UNIT – IV

EARTH QUAKES:

Seismology, the science dealing with the natural phenomena relating to earthquakes. The Greek word *seismos* means shaking. Earthquakes are vibrations or oscillations due to sudden disturbances in the earth, which produce elastic waves which travel away in all directions from the point of origin. These elastic waves are called seismic waves.

In seismic prospecting, artificial explosions (explosives, dynamites may produce elastic waves if they fire) are made to study the travel times of seismic waves through geological formations, suffer reflection or refraction and arrive at the surface of the earth where they are detected by geophones.

With the help of geophones fixed at suitable intervals on the ground, the different seismic waves (P,S and L waves) reaching the surface are recorded and time-distance curves (hodographs) are constructed.
Seismic waves are classed into three types:

1. Primary waves or P waves
2. Secondary waves or S waves
3. Surface waves or L – waves

Terminology of an earthquake:

- **Focus**: Place of origin of the earthquake in the interior of the earth.
- **Epicenter:** A point on the ground surface, which is vertically above the focus.
- **Seismic waves**: The enormous energy released from the focus at the time of earthquake is transmitted in all directions in the form of waves.
- **Elastic waves**: A wave propagated by a medium having inertia and elasticity in which displaced particles transfer momentum to neighbouring particles and are themselves restored to original position.
- **Isoseismal**: The imaginary line joining the points of same intensity of the earthquake.
- **Hodograph**: time - distance curve

- **Seismograph**: an instrument is used to detect/ record the seismic waves
- **Seismogram**: Recorded data in seismic methods

Of all geophysical methods, seismic prospecting is more complicated and expensive. However, seismic method consists of a number of geophones; an amplifier and a galvanometer are used in addition to explosive material.

Seismic methods are effective for depths more than a km but are not suitable for shallow exploration. Seismic methods are important to locate the anticline and synclinal structures in oil exploration, and to identify fault zones. It is also helped a great deal in understanding the internal structure of the earth.

Many seismological observations have been established in India. The major ones among them are at New Delhi, Colaba (Mumbai) Alipore (Kolkata); Shillong etc maintained by the Indian Meteorological Department and at Hyderabad by the National Geophysical Research Institute.

CLASSIFICATION AND CAUSES OF EARTHQUAKES: Earthquakes are grouped based on their depth of origin, and described as shallow or intermediate or deeper earthquakes. Earthquakes with a focus depth < 60 km are called shallow earthquakes. If the depth is > 60 kms but < 300 kms, they are called intermediate earthquakes. Other which have a focus depth > 300 kms are called deeper earthquakes. Earthquakes originating at depths > 700 kms are extremely rare.

TYPES: Based on the causes responsible for their occurrence, earthquakes are described as TECTONIC EARTHQUAKES AND NON-TECTONIC EARTHQUAKES.

<u>Tectonic earthquakes</u> are exclusively due to internal causes (i.e. disturbance of geological formations) that takes place in the earth's interior. Generally, Tectonic earthquakes frequency is less with high intensity and more destructive in nature.

Non-tectonic earthquakes are generally due to external causes. These are very frequent but minor intensity and not destructive in nature.

These earthquakes occur due to variety of reasons as follows:

- Due to huge water falls.
- Due to meteorites: Meteorites are bodies of various sizes wandering in space. When they come under the influence of the earth's gravity field, they suddenly fall on the earth's surface.
- Due to landslides
- Due to volcanic eruptions: Some volcanoes pour lava by throwing out the fire, smoke etc. to greater heights. Such violent eruptions sometimes cause earthquakes. e.g.: Indonesia volcano(1883) due to eruption of volcano.
- Due to tsunamis: Tsunamis are giant sea waves. They move shore wards and dash against the coastline. E.g.: Lisbon earthquake of 1775.
- Due to man-made explosions: During mining, and quarrying, many explosions are carried out.
- Due to collapse of caves, tunnels etc..
- Due to dams and reservoirs: when the reservoir was filled with water shows the signs of tremors. This is due to lateral thrust of reservoir water contributing stress.

SIZE OF EARTHQUAKES: The size of an earthquake is defined by its intensity and magnitude. **Intensity** is expressed based on the degree of destruction caused and varies from place to place. It is maximum around the epicentral area.

Earthquake intensities

Intensity	Effects
I	Not serious
II	Felt by few persons at rest, particularly on upper floors of buildings
III	Vibrations similar to a moving truck
IV	Windows and doors rattle; loose objects disturb
V	Breakage of dishes; wall plaster breaks
VI	Walls crack
VII	Slight to moderate damage in well-built structures
VIII	Falling of walls

IX	Ground cracks; breakage of underground pipes; considerable damage to buildings
X	Bending of rails; occurrence of land slides
XI	Buildings destroy
XII	Total destruction, surface displacements; objects thrown into air

The intensity at a place depends on several factors such as distance from the epicenter; depth of focus, geological formations and also on the type of construction of a structure..

Magnitude: Energy released during the time of an earthquake is commonly expressed as Richter's magnitude. Magnitude of an earthquake does not vary from place to place.

Energy released (E) is obtained from the expression: $\sqrt{E} = c\,(a/h)(d^2 + h^2)$

Where E = total energy released (ergs)

c = constant (taken as 0.625)

a = ground acceleration

d = distance (km) of the recording station from the epicenter

h = depth of focus (km)

Richter's scale has magnitude numbers up to 10. But the maximum known magnitude is around 9.6 only. An earthquake magnitude of 6.0 involves energy of around 2.5×10^{20} ergs (equivalent to that of an atom bomb) while for magnitude of earthquake is 7.0, it is around 80×10^{20} ergs (equivalent to that of a Hydrogen bomb). For an earthquake of magnitude is 8.0, then the energy may be around 2500×10^{20} ergs (most powerful).

The magnitudes of some of the important earthquakes in India are given below:

City	Date	Magnitude of earthquake	
Shillong	June12, 1897	8.7	
Kangra	April 4, 1905	8.0	
North Bihar	Jan 15, 1934	8.3	
Assam	Aug 15, 1950	8.6	
Koyna	Dec 11,	6.4	

(Maharashtra)	1967		
Chamoli (Uttaranchal)	Oct 20, 1991	6.5	Sand and mud with water was ejected
Killari (Latur)	Sept30, 1993	6.5	
Jabalpur (MP)	May 22, 1997	6.0	
Bhuj (Gujarat)	Jan 26, 2001	7.5	Vertical & partial collapse of a building
Andamans	Dec 26, 2004	9.0	

SEISMIC BELTS & SEISMIC ZONING MAP OF INDIA: On a seismic map, the country has been divided into 7 zones in terms of severity (magnitude). First seismic map (zoning map) was prepared in 1962 on the basis of historical data available regarding the occurrence of earthquakes all over the country. Subsequently the zoning map was revised in 1966.

