D.N.R.COLLEGE (AUTONOMOUS), BHIMAVARAM
III B.Sc., GEOLOGY
Engineering Geology

ROLE OF GEOLOGIST IN CIVIL ENGINEERING

Civil engineers design structures that are built on or in the ground. As such an understanding of how the ground behaves is fundamental to civil engineering design. Earth materials can pose significant problems that need to be predicted, planned and designed for. Engineering geologic studies are performed by a geologist or engineering geologist that is educated, trained and has obtained experience related to the recognition and interpretation of natural processes, the understanding of how these processes impact man-made structures (and vice versa), and knowledge of methods by which to mitigate for hazards resulting from adverse natural or man-made conditions. **The principal objective of the engineering geologist is the protection of life and property against damage caused by geologic conditions.** Engineering geologists investigate and provide geologic and geotechnical recommendations, analysis, and design associated with human development. The engineering geologist plays a crucial part in the management of projects that are to be completed successfully to time and within budget. So, the geologist is very much helpful to a civil engineer in **predicting the failure of the structure constructed due to geological hazards, used in advising the selection of the best site for engineering purposes and also to suggest selection of best engineering materials for construction.**

Bridges

Bridges form an important part of transportation routes. They are constructed across the rivers to carry highways and railways. The site of a bridge does not allow much freedom of choice.
Abutment: The abutment is a terminal support of the bridge. It is built on either side of a river valley where the road or railway joins the bridge.

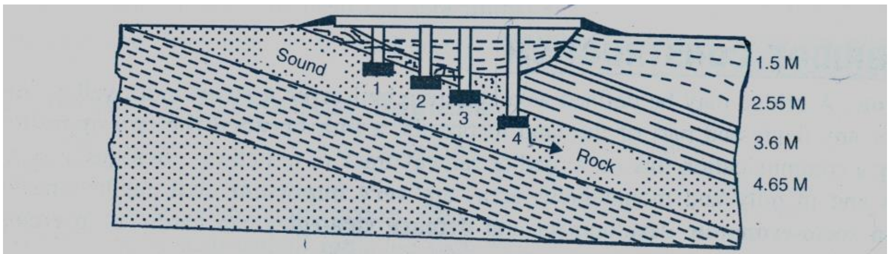
Piers: The pillars like supports that are constructed between the abutments are termed as Piers. The rocks selected for the construction of piers must be able to withstand the constant impact of running water.

GEOLOGICAL CONSIDERATION:

Big cities which are divided by rivers or streams, a bridge has to be placed where it is needed, irrespective of the subsurface geology. But in case of bridges also, the design, stability and durability depend, to a great extent, on the subsurface geological conditions that must be properly investigated and cautiously interpreted. The bridge abutments and piers should be placed on sound, strong and stable rock foundation below as possible. The geological characters that need to be investigated and thoroughly established are:

(a) The depth of the bed rock
(b) The nature of the bed rock
(c) The structural disposition of rocks.

Depth to Bed Rock: 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. So, the pier must be placed on **stable foundation.**

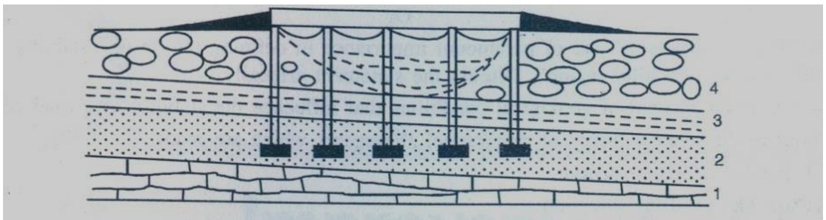


Depth to Bed Rock

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 upto 100 meter or more. Utmost care is needed not to mistake isolated big boulders buried underneath the river bed as the bedrock. Boulders cannot be trusted as foundations for bridge piers.

Nature of Bed Rock: Three types of loads are to be borne by a bridge pier foundation:

- The compressive, vertical loads due to the weight of the bridge span and that of pier material;
- The horizontal loads due to the thrust of the water flowing above as transmitted directly and through the pier;
- The dynamic, complex load, due to heavy traffic on the bridge.



