# VISVESVARAYA TECHNOLOGICAL UNIVERSITY
# BELGAUM

# ENGINEERING GEOLOGY

## (Subject Code: BCV303)

## LECTURE NOTES

## (MODULE-4)

### III-SEMESTER


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## AJIET

## A J INSTITUTE OF ENGINEERING & TECHNOLOGY

DEPARTMENT OF INFORMATION SCIENCE AND ENGINEERING

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**Subsurface investigation for deep foundation**

**Borehole data Dip and strike, and outcrop problems numerical problem geometrical/ simple trigonometry based, Electrical Resistivity meter, depth of water table, seismic studies, faults, folds, unconformity, joints types, recognitionand their significance in Civil engineering projects like tunnel project, dam project, , Ground improvements like rock bolting, rockjointing, grouting**

## DEFORMATION OF ROCKS

Rocks may deform in variety of ways in responses to stresses, largely imposed by plate tectonic processes. The record of rock deformation, in the form of macroscopic features such as folds and faults, provides valuable information on the tectonic history of an area. Whether rocks respond to these differential stresses by folding or faulting is determined by the pressure, temperature, composition of the rock and the rate at which the stresses are applied. We will examine the major types of folds and faults, as well as the relationship of these features to the tectonic settings in which they occur.

## BEDDING

Most sedimentary rocks are deposited under conditions, which favors development of distinct layers from bottom to top. These layers are often easily distinguished on the basis of variation in color, composition and grain size. A sit is sedimentary rocks are the most wide spread on the surface of the earth, forming more than 75 percent of all the rocks exposed. This layered character called stratification or bedding.

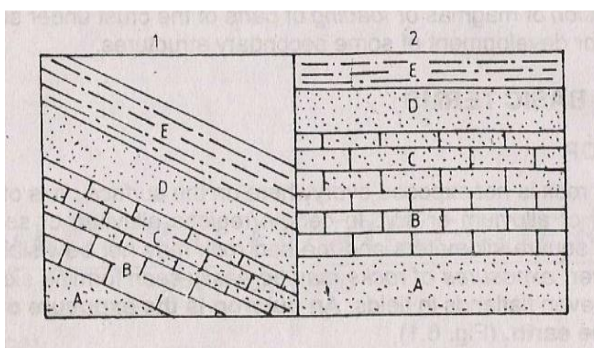



**Fig: Inclined Layers and Horizontal Layers**

## Dip

The dip is both the direction of maximum slope down an inclined surface and the angle between the maximum slope and a horizontal plane

OR

Dip is the direction in which the steepest angle is formed between the plane of the rock bed and the horizontal surface. The dip gives the steepest angle of descent of a tilted bed or feature relative to a horizontal plane, and is given by the number (0°-90°) as well as a letter (N,S,E,W) with rough direction in which the bed is dipping downwards

**Strike**

Strike is the direction of the line that is formed by the intersection of the plane of the rock bed with a horizontal surface or the strike is the direction of intersection of an inclined surface with any horizontal plane

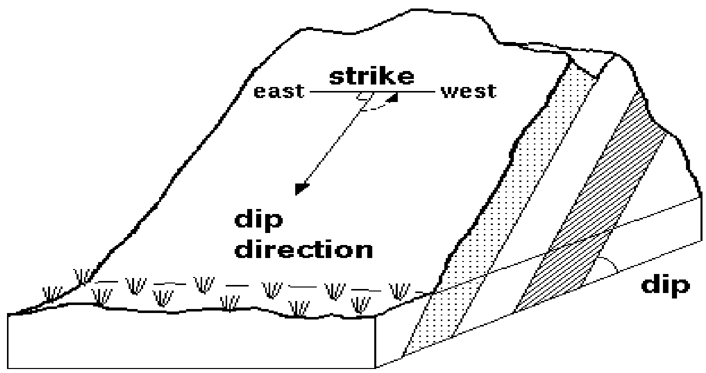



**Fig: showing dip and strike**

Apparent dip is the name of any dip measured in a vertical plane that is not perpendicular to the strike line. True dip can be calculated from apparent dip using trigonometry if strike is known. Geologic cross sections use apparent dip when they are drawn at some angle not perpendicular to strike.

**JOINTS OR FRACTURE**

Fractures are surfaces along which rocks or minerals have broken, thus generating two free surfaces where none existed before; Joints are natural divisional planes or fractures dissecting rock masses in patterns along which there has been no parallel movement of blocks of rocks. The joints are rupture deformation, but differ from fault in not accompanied by dislocation of blocks of rocks. However, there may be slight displacement at right angles producing an open fracture. tensional forces due to drying, shrinkage or contraction or compressive forces due to earth movement produce joints in rocks.

The spacing of joints may vary largely from centimeters to meters. Joints rarely occur lonely and they usually exist in groups running parallel to each other.

A set of parallel joints of common origin is called a joint set. A few joint sets may often intersect forming characteristic patterns. They may intersect perpendicularly or obliquely creating joint systems. Presence of joint systems or joint sets gives a fragmental appearance when they are closely spaced and a blocky appearance when widely spaced

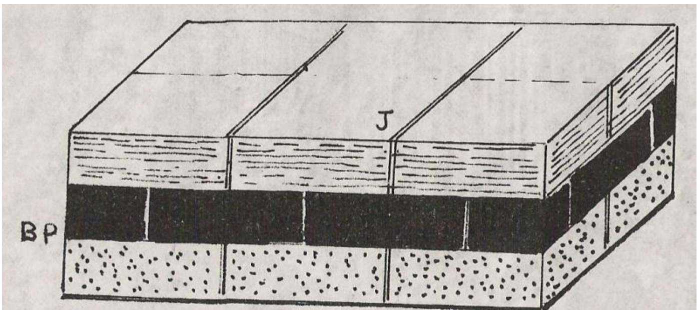



Fig. 10.1 Typical Joints
J = Joint plane BP = Bedding plane

**Fig: An example of vertical joint**

**Classification of joints**

Joints are classified based on

a) Forces causing the joints called genetic joints
b) The position of the joint relative to the dip and strike of the rock bed called geometric joints.

Joints of the former type are said to be of genetic type and the latter of geometric type

a) **Genetic Types of Joints**: - These joints are of two types, namely tension joints and shear joints. Tension joints are large as well as wide. These joints are formed by tensile forces which are induced due to change in volume of rocks due to drying shrinkage in the process of cooling or dehydration and stretching of the fold limbs of a strata. The tension joints appear rough, irregular with jagged surfaces. Rocks easily yield to tensile forces and the rock joints are mostly tension joints.

**Tension joints**

**I) Tension Joints in Igneous Rocks**: As magma undergoes cooling and solidifies or as lava gradually cools and becomes rigid, cracks or ruptures occur forming tension joints. These joints may be mural joints or sheet joints or columnar joints.

