Lecture 12

Role of Geology in Site Selection of

Highways, Airfields, Bridges

Dams, Reservoirs, Tunnels

Geology in Civil Engineering Projects

- A detailed and accurate knowledge inventory of geology is an essential consideration for civil engineering projects. Construction of civil engineering projects like highways bridges, airfields dams, reservoirs, tunnels etc.
- This knowledge allows projects to be planned & executed under the consideration of safety precautions, and using material which are more stable, durable and economical.
- Rocks are the most common material which is used in the construction of foundation. Geology provides us with information to chose the most suitable of the various types available. The local geology of an area is important when planning a major construction.
- The full knowledge of geology allows for a selection of a feasible site and increases the strength, stability, and durability of civil engineering projects.

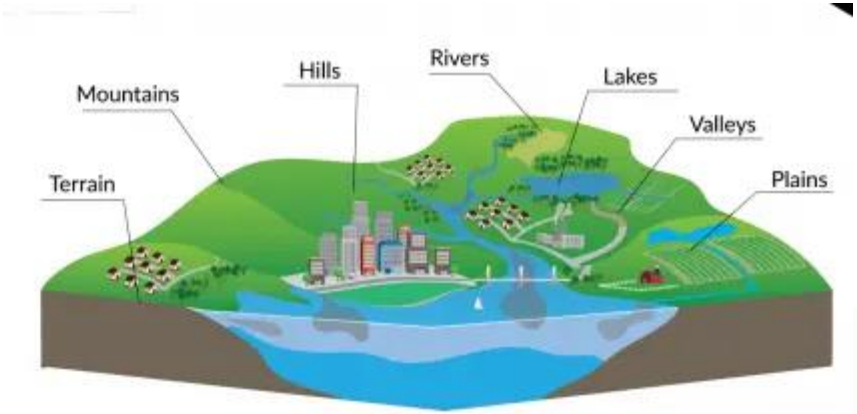
Geology in Civil Engineering

- Topography
- Geological Materials
  - As Foundation (Firm soil strata, rock strata)
  - As Construction Materials (sand, gravel, aggregate, rip-rap)
- Seismicity of the area (**risk** related to earthquake)

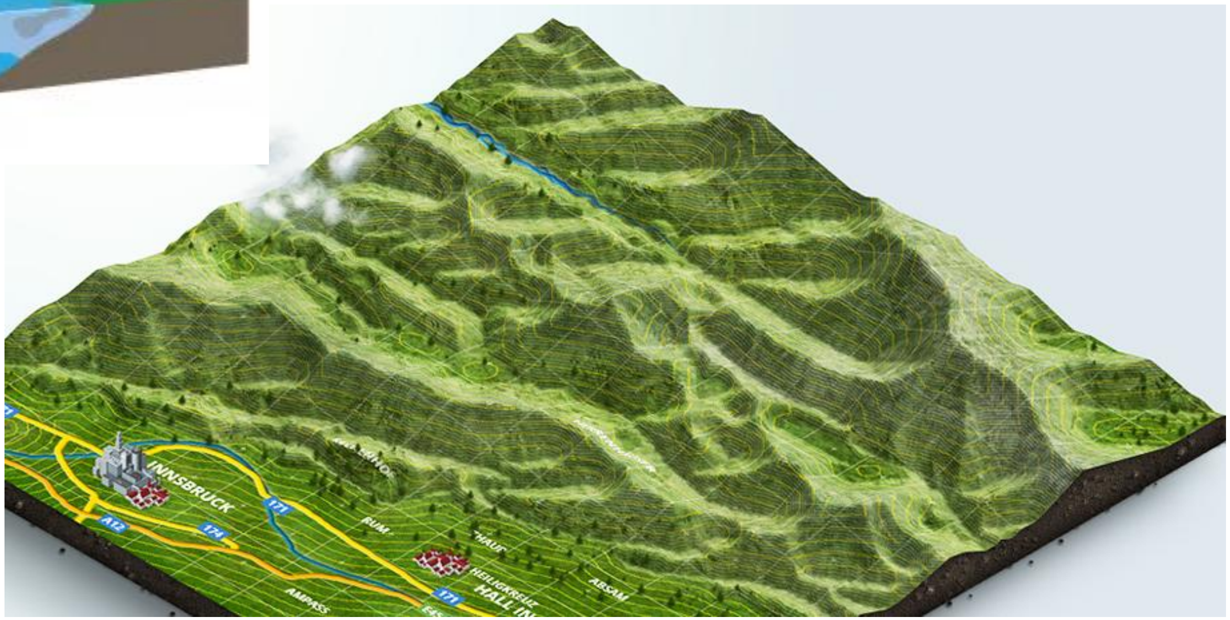
Topography & Geology

- Topography is the practice of graphic delineation in detail usually on maps or charts of natural and man-made features of a place or region especially in a way to show their relative positions and elevations. Topography is an expression, by means of physical features, not only of the geology of a country, but to a very large extent of its geological history.
- Geology is the study of the Earth, the materials of which it is made, the structure of those materials, and the processes acting upon them. It includes the study of organisms that have inhabited our planet. An important part of geology is the study of how Earth's materials, structures, processes and organisms have changed over time.