Nature of Rocks Below Piers
1 = Limestone 2 = Sandstone 3 = Shale (compressible) 4 = Boulder bed

The bed rock selected as foundation for the pier must be strong enough to bear the sum total of all these loads, not temporarily, but throughout the proposed life of the bridge. Most igneous and massive type of sedimentary and metamorphic rocks are quite strong, stable and durable as foundations for bridge piers and abutments.

Structural Disposition: Ideally, the horizontal attitude and uniformly massive structure with depth are desirable characters in the foundation rocks as these offer resistance against failure. Even inclined rocks are safe if these possess normal strength values. Folding and faulting might cause negative factors. When the bridge sites are located in the zones of seismic activity, the foundation are required to be designed for additional seismic loads. In the glaciated areas, special care must be taken to establish the existence of drowned or buried valleys that might be filled by secondary material of most heterogeneous characters.

Classification of Bridges: A bridge consists of a superstructure and substructure. The weight of the superstructure and the loads imposed on it are taken by the supports of the bridge and transmitted to the foundation; thus, every force acting on the superstructure ultimately reaches the foundation. there are three categories of bridges:

(1) the vertical loads seting on the superstructure are transmitted vertically to the founda tions (Fig. 1). (2) besides the vertical forces transmitted to the foundations by the supports, the horizontal thrust H pushes the supports outward (Fig.2).

(3) the vertical forces are transmitted to the foundations vertically, but for stability the superstructure has to be anchored to rock or a large concrete mass, and there are forces that tend to pull out the anchorage (Fig.3).

represents a , on two supports. The superstructure may be steel, reinforced concrete, or timber. It rests on or is fixed to the abutments. Abutment refers to a terminal support of the bridge. Obviously, a bridge has two abutments, and the traffic has to pass over both abutments in order to enter on the bridge and leave it. Abutments generally are made of concrete, plain or reinfor although in some bridges, other materials are used, e.g., steel or, in old bridges, rough rubble masonry (sometimes without mortar). The concrete abutments sometimes are faced with dimension stones Generally, dimension-stone facing may be applied to any exposed concrete surface of a bridge.

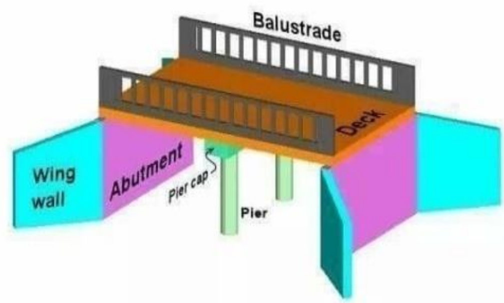
The bridge in Fig. has **one span** only supported by the abutments; this is a very common type of small bridge for highways. If the bridge consists of several spans of equal or variable length, the intermediate supports (between abutments) are piers. The term "pier" is used in engineering loosely; besides the concrete piers supporting buildings (Sec. 13.4), it also means a harbor structure for landing, loading, and unloading ships.

A **multispan bridge** may consist of a number of mutually independent girders supported at both ends on the , or a long girder may cover several spans ("continuous" girder). In all cases. of girders, the girder must be allowed to move a little for temperature expansion. For this purpose the girder should be fixed firmly on an abutmentor pier and placed on rockers or rollers on other supports.

Figure represents a **cantilever bridge** with two piers and two abutments. The weight of the superstructure is essentially carried by the piers, and the structure may be so balanced that the load on the abutments is negligible if any. The girders have protruding arms (cantilevers) and carry a relatively small, simple beam at the center of the bridge. The term "cantilever" generally is applied to a structure or a part of the structure, horizontal or nearly so, fixed firmly at one end and unsupported at the other end.

