Dams:

Dams are the costliest multipurpose civil engineering constructions. They deliver beneficial results for long time to mankind.

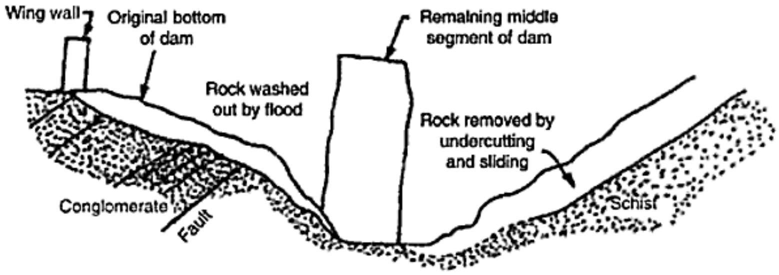
Importance of geology in Dam Construction:

To know the importance of geology in dam construction, we can refer to the cases of failures not due to any technical lapses but exclusively due to the adverse geological conditions of the concerned sites.

Case histories of Dam Failures due to adverse geological conditions:

St. Francis Dam of California:

This was a gravity dam having a height of 205' and length of 700'. It was constructed on a composite foundation of schists and soft argillaceous conglomerates. These, in turn, where mutually separated by a distinct fault (as shown in fig.). schists and argillaceous conglomerates are incompetent and hence unsuitable to serve as a foundation to such a dam. This conglomerate also had veins of gypsum, a soluble mineral. The main loads of dam acted on the poor quality of rock, which resulted in enormous leakage of stored water and the dam failed by sliding in 1928, two years after the reservoir began to be filled.



Halesbar Dam on the Tennesee River:

Hales Bar Dam was a hydroelectric dam once located on the Tennessee River in Marion County, Tennessee, USA. The dam construction in 1905 and completed it in 1913, making Hales Bar one of the first major multipurpose dams and one of the first major dams to be built across a navigable channel in the United States. This dam was constructed on cavernous limestones. Such rocks are naturally weak both physically and chemical. Leaks began to appear almost immediately after completion, however. In 1919, engineers attempted to minimize the leakage by pumping hot asphalt into the dam's foundation. This was temporarily successful, but by 1931, a study showed the dam was leaking at a rate of 1,000 cubic feet per second (28 m^3/s). To improve the site conditions and reduce the seepage, the leakages were filled up by using more than 3000 tons of cement and 1100 barrels of asphalt. After continued leakage, and after it was determined that expanding the dam's navigation lock would be too expensive, the dam is replaced by building Nickajack Dam 6 miles (9.7 km) downstream in 1968.

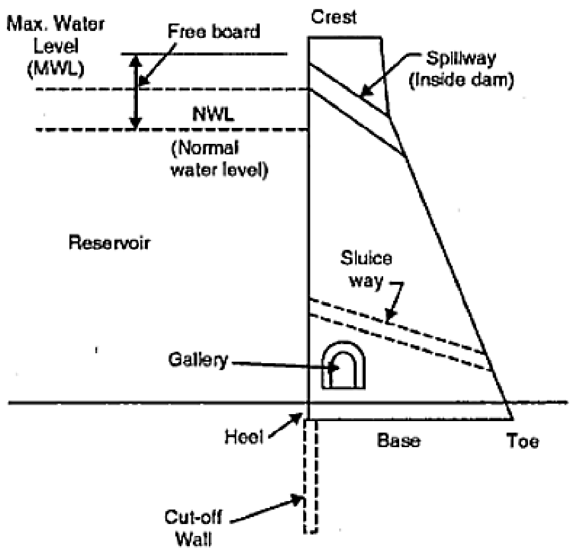
Austin Dam on colorada river texas:

This was a masonry dam of 68' height, 1090' length and 66' width (at its base). This dam was built on faulted limestone inter-bedded with shales. The strata had a gentle downstream dip. This means that both lithology and attitude of beds were undesirable at the dam site. The weathering had caused the development of large cavities in limestones. Further, undercutting took place below the toe of the dam. As a consequence of the nature of the attitude and the nature of these rocks, hydrostatic uplift pressure, the dam failed when it slipped along the shale layers in 1900, eight years after construction.

