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Hydraulic Structure I – CENG 3161

Chapter 1. Elements of Dam Engineering

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- **Chapter One :-** Elements of Dam Engineering
- **Chapter Two :-** Design Principles of Dams
- **Chapter Three:-** Dam Outlet Works
- **Chapter Four:-** Hydraulic Structures In Hydro power Stations
- **Chapter Five:-** Comparison of hand calculation with GEOSLOPE Software

CHAPTER ONE

Elements of dam engineering

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1.1 INTRODUCTION

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

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- **Dam** is a structure/ barrier/obstruction which is constructed across the river to store water on the 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.

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- Dams are generally constructed in the mountainous reach of the river where the valley is narrow and the foundation is good.



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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

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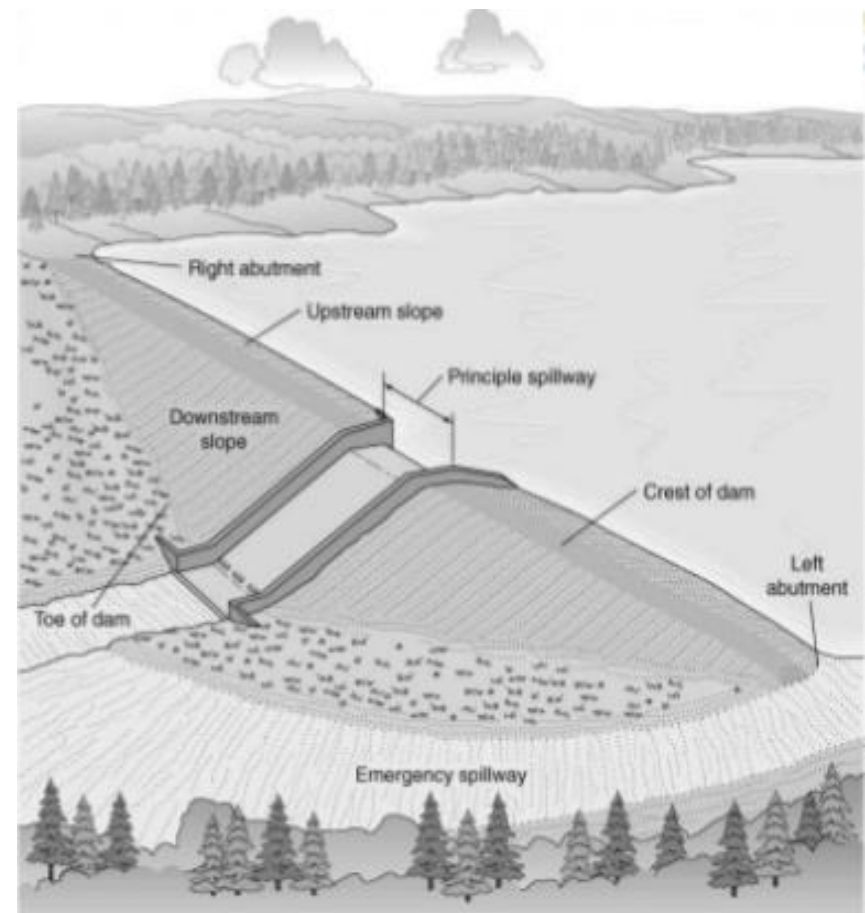
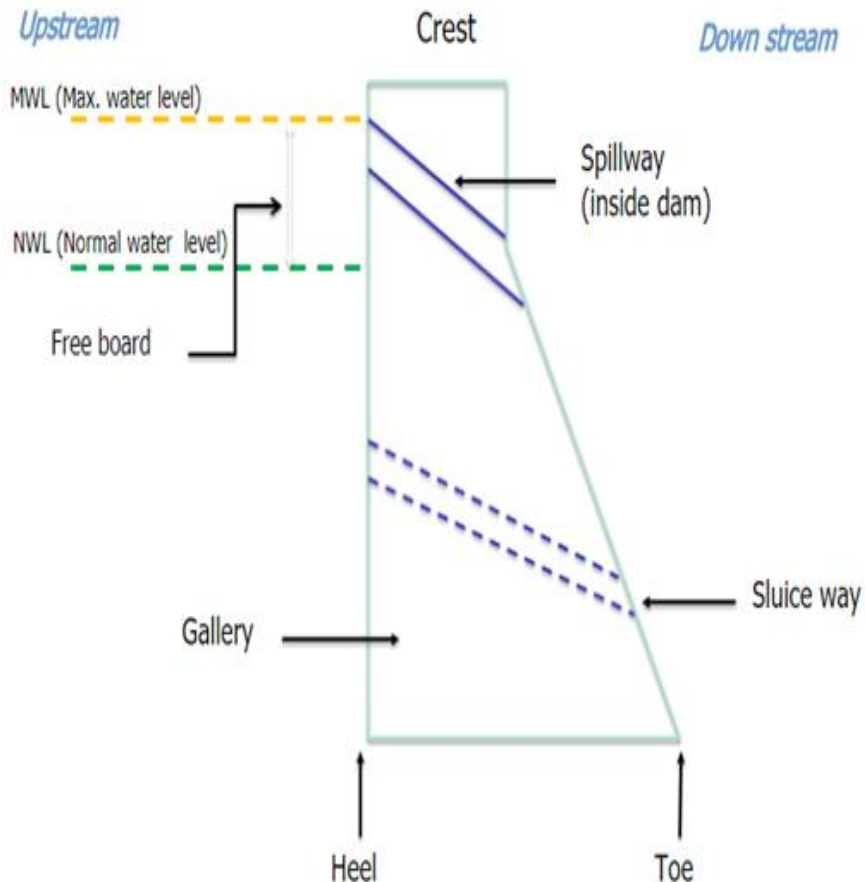
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- ❖ Creating head
 - ✓ Hydropower
- ❖ Maintaining water level
 - ✓ Navigation-transportation
 - ✓ Recreation-swimming, fishing
- ❖ Multipurpose

