Dams
A dam is a hydraulic structure of fairly impervious material built across a river to create a reservoir on its upstream side for impounding water for various purposes.

A dam and a reservoir are complements of each other.

Dams are generally constructed in the mountainous reach of the river where the valley is narrow and the foundation is good.
Generally, a hydropower station is also constructed at or near the dam site to develop hydropower.

Dams are probably the most important hydraulic structure built on the rivers.
Classification of Dams
Based on the function being served, dams can be classified into:

- Storage dams
- Detention dams
- Diversion dams
- Debris dams
- Coffer dams
Storage dams

- Storage (or conservation) dams are constructed to store water during the rainy season when there is a large flow in the river.

- The stored water is utilized later during the period when the flow in the river is reduced and is less than the demand.
◦ The water stored in the reservoir is used for a number of purposes, such as irrigation, water supply and hydropower.

◦ Storage dams are the most common type of dams and in general the dam means a storage dam unless qualified otherwise.
Detention Dams

- Detention dams are constructed for flood control.
- A detention dam retards the flow in the river on its downstream during floods by storing some flood water.
- Thus the effect of sudden floods is reduced to some extent.
The water retained in the reservoir is later released gradually at a controlled rate according to the carrying capacity of the channel downstream of the detention dam.

Thus the area downstream of the dam is protected against flood.
Diversion Dams

- A diversion dam is constructed for the purpose of diverting water of the river into an off-taking canal (or a conduit).

- A diversion dam is usually of low height and has a small storage reservoir on its upstream.

- The diversion dam is a sort of storage weir which also diverts water and has a small storage.

- Sometimes, the terms weirs and diversion dams are used synonymously.
- **Debris Dams**
  - A debris dam is constructed to retain debris such as sand, gravel, and drift wood flowing in the river with water.
  - The water after passing over a debris dam is relatively clear.
Coffer Dam

- A coffer dam is not actually a dam. It is rather an enclosure constructed around the construction site to exclude water so that the construction can be done in dry.

- A coffer dam is thus a temporary dam constructed for facilitating construction.
A coffer dam is usually constructed on the upstream of the main dam to divert water into a diversion tunnel (or channel) during the construction of the dam.

When the flow in the river during construction of the dam is not much, the site is usually enclosed by the coffer dam and pumped dry.

Sometimes a coffer dam on the downstream of the dam is also required.
(a) Diversion by tunnel

Construction zone

Upstream cofferdam

Downstream cofferdam

First stage

Flow in stream bed

Completed portion of dam

Construction zone

Flow through sluiceway

Second stage

(b) Typical two-stage diversion
Classification on Hydraulic design

- Overflow dam
- Non overflow dam
Overflow Dam

- An overflow dam is designed to act as an overflow structure.

- The surplus water which cannot be retained in the reservoir is permitted to pass over the crest of the overflow dam which acts as a spillway.

- The overflow dam is made of a material which does not erode by the action of overflowing water.

- Generally, cement concrete is used in overflow dams and spillways.
Most of the gravity dams have overflow sections for some length and the rest of the length as a non-overflow dam.

However, sometimes the entire length of the dam of low height is designed as an overflow dam.

The overflow dam is also called the spillway section.
Non overflow dam

- A non overflow dam is designed such that there is no flow over it.

- Because there is no overflow, a non–overflow dam can be built of any material, such as concrete, masonry, earth, rock fill and timber.

- As already mentioned, the non–overflow dam is usually provided in a part of the total length of the dam.
• However, sometimes the non overflow dam is provided for the entire length and a separate spillway is provided in the flanks or in a saddle away from the dam.

• Fig shows a non overflow earth dam.
Based on the materials used in construction, the dams are classified as follows:

- (1) Masonry dam,
- (2) Concrete dam,
- (3) Earth dam,
- (4) Rock fill dam,
- (5) Timber dam,
- (6) Steel dam,
- (7) Combined concrete–cum–earth dam, and
- (8) Composite dam.
Based on rigidity

- Rigid dams
- Non rigid dams
Rigid dams

- A rigid dam is quite stiff.

- It is constructed of stiff materials such as concrete, masonry, steel and timber.

- These dams deflect and deform very little when subjected to water pressure and other forces.
Non rigid dams

- A non–rigid dam is relatively less stiff compared to a rigid dam.
- The dams constructed of earth and rock fill are non–rigid dams.
- There are relatively large settlements and deformations in a non–rigid dam.
- Rock fill dams are actually neither fully rigid nor fully non–rigid.
- These are sometimes classified as semi rigid dams
Classification based on structural action

- Gravity dams,
- Earth dams,
- Rock fill dams,
- Arch dams,
- Buttress dams,
- Steel dams, and
- Timber dams.
Gravity Dams

- A gravity dam resists the water pressure and other forces due to its weight (or gravitational forces).