Topography



Mountains
Hills
Rivers
Lakes
Valleys
Plains
Terrain



INNSBRUCK
A12
174
171
RUM
ABSAM
AMPASS


116
116
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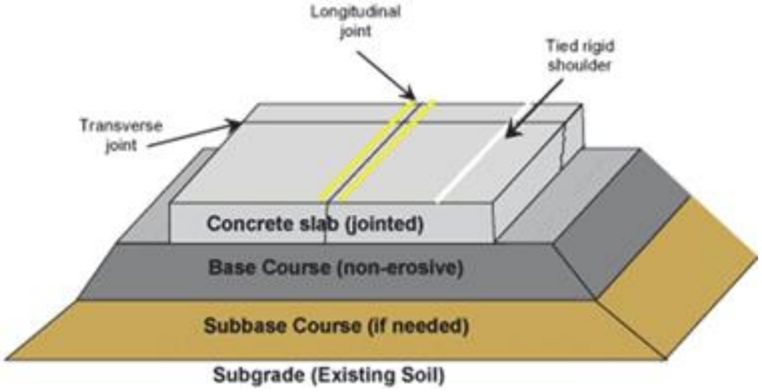
Los Trois Rivieres

Highways

- Highway Alignment Selection/Route Selection
- Geometric design

- Pavement design



Highways

- Route selection/Alignment selection
  - Terrain: The topography of the land traversed has an influence on the alignment of roads. Topography affects horizontal alignment, but has an even more pronounced effect on vertical alignment. To characterize variations in topography, engineers generally separate it into three classifications according to terrain—level, rolling, and mountainous. Very steep or difficult terrain poses significant engineering geological challenges
  - Unsuitable material for subgrade or unavailability of construction materials
  - Grade and horizontal & vertical curves (International criteria need to be fulfilled - AASHTO) – Purpose i.e. type of traffic highway is intended to serve
- The prediction of ground conditions for earthworks design and for slope and drainage protection works.
- Slope stability
  - Excavation cuts (soil/rock), embankments
  - Type of rocks (geological maps or geotechnical investigations)
  - Cost involved in protection works
  - Construction & maintenance requirements
- Grade separation required or not (due to high speed requirements or congestion or accidents avoidance). i.e. underpass or overpass
- Tunnels

Terrain

Level

Rolling

Mountainous

Highways

- Cut and fill involved in horizontal and vertical curves along with protection works and availability of suitable materials – effect on cost & construction time – overall determines the feasibility of a particular route/alignment
- Drainage requirements (slopes & structures) – cost effect
- Rock good quality – hard to excavate, low protection/maintenance
- Cut with respect to dip and strike (parallel to dip direction most feasible provided the rest of conditions are favorable)

Airfields

- An area of land set aside for the take-off, landing, and maintenance of aircraft.

Or

- A level area where aircraft can take off & land, with fewer buildings and services than an airport and used by fewer passengers

Airfields

- Every major phase of air transport is influenced by geology. Geology affects the installation of ground facilities, the accessibility of an airport to the community it serves, and the flight patterns that aircraft must adopt when approaching or leaving an airfield, and during take-off and landing operations.
- The proper selection and development of an airport site is conditioned by three primary factors, safety, accessibility, and economy. Of these, the most important is safety. Each of these three basic considerations is affected by the geology of any proposed airfield location.

- Just for additional knowledge on phases of a flight:

https://www.fp7-restarts.eu/index.php/home/root/state-of-the-art/objectives/2012-02-15-11-58-37/71-book-video/parti-principles-of-flight/126-4-phases-of-a-flight.html

Airfields

- Basic requirement of an airport is that it have a relatively flat area of land sufficiently large to accommodate the runways and other facilities and that this area be in a locality free from such obstructions to air navigation as mountains and tall buildings.
- Flat or very gently undulating land is necessary, because runways must be constructed according to restrictions on maximum allowable slopes - which in turn are governed by aircraft performance on landing and takeoff.
- The principal determinants of airport layout are the number of runways and their orientation, the shape of the available site. The location and orientation of runways is governed in turn by the need to avoid obstacles, particularly during landing and takeoff procedures. For the largest airports, obstacles to air navigation must be considered up to about 15 km (10 miles) from the runways.
- Natural drainage patterns (well drained area - less drainage works – less cost & time plus less maintenance)
- Underground water (availability, recharge productivity, water table w.r.t. during and after construction affecting strata, its potential pollution being an environmental aspect which is very important in airport site selection)

Airfields

- Volume & conditions of excavation, landfills and reuse of excavation materials
- Soil properties and treatment
- Ground access to airport: Development costs are also estimated, taking into account the nature of the terrain, soil and rock conditions, drainage requirements, and local land values (access roads, connecting highways, parking areas etc.).
- Geology controls the availability and quality of airport construction materials, and may either increase or decrease the cost of providing runways, taxiways and buildings.
- Since the natural soil on which most airports are built has resulted in large part from geological processes, the influence of geology is also reflected in the engineering problems presented by the properties of the soil at the site.
- Works management and materials for infrastructure platform
- Construction timing
- Seismic occurrence (probability, frequency, severity)

Bridges

- Bridge is the structure that spans horizontally between supports, whose function is to carry vertical loads.
- A bridge may be defined as a structure built over a river, a dry valley, low land or an estuary or any depressed part of the land to provide a link between the two opposite sides. It is essentially a communication link on a road or railway track or a highway. Bridges] especially over major rivers and in hilly and mountainous areas are very important civil engineering structures. Their role in socio-economic development and defence strategies can hardly be overemphasized.
- The prototypical bridge is quite simple—two supports holding up a beam—yet the engineering problems that must be overcome even in this simple form are inherent in every bridge: the **supports must be strong enough to hold the structure up**, and the **span between supports must be strong enough to carry the loads**. Spans are generally made as short as possible; long spans are justified where good foundations are limited.

