Nepal Engineering Council
नेपाल ईन्जिनियरिङ परिषद

PANA ACADEMY

Nepal Engineering Council Registration Examination

8. HYDROPOWER

[as per Civil Engineering Syllabus (ACiE08)]

-Er. Babu Ram Karki

PANA ACADEMY

8. Hydropower (ACiE08)

8.1 Planning of hydropower projects: power potential (gross, technical, economic) of Nepal and the world; stages of hydropower development, hydropower development in Nepal (history, policy, acts & regulation.) (ACiE0801)

8.2 Power and energy potential study: power and energy potentials; methods of fixing installed capacity of a plant; types of hydropower plants on various basis; components of different types of hydropower projects; reservoirs and their regulation. (ACiE0802)

8.3 Headworks of storage plants: components of a typical storage plant; dams (types, functions, selection, design, failure modes and remedies); stability analysis of gravity dam, seepage control and foundation treatment in dams; design of intake, spillway and energy dissipaters; gates (types and locations). (ACiE0803)

8.4 Headworks of run-of-river (ROR) plants: components of a typical ROR plant; design of intake; methods of bed and suspended load handling; design of settling basin (practice and concentration approach), estimation of sediment volume in settling basin, flushing of deposited sediment, estimation of flushing frequency for sediments. (ACiE0804)

8.5 Water conveyance structures: hydraulic tunnels, x-sections, and hydraulic design (velocity and sizing); tunnel lining; design of forebay and surge tanks; design of penstocks and pressure shaft; hydraulic transients (water hammer). (ACiE0805)

8.6 Hydro-electric machines and powerhouse: hydro-mechanical equipment and their functions; types of turbines and performance characteristics; selection of turbine and their specific speed; preliminary design of Francis and Pelton turbines; scroll case and draft tubes; generators (types, rating); governs; pumps and their performance characteristics; powerhouse (types, general arrangements, dimensions). (ACiE0806)

PANA ACADEMY

8.3 Headworks of Storage Plant

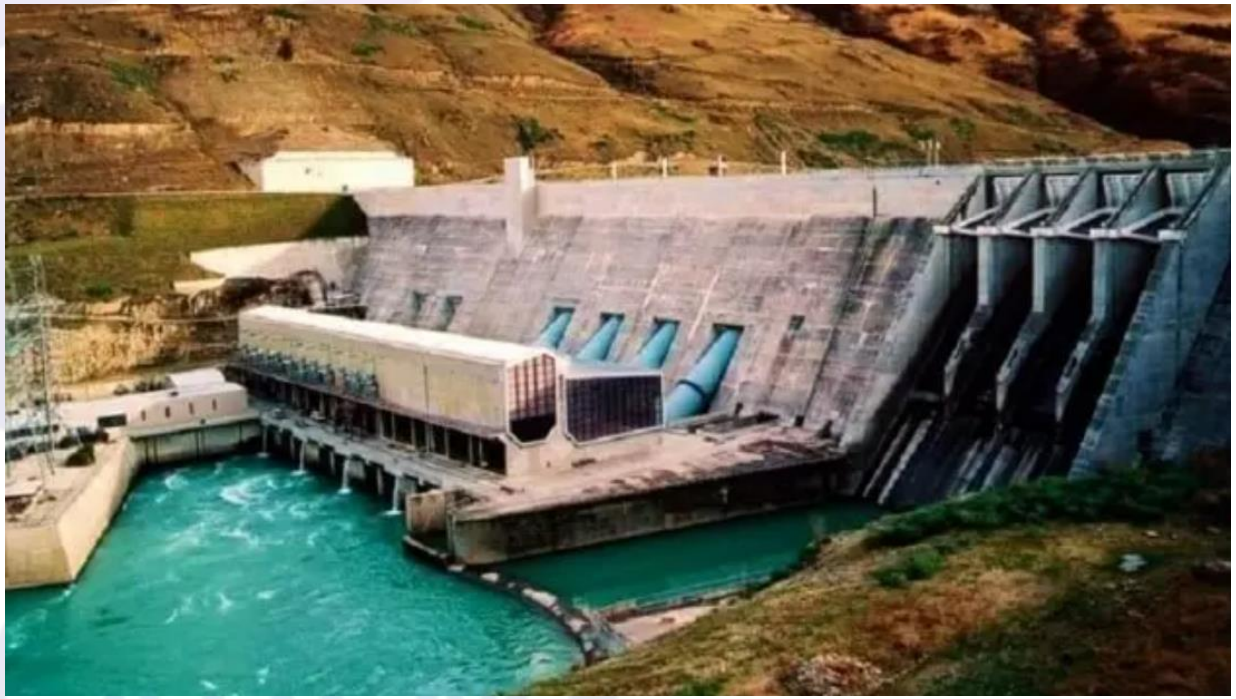
- Components of typical storage plant
- Dams(types, functions, selection, design, failure modes and remedies)
- Stability analysis of gravity dam
- Seepage control and foundation treatment in dams
- Design of intake, spillway and energy dissipaters
- Gates(types and locations)

PANA ACADEMY

8.3.1 Components of Typical Storage Plant

Based on layout storage plants can be:

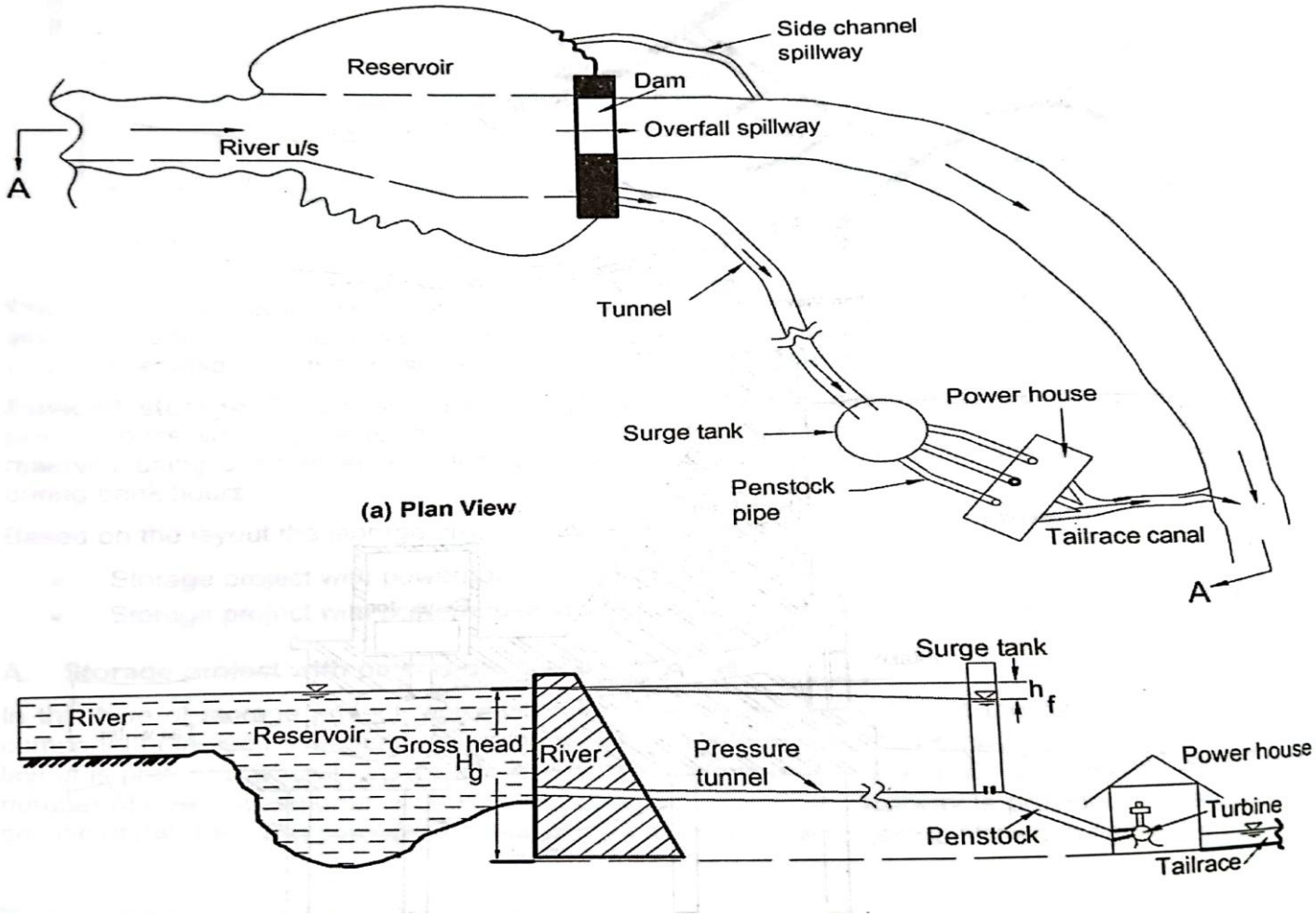
- Storage projects with **powerhouse at the dam toe**
- Storage projects with **powerhouse located certain distance downstream from the dam**



8.3.1 Components of Typical Storage Plant

PANA ACADEMY

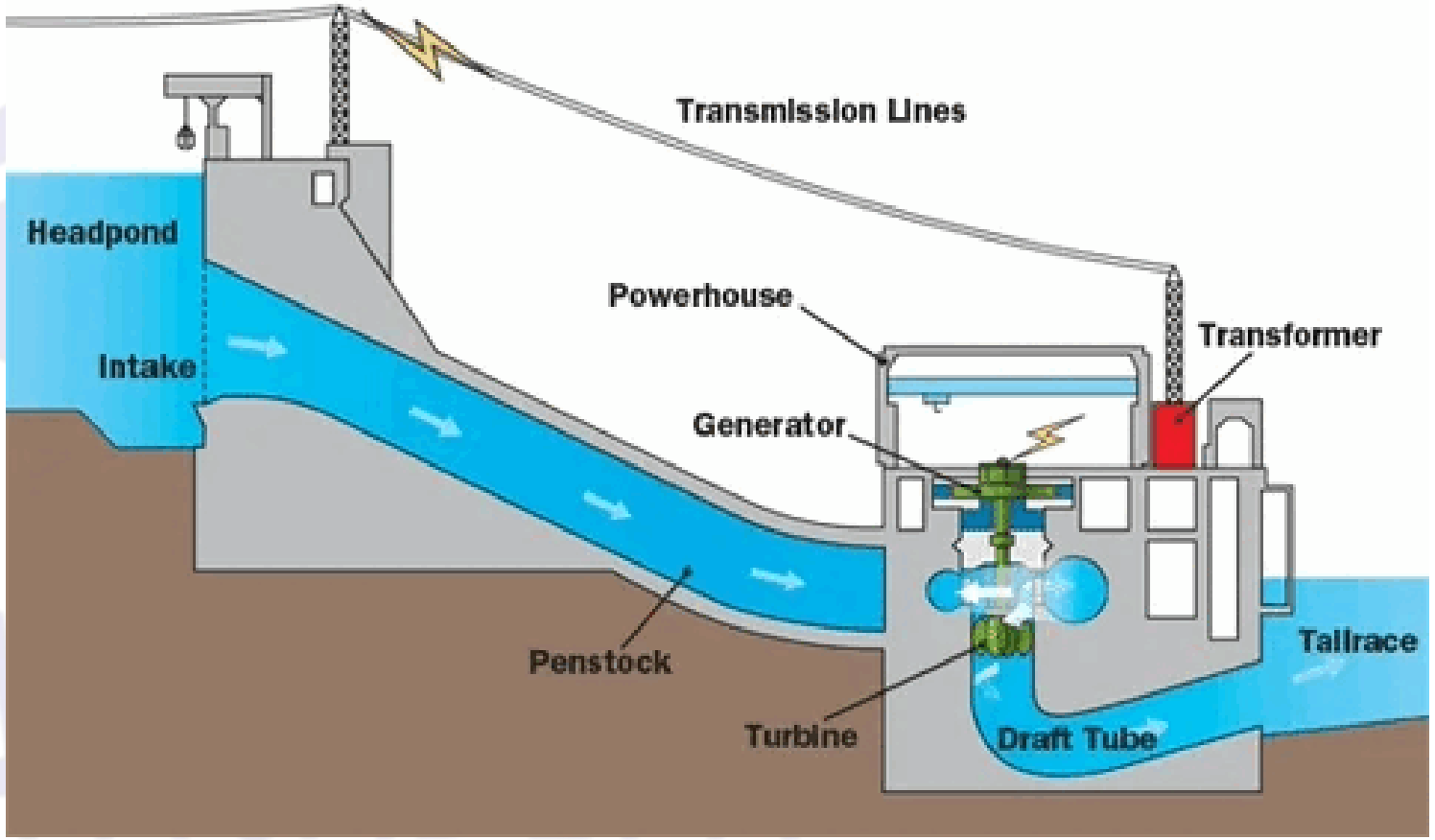
Layout of storage project:



PANA ACADEMY

8.3.1 Components of Typical Storage Plant

- Dam or reservoir
- Spillway
- Intake structure
- Headrace Tunnel
- Surge Tank
- Penstock
- Powerhouse
- Tailrace Tunnel
- Switchyard



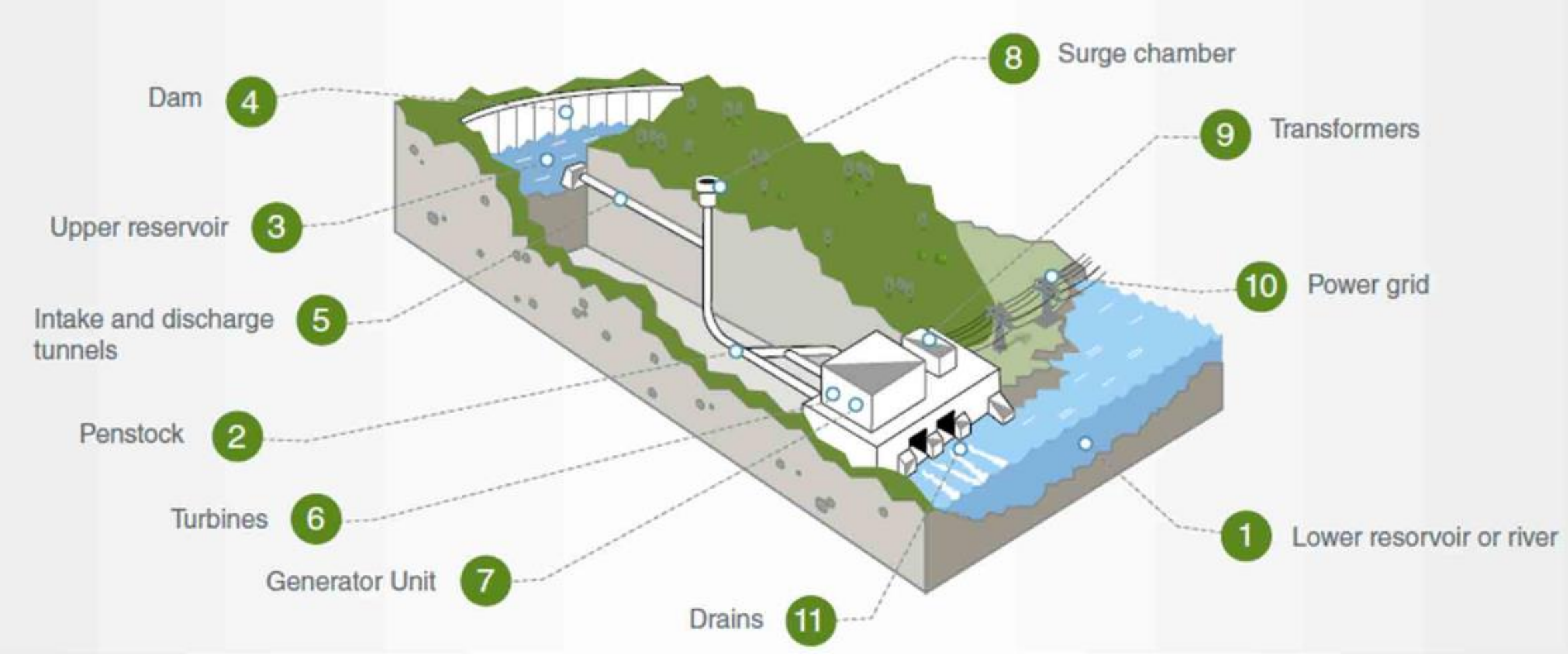
PANA ACADEMY

8.3.1 Components of Typical Storage Plant

Dam or Reservoir	Stores water to create hydraulic head for power generation.
Spillway	Controls excess water release to prevent dam overtopping.
Intake Structure	Diverts water from the reservoir to the headrace tunnel, filtering debris.
Headrace Tunnel	Transports water from the intake to the surge tank, minimizing energy loss.
Surge Tank	Absorbs pressure fluctuations to stabilize water flow.
Penstock	Channels pressurized water to the turbines in the powerhouse.
Powerhouse	Contains turbines and generators for converting hydraulic energy to electricity.
Tailrace Tunnel	Discharges water from the powerhouse back into the river.
Switchyard	Distributes electricity from the powerhouse to the grid.

PANA ACADEMY

8.3.1 Components of Typical Storage Plant



PANA ACADEMY

Where is the intake structure typically located in a storage plant?

A) Inside the powerhouse
B) At the tailrace tunnel exit
C) At the base of the dam
D) In the switchyard

Which component is responsible for transporting water from the intake structure to the surge tank while minimizing energy loss?

A) Headrace Tunnel
B) Tailrace Tunnel
C) Powerhouse
D) Switchyard

PANA ACADEMY

Where is the intake structure typically located in a storage plant?
A) Inside the powerhouse
B) At the tailrace tunnel exit
C) At the base of the dam
D) In the switchyard
Answer: C) At the base of the dam

Which component is responsible for transporting water from the intake structure to the surge tank while minimizing energy loss?
A) Headrace Tunnel
B) Tailrace Tunnel
C) Powerhouse
D) Switchyard
Answer: A) Headrace Tunnel

PANA ACADEMY

What is the primary purpose of a pumped storage power plant?

A) To generate electricity from solar energy
B) To store excess electricity for future use
C) To convert wind energy into electricity
D) To pump water uphill for later release to generate electricity

What is the function of the upper reservoir in a pumped storage power plant?

A) It stores excess electricity.
B) It filters debris from the water.
C) It absorbs pressure fluctuations.
D) It stores potential energy in the form of elevated water.

PANA ACADEMY

What is the primary purpose of a pumped storage power plant?
A) To generate electricity from solar energy
B) To store excess electricity for future use
C) To convert wind energy into electricity
D) To pump water uphill for later release to generate electricity
Answer: D) To pump water uphill for later release to generate electricity

What is the function of the upper reservoir in a pumped storage power plant?
A) It stores excess electricity.
B) It filters debris from the water.
C) It absorbs pressure fluctuations.
D) It stores potential energy in the form of elevated water.
Answer: D) It stores potential energy in the form of elevated water.

PANA ACADEMY

What is the advantage of using pumped storage for energy storage compared to other methods:

A) It has higher efficiency.
B) It can store more energy.
C) It is environmentally friendly.
D) It is less expensive to build.

In storage projects with a powerhouse at the dam toe, where is the powerhouse typically situated?

A) At the top of the dam
B) Below the dam, near the reservoir
C) Several miles downstream from the dam
D) Next to the spillway

PANA ACADEMY

What is the advantage of using pumped storage for energy storage compared to other methods:

A) It has higher efficiency.
B) It can store more energy.
C) It is environmentally friendly.
D) It is less expensive to build.

Answer: A) It has higher efficiency.

In storage projects with a powerhouse at the dam toe, where is the powerhouse typically situated?

A) At the top of the dam
B) Below the dam, near the reservoir
C) Several miles downstream from the dam
D) Next to the spillway

Answer: B) Below the dam, near the reservoir

PANA ACADEMY

What is the primary advantage of locating the powerhouse at the dam toe in storage projects?

A) It minimizes environmental impact.
B) It reduces transmission losses.
C) It allows for greater water storage capacity.
D) It increases water flow rate.

In storage projects with a powerhouse located a certain distance downstream from the dam, what is the primary purpose of this layout?

A) To improve water quality downstream
B) To enhance flood control capabilities
C) To increase the total head for power generation
D) To reduce construction costs

PANA ACADEMY

What is the primary advantage of locating the powerhouse at the dam toe in storage projects?

A) It minimizes environmental impact.
B) It reduces transmission losses.
C) It allows for greater water storage capacity.
D) It increases water flow rate.

Answer: B) It reduces transmission losses.

In storage projects with a powerhouse located a certain distance downstream from the dam, what is the primary purpose of this layout?

A) To improve water quality downstream
B) To enhance flood control capabilities
C) To increase the total head for power generation
D) To reduce construction costs

Answer: C) To increase the total head for power generation

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Function of DAM:

Dams are barriers across river with primary function of:

- Forming a reservoir which has capacity to store water
- Raising head to divert water flow into the conveyance system.

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Types of dams:

A) Based on Function

Storage Dams	- To store water for various purposes, such as: - Municipal water supply - Irrigation and agriculture - Hydropower generation - Recreation and tourism
Diversion Dams	- To redirect the flow of a river or stream for: - Irrigation and agriculture - Water supply to cities and industries - Navigation and shipping
Detention Dams	- To temporarily hold and control stormwater runoff, reducing downstream flooding.
Coffer Dams	- Temporary structures to create a dry work area in a water environment, such as a river or lake - To facilitate construction or repair activities.