Structure of Dam:

Generally Dam consists of following parts (shown in fig. A gravity dam).

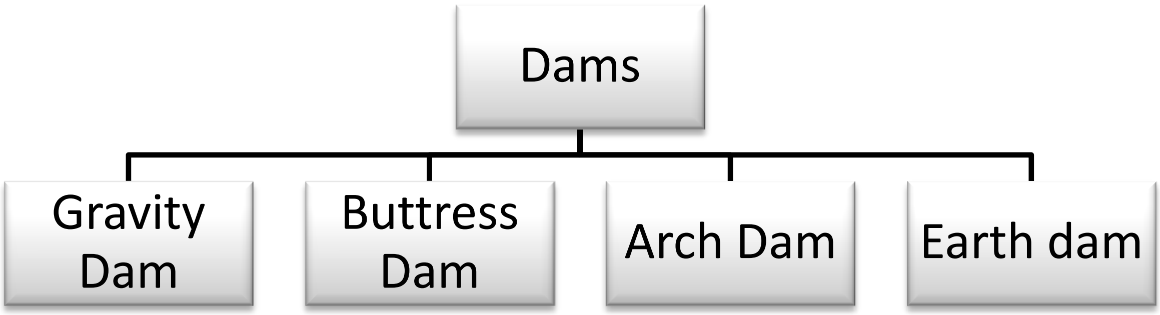
Heel	:	It is the part where the dam comes in contact with the ground on the upstream side.
Toe	:	It is the part where the dam comes in contact with the ground on the downstream side.



Abutments	:	These are the sides of the valley on which the dam structure rests.
Free board	:	It is the difference in level between the top of the dam wall and the highest storage level.
Galleries	:	These are small rooms left within the dam for checking operations
Diversion tunnels	:	These are the tunnels which are constructed beforehand for diverting the river water. This helps in keeping the river bed dry at the dam site and facilitates dam construction.
Spill way	:	It is the arrangement made in a dam near the top to let off excess water of the reservoir to the downstream side.
Sluice	:	It is an opening in the dam near the ground level. It is useful in clearing the silt of the reservoir.
Cut-off wall	:	It is an underground well-like structure of concrete in the heel portion. It is useful in preventing leakage under the

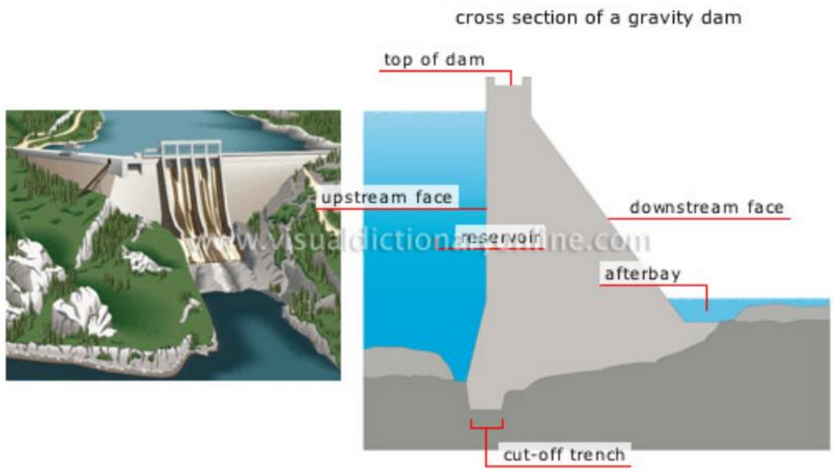
foundation and thereby avoiding undercutting of the heel as well as the uplift pressure (or upward thrust) on the dam, which are harmful to dam stability.

Different types of dams:



Gravity Dam:

In a gravity dam, the force that holds the dam in place against the push from the water is Earth's gravity pulling down on the mass of the dam. The water presses laterally (downstream) on the dam, tending to overturn the dam by rotating about its toe (a point at the bottom downstream side of the dam). The dam's weight counteracts that force, tending to rotate the dam the other way about its toe. The designer ensures that the dam is heavy enough that gravity wins that contest. In engineering terms, that is true whenever the resultant of the forces of gravity and water pressure on the dam acts in a line that passes upstream of the toe of the dam.