1.2. Dam structures and Reservoir

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1.2.1 Parts of dam/ structures/



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- **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 rooms like structure left within the dam for checking operations.

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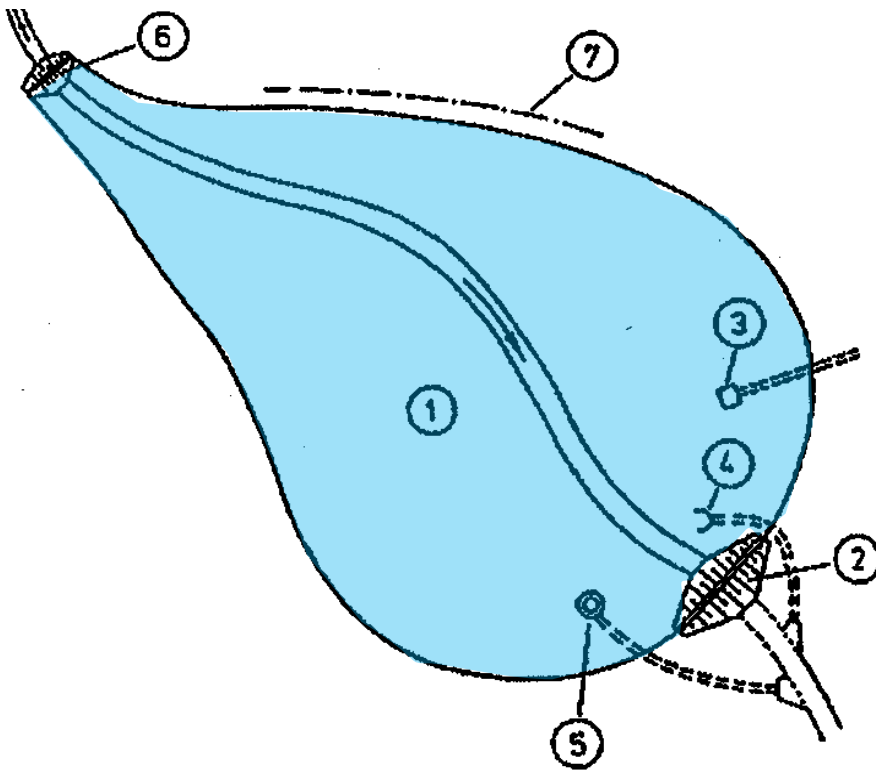
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- **Diversion tunnel:** Tunnels are constructed for diverting water before the construction of dam. This helps in keeping the river bed dry.
- **Spillways:** It is the arrangement near the top to release the excess water of the reservoir to downstream 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 side.