**i) Mural Joints**: These joints are common in granites and related plutonic rocks and some hypabyssal rocks. These joints appear in a three dimensional network, the joint sets being mutually perpendicular to each other. The joints break the rock into separate somewhat cubical blocks. Such block separation permits easy quarrying of the rock. The joints may be attacked by weathering agents due to whose actions the separated cubical blocks may get rounded.

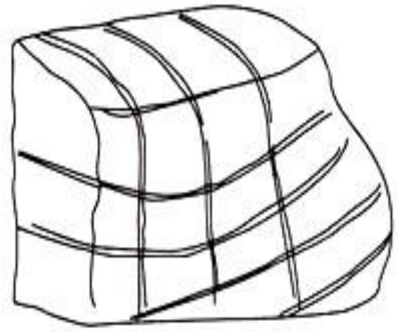


Fig. 17.46 Mural joints in granite

ii) **Sheet Joints**: These joints also are seen in granites and other plutonic rocks. In this case there is one set of **prominent joints parallel to the ground surface whose spacings generally increase with depth and a second set running at right angles.** The joints in this case separate the rock body into sheet like blocks

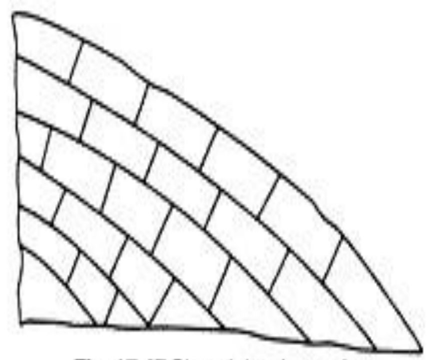


Fig. 17.47 Sheet joints in granite

iii) **Columnar Joints:** These joints are seen in basalts and some other volcanic igneous rocks. They consist of vertical and horizontal joints separating the rock body into a number of vertical polygonal (quite often hexagonal prismatic columns). When the horizontal lavas cool weak planes are developed by radial contraction causing these joints

Fig. 17.48 Columnar joints in basalt

**II) Tension Joints in Sedimentary Rocks:** When many layers of sediments are deposited, during their consolidation under high pressure ruptures occur breaking them into smaller volumes. These joints appear at right angles to each other in more or less regular intervals. These are common in massive and also the bedded sedimentary rocks. The most common tension joints of sedimentary rocks are called master joints.

**I) Master Joints**: These joints are mostly seen in sandstones and limestone's. These joints consist of three sets of mutually perpendicular joints. One set of joints is parallel to the bedding planes. The other two sets are perpendicular to the bedding planes and occur in staggered pattern. These joints continue for long distance maintaining regularity in spacing and width and are therefore named as master joints

**II)Shear Joints**: These are joints associated with deformed rocks especially folded rocks. These joints occur as intersecting or crisscrossing sets at a high angle. These joints are referred to as conjugate joint system. These joints are produced by the action of shear stresses occurring in folding and faulting stages. They are narrowly spaced intersection joints.

**a) Geometric Types of Joints**: In this case the joints are classified based on their attitude relative to the dip and strike of the rock strata. In this case the joints are classified into dip joints, strike joints and oblique joints. Dip joints run in the direction of the dip of the strata. (Ex: Extension joints)

i) **Extension and Release Joints:** These joints are seen in folded rock strata. These joints are formed in the crestal region of the fold and they extend parallel or at right angles to the axial plane or in both these directions. The joints running parallel are called release joints (they run along the strike of the folds) and the joints running at right angles to these are called extension joints.

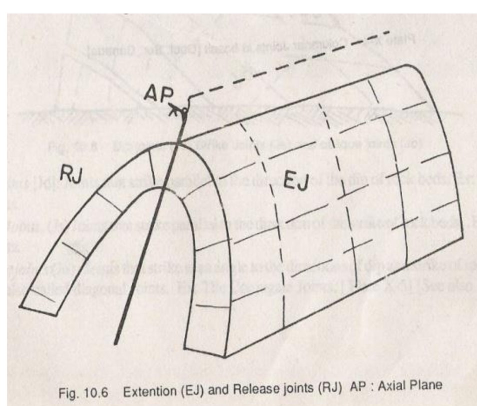



**Fig: Extension and Release Joints**

**Importance of joints:** joints are important not only in understanding the local and regional geology and geomorphology, but also are important in

1) Development of natural resources
2) The safe design of structures, and environmental protection
3) Joints have a profound control on weathering and erosion of bedrock. As a result, they exert a strong control on how topography and morphology of landscapes develop
4) The natural circulation (geo hydrology) of fluids,

Ex. ground water and pollutants within aquifers, petroleum in reservoirs, and hydrothermal circulation at depth, within bedrock. Thus, joints are important to the economic and safe development of petroleum, hydrothermal, and groundwater resources

5) Joints influence quarrying and blasting pattern
6) Joints planes provide potential depositional channels of mineralizing solutions
7) Joints render rocks weak and unstable
8) Joints are helpful in exploration of water and locating well sites

**FAULTS**

Fault is a fracture or fracture zone in rock along which there has been displacement of 2 sides relatively to one another parallel to fracture.

A fault is a rupture deformation produced either by tensional or compressive force.

# Parts of Fault:-

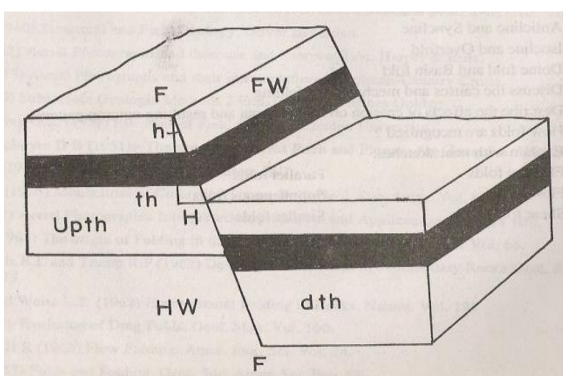



**Fig: Parts of Fault**

**<u>Fault plane:</u>**-The planar fracture surface along which the break and dislocation of rock beds have taken place.

In elevation and plan, ie the vertical and horizontal sections the fault plane appears as a line along which the dislocated beds remain almost in contact with each other.

The fault plane may be simple, clean cut smooth or slicken sided open fracture or a an irregular zone of a number or smaller intersection fracture making a small angle with the main fault called a shear zone often filled with crushed rock and flour.

The lower wall of an inclined fault plane is called the **footwall** and the upper wall the **hanging wall.**

**Throw:-**The vertical component of fault movement

The side of fault plane or trace, which appears to have moved down, ie the fault block above an inclined fault plane is called down, throw side.

The side that appears to have moved up relative to the down throw side is called the upthrow side. The amount of throw varies from a few centimeters to thousand of meters.

**Heave**: - The horizontal component of the fault movement, the shift in measured at right angles to the strike movement.