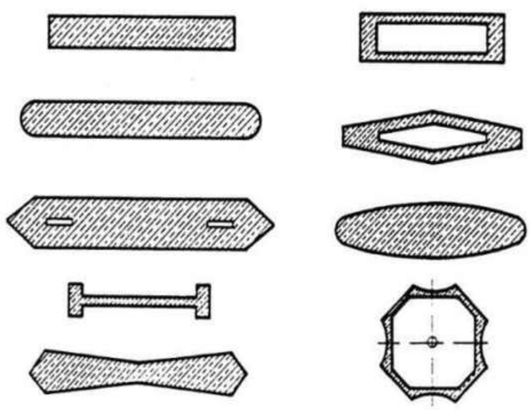
The **arch** and the rigid frame are also discussed. The bridges of these systems produce a vertical pressure and end to exert a horizontal thrust on their supports. Arch bridges may be steel, concrete, or timber. A number of old masonry arches still exist. As in the case of buildings, an arch bridge may be provided with a tie that takes up the horizontal thrust caused by the arch instead of the abutments doing so. A rigid-frame bridge may be steel or of rein forced concrete and is commonly of one or two spans.A **suspension bridge** consists of two cables, generally spun of strong wire, which rest on saddles firmly fixed at the top of the steel towers (some old bridges have masonry towers). The traffic deck is suspended on the cables. The loaded cables have the tendency to pull the towers inward, and to oppose this tendency, the cables are anchored either in natural rock or in a massive block of concrete that holds down the ends of the cables. In some suspension bridges, a stiffening truss is added to the structure to prevent undue deflection or oscillation of the cables. The longest span in a suspension bridge is the 4,200-ft span of the Golden Gate Bridge in San Francisco. California.

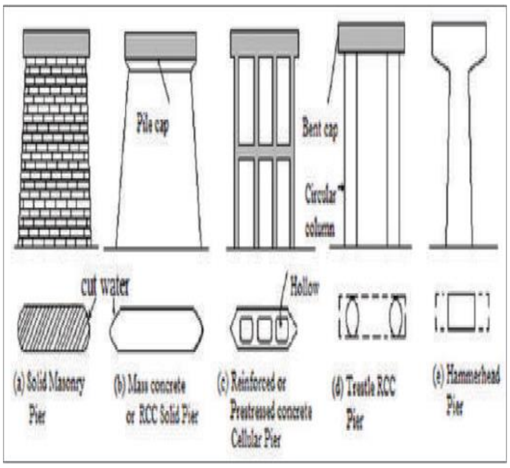
Abutments and Piers of a Bridge: The abutment connects the bridge to the roadway. This may be an embankment of variable height or merely the ground surface with perhaps a little grading. There are a number of intermediate cases.If the bridge access is an embankment, the abutment has to hold it back to prevent the earth from moving into and obstructing the waterway between the bridge supports. The abutment has to offer a seat for the superstructure and at the same time be a retaining wall for the embank ment. This is done by designing winged abutments. a straight-wing abutment is shown.
The plan of footing for a **beveled-wing abutment** is shown at the bottom.The straight-wing abutments are somewhat weaker than the beveled-wing type; the wings of the latter reinforce the straight retaining wall. The slight difference in simplicity and cost of construction, however, favors the **straight-wing type**.When the land is inexpensive, **U-shaped abutments** can be used. In this type only the central part of the embankment is contained between the wings, and the slopes are permitted to fall outside. If the substructure is narrow, this represents a strong structure, rather economical on account of savings in the concrete work. only half of the plan of the abutment is shown (item a); the side view (item b) shows how the abutment looks if sighted in the direction of the arrow. All portions covered with earth are shown as dotted lines.Besides these simple abutment types, there are a number of other arrangements serving the same purpose. Some of them are shows a flanking-span abutment in which the wings are omitted and the front wall, instead of being solid, may be provided with openings. The superstructure rests on the front wall, which is connected by short girders to a secondary wall placed on the embankment. The slopes of the embankment are permitted to fall free. arch bridges are very suitable for spanning waterways located between two rocky shores. It also shows that the bases of the two abutments of an arch may be located at two different levels. If one or both abutments of an arch should be located in soil materials, large massive concrete abutments would be required to prevent sliding, with an increase in cost of the structure.Sometimes the local topography and the presence of sound bedrock clearly indicate the abutment location. In a general case, however, the proper emplacement of an abutment is a problem requiring con siderable experience and judgment. Such are the cases of swampy low shores extending a large distance from the bridge or meandering streams that may change the location of their channels. In



questionable case it is advisable to find the proper location by comparing the results of geotechnical investigations at several possible lorations. In some cases of bridge construction, a channel is excavated and the bridge constructed in the dry, after which water of the stream is directed to the new channel. In the simplest type of abutment the superstructure is placed on the surface of the embankment without any concrete, but a steel or concrete contact plate is used for better pressure distribution. This can be done in frostless zones, e.g., California, provided the embankment is built of nonexpandable, properly compacted materials and proper drainage measures are taken.