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Dam Structures and Reservoir



- 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

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1.2.2. Reservoirs

- Functions of reservoir in hydraulic engineering are;
 - i. For 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

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- 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.

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➤ 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.

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- ❖ Based on the derived elevation-area curve and depth, elevation-volume can be computed using various methods:

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;

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

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

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2. Prismoidal method

➤ Storage volume between 3 successive contours is given by

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

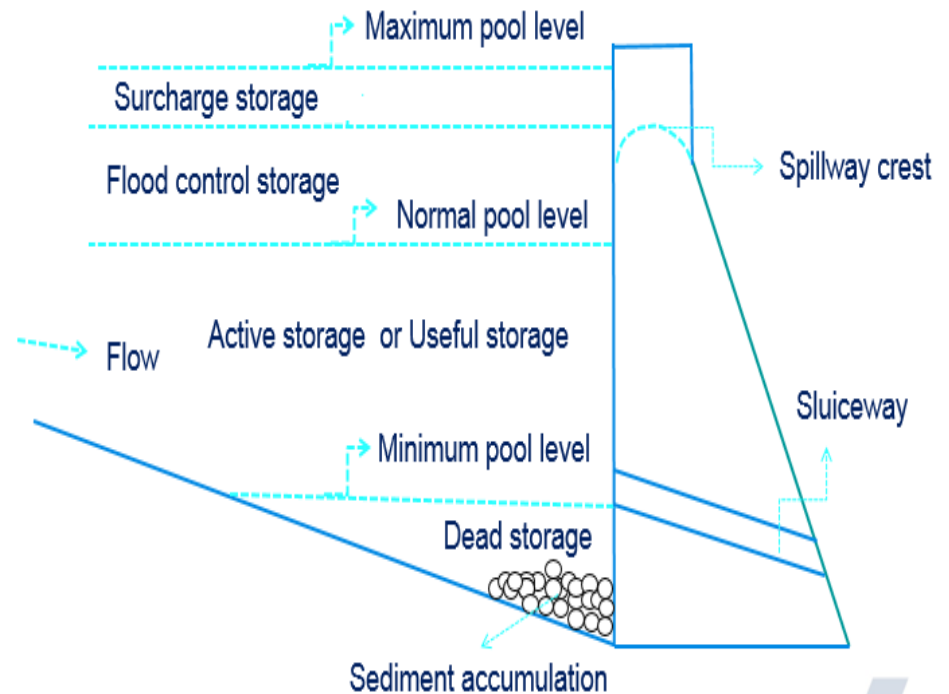
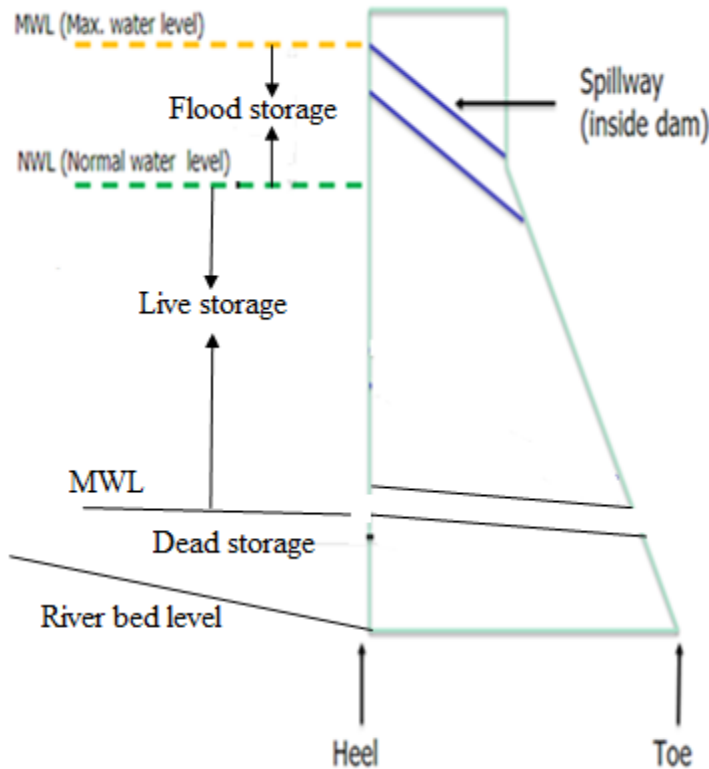
The total volume is given by;