**Hade**: - The angle between the inclined fault plane and the vertical. Hade is the compliment of the dip of the in degrees Hade is measured from the vertical and its fault plane expressed

**Slip**: - The displacement of the formerly adjacent points. The slip may be:-

a).**Translational**:-the direct down dip or upside movement of rocks blocks on the fault plane in the direction of its true dip called dip-slip or sideward movement called strike slip or a combination of these called oblique-slip

b).**Rotational**: -the fault blocks rotated relative to each other.

**Classification and Types of Faults**

Faults are classified and described on the basis of

(a).The direction of slip of beds, ie the apparent displacement of fault blocks relative to each other and the causative forces called the genetic types.

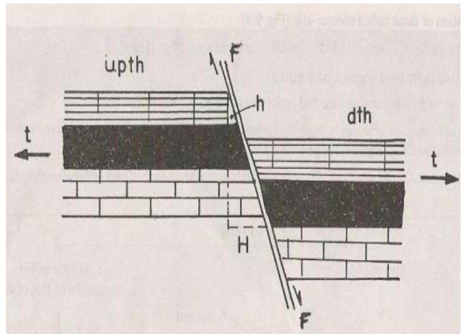
(b).The attitude of fault plane relative to the attitude of rocks beds called the geometric types.

1. **<u>Genetic types</u>**

The various types of faults the normal, reverse and lateral faults are the basic types.

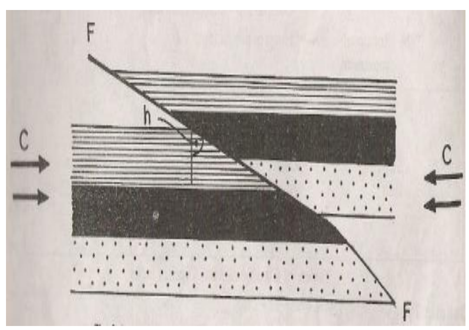
**Normal Fault**:-A normal fault is a high angle dip-slip fault in which the fault

Steeply with hade $10^0$-$20^0$ or less. the vertical component of the movement ie the throw is generally large. The fault traces of normal faults commonly run straight or slightly sinuous, but may be very irregular due to slumping of the sides later. Normal faults may small, local or regional features and area also called gravity faults.



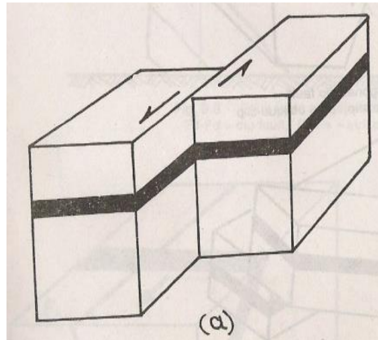

**Reversal Faults**:- Where the crust is being compressed, reverse faulting occurs, in which the hanging-wall block moves up and over the footwall block – reverse slip on a gently inclined plane is referred to as thrust faulting.

Reverse faults are produced by severe compressive forces and the fault planes commonly area gently dipping with large hade over$45^0$. when the heave or the horizontal of the movement is large, often many kilometers in case of larger faults. The up throw side is actually thrust over the down throw side due to great tangential forces. as such a reversal fault is also called thrust fault. when topography is high the fault trace of a reverse fault will be very irregular. Reverse fault may be small, local or regional.

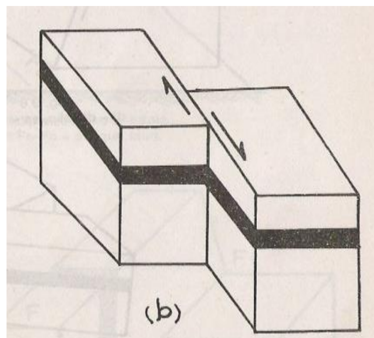



**Lateral Fault**:- A fault is a strike slip fault, ie. In which the dislocation is essentially horizontal in the direction of the strike of the fault plane without any dip-slip component Lateral faults are also called transverse, transcurrent or wrench faults. The fault plane is vertical of near vertical. Different types of lateral faults are:-

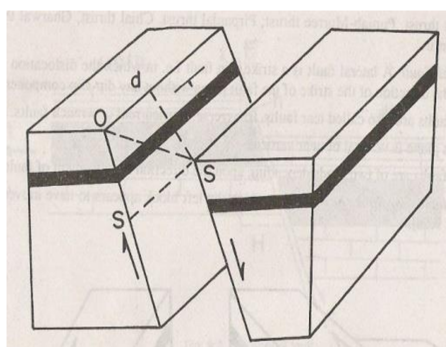
a.)**Left-Lateral Fault**- in which the left block appears to have moved towards the obsever



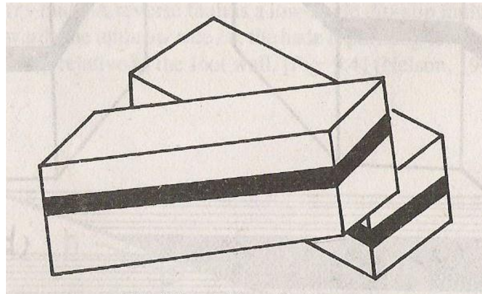

b.) **Right-Lateral or Dextral: -** in which the right side block appears to have moved towards the observer.




**c.) Diagonal-Slip Fault:-** this is an oblique-slip fault in which the dislocation is diagonal ie. At an angle to the direction of true-dip and strike of the fault plane, up or down both dip-slip and strike-slip components.




d.)**Hinge-Fault**:-A fault with an angular or rotational displacement in which the wall rocks of one side have rotated along an axis normal to the fault plane with respect to the rocks of the other wall.



**Geometric Types**

In regions of inclined and folded beds faults are described according to the trend of the fault trace relative to the attitude of rock bodies.

**Dip Fault**: - In which the fault plane trends in the direction of the dip of strata, i.e the fault strikes parallel to the dip of the strata.

**Strike Fault**: - In which the fault trace trends in the direction of the strike of the strata i.e the fault strikes parallel to the strike of the beds.

**Oblique Fault**:- when the fault trace trends at an angle to the dip and strike directions of the strata i.e. The fault strikes diagonally across the beds, hence it is also called as diagonal fault.

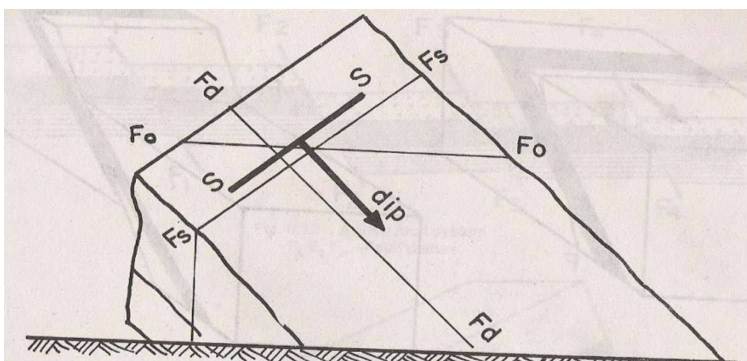



Fig. 9.8 Fault trace and directions of dip and strike of strata
Fd-Fd = dip fault. Fs-Fs = strike fault Fo-Fo = oblique fault.

