.5	1/3.5
7.	Coarse gravel including cobbles	3.0	1/3.0
8.	Boulders with same cobbles and gravel	2.5	1/2.5
9.	Soft clay	3.0	1/3.0
10.	Medium clay	2.0	1/2.0
11.	Hard clay	1.8	1/1.8
12.	Very hard clay *or* hard pan	1.6	1/1.6

Numerical Problem: Example 2

The following figure shows the section of a hydraulic structure founded on sand. Calculate the average hydraulic gradient. Also find the uplift pressures at points A, B, C, and determine the required floor thickness at these points. Assume specific gravity of the floor material: G = 2.24. **(Using Lane's Weighted Creep Theory)**