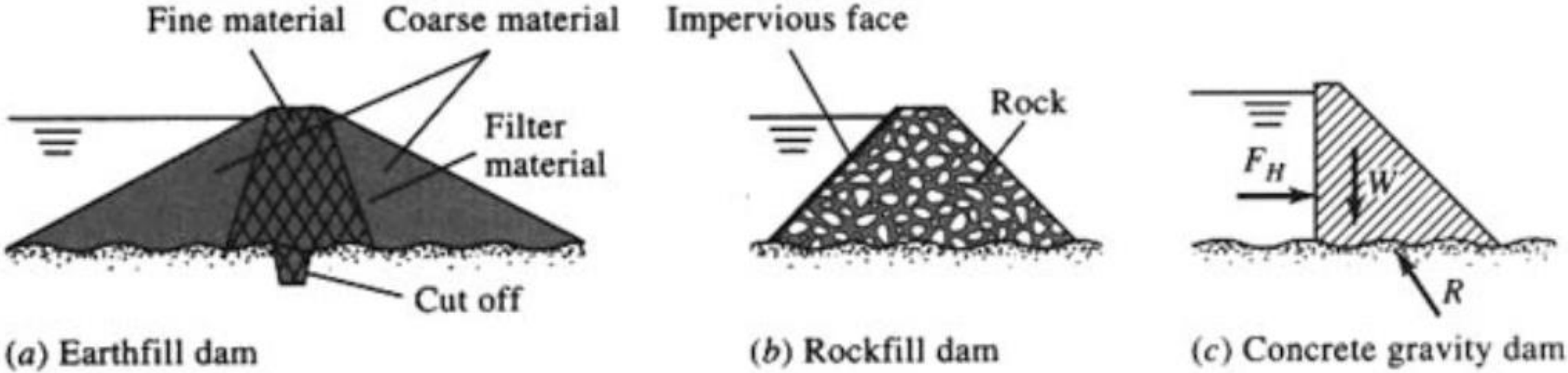
8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

PANA ACADEMY

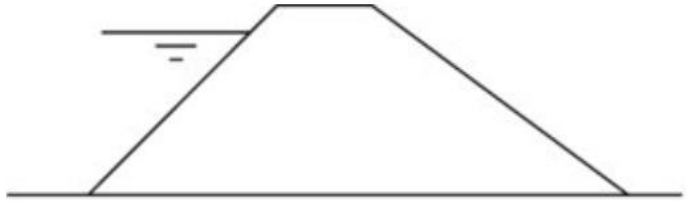
Types of dams:

B) Based on Construction Material

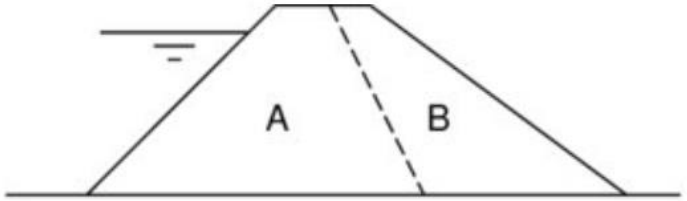
Concrete Dams	- Concrete, cement, and aggregates.
Earth Dams	- Soil, rock, gravel, and clay.
Masonry Dams	- Cut stone, rubble, or bricks in mortar.
Steel Dams	- Steel plates, beams, and components.
Timber Dams	- Timber or wooden materials, e.g., logs/planks.
Rubber Dams	- Rubber or flexible materials.



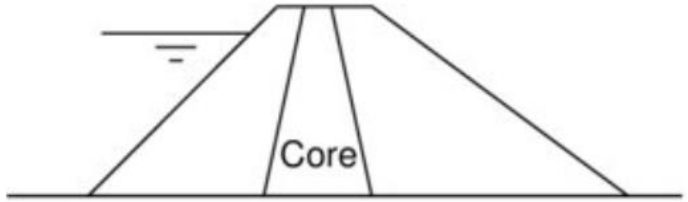
PANA ACADEMY



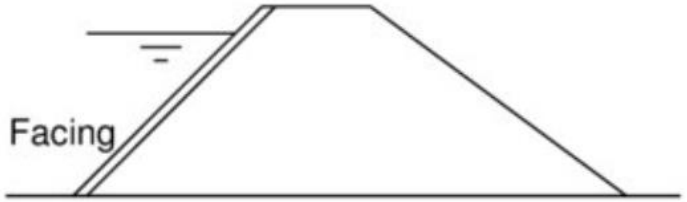
(a) Homogeneous earthfill



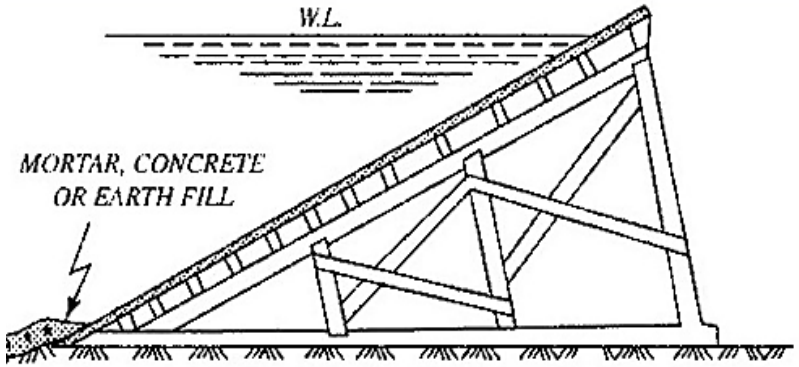
(b) Zoned earthfill



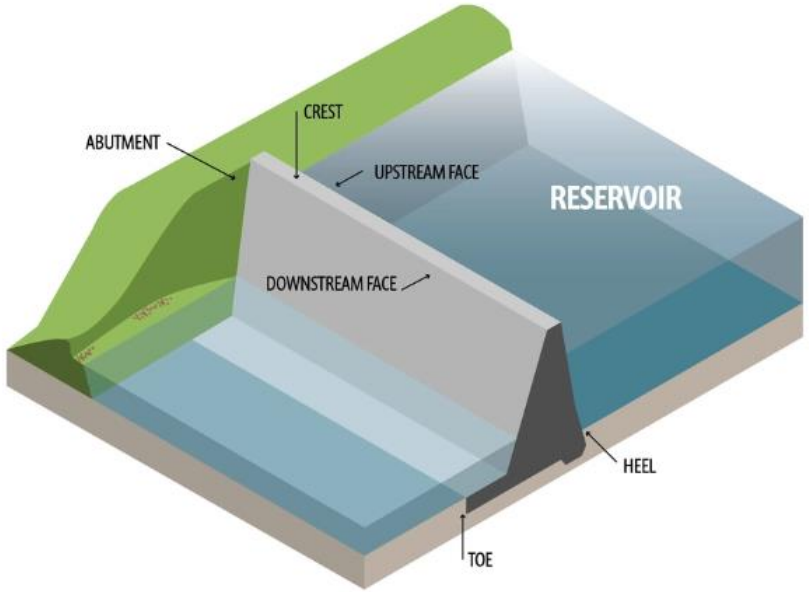
(c) Earthfill with corewall

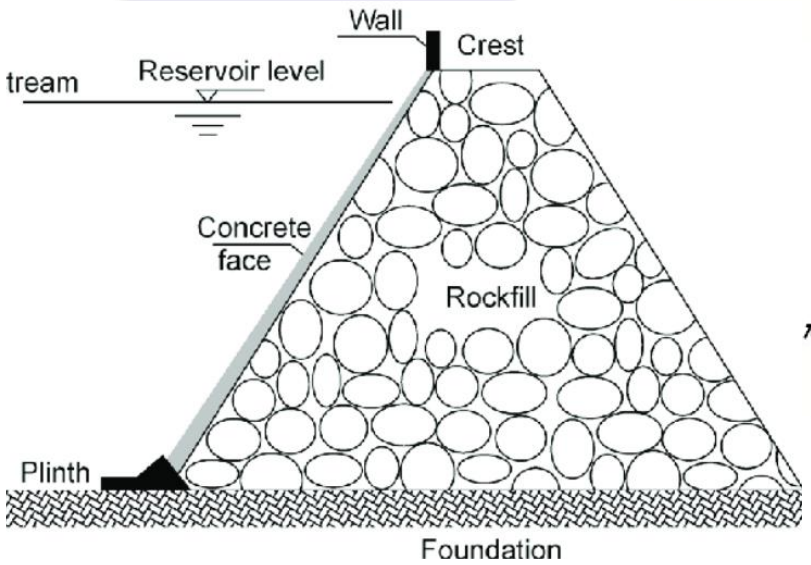


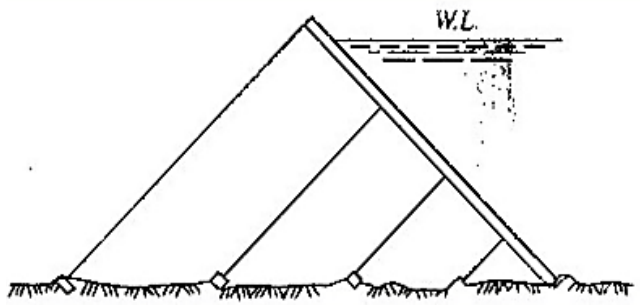
(d) Faced earthfill



Timber Dam







Steel Dam

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

PANA ACADEMY

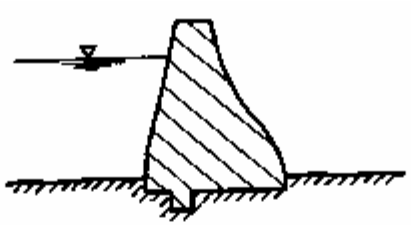
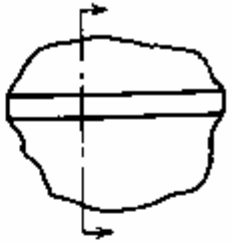
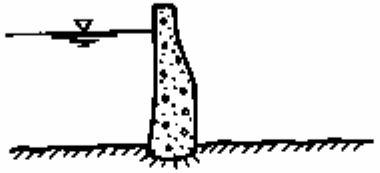
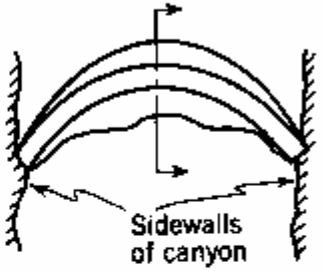
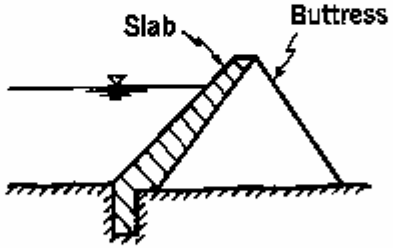
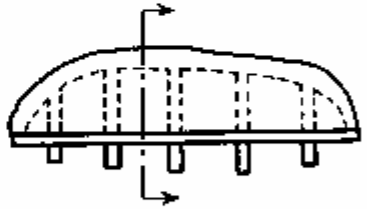
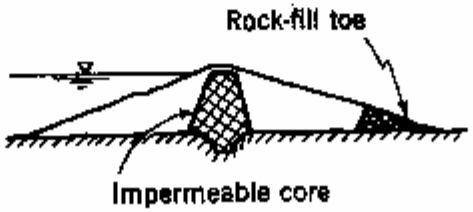
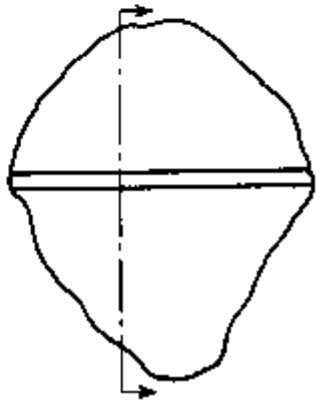
Types of dams | **C)** Based on **Structural Load Transfer Method(based on design Principle)**

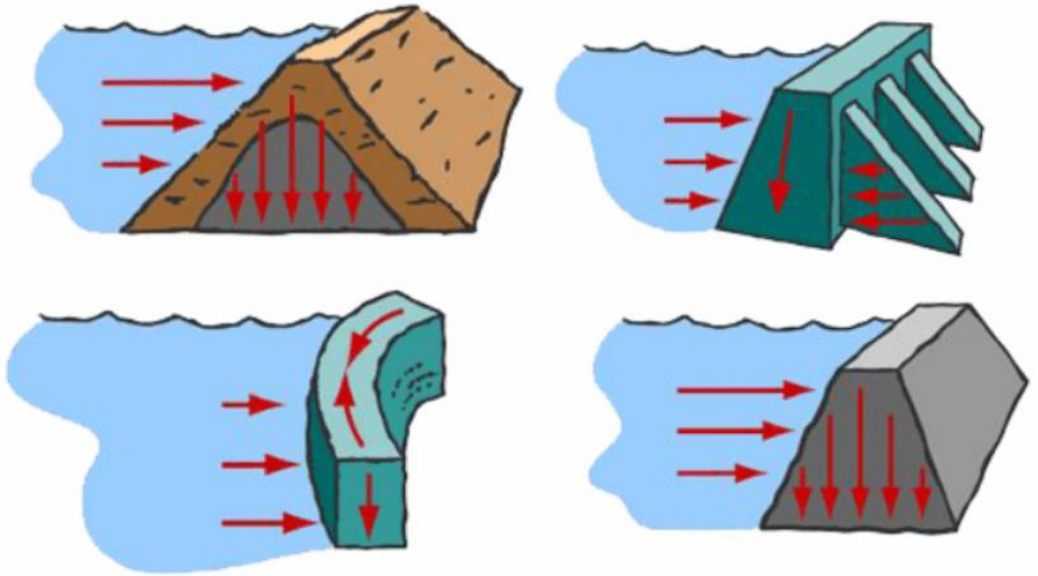
- **Rigid Dam:** Whole body of the dam acts as a single body and

Gravity Dams	- Transfer the load of impounded water and other forces directly to the foundation through their mass. Retained water thrust is restricted by the action of gravity.
Arch Dams	- Transfer the load to the abutments primarily through arch action, which resists compressive forces. An arch dam is a dam that is designed to have a single curved wall, shaped like an arch and having its convexity towards the upstream direction
Buttress Dams	- Use a series of supports (buttresses) on the downstream side to transfer water pressure and other loads to the foundation. This dam restrict water thrust with the help of buttresses.

- **Non Rigid Dam (Embankment DAM):** Earth or Rock fill Dam.

PANA ACADEMY

Gravity	Concrete, rubble masonry		
Arch	Concrete		
Buttress	Concrete also timber and steel)		
Embankment	Earth or rock		



PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Embankment Dam:

Types:

A) Earth Dam

i. Homogeneous Earth Dam

ii. Zone Earth Dam

iii. Diaphragm type Earth Dam- Thin core

B) Rock fill Dam

C) Composite Earth & Rock fill Dam

PANA ACADEMY

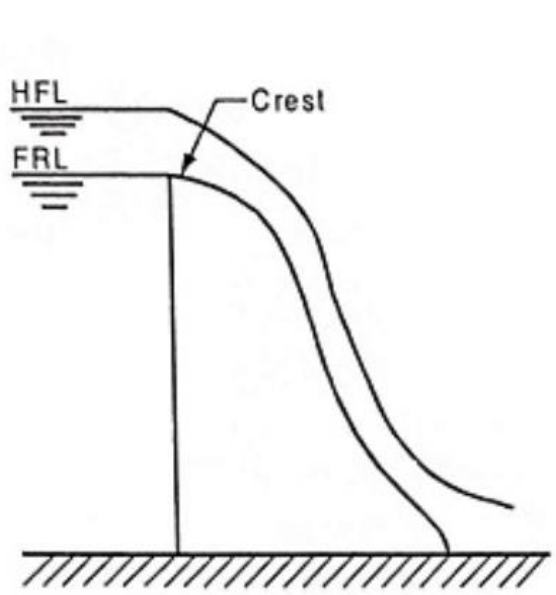
8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

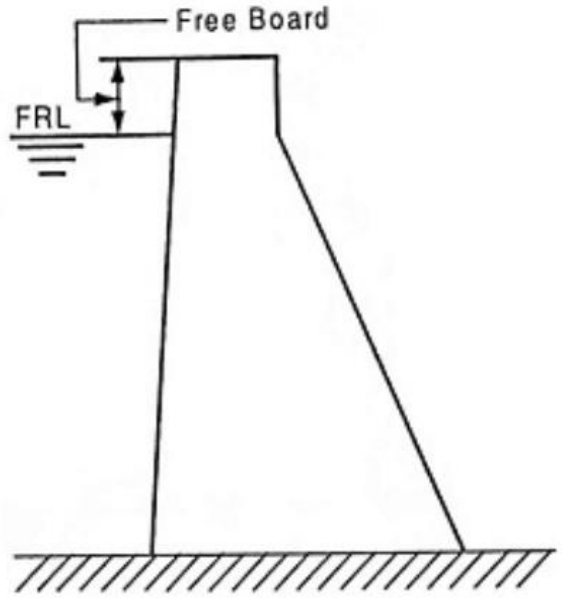
Types of dams

D) Based on Hydraulic Design

Overflow (Weir) Dams	- Designed to allow water to flow over the dam's crest, also called weir or low dam.
Non-Overflow Dams	- Designed to control water flow without allowing it to spill over the dam's crest.

PANA ACADEMY





PANA ACADEMY

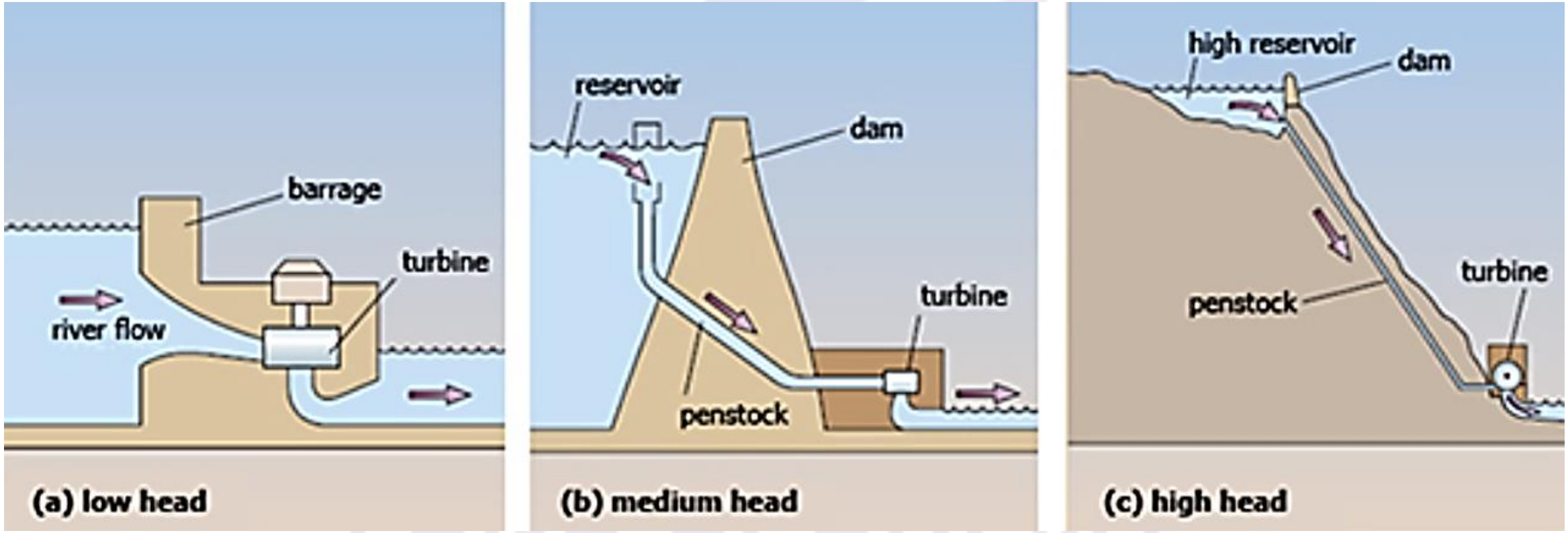
8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Types of dams:

E) Based on Head

Low-Head Dams	Few meters to 15 m
Medium-Head Dams	15 m to 50 m
High-Head Dams	Exceeding 50 m

PANA ACADEMY



PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Selection of Dams

S.N	Character of Site	Condition of site	Type of Dam
1	Availability of Construction materials	Ingredient of concrete ie. Sand gravel and cement – locally available	Concrete gravity Dam
		Locally available of the previous and impervious soil and stone	Earth/Rock-fill Dam
		Available stone in required size and specific gravity	Stone Masonry Dam
2	Foundation Character	Impervious solid rock such as schist and gneiss	Any type
		Poor rock, Gravel and coarse sands	Earth ort Rock fill dam
		Sand and Silt Clay	Earthen Dam
		Very fine and Uniform sands	Earthen Dam
		Silt and fine sand	Low gravity dam or earthen dam

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

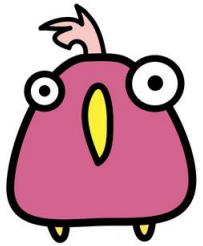
Selection of Dams

S.N	Character of the Site	Condition of site	Type of Dam
3	Topography	V-shape narrow gorge Narrow deep valley	Arch Dam Arch dam
		U shaped narrow gorge	Overflow concrete Dam
		Low wide George Wide valley	Earth/Rock Fill Dam Embankment Dam
4	Spillway requirement	Spillway location separate from main dam	Earthen Dam
		Adequate width for dam only	Gravity dam with overflow spillway
		Large spillway requirements	Overflow concrete dam
5	Character of the region	Seismic Zone	Earth dam &concrete gravity dam
		Excessive uplift pressure exerted	Arch dam

PANA ACADEMY

What type of dam is typically chosen for water storage reservoirs, hydropower projects, and flood control in areas with strong foundations and ample(enough) construction materials?

A) Arch Dams
B) Buttress Dams
C) Gravity Dams
D) Embankment Dams



In narrow canyon(deep gorge) locations with strong abutments, which type of dam is often selected due to its efficient use of materials and space?

A) Roller Compacted Concrete (RCC) Dams
B) Spillway Dams
C) Composite Dams
D) Arch Dams

PANA ACADEMY

What type of dam is typically chosen for water storage reservoirs, hydropower projects, and flood control in areas with strong foundations and ample(enough) construction materials?

A) Arch Dams
B) B) Buttress Dams
C) C) Gravity Dams
D) D) Embankment Dams

Answer: C) Gravity Dams

In narrow canyon locations with strong abutments, which type of dam is often selected due to its efficient use of materials and space?

