

Wollo University
Kombolcha Institute of Technology(KIOT)
Civil Engineering

Course name-Hydraulic Structure I

Course code-CEng3161

Pre-requisite-

**CEng3154, CEng3133, Soil Mechanics II and
Engineering Hydrology**

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Introduction

- ***What is Hydraulic structures?***

- Hydraulic structures are engineering structures which can be used to control, store, divert, distribute, measure and transport natural flow of water resources.
- “All structures in contact with water”
- Some of this structures includes;
 - ❑ Storage structures (dams)
 - ❑ Flow control structure (Spillway, outlet, gates)
 - ❑ Energy dissipation Structures (Stilling basins)

Chapter One

1. Elements of dam engineering

• What is a Dam?

- Dam is structure/ barrier/obstruction constructed across the river **to store water u/s** (behind the dam) for different purposes.
- Dams are structures **controlling the flow of a river by completely blocking** the valley of a given river or drainage system.
- The artificial lake created/the retained water/ behind the dam is called **reservoir**.
- The side on which water gets collected is called the **upstream side** and the other side of the barrier is called the **downstream side**.
- Dams are generally constructed in the mountainous reach of the river where the valley is narrow and the foundation is good.





New Inlet Channel
and Structure

Lake Jindabyne

Kosciuszko
Road

New Road Bridge
and Auxiliary Spillway

Existing Spillway

Proposed tunnel

Public Viewing Area

Cone Discharge
Valves

Concrete
Spillway
Chute

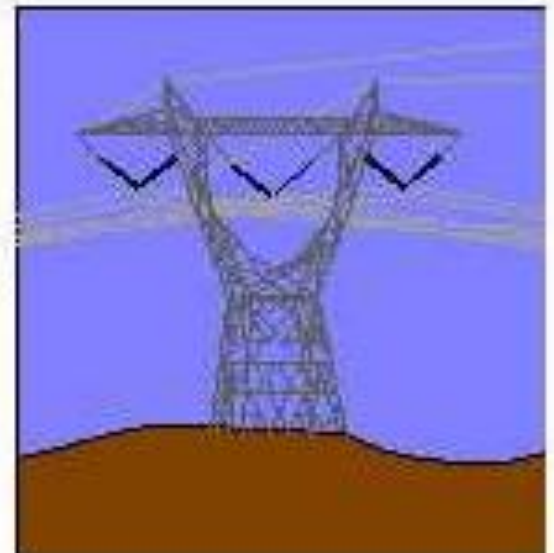
Mini Hydro
Power Station

Plunge Pool
Releases to
Snowy River



Functions of Dams

- ❑ The primary purpose of a dam can be seen as **providing for the safe retention and storage of water.**
- ❑ The specific functions of dams and reservoirs include;
 - ❑ *Storage*
 - ✓ *Water supply*
 - ✓ *Gefersa, Legedadi*
 - ✓ *Irrigation water for agriculture*
 - ✓ *Fincha'a, Beles, Tendaho*
 - ✓ *Hydropower*
 - ✓ *Gilgel Gibe, Tekeze, Abay/Hidase*
 - ✓ *Flood control*
 - ✓ *To retain debris or silts*
 - ❑ *Creating head*
 - ✓ *Hydropower*
 - ❑ *Maintaining water level*
 - ✓ *Navigation-transportation*
 - ✓ *Recreation-swimming, fishing*
 - ❑ *Multipurpose*

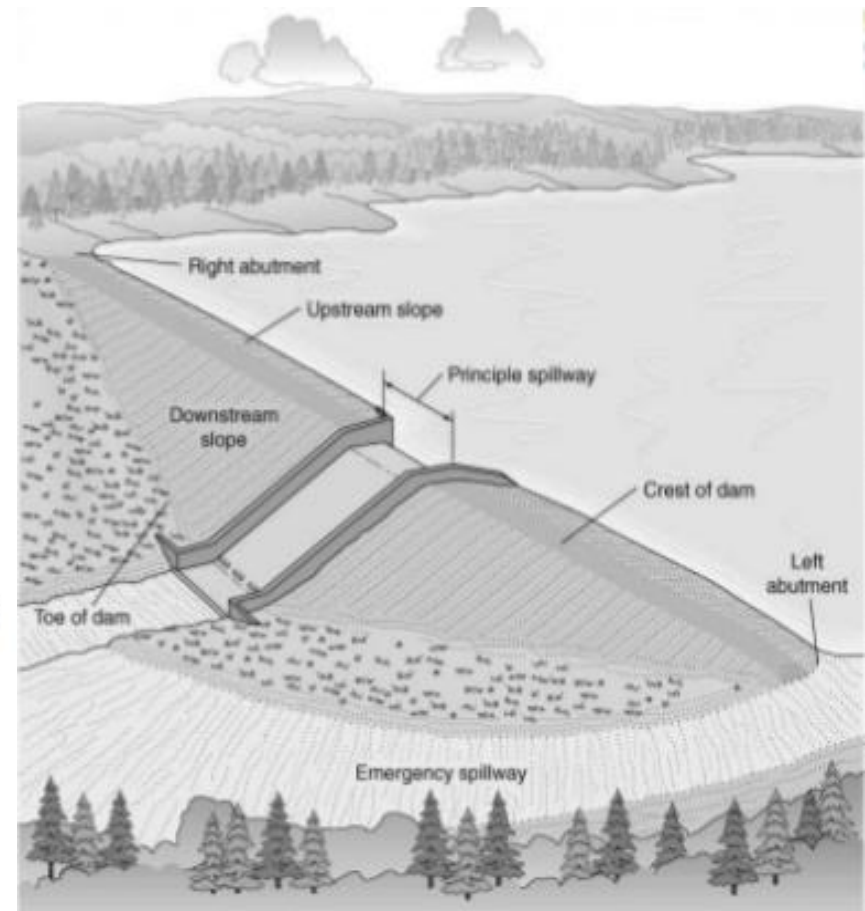
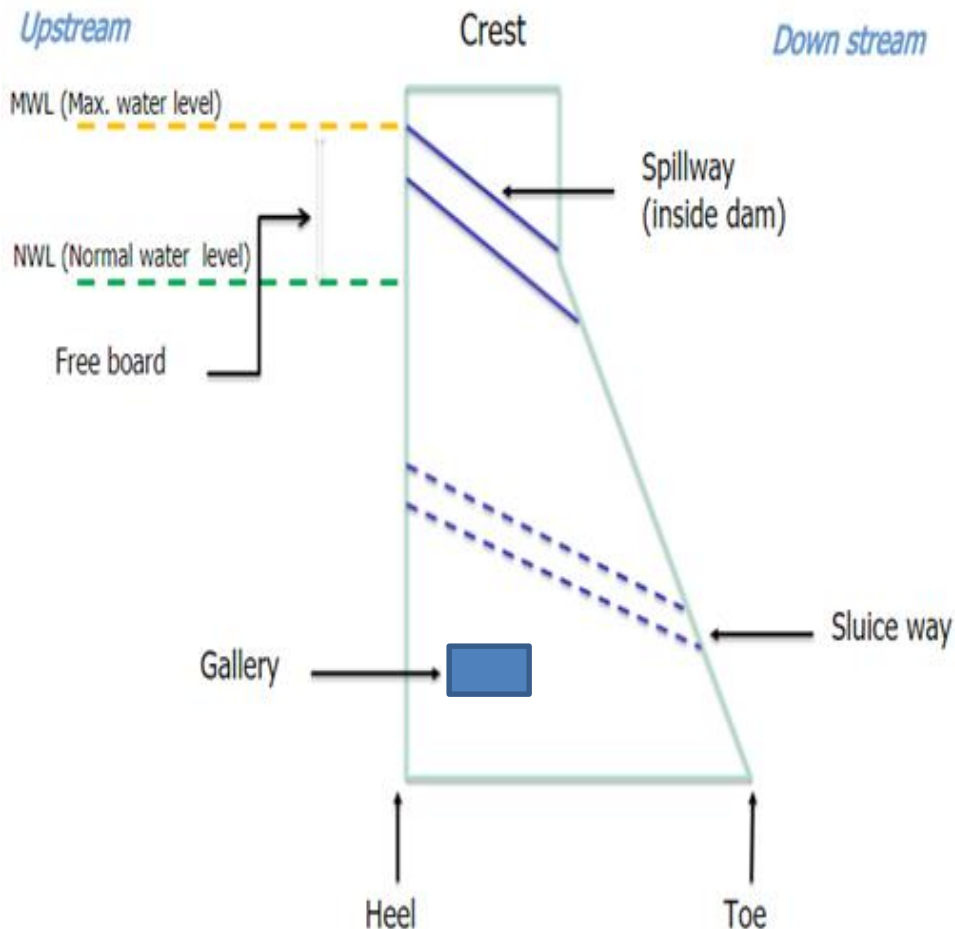


Functions of Dams cont...

- Dam provides the f.f things
 1. **create reservoir**(increases hydraulic head so then increases net pressure on power plant).
 2. **increases water surface/level** so it enables navigation and lake recreation
 3. To match supply and demand since water demand supply varies seasonally.
 4. Dam created to substantially raise water level and thus working head for hydropower production or to direct water into off taking canals.