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

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

1.3 Storage components

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- **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.

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Advantages of Dam

Dams gather drinking water for people.

Dams help farmers bring water to their farms.

Dams help create power and electricity from water.

Dams keep areas from flooding.

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

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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 problem
 - ❖ Change in groundwater level
 - ✓ damage to infrastructure
 - ✓ damage to farmland (water logging)

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- ❖ Influence on sediment balance
- ❖ Influence on fish/block migration of fish/
- ❖ Decrease downstream water
- ❖ Spread of water born disease/home to disease-bearing insects)
- ❖ Failure problem

1.4 Classification of dams

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- Dams are classified according to several conditions as indicated below

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.

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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



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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.

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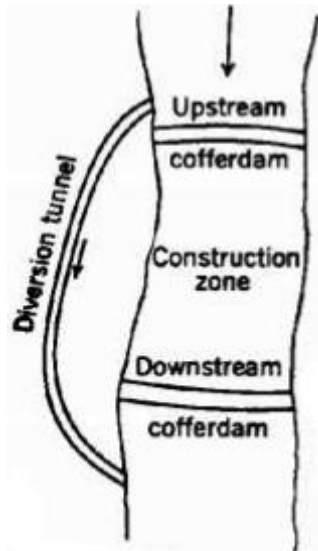


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e. Cofferd dams

- 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.



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f. Multipurpose dam

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

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

Cont....

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b. Non-overflow dam

- ✓ they are not designed to be overtopped.



a. Overflow dam



b. Non-overflow dam

Cont....

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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. earth fill and rock fill dam

Cont....

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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**.

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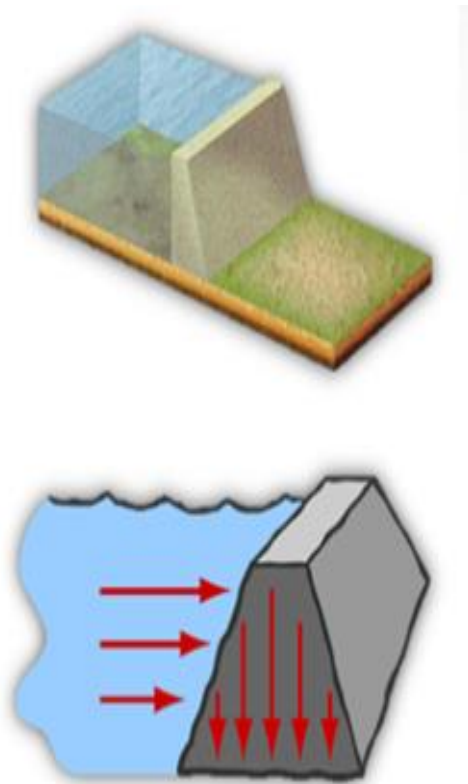
5. Classification based on structural action

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.