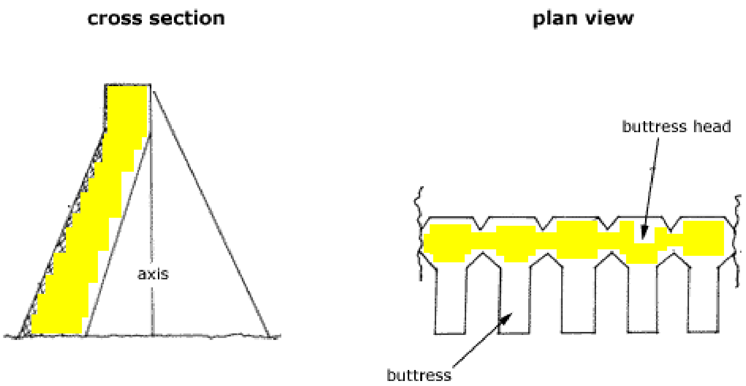


Furthermore, the designer tries to shape the dam so if one were to consider the part of dam above any particular height to be a whole dam itself, that dam also would be held in place by gravity. i.e. there is no tension in the upstream face of the dam holding the top of the dam down. The designer does this because it is usually more practical to make a dam of material essentially just piled up than to make the material stick together against vertical tension.

Note that the shape that prevents tension in the upstream face also eliminates a balancing compression stress in the downstream face, providing additional economy. The designer also ensures that the toe of the dam is sunk deep enough in the earth that it does not slide forward. For this type of dam, it is essential to have an impervious foundation with high bearing strength.

Buttress Dam:

A buttress dam or hollow dam is a dam with a solid, water-tight upstream side that is supported at intervals on the downstream side by a series of buttresses or supports. The dam wall may be flat or curved. Most buttress dams are made of reinforced concrete and are heavy, pushing the dam into the ground. Water pushes against the dam, but the buttresses are inflexible and prevent the dam from falling over.

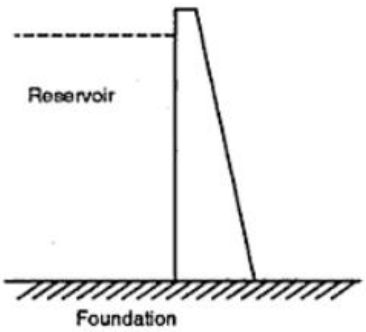


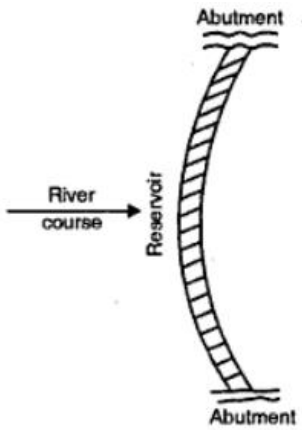
Buttress or hollow gravity dams were originally built to retain water for irrigation or mining in areas of scarce or expensive resources but cheap labour. A buttress dam is a good choice in wide valleys where solid rock is rare.

Arch dam:

An arch dam is a type of dam that is curved and commonly built with concrete. The arch dam is a structure that is designed to curve upstream so that the force of the water against it, known as hydrostatic pressure, presses against the arch, compressing and strengthening the structure as it pushes into its foundation or abutments. An arch dam is most suitable for narrow gorges or canyons with steep walls of stable rock to support the structure and stresses. Since they are thinner than any other dam type, they require much less construction material, making them economical and practical in remote areas.

Arch dams require a high level of stress and force analysis in order to create a sufficient design. The main force against an arch dam is the hydrostatic pressure provided by the reservoir behind it, uplift, which is water pressure beneath the dam, the weight of the dam itself, and all the forces combined. Other forces that affect a dam include, but are not limited to, temperature, chemical reactions, settling, silt accumulation, and earthquakes.