**Importance of Fault**

1) Fault movement triggers earthquake and landslides.
2) Fault zones are most undesirable features in dam and reservoir sites.
3) Faults provide passages for percolation of water and mineralizing solutions
4) Fault zones form sites of mineralization
5) Fault are responsible for lakes, swamp sand spring heads
6) Fault zones often form potential oil traps
7) Faults from a major defect in rock and there a potential hazards in engineering and mining works.

**FOLDS**

Fold occurs when rock deforms in such a way that it bends instead of breaking. The rocks, like any other material, deform to the action of external efforts. We do not grasp this deformation, but we know when a rock is deformed. Folds come from pressure on the rocks that occur over very long periods of time and vary in size from microscopic crinkles to mountain-sized folds

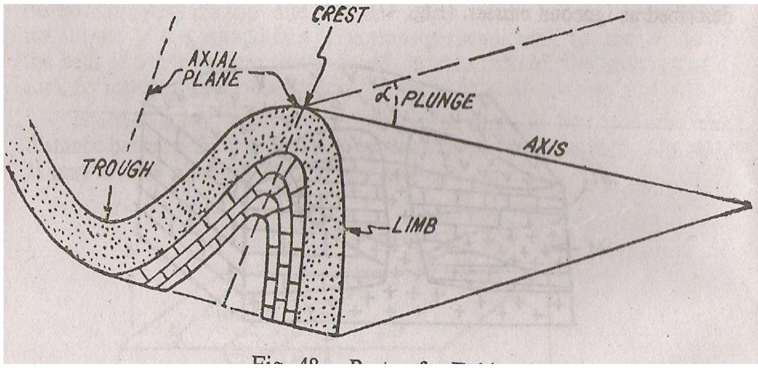



**Fig: folds**

**Axial line or Axis**:-The median line about which folding has taken place. The axis may be horizontal, inclined or vertical

**Axial plane**:-An imaginary plane that divides a fold into two more or less symmetrical halves. The axial plane may be vertical inclined or horizontal.

**Limbs**: - The two sides of a folds the left limb and right limb.

**Crest:** - Highest position of fold, it is always curving or angular.

**Crest line**: - The two sides of crest point are referred as **crest line;** If the fold axis is inclined then it referred as **Plunge of fold**.

## Classification of Folds

It is classified and described according to the attitude of the limbs, axis, axial plane and the nature of beds. The important types are:-

**Anticline: -** is a fold that arches up as both sides of the rock are pushed inward. You can remember that the anticline creates this type of fold because the arch looks like an 'A' (for anticline)

**Syncline: -** is a fold that sinks down as both sides of the rock are pushed inward. You can remember that a syncline creates this type of fold because the fold 'sinks' downward, which sounds like 'syncline.

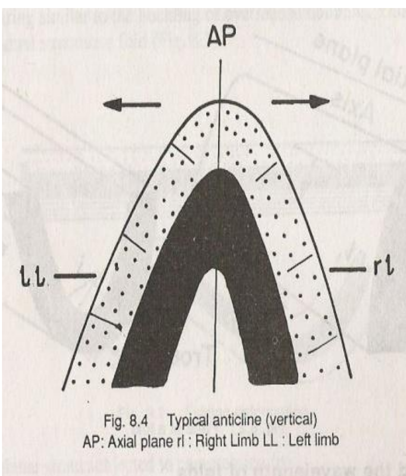
**Domes:** - which are like anticlines but instead of an arch, the fold is in a dome shape, like an inverted bowl.

**Basins:-**which are like synclines but again, instead of a sinking arch, the fold is in the shape of a bowl sinking down into the ground.

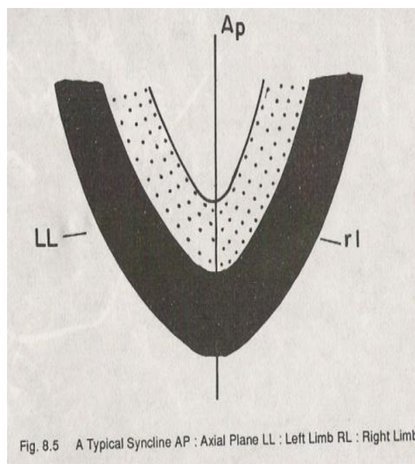
**Isoclinal Folds:-** are similar to symmetrical folds, but these folds both have the same angle and are parallel to each other. 'Iso' means 'the same' (symmetrical), and 'cline' means 'angle,' so this name literally means 'same angle.' So, isoclinal folds are both symmetrical and aligned in a parallel fashion.

**Overturned Folds:-** occur when the folding is so intense that the fold appears to have turned over on itself.

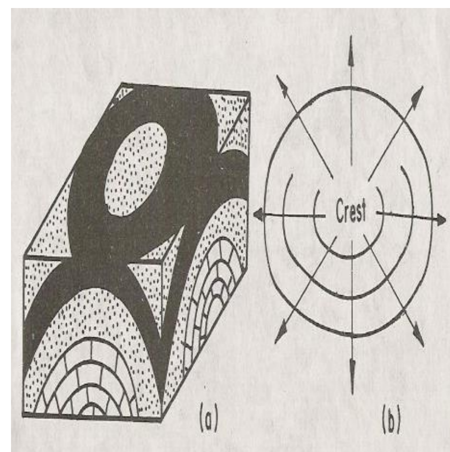
**Chevron Fold: -** If the crest point is a cute then it is referred as Chevron fold. This is due to very much of magnitude of force is acted on either side.



