

Chapter One: Element of dam Engineering

1.1. Introduction

Hydraulic structures are engineering structures constructed for the purposes of controlling and using water resources (groundwater, river, lakes, sea, etc) or for the prevention of the negative and destructive actions (floods, erosion, etc) of water on the surrounding environment.

There are a large variety of hydraulic structures to serve the many purposes for which water resources are put to use. The most important type of hydraulic structures is given below.

Table 1.1 Types of the hydraulic structures and their function

No.	Type	Purpose	Structure
1	Storage structures	To store water	Dams, tanks
2	Flow control str.	To regulate the quantity and pass excess flow	Spillway, outlet, gates, valves
3	Flow measurement Str.	To determine discharge	Weirs, orifices, flumes
4	Diversion structures	To divert the main course of water	Coffer dams, weirs, canals,
5	Conveyance to guide	To guide flow from one location to another	Open channel, conduits, sewers
6	Collecting structures	To collect water for disposal	Drain inlets, infiltration galleries
7	Energy dissipation structures	To prevent erosion and str. Damage	Check dams, surge tanks
8	Shore protection	To protect banks	Dikes, groins

- Dam** is a barrier constructed across a river or a natural stream to create a reservoir for impounding water (for irrigation, water supply, flood protection), or to facilitate diversion of water from the river, or to retain debris flowing in the river along with water.

The construction of dams ranks the earliest and most fundamental of civil engineering activities. All great civilizations have been identified with the construction of storage reservoirs appropriate to their needs, in the earliest instances to satisfy irrigation demands arising through the development and expansion of irrigated agriculture.

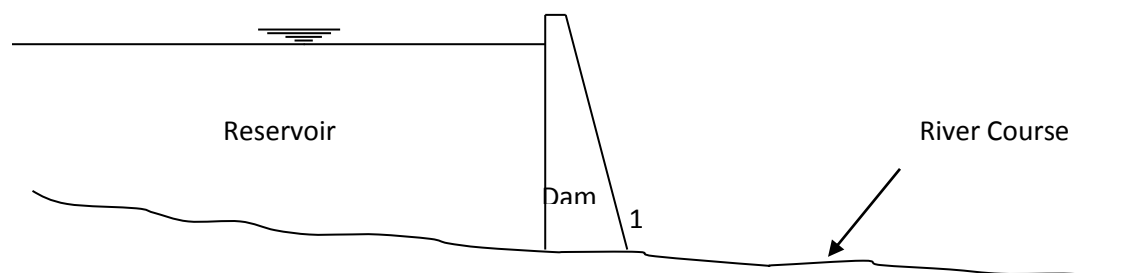


Figure1. Definition Sketch / dam, reservoir and river course/

2. **Reservoir** is the lake of water created upstream of the dam.
3. **Spillway** is a section of a dam designed to pass water from the upstream side of a dam to the downstream side. Many spillways have gates designed to control the flow through the spillway.
4. **Dike** is a stone or earthen wall constructed as a defence or as a boundary. The best known form of dike is a construction built along the edge of water body to prevent flooding onto adjacent lowland.
5. **Levee** is a natural or artificial structure, usually earthen, which parallels the course of a river. It functions to prevent flooding of the adjoining countryside. However it also confines the flow of the river resulting in higher and faster water flow.
6. **Weir** is a small overflow type (designed to be overtopped) dam commonly used to raise the level of a small river or stream. Water flows over the top of a weir, although some weirs have sluice gates which release water at a level below the top of the weir.
7. **Detention structure** is a structure used to detain flood temporarily and reduce flow velocity and control soil erosion.
8. **Diversion structure** is a type of structure that diverts all or a portion of the flow of a river from its natural course