Bridges

- In most cases the location of a bridge is decided more by socio-economic factors than by geological considerations.
- But the design, stability and durability depend, to a great extent, on the subsurface geological conditions that must be properly investigated and cautiously interpreted.
- In any major bridge construction project, the designer is keen to place the bridge abutments and piers on as sound, strong and stable rock foundation below as possible.

Bridges

- Suitable foundation material: In most cases, the river bed below the water is covered by varying thickness of unconsolidated natural deposits of sand, gravels and boulders.
- Such loose materials are not safe as foundations for bridge piers for at least two reasons: Firstly, piers placed directly on them would be unstable; Secondly, the cover material is liable to be removed due to scouring by river water.
- As such, the pier must be placed on stable foundation, preferably of rock, under a suitable thickness of cover material so that it is safe from scour by river water.
  - The depth to the bed rock;
  - The nature of the bed rock
  - The structural characteristics of rocks
- Such sound bed rocks might be available within a depth varying from 5 to 20 meters below a river bed or they might not at all be available even up to 100 meter or more. All that depends on the local geology which has to be investigated and understood.

Bridges

- The height of pier from under the span to the foundation level, therefore, depends on the ‘depth of the bed rock’ below the river water. Therefore, cost and availability of required technology to construct certain heights in the area affect the choice of site and type of bridge.
- Complex nature of loading demands (water thrust and dynamic traffic loading) for a thorough investigation of foundation strata
- Seismicity of the area – Location of fault lines w.r.t. bridge foundations
- When the bridge sites have to be located in the zones of seismic activity, the foundations are required to be designed for additional seismic loads as specified in the codes of respective areas.

Bridges

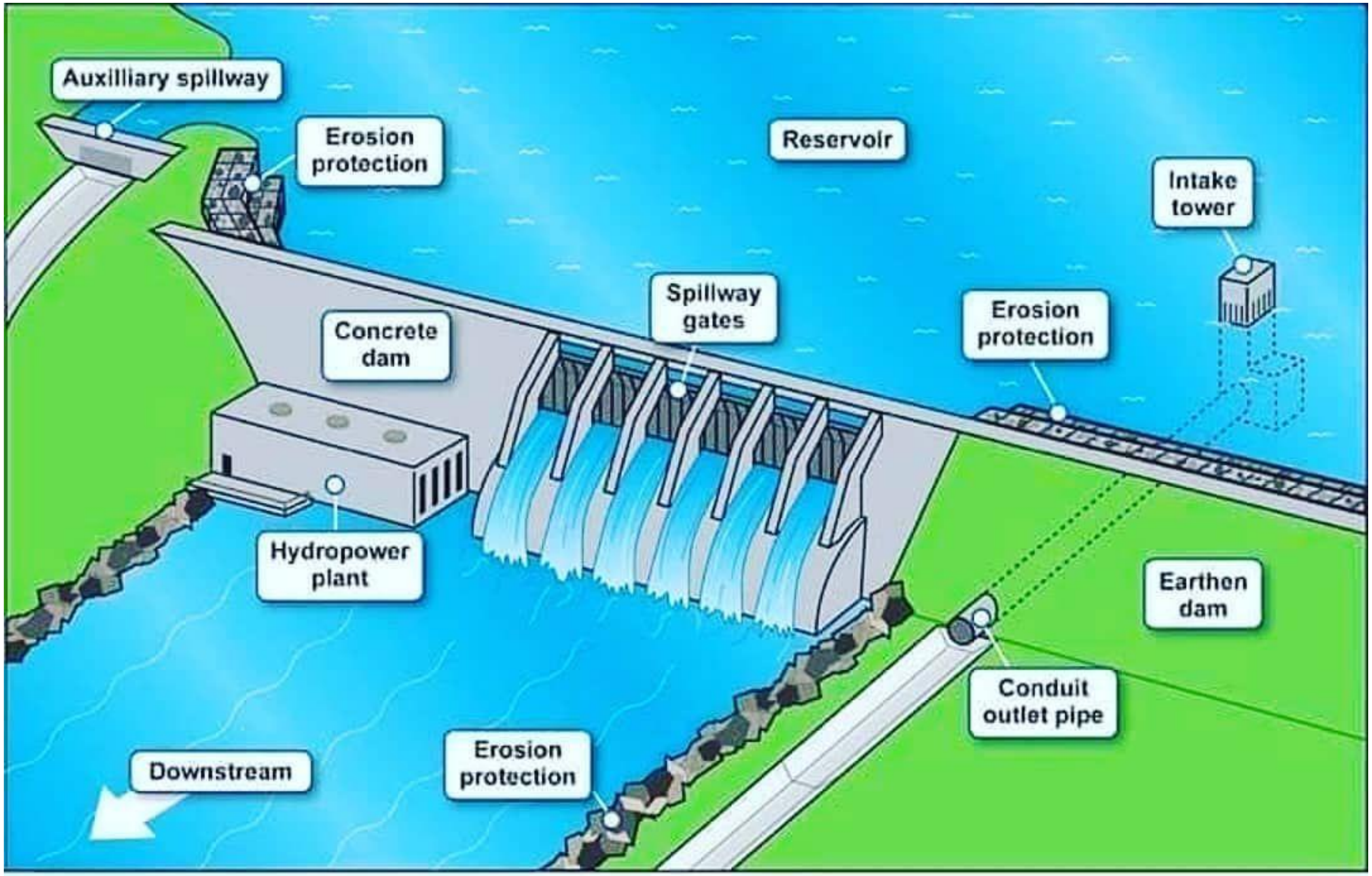
- The nature of the bed rock is commonly determined through study of petrological characters and engineering properties, especially the strength values, using the core samples obtained during drilling of test bore holes. In fact complete and very useful geological profiles could be prepared all along the centre line of the proposed bridge from the study of such core logs.
- These (profiles) would depict complete sequence (and even structural disposition) of the rock formations existing below the surface material up to a desired depth. A decision to place the pier on a particular rock at a particular depth is then matter of judgement and design requirements.
- Most igneous and massive type of sedimentary and metamorphic rocks is quite strong, stable and durable as foundations for bridge piers and abutments. The group of weak rocks which might behave badly in the presence of water includes such types as limestones, chalk, friable sandstones especially with clayey cements, shales, clays, slates, schists and the layers of peat and compressible organic material. **Many of them are amenable to treatment by artificial methods**.