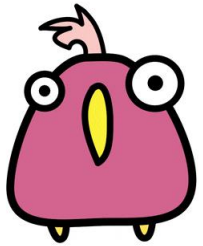
A) Roller Compacted Concrete (RCC) Dams
B) Spillway Dams
C) Composite Dams
D) Arch Dams

Answer: D) Arch Dams

PANA ACADEMY

For projects in areas with weaker foundation materials and challenging terrains, which dam type is suitable to effectively transfer loads and ensure stability?

A) Embankment Dams
B) Timber Dams
C) Composite Dams
D) Buttress Dams



Which type of dam is versatile and adaptable to various site conditions, making it a common choice for different project requirements?

A) Diversion Dams
B) Gravity Dams
C) Embankment Dams
D) Roller Compacted Concrete (RCC) Dams

PANA ACADEMY

For projects in areas with weaker foundation materials and challenging terrains, which dam type is suitable to effectively transfer loads and ensure stability?

A) Embankment Dams
B) Timber Dams
C) Composite Dams
D) Buttress Dams
Answer: D) Buttress Dams

Which type of dam is versatile and adaptable to various site conditions, making it a common choice for different project requirements?

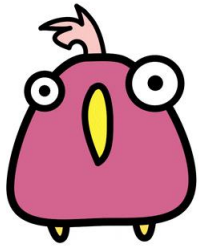
A) Diversion Dams
B) Gravity Dams
C) Embankment Dams
D) Roller Compacted Concrete (RCC) Dams
Answer: C) Embankment Dams

PANA ACADEMY

PANA ACADEMY

In scenarios where a cost-effective, durable, and quickly constructed dam is needed, which type of dam may be chosen?

A) Roller Compacted Concrete (RCC) Dams
B) Diversion Dams
C) Composite Dams
D) Timber Dams



In which type of terrain or geological condition are gravity dams often preferred due to their strong foundation requirements?

A) Rocky mountains
B) Alluvial plains
C) Weak soil conditions
D) Desert regions

PANA ACADEMY

In scenarios where a cost-effective, durable, and quickly constructed dam is needed, which type of dam may be chosen?

A) Roller Compacted Concrete (RCC) Dams
B) Diversion Dams
C) Composite Dams
D) Timber Dams

Answer: A) Roller Compacted Concrete (RCC) Dams

In which type of terrain or geological condition are gravity dams often preferred due to their strong foundation requirements?

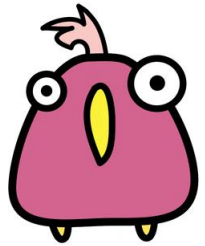
A) Rocky mountains
B) Alluvial plains
C) Weak soil conditions
D) Desert regions

Answer: A) Rocky mountains

PANA ACADEMY

What is the primary load-bearing mechanism in arch dams that makes them well-suited for narrow canyon locations?

A) Sheer mass
B) Arch action
C) Buttress support
D) Embankment design



In which type of topographical setting are arch dams typically most efficient in terms of material usage?

A) Flat plains
B) Narrow canyons
C) Plateaus
D) Coastal areas

PANA ACADEMY

What is the primary load-bearing mechanism in arch dams that makes them well-suited for narrow canyon locations?

A) Sheer mass
B) Arch action
C) Buttress support
D) Embankment design

Answer: B) Arch action

In which type of topographical setting are arch dams typically most efficient in terms of material usage?

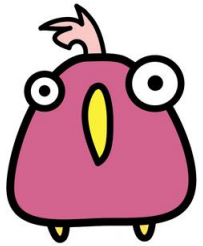
A) Flat plains
B) Narrow canyons/valley
C) Plateaus(large area of flat land that is higher than other areas of land)
D) Coastal areas

Answer: B) Narrow canyons

PANA ACADEMY

In which type of terrain or geological condition are buttress dams often preferred due to their effective load distribution?

A) Rocky mountains
B) Coastal regions
C) Alluvial plains
D) Plateaus



Which if the following is a type of Arch Dam:

A. Constant Radius Arch Dam
B. Variable Radius Arch Dam
C. Constant Angle Arch Dam
D. All of the above

PANA ACADEMY

In which type of terrain or geological condition are buttress dams often preferred due to their effective load distribution?

A) Rocky mountains
B) Coastal regions
C) Alluvial plains
D) Plateaus

Answer: C) Alluvial plains

Which if the following is a type of Arch Dam:

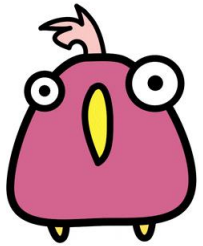
A. Constant Radius Arch Dam
B. Variable Radius Arch Dam
C. Constant Angle Arch Dam
D. All of the above

Answer: D) All of the above

PANA ACADEMY

What is the primary purpose of a cofferdam in construction and engineering projects?

A) To store large quantities of water
B) To create a temporary dry work area within a water body
C) To generate hydropower
D) To regulate water flow in rivers



PANA ACADEMY

What is the primary purpose of a cofferdam in construction and engineering projects?

A) To store large quantities of water
B) To create a temporary dry work area within a water body
C) To generate hydropower
D) To regulate water flow in rivers

Answer: B) To create a temporary dry work area within a water body

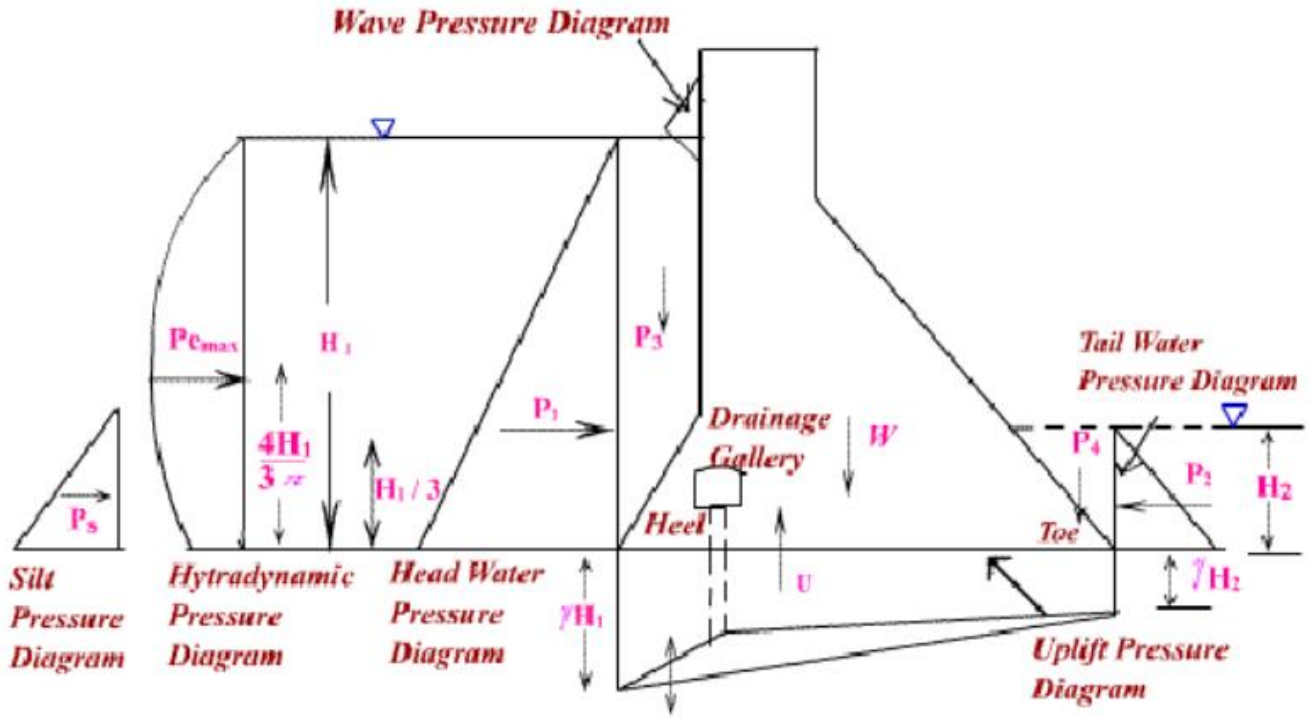
PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

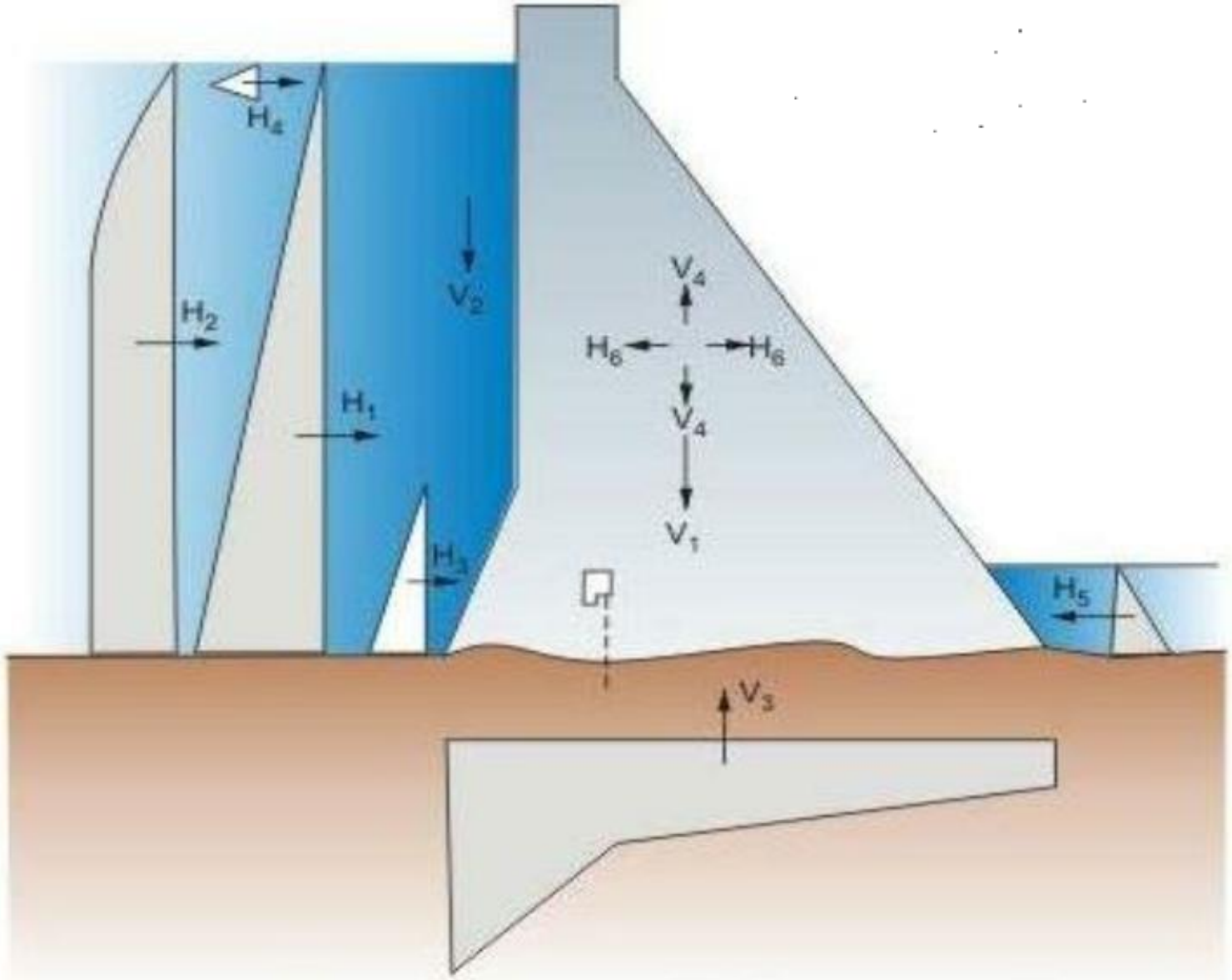
Design of Gravity Dam:

Forces acting on Dam

1. **Primary load**
   a. water Pressure
   b. Seepage or uplift Pressure
   c. Self weight load
2. **Secondary load**
   a. Sediment Load or Silt Pressure
   b. hydrodynamic load
   c. wave load
   d. Wind Load
   e. Ice Load
3. **Exceptional Load:**
   a. Seismic Loads



PANA ACADEMY



Vertical Forces

V1: Gravity acting on mass of dam

V2: Gravity acting on mass of water on upstream

V3: Uplift force

V4: Inertia force due to earth quake

Horizontal Forces

H1: Hydrostatic pressure on upstream face

H2: Inertia force of water due to earthquake

H3: Excess fluid pressure due to silt on the upstream face

H4: Impact of waves

H5: Hydrostatic pressure of tail water on downstream face

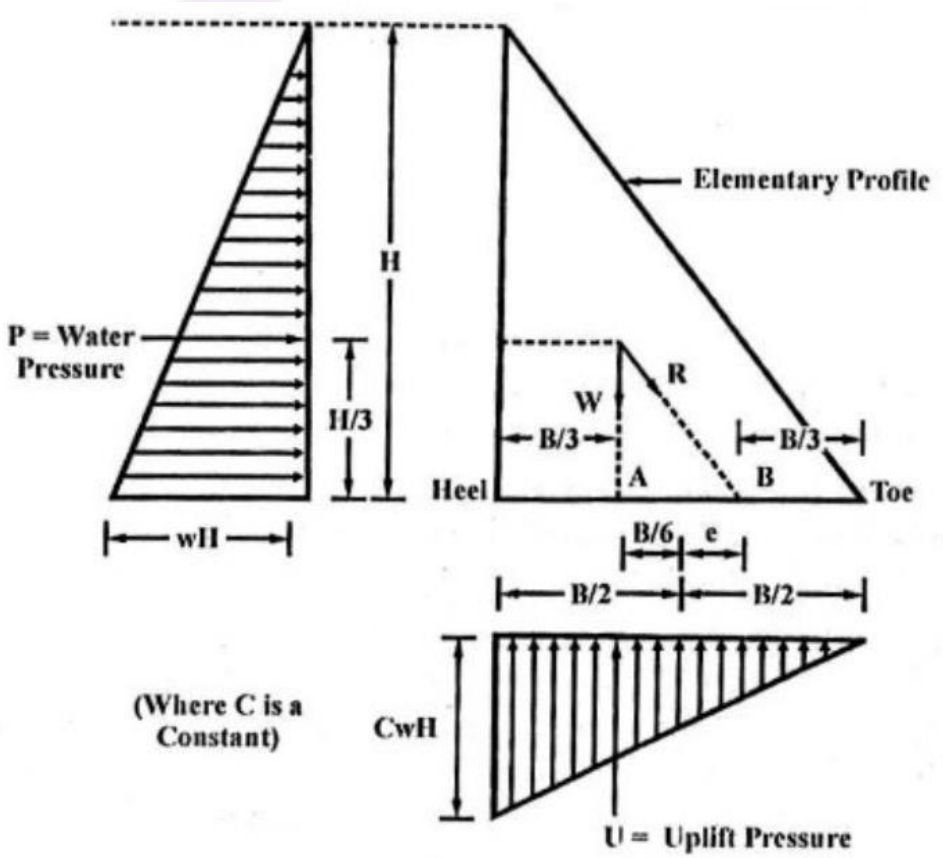
H6: Inertia force due to earthquake.

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

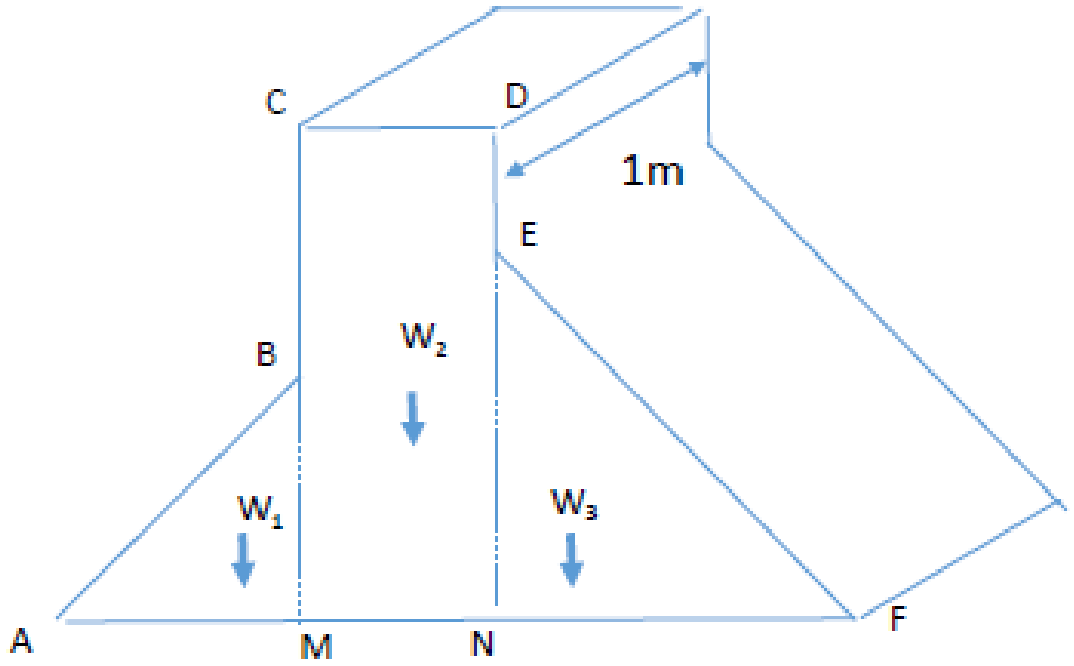
Forces acting on Gravity Dam:

1. **Primary load**
   A. Self weight load
   B. Water Pressure
   C. Seepage or uplift Pressure



8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

A) Self Weight of Dam:



Weight of Dam = $W_1+W_2+W_3$

W_1 = Weight of triangular portion (ΔABM)

= Υ_c x Area of ΔABM x 1 m

W_2 = Υ_c x Area of ▭ MNCD x 1 m

W_3 = Υ_c x Area of ΔEFN x 1 m

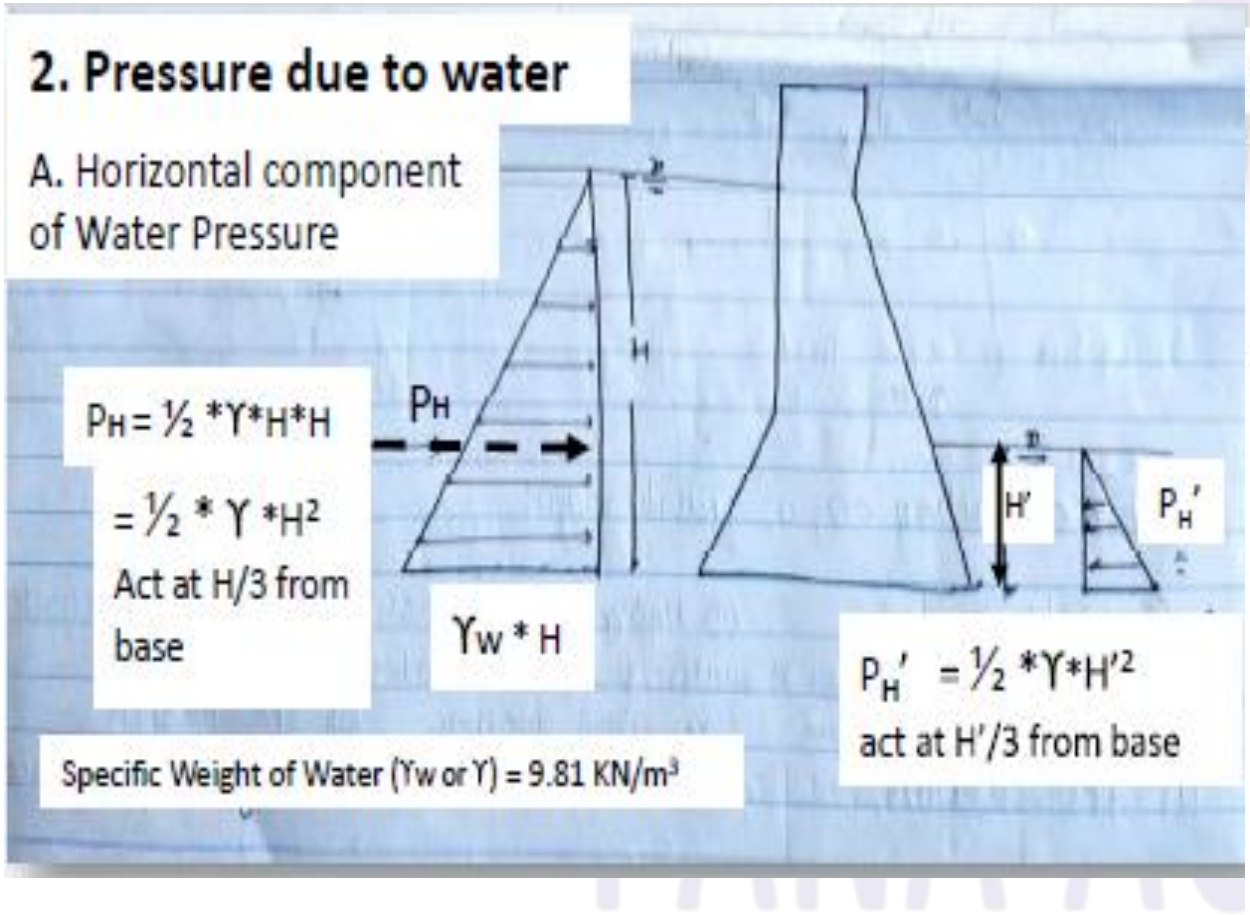
These loads act through C.G. of the area