1.2 Dam Structures and Reservoirs

1.2.1 Dam structure/components

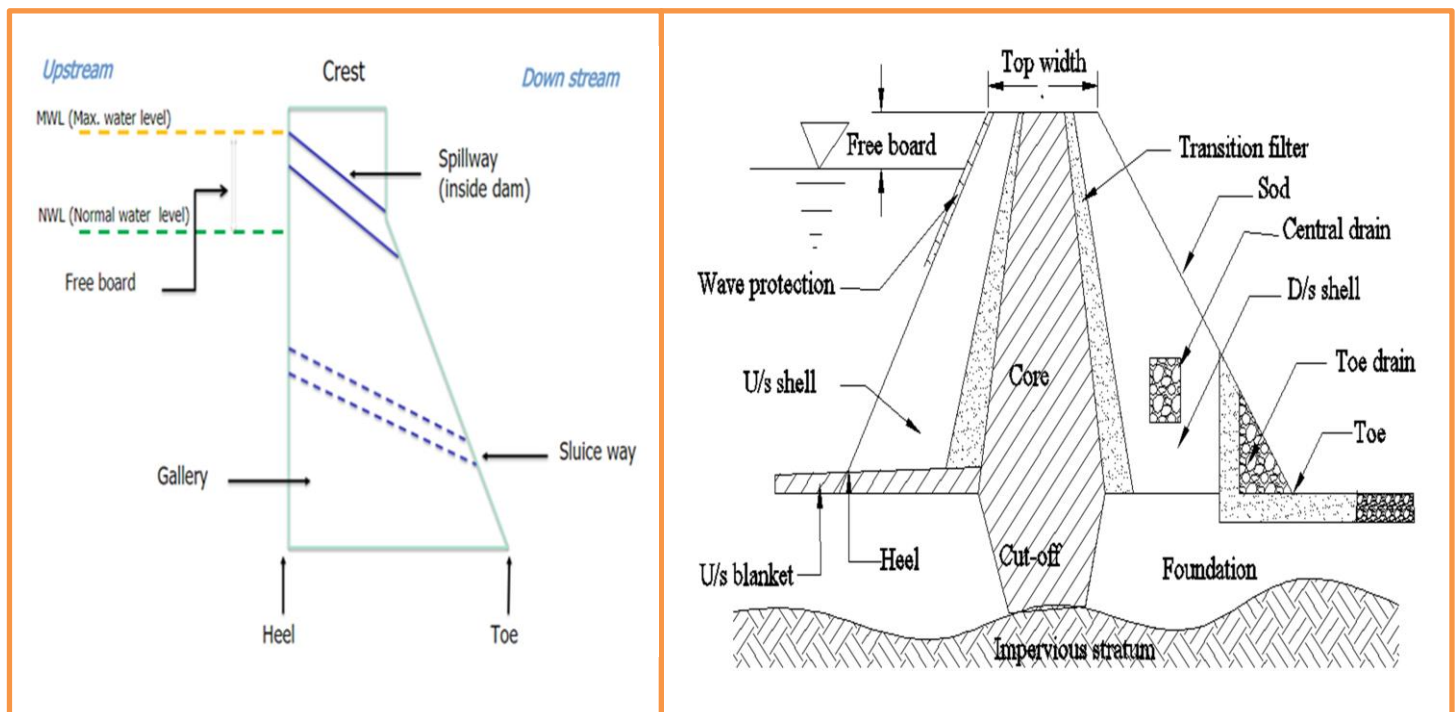


Figure2. Dam components in both concrete and embankment

- **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.
- **Diversions 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.

1.2.2 Reservoir Planning

The absence of natural storage of adequate capacities necessitates construction of some artificial storage works. Development of natural storages may also be included in this category sometimes (Cherecherea weir at Lake Tana). In rainy season there is excess flow down the valley in a river. An impounding reservoir can be constructed in the valley to store this excess water which will meet the demand in dry periods.

Storage works may be designed and constructed to serve single or multipurpose. The various purposes for which storage works are required are mentioned below

1. Irrigation
2. Hydro-electric power generation,
3. control of destructive floods
4. Low water regulation for navigation
5. Domestic and industrial water supply
6. Recreation
7. Preservation and breeding of useful aquatic life, etc.

Before any dam is built, certain hydrological information is necessary regarding river discharge, rate and character of siltation, and the location and duration of flooding. A critical concern in rivers is the magnitude and duration of discharge with respect to time. Feasibility studies are necessary in assessing the water budget for future industrial operations. Relevant studies involve meteorological monitoring, hydrological measurements, reservoir capacity, safe yield, and flood frequency. Questions that need to be confronted during dam site investigation include the depth at which adequate foundation materials exist, the strength of the rocks and soils, and the likelihood of water leakage.

By analysis of storage data, availability of water is ascertained before any project is contemplated. The next step in reservoir planning is to fix the reservoir capacity. The reservoir has to provide sufficient storage for various purposes, namely

1. Dead storage to contain silt deposition,
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. It can be arrived at by plotting the mass curves of demand and inflow of accumulated flow or rainfall plotted against time. 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. In some cases it is necessary to cover a period of successive dry years to consider storing of sufficient water to meet the demand during periods of prolonged drought.

DAM TERMINOLOGIES AND TYPICAL LAYOUTS (FIGURES)

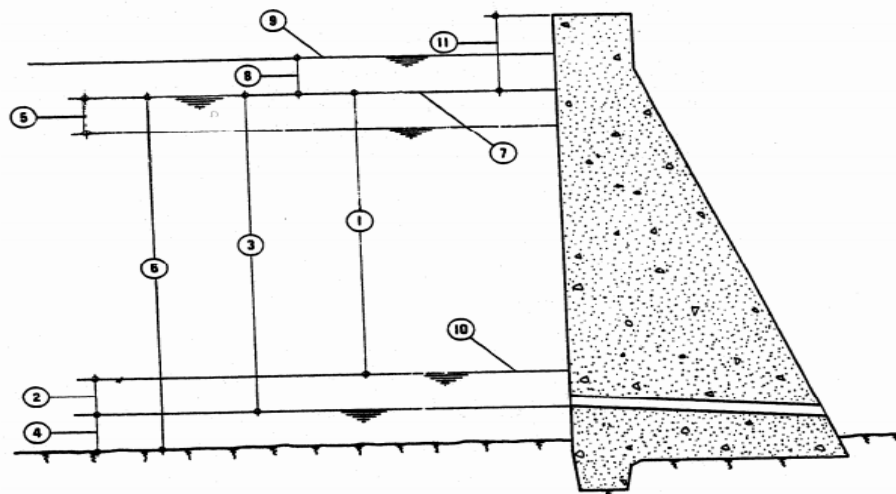


Figure 3. Layout of dam

1. Active storage
2. Inactive storage
3. Live storage
4. Dead storage
5. Flood storage
6. Reservoir capacity; gross capacity of reservoir; gross storage; storage capacity
7. Retention water level; top water level; normal top water level; full supply level; normal water level
8. Flood surcharge; surcharge
9. Maximum water level; top of joint use
10. Minimum operating level; top of inactive storage
11. Freeboard

Reservoir Capacity determination

The most important physical characteristics of a reservoir is nothing but its storage capacity. The capacity of reservoir on the dam sites is determined from the contour map of the area. A topographic survey of the dam site is carried out and contour map of the area is drawn. The area enclosed within each contour can be measured with a plain meter. The volume stored between two successive contours can be computed by using different methods. Some of these are trapezoidal method (simple average method), Prismoidal method, Integration method, Cone method etc.....