Many of the areas in zone V and VI were merged into one because of their high risk. In the zone map brought out in the year 2000, the earlier zones II and I were merged. So the number of zones got reduced from 7 to 5. Zone – I is least severe and the Zone VI is most severe. Entire NE regions, parts of Uttaranchal, Rann of Kutch (Gujarat) & Srinagar are included in zone V where the earthquake severity is high. All regions in Southern India are included in Zone III. Rest of the parts of India are included in Zone I & II. Zone 4 is also treated as severity.

Precautionary measures for the construction of buildings, dams/reservoirs etc. in seismic areas: To make suitable constructions in seismic areas, IS codes 1893 – 2970 give guidelines.

For Construction of Buildings: In addition to the safety factors considered there are other precautionary measures which help in increasing the stability of buildings in seismic areas. They are as follows:

- Buildings should be founded on hard bedrock and never on loose soils or fractured rocks. This is so because loose ground can easily expose to earthquake vibrations.
- Foundation should be of same depth throughout for continuity.

- Buildings situated near hill sides, near steep slopes, on undulating ground or on marshy ground always suffer more when earthquake occurs. Therefore these situations may be avoided.
- Buildings should have light walls.
- Different parts of a building should be well tied together so that the whole structure behaves like a single unit to the vibrations.
- Proper proportionate of cement and mortar should be used.
- Doors and windows should be kept to a minimum and they should not be in vertical rows but preferably along the diagonals.
- The building should have uniform height and additional features such as parapets, cantilevers, domes and arches are undesirable.
- Buildings should have flat RCC roofs and they should be designed not to yield to lateral stress.
- Projections above the roofs are undesirable.

For Construction of Dams: Dams being very costly projects their consideration in seismic areas needs careful study to ensure their safety precautionary measures which are as follows:

- Forces in the dam due to reservoir water and due to the dams weight are to counter balanced by introducing additional stress in the design of the dam.
- Design of the dam is to be made such that during an earthquake they move along with the foundations below.
- Dams should not ordinarily be built along or across the faults because possible slipping along these planes during earthquakes will introduce additional complications.
- The resonance factor value (vibrations due to sound) should be given due consideration because a coincidence in the period of vibration of the dam and the earthquake vibrations can produce cumulative effects.

LANDSLIDES

The term landslide refers to the downward sliding of huge quantities of land masses. Such sliding occurs along steep slopes of hills or mountains.. It may be sudden or slow in its occurrence. Also, in magnitude, it may be major or minor.

Often, loose and unconsolidated surface material undergoes sliding. But sometimes, huge blocks of consolidated rocks may also be involved. If landslides occur in places of importance such as highways, railway lines, valleys, reservoirs, inhabited areas and agricultural lands leads to blocking of traffic, collapse of buildings, harm to fertile lands and heavy loss to life and property. In India, landslides often occur in Kashmir, Himachal Pradesh and in the mountains of Uttar Pradesh.

CLASSIFICATION OF EARTH MOVEMENTS: All movements of land masses are referred to as landslides and grouped them under "earth movements". The classification of earth movements us as follows:

EARTH MOVEMENTS	EARTH FLOWS	Solifluction
		Creep
		Rapid flows
	LANDSLIDES	Debris slides and slump
		Rock slides
		Rock falls
	SUBSIDENCE	Compaction
		Collapse

Earth Flows: There are three types of earth flows viz., solifluction; creep and rapid flows.

Solifluction refers to the downward movement of wet soil along the slopes under the influence of gravity.

Creep refers to the extremely slow downward movement of dry surface material. This is very imp from the civil engg point of view due to slow movement of mass. On careful examination, bending of strata ; dislodgement of fence posts ; telephone poles, curvature of tree trunks; broken retaining walls etc. offer clues to recognize creep.

Rapid flows are similar to creep but differ with reference to the speed. Rapid flows generally accompany heavy rains. Mud flows are similar to rapid flows.

Landslides include Debris slides, rock slides and rock falls.

Debris slides are common along the steep sides of rivers, lakes. Debris slides of small magnitude are called slumps..

Rock slides are the movements of consolidated material which mainly consists of recently detached bedrocks. For e.g.: a rock slide that took place at Frank, Alberta in 1903 killing 70 people.

Rock falls refer to the blocks of rocks of varying sizes suddenly crashing downwards along steep slopes. These are common in the higher mountain regions during the rainy seasons.

Subsidence may take place to the compaction of underlying material or due to collapse.

Subsidence due to compaction: Sediments often become compact because of load. Excessive pumping out of water and the withdrawal of oil from the ground also cause subsidence.

Subsidence due to collapse: In regions where extensive underground mining has removed a large volume of material, the weight of the overlying rock may cause collapse and subsidence.

CAUSES OF LANDSLIDES: Landslides occur due **to internal causes** (inherent). The internal causes are again of various types such as Effect of slope; Effect of water; Effect of Lithology; Effect of associated structures ; Effect of human factors etc..

1.Effect of slope: This is a very important factor which provides favorable conditions for landslide occurrence.

Steeper slopes are prone to land slips of loose overburdens due to gravity influence. However, it should be remembered that hard consolidated and fresh rocks remain stable even against any slope.

2.Effect of water: The presence of water greatly reduces the intergranular cohesion of the particles of loose ground causing weakness of masses and prone to landslide occurrence.

Water, being the most powerful solvent, not only causes decomposition of minerals but also leaches out the soluble matter of rocks. This reduces the compaction of rock body and makes it a weak mass.

3.Effect of Lithology; Rocks which are highly fractured, porous and permeable are prone to landslide occurrence because they give scope for the water to play an effective role. In addition, rocks which contain clay minerals, mica calcite, glauconite, gypsum etc. are more prone to landslide occurrence because, all these minerals are easily leached out.

4.Effect if associated structures ; The geological structures such as bedding planes, joints, faults or shear zones are planes of weakness and cause landslide occurrence.

5.Effect of human factors Human beings sometimes, interfere with nature by virtue of their activities and cause landslides. For e.g.: laying roads ; railway tracks etc..

When construction works are carried out on hill tops, the heavy loads on the loose zone of overburden create a sliding of rock masses.

Land slides in India: Land slides are reported in the hilly terrains in different regions of India. The most disastrous land slides that have taken place in recent past are in the Himalayan terrain in the North and the Nilgiris hill region in south.