1.2. Dam structures and Reservoir

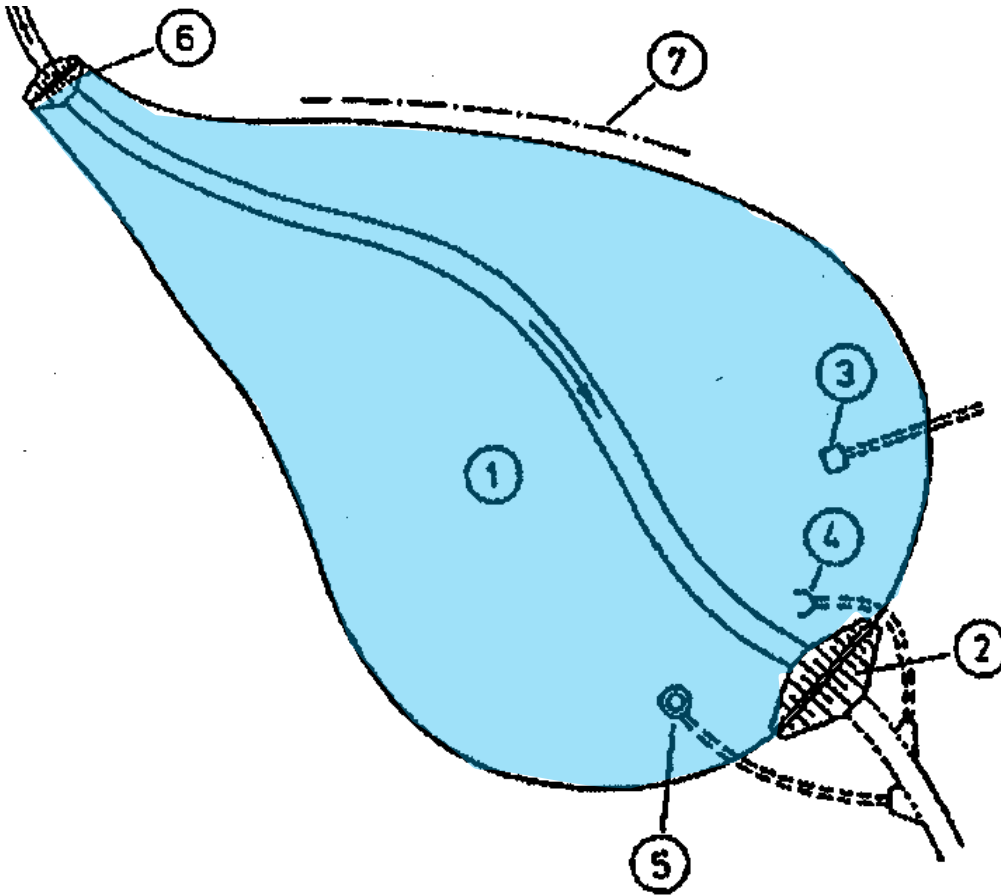
1.2.1 Parts of dam/ structures/



Parts of dam cont...

- **Heel:** contact with the ground on the upstream side
- **Toe:** contact on the downstream side
- **Abutment:** Sides of the valley on which the structure of the dam rest
- **Galleries:** small room like structure left within the dam for checking operations.
- **Diversion tunnel:** Tunnels are constructed for diverting water before the construction of dam. This helps in keeping the river bed dry.
- **Spillways:** It is the arrangement near the top to release the excess water of the reservoir to downstream side (*It is a safety value for a dam.*)
- **Sluice way:** An opening in the dam near the ground level, which is used to clear the silt accumulation in the reservoir and withdrawing water for the intended purpose.

Dam Structure and Reservoirs



❑ The following are the structures related to dam;

1. Reservoir
2. Dam
3. Service Intake
4. Bottom outlet/sluice way
5. Spill structure/spillway
6. Diversion structure
7. Service road

1.2.2. Reservoirs

❑ Functions of reservoir in water engineering are;

i. Balancing water demand and supply

- River flow varies seasonally
- Water demand varies seasonally

ii. For storage

❑ Depending upon the purpose served by a given reservoir, the reservoir may be broadly classified

1) Storage or conservation reservoir:- are those reservoirs which retain/store excess supplies during period of peak flow/rainy season and can release them gradually during low flows or when the need arises.

2) Flood control reservoirs:- store a portion of flood flows in such a way to minimize the flood peaks at the area to be protected downstream.

3) Multipurpose reservoirs:- are those reservoirs which are planned and constructed to serve for more than one purpose.

Reservoir cont...

❑ Reservoir parameters

- The most important reservoir parameters are:-
 1. Reservoir volume(storage)- $S(m^3)$
 2. Reservoir area- $A(m^2)$
- These parameters can be computed with the help of topographic map or surveying.
- The reservoir surface area can be computed using planimetry related to a given contour height.
- Based on the derived elevation-area curve and depth, elevation-volume can be computed using various methods:

Reservoirs cont...

1. Average area or trapezoidal method

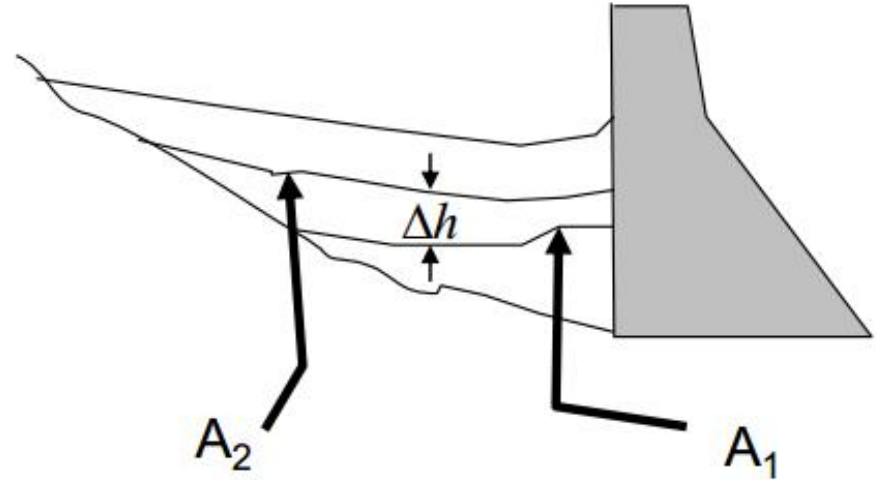
- The storage volume between two successive contours of areas A_i and A_{i+1} is given by;

$$\Delta V_i = \Delta h_i \frac{A_i + A_{i+1}}{2}$$

- Therefore total volume V is given by;

$$V = \Delta V_1 + \Delta V_2 + \Delta V_3 + \dots = \sum \Delta V$$

$$V = \frac{h}{2} [A_1 + 2A_2 + 2A_3 + \dots + 2A_{n-1} + A_n]$$



2. Prismoidal method

- Storage volume between 3 successive contours is given by

$$\Delta V_i = h \left(\frac{A_1 + 4A_2 + A_3}{3} \right)$$

- The total volume is given by;

$$V = \frac{h}{3} [(A_1 + A_n) + 4(A_2 + A_4 + A_6 + \dots) + (A_3 + A_5 + \dots)]$$

- Where A_3 and A_5 , etc are the areas with odd numbers; A_2 , A_4 and A_6 , etc are the areas with even numbers and A_1 and A_n are the first and the last areas respectively

Reservoirs cont...