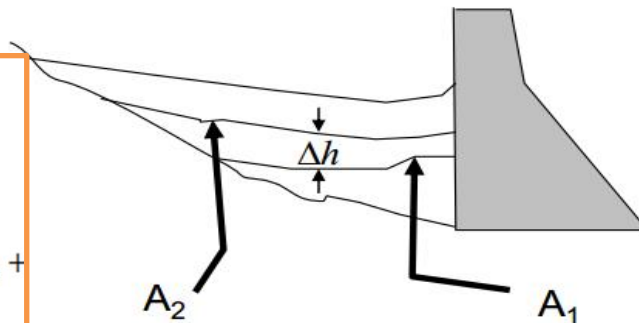
1. **Average area or trapezoidal method:** The storage volume between two successive contours of areas A_i and A_{i+1} is given by;

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

➤ Therefore total volume V is given by;

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

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



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;

$$\Delta S = \text{Storage} = \frac{\Delta h}{6} [A_1 + 4A_2 + A_3]$$

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. Classification of dam

1.3.1 Based on function (use)

i) Storage Dams

Storage dams are constructed to create a reservoir to store water during the periods when the flow in the river/stream is in excess of the demand, for utilization later on during the period when the demand exceeds the flow in the river/stream.

ii) Detention Dams

Constructed to temporarily detain all or part of flood water of a river and gradually release the stored water at controlled rates so that the entire region on the d/s side of the dam may be safe guarded against the possible damage due to floods. Detention dams are also constructed to trap sediment. These are often called debris dams.

iii) Diversion Dams

These small dams are used to raise the river water level in order to feed an off-taking canal and/or some other conveyance systems. They are useful as irrigation development works. A diversion dam is usually called a weir or a barrage.

1.3.2. Classification based on Hydraulic Design

i) Overflow Dams

They are designed to pass the surplus water over their crest. They must be made of materials which will not be eroded by such discharges. E.g. Concrete, masonry etc...

ii) Non-overflow Dams

They are those which are not designed to be overtopped. This type of design extends the choice of materials to include earth fill and rock fill dams.

iii) Composite Dams

It is the combination of over flow and non –over flow dams. Many times these types are combined together to form a composite structure.

1.3.3 Classification based on capacity

1 Large dam

All dams above 15 m height, measured from the deepest foundation level to the crest, as also the dams between 10 m and 15 m height provided they comply with at least one of the conditions that:

- ❑ crest length of the dam is not less than 500m,
- ❑ maximum flood discharge is not less than 2000 m³/sec,
- ❑ reservoir capacity formed by the dam is not less than 100, 000 m³
- ❑ dam has especially difficult foundation or of unusual design

2 **Small dam** : All dams below 15 m in height.

1.3.4 Classification based on material of construction

i) Rigid dam

It is a dam constructed from rigid materials such as masonry, concrete, etc...Examples are Gravity, arch and buttress dams.

Concrete gravity Dam: Resists the forces exerted up on it by its own weight. Its cross section is approximately triangular in shape.

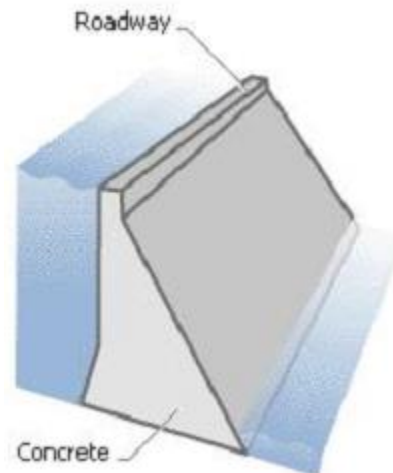
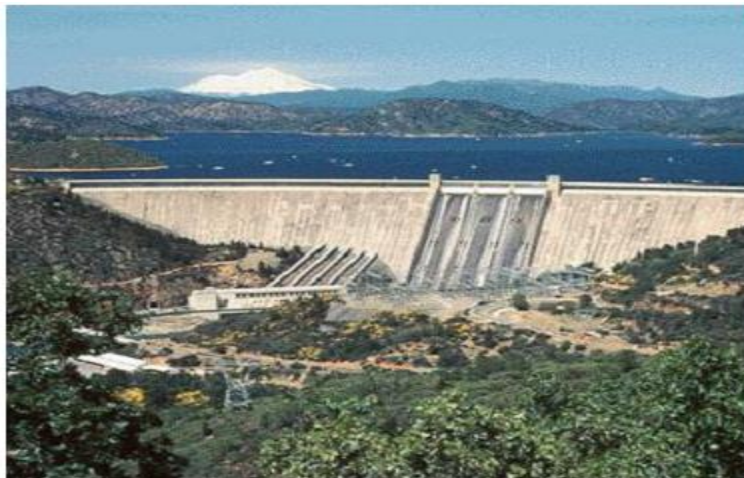


Figure-4: Examples of concrete gravity dam

Arch Dam: Is a curved concrete dam, convex u/s, which resists the forces exerted up on it by arch action. It is structurally more efficient than the gravity or buttress dams, greatly reducing the volume of concrete required.

