Catalog

UNIT IV

STRUCTURAL GEOLOGY AND GEOPHYSICAL METHODS

4.1 STUDY OF STRUCTURES-FOLDS

SYLLABUS

Geological maps – attitude of beds, study of structures – folds, faults and joints – relevance to civil engineering - Geophysical methods – Seismic and electrical methods for subsurface investigations.

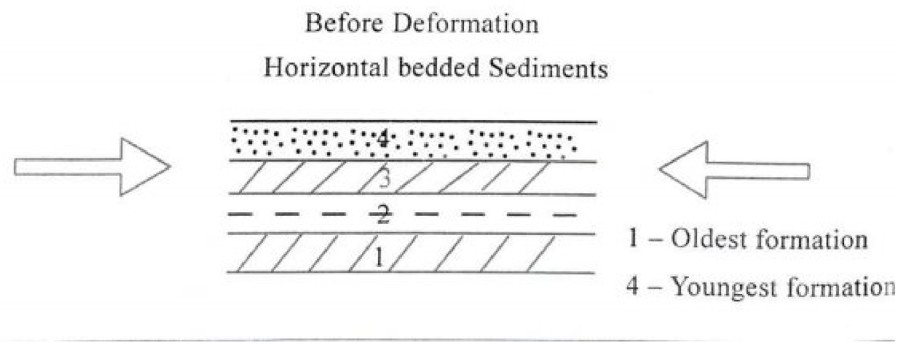
Dip: The dip direction is the direction along which the inclination of the bedding plane occurs. The dip amount is the angle of inclination between the bedding plane and a horizontal plane. For example the beds are inclined at 30^0 to the horizontal and the dip may be expressed as S 60^0 E; when the strike direction is N 30^0 E or S 60^0 W.

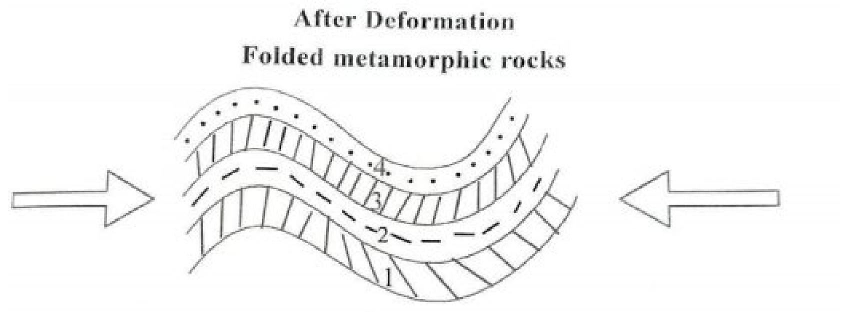
Strike: When a bedding plane (or a joint plane, or a fault plane) is cut by a horizontal plane, a line of intersection will be obtained at the surface. This direction is known as the strike, or the direction of the strike, or the line of the strike. Strike direction can obviously be represented as N 30^0 E or as S 30^0 W.

Study of Structures – Folds

Folds are wavy undulations developed in country rocks, whenever the region is subjected to severe pressure or stress.

The sides of a fold or the stretch of the rock beds lying between any crest and any of the adjacent troughs on either side are called a limb.





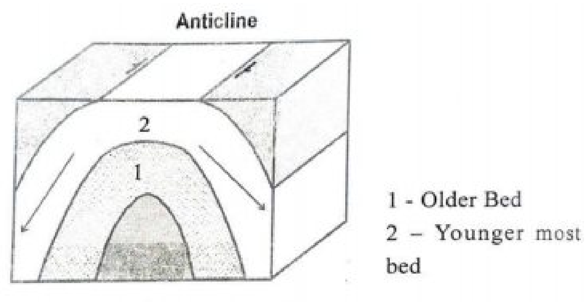
Types of folds

1. **Anticline:**

i. Anticline is the fold which is convex upwards.

ii. In anticlines, both the limbs are dipping away from each other.

iii. Progressively older beds are found to occur towards the center of curvature of the fold.

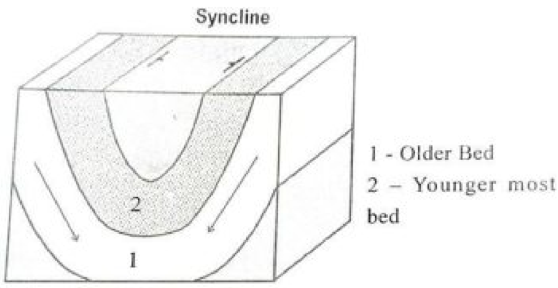


2. **Syncline:**

i. Syncline is a fold which is convex downwards.

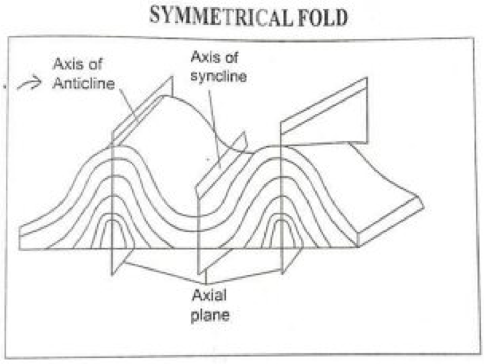
ii. The limbs of the fold are dipping towards each other.

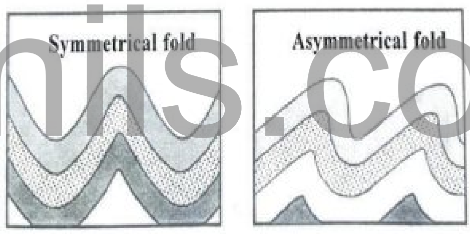
iii. Progressively younger beds occur towards the center of curvature of the fold.