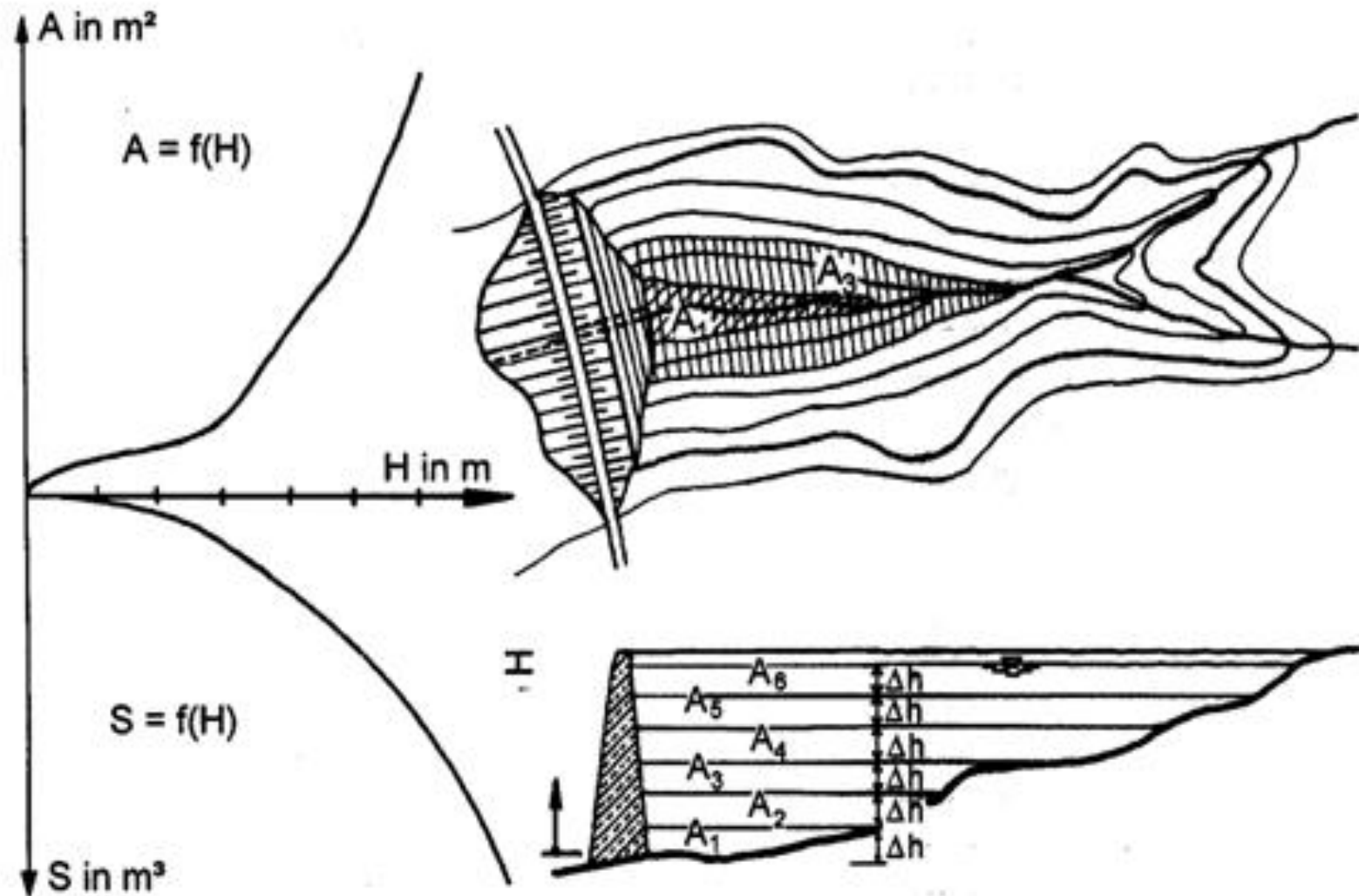
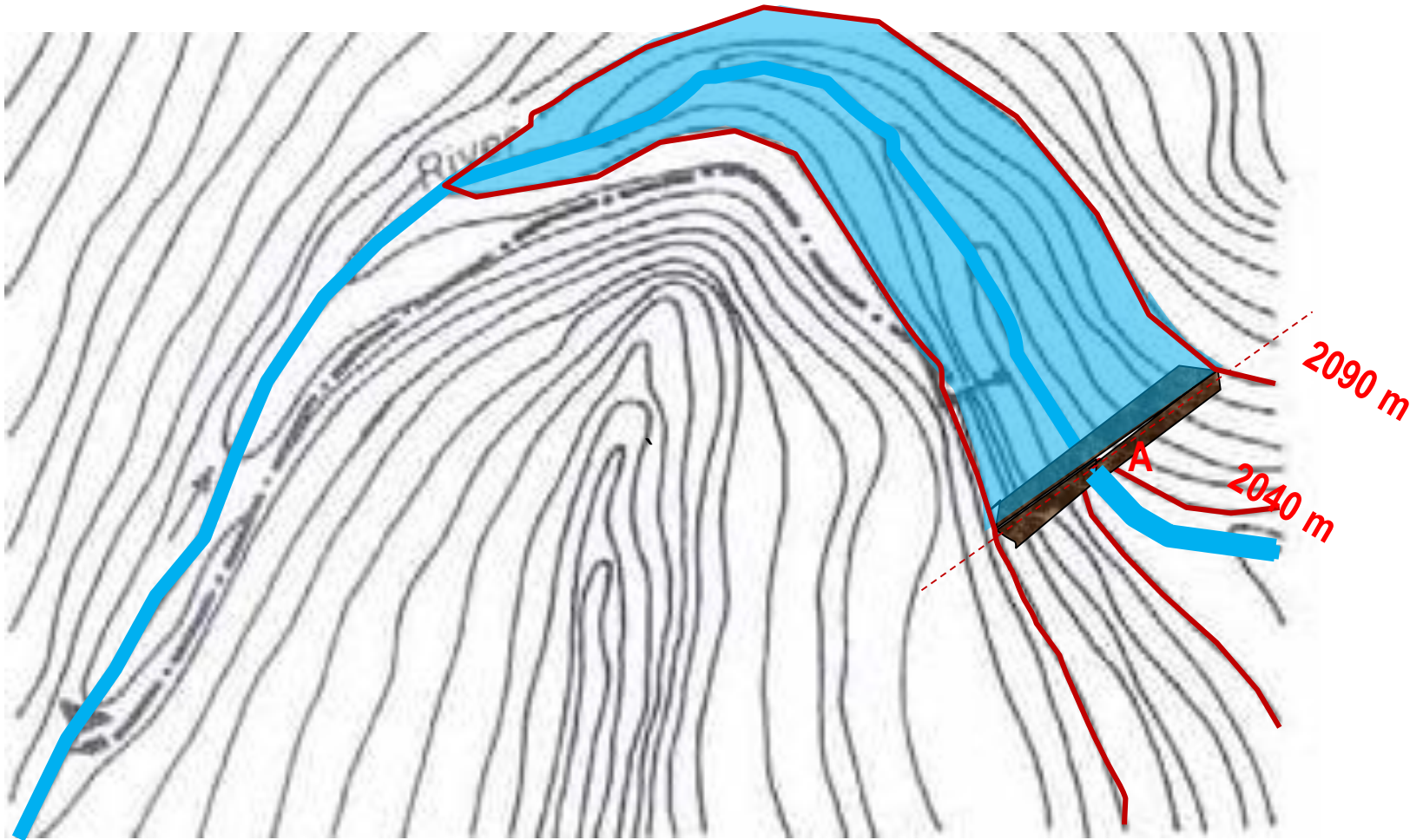


Figure 1.3: Reservoir Capacity Curve

Dam at Site A
Dam of 50m high
Topo 10 m interval



Example

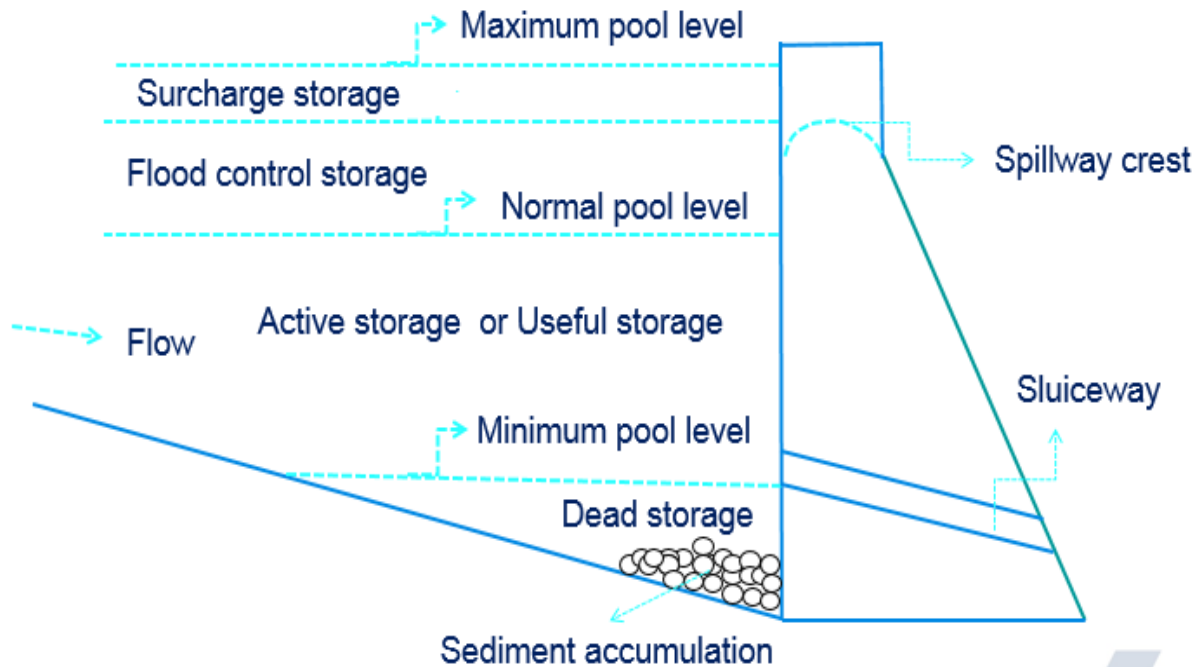
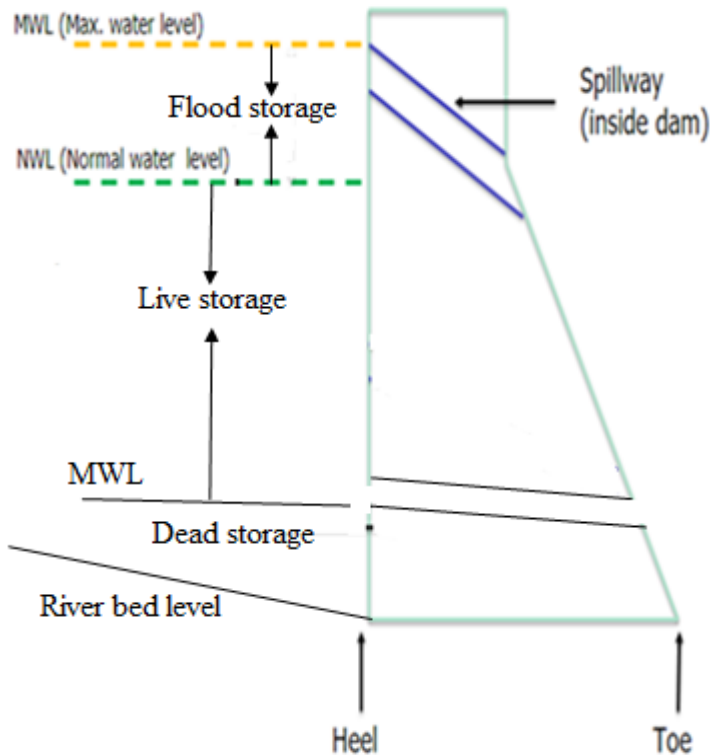
- Calculate the capacity of reservoir between the elevation 200m and 300m, using Trapezoidal and Prismoidal method.