Types of piers: Piers These intermediate bridge supports are built mostly of concrete, often with granite facing. Occasionally steel is used or even timber in bridges formed by piles protruding over the high-water level. As a general rule, the larger the stream, the higher the piers and the deeper the foundations. There are many exceptions, however. In wide, shallow rivers, the piers are generally low and foundations rather shallow; the bridges of the Pennsylvania Railroad over the Susquehanna River near Harrisburg consist of a great number of small span arches. High of the bridge: Railroad way piers are long perpendicular to the general direction of eg, for a four-lane bridge, a pier may up oft long. 50 to 60 ft bridges generally are much narrower, their width depending on the num ber of tracks they have to carry. Small bridges generally have no piers but in rare cases may have one or two. It has triangular (or rounded) ends directed against the current, though in many cases the piers have symmetrical ends. The pier is baltered on all sides, though in modern bridge piers the downstream end is often vertical. The pier may be provided with a starling (Fig. 14.8e), most of which should be located below the high-water level. The function of the starling is to regulate the passage of water and, particularly, to serve as an ice breaker in the spring. Ice lumps tend to ascend the starling and break under their own weight. A few types of hollow piers for medium size bridges. In a long structure with a con siderable number of spans, piers similar to those are generally called bents. Piers for larger bridges gen erally are hollow and somewhat similar in shape to the diminutive bents. They consist of combinations of high vertical shafts, straight stepped or circular (cylindrical) with portals, and other architectural features.





ROADS AND HIGHWAYS

Roads and highways are very important projects for any country and an index of its development. For any civil engineering project, geological investigations play important role in the design, stability and economical construction and maintenance of the roads. Such investigations are aimed in regarding **topography of the area, lithological characters of the rocks or soil and the groundwater conditions.**

1) Topography: It is the single most important factor that controls the selection of alignment of a road project. Topographic maps will reveal all the topographic features like hill, mountains, streams, various undulations, plateaus, etc.,. Knowledge of these features is very essential for the right alignment and also to decide where the cuttings are required, where the slopes could be left at their natural inclination or have to be supported by breast walls, etc.,.

2) Lithological Character: Geological surveys provide all details regarding the composition, texture, structure and origin of rocks and sediments making the ground through which the highway has to pass. Massive groups of rocks include all varieties of igneous, sedimentary and metamorphic rocks which can stand even with vertical slopes (when they are free from joints and fractures), but these rocks require extensive blasting operations. The Unconsolidated group presents engineer many complicated problems. Presence of clay seams should be investigated as these rocks often swell on coming in contact with moistures, and create adverse situations for road stability and safety.

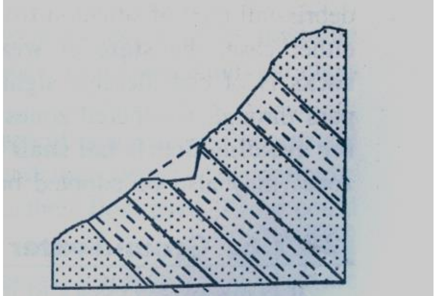
3)Geological Structures: The structural features of rocks, especially in those of sedimentary and metamorphic origin, have very important bearing upon the design of cuts as well as on the stability of the road as a whole. Structural features include dip and strike, joints, fault planes and shear zones.

(a)Dip and Strike: There are three possibilities for making cut in inclined beds. They are:

(i) Cut is parallel to the dip direction: Failure is minimal in this case, as the layers offer a uniform resistance on either side of the cut.

(ii) Cut is made parallel to the strike: When a cut is made parallel to the strike i.e., perpendicular to the dip direction the condition will be safe if the strata dip into the hill rather than on to the road.

(iii) Cutting inclined to Dip and strike: This condition would give rise to similar difficulties as encountered in cuts parallel to strike. If there is no alternative to cut either parallel to or inclined to strike then some of the measures have to be followed, like Enlarging of the cutting section, constructing retaining walls, very efficient drainage system to remove water from the affected slopes.



Road Cut Parallel to Strike. Beds Dip into the Hill Safe

(b) Joints: Presence of the joints will make even the hardest rocks into loosely held up blocks on the side of a cut which will tumble down on slight vibration. So, they have to be provided with artificial supports by breast walls and retaining walls for stability.