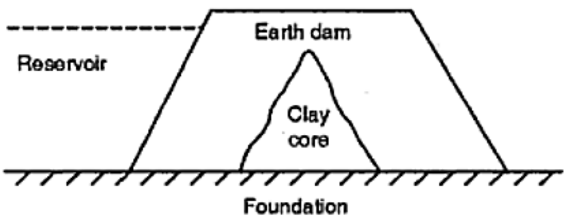




Most often, the arch dam is made of concrete and placed in a "V"-shaped valley. The foundation or abutments for an arch dam must be very stable and proportionate to the concrete. There are two basic designs for an arch dam: constant-radius dams, which have constant radius of curvature, and variable-radius dams, which have both upstream and downstream curves that systematically decrease in radius below the crest. A dam that is double-curved in both its horizontal and vertical planes may be called a dome dam. Arch dams with more than one contiguous arch or plane are described as multiple-arch dams.

Earth Dam:

Earth Dam or An embankment dam is a massive artificial water barrier. It is typically created by the emplacement and compaction of a complex semi-plastic mound of various compositions of soil, sand, clay and/or rock. It has a semi-permanent waterproof natural covering for its surface, and a dense, waterproof core. This makes such a dam impervious to surface or seepage erosion. The force of the impoundment creates a downward thrust upon the mass of the dam, greatly increasing the weight of the dam on its foundation. This added force effectively seals and makes waterproof the underlying foundation of the dam, at the interface between the dam and its stream bed. Such a dam is composed of fragmented independent material particles. The friction and interaction of particles binds the particles together into a stable mass rather than by the use of a cementing substance.

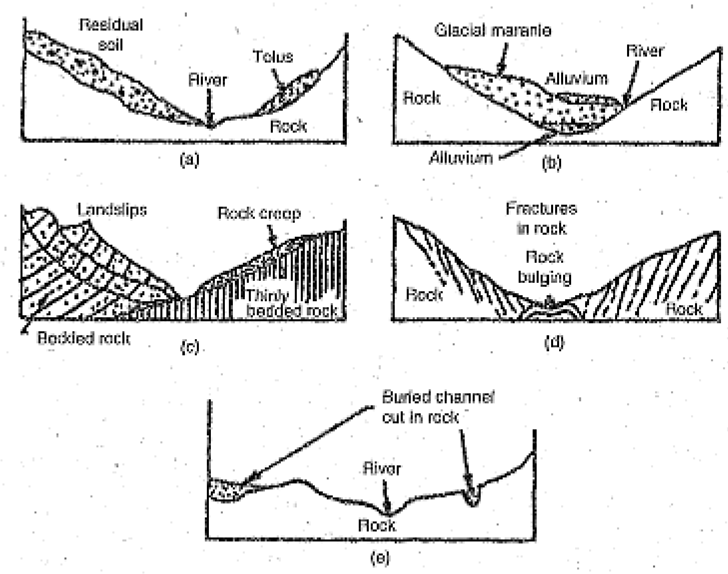


Embankment dams come in two types: the earth-filled dam (also called an earthen dam or terrain dam) made of compacted earth, and the rock-filled dam. A cross-section of an embankment dam shows a shape like a bank, or hill. Most have a central section or core composed of an impermeable material to stop water from seeping through the dam. The core can be of clay, concrete or asphalt concrete. This dam type is a good choice for sites with wide valleys. Since they exert little pressure on their foundations, they can be built on hard rock or softer soils. For a rock-fill dam, rock-fill is blasted using explosives to break the rock. Additionally, the rock pieces may need to be crushed into smaller grades to get the right range of size for use in an embankment dam.

Geological Considerations in the Selection of Dam Site:
Careful geological studies bring out the inherent advantages of any site selected for the dam, and it also reduce the cost of the dam considerably. The important geological requirements that should be considered in the selection of a dam site are as followed.

1. Narrow River Valley.
2. Occurrence of the bedrock at a shallow depth.
3. Competent rocks to offer a stable foundation.
4. Proper geological structures.

Narrow River Valley:
If the proposed site contains a narrow river valley, only a small dam is required, which means the cost of the dam construction is also will be less. On the other hand if the valley is wider, construction cost will be very high and maintenance of the dam will also be high. Yet if the valley is narrow, following considerations should be taken in to account.



- Deceptive narrowing of a valley due to the occurrence of thick superficial deposits such as residual soil and talus[1], in recently glaciated regions, moraine[2], boulder clay, sand, gravel and river alluvium (as shown in a,b).