Elevation(m)	200	220	240	260	280	300
Area (km ²)	150	175	210	270	320	400

Reservoirs components

- ❑ The reservoir has to provide sufficient storage for various purposes, namely
 1. Dead storage to contain silt deposition, 10-25% of gross storage
 2. Storage to account for evaporation loss
 3. Live storage to meet the downstream demands for irrigation domestic or industrial supply, power generation, etc.
 4. Storage to act as flood protection.
- ❑ The basis of fixing storage capacity for dead storage and evaporation loss depends upon the **amount of incoming sediment and the annual evaporation loss** respectively.
- ❑ Requirement for flood protection depends on the **intensity and volume of flood flow**.
- ❑ The live storage capacity of a reservoir depends on the **demand for various purposes**.
- ❑ The capacity of the reservoir is fixed in such a way as to take care of the **demands during the minimum flow period in the driest year** on record.

Storage components



- **Maximum water Level:** The level to which the water will **rise during the design flood**
- **Normal water Level:** The level to which water will rise during ordinary conditions of operation of reservoir.
- **Minimum water Level:** The level to which water from the reservoir in ordinary conditions may be drawn.

Advantages of Dam

Dams gather drinking water for people.



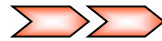
Water Supply

Dams help farmers bring water to their farms.



Irrigation

Dams help create power and electricity from water.



Hydroelectric

Dams keep areas from flooding.



Flood Control

Dams create lakes for people to swim in and sail on.



Recreation



Navigation

Impacts/disadvantage of Dams

❑ The presence of a dam interferes with natural systems. The main disadvantages includes

- ❑ Resettlement and relocation
 - ✓ over 1,000,000 dams so far built
 - ✓ 40 to 80 million displaced
- ❑ Destruction of fauna and flora/submergence prob
- ❑ Change in groundwater level
 - ✓ groundwater level rise sometimes up to 90m
 - ✓ damage to infrastructure
 - ✓ damage to farmland (water logging)
- ❑ Influence on fish/block migration of fish/
- ❑ Decrease downstream water
- ❑ Spread of water born disease/home to disease-be
- ❑ Failure problem

❑ Three Gorges Dam in Yangetz river in China

❑ 181 m high, 2.335 Km long Gravity dam

❑ Reservoir, surface area 1024 Km²

❑ Reservoir length 600 Km

❑ Uses

- ✓ Produces 22,000 MW,
- ✓ flood protection
- ✓ Naviagtion

❑ Impacts

- ✓ 1.24 million people displaced
- ✓ Over 6000 species of plants

1.3 Classification of dams

❑ Dams are classified according to several conditions as indicated below;

1. based on their use/purpose

- i. Storage dams
- ii. Detention dams
- iii. Diversion dams
- iv. Debris dams
- v. Cofferdams
- vi. Multi purpose dams

2. based on hydraulic design

- i. Overflow dam
- ii. Non overflow dam

3. based on rigidity

- i. Rigid dams
- ii. Non rigid dams

4. based on material of construction

- i. Concrete dam
- ii. Embankment dam

5. Based on structure and design

- i. Gravity dam
- ii. Arch dam
- iii. Buttress dam
- iv. Embankment dam

Dam classification cont...

1. Classification based on their use/purpose

a. Storage dams

- They are dam constructed to store water during the periods of excess water to be used later during periods of deficient supply.



Dam classification cont...

b. Diversion dam

- These are small dams constructed for the purpose of diverting water of the river in to off-taking canal by raising the water level in the river.
- e.g Weir, Barrage



Dam classification cont...

c. Detention dam/ used for flood control/

- Constructed to temporary store flood waters and gradually release it at such a safe/controlled rate that it may not flood downstream side.
- Retards river flow by storing some amount of flood water.

d. Debris dam

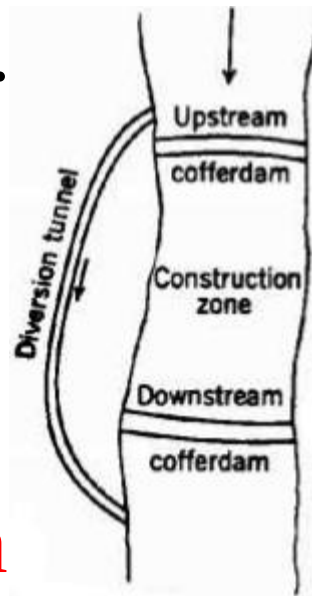
- Constructed to retain debris such as sand, gravel and drift wood flowing in the river with water



Dam classification cont...

e. Cofferd dams

- It is a temporary dam constructed upstream of the main dam to divert flow to diversion tunnel along main river for facilitating construction by keeping main dam site dry.



f. Multipurpose dam

- A dam constructed to serve for more than one purpose.

Dam classification cont...

2. Classification based on hydraulic design

a. Overflow dam

- designed to pass surplus water over their crests.
- They are often called Spillways.
- They should be made of materials which will not be eroded by such discharges

b. Non-overflow dam

- ✓ they are not designed to be overtopped.



a. Overflow dam



b. Non-overflow dam

Dam classification cont...

3. Classification based on rigidity

a. Rigid dam

- It is a dam constructed of stiff/rigid/hard/non-yielding materials such as concrete, masonry, steel and timber.

b. Non-rigid dam

- These are dams constructed of non rigid materials such as earth and rock fill...etc.
- E.g. earthfill and rockfill dam

4. Classification based on material of construction

a. Concrete dams

- ✓ are constructed of **mass concrete**.
- ✓ E.g Gravity dam, Arch dam and Buttress dams.

b. Embankment dams

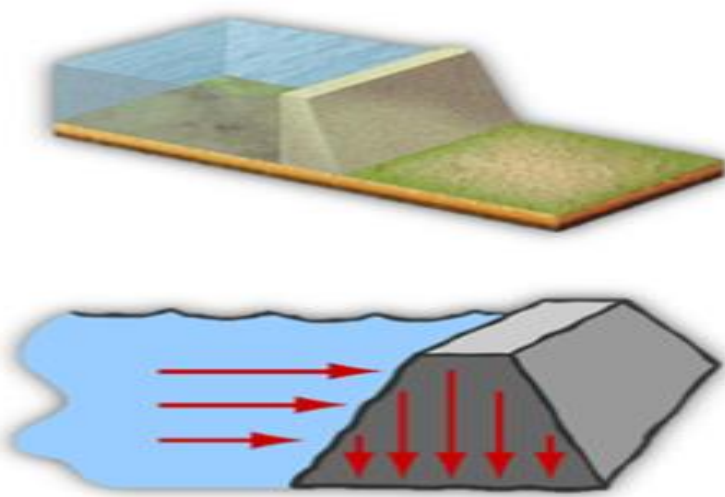
- ✓ are constructed of earth **fill and/or rock fill**.

Dam classification cont...

5. Classification based on structural action

a. Gravity dam

- Is a rigid dam constructed of mass concrete or stone masonry, or both, which relies on its weight for stability.
- *As the entire load is transmitted on the small area of foundation, such dams are constructed where rocks are competent and stable.*
- *Its profile is essentially triangular, to ensure stability and to avoid overstressing of the dam and its foundation.*

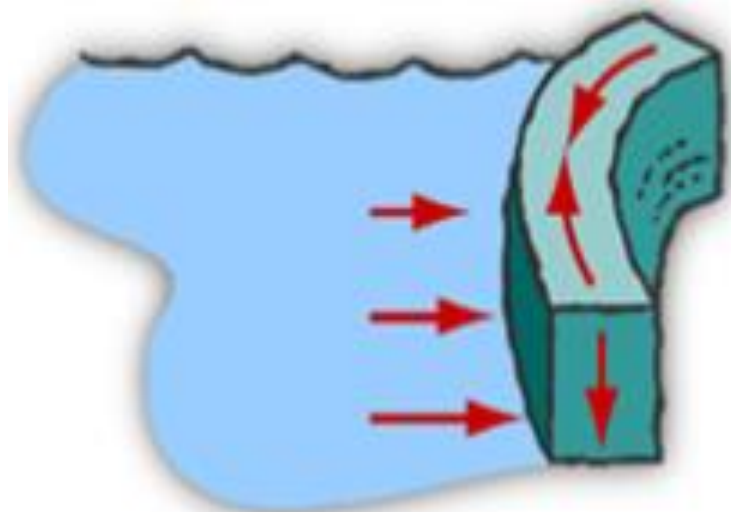
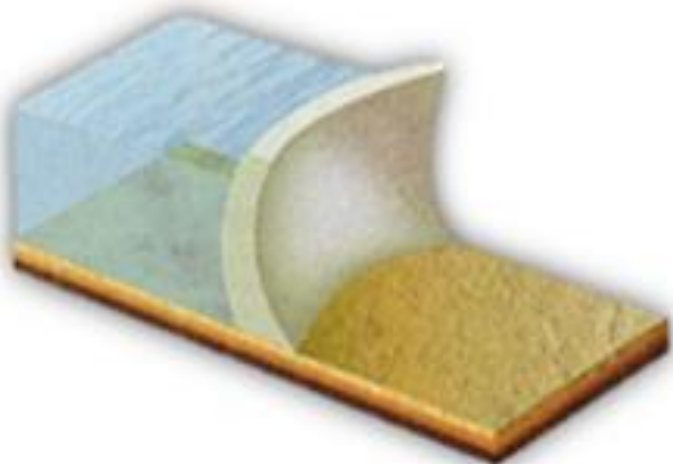