In July 1970, heavy debris from Patalganga valley has been transported into Alaknanda in the Garhwal region of Uttaranchal. The flooding in Alaknanda due to these landslides has resulted in a silt and rock fragment accumulation of about 9 M cum.

Another disastrous land slide took place on 18th Aug 1998 in Malpa village which is located on the banks of Kali River in Pithorgarh district of Kumaon Himalayas. The piled debris was around 20 m in height.

In 1968, numerous landslides occurred during heavy rainfall of about 500 to 1000 mm in the Darjeeling and Sikkim regions where the 60 km highway between Darjeeling (West Bengal) and Gangtok (Sikkim) was disrupted.

EFFECTS OF LANDSLIDES: From the civil engineering point of view, landslides may cause (1) disruption of transport

(2) damaging roads and railways and telegraph poles
(3) obstruction to the river flow in valleys
(4) damaging sewage and other pipe lines.
(5) destruction of buildings and civil structures

Recent landslides in the Himalaya terrain are listed below:

Himachal Pradesh region:
Nathpa (Nov 1989): Road destroyed about a km
Kullu (Sep 1995): Road 1km destroyed and 32 persons killed

Uttaranchal region:
Kalisaur (July 1968): Road damaged extensively
Malpa (Aug 1998): Road to Manasarovar damaged & 205 persons killed

Jammu & Kashmir region:
Nashri (Jan 1982) Every year causes damage to the roads
Malori (Jun 1995): National Highway 1-A damaged and 6 persons killed

West Bengal Region:
Kalimpong, Darjeeling (Aug 1993):40 persons killed with heavy loss of property

Arunachal Pradesh Region:
Itanagar (July 1993): 2 km road damaged and 25 persons killed

Mizoram region:
Aizwal (May 1995): 25 persons killed and road extensively damaged

Nagaland region:
Kohima (Aug 1993): 200 houses and 5 km road damaged. 500 persons killed.

Selected landslides in South India are listed below:

Major Land slides took place in the Nilgiri Hill region include Runnymede, Glenmore, Coonoor areas. Amboori landslide in Kerala: On Nov 9th, 2001, a disastrous land slide occurred around Amboori (20 km from Thiruvananthapuram) due to heavy rains and water logging.

PREVENTION OF LANDSLIDES:

1. Provision of adequate surface and subsurface to enable water to freely drain out . Construction of suitable ditches and waterways along slopes to drain off the water from the loose overburden.

2. Construction of retaining walls against slopes, so that the rock masses which rolls down is not only prevented from further fall but also reduces the slope.
3. Modifying the slopes to stable angles.
4. Growing vegetation to hold the material together.

Avoiding heavy traffic and blasting operations near the vulnerable places naturally helps in preventing the occurrence of landslides.

GEO PHYSICAL METHODS:

By measuring certain physical properties of rock types, the subsurface data, the location of ore deposits, groundwater conditions etc. can be achieved by using Geophysical investigations.

To ensure safety, economy in construction of civil engineering structures, it is necessary to aware of the geology and subsurface structure of the concerned site. In order to acquire the subsurface details, only two approaches exist. They are:

Direct observations by means of digging, trenching and drilling of the ground. Such processes are expensive and time consuming process.

Indirect inferences are drawn by means of Geophysical methods which provide the subsurface date quickly without much expensive. The other advantages include:

Large areas can be investigated in short period and hence time is saved. The Geophysical devices are simple, portable and can be operated easily. The Geophysical investigation does not include any consumables and these methods are economical.

CLASSIFICATION OF GEOPHYSICAL METHODS. These include:

GRAVITY METHODS;
MAGNETIC METHODS;
ELECTRICAL METHODS;
SEISMIC METHODS;
RADIOMETRIC METHODS and

GEOTHERMAL METHODS.

Importance of geophysical methods: The Geophysical investigations are multipurpose. The obtained data can be interpreted for knowing the subsurface rock types, regional geology of an area; geological structures which are favorable for accumulation of oil and gas; groundwater potential and its quality; locating and estimation of ore deposit reserves and also to solve the Engineering Geology problems such as:

1. To determine the thickness of overburden
2. Locating fault zones, shear zones which act as places of leakage in reservoirs or as places of weakness in foundation sites;
3. To locate places where building materials occur at a shallow depth
4. To solve some of the Non-geological problems such as

- location of buried iron pipe lines (by magnetic methods);
- location of areas of buried pipes carrying oil & gas (by electrical methods);
- location & liquidation of underground fire (by geothermal methods)
- location of cavities in masonry constructions of dams (by radio wave absorption methods)

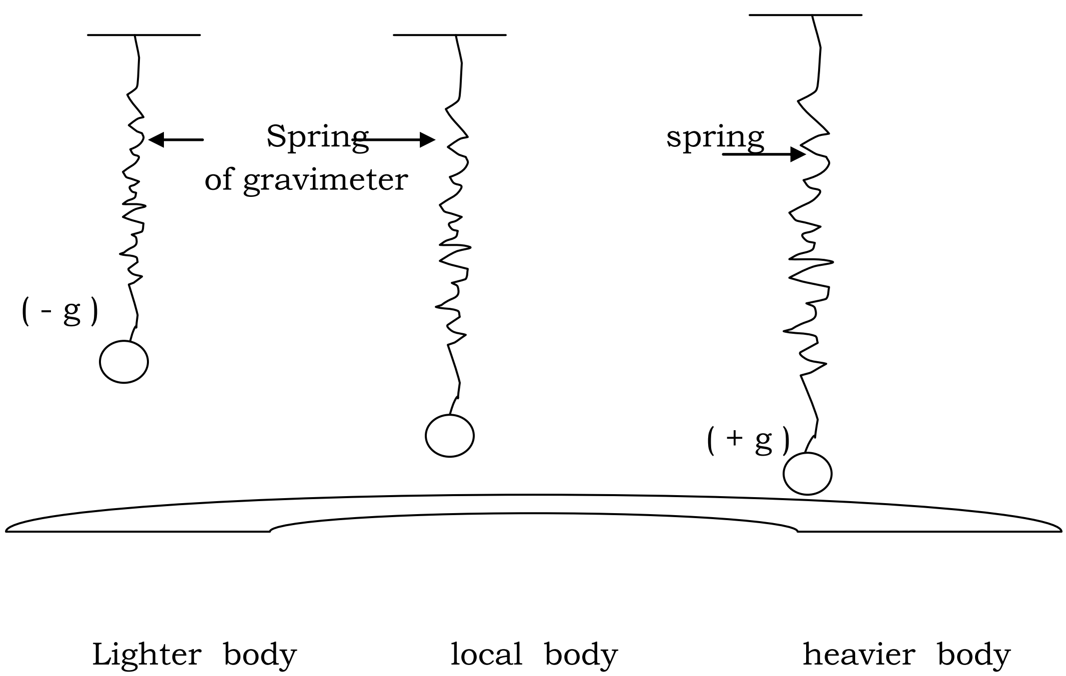
GRAVITY METHODS: In gravity methods, the nature of distribution of gravity (g) on the surface is analyzed. The instruments for gravity prospecting may be divided into three types.