1- Talus-a sloped portion of a fortified wall, 2- moraine is any glacially formed accumulation of unconsolidated glacial debris

- Narrow valley due to deceptive rock outcrops which are the result of lad slip, rock creep and rock fracturing (as shown in fig. c,d).

- The occurrence of buried river channels crossing the site, either below the bed or adjacent to it (as shown in fig. e).
- Unsuitability of rocks in some places due to the presence of soluble materials like gypsum or due to faulting (i.e., when the river flows along a fault) which may be concealed beneath sediments.

Occurrence of bed rock at shallow depths:
If the dam rest on very strong and stable rocks, the stability and safety of the dam will be very high. This also reduces the cost of the dam. On the other hand the dam cost will be high and the work of excavation will be overburden. This also requires heavy concrete refilling. For example, at the site of Bhakra dam on Sutlej river, the sound bedrocks were at a great depth below the ground and the walls of the gorge[1] and, as a consequence, excavation for the foundation was one of the major items of work of that project.

In the case of deposition along the river valley depends on the stage of river. If the river is in young stage, the erosion might have exposed the strong bed rocks that may occur at the surface this would be competent for the dam construction. Yet some of the points are to be considered while selecting the dam site at such a location. This is because, the hilly terrain which occurs in these stages may not provide a suitable topography for the occurrence of a large reservoir basin and the flow of water itself may not be high in such developing rivers for obvious reasons. In older stage, the deposition will be resulting in overburden. This means that suitable bedrock may lie at a considerable depth and hence proves uneconomical.

The general occurrence of material like clay, silt, sand and gravel along the river bed, naturally makes it difficult to assess the thickness of loose overburden by mere surficial studies. Therefore, to know the bedrock profile in the river valley along the axis of the proposed dam, geophysical investigations such as "electrical resistivity studies" or seismic refraction studies" are carried out carefully. The data recorded in the field during investigations are interpreted and the required bedrock profile is visualized. Such a result gives scope for estimating the amount of excavation work of loose material and concrete refilling required upon only after necessary checks and scrutiny. For this purpose, a suitable number of bore holes are drilled at selected points and the actual bedrock depths as observed at those places are recorded. Then the results of earlier interpretations are compared with the actual observations made. If they are found to tally, then the inferred data can be deemed to be correct and reliable.

In certain places particularly in glaciated regions, the occurrence of buried river valleys, a buried river valley may occur in the riverbed that is generally deep, and is composed of

1-gorge-Canyon (a deep ravine between cliffs often carved from the landscape by the river).

loose drift which is a highly porous and permeable material. This poses problems of weakness and leakage which are dangerous for the success of the dam. If buried river valleys are missed (i.e. remain undetected), excavation must be undertaken down through the drift to the underlying solid rock. In other words, buried river valleys, if present, deeper excavations in the trench are made for the foundation of the dam, this will be an extra expenditure on the dam construction.

Like buried river valleys, occurrence of huge boulders in glaciated regions may also create unanticipated difficulty during the construction of a dam. Glaciers, which are huge bodies of moving ice in mountainous regions, are capable of transporting big boulders along with them and leave them at lower levels. These boulders will naturally be resting over loose and unconsolidated material. Such giant boulders, if present along the river valley, may be mistaken for real bedrocks during investigation or trial borings. Therefore, to ensure that the bedrock has actually been reached, bores should be drilled for 20” or more through the rocks, in glaciated regions.

If the thickness of the loose overburden is negligible, the country rocks may be found to occur exposed frequently along the river valley. The converse may not be true. Also, the mere presence of a few outcrops of country rocks within the river bed does not necessarily indicate that the thickness of the overburden is negligible all over the floor and the abutments of the valley.

Competent rocks for Safe Dam:

If the dam site consists of igneous rocks, they will offer a safe basis. If sedimentary rocks, particularly shales, poorly cemented sandstones and cavernous limestones, they are undesirable. Though igneous rocks along with metamorphic rocks occupy 95% earth crust, on the surface igneous rocks occur only 30% and in them granites and basalts are most common ones. So location containing granites and basalts will be much competent for the site of the dam. Yet another point of care should be taken that, the granites and basalts will occur with the sedimentary formations like shales, sandstones and limestones. If the composition of sedimentary formation is more, thorough investigation is needed and this will increase the dam construction cost, including excavation.