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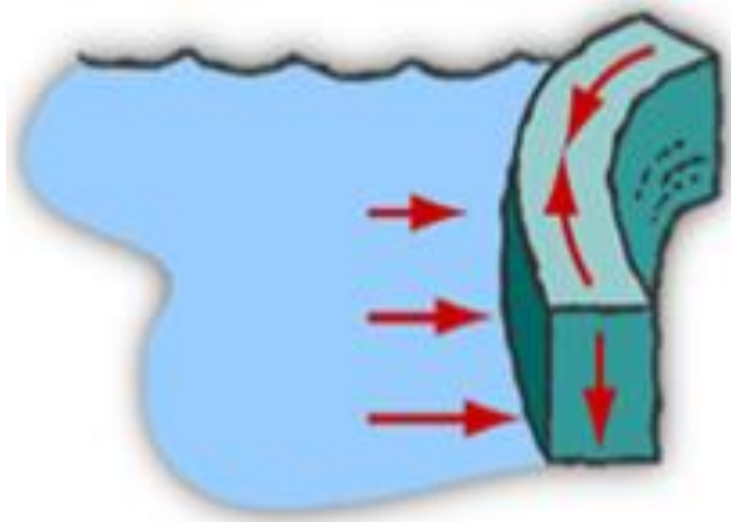
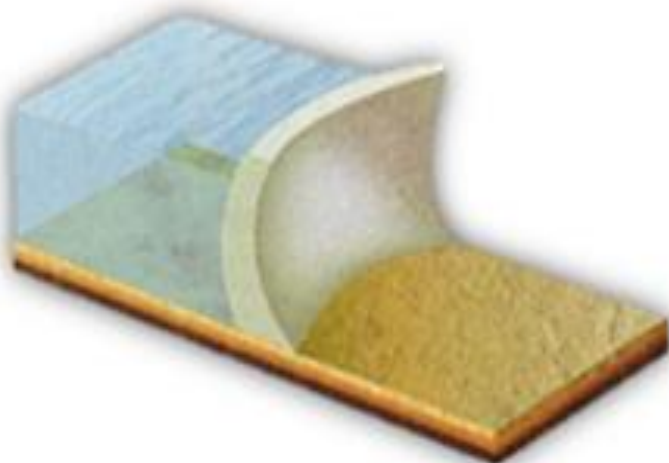