(a) Pendulum
(b) Torsion balance
(c) Gravimeters (WORDEN GRAVIMETER)

Among these, only gravimeters are very popular. A gravimeter measures the relative variations in the vertical component of the gravitational force. It is somewhat like a spring balance which weighs a constant mass and detects the relative difference in weight with great accuracy of the region.

If the subsurface has a relatively heavier body, the gravity pull is more there (+g) and the spring extends becoming longer. If the subsurface has relatively a lighter body there the gravity pull is less (-g) and the spring contracts becoming shorter. Hence, g values reflect the subsurface geological strata.

Gravity methods are carried out during oil and gas exploration. These investigations are also useful in finding iron ore, manganese ore, graphite, coal, Chromite and bauxite deposits.



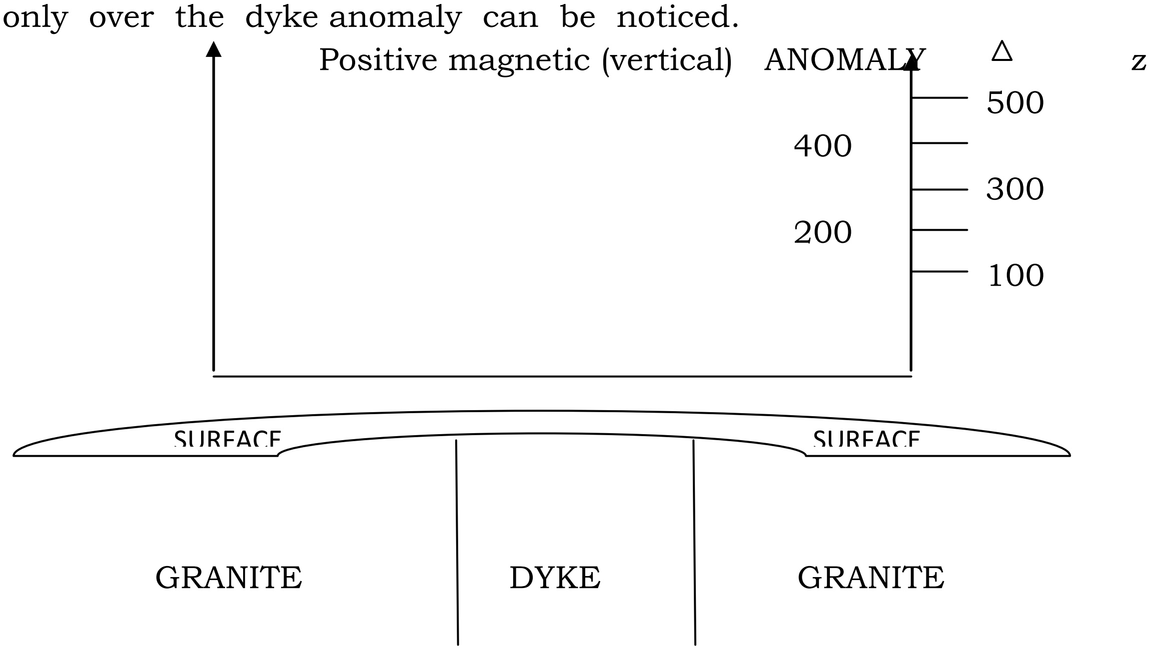
Thus in a particular region, if subsurface bodies whose densities are different from the surrounding rocks exist, the gravity field deviates from the normal value that is expected . From these deviations, it is possible to locate the inhomogeneous bodies in the subsurface.

Geological age	Lithology	Av density (gm/cc)
Gondawanas	Calcareous Sandstones	2.55
	Ferruginous sandstones	2.33
Vindhyans	shales	2.65
	Limestones with shale intercalations	2.72

	sandstones	2.13
cuddapahs	Calcareous shales	2.77
	limestones	3.10
	Phyllites	2.72
	Quartzites	2.65
Archaeans	Granites	2.65
	gneisses	2.65
	charnockites	2.82
	Khondalites	2.50

MAGNETIC METHODS: Like gravity methods, these investigations also related to the findings of subsurface geology. In general, the magnetic field of the earth or one of its components (vertical or horizontal component) is measured on the surface to know the subsurface bodies data by studying the anomaly. Any deviations in the measured quantities help to locate the anomalous objects.. For e.g. a dolerite dyke which is occurring in a granitic terrain shows variations in the magnetic anomalies.

During the magnetic surveys in the field, when the dyke is approached the magnetic intensities $\Delta(z)$ becomes more and then becomes less after the dyke is crossed. Away from the dyke, on either side (Δz is nearly same and only over the dyke anomaly can be noticed.



The different parameters measured during magnetic investigations are total magnetic field and different space components (i.e. vertical component z; horizontal component H; inclination I and declination D). The magnetic field is measured in terms of gamma.

Different magnetometers are available at present for conducting magnetic surveys. Some of them are as follows:

The SCHMIDT MAGNETOMETER
TORSION MAGNETOMETER
FLUX GATE MAGNETOMETER

A **magnetometer** is a measuring instrument used to measure the strength or direction of magnetic fields.

The SI unit of magnetic field strength is tesla. As this is a very large unit for most practical uses, scientists commonly use the nanotesla (nT) as their working unit of measure. Engineers often measure magnetic fields in Gauss (1 Gauss = 100,000 nT, or 100,000 gamma).

The Earth's magnetic field (the magnetosphere) varies both temporally (there is a daily variation of around 30 nT at mid latitudes and hundreds of nT at the poles) and spatially (from around 20,000 nT near the equator to 80,000 nT near the poles) for various reasons, such as the in homogeneity of rocks and the interaction between charged particles from the Sun and the magnetosphere.

Applications:

Magnetometers can detect magnetic (ferrous) metals.

Magnetometers can be used to help map basin shape at a regional scale, and commonly used to map hazards in coal mining.

Also used to demarcate the basaltic intrusions such as dykes, sills etc.