Bridges

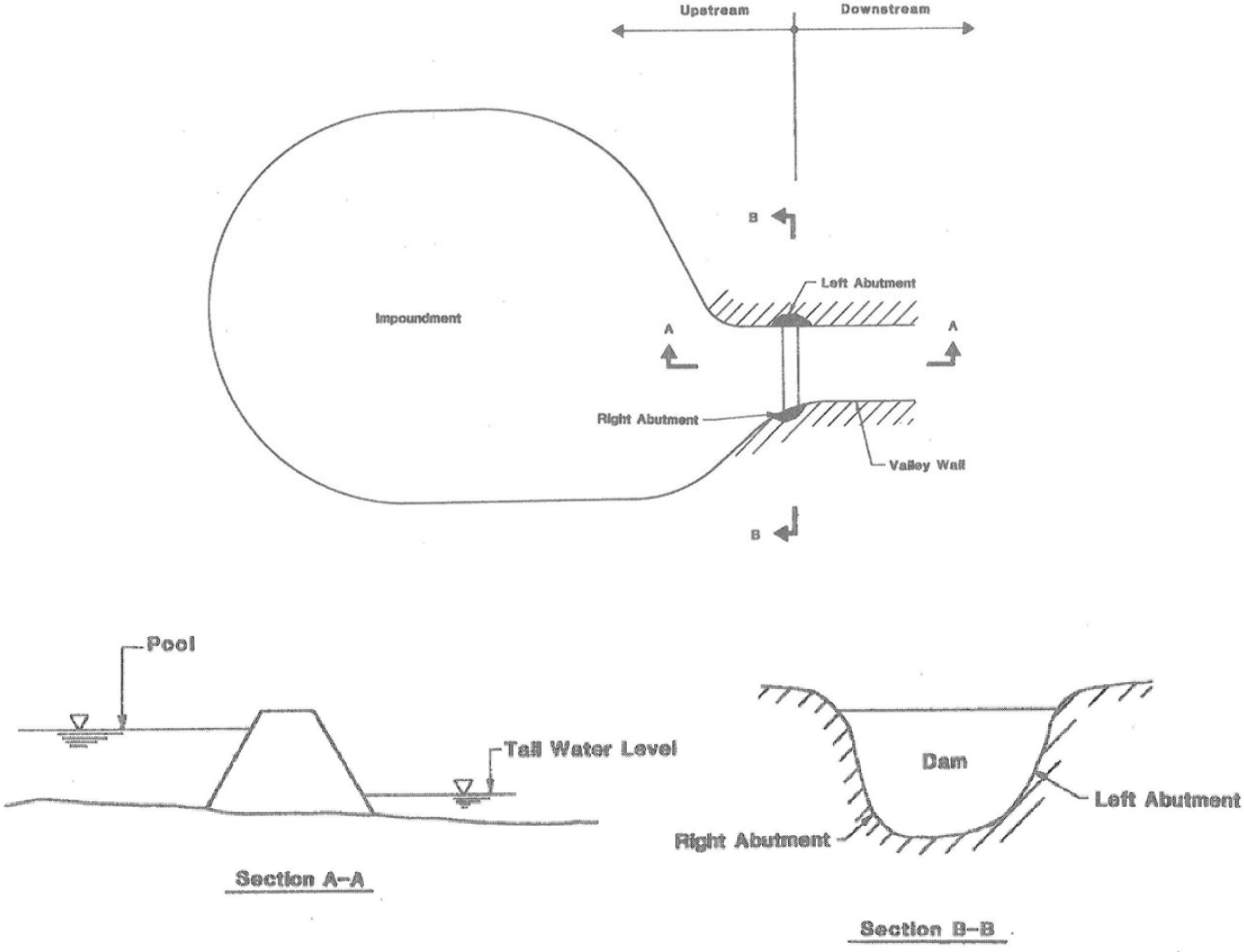
- Type of foundation required and that available in the area
- Scouring is also an important factor which is also dependent partially on river bed material.
- Balance to be found between cost of substructure and superstructure while finalization of a site for bridge site.