3. Symmetrical fold:

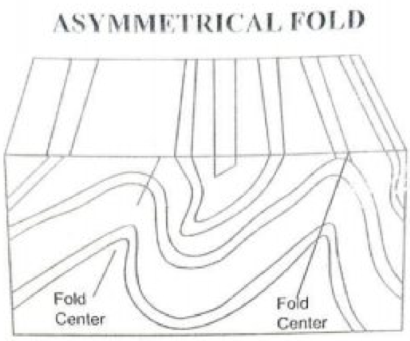
It is a fold in which the axial plane is essentially vertical and both the limbs have the same amount of dip.





4. Asymmetrical fold:

In asymmetrical fold (whether anticline or syncline), the axial plane never remains vertical. So, both the limbs have unequal dips.

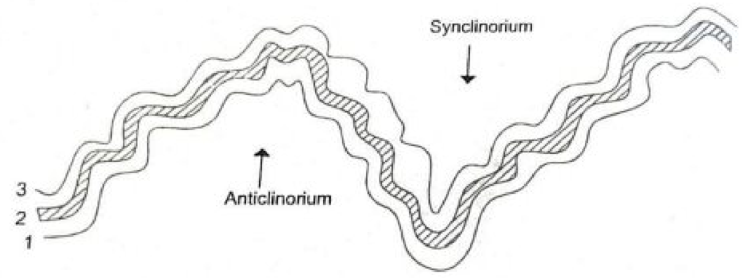


5. Anticlinorium:

A large anticline with a number of minor secondary folds developed on it is known as anticlinorium.

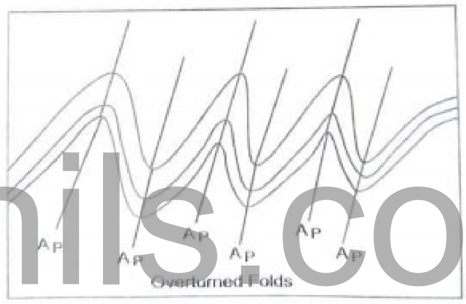
6. **Synclinorium:**

A large syncline in which a number of minor secondary folds are developed is called a synclinorium.



7. **Overturned fold:**

A fold in which one of the limbs appears to be rotated and completely overturned from its normal position, is called overturned fold.



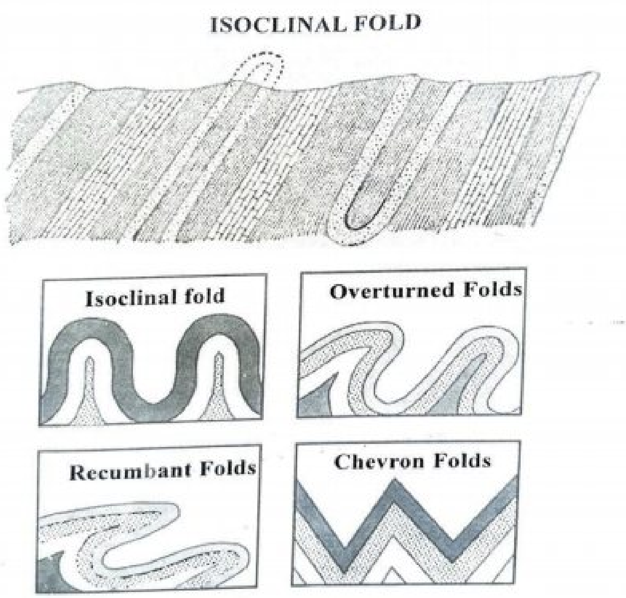
8. **Fan fold:**

If in any fold, both the limbs are overturned, the same assumes the shape of a fan and is known as fan fold.

FAN FOLD

9. **Isoclinals fold:**

If both the limbs of a fold have the same amount of dip towards same direction it is called an isoclinals fold.



10.Recumbent fold:

If the axial plane of a fold is horizontal, it is called recumbent fold.

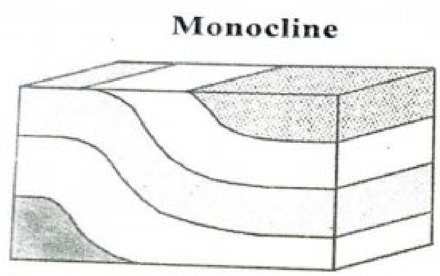
11. Chevron fold:

If the crests and toughs of a fold are sharp and angular, it is described as chevron folds.

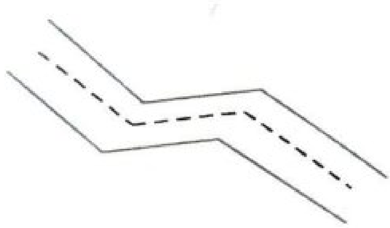
12.Monocline and structural terrace:

In monocline, the bed is relatively flat, but appears to be bent locally to exhibit higher dips.

In a structural terrace, the dipping bed becomes horizontal at a particular place and then continues to follow their original dip.



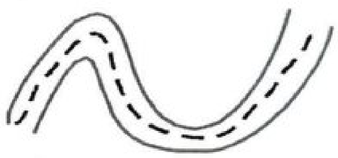
Structural Terrace



13.Open fold:

The constituent beds have uniform thickness everywhere within the fold.