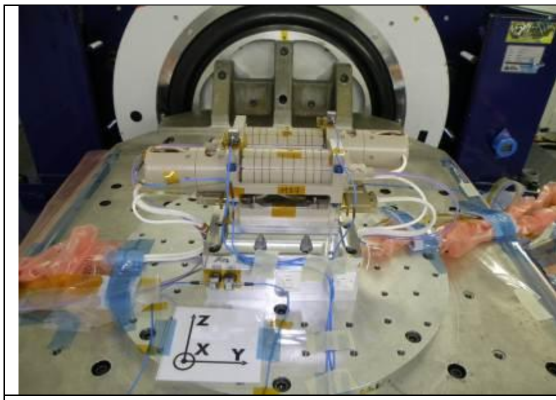
Magnetometers can also locate zones ignited by lightning and map siderite (an impurity in coal).

Modern surveys generally use magnetometers with GPS technology to automatically record the magnetic field and their location.

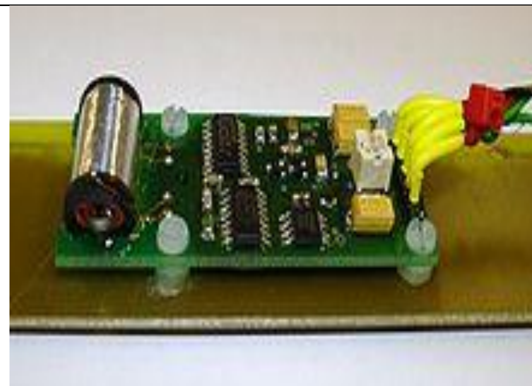
Magnetometers are one of the primary tools used to locate the deposits of gold, silver, copper, iron, tin, platinum and diamonds.

Types: Magnetometers can be divided into two basic types:

- **Scalar magnetometers** measure the total strength of the magnetic field to which they are subjected, and
- **Vector magnetometers** have the capability to measure the component of the magnetic field in a particular direction, relative to the spatial orientation of the device.



Scalar magnetometers


Fluxgate magnetometer

Vector magnetometers: The Earth's magnetic field at a given point is a vector. A *vector magnetometer* measures both the magnitude and direction of the total magnetic field.. Examples of vector magnetometers are fluxgates.

Scalar magnetometers: Scalar magnetometers measure the total magnetic field strength but not its direction. A magnetograph is a magnetometer that continuously records data.

Since magnetic surveys have certain inherent limitations (i.e. orientation of instruments), magnetic prospecting is often carried out along with gravity or other geophysical methods for accurate solutions. Magnetic investigations are employed for solving the following geological issues:

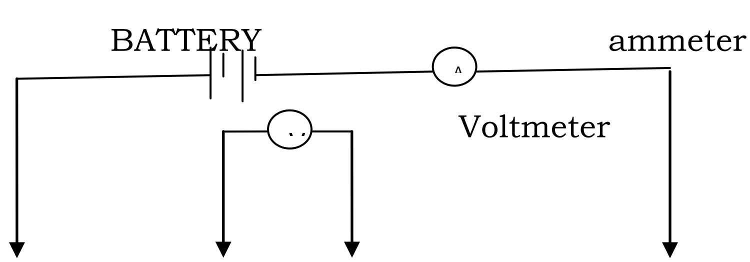
1. Delineation of large structural forms where usually accumulation of oil and gas deposits takes place
2. Detection & demarcation of basic and ultrabasic bodies such as dykes.
3. Locating iron ores and other deposits such as chromite, manganese and bauxite deposits.
4. Also to demark the ore bodies of copper and nickel sulphides.

ELECTRICAL METHODS: Electrical resistivity methods, electromagnetic methods, self-potential methods and induced polarization methods are the important categories of electrical methods. All geological formations have a property called electrical resistivity (ρ) and this resistivity is expressed in the units of Ohm-meters (Ωm). The electrical resistivities of subsurface formations vary from one another if they are inhomogeneous and are studied with the help of the electrical resistivity methods.

The various geological factors which influence the electrical resistivity of the subsurface formations are :

1. Mineral content (most of the rock forming minerals have high resistivity except sulphide minerals)
2. Compactness
3. Moisture (moisture may occur in the rocks)
4. Salinity of moisture.
5. Texture of the rock (fine grained rocks show a higher resistivity compared to coarse grained ones)

EQUIPMENT: A resistivity meter is used in carrying out the electrical methods to calculate the apparent resistivity (***Pa).*** It is necessary to remember that what is measured in the field during resistivity investigation is the "Apparent resistivity" and not the true resistivity of the subsurface. To get true resistivity, the apparent resistivity is to be multiplied by a constant (K) as per the spacing pattern. Electrical resistivity values decreases considerably if the rocks contain moisture in the pore spaces (not for always).
Fig shows the pattern of distribution of current and equipotential lines in a homogeneous ground. Current is sent inside the ground through metallic electrodes C1 and C2. The potential difference is measured by non-polarising electrodes P1 and P2.



C1 P1 P2 C2

C 1 and C2 = current electrodes & P1 and P2 = Potential electrodes

- - - - - - distribution of current lines

______ distribution of equipotential lines

Resistivity methods are classified into:

1. Profiling Method (Lateral exploration)
2. Sounding method (Vertical exploration)
3. Potential Method

Profiling is done to detect lateral changes in resistivity which reflects the subsurface lithology in a large area whereas sounding (also known as Vertical Electrical Sounding VES) is done to determine vertical changes in resistivity which reveals the changes in Lithology at a particular place with increasing depth.

In profiling or sounding, there is scope for electrode arrangements to be made in different ways in the field as such arrangements are called “electrode configurations”.