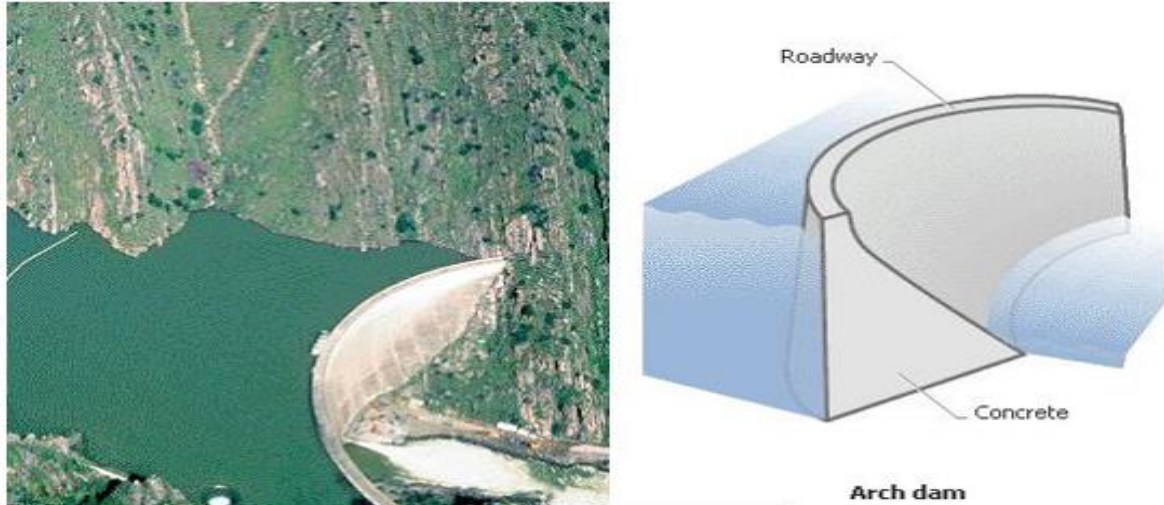


Figure-1.5: Sample of Arch dam

Buttress dam: It consists of water retaining sloping membrane or deck on the u/s which is supported by a series of buttresses or counter forts. The sloping membrane is usually R.C. slab. In general the structural behavior of buttress dam is similar to that of gravity dam. It may be considered as a lightened version of gravity dam.

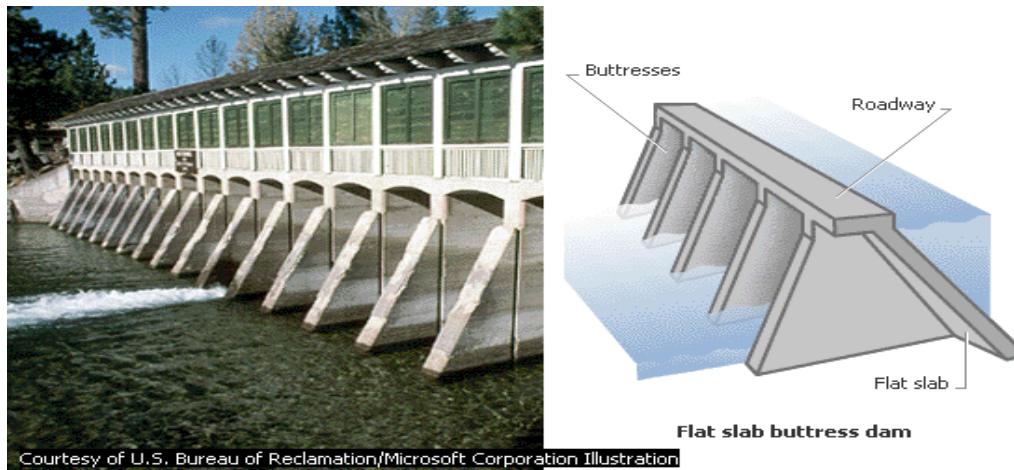


Figure-6: Profile of Buttress dam

ii) Non Rigid dams

A dam which is constructed from non-rigid materials such as earth, rock-fill etc.... are called non-rigid dams. Earth-fill and rock-fill dams are non-rigid dams. They are usually called embankment dams.

a. Earth-fill embankment dams:

- Indicates types of dams consisting more than 50 % of compacted earth-fill
- Constructed uniformly and intensively in relatively thin layers and at controlled moisture content

- Designed to resist load by mechanism of embankment stability
- It resists the forces exerted upon it mainly due to shear strength of the soil. Although the weight of the earth dam also helps in resisting the forces, the structural behavior of an earth dam is entirely different from that a gravity dam.
- They are strictly non-overflow types.



Figure7-: Sample of earth fill dam

b. **Rock-fill embankment dams:**

- Indicates types of dam consisting more than 50 % of compacted rock-fill
- Includes a discrete impervious element of compacted earth-fill or a slender concrete or bituminous membrane
- Rock-fill dams require foundation stronger than those for earth dams
- Rock-fill dams are quite economical when a large quantity of rock is easily available near the site