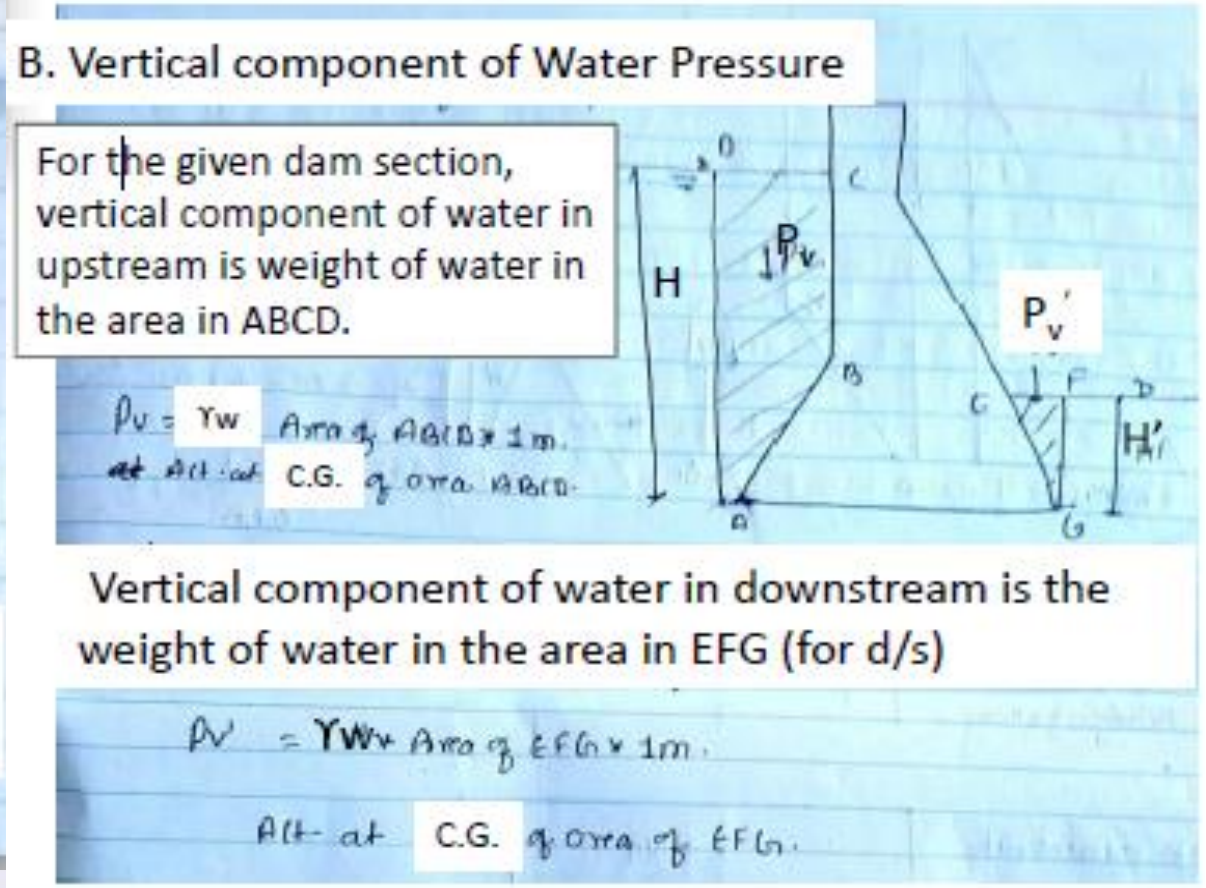
Y_C= Unit Weight of Concrete (24 KN/$m^{3)}$

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

PANA ACADEMY

B) Water Pressure:

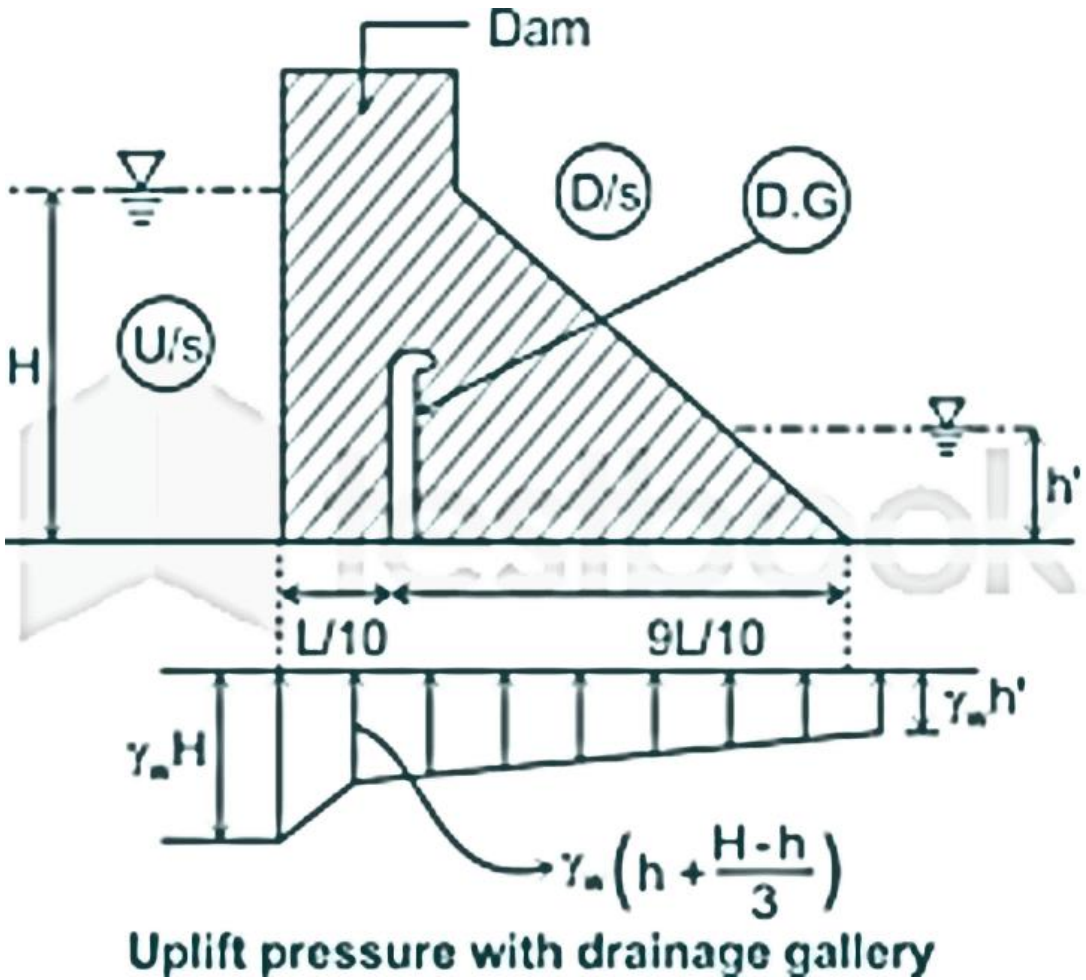




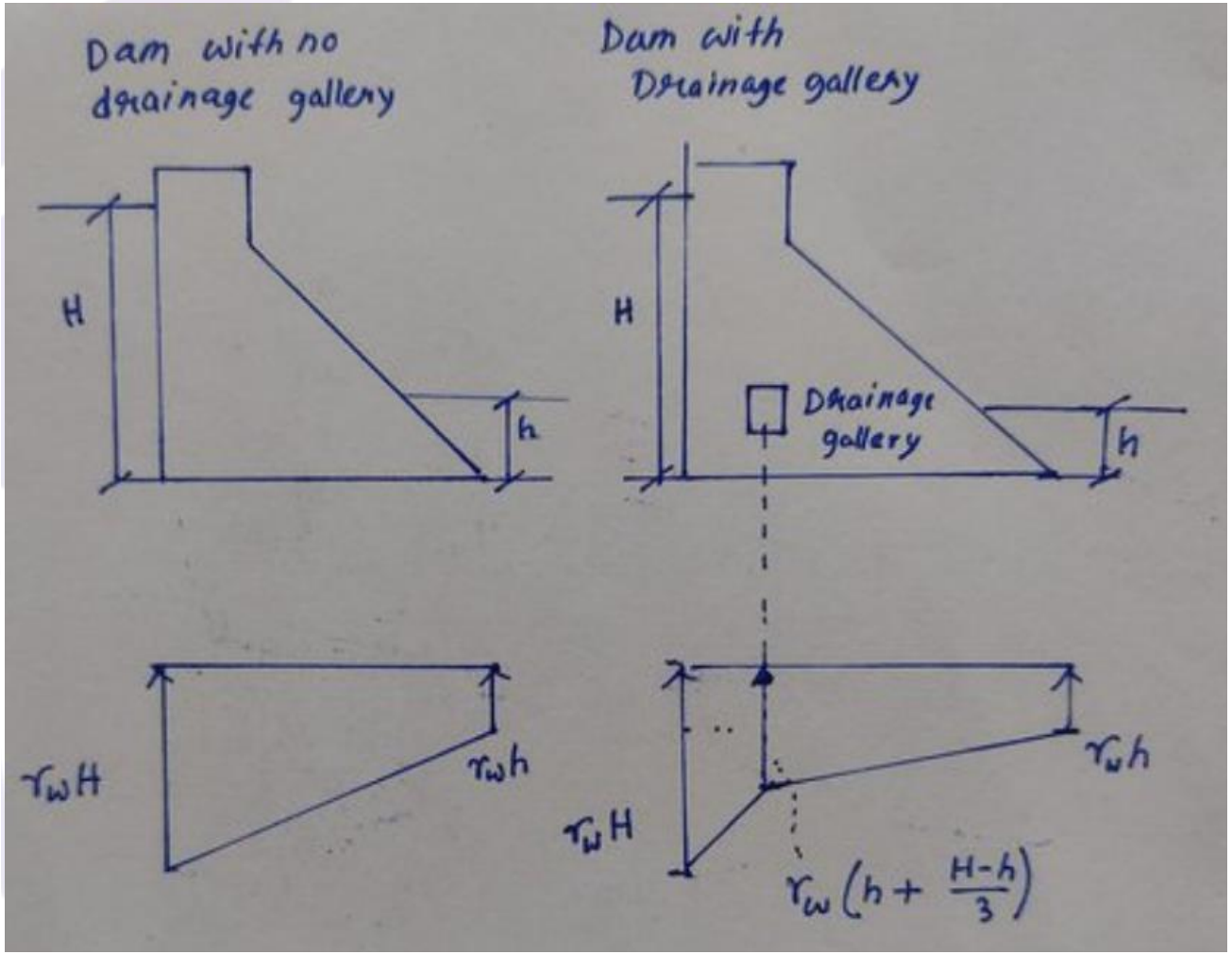
8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

PANA ACADEMY

C) Seepage or Uplift Pressure:



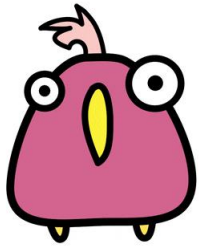
Uplift pressure with drainage gallery



PANA ACADEMY

What is the main function of a drainage gallery in a dam?

A) To store water for future use
B) To provide access for maintenance workers
C) To facilitate the drainage of seepage water from the foundation
D) To regulate the flow of the spillway



How can uplift pressures be minimized or controlled in dam design?

A) By increasing the weight of the dam
B) By reducing the seepage through the foundation
C) By enlarging the spillway
D) By increasing the height of the dam

PANA ACADEMY

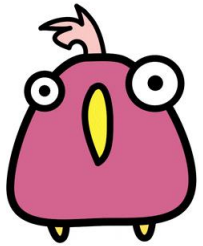
What is the main function of a drainage gallery in a dam?
A) To store water for future use
B) To provide access for maintenance workers
C) To facilitate the drainage of seepage water from the foundation
D) To regulate the flow of the spillway
Answer: C) To facilitate the drainage of seepage water from the foundation

How can uplift pressures be minimized or controlled in dam design?
A) By increasing the weight of the dam
B) By reducing the seepage through the foundation
C) By enlarging the spillway
D) By increasing the height of the dam
Answer: B) By reducing the seepage through the foundation

PANA ACADEMY

Intensity of Uplift pressure is maximum at

A) U/S end of dam
B) D/S end of dam
C) Constant throughout
D) None of the above



The recommended uplift at the face of the drainage gallery is equal to……. , where H and H' are water head at u/s and d/s respectively

A) $\gamma k [H' + (H - H')/3]$
B) $\gamma k H'$
C) $\gamma k (H - H')/3$
D) $\gamma k [H - (H - H')/3]$

PANA ACADEMY

Intensity of Uplift pressure is maximum at
A) U/S end of dam
B) D/S end of dam
C) Constant throughout
D) None of the above
Answer: A) U/S end of dam

The recommended uplift at the face of the drainage gallery is equal to……. , where H and H' are water head at u/s and d/s respectively
A) $\gamma k [H' + (H - H')/3]$
B) $\gamma k H'$
C) $\gamma k (H - H')/3$
D) $\gamma k [H - (H - H')/3]$
Answer: A) $\gamma k [H' + (H - H')/3]$

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Forces acting on Dam:

2. Secondary load

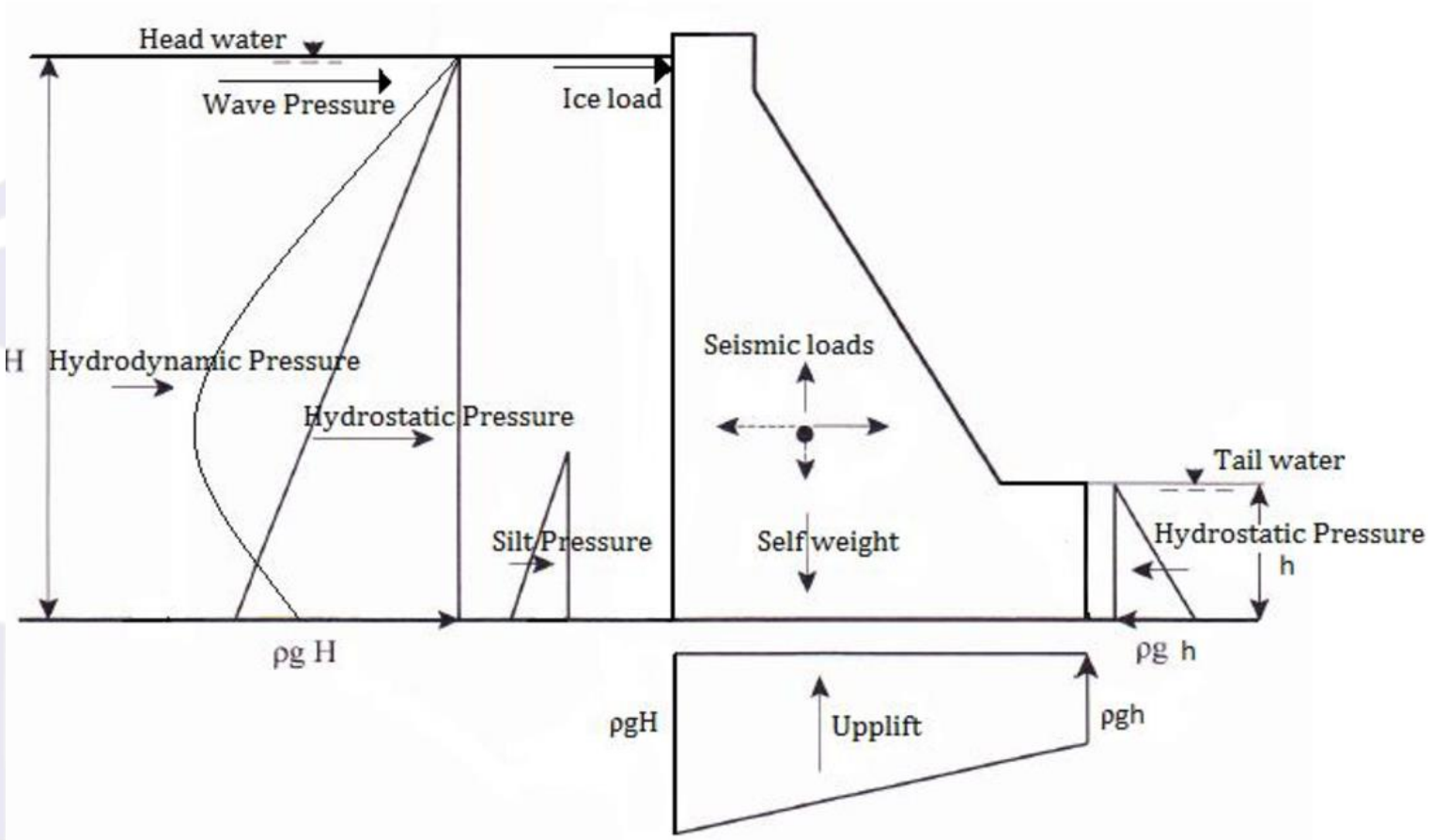
a. Sediment Load

b. Hydrodynamic

c. wave load

d. Wind Load

e. Ice Load



PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

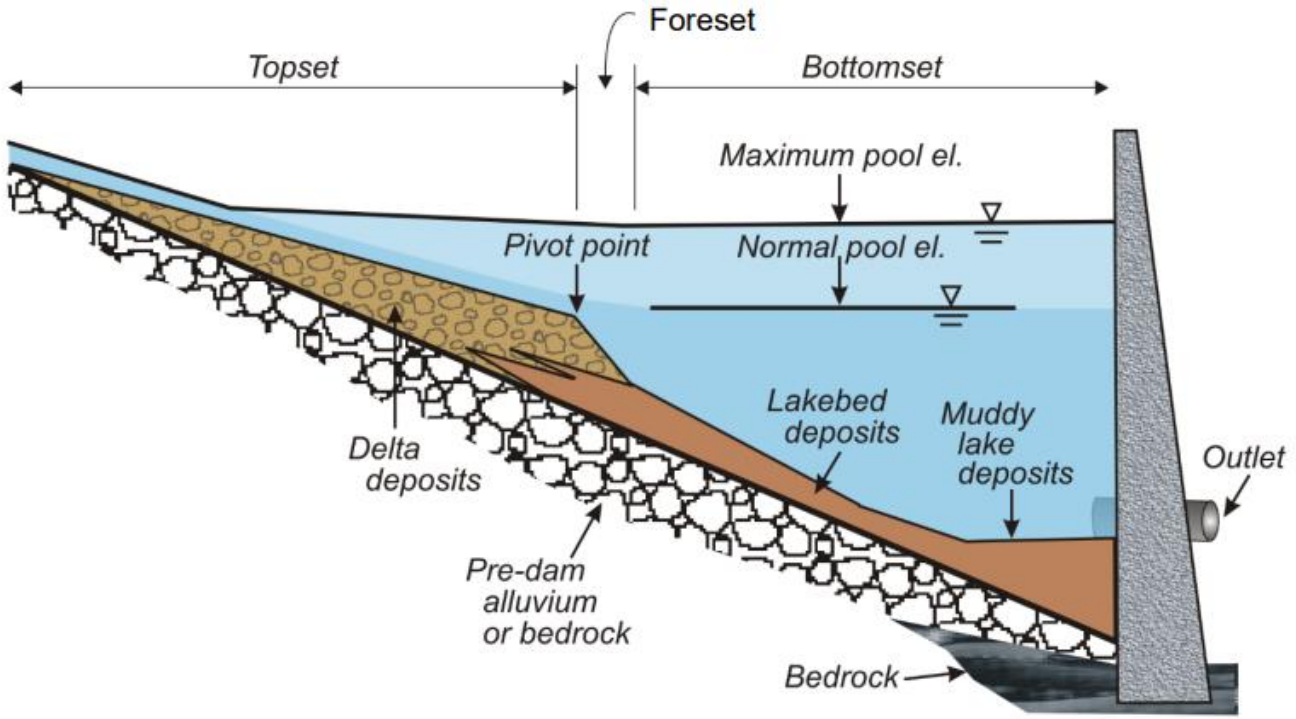
Secondary Load | **Sediment Load**

Rankine formula is used

1. Horizontal Silt pressure
   = (1/2)* ϒs * Ka * h^2
2. Acts at h/3 from base
3. Ka= active earth pressure = $\frac{1-\sin\emptyset}{1+\sin\emptyset}$

   Ø is angle of internal friction

   ϒs= ϒsilt- ϒwater



PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Failure Modes in Gravity Dam

1. Overturning of Dam
2. Sliding of Dam (shear failure)
3. Crushing of Dam (compression)
4. Development of Tension in Dam

PANA ACADEMY

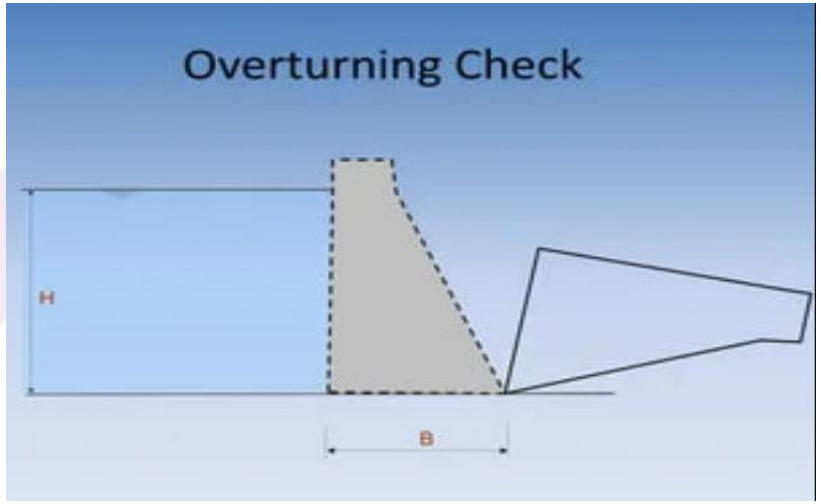
8.3.3 Stability analysis of Gravity Dam

Stability Analysis:

1) Stability against overturning:

Factor of Safety (F.S)= $\frac{\text{Resisting Moment (Mr)}}{\text{Overturning Moment (Mo)}}$