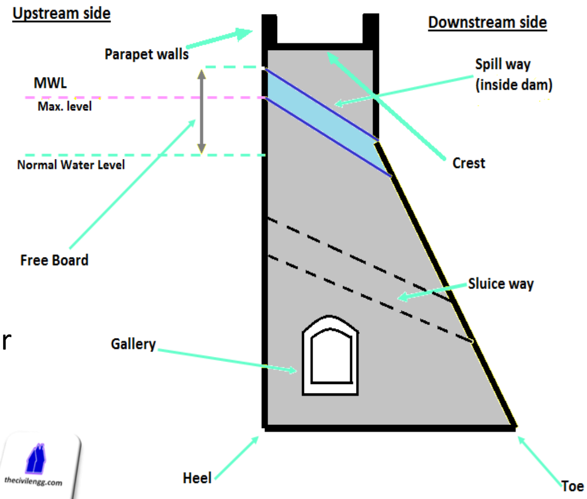
(c) Faults: Faulting leads to the crushing of the rock along the fault planes and shear zones. Such a situation is unfavorable for a cut. So, they should not be left untreated in any case. They are the worst type that leads to failure.

DAMS

A **Dam** may be defined as a solid barrier constructed at a suitable location across a river valley with a view of impounding water flowing through that river. They are constructed for achieving the following objectives:
(i) Generation of hydropower energy
(ii) Providing water for irrigation facilities
(iii) Providing water supply for domestic consumption and industrial uses.
(iv) Fighting droughts and controlling of floods
(v) Providing navigational facilities.

PARTS OF A DAM:

Heel: It is that part where the dam comes in contact with the ground on the upstream side.
Toe: It is that 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 with in 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.
Spillway: 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 wall -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 on the dam, which are harmful to dam stability.

TYPES OF DAMS:

The dams may be classified into two groups, based on construction material used : (i) concrete and masonry dams, and (ii) earth fill dams. The concrete and masonry dams are commonly built to big heights. The earth dams, however, are used for small projects with a maximum height of about 100 meters. Based on design, the concrete dams are further grouped into Gravity dams, Buttress dams, and Arch dams.

1. Gravity Dam: It is a massive structure of concrete or masonry which stands by its own weight. Generally a sound foundation rock is required for the construction of gravity dams.
2. Arch Dam: It is an arch-shaped structure of a single concrete wall, the convex side of which faces upstream. The arch dams transmit water pressures to the abutments by arch action. Hence very strong abutment rocks are required for constructing arch dams.
3. Buttress Dam: In this type of dams buttresses are constructed at the downstream side to support an upstream deck of reinforced concrete. The buttress dams are usually constructed on a good foundation rock.
4. Earth Dam: The earth dams are constructed mainly by soil or earth. These dams have an advantage as they can be built on earth or poor rock conditions.

GEOLOGICAL CONSIDERATION FOR THE CONSTRUCTION OF A DAM

Geology of the Area:

Preliminary geological surveys of the entire catchment area followed by detailed geological mapping of the reservoir area have to be conducted. These should reveal

(i) Main topographic features,

(ii) Natural drainage pattern,

(iii) General characters and structures of rock formations such as their stratification, folding and faulting and igneous intrusions, and

(iv) The trend and rate of weathering and erosion in the area.

Geology of the Site:

(a) Lithology: The single most important feature that must be known thoroughly at the site and all around and below the valley up to a reasonable depth is the Lithology, i.e. types of the rocks that make the area. Surface and Subsurface studies would reveal the type, the composition and textures of the rocks exposed along the valley floor, in the walls and up to the required depth at the base. It is significant to know what classes of rock make up the area: Igneous, Sedimentary or Metamorphic; and also it is essential to know whether the site is made of one type of rock or not. Complex lithology definitely poses challenging design problems.