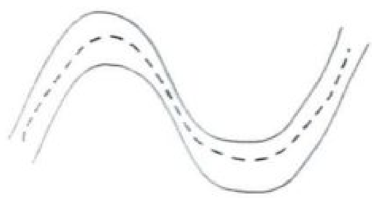
OPEN FOLD



14.Tight fold:

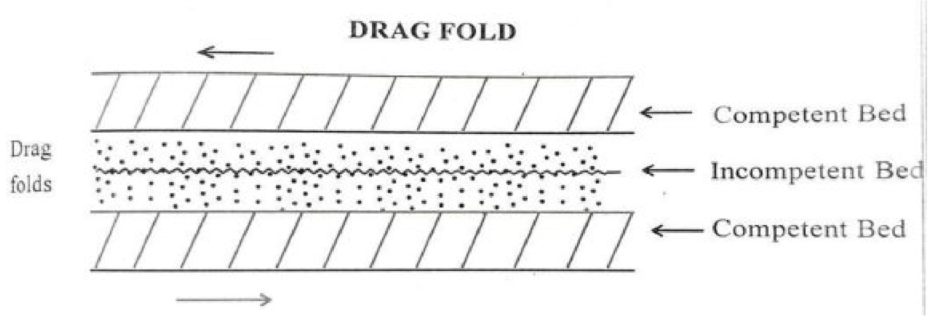
In a tight or closed fold, the relatively mobile beds thin out at the limbs and thicken at the crests and troughs due to plastic flow of constituent beds.

TIGHT FOLD



15.Drag fold:

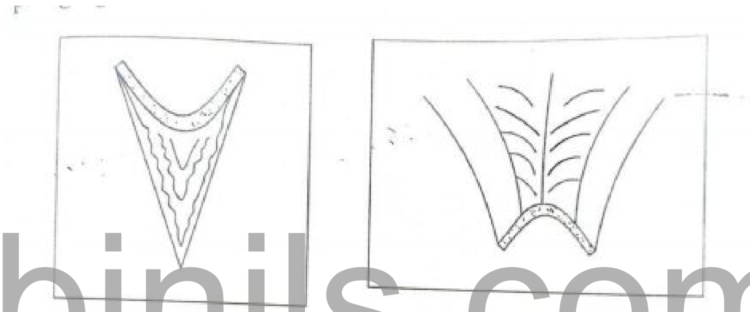
When a comparatively weak bed (incompetent) lies between two strong (competent) beds, any sliding motion in the stronger beds leads to the development of minor asymmetric folds known as drag fold within the weaker bed.



16.Plunging and doubly plunging fold:

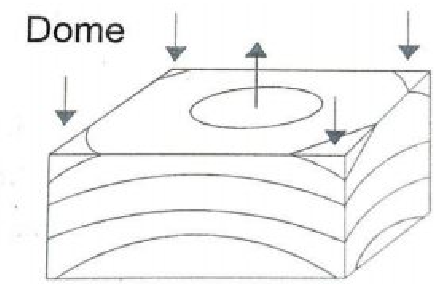
When the axis of a fold slopes towards some direction, it is said to be a plunging fold.

When folds often plunge along two opposite directions, they are called doubly plunging folds.



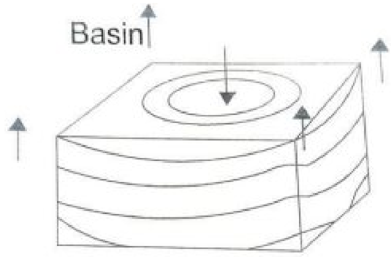
17.Dome:

An anticlinal uplift with quaquaversal dip (i.e., dip in all directions from a central region) is known as a dome.



18.Basin:

A synclinal depression with centraversal dip (i.e., dip from all directions towards a central region) is known as a basin.



19.Geosynclines:

It is a very large, shallow and linear depression which accommodates a considerable thickness of sediments.

20.Geanticlines:

It is an area from which sediments are derived and deposited in the geosynclines.

Engineering importance:

Folded regions are always under strain. The outer layers (peak) of the trough & crest will be always under tension and the inner layers of the crest and trough will be under compression. Hence there will be shattering & jointing of strata along axial planes. So, dams aligned along axial regions of folds would be resting on unsound rocks, leading to failure of the project.

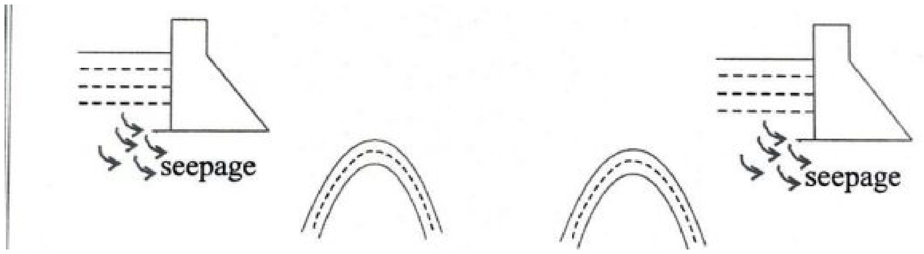
Dams constructed on synclinal upstream limbs lead to leakage of water beneath the dam.

Similarly, strain energy will be always stored in the curvature of folds. Whenever, for tunneling project, the rocks in folded region are excavated, there is possibility of sudden release of strain energy, leading to bursting of rocks. Hence, proper care to be taken while designing tunneling project and also other civil engineering projects.

Fold – Favourable situations for civil engineering projects:

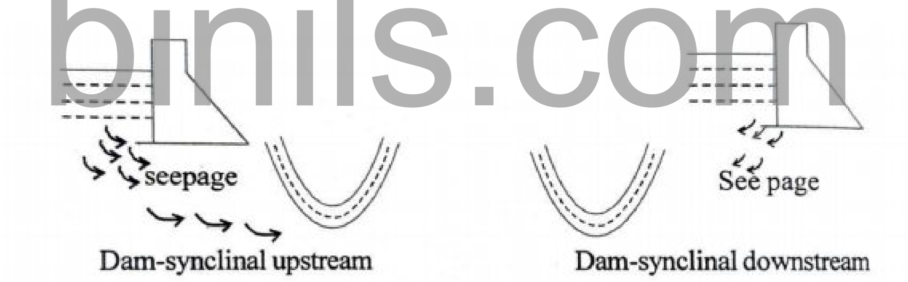
1. **Dam along upstream side of anticline:**

The upstream side of the anticline will be a favourable site for dam, because, seepage from reservoir, if any, will be along the upstream side of the anticline, i.e., within the reservoir side itself.