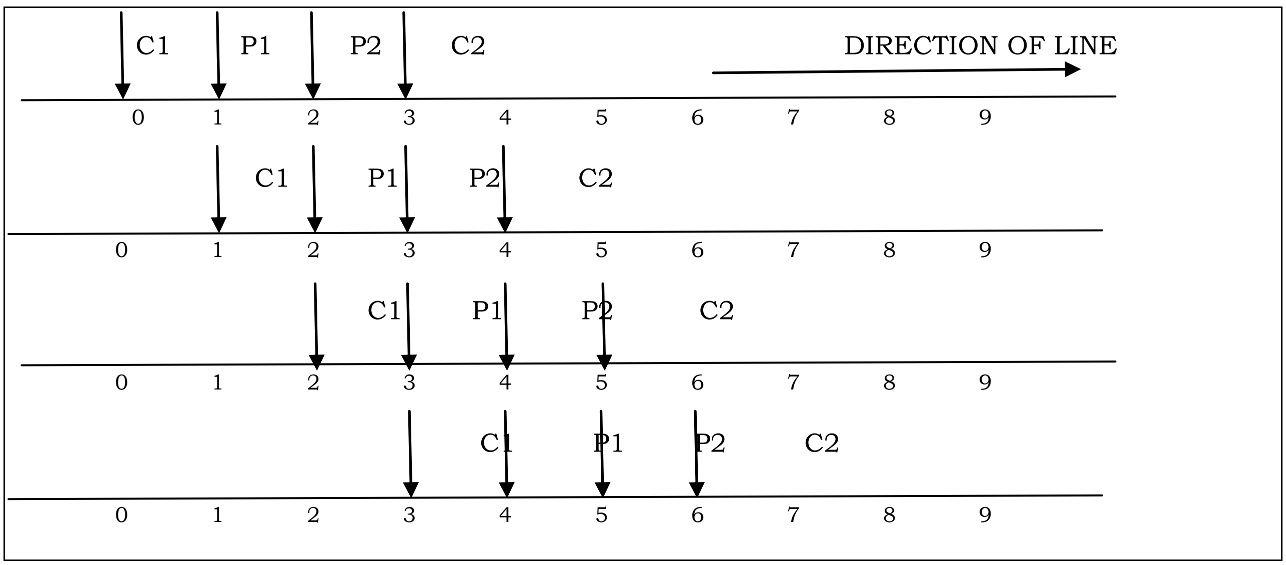
Profiling method is carried out by adopting the Wenner configuration.

The Wenner configuration: This method was developed by Wenner in 1915. In this configuration, the outer electrodes, C1 and C2 are used to send current into the ground and the inner electrodes, P1 and P2 are used to measure the potential. The important feature of this setup is that the distance between any two successive electrodes is equal. The apparent resistivity measured in the Wenner method is given *by* $\boldsymbol{Pa = 2\pi a(V/I)}$ *where*

a = Electrode separation
v = Potential difference measured
I = Current sent into the ground
*P*a = apparent resistance (ohm-mts)

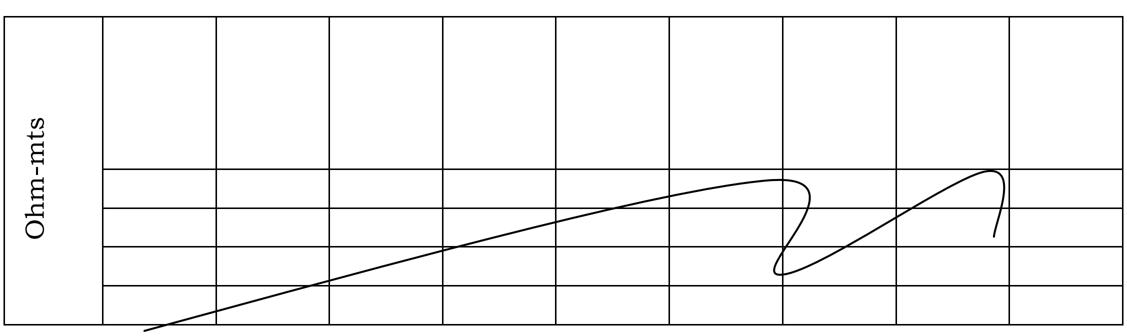
Profiling Method: This is also known as Lateral Electrical investigation. In this process, the electrode array i.e., setup as a whole is moved from place to place with same intervals (constant electrode spacing) along a given line and the *P*a value at each of the station is determined. The changes in *pa indicate* lateral variations in the subsurface to a certain depth.

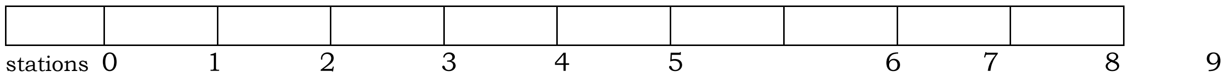
It is obvious that the profiling technique will be useful in detecting only the dyke bodies or vertical beds. The presentation of profiling data is done on a ordinary graph sheet on X-axis (station) and true resistivity values on Y-axis (ohm-mts). The interpretation of profiling data can demarcate the high and low resistivity values of the sub-surface.



PROFILING METHOD (The diagram shows four steps, denoting how an electrode arrangement with fixed separation is moved along successive stations of a traverse line) .

C1 and C2 are current electrodes & P1 and P2 are Potential electrodes.





Graph shows a plot of resistivity data for the above traverse

The Schlumberger Configuration: This method was developed by Schlumberger in 1916. In this method, potential electrodes are kept at smaller side compared to the current electrodes. In general, the electrode separation MN $\leq$ 1/5 AB relation is maintained in this investigation. Here A and B are the current electrodes and M and N are the potential electrodes. The apparent resistivity measured in the Schlumberger configuration is given by ***P*a= K (V/I)** where K is a constant and the value varies as per AB distance

Sounding: This method is popularly known as Vertical Electrical Sounding (VES). In this method, a number of *p*a values are measured at the same place by increasing the distances between the current electrodes each time after taking the reading. The successive increasing in distance makes the current penetrate more and more deeply. Generally, the depth of penetration of the current (i.e. depth) is about $1/3^{rd}$ of the distance between the current electrodes. It is necessary to cancel the self-potential before taking V and I readings for every electrode separation. From I/V values of each electrode separation, *p*a is obtained and it is multiplied by the configuration constant (K) to obtain true resistivity values.

The values are plotted on log–log sheet by plotting the electrode separation (station/distance) on x-axis and true resistivity values (ohm-mts) on y-axis. The obtained curve is to be matched with master curves.

Self-Potential methods: In self-potential methods, the natural electric field existing in an area is investigated whereas in other methods, the ground is charged by an artificial electric field and the results on the surface are investigated.

Self-potential method involves measuring the potential between the potential electrodes for different electrode spacing without any current into the ground. This method is also known as the “Spontaneous Polarization method”. This means the potential measured is the natural potential existing in the ground all the time. Several sulphide ores such as pyrite, pyrrhotite, chalcopyrite, molybdenite, cobaltite etc.. show spontaneous polarization. Anthracite (coal) and graphite are known to give strong SP effects.

The instruments required for carrying out SP surveys are:

(1) A pair or non-polarizing electrodes to pick up the potentials from the ground.

(2) A devise i.e. DC potentiometer or electronic milli volt meter to measure the value of the potentials (voltages) in the ground picked up through electrodes.