Dams

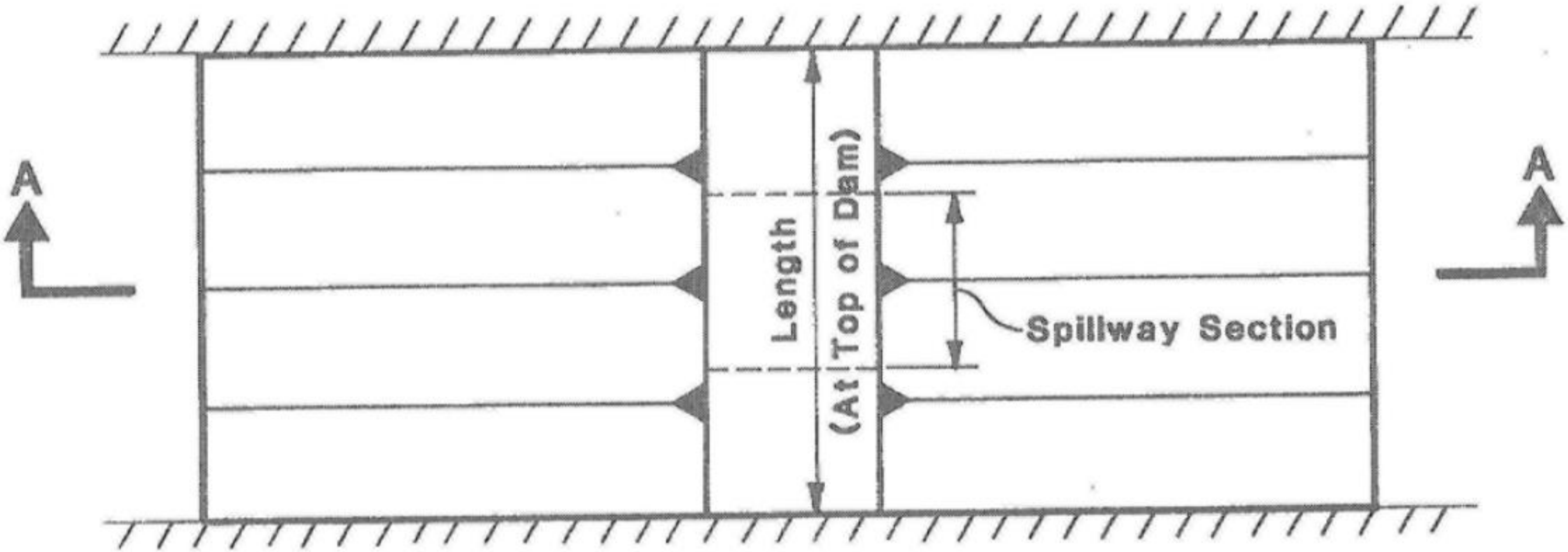
- Dam body
- Reservoir
- Spillways (service, auxiliary, emergency)
- Tunnels
- Power Plant
- Coffer dams
- Sightseeing area
- Labor residence and later employees colonies


Auxilliary spillway
Erosion protection
Reservoir
Intake tower
Spillway gates
Erosion protection
Concrete dam
Hydropower plant
Earthen dam
Conduit outlet pipe
Downstream
Erosion protection