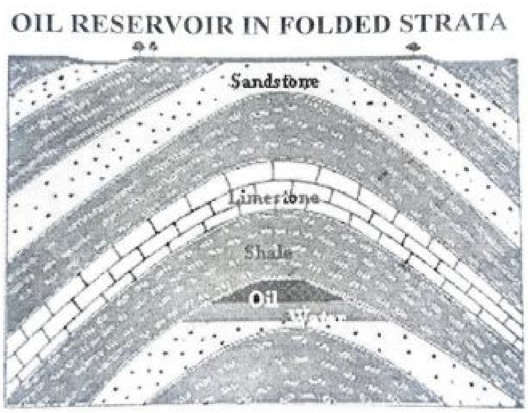


2. **Dam along downstream side of syncline:**

The downstream side of the syncline will be a favourable site for dam, because, seepage from reservoir, if any, will be along the downstream side of the syncline, i.e., within the reservoir side itself.



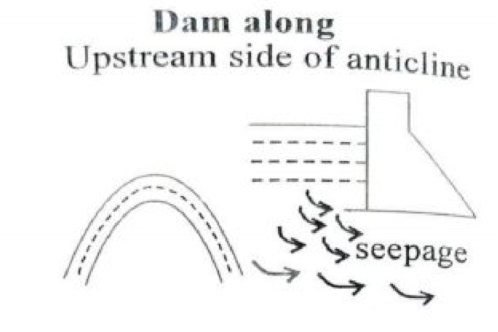
Folded strata are found favourable for accumulation of oil and natural gas.



Fold – Unfavourable situations for civil engineering projects:

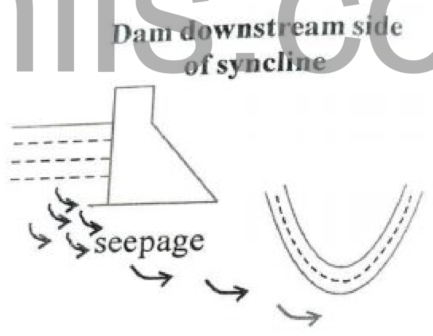
1. **The downstream side of anticline:**

   Unfavourable for dam project, because, there will be loss of water to reservoir, due to seepage towards the downstream side of the dam.



2. **The upstream side of syncline:**

   Unfavourable for dam project, because, there will be loss of water to reservoir, due to seepage towards the downstream side of the syncline as well as dam.



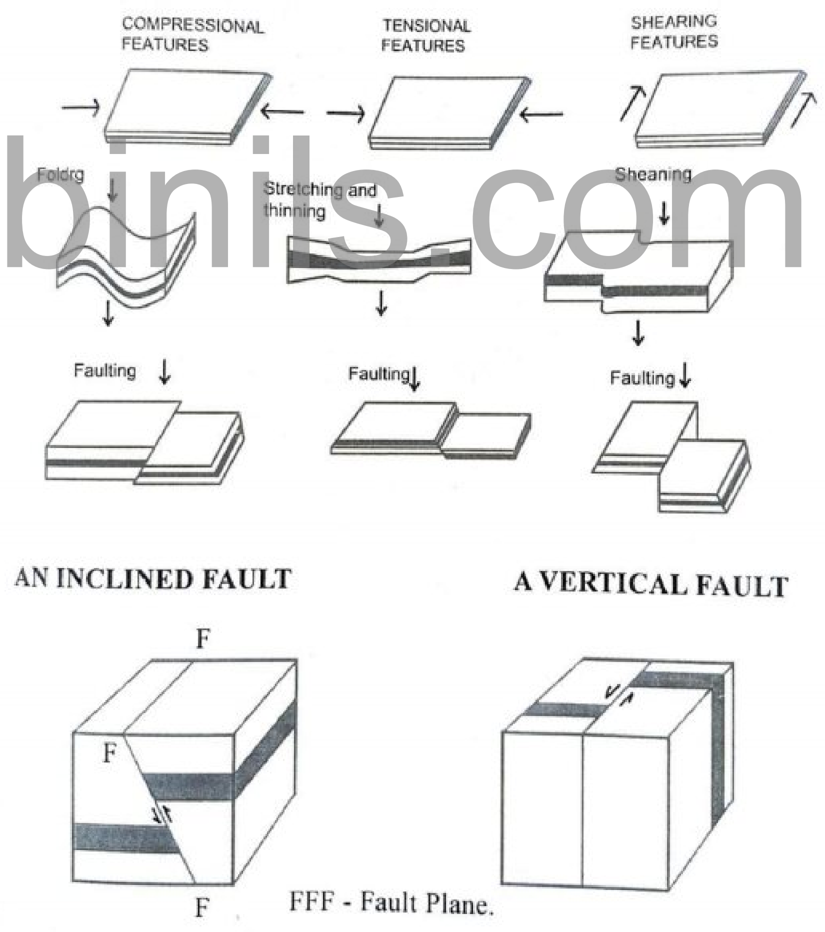
4.2 STUDY OF STRUCTURES - FAULTS

Faults are well defined cracks along which the affected rock masses on either side have suffered relative displacement. This displacement may occur in any direction, due to rotational movement of fractured blocks.

The faults may be vertical or inclined.