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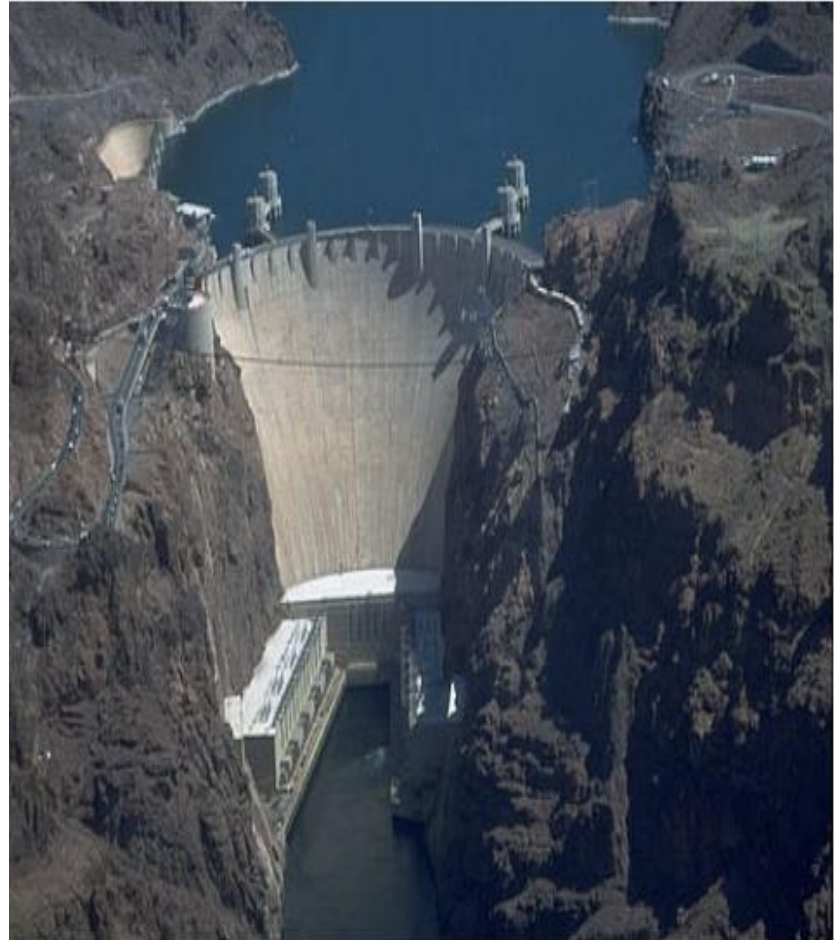
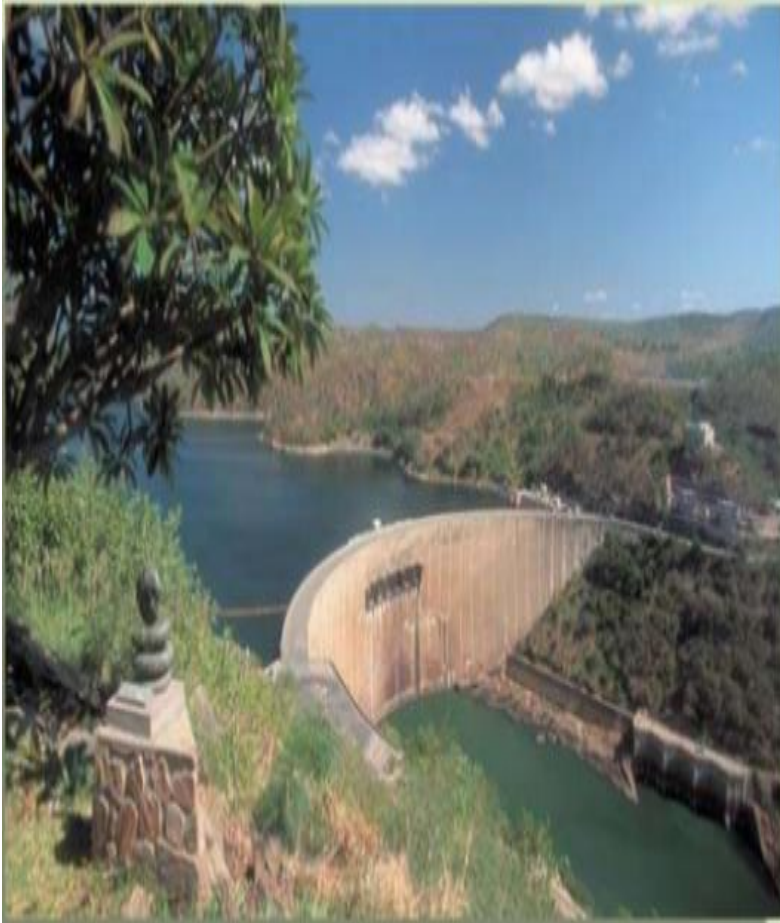
b. Arch dam

- 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.