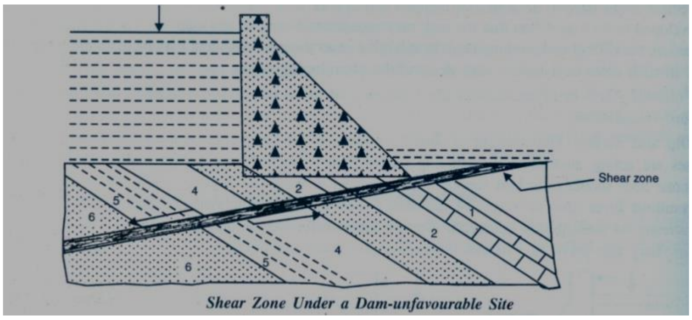
(b) Structures: Along with lithology, the structural features of rocks of the site are also thoroughly investigated. This involves detailed mapping of planes of weakness like bedding planes, schistosity, foliation, cleavage, joints, shear zones, faults and fault zones, folding and the associated features. It is because each one of these modifies the engineering properties of the rocks to a great extent. Their attitude, spacing and nature have to be recorded properly.

Dip and Strike: Gently upstream dipping layers offer best resistance to the resistance forces in a dam. They also serve as a natural obstruction for leakage. The easiest direction for slippage is stratified rocks is along the bedding planes. The most unfavorable condition is when the dam is laid on the beds dipping in downstream side. So, it must be avoided as far as possible. Horizontal beds offer best support for the weight of the dam; it won't cause much leakage like the beds dipping in downstream side.

Faults: These structures can be source of danger to the dam in a number of ways. They are:

(i) The faulted rocks are generally shattered along the rupture surfaces;

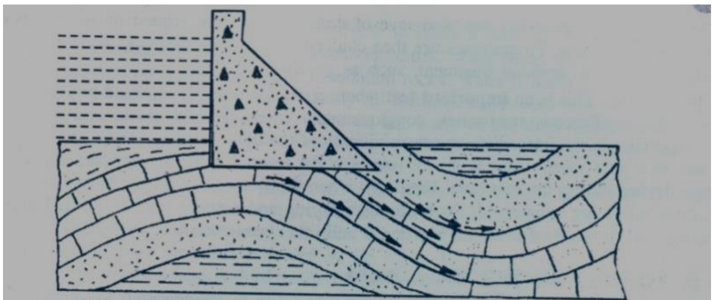
(ii) Different types of rocks may be present on either side of a fault plane. In case some fault surface or zone gets ignored or overlooked, the stability of dam gets endangered.



Shear Zone Under a Dam-unfavourable Site

(iii) Dams constructed on major fault zones are more liable to shocks during an earthquake compared to dams on non-faulted rocks. So, it is better to avoid the fault zones for dam foundations. Small scale fault zones can be treated effectively by grouting. But in case of major shear zones, weak material would have to be excavated and the space backfilled with hard material like concrete up to the required depth.

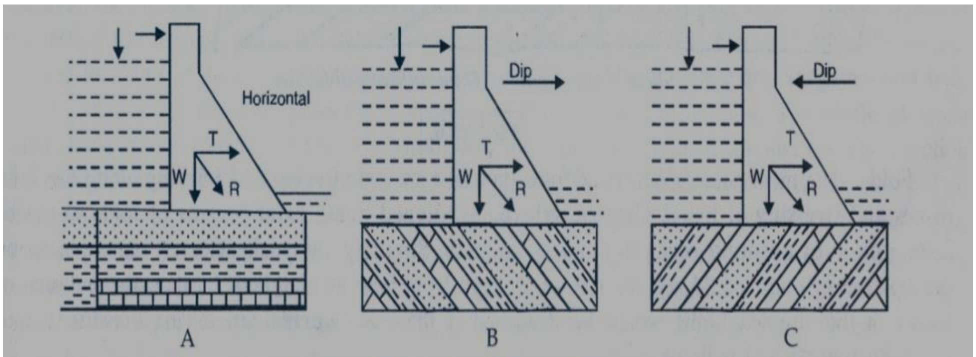
Folds: The most notable effects of folds on rocks are: Shattering and jointing along the axial planes and stressing of limbs. Consequently, dams aligned along axial regions of folds would be resting on most unsound rocks in terms of strength. Dams placed on the upstream limbs would run the risk of leakage from beneath the dam. The stressed limbs would be disturbed if these are opened up during construction of diversion tunnels and galleries.


Effect of Folding on Dam Site. Upstream Face of Syncline – Unsafe.

Joints: No sites are free from jointing. Hence, sites cannot be abandoned, even if profusely jointed. Occurrence of micro joints has to be established with still greater care as such joint systems, if left untreated, could be source of many risks. They have to be thoroughly treated with grouting (process of filling the gaps with cementing material, to seal off).