The ground immediately above the ore body will therefore be an area of lowest potential, theoretically speaking the negative center. The location of such negative centers is the target of S.P. surveys, since the ore body can be discovered usually below such centers.

The negative centers can be located either by determining the lines of equal electric potential (i.e. **equi-potential lines**) directly on the ground. The ore body is often met below the negative centre.

SEISMIC METHODS

RADIOMETRIC METHODS: The nuclei of certain elements are unstable (U, Th) and change spontaneously into the nuclei of other elements. This change is accompanied by emission of radiations known as alpha; beta and gamma rays. Hence, these rays are measured in the study of radiometric methods. Instruments used in radiometric prospecting are called radiometers. A radiometer consists of three basic components:

(i) a detector of radiations
(ii) an amplifying and recording unit and
(iii) a power supply unit .

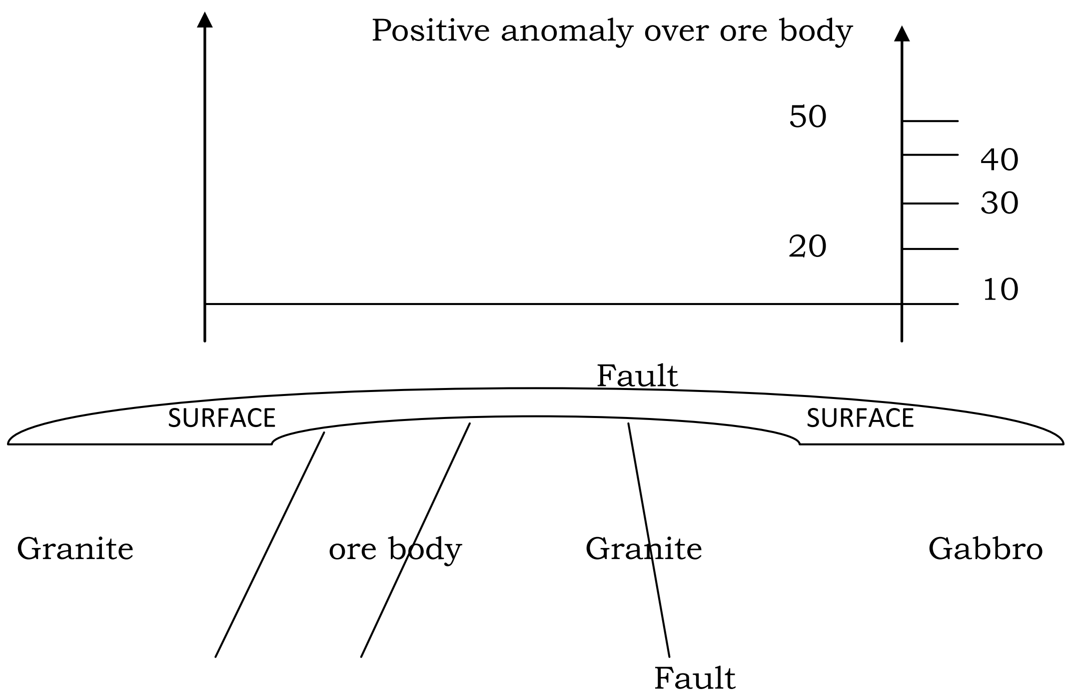
The radioactivity is different in various types of rocks.

In igneous rocks, the radio activity decreases with decreasing acidity as:
Plutonic rocks $\longrightarrow$ basic rocks $\longrightarrow$ ultrabasic rocks
(Radioactivity is high) ……………………………… (Radioactivity is least)

In sedimentary rocks, the radioactivity decreases as :

Shales ⟶ sandstones ⟶ limestones

Thus based on radioactivity, it is not only distinguish different rock types but also to detect ore bodies. Under favorable conditions, it may be possible to identify geological structures such as faults and folds in the subsurface.



Radiometric methods of investigation are useful in:

- Exploration of U and Th mineral deposits
- Indirect location of rare elements such as Zr, Be, Li etc. occurring in pegmatites and Tantalum, Niobium etc. occurring in some alkaline rocks.
- In case of exploration of oil and gas due to the low values of gamma rays.
- By means of radioactive techniques, it is possible to study the velocity of ground water, its direction, salt water bodies etc.
- Radioactive tracer techniques may be utilized for finding leakages in water storage structures.

GEOTHERMAL METHODS: Geothermal methods deals with measurements of the physical properties of the earth. The emphasis is mainly related to **temperature** and **fluid content** of the rocks. The important physical parameters in a geothermal system are:

temperature;
porosity;
permeability;
chemical content of fluid (salinity); and
(pressure)

The aim can be to delineate a geothermal resource, to locate aquifers, or structures that may control aquifers etc..

Temperature distribution on the surface of the earth is due to three different sources. They are:

(i) Heat received from the sun (varies with the time of the day and with the season) up to a few meters depth only.
(ii) Heat conveyed from the hot interior of the earth due to conduction and convection processes
(iii) Heat due to decay of radioactive minerals in the crust of the earth.

By eliminating (i) and (ii), the solar heat component and the heat contribution of radioactive mineral decay, the only one is to interpret the values of temp of the earth's surface. For the measurement of the temperature on the surface of the earth, in shallow holes or in deep bore holes, THERMISTOR THERMOMETERS and PLATINUM RESISTANCE THERMOMETERS can achieve an accuracy of 0.01°C are used. The geothermal methods find application to locate structural bodies, oil and gas structures, ore deposits, ground water studies etc....

Thermal methods include direct measurements of temperature and/or heat, and thus correlate better with the properties of the geothermal system than other methods. To measure temperatures close to the surface, in the uppermost part of the earth crust is fairly simple. Knowledge about status at deeper levels is based on the existence of wells, usually shallow gradient wells (e.g. 30-100 m deep), from which the thermal gradient can be calculated and possibly the depth to the exploitable geothermal resource. Drilling is though usually fairly expensive, and puts practical limits to the use of the method. Furthermore, shallow wells are not always adequate to get reliable values on the thermal gradient.

The heat exchange mechanism in the earth is important for interpretation of thermal methods. A distinction is made between:

• Conduction, which is based on atomic vibrations, and is important for transfer of heat in the earth's crust;
• Convection, which transfers heat by motion of mass, e.g. natural circulation of hot water; and
• Radiation, which does not influence geothermal systems.

The parameter k, the thermal conductivity (W/m°C), is a material constant, which ranges between 1 and 5 W/m°C, with the low values usually associated with sedimentary formations and the higher for crystalline rocks. The thermal gradient,)T/)z, gives information on the increase of temperature with depth, and its distribution can be important information for understanding and delineation of the geothermal resource, both on a regional scale and local scale. If the conductive hear transfer, Q, is 80- 100 mW/m2 or higher, it may indicate geothermal conditions in the subsurface.