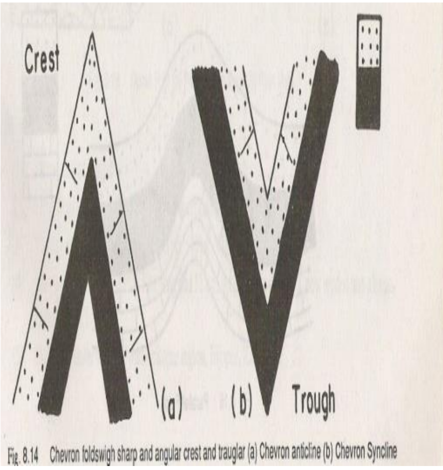

Anticline



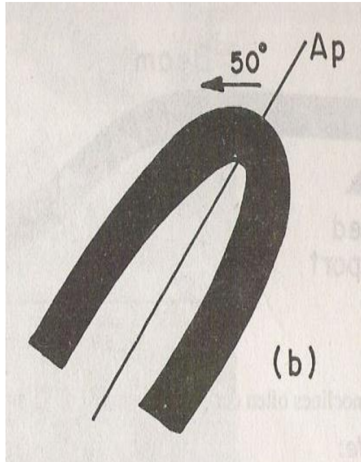

Syncline



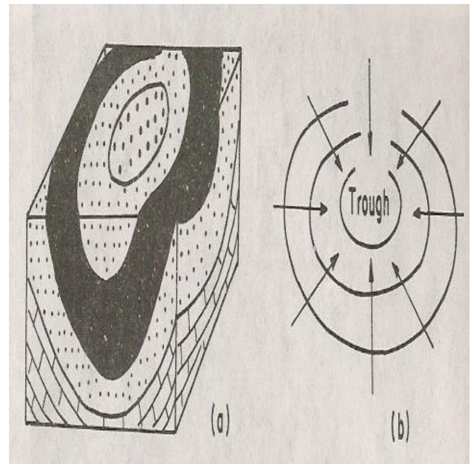

Domes



Chevron



Isoclinal Folds



Basins

**Fig: Different types of folds**

**<u>Effects of erosion on Folded Strata</u>**

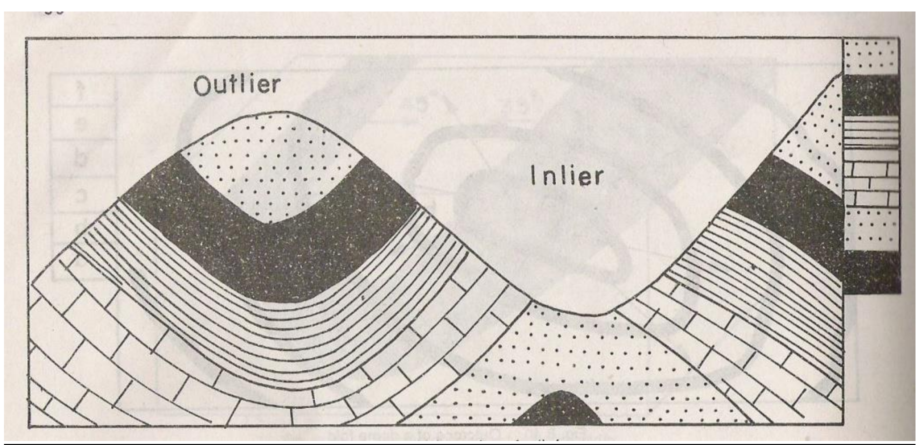



**Fig : Deposition of sediments**

Normally anticlines form ridges and synclines rough. but on erosion anticlines are eroded down along with crest, which will be in strata of tension and form long channels called anticline valley or Inliers.

In case of synclines the limbs are easily eroded and the trough region being compressed tightly standing ridges resisting erosion called synclinal hills or outlier.

Importance of Folds

Folded strata is greatly strained broken and incompetent, therefore form weak and unsafe zones in construction areas especially excavation for tunneling, hillside cutting, dam and bridge sites.

Anticline and other upfolds form potential oil traps while synclines and other down fold form potential aquifer for ground water. in some instances down folds like synclines when filled with groundwater artesian conditions under going pressure affecting the stability of the ground above and therefore the stability of structure constructed in such ground.

# Unconformities

When stratified rock formations are deposited regularly and continuously one above the other without any disturbance or break in the succession presenting a series of parallel beds, the sequence is called conformable beds or series and the structure is called conformity.

An unconformity is a buried erosion or non-depositional surface separating two rock masses or strata of different ages, indicating that sediment deposition was not continuous. In general, the older layer was exposed to erosion for an interval of time before deposition of the younger, but the term is used to describe any break in the sedimentary geologic record.

Unconformity indicates discontinuity, disruption or breaks the deposition and therefore a time gap. The relief of the erosion surface between the older and the new or younger series may be smooth or irregular.

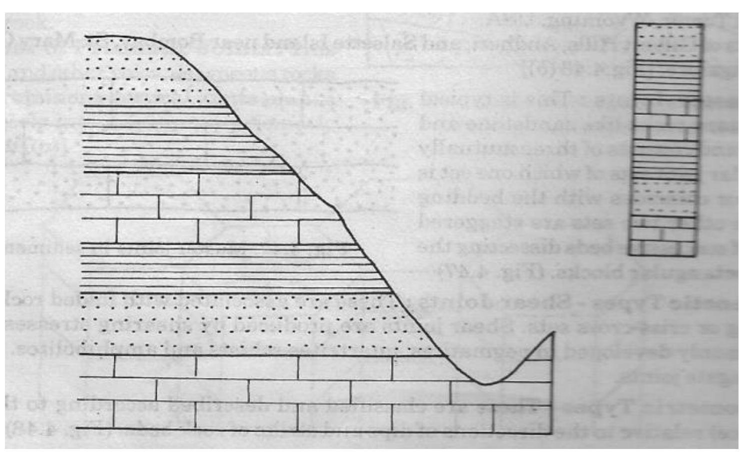
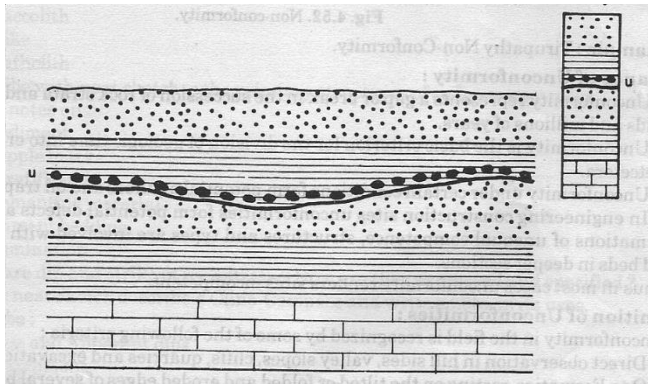


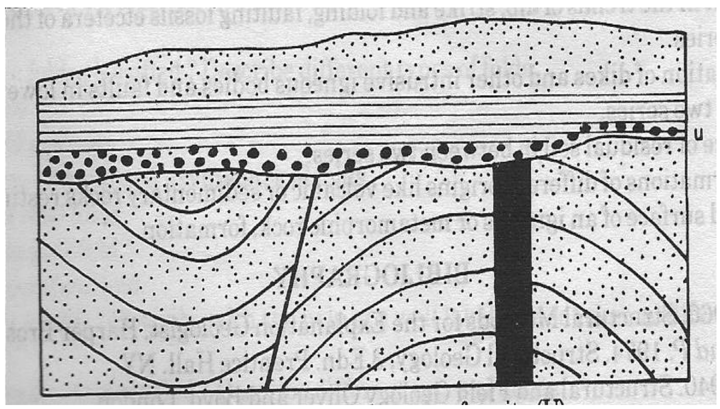
**Fig: Unconformity**

## Types of Unconformities

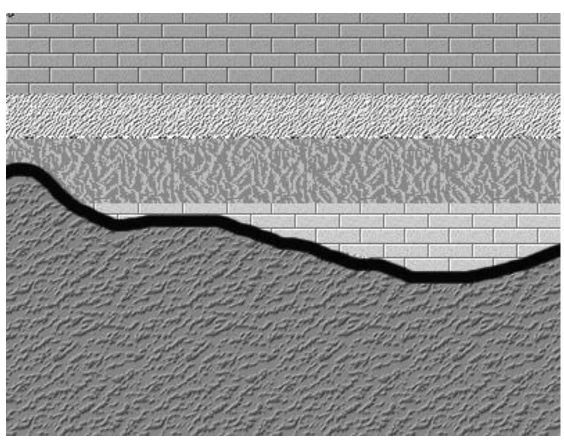
**Parallel unconformity or Disconformity: -** An erosion surface with an uneven relief between two parallel series.