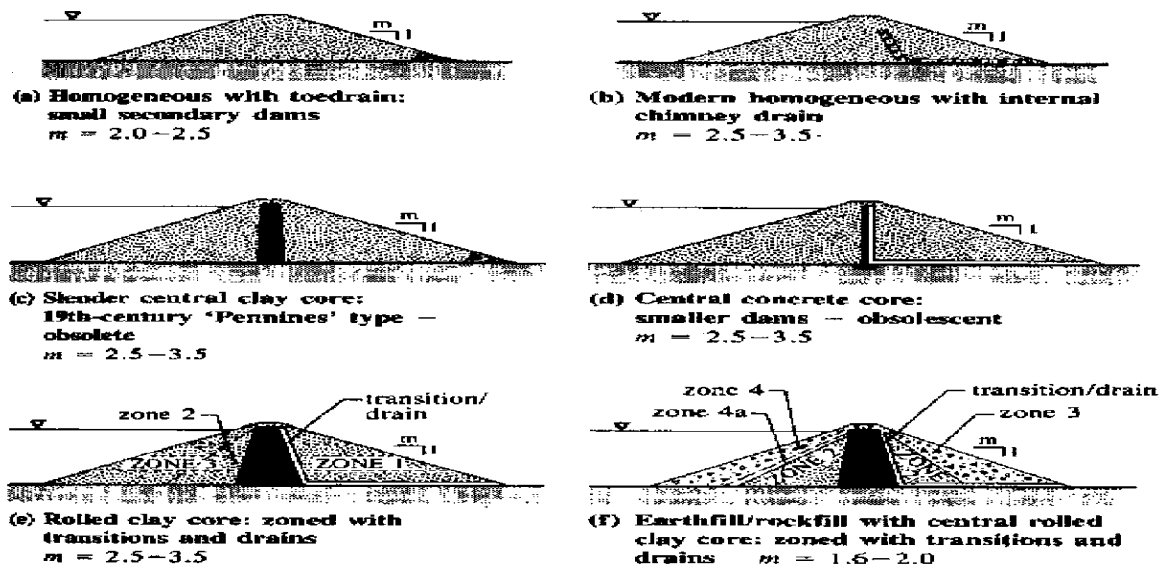


Figure 1.2. Principal variants of earth-fill and earth-fill/rock-fill embankment dams (values of m are only indicative)

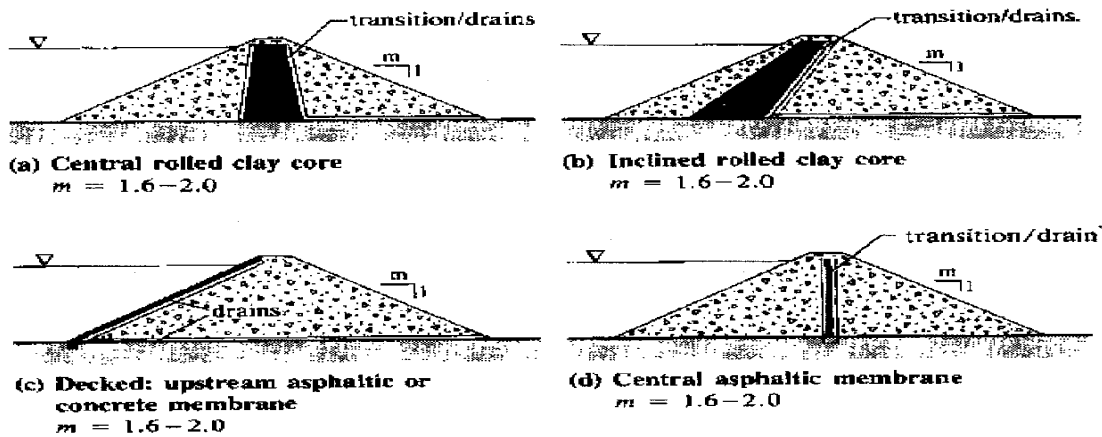


Figure 1.3. Principal variants of rock-fill embankment dams (values of m are only indicative)

Relative advantages of Embankment dams:

- Adaptable to any type of foundation. Rock-fill dam, however, imposes some restrictions on the quality of foundations
- The construction is effectively continuous and highly mechanized process
- Adaptable for sites in seismic zone
- Economical in first cost if sustainable earth for construction is available near the site
- Permits use of wide variety of available materials

- Comparatively unskilled labour can be employed
- Earth dams are more earthquake resistance than gravity dams

Relative disadvantages of Embankment dams:

- Susceptible to damage by overtopping or burrowing of animals
- Cannot be used as overflow dam. So, separate spillway is required
- High maintenance cost
- Vulnerable to concealed leakage and internal erosion in dam and foundation
- Not suitable for narrow gorges with steep slopes
- Cannot be constructed in regions with heavy down pore, as the slopes -might be washed away
- Fails suddenly without any sign of imminent failure

Concrete dams and their characteristics

a. Gravity dams:

- It is a dam that depends on self-weight to resist the action of water stored on the upstream side
- It is constructed of concrete, approximately triangular in section to ensure stability and to avoid over stressing of the dam or its foundation
- It may be curved or straight in plan
- It is best suited to sites with relatively sound rock foundation
- They are quite suitable for the gorges with very steep slopes
- Low dams ($H < 15$ m) might be constructed on alluvial foundation with proper cut-offs and foundation treatment