- Thus the stability of a gravity dam depends upon its weight.

- The gravity dams are usually made of cement concrete.
In the past, the gravity dams were made of stone masonry but now the masonry dams are rarely constructed, except for very small heights.
- The gravity dams are generally straight in plan (i.e. axis is straight from one abutment to the other) and are called straight gravity dams.

- However, sometimes they are slightly curved in plan, with convexity towards the upstream and are called curved-gravity dams (Hoover dam).

- The gravity dams are approximately triangular in cross-section, with apex at the top.
• The gravity dams are generally more expensive than earth dams but are more durable.

• They are quite suitable for the gorges with very steep slopes. They require strong rock foundation.

• However, if the foundation consists of soil, the height of the gravity dams is usually limited to 20 m or so.
A gravity dam is called solid gravity dam when it is a solid mass of concrete (or masonry) with no hollow spaces inside the dam, except for small drainage galleries or shafts.

On the other hand, a hollow gravity dam has large hollow spaces left within the body of the dam for the purpose of reducing the weight and for more effective use of concrete for resisting the stresses.

Hollow gravity dams are similar to buttress dams.
Hollow gravity dams are rarely constructed these days.

Hence, the gravity dam, in general, means a solid gravity dam.
Concrete Gravity Dam with Overflow Section
Advantages

◦ Gravity dams are quite strong, stable and durable.

◦ Gravity dams are quite suitable across moderately wide valleys and gorges having steep slopes where earth dams, if constructed, might slip.

◦ Gravity dams can be constructed to very great heights, provided good rock foundations are available.

◦ Gravity dams are well adapted for use as an overflow spillway section. Earth dams cannot be used as an overflow section.
- Even in earth dams, the overflow section is usually a gravity dam.

- Gravity dams are specially suited to such areas where there is very heavy downpour.

- The slopes of the earth dams might be washed away in such an area.

- The maintenance cost of a gravity dam is very low.
The gravity dam does not fail suddenly. There is enough warning of the imminent failure and the valuable property and human life can be saved to some extent.

Gravity dam can be constructed during all types of climatic conditions.
Disadvantages

- Gravity dams of great height can be constructed only on sound rock foundations.

- These cannot be constructed on weak or permeable foundations on which earth dams can be constructed.

- However, gravity dams up to 20 m height can be constructed even when the foundation is weak.
- The initial cost of a gravity dam is usually more than that of an earth dam.

- At the sites where good earth is available for construction and funds are limited, earth dams are better.

- Gravity dams usually take a longer time in construction than earth dams, especially when mechanised plants for batching, mixing and transporting concrete are not available.
Gravity dams require more skilled labour than that in earth dams.

Subsequent raising is not possible in a gravity dam.
Earthen dams

- An earth dam is made of earth (or soil).
- 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 behaviour of an earth dam is entirely different from that of a gravity dam.
- The earth dams are usually built in wide valleys having flat slopes at flanks (abutments).
• The foundation requirements are less stringent than those of gravity dams, and hence they can be built at the sites where the foundations are less strong.

• Height of the dam normally depends upon the strength of the foundation material too.

• Normally have zoned sections, with an impervious zone (called core) in the middle and relatively pervious zones enclosing the impervious zone on both sides.
- If the earth dam is built on a pervious foundation, a concrete cut off wall or a steel sheet pile line is also provided in the continuation of the core section.

- Moreover, a drainage filter or a rock toe is provided on the downstream to carry away the water that seeps through the dam and its foundation.

- Earth dams are usually cheaper than the gravity dams if suitable earth in abundant quantity is easily available near the site.
(a) Simple zoned embankment

(b) Earth dam with core extending to impervious foundation
Advantages

- Earth dams are usually cheaper than gravity dams if suitable earth for construction is available near the site.
- Earth dams can be constructed on almost all types of foundations, provided suitable measures of foundation treatment and seepage control are taken.
- Earth dams can be constructed in a relatively short period.
- The skilled labour is not required in construction of an earth dam. Earth dams can be raised subsequently.

- Earth dams are aesthetically more pleasing than gravity dams.

- Earth dams are more earthquake-resistant than gravity dams.
Disadvantages

- Earth dams are not suitable for narrow gorges with steep slopes.
- An earth dam cannot be designed as an overflow section. A spillway has to be located away from the dam.
- Earth dams cannot be constructed in regions with heavy downpour, as the slopes might be washed away.
The maintenance cost of an earth dam is quite high. It requires constant supervision.

An earth dam fails suddenly without any sign of imminent failure. A sudden failure causes havoc and untold miseries.
Rock fill dam

- A rockfill dam is built of rock fragments and boulders of large size.

- An impervious membrane is placed on the rockfill on the upstream side to reduce the seepage through the dam.