The suitability of the site for the dam construction can be estimated by the following factors:

1. The existing rock type at the dam.
2. The extent of weathering it has undergone.
3. The occurrence of intrusions.
4. The extent of fracturing.
5. The occurrence of geological structures.
6. The mode and number of rock types.

Suitability of igneous rocks:

These are the most desirable rocks at the dam site. Because these are strong and durable due to their dense character, interlocking texture, hard silicate mineral composition, occurrence of negligible porosity and permeability, absence of any inherent weak planes, resistance to weathering and their tendency to occur over wide areas. Yet it should be checked that the selected rocks are not affected by weathering or fracturing or dykes or any geological structures like shearing, faulting and jointing. Thus, all plutonic rocks like granites, syenites, diorites and gabbors are very competent and desirable rocks for the foundation at the dam site. Yet another consideration should be taken in to account, i.e. volcanic rocks, which are generally vesicular or amygdaloidal, are not desirable since they will be permeable and contribute to porosity and hollowness, in turn contributing to weakness of rocks. The case of massive basalts, which are very fine grained, are one of the toughest rocks in the nature. Yet they can be adversely effected when they are vesicular and permeable.

Suitability of sedimentary rocks:

In the case of sedimentary rocks following factors affect the construction of dam.

1. The bedding and its orientation.
2. Thickness of beds.
3. Nature and extent of compaction and cementation.
4. Grain size.
5. Leaching of soluble matter.
6. Porosity and permeability.
7. Associated geological structures and
8. Composition of constituents.

Basing on the above factors the suitability of the sedimentary rocks for dam site can be listed as followed:

Sedimentary rocks those are undesirable:

- Shales are the most undesirable at the dam site, as they form slippery bases.
- Laterites and conglomerates are undesirable, because of their porosity and permeability.
- Limestones are competent if they are massive, i.e, unaffected by the solution phenomenon, but are liable to become dangerously porous for the same reason at any time in future.
- Alternating soft and hard rocks for small thickness are undesirable.

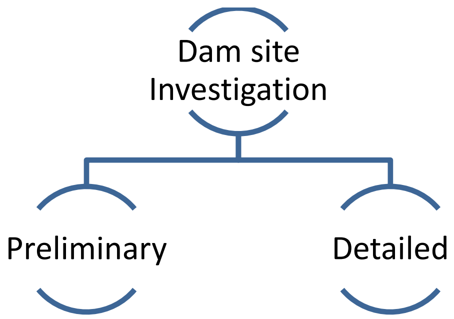
Sedimentary rocks those are desirable:

- Among sandstones, well-cemented siliceous and ferruginous types are competent and suitable for dam foundation.
- Thick massive sedimentary formation with less porosity is desirable.

Suitability of Metamorphic rocks:
Among the metamorphic rocks,

1. "Gneisses" are most competent rocks like granites, unless they possess a very high degree of foliation and are richly accompanied by mica-like minerals.
2. "Schists" are undesirable because
    a. Their constituent minerals are soft and possess a very well developed cleavage.
    b. The schistose structure results because of the foliation of minerals present in the rock.
3. Quartzites are very hard and highly resistant to weathering. They are neither porous nor permeable.
4. Marbles, like quartzites, are compact, bear a granulose structure, are not porous, not permeable and reasonably strong too. But by virtue of their chemical composition and mineral composition they are unsuitable at dam sites.
5. Slates bear a typical slaty cleavage (due to the presence of minute flakes of mica). Hence this rock is soft and weak, and undesirable at the dam site.
6. Khondalites, which are feldspar-rich, are to some extent heterogeneous in terms of their mineral compostion. They often contain soft graphite, hard granet, etc. in addition to other minerals. They are highly weathered and hence unsuitable at dam site.

Investigation of dam site:



Preliminary investigation is done on the site to collect the information about the disadvantages or advantages of the site. This is more flexible because the detailed investigation will be more expensive, extensive and laborious.
The important information collected at this stage is based on the factors as followed:

1. Lithology
2. Structure
3. Physiography (Topography)
4. Ground water Conditions.

Lithology provides the details of rocks types occurring in the dam site. The details include the types of rock present, their nature and extent of weathering, the occurrence of soil, rock debris, etc. Lithology also gives a broad idea of the presence or absence of competent rocks, the weathering it has undergone and other related information.