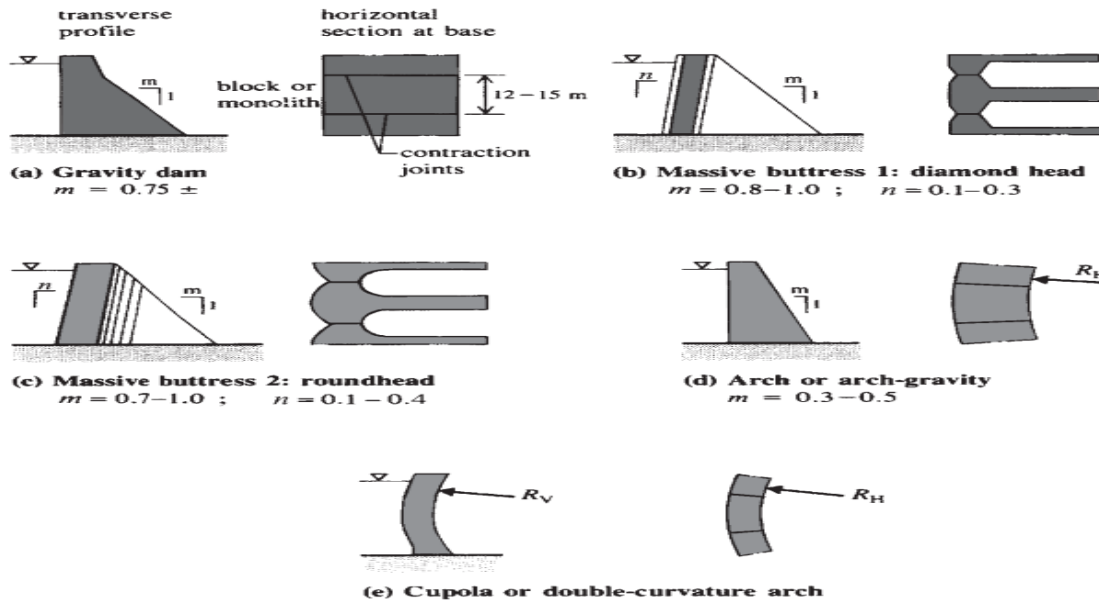
b. Buttress dams:

- Consists of a continuous up stream face supported at regular intervals by down stream buttresses. It normally needs up to 60 % less concrete than gravity dam of the same height, but needs form work and reinforcement
- A decked type buttress dam consists of a sloping deck supported by buttresses. Buttresses are triangular concrete walls that transmit the water pressure from the deck slab to the foundation. Buttresses are compression members. The deck is usually a reinforced concrete slab supported between the buttresses, which are usually equally spaced.

c. Arch dams:

- Loads resisted mainly by arch action and transmitted through abutments.
- It is quite suitable for narrow canyons with strong flanks that are capable of resisting the trust produced by the arch action.

- Suitable in narrow gorges when the length of the crest is not more than five times the height of the dam.
- Requires solid and strong abutments.
- Its particular derivation is the Cupola or double curvature arch dam, which is the most sophisticated concrete dam, is extremely economical in concrete.
- An arch dam is curved in plan, with its convexity towards the upstream.
- The system of an arch dam is approximately triangular like a gravity dam but the section is comparatively thinner.



Relative advantages shared by most of the concrete dams:

- Concrete dams are suitable to the site topography of wide component rock foundation if available at shallow depth.
- Concrete dams are not sensitive to overtopping.
- Concrete dams can accommodate crest spillway hence cost of separate spillway is reduced.
- Outlet pipe works, valves and other auxiliary works can be provided with in the body of the dam.

Relative disadvantages shared by most of the concrete dams:

- They are relatively demanding with respect to foundations requiring sound rock.
- Requires importation of proposed material to the site.
- Traditional mass concrete construction is labour intensive and relatively discontinuous and requires certain skills.
- Compacted unit costs are very much higher than for embankment fills, which seldom balanced by the much lower volume of concrete required in a dam of certain height.

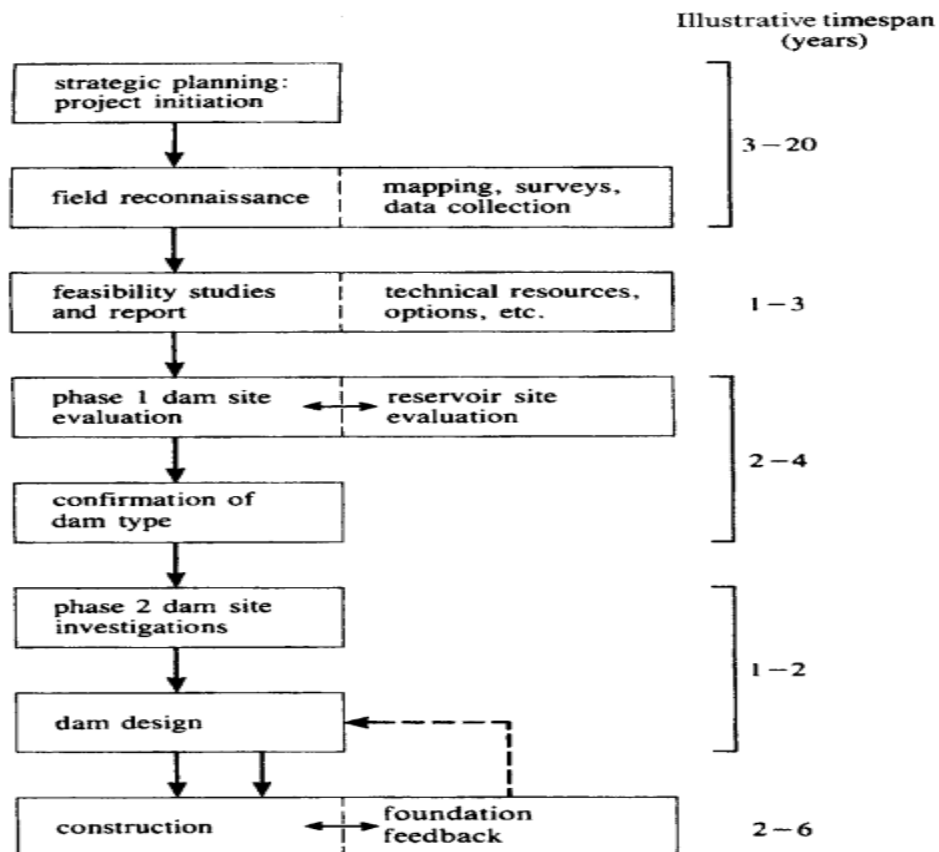
1.5. Site assessment and selection of appropriate type of dam

a) *General site appraisal*

A satisfactory site for a reservoir and dam must fulfil certain functional and technical requirements. The following are the major considerations:

1. Major inputs: - Geotechnical, structural, hydraulic, hydrological and environmental impacts/effects.
2. Optimum design solution: - Solutions of appropriate dam type (no clear-cut rule) which is derived from the interaction of the above inputs with economic factors including construction constraints.
3. As 2 implies, there are frequently several alternatives which are equal technical, but of different economic validity. Note that both relative economic validity to a lesser extent of technical validity are subjected to change as technology develops.
4. Each and every dam is quite unique to the problems of the site in question, in terms of the balance of technical and economical factor at times of consideration.

b) *Logical sequence of stages in dam site appraisal and project development*



i) Reconnaissance:

- The principal objective is to collect adequate topographical, geological and hydrological survey data.
- Aerial reconnaissance employing modern technique is of prime importance particularly in well-developed region. In the hands of skilled interpreter, aerial survey in addition to topography give good information on geology, possible dam sites and availability of construction materials.
- A visit is then made to all possible sites to collect information that will be useful for further planning and conducting detailed surveys and investigations.

ii) Feasibility:

- Its report is prepared at the conclusion of the reconnaissance phase assembles and interprets all available information, data and records, and makes initial recommendations with respect to the technical and economic validity of the reservoir.
- Option with regard to location, height and type of dam are set out, and comparisons drawn in terms of estimated costs and construction program.
- On the strength of this report a decision can be made with respect to the future detailed investigations required to confirm the suitability of the reservoir basin and preferred dam site (sites).
- Two key concepts should be kept in mind through the investigation stage:
 - Dam/Reservoir interaction: - Water tightness/stability at reservoir must consider regional and local geology.
 - Dam/Foundation/Abutment interaction: - Relationship of hydraulic gradient and loads associated with different types of dams must be limited to foundation/abutment conditions.

iii) Dam site selection and evaluation:

The validity of the preferred dam site identified in feasibility study must be confirmed. Extensive subsurface exploration on conformation of site geology and geotechnical characteristics and on the evaluation of source of materials required.

In general, the extent of superficial and draft deposit, overburden depth is examined through surface examination, borehole data, etc. Site geology is examined and interpreted with the context of rock structure at depth is carried out through drilling. Foundation competence is determined by stability and effective impermeability. All are in relation to size of the dam proposed.

The selection of site for dam is governed by the following factors:

1. Suitable foundations
2. Economy, the length of the dam should be as small as possible, and for a given height, it should store the maximum volume of water. It, therefore, follows, that the river valley at the dam site should be narrow but should open out upstream to provide a large basin for a reservoir
3. Bed level at a dam site should preferably be higher than that of the river basin. This will reduce the height of the dam and facilitate drainage problem.
4. A suitable site for spillway should be available in the near vicinity. If the spillway is to be combined with the dam the width of the gorge should be such as to accommodate both.
5. Material required for the construction should be easily available, either locally or in the near vicinity, so that the cost of transporting them is as low as possible.
6. The reservoir basin should be water-tight. The stored water should not escape out through its side walls and bed.
7. The value of land and property submerged by the proposed dam should be as low as possible. The environmental impact of the construction of the dam on the nature of the river and the vicinity must be as low as possible.
8. The dam site should be easily accessible, so that it can be economically connected to important towns and cities by road
Site for establishing labor and a healthy environment should be available in the near vicinity.

c) ***Selection of appropriate dam type***

The selection of an appropriate dam at a given site depends up on many physical factors such as topography, geology, foundation conditions, availability of materials, suitable site for spillway, etc. A summary of the characteristics of the site conditions vis-à-vis type of dam suitable for the situation is discussed in the following table.

No.	Character of the site		Type of dam
I	Foundation characteristics	a Impervious solid rock such as schist and gnesis	Any type
		b Gravel and coarse sands	Earth/rock-fill
		c Grit, sand and silt clay	Earth
		d Very fine and uniform sands	Earth
		e Clay, plastic clay	Earth fill with very flat slope
		f Silt and fine sand	Low gravity or earth dam
		g Heavy over-burden on rock layer	Earth/r buttress
II	Character of gorge	a V-shaped narrow gorge	Arch
		b U-shaped	Overflow concrete
		c Low-wide gorge	Earth/rock-fill
III	Character of construction materials	Ingredients of concrete, i.e., sand, shingle and cement -----if locally available	Concrete
		Sand, shingle and cement involve long distance carriage	Buttress
		Pervious and impervious soils and stone (for rip-rap) locally available	Earth/rock-fill
		Stone of required specific gravity and size available	Stone masonry
IV	Spillway requirement	Spillway location separate from main dam	Earth
		Adequate width for dam only	Gravity with overflow spillway
		Large spillway requirement	Overflow concrete
V	Region character risks	Seismic zone	Earth and concrete gravity
		Excessive uplift pressure exerted	Arch

Figure 1.6a. Characteristics of the site with type of dam

1.6. Foundation of dams 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

For convenience, foundation may be classified as rock, coarse grained materials and fine grained materials foundations.

A. *Rock Foundations:*

Most unweathered cemented rocks possess sufficient strength to support dams of usual height. However, the usual problems are leakage, sliding because of cracks, faults, fissures, etc. Surface rock is usually weathered hence the weathered portion has to be removed and excavation has to be deep enough to give a firm “toe hold”.