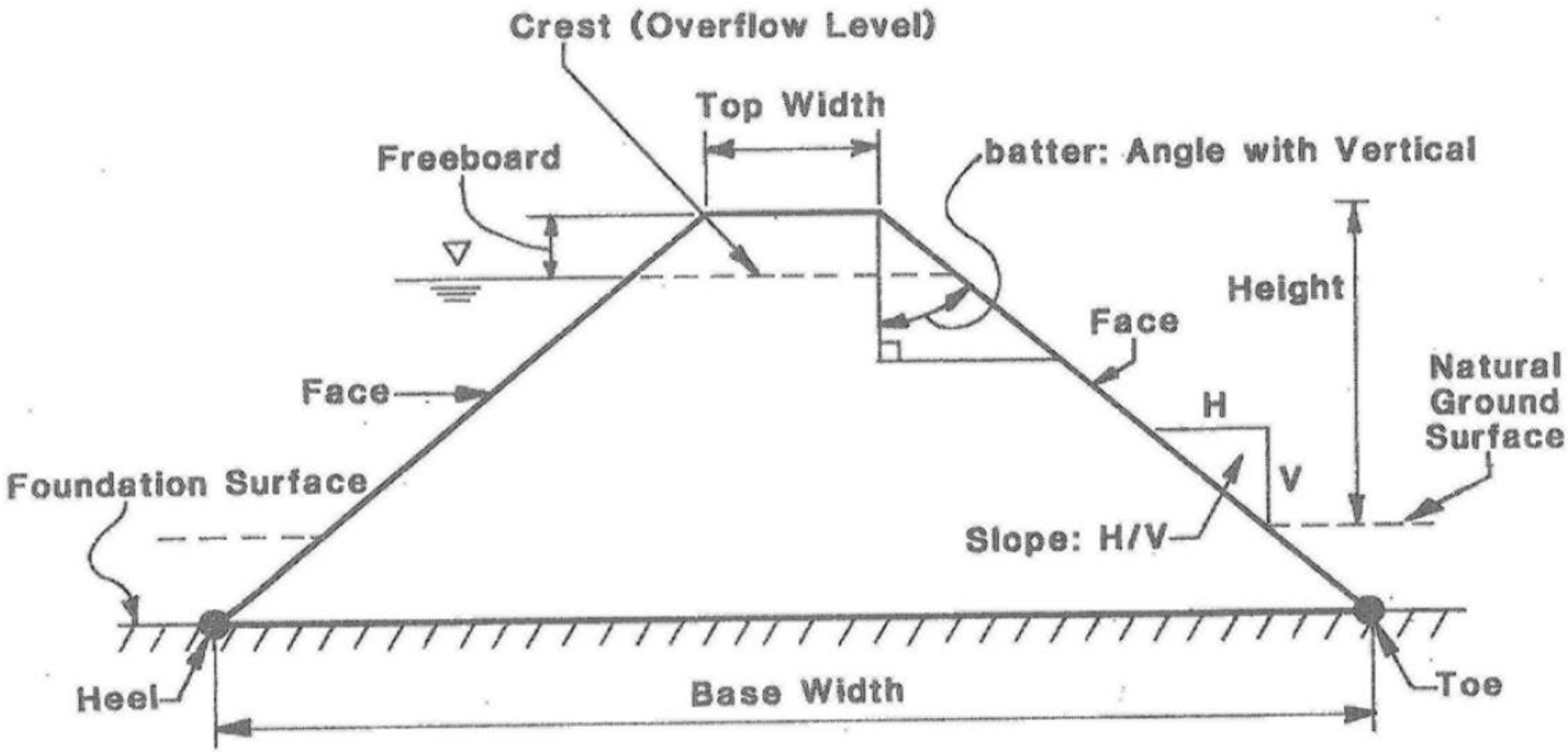
BASIC NOMENCLATURE OF A DAM



DAM GEOMETRY



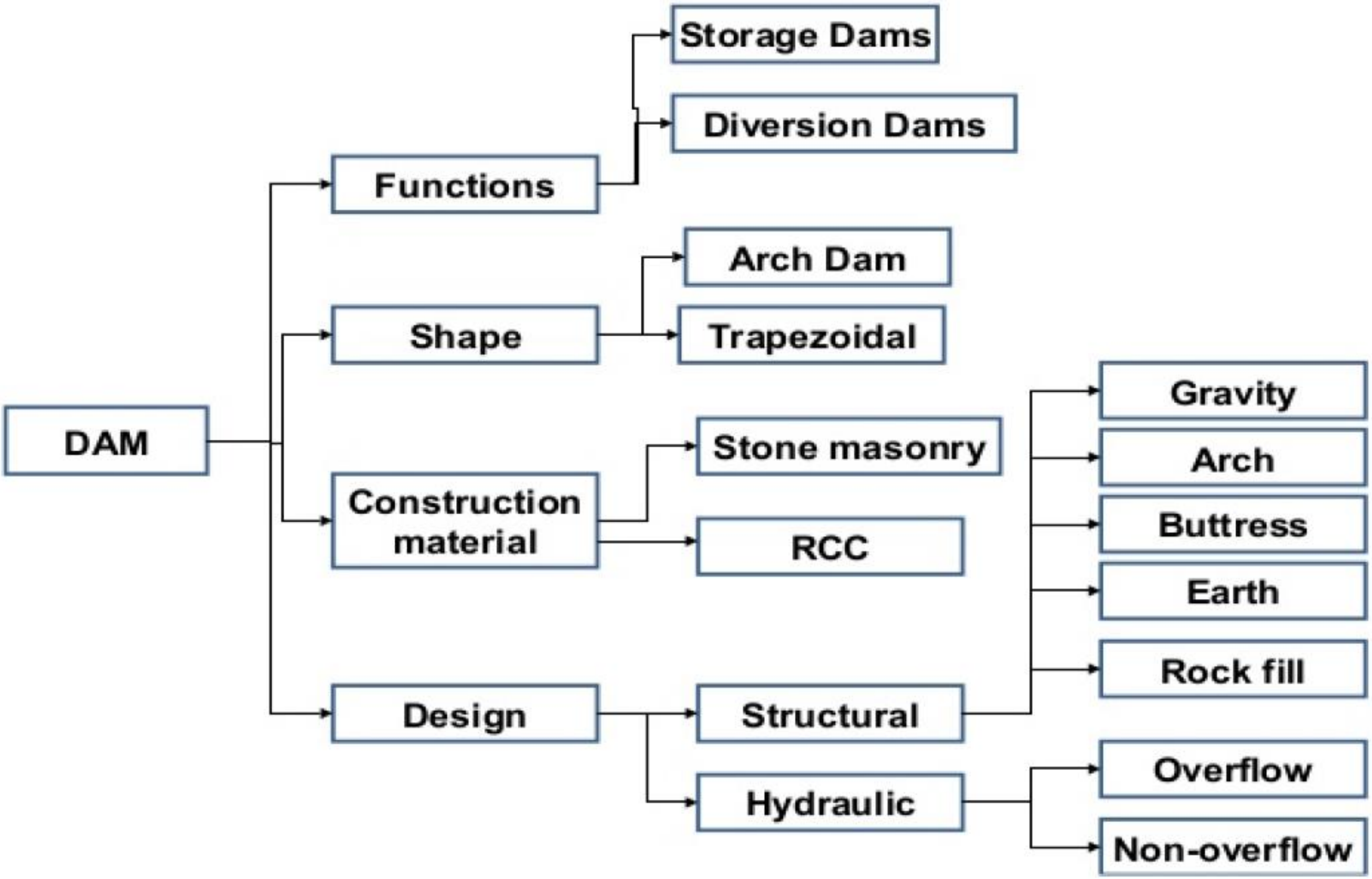
PLAN VIEW



Crest (Overflow Level)
Top Width
Freeboard
batter: Angle with Vertical
Height
Face
Face
H
V
Natural
Ground
Surface
Foundation Surface
Slope: H/V
Heel
Base Width
Toe

SECTION A-A

Dams - Classification



Types of Dams (w.r.t. Materials)

- Earthen dams
- Rock-fill dams
- Concrete dams
- Masonry dams
- Timber dams
- Steel Dams

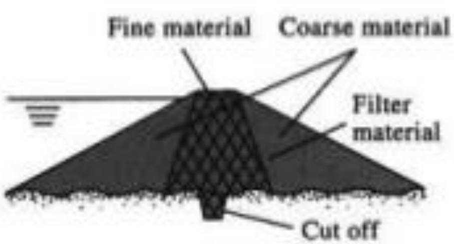
FACTORS AFFECTING SELECTION OF TYPE OF DAM

- Topography
- Geology and Foundation Conditions
- Availability of materials
- Spillway size and location
- Earthquake zone
- Height of the Dam
- Other factors such as cost of construction and maintenance, life of dam, aesthetics etc.