Forces responsible for formation of Faults:

- ✓ Tensional force
- ✓ Compressional force
- ✓ Shear force

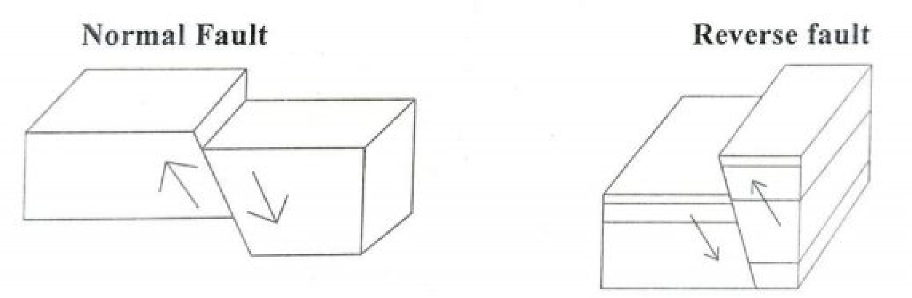


Types of Faults:

1. **Normal fault and reverse fault:**

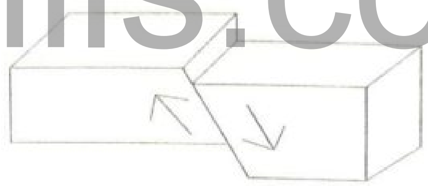
A vertical or an inclined fault along which the hanging wall side appears to have a moved relatively downwards in comparison with the adjoining foot-wall side is said to be a normal fault.

A vertical or an inclined fault along which the foot wall side appears to have been shifted downwards in comparison with the adjoining hanging wall side is said to be a reverse fault.



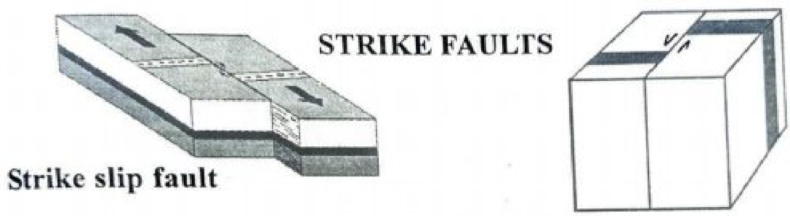
2. Dip fault and strike fault / strike slip fault:

A vertical or inclined fault striking parallel to the direction of dip of the country rocks is known as dip fault.



Normal fault & Dip fault

A vertical or inclined fault striking necessarily parallel to the strike of rock beds forming the country is called strike fault.

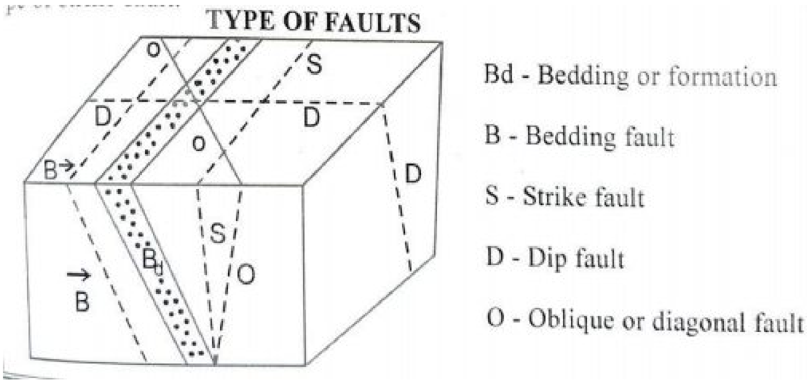


3. Oblique or diagonal fault:

A vertical or inclined fault striking in any direction other than the directions of dip and strike of the country rocks is described as an oblique or diagonal fault.

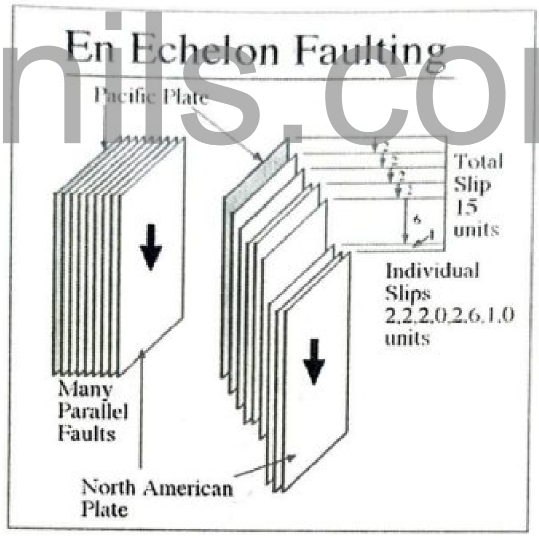
4. **Bedding fault:**

A bedding fault necessarily runs parallel to the bedding planes of the country rocks.



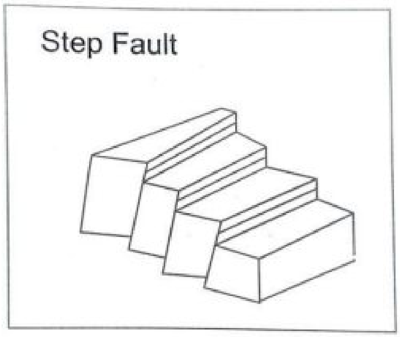
5. **Parallel faults and Enechelon faults:**

A series of faults having the same dip and strike constitute a group of parallel faults.