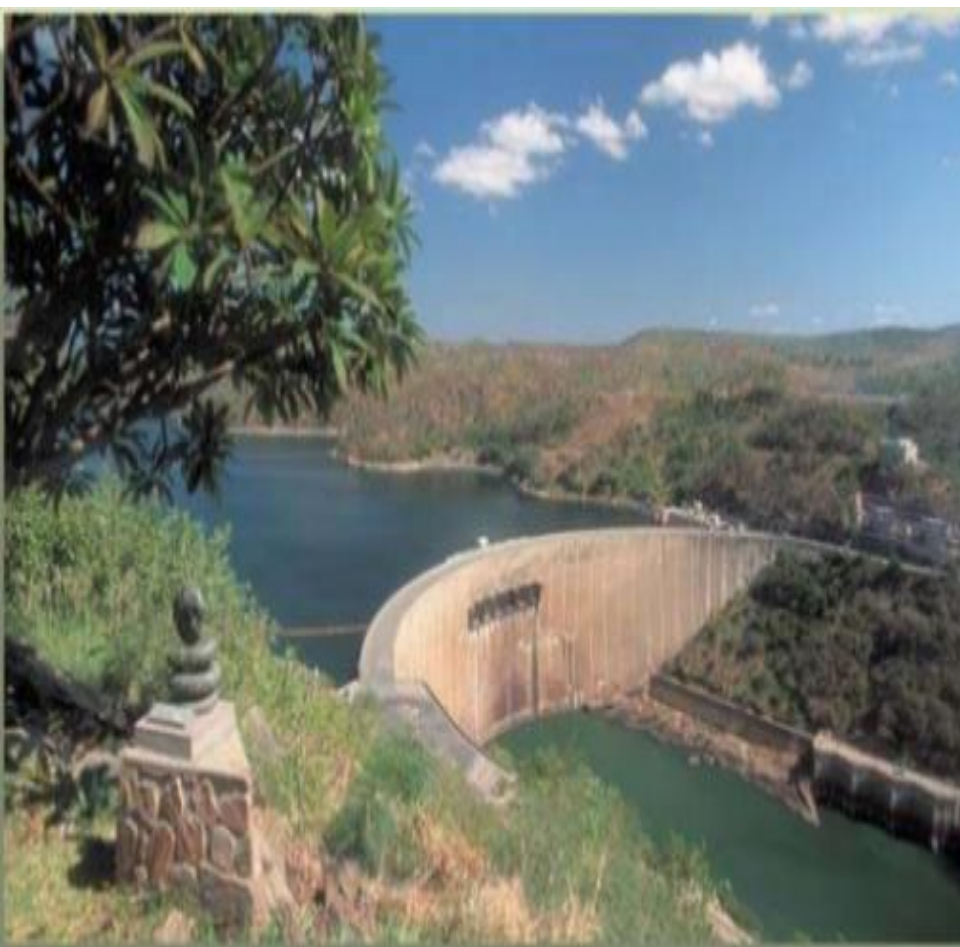
Dam classification cont...

b. Arch dam

- a dam having **upstream curvature/convex/** which transmits the load of water and other forces to the **abutments** rather than to the bottom foundation **by arch action**.
- The type is suitable in **narrow, V-shaped valleys and very steep slopes** **having** the length of the crest is not more than 5 times the height of the dam.
- It is structurally more efficient than the gravity or buttress dam, because it is **thinner** and greatly **reduce the volume of concrete** required (50-85% than gravity dam).



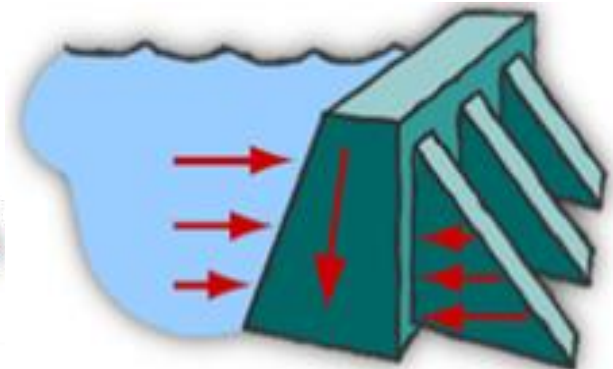
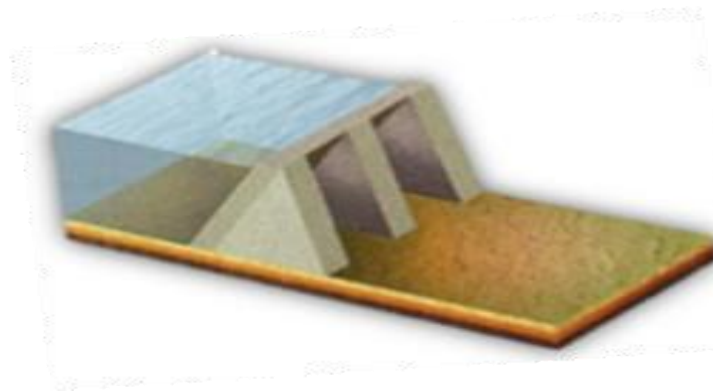
Dam classification cont...



Dam classification cont...

c. Buttress dam

- A dam consisting of a watertight slopping membrane at upstream which is supported by series of buttresses which is spaced at equal intervals on the downstream side.
- It's stability comes from **weight of dam** and **weight of water on u/s face**.
- Sloping membrane is made of R.C.C deck slab.
- Buttresses are triangular concrete walls which transmit the water pressure from the deck slab to the foundation.
- ✓ **Concrete saving** relative to the corresponding gravity dam is 30 – 60%, but it needs more formwork and reinforcement.
- ✓ This type of structure can be considered even if the foundation rocks are little weaker.



Dam classification cont...



Inclined U/S face



Buttresses
/triangular wall/

Dam classification cont...

d. Embankment dams

- ✓ Are non-rigid dams constructed of naturally excavated materials (clay, sand and gravel) placed without addition of binding material other than those inherent in the natural material.
- ✓ These dams depends on shear strength of soil for stability.
- ✓ These dams are trapezoidal in shape and are constructed where the foundation weak to support concrete dams.
- ✓ These dams are classified in to two;

i. Earth fill embankment dams

- ✓ constructed primarily of **compacted earth** or **soil**, and containing more than 50% of earth material.
- ✓ **Soils:** Clay, Silt, Sand, and Gravel

ii. Rock fill embankment dams

- ✓ constructed primarily of **rock**, as a major structural element and containing more than 50% of rock.
- ✓ **Rocks:** Cobbles (> 70mm), boulders, crashed rocks

Earthfill dam



Rockfill dam



1.4 Factors governing the selection of particular type of dam

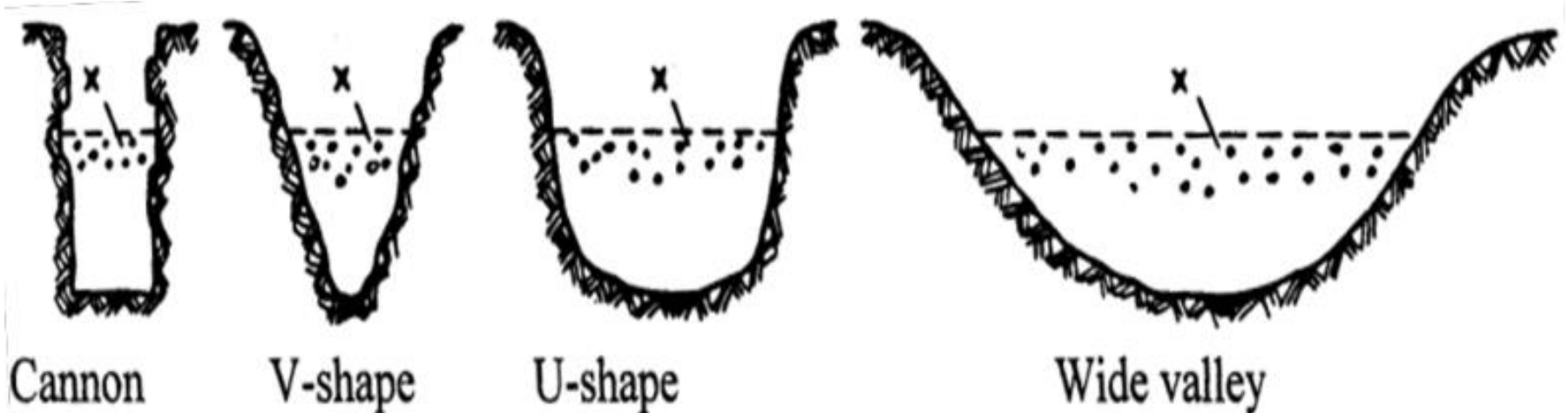
- Whenever we decide to construct a dam at a particular place, the first problem which faces us, is to choose the kind of the dam. *‘Which type of dam is most suitable and most economical?’*
- Two, three kinds of dams may be technically feasible but only one of them will be the most economical.
- **Factors which affect the choice of particular type of dam are described below;**
 - i. Topography
 - ii. Geology and foundation conditions
 - iii. Availability of construction materials
 - iv. Spillway Size and Location
 - v. Earthquake Zone
 - vi. Economy
 - vii. Diversion problems

Cont...