**Angular Unconformity**:- An unconformity in which a younger parallel series deposited on an erosion surface of a lower deformed (tilted, folded and or faulted) older series with an angular discordance.




**Non-Conformity**:- An unconformity between two series of rock of different origins like an upper younger stratified formation and an older non-stratified or massive igneous or metamorphic rock.



**<u>Importance of Unconformity</u>**

1. Unconformity represents a gap or break in the succession of rock strata and a time gap of thousands of millions of years.
2. Unconformity is the basic criterion for the division of geologic time into era, periods etc.
3. Presence of residual soil in between 2 series
4. Rock formations of different origin like volcanic or sedimentary rock resting upon the eroded surface of a igneous or metamorphic rock formation
5. Contrast in the trends dip, strike and folding, faulting fossils etc of the two adjacent or successive series
6. Termination of dikes and other intrusive igneous bodies and faults in lower series at the junction of 2 series

# Selection of Site for Dams and Reservoirs

A **dam** may be defined as a solid barrier constructed at a suitable location across a river valley. The principle uses are to provide stream regulation and storage for communities or industrial water supply, power, irrigation, flood control. A dam that serves more than 1 such purpose is known as multipurpose dam.

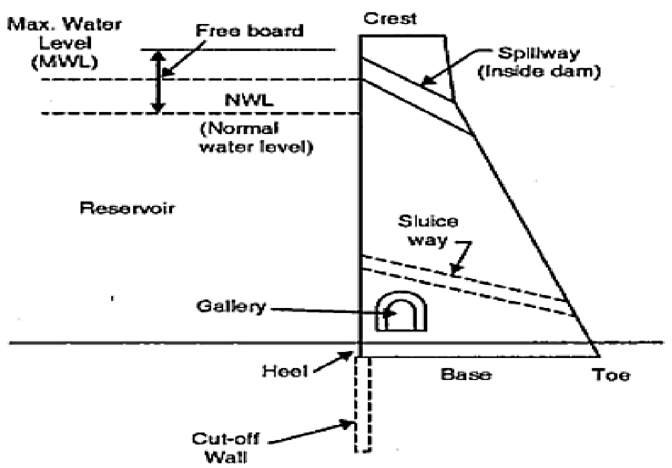



**Fig- Schematic Cross Section of Dam**

**Structure of Dam:** Generally Dam consists of following parts

**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 way** : 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.

1. Gravity Dam
2. Buttress Dam
3. Arch Dam
4. Earth dam

1. **Gravity Dam** :- A gravity dam is a solid masonry or concrete structure generally of a Triangular in cross section. solid gravity dam drive their stability from weight of the materials comprising the structure. Axis may be straight line it is designed that it can with hold a percolated volume of water by its weight. All the applied forces on such a dam is due to water and weight of the dam itself are assumed to be directly transmitted to the foundation rock.

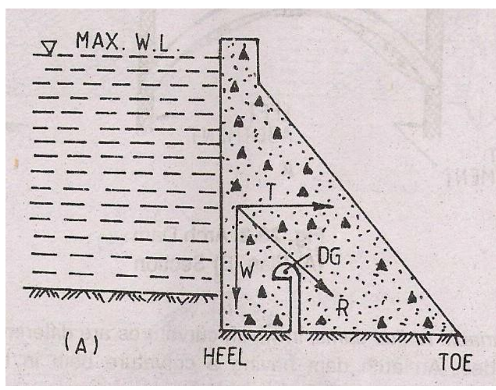



**Fig: A Typical Cross Section of Gravity Dam**

1. **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.

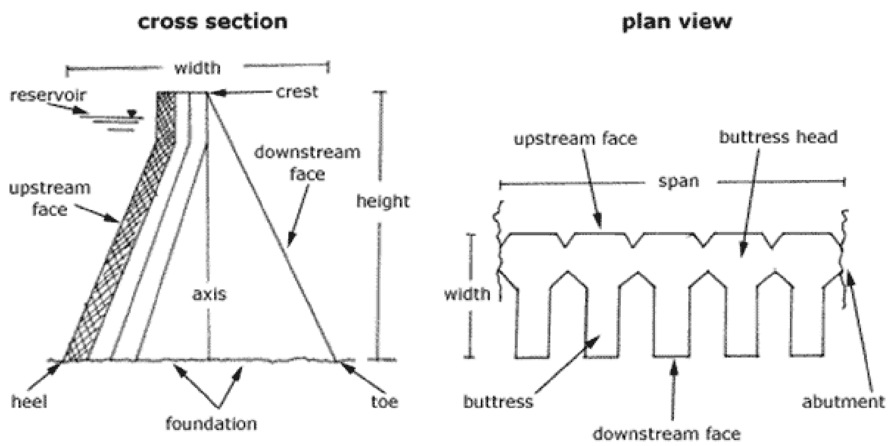



**Fig: Buttress Dam Cross Section and Plan**

2. **Arch Dam**: - An arch dam is an impermeable concrete shell shaped an arch in plan when curved in vertical section it forms a dome shape. Many gravity dams are arched in plan. But he characteristic of an arch dam is that it's cross section. Arch dam are thin, they require the least volume of construction materials of all designs yet their shape makes them strongest of all.

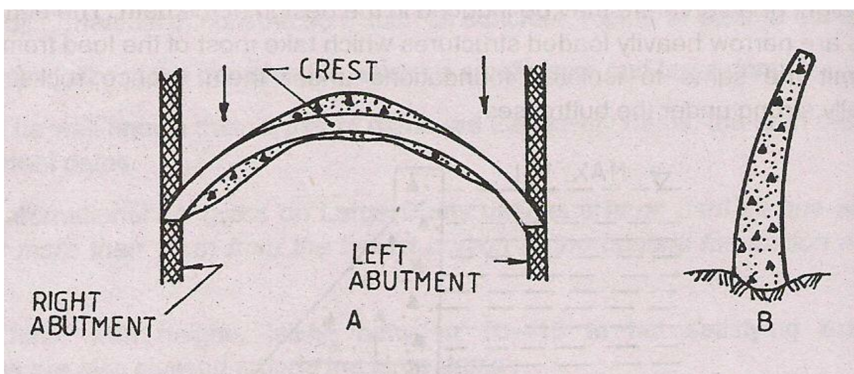



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**Fig: Arch Dam**

3. **Earth dam**: - These consists essentially core of impermeable material, such as clay or concreted, supported by permeable boulders of earth and rockfill, when a clay are used it is normally flanked by filters of permeable material such as sand to protect the core from erosion by the seepage of reservoir water through dam. Embankment dams, by virtue of the slopes required for their stability. Earth fill and rock fill dam are terms used to described suitable sedimentary materials such a clay, sand and rock blocks that can be placed to forming safe embankment.