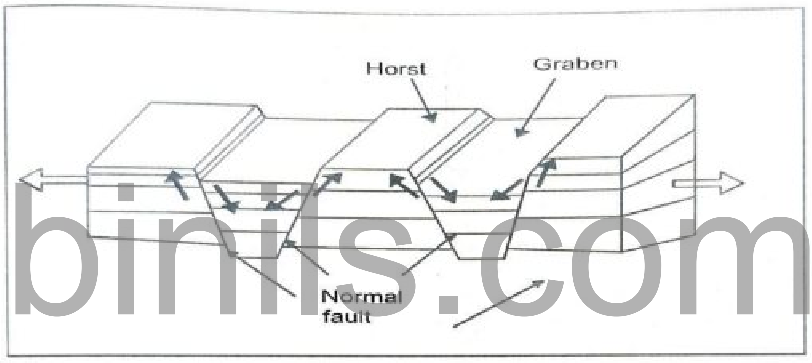
6. **Step faults:**

If in a series of parallel faults, the succeeding blocks have more and more exceeding down throw towards a particular direction, the resulting structure will be looking like "steps in a staircase" and is known as step faults.



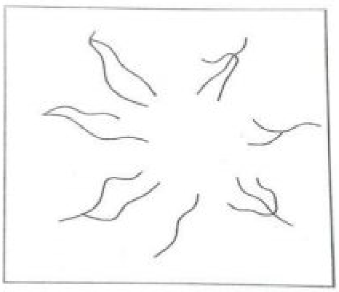
7. Horst and Graben:

The elevated blocks are known as horsts and depressed ones, the grabens. Horsts and grabens of large size give rise to what are known respectively as Block Mountains and Rift valleys.



8. Radial faults:

A number of faults showing a radiating pattern is said to form a group of radial faults.



9. Arcuate or peripheral faults:

Curved faults, more or less circular or arc like in outline are known as Arcuate or peripheral faults.

10.Low angle faults:

Faults dipping an angle of less than 45 degree are known as low angle faults.

11.High angle faults:

Faults dipping an angle of greater than 45 degree are known as high angle faults.

Recognition of Faults:

- Appearance of fault scarp (steep slopes) on the topography.
- Appearance of aligned springs.
- Presence of slicken sides (polished surfaces) along the fault planes.
- Repetition and omission of strata.
- In the down through side of a fault, a younger bed occurs against an older bed in the corresponding up throw side.

Engineering importance of Faults:

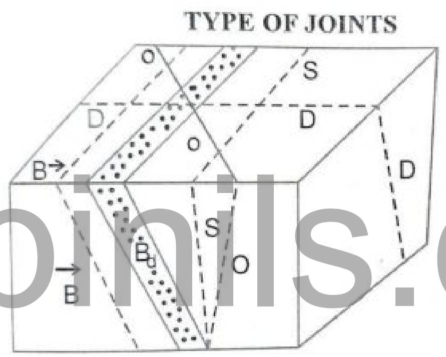
Faulted areas are associated with earthquakes or tectonic movements. Hence for the safe execution of engineering projects, the tectonic history of the project area should be thoroughly studied and established. Proper quake poof structure should be designed for the safety of the project.

4.3 STUDY OF STRUCTURES – JOINTS

The regular or irregular cracks, developed in rocks, due to tensional or Compressional forces acting within the crust, with no relative displacement between the affected rock blocks are called joints.

Types of joints:

1. **Primary joints:** The joints developed in igneous rocks, due to cooling and contraction of magma mass is known as primary joints.
2. **Master joints:** A very large joint, which can be traced over an extensive area, is called a master joint.

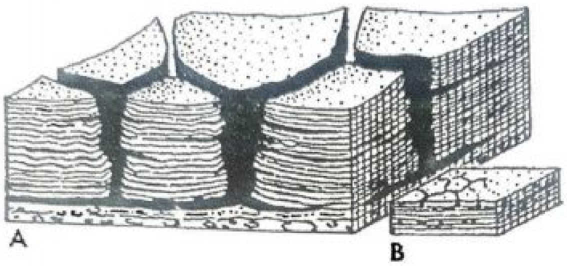


3. **Dip joint:** A dip joint necessarily strikes parallel to the direction of dip of the beds forming the country.
4. **Strike joints:** A strike joint strikes parallel to the strike of the country rocks.
5. **Oblique or diagonal joint:** An oblique or diagonal joint strike neither parallel to the strike of the country rock nor parallel to its dip direction .i.e., its strike direction lies in between the dip and strike.
6. **Joint system:** Two or more joint sets together constitute a joint system.
7. **Columnar joints:** Columnar joints are developed, due to tensional forces, in lava flows. They are developed due to intersection of two or more vertical joint sets within the affected rock mass.

COLUMNAR JOINTS - PLAN

8. **Conjugate joint system:** Whenever two interesting joint sets (whether vertical or inclined) are oriented at right angles to each other, they are said to form a conjugate joint system.
9. **Sheet jointing:** A number of closely spaced parallel joints which are horizontal in attitude are called sheet joints.

SHEET JOINTS IN ROCKS



10. **Mural joints:** When three sets of joints (2 vertical and 1 horizontal) are developed with equal spacing between them, they split up the rock masses into cubical blocks. Such a jointing pattern is called mural jointing. They are well developed in granites.

Engineering importance:

As far as **water supply projects** are concerned, regions of jointed strata are considered to be suitable for groundwater exploration, because jointed zones will serve as aquifers.

In case of **dam & reservoir project**, the foundation should be made on a sound massive bed rock.

On the other hand, if the rock strata are heavily jointed, there will be significant leakage of stored water in the reservoir of dam.

For **tunnel projects**, the rocks should be free from joints.

If the roof or walls of a tunnel are highly jointed, there will be seepage of water into the tunnel. Lining of tunnels may be required in such cases.

In hilly terrains, jointed rocks cause instability of slopes, leading to landsliding. Many landslides and slope failure are due to the jointed nature of rocks.