Should not be less than 1.5

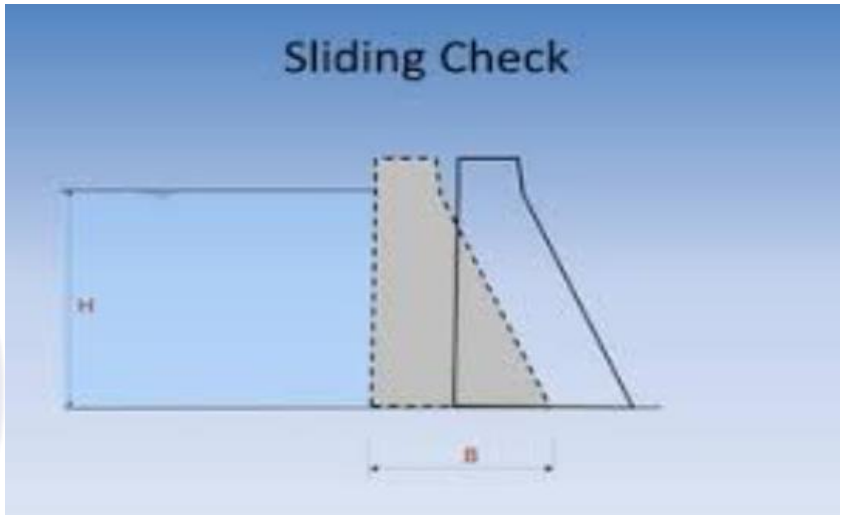


2) Factor of safety against sliding

- **In Case of low masonry dam**

F.S= $\frac{\mu \Sigma V}{\Sigma H}$ Should always be greater than 1

μ= coefficient of friction (0.6 to 0.75)



PANA ACADEMY

8.3.3 Stability analysis of Gravity Dam

- **In Case of large high dam**

Shear Friction Factor (S.F.F) :

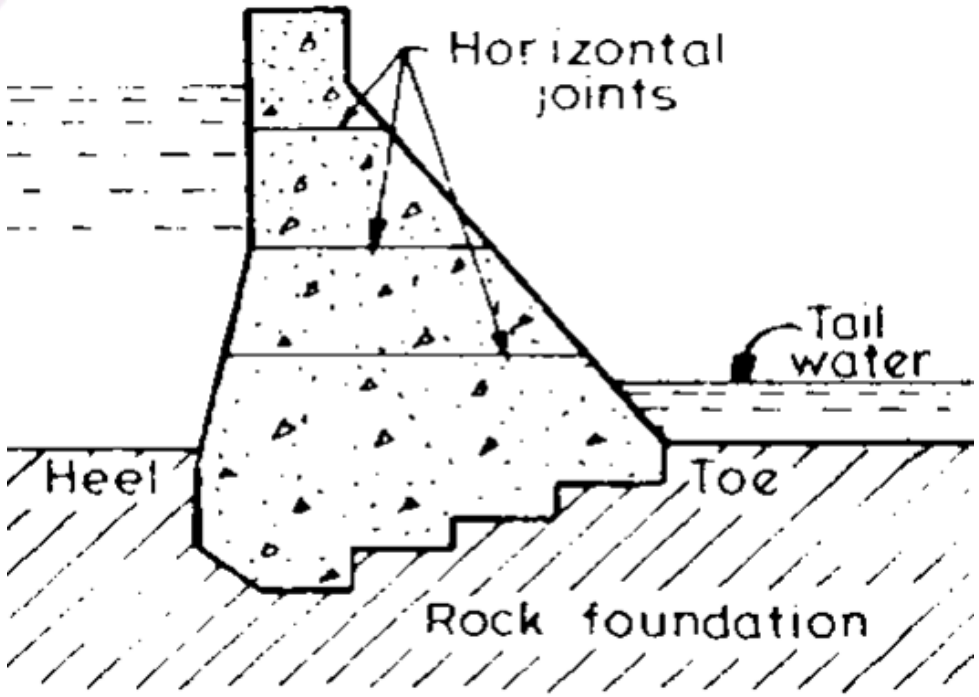
In case of large high dams, the shear strength of the joint should also be considered along with static coefficient of friction, In this case the factor of safety is known as **Shear Friction Factor (S.F.F)**

$$\text{S. F. F} = \frac{\mu \Sigma V + Bq}{\Sigma H}$$

B= Width of joint or section

q=Shear strength of joint usually taken as 14 kg/cm2

Safe value of S.F.F should lie between 4 and 5.



PANA ACADEMY

8.3.3 Stability analysis of Gravity Dam

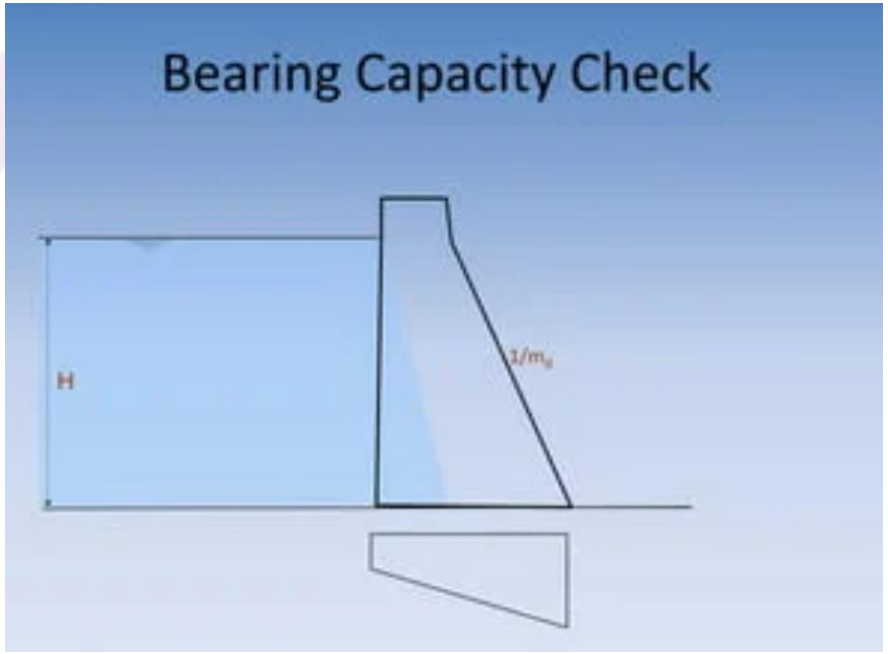
3) Crushing or Compression Failure

$$P_n \leq f_c$$

$$P_n = \frac{\Sigma V}{B}\left(1 \pm \frac{6e}{B}\right)$$

Where ΣV is sum of vertical forces, B is width of Dam,
e is eccentricity, P_n = Normal Stress,

f_c = Allowable compressive stress for foundation material



4) Tension Failure

Since concrete and masonry are very weak in tension, tension is not allowed to be developed

PANA ACADEMY

8.3.3 Stability analysis of Gravity Dam

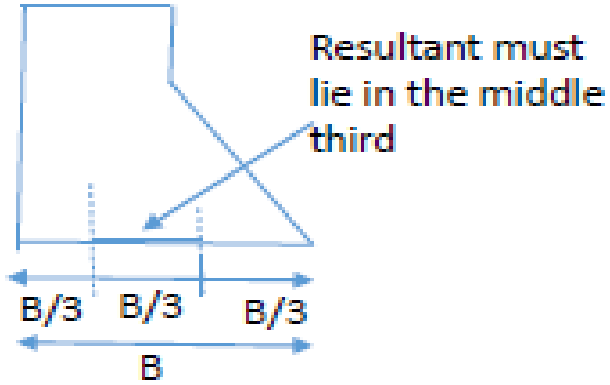
Middle Third Rule

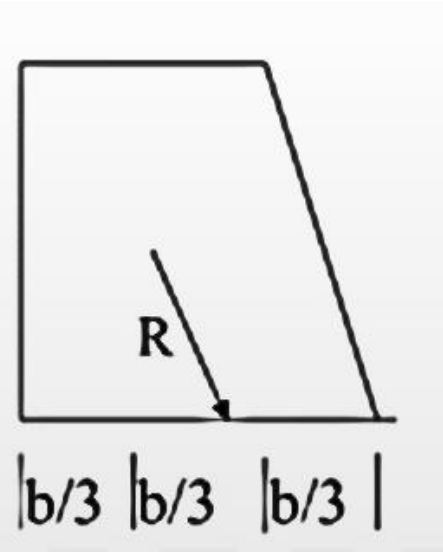
- For no tension condition, the resultant must lie in the middle third
- Maximum eccentricity that can be allowed on either side from center is equal to B/6

Where eccentricity (e) ,

$$e = B/2 - \bar{X} \quad , \quad \mathbf{e <= B/6}$$

$$\bar{x} = \frac{\Sigma M}{\Sigma V}$$





PANA ACADEMY

8.3.3 Stability analysis of Gravity Dam

Stability Analysis:

Shear Friction Factor (S.F.F) :

(FoS against shear failure)

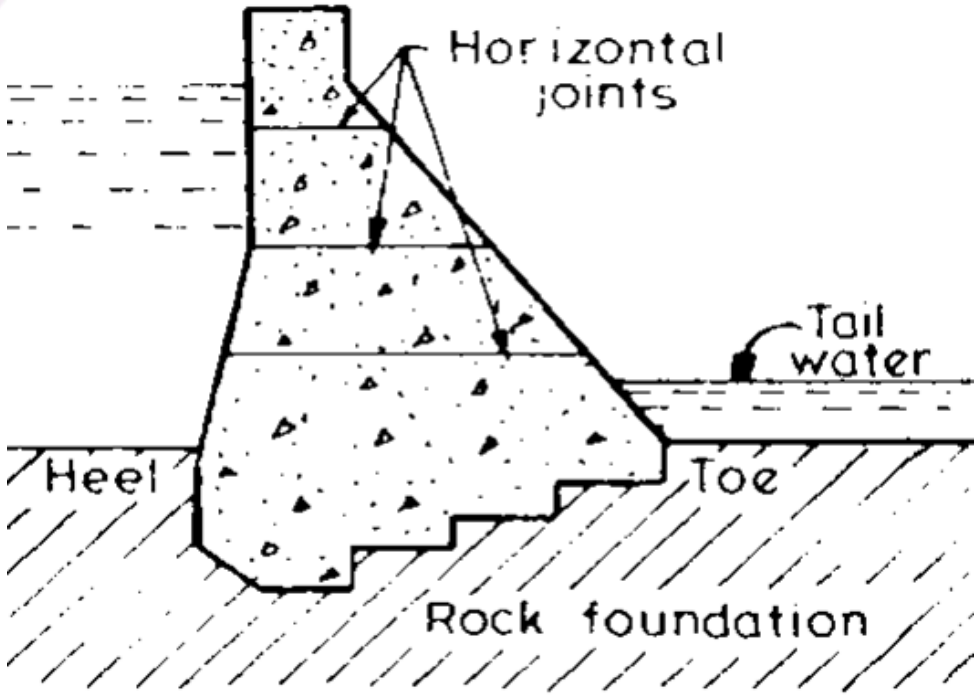
In case of large high dams, the shear strength of the joint should also be considered along with static coefficient of friction, In this case the factor of safety is known as **Shear Friction Factor (S.F.F)**

$$\text{S. F. F} = \frac{\mu \Sigma V + Bq}{\Sigma H}$$

B= Width of joint or section

q=Shear strength of joint usually taken as 14kg/cm2

Safe value of S.F.F should lie between 4 and 5.



8.3.3 Stability analysis of Gravity Dam

PANA ACADEMY

Minimum Base width of DAM:

1) Minimum Base width for no tension at the hell is given by,

- $B=H/\sqrt{(G-K)}$

Where,

- H= Height of water level on u/s end
- G= Specific gravity of the material
- K= Coefficient of uplift pressure
- μ= coefficient of friction (0.6 to 0.75)

2) Minimum base width for no slide condition is,

- $B=H/\mu(G-K)$

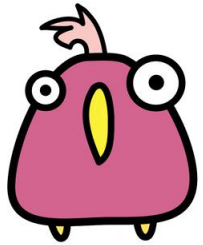
Q) Calculate the base width of gravity dam for no tension condition if ht of dam is 150 m, sp. Gravity of dam material is 2.4, consider no or zero uplift pressure

a) 96.82 m b) 150 m c) 100 m d) 95.82 m

PANA ACADEMY

What is the Middle Third Rule in the context of dam engineering?

A) A guideline for designing spillways
B) A principle for estimating live loads
C) A rule of thumb for determining the proper location of the dam's center of gravity
D) A criterion for ensuring the structural stability of a dam's cross-section



According to the Middle Third Rule, where should the center of gravity of the dam cross-section ideally be located?

A) In the upper third of the cross-section
B) In the middle third of the cross-section
C) In the lower third of the cross-section
D) At the crest of the dam

PANA ACADEMY

What is the Middle Third Rule in the context of dam engineering?
A) A guideline for designing spillways
B) A principle for estimating live loads
C) A rule of thumb for determining the proper location of the dam's center of gravity
D) A criterion for ensuring the structural stability of a dam's cross-section
Answer: D) A criterion for ensuring the structural stability of a dam's cross-section

According to the Middle Third Rule, where should the center of gravity of the dam cross-section ideally be located?
A) In the upper third of the cross-section
B) In the middle third of the cross-section
C) In the lower third of the cross-section
D) At the crest of the dam
Answer: B) In the middle third of the cross-section

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Design of Earth Dams

1. **Height of dam :** High flood level(HFL) + Free Board (FB)

2. **Top width of dam:**

Top width should be minimum 3 m and is generally govern by the minimum roadway width requirements.

Thumb rule:

a) W = H/5 +3 for very low dams,

b) For dams lower than 30m $W = 0.55(H)^{0.5} + H/5$

c) For dams higher than 30m, $W = 1.65(H + 1.5)^{1/3}$

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Design of Earth Dams

3. Fixation of Free Board

Difference between top of dam and normal reservoir level. Depends on wave height. Should be atleast 1.5 times wave height.

4. Upstream and Downstream slopes

The u/s and d/s slopes should be flat enough to provide sufficient base width at the foundation

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 than 15 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

PANA ACADEMY

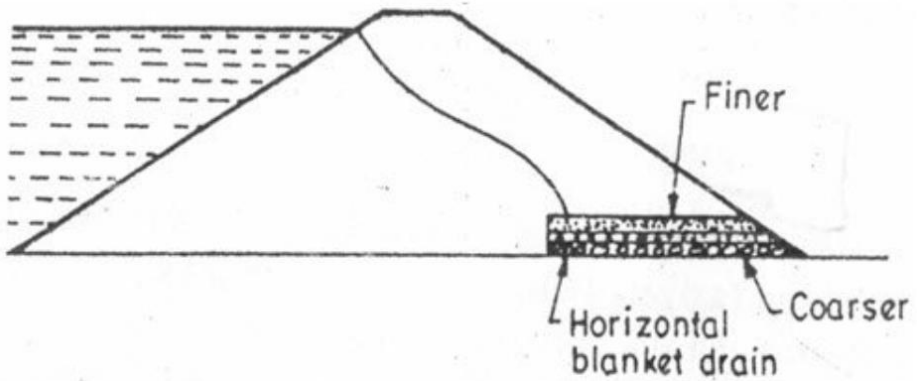
8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Design of Earth Dams

5. Central Core of dam : Minimum width of central core should be 3m

6. Drainage from downstream side of dam:

The seepage line (phreatic line) should remain within the downstream face of the dam, so that no sloughing of the face occurs.

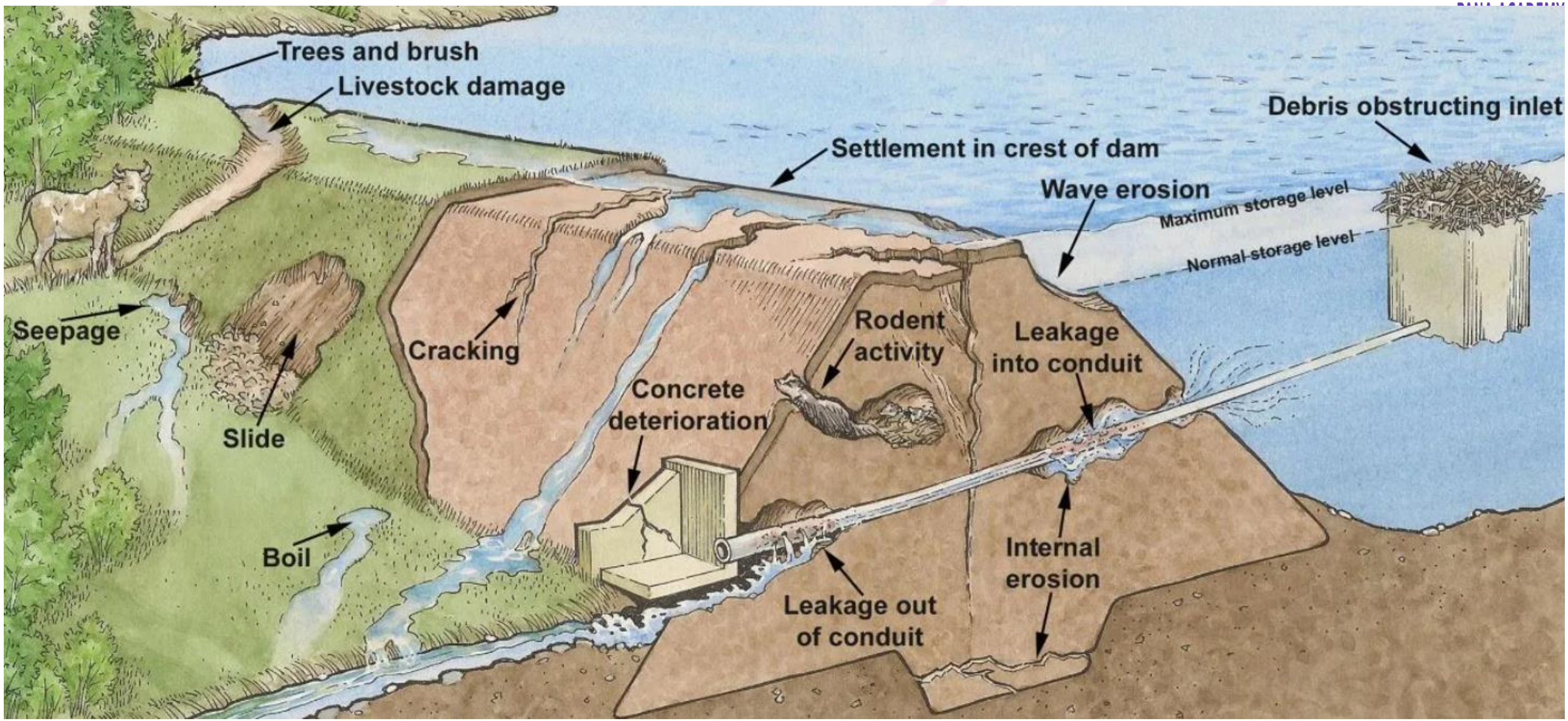


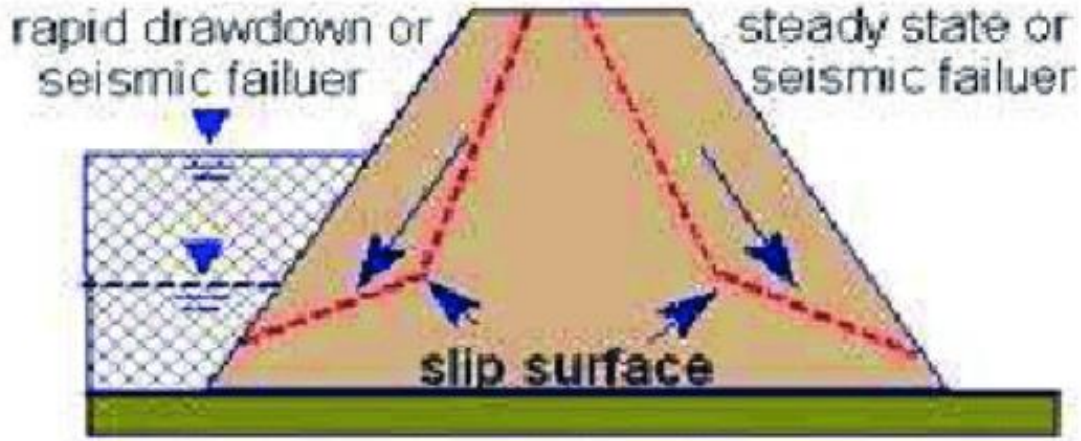
PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

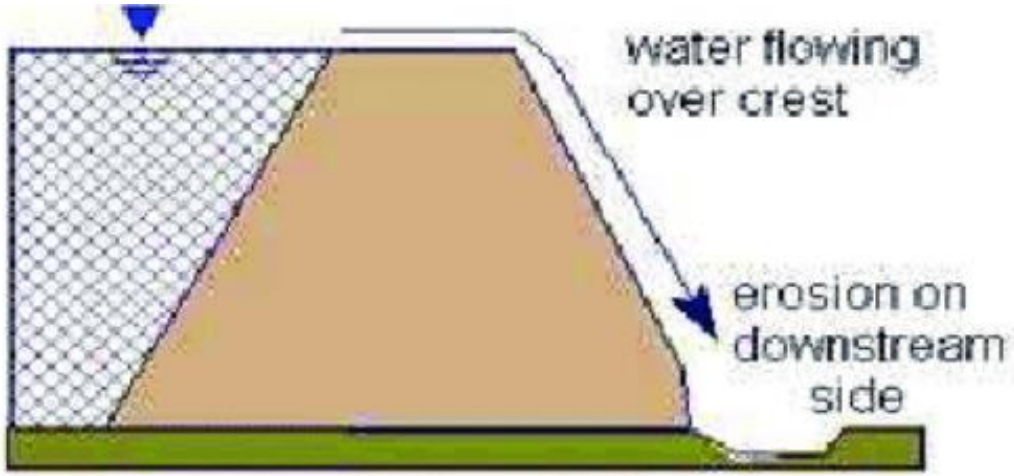
Failure in Earthen Dam:

1. **Hydraulic Failure**
2. **Seepage Failure**
3. **Structural failure**

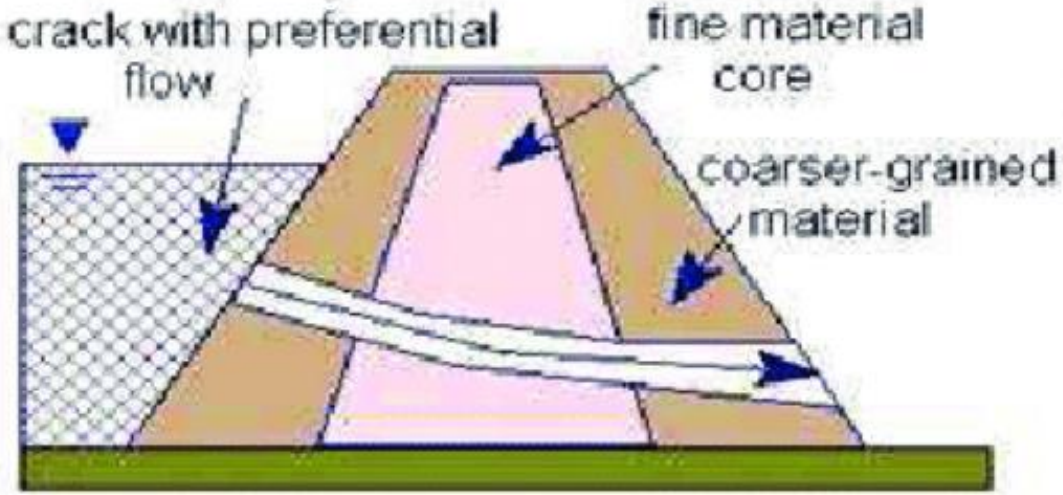

Trees and brush
Livestock damage
Settlement in crest of dam
Debris obstructing inlet
Wave erosion
Maximum storage level
Normal storage level
Seepage
Cracking
Rodent activity
Leakage into conduit
Concrete deterioration
Slide
Boil
Internal erosion
Leakage out of conduit



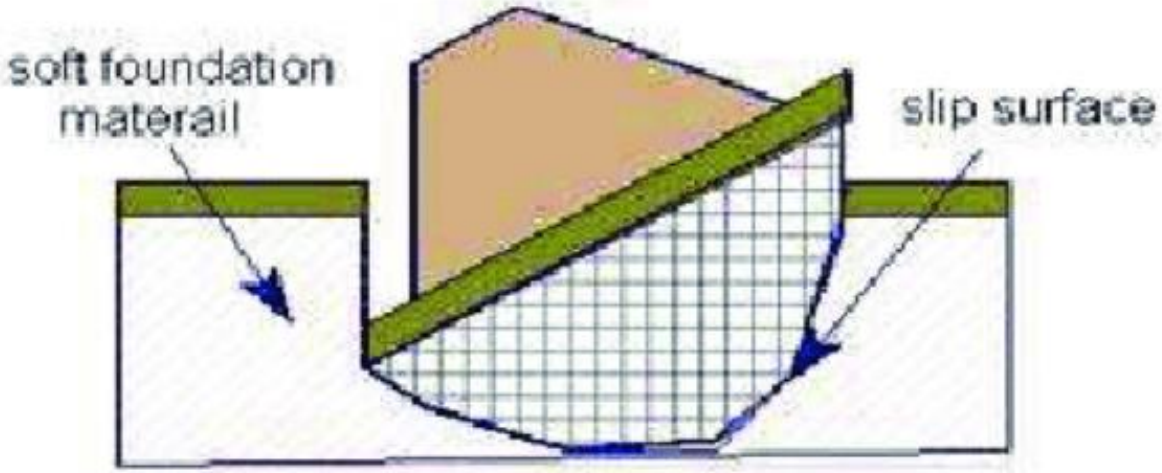
a) slope stability failures



c) overtopping failure



b) piping failure



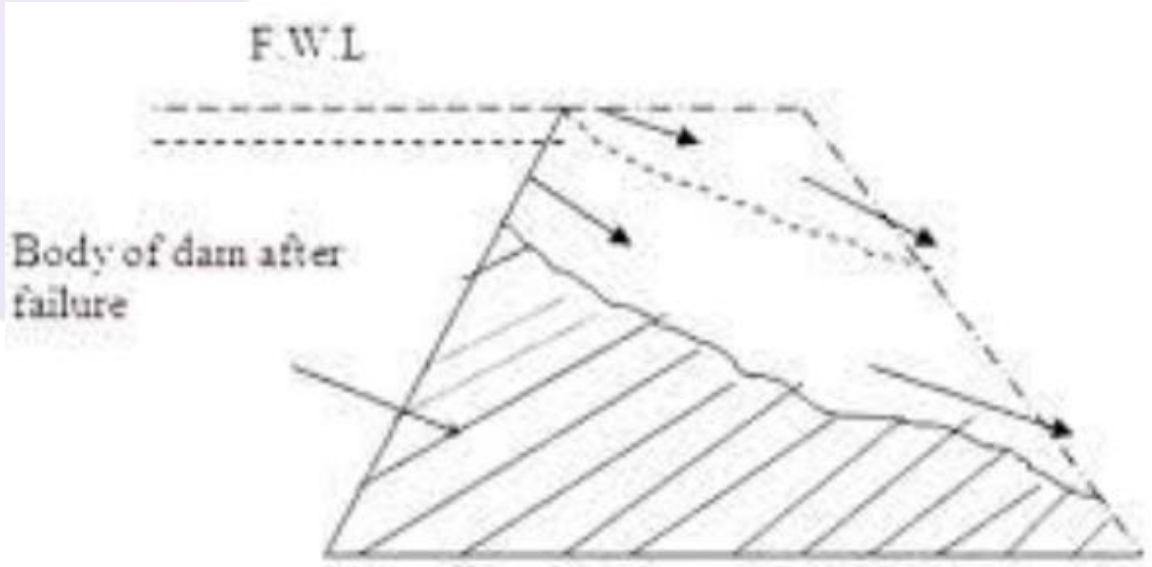
d) foundation failure

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Hydraulic Failure

1. Overtopping
2. Erosion of U/s face
3. Erosion of D/s face by rain wash
4. Erosion of downstream toe by tailwater
5. Cracking due to frost action

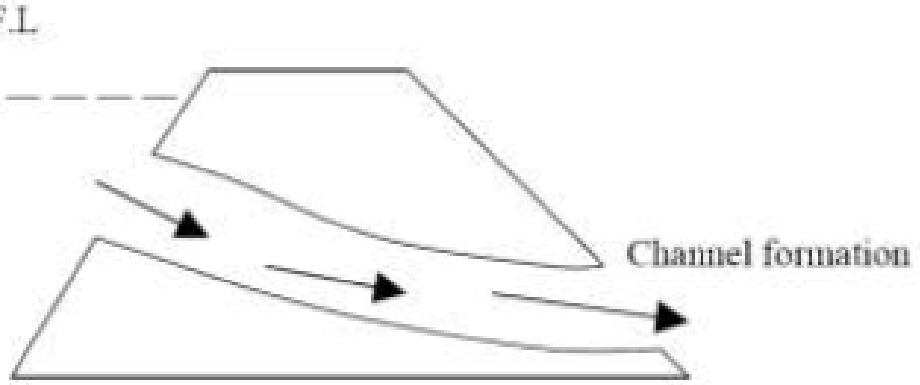


PANA ACADEMY

8.3.2 Dams (types, functions, selection, d

Seepage Failure

1. Piping through dam body
2. Piping through the foundation



Piping through dam body.

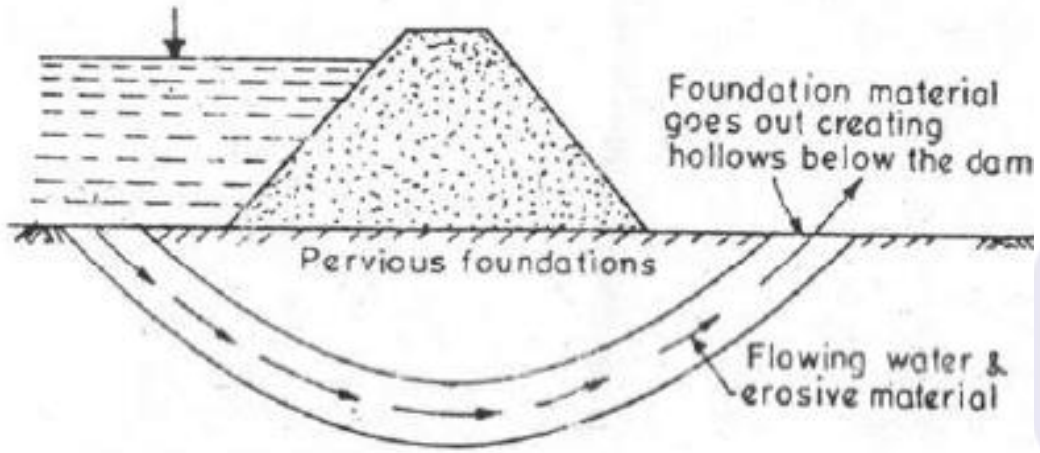


Fig: Piping through foundation

PANA ACADEMY

8.3.2 Dams (types, functions, selection, design, failure modes and remedies)

Structural Failure

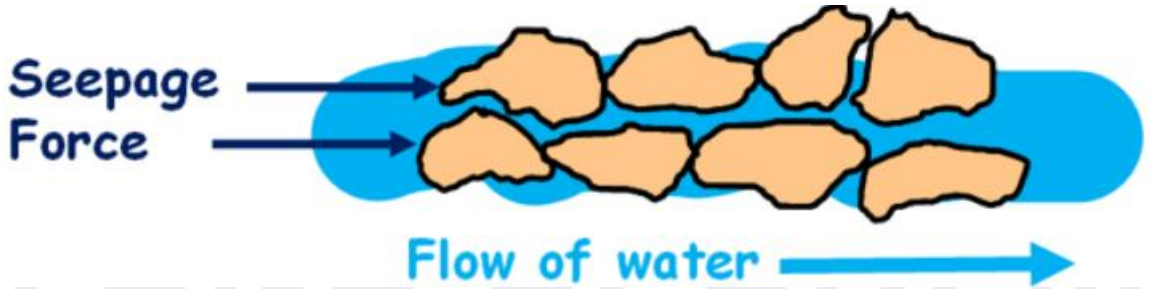
1. Sliding due to weak foundation
2. Sliding of upstream face due to sudden drawdown
3. Sliding of downstream face due to slope being too steep
4. Faulty construction
5. Failure of dam by burying animals

PANA ACADEMY

8.3.4 Seepage Control & Foundation Treatment in Dams

Seepage Control:

1. Seepage control through the dam
2. Seepage control through the dam foundation

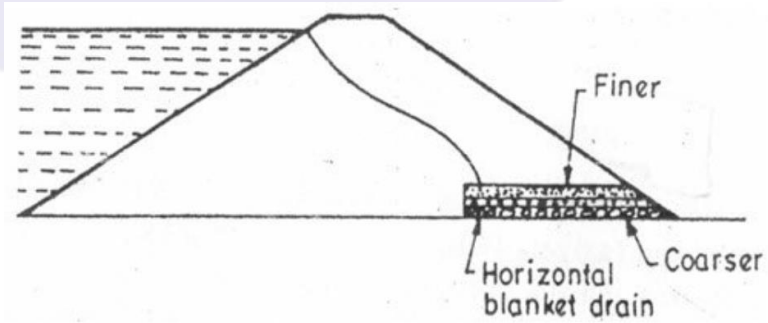


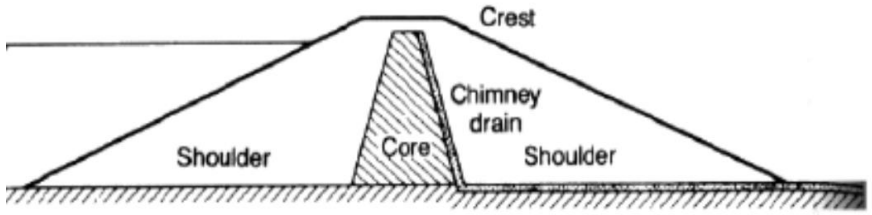
PANA ACADEMY

8.3.4 Seepage Control & Foundation Treatment in Dams

Seepage Control | **Seepage control through the dam**

1. Rock toe or toe filter
2. Horizontal blanket drains
3. Chimney drains





By providing horizontal drainage filter L = 3*H or 25 to 100% of horizontal distance between the centre line of the top width to the toe.

Phreatic Line in Embankment Dams

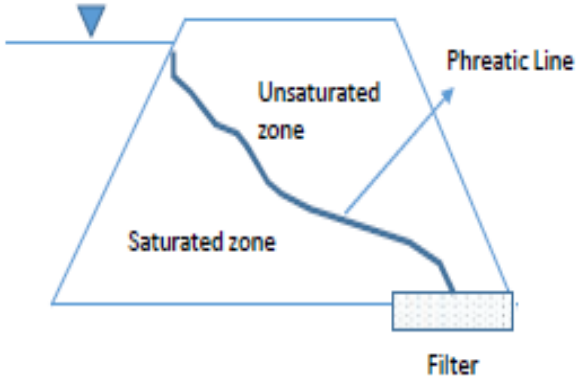
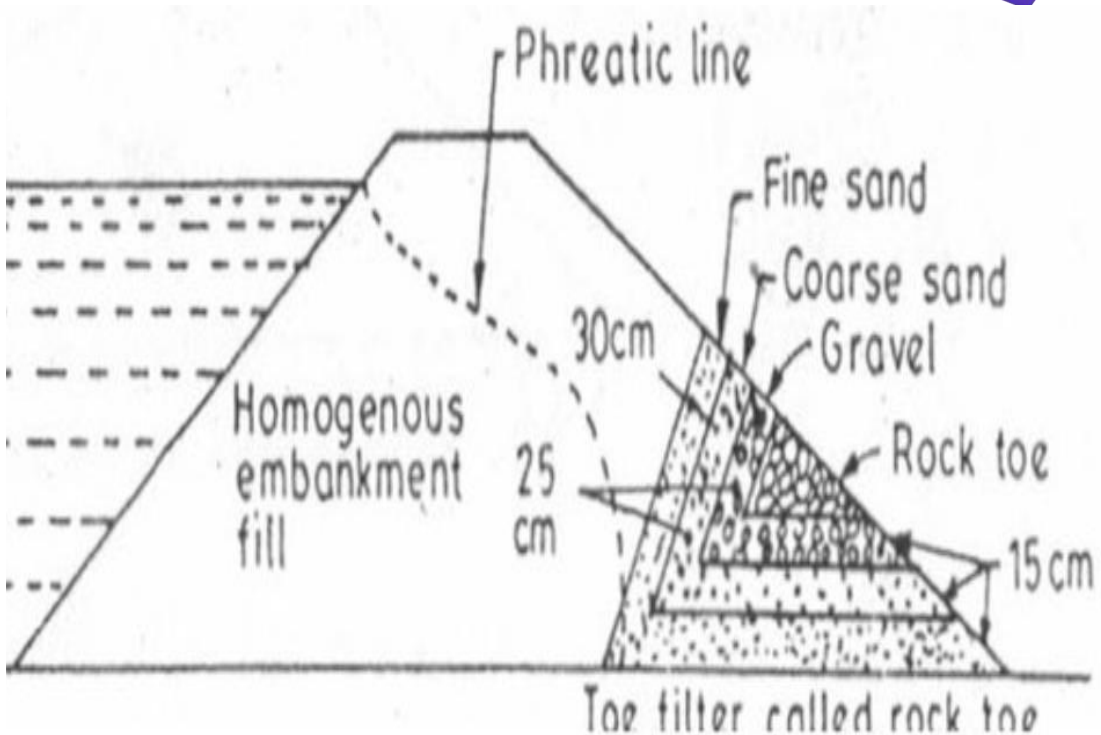


Fig: Phreatic Line in Embankment Dams



- Phreatic line is a divide line between dry and saturated (submerged) soil.

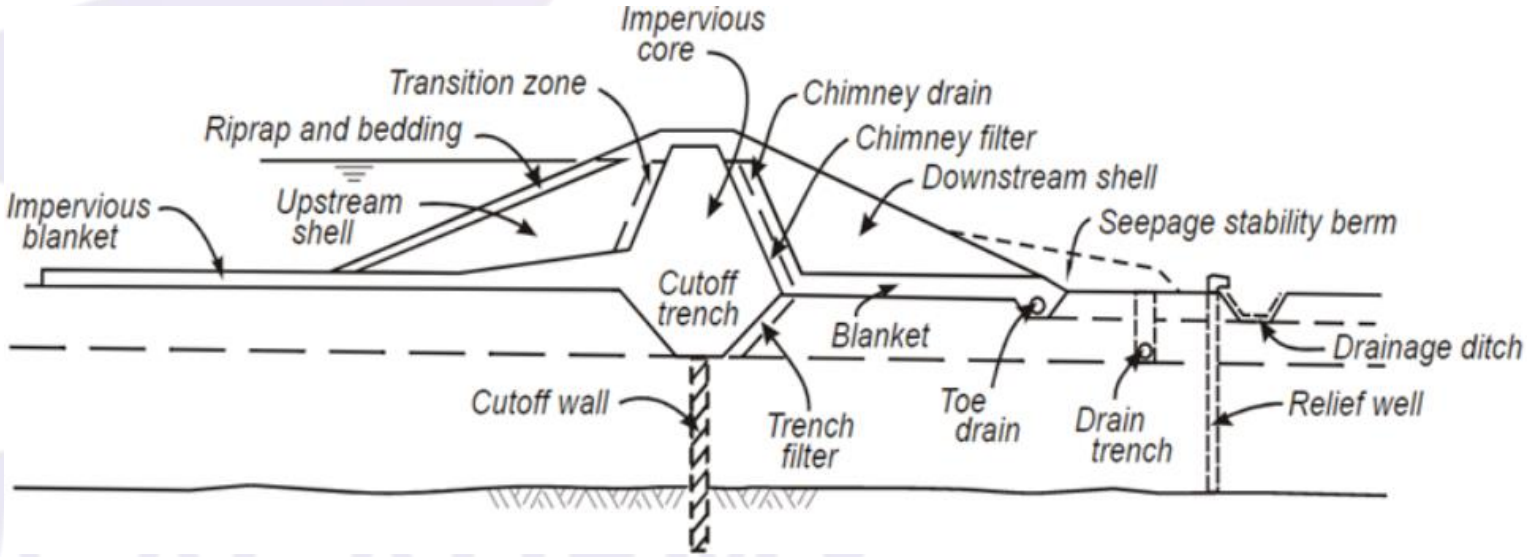
By providing filter drainage - filter in inclined to the toe height of the rock toe 25 to 30% of H

PANA ACADEMY

8.3.4 Seepage Control & Foundation Treatment in Dams

Seepage Control | **Seepage control through the dam foundation**

1. Impervious Cutoff wall
2. Relief wall or drain trench
3. Upstream blanket
4. Grouting and grout curtain



8.3.4 Seepage Control & Foundation Treatment in Dams

PANA ACADEMY

Foundation Treatment of Gravity Dams:

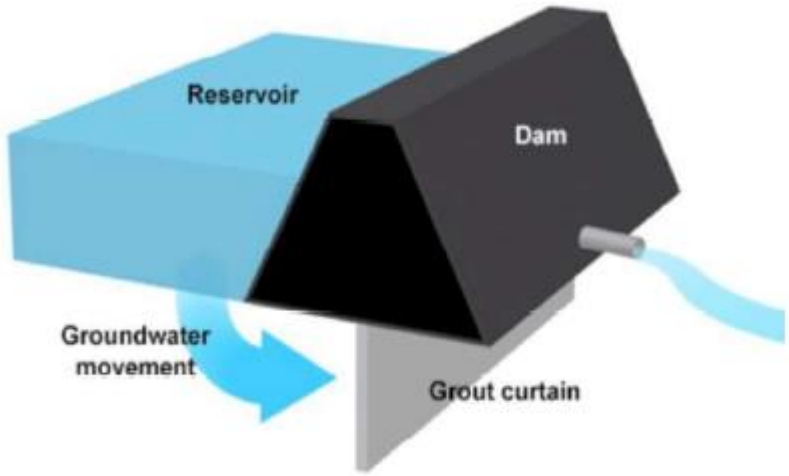
A. Preparation of Surface

B. Foundation Grouting

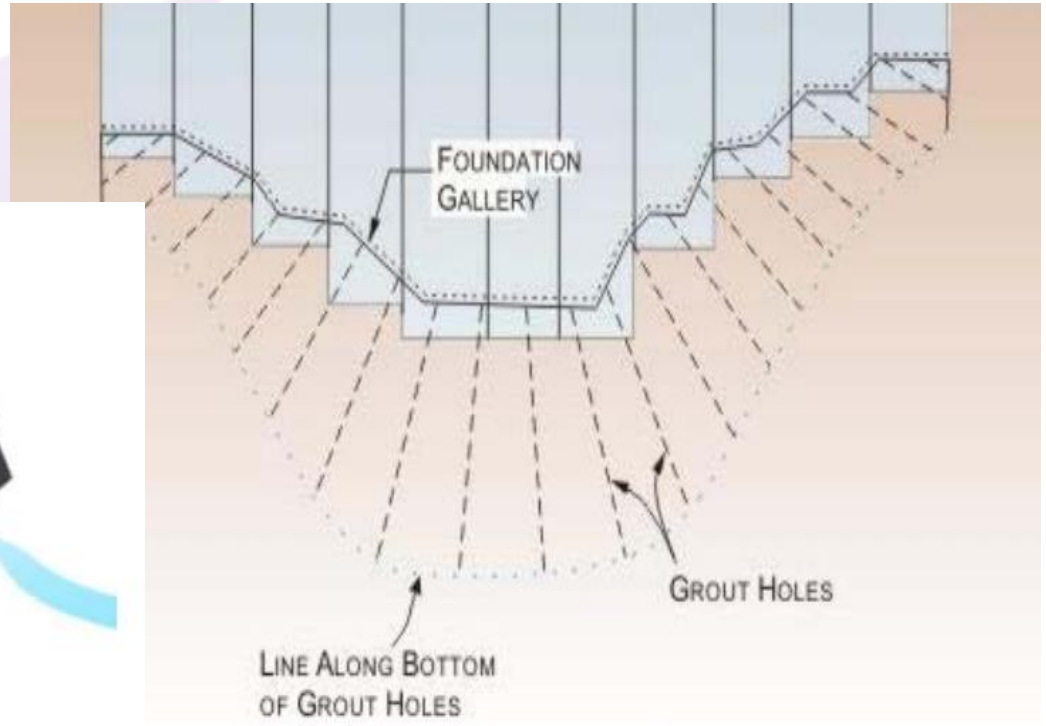
a. Consolidation grouting

b. Curtain grouting

C. Foundation Drainage



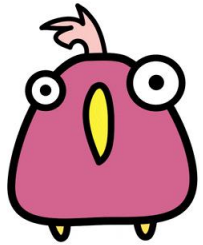
Curtain Grouting



PANA ACADEMY

What is the primary function of horizontal blanket drains in dam engineering?