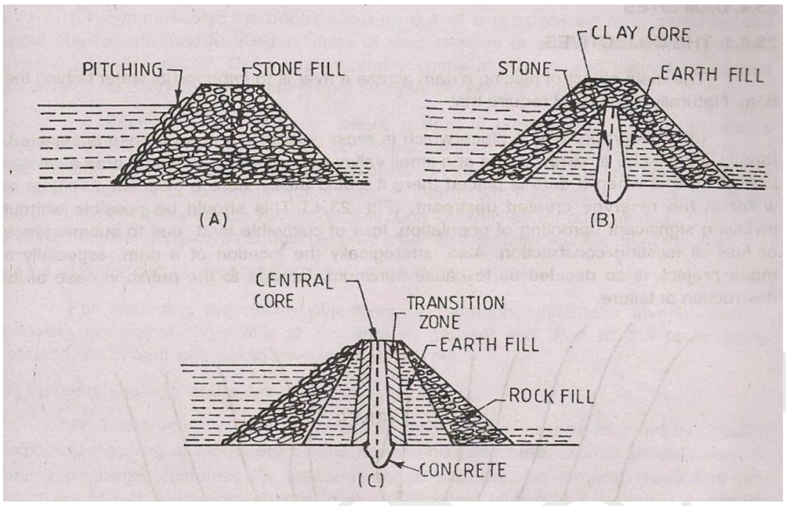



**Fig: Earth Dam**

## Geological Considerations in the Selection of Dam Site

The important geological environment 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.

1. **Narrow River Valley**

i) 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.

ii) Deceptive narrowing of a valley due to the occurrence of thick superficial deposits such as residual soil and talus in recently glaciated regions, moraine, boulder clay, sand, gravel and river alluvium.

iii) Narrow valley due to deceptive rock outcrops which are the result of land slip, rock creep and rock fracturing

iv) The occurrence of buried river channels crossing the site, either below the bed or adjacent to it

2. **Occurrence of the bedrock at a shallow depth**

i) 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.
ii) 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.
iii) 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.
iv) 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.
v) In certain places particularly in glaciated regions, the occurrence of buried river valleys, a buried river valley may occur in the river bed that is generally deep, and is composed of 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.

**Competent Rocks for Safe Dam**: 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.

**Sedimentary rocks those are undesirable:**

1. Shales are the most undesirable at the dam site, as they form slippery bases.
2. Laterites and conglomerates are undesirable, because of their porosity and permeability.
3. Lime stones 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.
4. Alternating soft and hard rocks for small thickness are undesirable.

**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.

# 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.

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.

**Geological Considerations of tunnel sites**

**1) Lining of tunnels:**

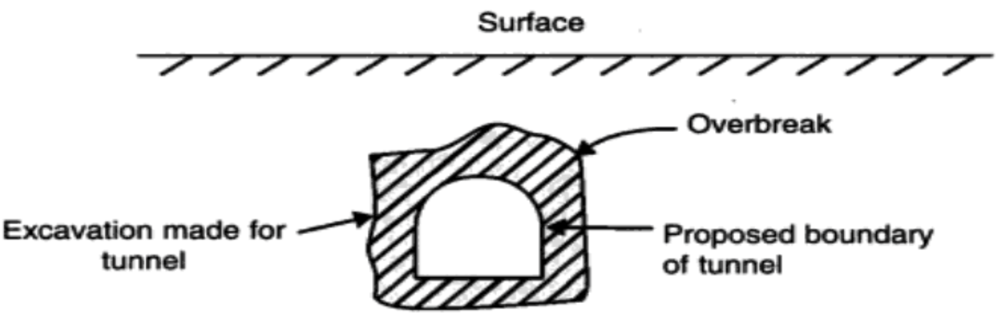
i) When tunnels are made through weak or loose or unconsolidated formations, they are provided with suitable lining for safety and stability. Lining refers to the support porvided to tunnel. Lining may be in the form of steel structures or concrete.

ii) 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.

iii) The thickness of concrete lining dependes on the extent of protection required, and the degree of weakness of the ground. Lining is provided to support weak parts 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.

2) **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:

1) The nature of the rocks.
2) The orientation and spacing of joints or weak zones in them.
3) In the case of sedimentary rocks, the orientation of the bedding planes
4) Thickness of the beds with respec to the alignment of the tunnel.

**Geological factors influencing the overbreak:**

1.) Massive and soft rocks of a homogenous nature cause less overbreak than harder rocks with well developed joints or weak zones.

2.) 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. 3.) 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.

4.) 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.

## Site Selection for Bridge

A **bridge** is a structure built to across physical obstacles without closing the way underneath such as a body of water, valley, or road, for the purpose of providing passage over the obstacle.

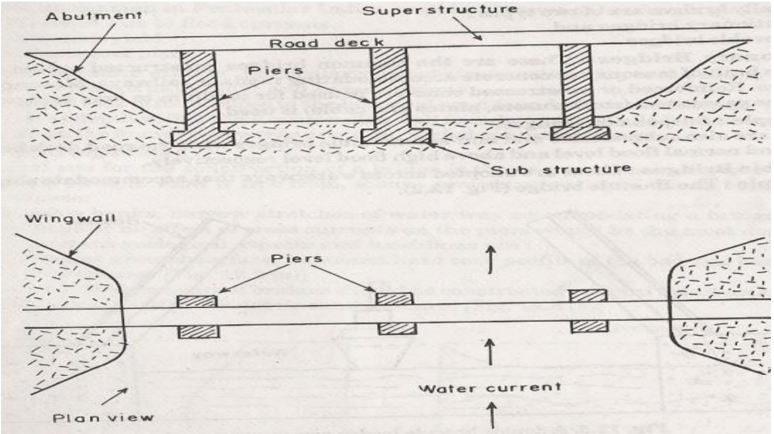



**Fig: Cross Section of Bridge**

## Parts of Bridges

**Bed:-**Surface of firm ledge or bed rock providing a stable foundation for bridge piers.

**Abutment:** -The end supports of a bridge to withstand thrust

**Wing wall**: - A masonry or concrete wall that guides a river into a bridge.

**Pier:-** A rectangular, oval or circular masonry or RCC column that supports the super structures of a bridge erected from a firm bearing bed for stability.

## Components of Bridge

1. Sub Structure:- constructions on the banks, piers, wing walls and foundations.
2. Super Structure: - comprises of construction that res on the piers and the abutments including girders and beams.