The Structural study gives information on the strike and dip of the beds. It also reveals the occurrence of geological structures like folds, faults, joints, unconformities and foliation. Details of these features are very important because they have a great influence on the suitability of site for dam.

Topography (Physiography) gives information about important surface features like valleys, hills, the trend of the river course, slopes and terraces present in the area. These details indicate the stability of the slope and the slope of the occurrence of landslides. Topographic studies also help in rough assessment of the depth of the bedrock at the site. The nature of seismic activity in the region can also be known by suitable studies.

Groundwater conditions are related to the study of occurrence of springs, seepages, swamps, wells etc. present in the selected area. This type of study indicates the water table position and the scope for leakage of water from the associated reservoir. This also indicates the occurrence of solution cavities, if any, in the area.

Detailed Investigation:

If the Dam Sites is found to be good in the preliminary investigations, then it is taken up for detailed investigation. This process comprises of surface and subsurface investigations.

Surface investigations:

The surface investigations include closer examination of lithology, structure, physiography and groundwater conditions. The thorough investigation of the above factors, with the support of laboratory studies of the materials at the dam site will reveal the conditions of outcrops, faults, joints, folds, & their attitudes, weathering details, soil occurrences, engineering properties like compressive strength, tensile strength, porosity, permeability and durability.

Subsurface investigations:

These also include the factors of investigations as said above. But the studies include the study of deeper layers of the dam site for ensuring the standards and safety of the dam.

Tunnels:

Tunnels are the underground passages or routes through hills, mountains or earth crust used for different purposes. These passages are made by excavating rocks below the surface or through the hills, mountains.

Types of tunnels:

Tunnels are basically made to serve some specific purposes. For instance:

1. Transportation tunnels: tunnels made across hills or high lands to lay roads or railway tracks for regular traffic and transportation purpose.
2. Traffic tunnels: Tunnels laid to reduce the distance between places of interest across natural obstacles like hills, to save time and provide convenience are called traffic tunnels. These have the advantage of leaving the ground surface undisturbed so that it can be used as desired.
3. Diversion tunnels: The tunnels layed for diverting normal flow of river water to keep the dam site dry are called diversion tunnels.
4. Pressure tunnels: these are also called as hydropower tunnels. These are used to allow water to pass through them under force, used for power generation.
5. Discharge tunnels: These are meant for conveying water from one point to another under gravity force, like across hill.
6. Public utility tunnels: These are the tunnels layed for public supplies like drinking water supply, cables laying, sewage discharge or oil supply etc.

Effect of tunnelling on the ground:

- Deterioration of the physical conditions of the ground is the common effect of tunnelling. This happens because due to heavy and repeated blasting during excavatin, the rocks get shattered to a great extent and develop numerous cracks and fractures. This reduces the cohesiveness and compactness of rocks.
- At normal conditions the earth crust or underground rocks are under great preassre (overburden) or they will be in association with some geological structures like folding will be at equilibrium stress holding the previaling strain intact. When the tunnel is created, such rocks which are at equilibrium gets distrubed resulting in the collapse of the roof. Freequent bursts may also occur. This phenomenon of fall of rocks in brittle and hard rocks is called *Popping*.
- Due to tunnelling, the overlying rocks deprive of support from the bottom and may become unstable. Such unstable conditions become still more precarious if the tunnelled beds are incompetent or loose or unconsolidated or saturated with ground water.

Geological Considerations of tunnel sites:

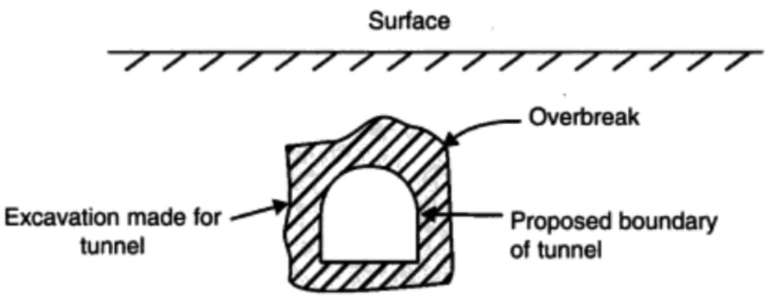
Refer to structural geology.