TUNNELS

Tunnels may be defined as underground routes or passages driven through the ground without disturbing the overlying soil or rock cover. Tunnels are driven for a variety of



Different Possible Positions of a Gravity Dam
A. On horizontal bedded rocks – stable condition, B. On downstream dipping rocks–unsafe.
C. On upstream dipping rocks – safe against R

purposes and are classified accordingly. Chief classes of tunnels are: **Traffic Tunnels, hydro-power tunnels and public utility tunnels.** Tunneling has been practiced for ensuring better and faster communications through roads and railways.

Traffic Tunnels:

This group includes all tunnels which are excavated to divert the traffic load of whatsoever type from surface to subsurface routes for a short length with a view of facilitating the flow of traffic at a desired speed, maximum convenience and at minimum cost. Time will also be saved because of the reduction in distance. **Eg:** The Jawahar Tunnel is a double tube highway tunnel on the National Highway in India, The Hokoriku Tunnel in Japan is a double track railway tunnel, etc.,.

Hydropower Tunnels:

During 20th century most of the tunneling has been in connection with hydropower generation. Such tunnels are aptly called "Hydropower" tunnels. These are driven through rocks for the purpose of conveying water under gravity, as for example, to cross a hill. In such cases they are called Discharge tunnels. The other types are those which feed water under great pressure to turbines and are known as **pressure tunnels**. Yamun – II, Koyna are few examples of Hydropower tunnels.

Public Utility Tunnels:

This group includes a variety of underground excavation made for specific purposes such as for disposal of urban waste (sewage tunnels), for carrying pipes, cables and supplies of oil, water, etc.

Geologically speaking, only two classes of tunnels are recognized: tunnels driven through rocks (rock tunneling) and tunnels driven through soil, loose sediments or saturated ground (soft-ground tunneling).

GEOLOGICAL CONSIDERATION IN TUNNELING:

Tunneling through rocks requires blasting. If the rocks met with are structurally poor, support is often placed under the tunnel ceiling to prevent the rocks from falling during blasting. The geological factors which influence tunneling are Lithology, the attitude of the beds in which the tunneling is developed, various structures present, water bearing properties, etc.,.

(a) Lithology: The information regarding mineralogical composition, textures and structures of rocks through which the proposed tunnel is to pass is of great importance in deciding:

(i)the method of tunneling,

(ii) the strength and extent of lining and, thus

(Iii) the cost of the project.

Hard and Crystalline Rocks are the favorites with the tunnel engineers. These are excavated by using conventional rock blasting methods (RBM) and also by tunnel boring machines

(TBM) of suitable strength. The excavations in hard and crystalline rocks are very often self supporting so that these could be left unlined. Igneous rocks like Granites, basalts, gabbro, sedimentary rocks like sandstones, limestones and metamorphic rocks like quartzite’s, phyllites, etc come under this category. Excavation cost of soft rocks may be lower than those in hard rocks. However, these rocks have to be self-supported, which requires addition time and cost.

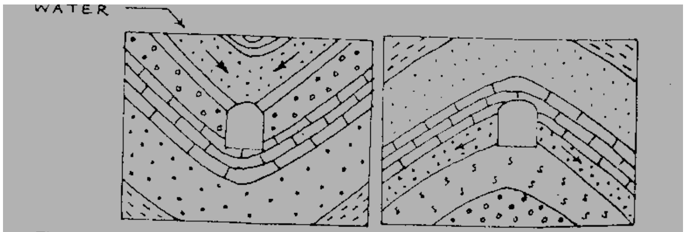


Fig. 10.13. Tunnel along the axis of a syncline. Pressure on the roof and sides is more.

Fig. 10.14. Tunnel along the axis of an anticline. Pressure on the roof and sides is less and water troubles are also less.

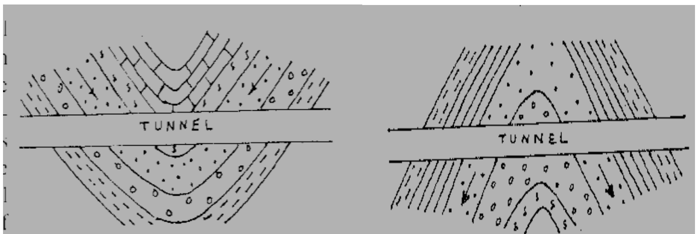


Fig. 10.15. Tunnel across the axis of a syncline.