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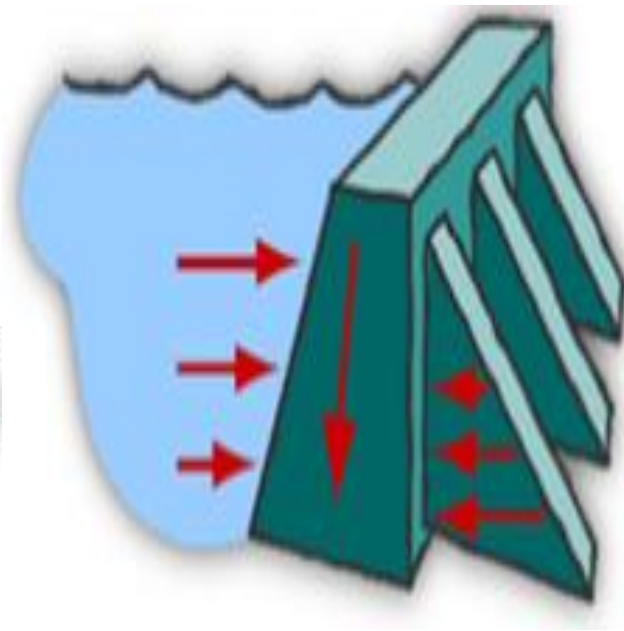
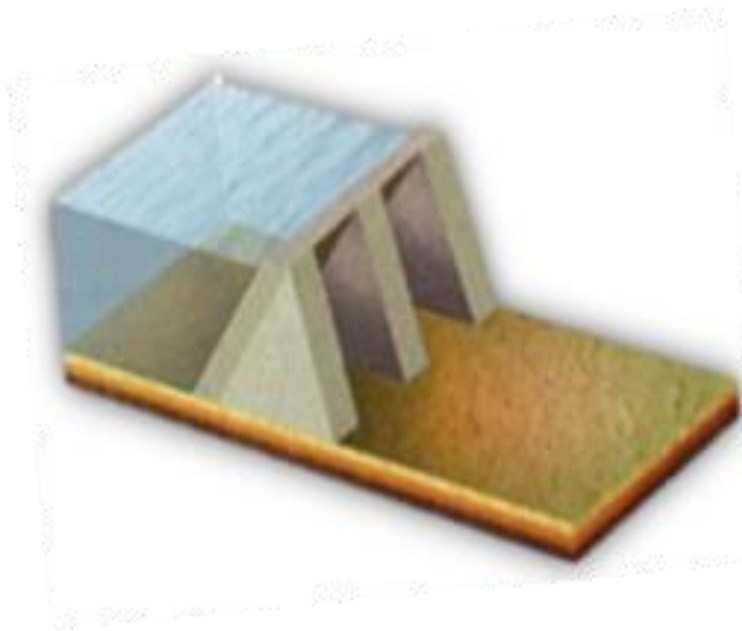
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c. Buttress dam

- 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.

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Inclined U/S face



Buttresses
/triangular wall/

Cont....

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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;

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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 ($> 70\text{mm}$), boulders, crashed rocks

Cont....

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Earth fill dam



Cont....

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Rock fill dam



1.5 Factors governing the selection of particular type of dam

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1.5.1. TOPOGRAPHY

- Topography dictates the first choice of the type of dam and the most important factor in this respect is the shape of the valley.
- 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 earth fill dam.

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1.5.2. 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

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- ❖ **Gravel course sand Foundation-** unable to bear the weight of high concrete dams and serious seepage problem-suitable for earthen and rock fill dams ($H < 15\text{m}$)
- ❖ **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

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1.5.3 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.

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1.5.4 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.

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1.5.5 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.
- ❖ Economy & Diversion problems are also factors governing the selection of particular type of dam.

1.6 Investigation of site for dam

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- 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;
 - a. 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.

Cont....

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b. Topography

- ✓ For economy the length of dam should be small /narrow river section/ as possible.

c. Construction Material

- ✓ Material required for the construction should be easily available.

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.

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- ✓ 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.

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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.

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- 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

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- Generally site investigation for dam broadly classified under three categories,
 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.

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➤ 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

Cont....

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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...

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3. Final investigation

- Final investigations are conducted for one site.
- 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

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- 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

THANK YOU