Lining of tunnels:
When tunnels are made through weak or loose or unconsolidated formations, they are provided with suitable lining for safety and stability. Lining refers to the support porvided to tunnel. Lining may be in the form of steel structures or concrete.

The main purposes of lining are to resist the pressures from the surroundings and to protect the shape of tunnel. It takes care of the weaknesses of the ground. It also helps in checking leakage of ground water into tunnel.

The thickness of concrete lining dependes on the extent of protection required, and the degree of weakness of the ground. It also depends on the overbreak phenomenon. Lining is provided to support weakparts of the tunnel. Lining is also provided in such places where the seepage of water into the tunnel occurs and creating problems. In the case of very weak rocks with unfavorable geological structures, lining may be necessary through out the length of the tunnel. The zones of faulting or shearing also need suitable lining to impart strength to them.

Overbreak:
During tunneling the excavations normally involve the removal of extra rocks or matter around the tunnel. The quantity of rock broken and removed, in excess of what is required by the perimeter of the proposed tunnel, is known as *overbreak*.

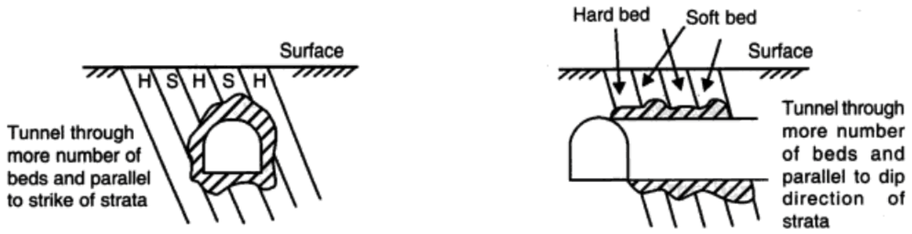


Factors governing the amout of overbreak:
- The nature of the rocks.
- The orientation and spacing of joints or weak zones in them.
- In the case of sedimentary rocks, the orientation of the bedding planes
- Thickness of the beds with respec to the alignment of the tunnel.

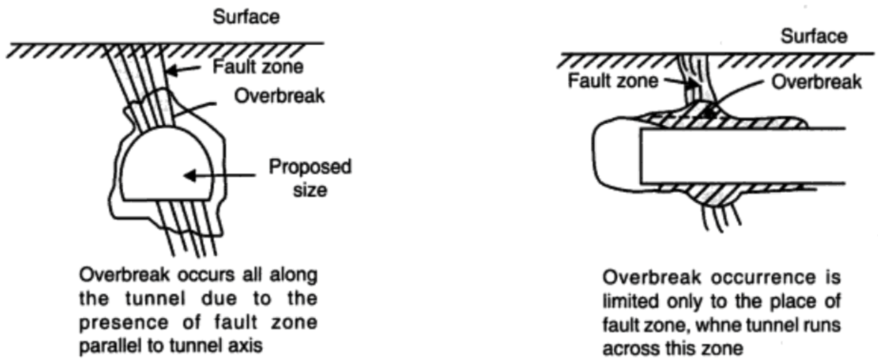
Geological factors influencing the overbreak:
- Massive and soft rocks of a homogenous nature cause less overbreak than harder rocks with well developed joints or weak zones.
- In sedimentary rocks, thin formations and those with alternating hard and soft strata produce more overbreak. This is because, during excavation, softer rocks yield more than the hard rocks.

- In metamorphic rocks, foliated and soft formations like slats and schists produce more overbreak if the tunnel lies parallel to them and less overbreak if they are mutually across.
- Tunnels that pass through a single thick homogenous formation without structural defects produce little overbreak, whereas tunnels which pass through a variety of rocks with structural defects like fault zones or which are less thickness of strata or alignment cutting across different strata along the dip direction, produces more overbreak.

Cases where overbreak occurs less



Cases where overbreak occurs more



Overbreak due to fault zones