**Bridge Types**: -It is classified into

I). **Stationary bridges: -** these are common bridges constructed across valley and depression built of masonry or concrete accommodating roads or railways. masonry is used for arch bridges, reinforced of prestressed concrete used for medium to long bridges.

II). **Movable bridges: -** These are adopted across water ways that accommodate shipping. These are consists of one or two movable steel sections or spans-single or double bascules. These are lifted up at either end to allow ships to pass through and then lowered back to position providing normal road or railway

**The important bridge problems that lead to the failure are**

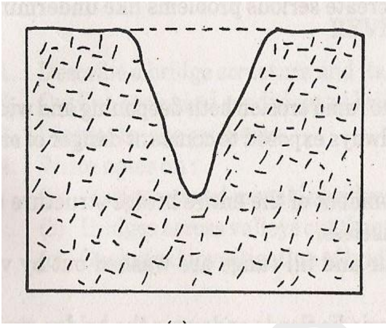
1. Erosion of the piers and wing walls
2. Deep scouring and collapse of bridges
3. Wash out due to flood currents
4. Settlement of piers
5. Earthquake effects

## Geology of Bridge Sites

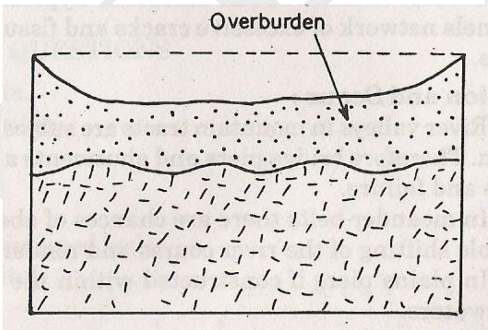
An ideal site for the construction of a bridge is the one across a valley cut in sound rock and where the stream flow is free from scour, provoking currents due to bends and other causes. A high stable bank, narrow stretches of water accommodating a bridge of minimum length with little or no effect.

**The important geological aspects and conditions are**:-

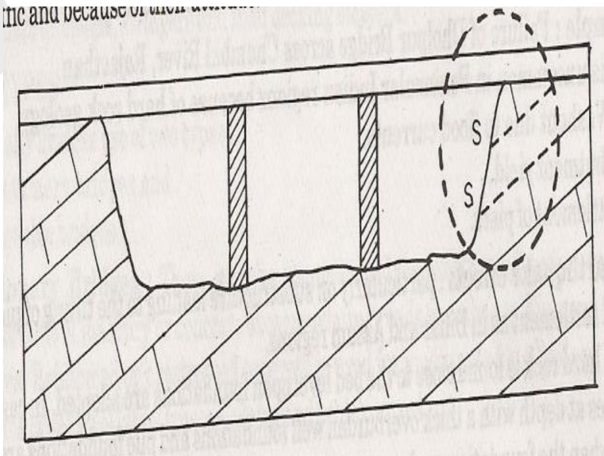
1. Bed rock at round surface i.e. sound hard rock profile of the bed and banks of valleys, canals and depressions.



2. The piers and abutments of bridges should be constructed on hard intact rocks only and not on over burden such as fill, rock debris, sand etc.




3. Rock formation should be intact, strong and tough without defects and weak planes.
4. Intact intrusive igneous rocks like granite, compact basalt, Sedimentary like hard Sand stone free from excessive joints and metamorphic like massive gneiss, quartzite provide excellent foundation abutment and bearing materials.
5. Bedded and Jointed formations especially those dipping into the river at lesser angle than the slope of the natural banks always dangerous as they tend to slide at any movement it is shown in figure.



6. Faulting brings rocks of diverse character strength together along the fault line. Any further displacement at the fault contact may adversely affect the piers like displacement, tilting. Therefore it is very essential to treat the fault one well and substructure suitability designed.
7. soluble formation like lime stone, gypsum rocks are enlarged with elongated joints solution channels networks of excessive cracks create serious problems like understanding of banks.

**Ground improvements like rock bolting, rock jointing, grouting**

Rock bolting is the systematic reinforcment and/or anchorage of rock slopes by the insertion and grouting of steel bars into holes predrilled into the more or less fractured rock mass, improving its stability. The deformed steel bars are typically 25 to 50 mm in diameter and up to 12 to 15 m in length. Long bolts are typically formed by joining shorter threaded bars using special couplers, to facilitate handling. For convenience of installation, strand anchors (see fact-sheet 6.8) are normally used where longer bolts are required. Bolts are installed across the discontinuities or the potential failure surfaces at a dip angle flatter than the normal and typically work mainly in tension and only subordinately in shear and bending.

Typically, drillholes in rock are self supporting. However, critical drilling conditions with potential loss of borehole stability may be encountered when drilling through higly fractured or milonitic zones, especially if water is also encountered in the drillhole. In this case, it may be simpler to grout and redrill the hole, rather than using a casing.

In relation to the degree of relaxation or loosening of the fractured rock to be reinforced and/or to be tied to the more competent rock below the bolts can be un-tensioned or tensioned. Relaxation and or loosening of the rock mass is a process that takes place as a results of unloading and weathering; once relaxation or loosening has been allowed to take place there is a loss of interlock between the blocks of rock and a significant decrease in the shear strength along the discontinuities and in the rock mass as a whole. Once relaxation or loosening has taken place, it is not possible to reverse the process. For this reason:

- where the degree of relaxation or loosening is relatively modest, it is possible to use passive (untensioned) rock bolting acting as pre-reinforcement (Moore and Imrie, 1982; Spang and Egger, 1990); the deformations necessary to activate the bolts are sufficiently small not to result in a significant reduction of the shear strength characteristics of the discontinuities and of the rock mass as a whole;

- where significant relaxation and loosening have already taken place, it may be necessary to install tensioned bolts in order to prevent further displacements and loss of interlock.

The advantages of using un-tensioned bolts are the lower costs and quicker installation compared with tensioned bolts.

From a conceptual point of view, un-tensioned (passive) rock bolts work in the same way as nails of soil nailing structures.

They are grouted for their full length in a single operation both below and above the potential failure surface. In slope applications, where the drillhole dips into the ground, there is no need for anchoring the distal end of the bolt. Even though in many situation a head plate is not strictly required, a end plate is normally fitted to the bolt at the surface and this may be usefull to anchor netting and or other facings that may be required.

From a conceptual point of view, tensioned (active) rock bolts work like anchors in tieback retaining structures. They are characterized by a anchor head, a free-stressing length and a bond length, located beneath the discontinuity or the potential failure surface.

Tensioned (active) bolts must satisfy three basic requirements:

1. There must be a suitable method of anchoring the distal end of the bolt in the drill hole;

2. A known tension must be applied to the bolt without creep and loss of load over time;

3. The complete bolt assembly must be protected from corrosion for the design life of the project.

**QUESTION BANK**

1. Explain folds and its classification
2. Explain faults and its types
3. With a neat sketch explain Dip and strike
4. Explain ground Improvements
5. Define conformities and its types