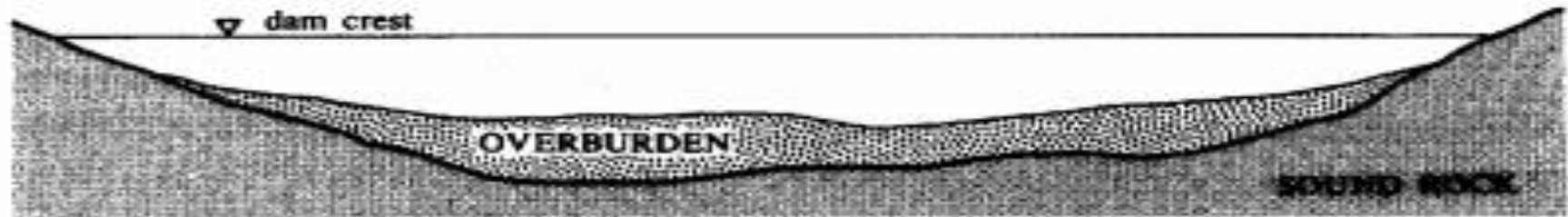
a. Topography (valley shape and depth of overburden)

❖ Valley shape

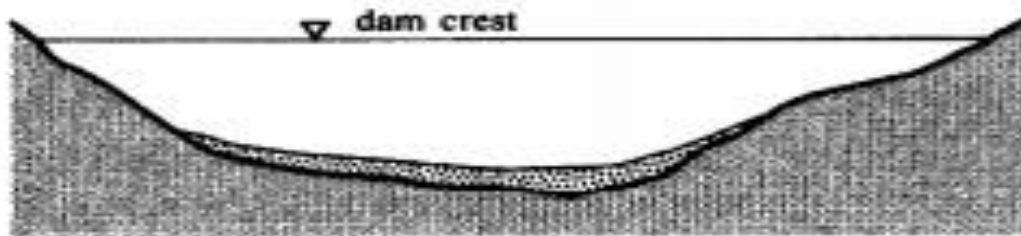
1. A narrow V-shaped valley with sound rock in bed and abutments is suitable for an arch dam.
2. A narrow or moderate U-shaped valley with sound rock foundation is suitable for gravity or buttress dam.
3. A wide valley with foundation of soil material favors earthfill dam.



❖ Depth of overburden



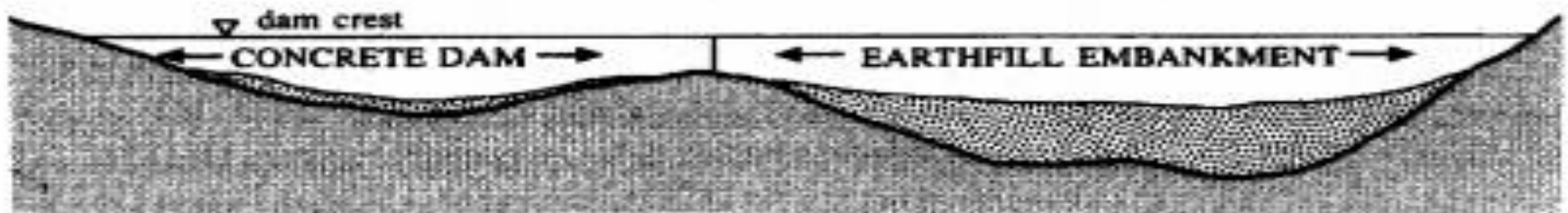
(a) **Wide valley with deep overburden:**
morainic or alluvial deposits over 5 m deep favour earthfill embankment dam



(b) **Valley with little overburden:**
suitable for embankment,
gravity, or buttress dam



(c) **Narrow valley, steep sides, little overburden:**
suitable for arch, cupola, or
rockfill embankment dam



(d) **Valley with irregular depth of overburden:**
possible composite solution as shown; spillway on concrete dam

Cont...

b. Geology and foundation conditions

- The foundation has to carry weight of the dam.
- The dam site must be surveyed by geologists, so as to detect the thickness of the foundation strata, presence of faults, fissured materials and their permeability, and slope, etc.
- The various kinds of foundation generally encountered are discussed below:
 - **Solid Rock Foundations**-suitable for all types of dams
 - **Gravel course sand Foundation**-unable to bear the weight of high concrete dams and serious seepage problem-suitable for earthen and rock fill dams ($H \leq 15\text{m}$)
 - **Silt and Fine Sand Foundation**- suitable for earth dams or very low gravity dams ($H \leq 8\text{m}$)
 - **Clay Foundation**- suitable for earth dams after treatment

Cont...

c. Availability of construction materials

- Materials required for particular type of dam should have to be available nearby without requiring much of transportation.
- E.g. -Availability of **crashed stone, gravel** and **sand** leads to choice of concrete dam and
- E.g. -Availability of **good soil** leads to choice of earth dam.

Cont...

d. Spillway size and location

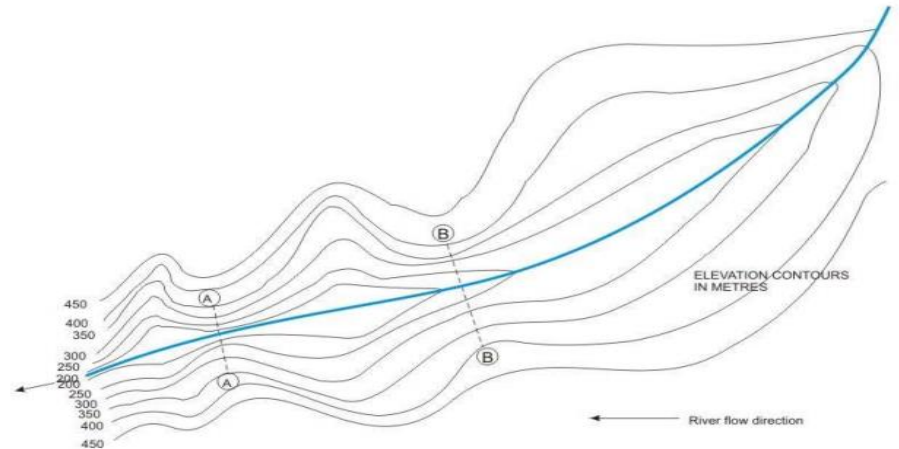
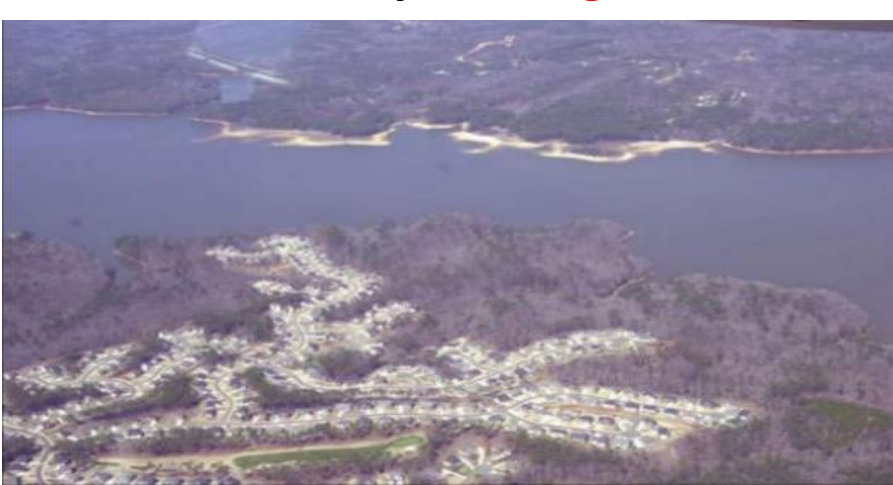
- ✓ If large spillway required and there is **no separate location** to keep the spillway away from dam, concrete gravity dam is adopted.
- ✓ A small spillway requirement favors the selection of earth fill or rock fill dam even in narrow dam sites.
- ✓ If there is no suitable separate site for the spillway, a gravity dam with overflow spillway is required.
- ✓ For embankment dam, **separate spillway** is required.

e. Earthquake Zone

- If the dam is to be situated in an earthquake zone, earthquake force needed to be included in design.
- Earthen dams and concrete gravity dams are recommended.