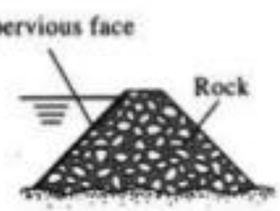
EARTHFILL DAM & ROCK-FILL DAM

- Earthfill dam, also called Earth Dam, or Embankment Dam
- Dam built up by compacting successive layers of earth, using the most impervious materials to form a core and placing more permeable substances on the upstream and downstream sides.
- A facing of crushed stone prevents erosion by wind or rain, and an ample spillway, usually of concrete, protects against catastrophic washout should the water overtop the dam.

- Rock-fill dams are embankments of compacted free-draining granular earth with an impervious zone.
- The earth utilized often contains a high percentage of large particles, hence the term "rock-fill".
- The impervious zone may be on the upstream face and made of masonry, concrete, plastic membrane, steel sheet piles, timber or other material.

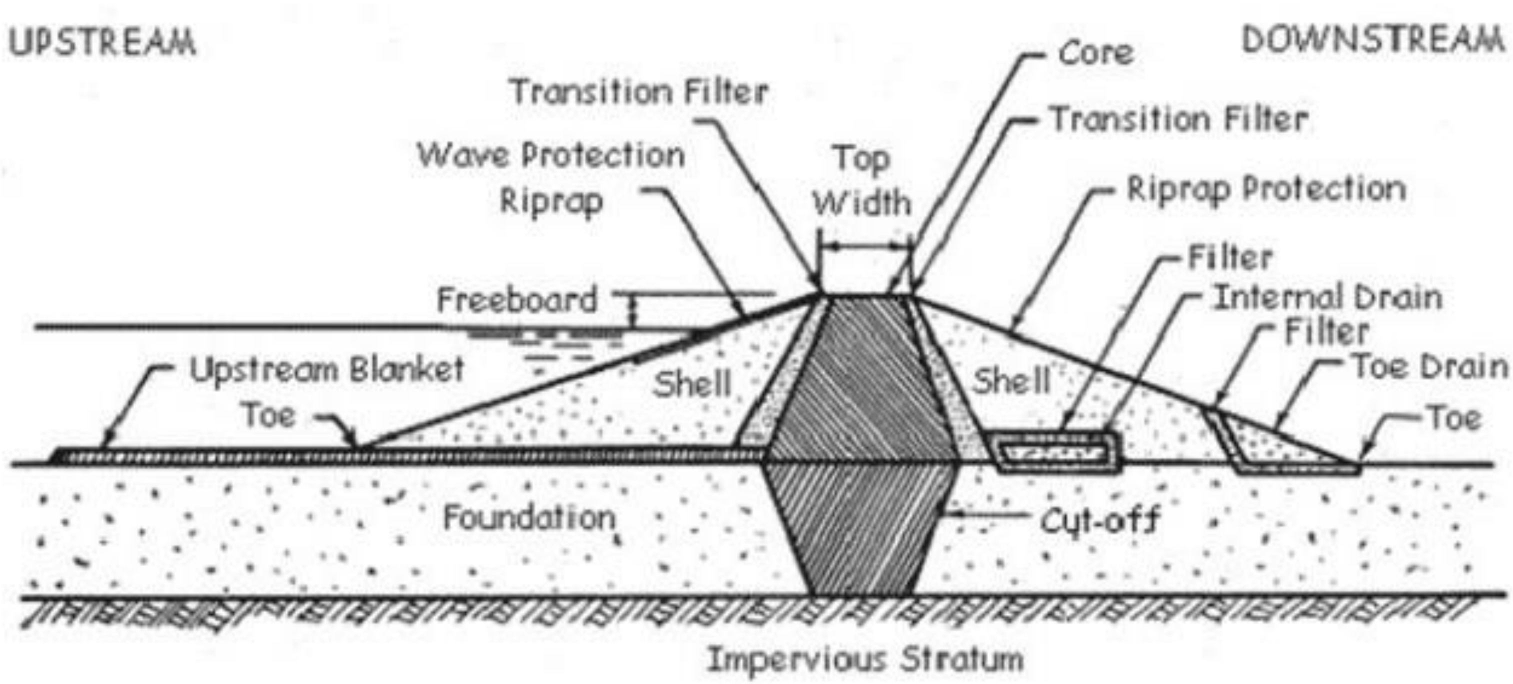


(a) Earthfill dam



(b) Rockfill dam

Components of Earthen Dam



Site Selection for Dams

- In order to maximize a reservoir's usage of a river, it is essential to make an all embracing plan that considers long-term prospects and proceeds with the project as planned. The selection of dam type should be based on full consideration of all topographical and geological conditions, hydrological features, availability of construction materials, safety, environmental issues, and economic evaluation.
- In order to maximize a reservoir's usage of a river, it is essential to draw up a total plan that considers all aspects as well as long-term prospects. Once approved it is necessary to proceed with the project strictly as planned.
- The site for the dam must be determined by investigating all possible locations, making case studies on single or multiple cases and at various scales, and comparing their advantages and disadvantages very carefully so that maximum benefit can be achieved at minimum cost, and minimum risk, in accordance with the total project plan.

Dams

- The following main factors are examined at the stage of selection of dam site:
  - Topography and geological conditions of the proposed dam site,
  - Availability of suitable materials for the dam,
  - The feasibility of spillway construction, and
  - The need to be able to cope with conditions of extreme flood or earthquake.