A) To increase the dam's height
B) To facilitate hydroelectric power generation
C) To promote seepage through the foundation
D) To intercept and divert seeping water away from the dam



What is the primary purpose of chimney drains in dam construction?

A) To add stability to the dam's crest
B) To provide an outlet for floodwaters
C) To control seepage and uplift pressures in the dam's core
D) To create a pathway for hydroelectric power generation

PANA ACADEMY

What is the primary function of horizontal blanket drains in dam engineering?

A) To increase the dam's height
B) To facilitate hydroelectric power generation
C) To promote seepage through the foundation
D) To intercept and divert seeping water away from the dam

Answer: D) To intercept and divert seeping water away from the dam

What is the primary purpose of chimney drains in dam construction?

A) To add stability to the dam's crest
B) To provide an outlet for floodwaters
C) To control seepage and uplift pressures in the dam's core
D) To create a pathway for hydroelectric power generation

Answer: C) To control seepage and uplift pressures in the dam's core

PANA ACADEMY

8.3.5 Design of Intake, Spillway and Energy Dissipator

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Intake is the hydraulic structure provided at the mouth (entrance) of a water conveyance system to withdraw water from the reservoir or river to power house.

Location of intake:

It has to be decided based on following primary considerations:

- Adequate inflow
- Less silt inflow
- Least head loss
- Least Environmental impact
- Best location for intake is outer or concave bank to avoid sediment load

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Depending upon the type of power plant and its layout:

A) ROR type plant

-draw water from fresh continuous river flow without any appreciable pondage

i. Side (lateral) intake

ii. Frontal intake

iii. Drop intake/ bottom/ trench

B) Reservoir Intake

i. Dam Intake

ii. Shaft or Glory hole intake

iii. Tower intake

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Design of intake structure

(i) Selection of Type of intake:

Based on site and hydraulic conditions either side, frontal, trench, pressure, non-pressure intake is adopted.

ii) Determine the capacity of intake

The design discharge should be taken as 10-20% more than that of turbine discharge

iii) Fixing intake invert level:

Based on sediment content (bed load) in the river and experience on design and construction, invert level shall be 0.5 m to 2 m above the under sluice level according to the site condition

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Design of intake structure

(iv) Satisfy velocity Criteria:

The entrance velocity should be less than 0.6m/s to 0.8m/s however upto 1m/s for small system.

(v) Determination of number of opening

(vi) Account the contraction loss due to the pier, abutment: generally effective length is taken as 0.9-0.95 times the actual opening.

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

(vii) Intake opening/orifice- is designed as broad crested weir with submergence or free flow condition depending upon the water level at u/s, d/s and on the weir. The intake opening under the gate control can also be designed based on orifice flow equation:

$Q_d = A*C*\sqrt{2g*(H - h)}$

Where, H=river water level =depth of river water in front of intake

h=canal water level=depth of water in canal

C=constant depends on the shape of opening. For sharp edge and roughly finished opening=0.6 and for carefully finished=0.8

(viii) Calculate hydraulic loss:

trash rack loss entrance loss

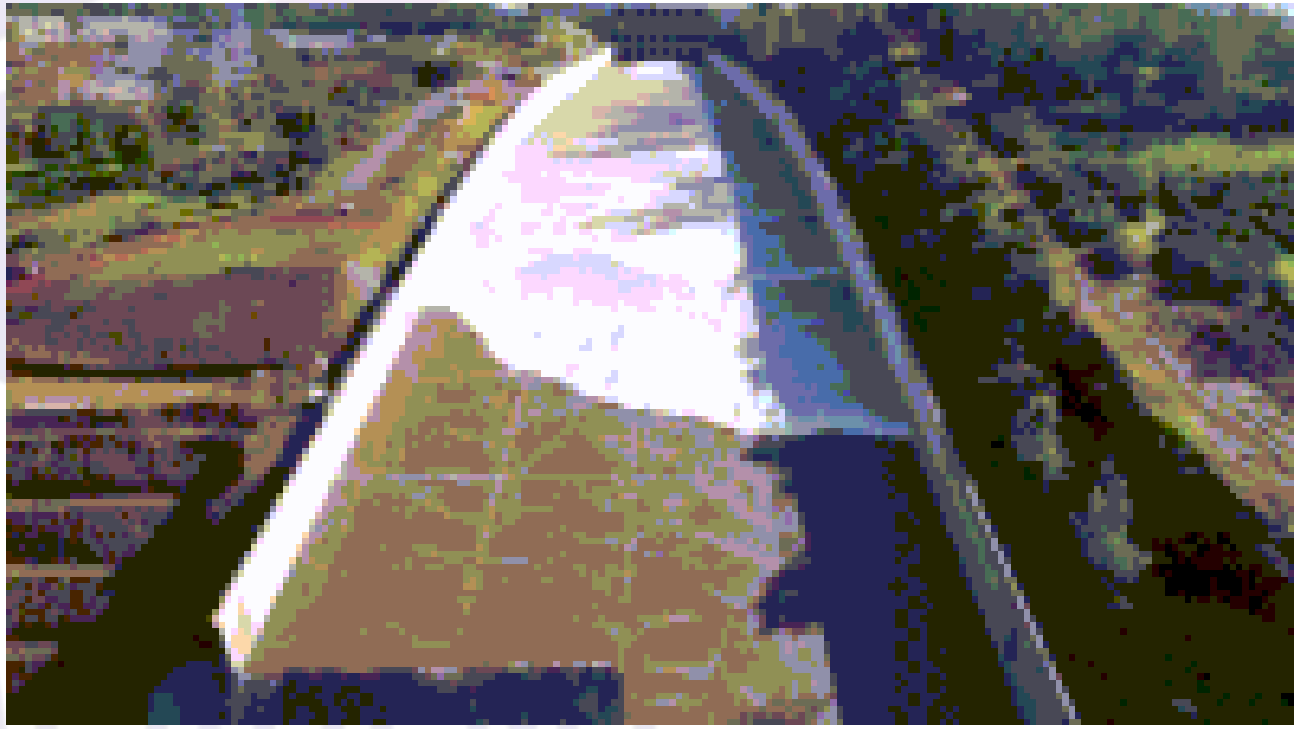
transition loss gate loss

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Spillway:

A spillway is a structure constructed near the dam/weir site to dispose surplus water from the reservoir to the channel downstream.



It acts as a safety valve.

8.3.5 Design of intake, Spillway and Energy Dissipator

Types of Spill Way:

1. Based on control of water flow:

a) *Controlled spillway – with gates*

b) Uncontrolled spillway – no gates

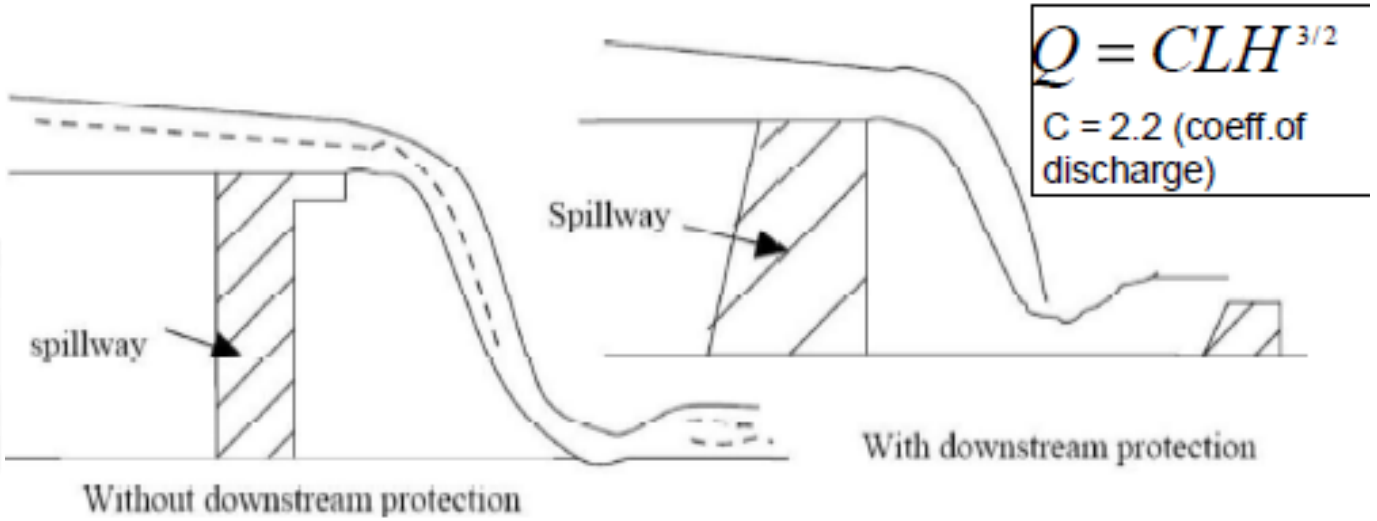
2. Based on structures :

a) Straight drop spill way:

- Q = design flood, H = head over the crest, L = length of spillway

$$Q = CLH^{3/2}$$

C = 2.2 (coeff.of discharge)



8.3.5 Design of intake, Spillway and Energy Dissipator

b) Overflow (Ogee) spill way:

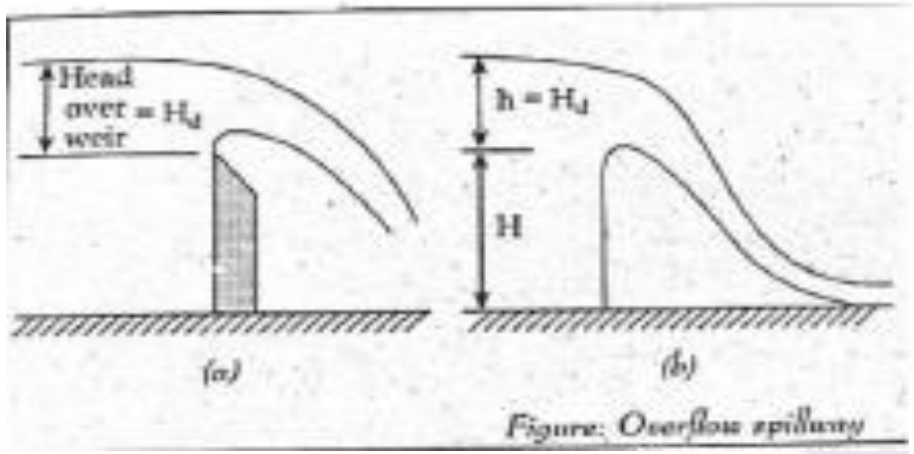


Figure: Overflow spillway

$$Q = CLH^{\frac{3}{2}} \quad (1)$$

where, L is effective crest length.

$H = \left(h + \frac{V^2}{2g}\right)$ is total head at crest including velocity approach.

C is a variable coefficient of discharge, whose value varies from 2.1 to 2.5 depending on the various factors.

c) Chute Spillways/ trough spillways:

d) Side Channel spillways:(***C=2-2.1)***

E) Shaft Spillways/ Drop Inlet /Morning Glory Spillway

F) Siphon spillways

$$Q = CLH^{3/2}$$

C = 2.2

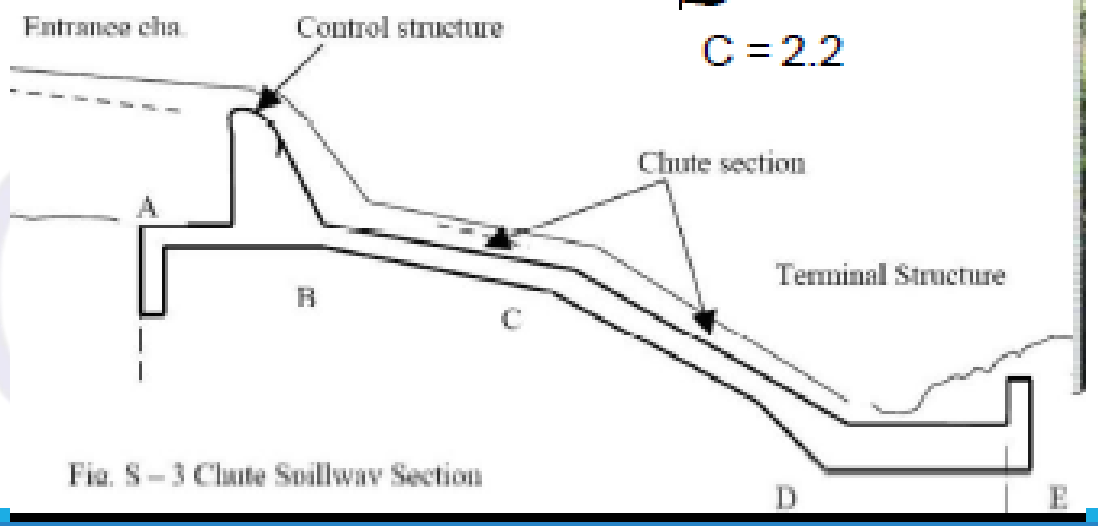


Fig. 8 – 3 Chute Spillway Section

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Design of Spillway

The mostly used spillway in concrete gravity dams, arch dams are Ogee or Overflow spillway.

It is also called as nappe shaped spillway as the downstream face of the spill way is provided to follow the lower face of free flow nappe.

The design discharge Q of the spillway is given by

$$Q = C\, L_e\, H_0^{3/2} \quad \text{or } q = CH_0^{3/2}$$

Where, C = coefficient of discharge approximately equals to 2.2[range of 2.1-2.5]

H0 measured head over the crest including velocity head = $H_0=h_0+V^2/2g$,

L_e = effective length of the crest weir

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipater

Energy Dissipater:

When flood discharge passes over the spillway crest, it has high potential energy which gets converted into kinetic energy as it slides down. It causes erosion at the downstream toe of the dam. So, Energy dissipaters are placed at such places.

A spillway provided in the dam site always consists of an energy dissipating structure at the toe of the dam. It kills the excess energy of surplus water and thus prevents damages to the dam and any other appurtenant structures in the downstream by creating hydraulic jump.

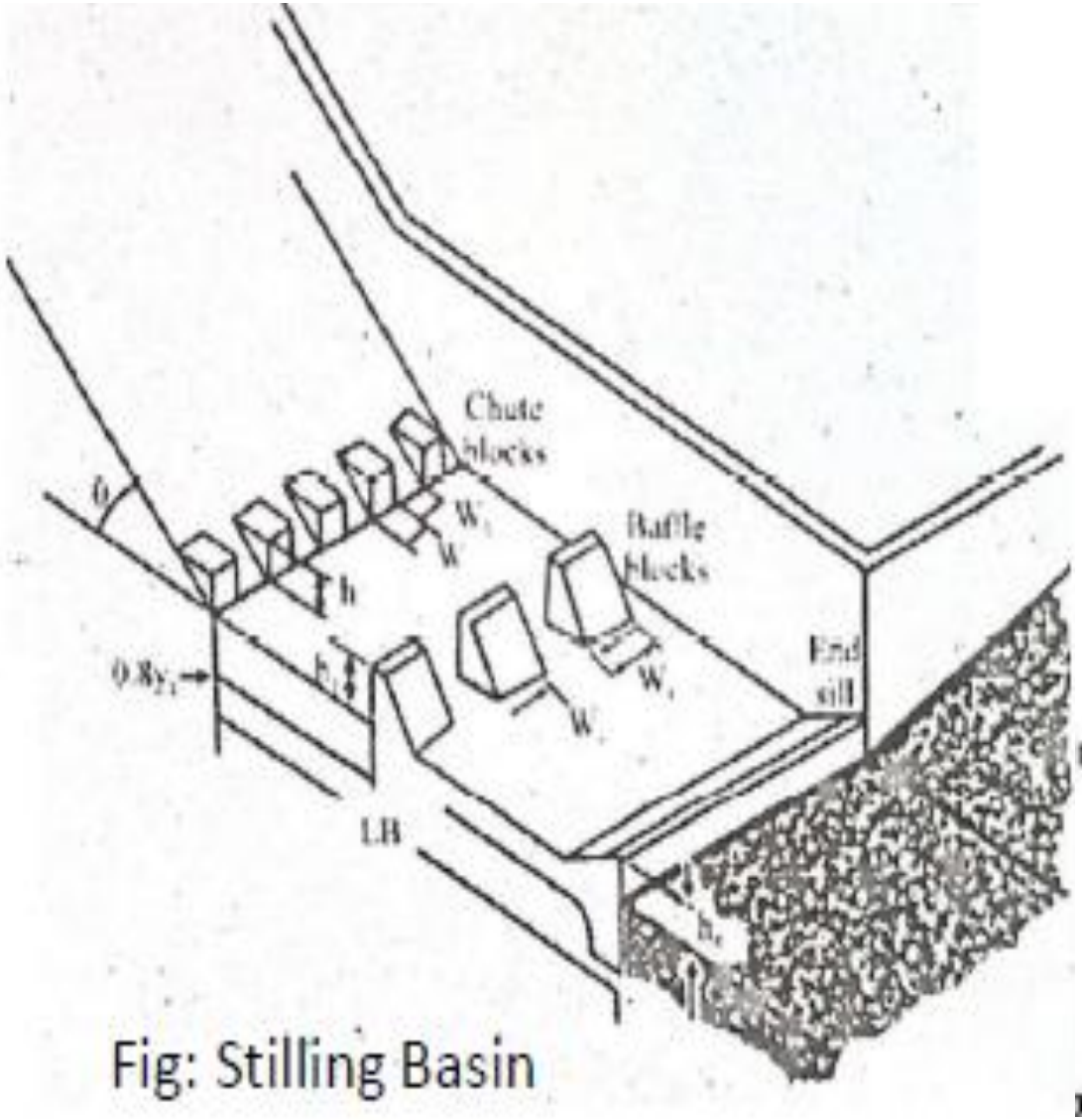


Fig: Stilling Basin

Design Concepts of Stilling Basin and Apron

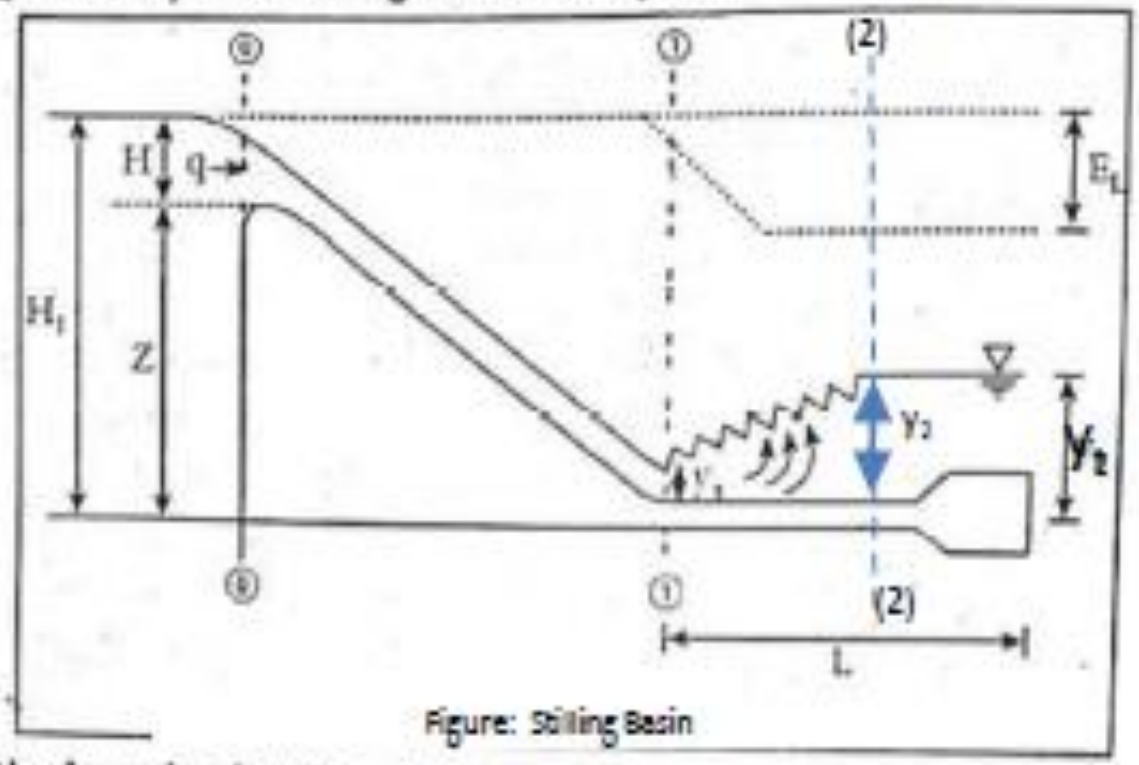


Figure: Stilling Basin

re, L is the length of stilling basin apron.

q is the discharge per unit width.

H_1 is the total energy upstream jump.

y_1 is pre-jump depth (super critical flow *i.e.*, $F_r > 1$)

y_2 is the post-jump depth (sub critical flow *i.e.*, $F_r < 1$)

$$y_2 = \frac{y_1}{2}\left[\sqrt{1 + 8F_1^2} - 1\right]$$

$$F_1 = V_1/\sqrt{gy_1}$$

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

Tail water depth and characteristics of hydraulic jumps govern the choice of energy dissipating structures.