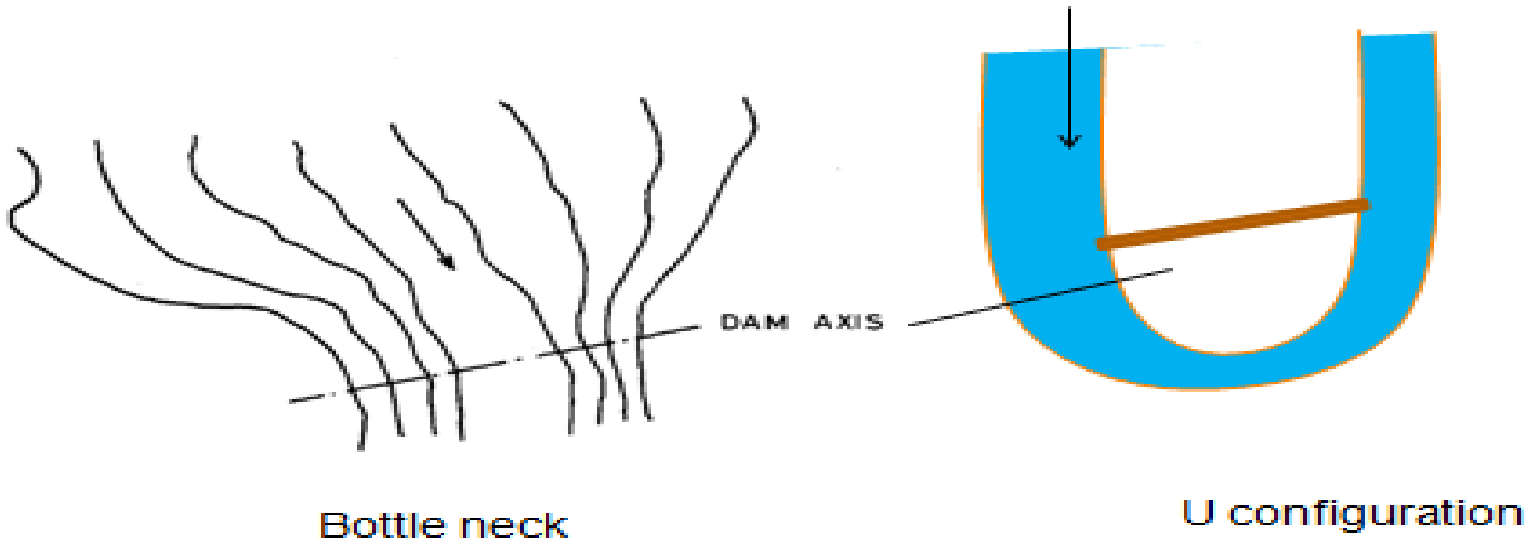
1.5 Investigation of site for dam

- A dam is huge structure requiring a **lot of funds**.
- **Extreme care** shall be taken while selecting the site of a dam.
- A **wrong decision** may lead to **excessive cost** and **difficulties in construction and maintenance**.
- Factors that are considered when selecting the site of a dam are;
 - Suitable foundations**
 - ✓ faults, joints, fissures and weak geologic formation should be avoided/treated
 - ✓ bearing capacity, permeability, stability of foundation should be checked.
 - ✓ Organic and compressible materials should be avoided.
 - Topography**
 - For economy the length of dam should be small/**narrow river section**/ as possible.



Cont....

- A site where the river has a **U-bend 'or an S-curve** is advantageous in layout as **tunnels** needed for diversion or conveyance can be aligned across the bend and thus be shorter in length.
- For storage at economic costs a **bottleneck configuration** is required.



c. Construction Material

- Material required for the construction should be easily available.

Cont...

d. Reservoir and Catchments area

- ✓ The **reservoir basin should be water-tight**.
- ✓ The stored water should not escape out through its side walls and bed.
- ✓ The **value of land and property submerged** by the proposed dam should be as low as possible.
- ✓ Preferably the catchments area should be such that it produces maximum runoff and minimum silt.

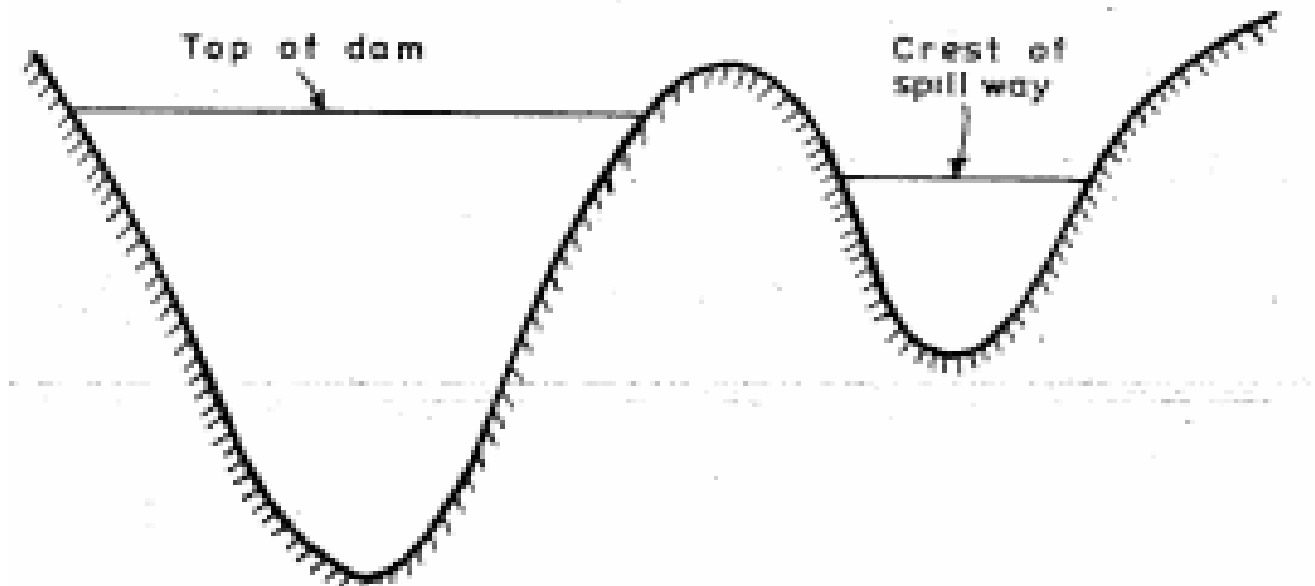
e. Accessibility

- ✓ The site selected should have a better communication, roadway, health facilities, seismic risk, availability of labor, etc.
- ✓ The dam site should be easily **accessible**.

Cont...

f. Site for spillway

- ✓ Suitable **site for the spillway** should be available near the site.
- ✓ Good site for the location of a separate spillway is essential incase of earth or rock fill dam.
- ✓ For concrete dam, spillway may be located at its middle.
- ❖ The best dam site is one in which a narrow deep gorge is separated from flank with its surface above the dam.



Cont...

- Generally site investigation for dam broadly classified under three categories, viz
 1. **Reconnaissance**
 - ✓ Visiting all available sites which have a possibility of being utilized and gathering information
 2. **Preliminary investigation**
 - ✓ The collected data is used for the **preliminary design and estimates**.
 3. **Final investigation**
 - Final investigations are conducted for onsite.
 - This investigation are done in detail so that the complete design and estimates can be prepared.
 - During site investigation for dam the following information is collected and investigated;
 - i. Topographic data
 - ii. Geo-technical data
 - iii. Hydro-metrological data
 - iv. Environmental and Social investigation data

Cont...

Geo-technical investigation

It includes

- Strength and stability of foundation materials
- Water tightness of foundation and reservoir basin
- Presence of faults, joints and other weak zones
- Availability of construction materials

Hydro-metrological investigation

- Yield of stream flow
- Reservoir yield
- Water requirement for project purpose
- Sediment
- Flood flow (peak flow)
- Groundwater condition
- Precipitation, evaporation, humidity, wind speed, temperature, etc

1. Reconnaissance

- ✓ Involves visiting all available sites which have a possibility of being utilized and gathering information which will be useful for planning the detailed surveys and investigations.

2. Preliminary Investigation

❑ The collected data is used for the **preliminary design and estimates**.

➤ The following data are selected during preliminary investigation;

a) Preliminary survey

- Topographic map of the site, longitudinal and x-section of the river

b) Geological studies

- Subsurface exploration to determine overburden and nature of rock
- Few borings are done to determine subsurface data
- Type of rock, presence faults and geological details

c) Hydrological studies

- Possible runoff, yield, maximum discharge and high flood level ..collected
- Length and capacity of spillway is estimated
- Storage capacity of reservoir is estimated
- Determination of sediment load of the stream

d) Construction materials

- Investigations of construction materials, e.g. earth, gravel, concrete aggregate etc...