In all the above cases, a treatment is required, called "grouting", to improve the strength of the rocks.

3.4 ELECTRICAL AND SEISMIC METHODS FOR CIVIL ENGINEERING APPLICATIONS

Applications of Electrical and Seismic Refraction methods:

- ✓ For groundwater prospecting, required for various Govt. water supply schemes.
- ✓ For soil exploration studies, required for Foundation design of various civil engineering structures.
- ✓ Bed rock investigation, required for dam & reservoir projects, etc.

Electrical Resistivity method:

Principle:

All the materials (whether soil or rock) will conduct or resist current. If they conduct current, it will be in various proportions, based on their composition and moisture content present. The conductivity of any rock / soil is the reciprocal of its resistivity. Knowing the resistivity values, different rock strata present in earth's crust is inferred and their aquifer characteristics are studied. Ohm's law is the basis for the principle of this method.

Equipment used:

1. Resistivity meter
2. Two current electrodes & two potential electrodes
3. Power pack
4. Cables, hammers, etc

Types / methods of Resistivity survey:

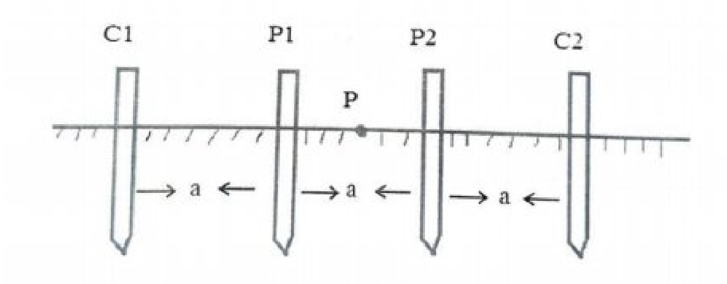
1. Wenner Electrode Array
2. Schlumburger Electrode Array

Procedure:

In both the methods, all the four electrodes are erected firmly into the ground and a known current (I) is sent into the ground through the two current electrodes (C1& C2) and the potential difference (V) between the two potential electrodes (P1 & P2) is measured.

In the case of Wenner configuration of electrodes, all the four electrodes are equally spaced where as in case of Schlumberger configuration, the potential electrodes are closely spaced and current electrodes are placed further apart.

Wenner Array:



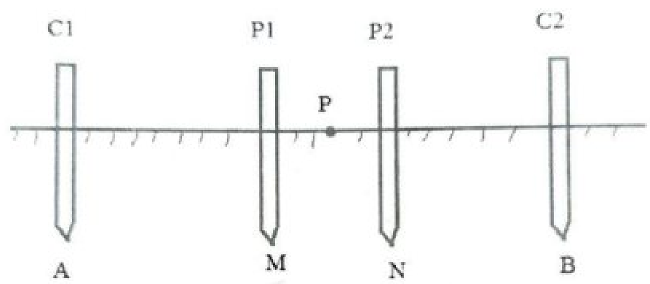
a = Electrode spacing

C1, C2 = Current electrodes

P1, P2 = potential electrodes

P = Point of exploration

Schlumberger Array:



Formula applied:

Wenner array:

$\ell_a = 2\,\pi\,a\,(V / I)$ ohm m

Where ℓ_a = apparent resistivity in ohm m a = electrode spacing

V = potential difference between 2 potential electrodes in millivolts / volts

I = current sent in Ampere / milli amps

Schlumberger array:

$$\ell_a = \frac{[(\frac{AB}{2})^2 - (\frac{MN}{2})^2]}{MN} \times (\frac{V}{I})\ ohm\ m$$

Where AB = spacing between current electrodes

MN = spacing between potential electrodes

All the four electrodes are moved laterally at a uniform spacing / span (in case of Wenner) and only the two current electrodes are shifted laterally (in case of Schlumberger), in order to increase the depth of exploration and at every shifting of electrodes, current is sent and potential difference between electrodes is measured. This process is repeated till the total depth of exploration is reached.

In case of Schlumberger, after reaching certain depth of exploration (say 50m), the potential electrodes are shifted to 1/5th distance of current electrodes (say 10m) and the procedure is repeated.

The linear expansion of electrodes denotes the depth of exploration at the point of investigation. Then applying the relevant formula, the apparent resistivity values (ℓ_a) are calculated.

Sedimentary strata	**Resistivity (in ohm m)**	**Hard rock terrain strain**	**Resistivity (in ohm m)**
Sand	8-15	Top soil	> weathered strata
Clay	Less than 5	Weathered strata	25-80
Sandy clay / clayey sand	5-8	Fractured rock	80-150
Kankar	25-40	Jointed rock	150-300

Sea water intrusion	Less than 1	Massive bed rock	> 300

Application civil engineering:

1. **For water supply schemes:**

   Depending upon the water table conditions of the study area and available favourable rock formations, the investigated location is recommended for open well or bore well or rejected, if unfavourable.