Energy dissipation of water passing over the crest of spillway may be achieved by one of the following methods:

a) **Hydraulic Jump Type Stilling Basin**
b) **Roller Bucket**
c) **Deflector Bucket / Flip Bucket / Ski Jump Bucket / Trajectory Bucket**

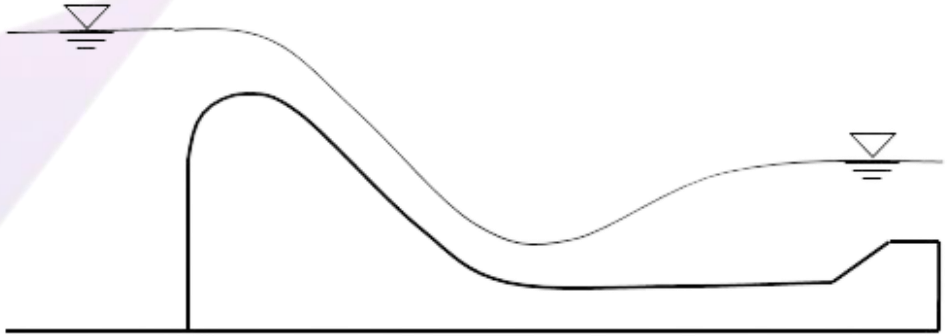
PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

1. Hydraulic Jump Type Stilling Basin

A stilling basin is a structure provided at the toe of spillway in order to dissipate the energy of excess water coming from spillway by formation of hydraulic jump within the confines of the basin. The flow passing at critical depth over the crest of spillway becomes super critical at dam toe which when meets the normal flow at subcritical depth in the downstream side. The stilling basin consists of,

i. Chute blocks
ii. Baffle blocks
iii. End Sills



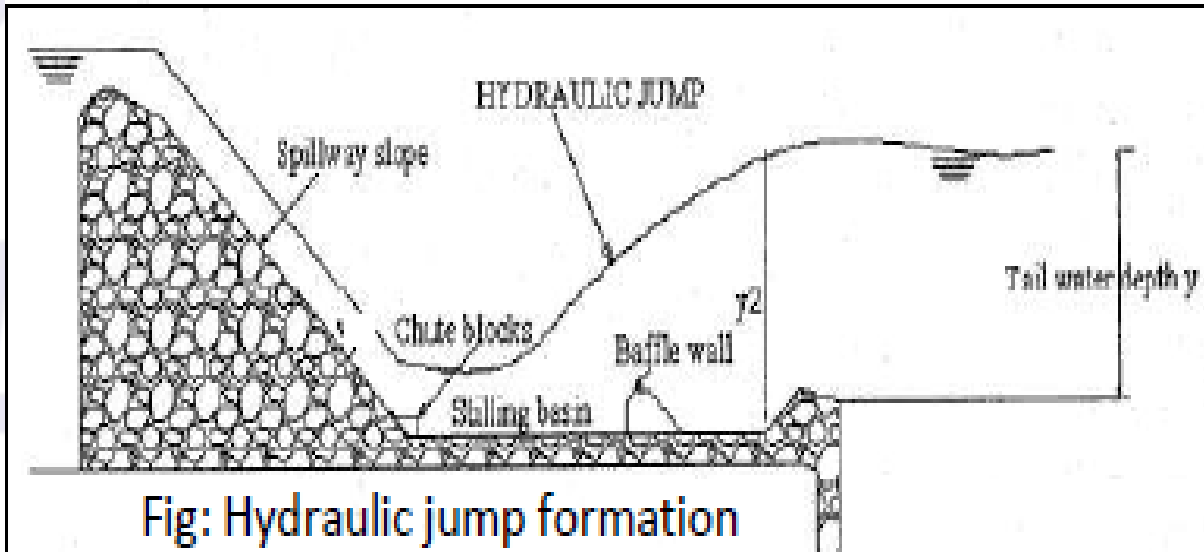


Fig: Hydraulic jump formation

PANA ACADEMY

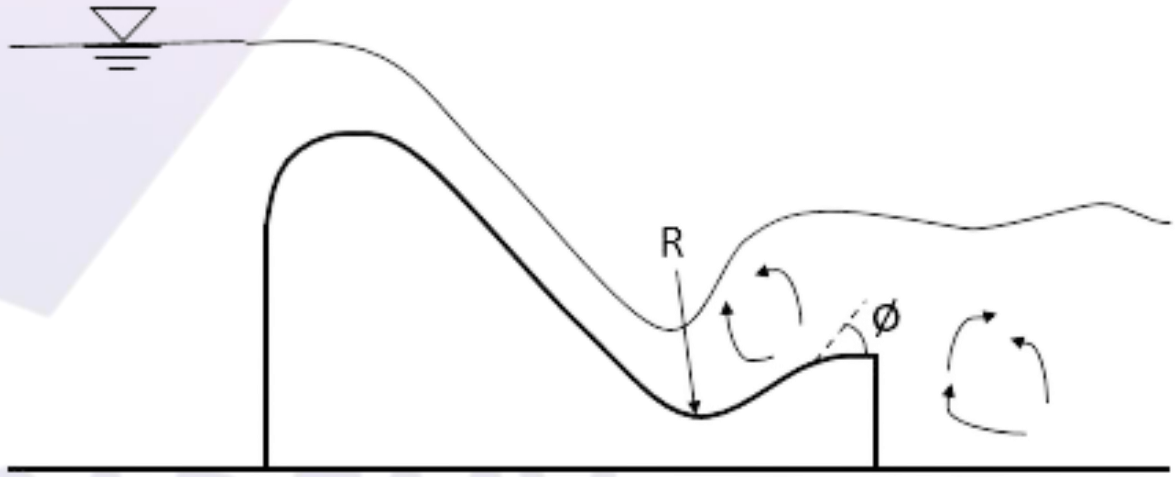
8.3.5 Design of intake, Spillway and Energy Dissipator

2. Roller Bucket

Roller bucket is used to dissipate the energy in situation when the tail water depth is much more than the post jump depth.

Roller bucket is spoon type structure at the toe of the spill way

When high velocity sheet of water slides down the spillway, it gets arrested by the tail water.

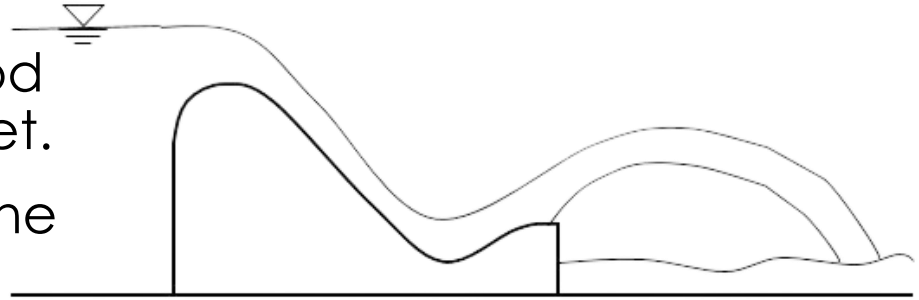


PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

3. Deflector Bucket / Flip Bucket / Ski Jump Bucket / Trajectory Bucket

Used when the tail water depth is insufficient for the formation of hydraulic jump. i.e. tail water depth is much less than post jump depth.



Suitable for the situation where foundation rock is of good quality and can withstand the erosive action of striking jet.

The trajectory bucket deflects the high velocity jet into the air and is made to strike the river bed at a considerable distance from the structure.

The energy dissipation is achieved due to combined action of air resistance, viscous effect and turbulence due to impact on the river bed.

PANA ACADEMY

8.3.5 Design of intake, Spillway and Energy Dissipator

USBR Recommendation

USBR has standardized stilling basin for the different ranges of Froude numbers. The important of these basins are:

i) USBR type basin I (Fr < 1.7 and incoming velocity (V_1) < 15 m/sec.)

ii) USBR type basin II (Fr ≥ 4.5 and incoming velocity (V_1) ≥ 15 m/sec.); $L_{sb}=4.3y_2$

iii) USBR type basin III (Fr ≥ 4.5 and V_1 < 15 m/sec.); $L_{sb}=2.7y_2$

iv) USBR type basin IV (2.5 < Fr <4.5 and V_1 < 15 m/sec); $L_{sb}=6.1y_2$

PANA ACADEMY

8.3.6 Gates (types and location)

The barrier installed over the permanent crest of the spillway, for storing additional water during dry weather season.

The small flows in excess above the spillway gates is allowed to pass over the gates, but in case of large flood, the spillway gates are opened and the full capacity is used to remove excessive flood water.

Spillway gates can be provided on all types of spillways except siphon spillway.

PANA ACADEMY

8.3.6 Gates (types and location)

Based on the gate operations, the gates can be of two types i.e.

a) Manual type and

b) Machine operated gates.

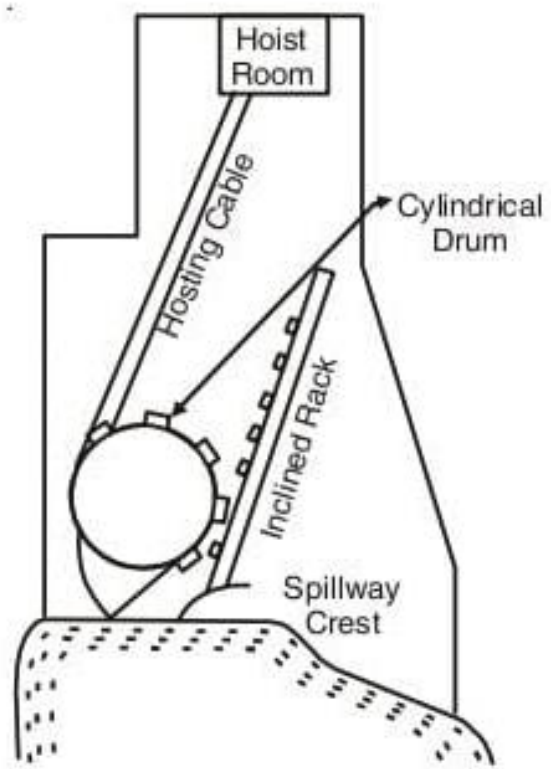
The machine operated gates are of heavy and of large size.

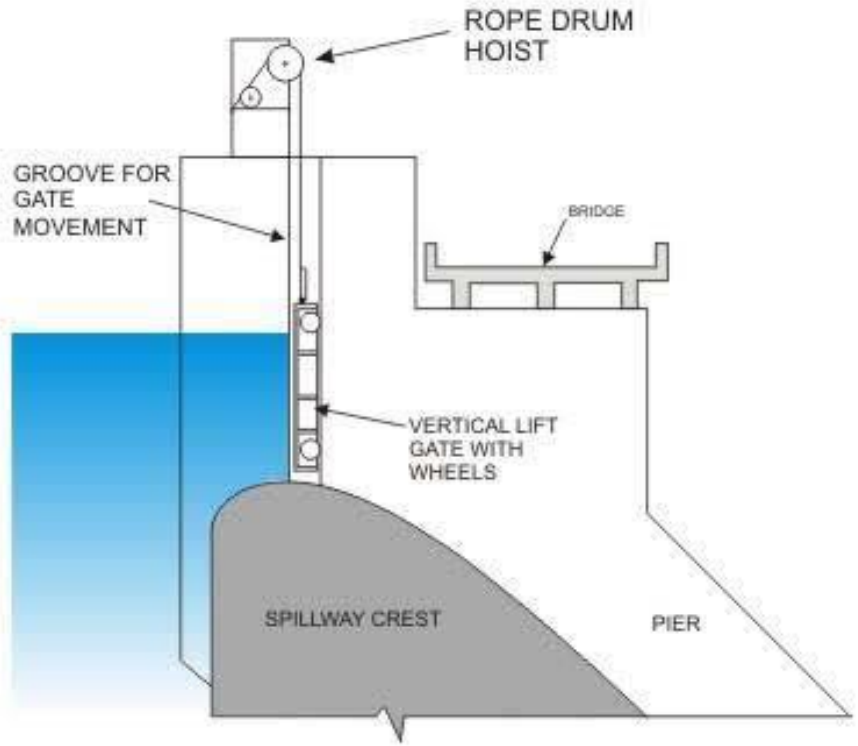
PANA ACADEMY

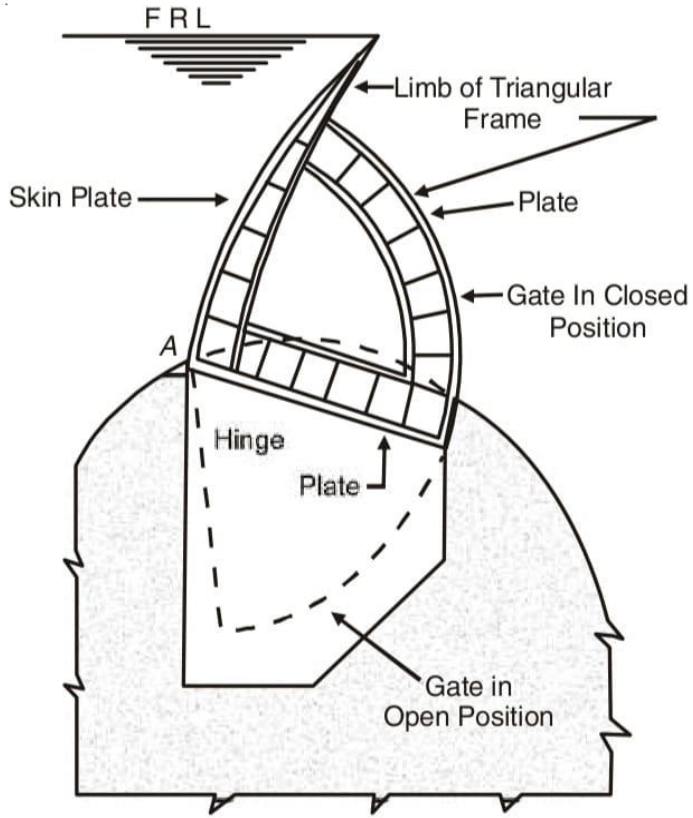
8.3.6 Gates (types and location)

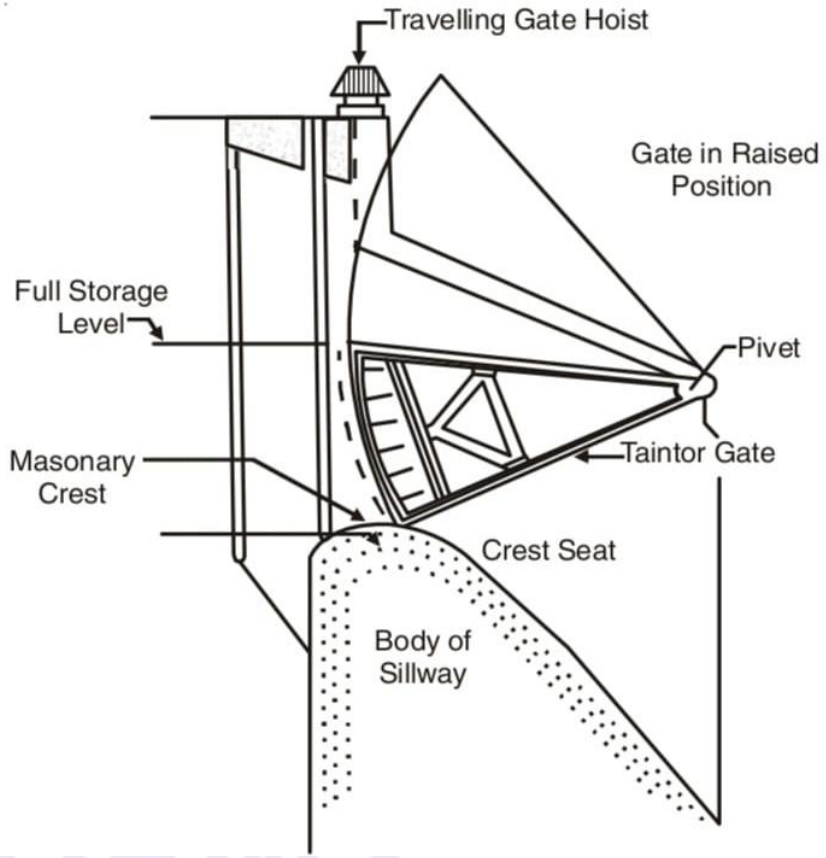
Following types of spillway gates are commonly used:

a) Flash board gates
b) Stop logs or needle gates
c) Radial gates
d) Vertical lifts gates i.e. ordinary gate
e) Rolling gate like a shutter
f) Drum gate
g) Bear and trap gate


Hoist Room
Hoisting Cable
Cylindrical Drum
Inclined Rack
Spillway Crest


ROPE DRUM HOIST
GROOVE FOR GATE MOVEMENT
BRIDGE
VERTICAL LIFT GATE WITH WHEELS
SPILLWAY CREST
PIER


F R L
Limb of Triangular Frame
Skin Plate
Plate
Gate In Closed Position
A
Hinge
Plate
Gate in Open Position


Travelling Gate Hoist
Gate in Raised Position
Full Storage Level
Pivet
Masonary Crest
Taintor Gate
Crest Seat
Body of Sillway

PANA ACADEMY

Let's move to, Multiple Choice Questions

8.3 Multiple Choice Questions

PANA ACADEMY

1. What is the primary function of an embankment dam?

A) To generate hydroelectric power

B) To store large volumes of water

C) To prevent flooding

D) To regulate water flow for irrigation purposes

2. What is the most suitable type of dam for narrow valleys with steep slopes?

A) Concrete dam

B) Rock fill dam

C) Arch dam

D) Earth fill dam

8.3 Multiple Choice Questions

PANA ACADEMY

3. Which of the following factors is NOT considered when selecting a dam site?

A) Large storage capacity

B) Good hydrological conditions

C) Proximity to urban centers

D) Low silt inflow

4. In case of non availability of space due to topography, the most suitable spillway is,

A) Straight drop spillway

B) Shaft spillway

C) Chute spillway

D) Ogee Spillway

8.3 Multiple Choice Questions

PANA ACADEMY

5. The function of a cut off in an earth dam is to

(a) Support the dam

(b) prevent undermining of foundation

(c) Reduce uplift pressure of dam

(d) increase loss of stored water

6. An arch dam is constructed with

(a) Earth

(b) concrete

(c) Boulders

(d) None of above

8.3 Multiple Choice Questions

PANA ACADEMY

7. The self weight of gravity dam

(a) Favors stability

(b) causes uplift

(c) causes overturning

(d) causes sliding

8. A site where there is a requirement of large capacity spillway, what type of dam is suitable

(a) Arch dam

(b) Earthen dam

(c) Rock fill dam

(d) Over flow dam

8.3 Multiple Choice Questions

9. What is the highest elevation of water level that can be maintained in the reservoir without any spillway discharge either with gated or non-gated spillway?

a) Normal Water level

b) Minimum Water level

c) Weighted average level

d) Operating head

10. Trash racks are built for…..

a) discharging the water freely from the turbine exit to tailrace

b) preventing the turbine from the floating and other materials

c) creating artificial head to store sufficient potential energy of water

d) controlling the opening of valves

8.3 Multiple Choice Questions

11. Dam having very wide base as compared to its height is called.

a) buttress dam

b) arch dam

c) earth dam

d) solid gravity dam

12. Spillway discharges the overflow water to the downstream side when the reservoir is full.

a) True

b) False

8.3 Multiple Choice Questions

PANA ACADEMY

13. In a hydro-electric plant, spillways are used

a) To dissipate energy of surplus water

b) To discharge surplus water on the downstream side of dam

c) Water is not available in sufficient quantity

d) None of the above

14. Gross head is the difference between

a) head race and tail race

b) head race and net head

c) head race and friction losses

d) net head and friction losses

8.3 Multiple Choice Questions

15. What is the main component of a hydropower system?

a) Dam

b) Turbine

c) Generator

d) All of the above

16. Which of the following is not a potential failure mode for a dam?

a) Overtopping

b) Seismic activity

c) Erosion

d) Volcanic eruption

8.3 Multiple Choice Questions

17. What is the purpose of seepage control in dams?

a) To prevent water from flowing under the dam

b) To prevent water from flowing over the top of the dam

c) To prevent water from eroding the sides of the dam

d) To prevent water from entering the reservoir too quickly

18. Which of the following is a type of foundation treatment used in dam construction?

a) Grouting

b) Piling

c) Blasting

d) All of the above

8.3 Multiple Choice Questions

19. Which of the following is not a type of energy dissipater?

a) Stilling basin

b) Roller bucket

c) Flip bucket

d) Inverted umbrella

20. A ski-jump bucket is also known as _____

a) flip bucket

b) solid roller bucket

c) slotted roller bucket

d) flexible bucket

8.3 Multiple Choice Questions

PANA ACADEMY

21. What is the function of a spillway in a dam?

A) To generate hydroelectric power

B) To regulate water flow for irrigation purposes

C) To provide an emergency release for excess water

D) To prevent water seepage

22. What is the primary cause of dam failure due to overtopping?

A) Inadequate spillway capacity

B) Poor design of the dam foundation

C) Natural disasters such as earthquakes

D) Human error during construction or maintenance

8.3 Multiple Choice Questions

PANA ACADEMY

23. What is an energy dissipater in a dam structure?

A) A device that generates hydroelectric power

B) A structure that reduces the velocity of water flowing downstream of the dam

C) A gate that regulates the flow of water through the dam

D) A mechanism that controls the water level in the reservoir

24. A site where spillway location is available separate from dam, what dam is suitable

(a) Arch dam

(b) gravity dam

(c) Ogee dam

(d) earth dam

8.3 Multiple Choice Questions

25. A Dam with crest level of 1510masl has water elevation of 1505 msl. What is the elevation at which the point of application of horizontal component of hydrostatic pressure acts if the base of the dam is at 1450 msl.

a) 1458.28
b) 1479.55
c) 1468.33
d) None of the above

26. The recommended uplift at the face of the drainage gallery is equal to……. , where H and H' are water head at u/s and d/s respectively

a) γ_w k [H' + (H – H')/3]
b) γ_w k H'
c) γ_w k (H – H')/3
d) γ_w k [H – (H – H')/3]

PANA ACADEMY

THANK YOU