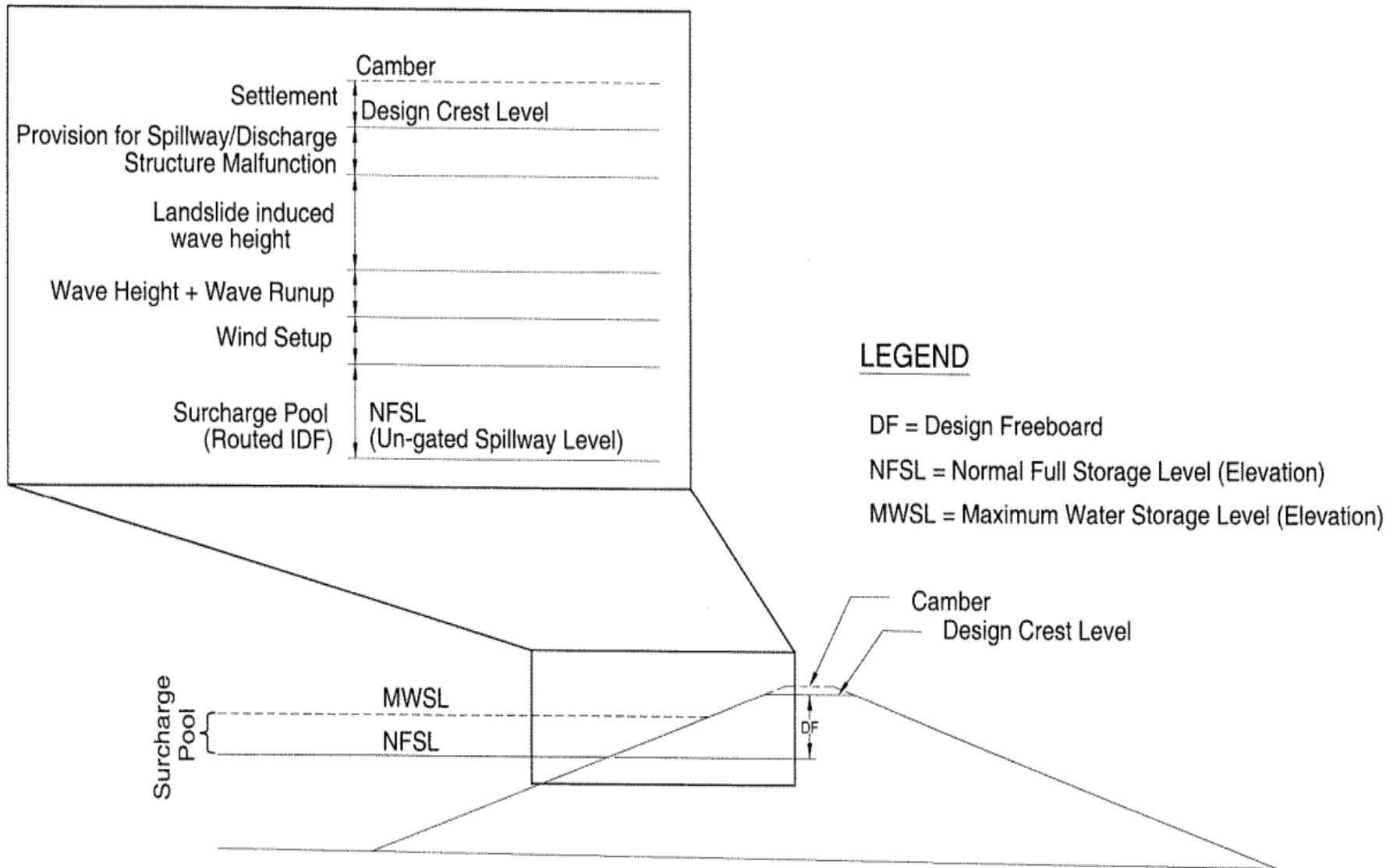
Cont...

- **3. Final Investigation:**
- Final investigations are conducted for onsite finally selected in preliminary investigations.
- This investigation are done in detail so that the complete design and estimates can be prepared.
- Final investigation involves the following items.
 - a) Detail survey is carried out
 - b) Detail geological investigation is carried out
 - c) Determination of the final location and type of dam to be constructed
 - d) Foundation treatment on the basis of subsurface investigation
 - e) Determination of the extent of land which would be submerged in the reservoir and the arrangements for rehabilitation of the residents of that area.
 - f) Obtaining sufficient information for accurate estimate of cost

Freeboard

- **Freeboard**: is the vertical distance between the crest of the dam (without camber) and the reservoir water surface.
- **Normal Freeboard**: vertical distance between the crest of the dam and the Normal Water Level.
- **Minimum Freeboard**: vertical distance between the crest of the dam and the Maximum Water Level.

cont



Freeboard Design Considerations

- Wind-generated wave action, wind setup, and wave runup;
- Earthquake and/or landslide-generated waves and runup;
- Post-construction settlement of embankment dams and foundations;
- Provision for malfunction of spillways (especially gated structures) and outlet works, and
- Site-specific uncertainties including flood hydrology

Load on dam

The classification is made in terms of the applicability and/or the relative importance of the load.

- **Primary loads** are identified as universally applicable and of prime importance to all dams, irrespective of type, e.g. water and related seepage loads, and self-weight loads.
- **Secondary loads** are generally discretionary and of lesser magnitude (e.g. sediment load) or, alternatively, are of major importance only to certain types of dams (e.g. thermal effects within concrete dams).
- **Exceptional loads** are so designated on the basis of limited general applicability or having a low probability of occurrence (e.g. tectonic effects, or the inertia loads associated with seismic activity).

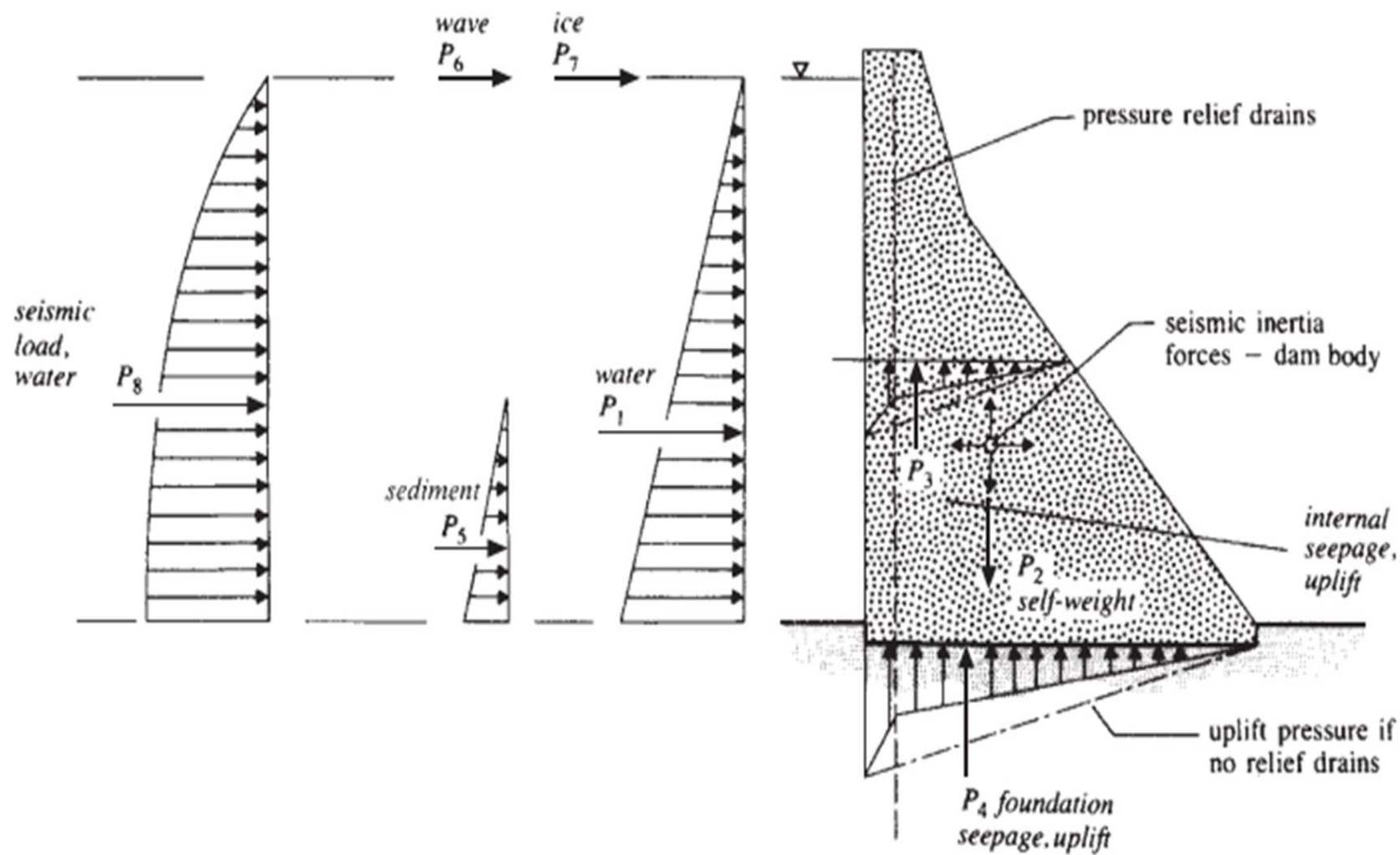


Fig. 1.8 Schematic of principal loads: gravity dam profile

1.6 Foundation of dam and their treatment

- Foundation is that part or area under and adjacent to the dam (bottom and abutment) which is affected by loading, scour or leakage.

A good foundation must:

- have **sufficient strength** to withstand the **weight of the structure** and prevent sliding
- be **tight enough** to prevent excessive **leakage** and **uplift** must be reduced as much as possible
- not be **damaged** by **overflow** discharge and **outlet** discharge
- foundation may be classified as **rock**, **coarse grained** materials and **fine grained** materials foundations

Treatments of foundation

- ***Rock Foundations***
 - ***Surface preparation***
 - ***Foundation grouting***
 - *Consolidation grouting*
 - *Curtain grouting*
- ***Silt and Clay Foundation (fine grained material for foundations)***
 - Remove soil of two shearing strength. Practicable if cost of excavation and removal of soft strata is less than providing embankment of flatter slopes.
 - Providing drainage of the foundation to permit increase of strength during construction.
 - Use flatter slopes so as to reduce magnitude of average shearing strength along the potential surface of sliding.
 - If the foundation is quite very bad, the site will be left due to the unsuitability of foundation condition
- ***Sand and Gravel Foundation (coarse grained material for foundations)***
 - Adequate measures have to be provided to reduce the danger of piping.