- The membrane is usually made of cement concrete or asphaltic concrete.
In early rockfill dams, steel and timber membrane were also used, but now they are obsolete.

A dry rubble cushion is placed between the rockfill and the membrane for the distribution of water load and for providing a support to the membrane.

Sometimes, the rockfill dams have an impervious earth core in the middle to check the seepage instead of an impervious upstream membrane.

The earth core is placed against a dumped rockfill.
- It is necessary to provide adequate filters between the earth core and the rockfill on the upstream and downstream sides of the core so that the soil particles are not carried by water and piping does not occur.

- The side slopes of rockfill are usually kept equal to the angle of repose of rock, which is usually taken as 1.4:1 (or 1.3:1).

- Rockfill dams require foundation stronger than those for earth dams. However, the foundation requirements are usually less stringent than those for gravity dams.
Rockfill dams are quite economical when a large quantity of rock is easily available near the site.

These dams have the same advantages over the gravity dams as the earthen dams but the particular ones over the earthen ones are
Advantages

- Rockfill dams are quite inexpensive if rock fragments are easily available.
- Rockfill dams can be constructed quite rapidly.
- Rockfill dams can better withstand the shocks due to earthquake than earth dams.
- Rockfill dams can be constructed even in adverse climates.
Disadvantages

- Rockfill dams require more strong foundations than earth dams.
- Rockfill dams require heavy machines for transporting, dumping and compacting rocks.
Arch Dams

- An arch dam is curved in plan, with its convexity towards the upstream side.

- An arch dam transfers the water pressure and other forces mainly to the abutments by arch action.

- An arch dam is quite suitable for narrow canyons with strong flanks which are capable of resisting the thrust produced by the arch action.

- The section of an arch dam is approximately triangular like a gravity dam but the section is comparatively thinner.
The arch dam may have a single curvature or double curvature in the vertical plane.

Generally, the arch dams of double curvature are more economical and are used in practice.

The quantity of concrete required in an arch dam is less than that for a gravity dam, but it is not necessarily less expensive because of high cost of concrete and form work.
Advantages

- An arch dam requires less concrete as compared to a gravity dam as the section is thinner.

- Arch dams are more suited to narrow, V-shaped valley, having very steep slopes.

- Uplift pressure is not an important factor in the design of an arch dam because the arch dam has less width and the reduction in weight due to uplift does not affect the stability.
Disadvantages

◦ An arch dam requires good rock in the flanks (abutments) to resist the thrust. If the abutments yield, extra stresses develop which may cause failure.
◦ The arch dam requires sophisticated formwork, more skilled labour and richer concrete.
◦ The arch dam cannot be constructed in very cold climates because spalling of concrete occurs due to alternate freezing and thawing.
◦ The arch dams are more prone to sabotage.
◦ The speed of construction is relatively slow.
Buttress dam

- Buttress dams are of three types:
  - Deck type,
  - Multiple archtype,
  - Massive–head type.
A deck type buttress dam consists of a sloping deck supported by buttresses.

Buttresses are triangular concrete walls which 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.
In a multiple-arch type buttress dam the deck slab is replaced by horizontal arches supported by buttresses. The arches are usually of small span and made of concrete.

In a massive-head type buttress dam, there is no deck slab. Instead of the deck, the upstream edges of the buttresses are flared to form massive heads which span the distance between the buttresses.
The buttress dams require less concrete than gravity dams. But they are not necessarily cheaper than the gravity dams because of extra cost of form work, reinforcement and more skilled labour.

The foundation requirements of a buttress dam are usually less stringent than those in a gravity dam.
Multiple Arch Buttress Dam (u/s side)
Hydrostatic load

Section through massive buttress

Buttress

Haunch

Mushroomed head buttress
Advantages

- Buttress dams require less concrete than gravity dams.
- The uplift pressure is generally not a major factor in the design of buttress dams.
- Buttress dams can be constructed on relatively weaker foundations.
- Power house and water treatment plants, etc. can be housed between buttresses.
• The ice pressure is relatively less important because ice tends to slide over the inclined deck.

• The vertical component of the water pressure on deck prevents the dam against overturning and sliding failures.

• Buttress dams can be designed to accommodate moderate movements of foundations without serious damages.
- The back of the deck and the foundation between buttresses are accessible for inspection.

- Buttress dams can be easily raised subsequently by extending buttresses and deck slabs.
Disadvantages

- Buttress dams require costlier formwork, reinforcement and more skilled labour.
- Consequently, the overall cost of construction may be more than that of a gravity dam.
- Buttress dams are more susceptible to damage and sabotage.
- Buttress dams cannot be constructed in very cold climates because of spalling of concrete.
- Because the upstream deck slab is thin, its deterioration may have very serious effect on the stability.
- Timber and steep dams are not used extensively and are not part of the course.
Surveys for site selection
The object of investigation survey for a dam site is to evolve a suitable location, design and construction of the dam structure which is expeditious, economical and at the same time effects the desired impounding of water.