2. **For foundation studies in civil engineering:**

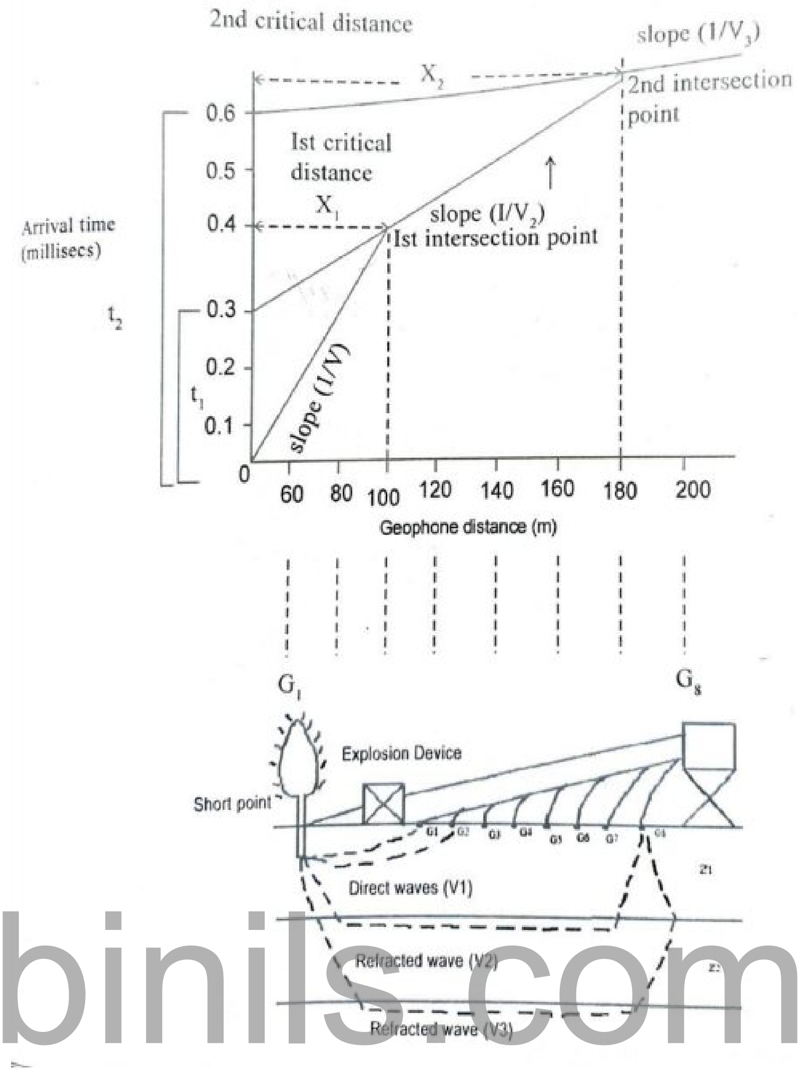
   The soil their nature type and depth to bed rock are inferred and based on the details of soil and rock types, foundation design is made for the civil engineering structures.

Seismic Refraction method:

Principle:

Seismic reflection methods are based on the principle that seismic or elastic waves travel with higher velocity through denser media and with lower velocity in denseless or rarer media.

Seismic refraction methods are for getting information on deep seated rock strata (say 750m or more) while the refraction methods cover only few hundred meters below the ground surface.



Procedure:

- An explosion pit is made (shot point) in the investigation site.
- A number of geophones (G1, G2, G3, etc.) or detectors are placed over the ground laterally. The number of geophones depends upon the depth of exploration required.
- All the geophones are connected to the recording device (seismograph), which is placed away from the shot point, as shown in the figure given above.
- The explosive is fired or detonated.
- The elastic waves generated, due to the detonation of explosives will start travelling in all direction.
- Some waves are directly reaching geophones travelling through the top soil. They are called direct waves.

- Some other waves get refracted in the 2^{nd} and 3^{rd} layers of strata and picked up by other geophones and recorded as electrical pulses.
- Arrival times of waves at different geophones are recorded and geophones distances from the energy source are known. So, the velocity of waves propagating through each rock stratum can be calculated.
- It is a known fact that the velocity of propagating waves in the underlying strata is higher than that in the overlying stratum.
- Critical time: The time taken by the wave, after denotation, to get refracted from its original path is called critical time. There are two critical times here (t_1 & t_2).
- Critical distance: The distance from the shot point, beyond which refraction of waves takes place is called critical distance. There are two critical distances here (X_1 & X_2).
- A travel time graph (time vs distance from geophone) is drawn as shown in figure and t_1, t_2, X_1 and X_2 values are obtained.
- For civil engineering applications in foundation design and or groundwater aquifer studies for water supply projects, the depth to bed rock should be known. So, the depth of the different layers of rock (say Z_1 & Z_2) is calculated as follows,

Depth I layer (Z_1):

$$Z_1 = \frac{X1}{2}\sqrt{V_1 V_2/(V_1 + V_2)}$$

Where V_1 & V_2 are velocities of waves in I & II layers

X_1 = first critical distance

Or

$$Z_1 = \frac{t_1}{2} = \frac{V_1 V_2}{\sqrt{V_2^2 - V_1^2}}$$

Where t_1 = first critical time

Depth to II layer:

$$Z_2 = \left[\frac{t_2}{2} - Z_1 \left(\frac{\sqrt{V_3^2 - V_1^2}}{V_3 V_1}\right)\right] \frac{V_3 V_2}{\sqrt{(V_3^2 - V_3^2)}}$$

Where t_2 = second critical time

V_3 = velocity of wave in III layer

Average velocities of seismic waves in different soil and rock strata are listed below for interpretation & field applications.

Soil / rock strata	**Velocity range (m/sec)**
Dry sand / loose sand	150 - 400
Alluvium	500 - 1500
Wet sand	600 - 1800
Clays	900 - 3000
Sand stone	2000 - 4300
Shale	2100 - 4000
Lime stone	3000 - 6000
Deccan trap	4000 - 5000
Compact igneous & metamorphic rocks	4500 - 6500

Application in civil engineering:

1. **For foundation studies:** Soil and rock strata below the surface of the earth are inferred. Knowing the soil type and their characteristics, the type of foundation for buildings and other civil engineering structures may be decided.
2. **For dams & reservoir projects:** The depth to bed rock is inferred from seismic refraction studies, which help in selection of site for a dam & reservoir project.
3. **For water supply projects:** Aquifer and its characteristics can be inferred and studied, from the interpretation of seismic data.