The foundation treatments commonly adopted are surface preparation and foundation grouting.

A.1. *Surface preparation:*

- Removing the entire loose soil till sound bedrock is exposed without damaging the underlying rock.
- If faults, seams or shattered rock zones are detected in the exploratory geological investigations, special steps and remedies must be taken to ensure their removal.

A.2. *Foundation grouting:*

It is the process of injecting grout consisting of cementitious material in to the foundation of the dam to act as a binder and fill the voids for improving the stability and impermeability of the pervious foundation.

a. *Consolidation grouting:*

- It is also called area or blanket grouting
- The objectives of consolidation grouting are to strengthen the rock, to stop water passage through the disintegrated rock, to increase bearing strength of the strata and to seal off major crevices.
- It is done in an area, usually the entire dam foundation, by drilling shallow holes (3 to 15 m deep) on a grid pattern at a spacing of 5 to 30 m. The drilled holes are grouted by a mixture of cement and water termed as grout at a low pressure of not higher than 3.5 kg/cm^2 .
- This comparatively shallow and low pressure grouting is done for the general consolidation of the foundation before concreting of the dam section and is followed by high pressure grouting after some concreting of the dam has taken place.
- It also helps in checking the leakage of high-pressure grout used later in the curtain grouting.

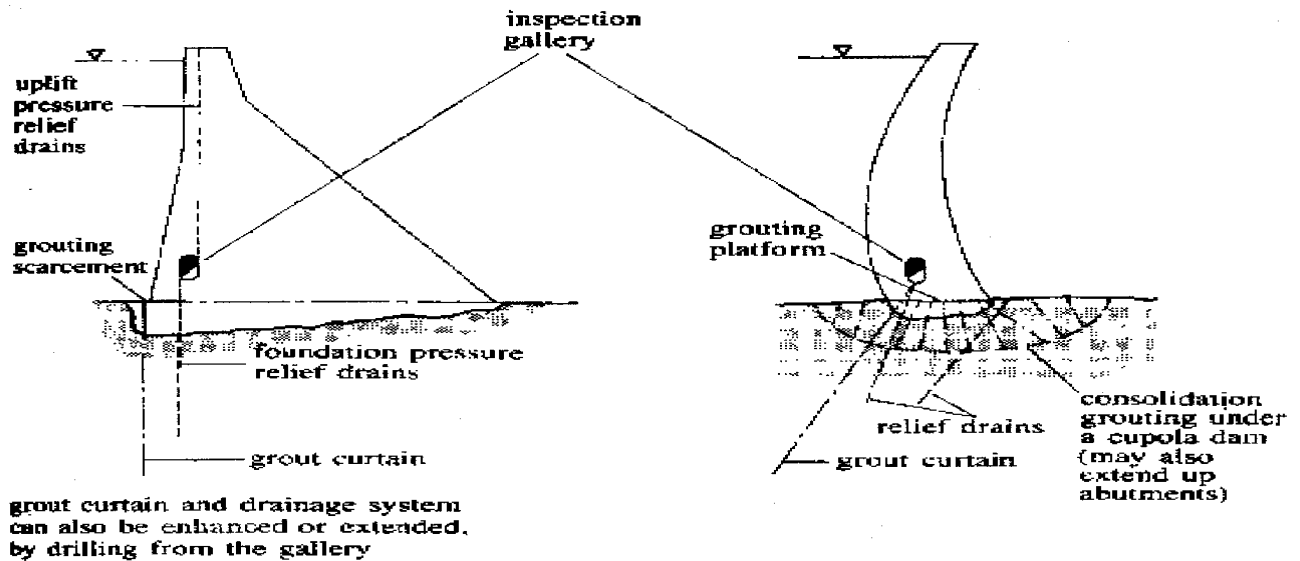


Figure 1.8. Grouting and pressure relief drain systems

b. Curtain grouting:

- Curtain against the seepage (leakage) through the foundations, and thus reduces the uplift pressure. It helps in reducing seepage through the foundation. To achieve this, high pressure grouting is required and relatively deeper holes are drilled near the heel of the dam.
- Curtain grouting (or high pressure grouting) is done to form a deep curtain wall or an impervious barrier in the foundation just down-stream of the heel of the dam.
- Holes required for curtain grouting are quite deep. The holes are usually vertical but sometimes it could be inclined. Inclined holes are required to intercept the inclined joints in the rock to develop an effective grout curtain.
- Generally, only one line of grout holes parallel to the axis of the dam is sufficient. However, in the case of very high dam, another set of holes may also be required after the first set has been grouted at a relatively lower pressure.

B. Silt and Clay Foundation (fine grained material for foundations):

Such foundation materials are sufficiently impervious. The main problem is bearing capacity. The method of treatment of the foundation is based on the type of soil, the location of water table and the state of compaction of the soil.

The treatment is actually depends on the compression characteristics of the soil foundation. If appreciable post construction settlement is not expected up on saturation, little foundation treatment is necessary. If appreciable post construction settlement is expected up on saturation, measures to minimize the settlement should be adopted.

- *Some of the treatment methods for fine-grained soil foundations are as follows:*

- 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.

C. *Sand and Gravel Foundation (coarse grained material for foundations):*

These types of foundations are largely of alluvial origin, and basically seepage and force exerted by seepage are the main problems encountered. The extent of treatment of these problems is dependent on:

- The purpose of the dam (seepage quantity is little concern for detention dams)
- The necessity of down-stream releases

However, regardless of seepage, adequate measures have to be provided to reduce the danger of piping.