Dams

- It has been said that construction of a dam and reservoir causes more interference with natural conditions than does any other civil engineering operation. Knowledge of the geological situation is essential as a basis for sound engineering, especially in the investigation of dam and reservoir sites, for an error in geological interpretation or the failure to discover some relatively minor geologic detail may be costly and sometimes hazardous.
- To judge properly the feasibility of a proposed dam and reservoir project, it is necessary to know the kind, distribution, and succession of the rocks and other geologic units in the project area, for the stability of the dam and the water-holding ability of the reservoir are directly related to them. Facets of geology that must be evaluated in determining the suitability of a project site include (1) the attitudes of the units—that is, whether they are flat lying or inclined; (2) the depth and extent of weathering; (3) the presence and condition of discontinuities, such as open or closed joints, faults, or solution channels; (4) the presence of layers of sand or silt and of old soil zones. The engineering properties of the geologic units—for example, their strength or ability to bear the weight of the dam, their reaction to alternate wetting and drying, and their permeability—are directly related to the kind of rock or unconsolidated material involved and, therefore, to the geology.

Dams

- As a short dam is most economical to construct, the site selected should be at a point where the valley is narrow. The valley upstream should have sides high enough to contain the planned reservoir without necessitating construction of small dams or dikes in low divides.
- The reservoir sides should be relatively steep so that a minimal area would be exposed by the lowering of the water surface during normal operation of the reservoir. However, if swimming is one of the water-based activities being planned, there must be an adequate depth of water in the vicinity of gently sloping shores. Steepness of the slopes in the entire watershed influence the rate at which water runs off the surface of the land, which is an important factor in both dam and spillway design. They are important also because they influence the potential rate of erosion, the probable amount of siltation to be expected, and the adaptability of the project to certain uses.
- If the proposed project involves the maintenance of wildlife, the topography of the site must insure a sufficient depth and supply of water throughout the dry season. The reservoir should be planned to avoid large areas of water less than 4 feet deep because aquatic plants become a nuisance in such shallow water, and water less than 2 feet deep becomes choked with marsh plants. The latter condition also creates a mosquito problem.

Dams

- Generally dam type is classified according to the main material of dam-body, design feature, and execution of work. The type of dam is selected based on many factors, however, the local geological conditions, particularly foundation conditions play an important role. E.g. Rigorous conditions are not required for the dam foundation, while hard and sound rock foundation is necessary for concrete dams. Embankment dams can be constructed even on the alluvial deposit and pervious foundations. It is considered to construct gravity or arch type dam if the valley consists unfolded, non broken rocks.
- Preferred locations for a spillway include the dam abutments adjacent to or near the ends of the dam. Locating the spillway would also be dependent on topography, geology, and economics.
- Availability of suitable construction (fill) material is vital for construction of a stable dam. If not available, the nearest available geological source for materials must be investigated. Access to the material quarries is also important when selecting the dam site. Quality of material also determines potential maintenance costs. Slope stability of dam is also to be considered based on pore pressure considerations.

Dams

- The topography of the dam site, the geological structure of the basin and the slopes, the power of carrying, possible faults, cracks, alluvium thickness, full weir location and capacity, transportation situation. If the dam site is close to existing roads, which reduces the cost of new road construction. (if temporary roads, terrain & geology plays a role in determining cost).
- The types of rocks, the thickness and impermeability of the rocks, the features of the lake area such as water retention, the stability of the lake slopes and the landslide condition are important. Where there are discontinuities (stratum, cracks, etc.) and their direction is perpendicular to the axis of the dam, the water in the dam may escape through the permeable rocks. Parallel or inclined stratification is preferred.
- One of the important factors in the selection of the dam site is the valley shape. The valley types constitute an important criterion for determining the types of dams to be built on them. For example, concrete arch dam is not made on a wide valley. Rock filled or soil filled dams are considered to be constructed on wide valleys.

Dams

- **Solid rock foundations :** They have a high carrying capacity, homogeneous and generally impermeable. They are suitable for all types of dams. On such bases, the dissociated surface rock must be stripped and the cracks must be blocked by injection.
- **Gravel foundations :** On these foundations, the carrying power is quite good, but the permeability is high. These are generally not suitable for arches dams. Since there may be a large amount of water infiltration, some leakage reducing measures must be taken.
- **Silt or fine sand foundations:** Erosion may occur on these bases. They have low strength, there may be large settlements and high permeability. It is therefore suitable foundations for low concrete and soil filled dams. Basic settlement, Excessive infiltration loss and the carving of the downstream façade are important problems.
- **Clay foundations:** Their carrying capacity is very small, due to consolidation, the settlement is very high but their permeability is low. They may be recommended only for low-earth-fill dams. Such projects require special measures and experienced engineers

Dams

- There are Leakage possibilities from reservoir area as well as from dam and dam foundation (seepage & piping failure). Strata and materials need to be thoroughly investigated.
- Erosion, sedimentation & siltation considerations: Accumulation of sediment may soon reduce the usefulness of a reservoir and may ultimately destroy its capacity. In Illinois, silt derived from surficial deposits of loess becomes trapped in reservoirs; for this reason, a percentage of reservoir capacity is allotted to sediment storage. Sediment control is probably one of the most difficult of soil conservation problems and requires the cooperation of all land users in the drainage area tributary to the reservoir. Where siltation is severe, it may be desirable or even necessary to consider two reservoirs in series, the upstream one designed to function as a sedimentation basin to prevent the rapid accumulation of silt in the downstream reservoir.