Fig. 10.16. Tunnel across the axis of an anticline.

Fissured rocks include any type of hard and soft rock that has been deformed extensively due to secondary fracturing as a result of folding, faulting, etc,.Tunneling in such rocks is always hazardous and very challenging job for an engineer.

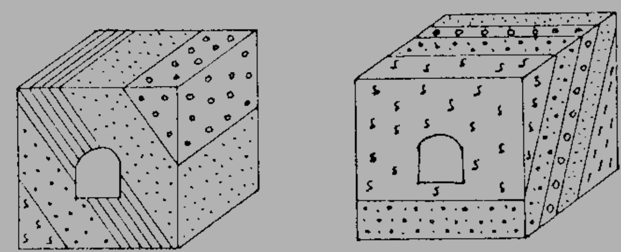


Fig. 10.11. Tunnel along the strike of strata. Pressure concentration is at one side of the tunnel.

Fig. 10.12. Tunnel across the strike of strata. Pressure is downward from the roof.

(b) Geological Structures: The design, stability and cost of tunnel depend not only on the type of rock but also on the structures developed in these rocks. The main structural features that have to be thoroughly determined along the tunnel route are: dip and strike, folding, faulting, shear zones and joint systems.

Dip and Strike: In inclined rock beds when a tunnel is **driven parallel to the strike direction**, there is a tendency in the rocks to fall into the tunnel from the side where the beds dip into the tunnel. This is peculiar if sandstones and shale are interbedded. When a tunnel is made **parallel to the strike of rocks**, it will traverse beds of different rocks. In such cases there will be a downward pressure from roof. In case of horizontal beds the individual layers must be very thick and the tunnel diameter should not be very large, this situation is a favorable one.

Folded Rocks: If tunnels are driven through synclinal folds, the joint blocks from inverted keystones cause rock falls. In case the rocks happen to be water-bearing, the water flows into the tunnel and cause great difficulties. If a tunnel is driven through an anticline, the danger from sudden rock fall is less because the joint blocks are in the shape of normal keystones; they are unlikely to fall into the tunnel. If the water bearing strata are met with, the water trouble will be less because in anticlines the water flows away from it.

Fault zones: Faults are commonly found associated with a zone of highly crushed rock or clay gouge. The crushed rock being highly permeable allows the ground water to seep into the tunnel. Besides this they also form unstable roof rock. The clay gouge on wetting becomes plastic and caves into the tunnel. Faults are therefore a source of major trouble in tunnelling. It's better to avoid the fault zones. If not possible, tunnels have to be driven at right angles to the fault to meet the disturbed zone for a minimum distance. Strong lining is required in the fault zone sections.

Jointed Rocks: Joints at one hand may help in excavating the rocks but on the other hand they may present difficulties in tunnelling. If the joints are closely spaced and water-bearing, rockfalls and ground water seepage may occur into the tunnel.

Water bearing rocks: Driving a tunnel through water-bearing rocks is a difficult job. During excavation the groundwater rushes into the tunnel and causes flooding. This makes construction work difficult. If some clayey rocks are present, their strength may be strongly affected by the flow of water through them.

TERMINOLOGY:

OVERBREAK: During the excavation work some rock outside the desired perimeter of the tunnel is removed so that a concrete lining of proper thickness may be placed. The rock excavated beyond the required cross-section of the tunnel is known as "Overbreak". They increase the cost of lining as they have to be filled back with the concrete.

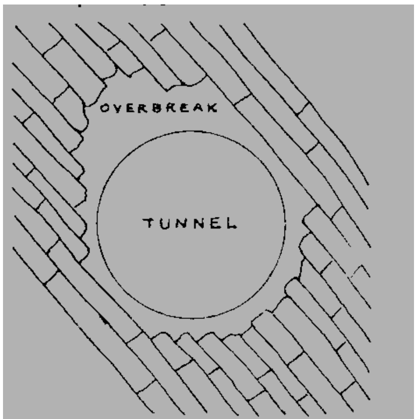


Fig. 10.9. Overbreak in inclined strata.