Topographic Survey may either be preliminary or final.
Along with reconnaissance of area, the preliminary survey aims at obtaining sufficient details to establish merits and demerits of various site, the most economical and suitable dam site & tentative cost.

It also includes trial borings, geological and hydrological studies.
Final survey is conducted in respect of the finally selected site to obtain precise data for detailed design and precise estimates of the construction cost.

Other benefits of carrying out a final survey include:
The dam site topographical map is prepared to cover an area sufficient enough to accommodate all possible arrangements that include spillway, outlet works and diversion works etc.

- the plan covers an area of approximately 200m u/s and 400m d/s.
The reservoir submergence plan may be prepared showing elevation high enough to allow anticipated maximum reservoir level.

- Command area plan is prepared
- River is surveyed 10km u/s and 10km d/s.
- Longitudinal section is of canals originating from the reservoir is also prepared.
Survey plan of power house is prepared.

L-section of penstock and tail race channel is prepared.

Survey plan of surge tank area is prepared.

Plain table surveying for the selection of suitable site for residential colony, workshop and complex etc is also carried out.
- Estimates for excavation, filling and concrete works are also prepared.

- Computation of the quantity of land acquisition along with the compensations for the land and the property to be submerged is also made.
- Determination of type and height of dam is also done.

- Areal survey is also carried out as it helps in computing the storage capacity at various levels along with the land and properties to be submerged.

- Reservoir capacity is also determined.

- Reservoir area can also be computed.
Geological investigation

- This is carried out to collect data regarding
  - Geological features folds, faults, fissures etc their nature and extent.
  - Water tightness of the reservoir basin
  - Existing and potential slide area
  - Assessment of valuable minerals in reservoir area
  - Ground water condition
  - Seismic conditions etc.
Foundation investigation

- Foundation Investigation for earth, rock fill and masonry dams includes investigation to determine properties of foundation soil, hidden weak spots and shear zones etc and depth of overburden.

- Usual methods of exploration include
  - Bore holes
  - Excavation of open pits
  - Tunneling into the side of the valley
  - Core drilling
Meteorological studies

- On the watershed plan, normal annual isohyets (rainfall contours) location of rain gauge stations, gauge and discharge sites and interprovincial boundaries are supposed to be shown.

- Assessment of rainfall in the catchments

- Collection and evaluation of data and frequencies of heavy rain fall

- Mean monthly temperature, wind velocities, relative humidity etc.
Hydrological Investigation

- Gauge and discharge observation, past flood, hydrographs to fix spillway capacity, rainfall–runoff correlation studies etc.

- Loss of storage capacity by silting is a very vital issue for determining the useful life of the reservoir.

- Sediment observation shall be carried for 3 years for suspended load, bed load and natural soil conditions including catchment characteristics from point of erosion.
A map showing the location and availability of construction material is prepared.

A map showing existing roads, proposed roads water and rail routes with information on load and size limitation, electric power source and transmission lines, telephone lines and rerouting of communication system if disrupted is also prepared.
The environmental impact of the project on navigation, fish culture, wild life, ground water and ecology of the area is investigated.
Selection of Dam site

- Good catchment u/s of dam
- Minimum length of dam
- Minimum height of dam
- Suitable foundation
- Availability of suitable location for spillway.
- Availability of suitable construction material
- Ensure adequate capacity of reservoir
- Minimum construction and maintenance cost
- Suitable site for residential colony and offices
- Diversion of river possible during the project period
- Land to be submerged should be of low value
- Location of dam and appurtenant (related works) should be in one province
- Good water supply carrying minimum sediments
Dam site selection
It depends upon

**Topography**

U- Shaped volley suitable for concrete overflow dam.

A narrow V- shaped valley is suitable for arch dam.

A wide gorge with separate site for spillway is suitable for earthen dam.
Geology and nature of dam
Masonry and concrete dams are constructed on rocky foundation.

Well compacted gravel foundation is suitable for low gravity dam, earthen dam and rock fill dam.

Silty and fine sandy foundation is suitable for earth dam.

Clay foundation is suitable for earthen dam.
- A suitable site for the required size and type of spillway governs the type of dam to be constructed.

- The type of dam suitable for the given foundation and site conditions is also governed by the safety consideration.

- Economical availability of construction materials determines the type of dam to be constructed.
Earthquake factor should also be considered in the design of a dam.

The type of dam to be constructed depends on the purpose to be served e.g. storage dam for hydro power, irrigation & floods.

Concrete and masonry dams have more life than earthen and rock fill dams.