FUNDAMENTAL ASPECTS OF ROCK MECHANICS: "Rock mechanics" is the name given to the study of behavior of rocks under loads imposed upon them in the laboratory with all possible combinations.

From civil engineering point of view, rocks are used for various purposes i.e. for laying foundations, as building stones (for walls, columns, lintels and arches); as concrete aggregate, as roofing material, as flooring material, as polished stones for face work, as paving stones of roads, for making statues, as road metal, as railway ballast, as construction stones for bridges, piers, abutments, retaining walls, light houses, dams, for tunneling and so on..

Certain rock mechanics (physical properties of rocks) are necessary to make rocks suitable for certain purposes. A number of IS codes are available to determine the different engineering properties for rocks such as Crushing strength, shearing strength, density, toughness, resistance to abrasion, durability. For e.g.:

Strength of a rock is important for foundation purposes to withstand heavy loads (color, appearance etc are unimportant).

Resistance to abrasion is also important when rocks are used for flooring purposes.
Durability (resistance to weathering) for roofing purpose
Absence of reaction with chemicals for concrete aggregates;
Softness for carving purpose
Lightness is important for rocks/stones used in arches and so on.

E.g.: Marble, is well known for its pleasant colors, good appearance, easy workability, ability to take a high degree of polish is selected for sculpture works whereas it is unsuitable to serve as a foundation rock whereas basalt is just the opposite of marble in its nature and suitability.

Hence, the engineering properties of rocks can be studied under:

(i) For construction purposes especially foundation of dams
(ii) Rocks utilized as materials of construction i.e. building stones
(iii) Rocks used as aggregate (small broken pieces) of concrete.
Engineering properties to be tested for rocks

Foundation purposes	**Building stone for construction purpose**	**As aggregates for concrete purpose**
Uniaxial compressive strength	Crushing strength	Hardness test
Tensile strength	Transverse strength	Toughness test
Shear strength	Porosity	Binding properties
Modulus of elasticity	Density	Crushing strength
	Abrasive resistance	
	Frost & fire resistance	
	Durability	

Uniaxial compressive strength: This test is carried out on cylindrical specimens with a length - diameter ratio of 2 and the results are reduced to a length – diameter ratio of 1 by using the formula:

$Co = Cs \ [\ 0.8 + (0.2 / (L/D)]$ where Co is the observed compressive strength, Cs is the standard Uniaxial compressive strength ; L is the length of the cylinder and D is the diameter of the cylinder.

Tensile Strength: The test consists of loading a test cylinder diametrically in such a way that the applied loads would develop tensile rupturing along the diametrical plane of the specimen. The loads are gradually increased till the cylinder is fractured. The load P at rupture thus being known, Transverse strength Ts is calculated by using the formula: $Ts = 2P / \ DL$; where D and L are the diameter and length of the specimen respectively and P is the load.

Shear strength: A bar shaped specimen is held under grips and supported at its ends below. It is loaded from above and rupture occurs as a result of failure along two planes when the shearing strength is exceeded. The shearing strength is calculated by using the formula $(P/2) / A$, where P is the load at failure and A is the area of cross-section of the specimen under load.

Modulus of Elasticity (Young's modulus): The modulus of elasticity of rocks indicates their deformation under loads. Such deformation is recovered when loads are removed. The value of E is required especially in tunnel works and the abutments of arch dams. E is expressed by the relation s / e where s is the stress and e is the strain.

NECESSITY OF GEOPHYSICAL INVESTIGATIONS

To ensure safety, success and economy in construction of major civil engineering structures, it is necessary to be thoroughly aware of the geology of the concerned site. The relevant details can be readily obtained if a suitable and large number of outcrops of *in situ* rocks are noticed on the surface. This happens due to various reasons such as occurrence of soil cover, intense weathering of exposed rocks, sprawling cultivated lands, townships, forests, surface water bodies and so on at the concerned site. In such cases in order to acquire the subsurface details only two approaches exist. They are: *direct observations* or *indirect inferences.*

(i) Direct observations can be made by digging, trenching or drilling the ground. Such processes are expensive, laborious and time consuming. But they give exact data of the existing subsurface conditions of the site.

(ii) Indirect inferences are drawn by means of geophysical methods of investigation. These provide quick, inexpensive, easy and fairly reliable means to get subsurface details.

IMPORTANCE OF GEOPHYSICAL INVESTIGATIONS: Geophysical investigations are gaining importance very rapidly because of their success in solving a vast variety of problems. The other advantages are:

(1) These investigations are carried out quickly. This means large areas can be investigated in a reasonably short period and hence *time is saved.*

(2) The geophysical instruments used in the field are simple, portable (mostly) and can be operated easily. This means the fieldwork is not laborious.

(3) Since the work is carried out quickly and only physical observations are made without the use of consumables (like chemicals), it *is economical too* (particularly in the case of gravity, magnetic and some electrical methods of investigations).

(4) Different inferences to suit different purposes can be drawn from the same field data.

(5) *Scope to check* the correctness of conclusions is possible

(6) To suit the requirements and to be economical, geophysical investigations are amenable to be carried out on different scales. This means that if only preliminary information is required; reconnaissance surveys are enough. Then the scale of survey may range from 1: 100,000 to 1: 1,000,000. However, if more details are required, detailed surveys can be taken up with the scale of survey ranging from 1: 1000 to I: 10,000.

Applications of geophysical investigations which account for their inherent importance are as follows:

(I) *Non-geological:* Detecting hidden treasures, ammunition dumps, buried Pipeline patterns or pipes come under this category. Such applications are not many.

(2) *Geological:* Such applications are numerous, important and widely varied.

These can be broadly grouped into five kinds as follows:

(i) Investigations aimed at solving problems of regional geology;
(ii) Investigations aimed at locating geological structures which are favorable for accumulation of oil and gas;
(iii) investigations aimed at locating and estimating economically important mineral deposits;
(iv) investigations aimed at locating and assessing ground water potential and its quality; and

(v) investigations aimed at solving problems connected with "engineering geology". "Exploration geophysics" comprises five branches, namely; regional geophysics, oil and gas geophysics, ore geophysics, ground water geophysics and engineering geophysics

UNIT - V: DAMS, RESERVOIRS& TUNNELS

The enormous requirement of water for irrigation, industries, power generation, constructional activities, domestic and other purposes are met either by surface water resources (like tanks, lakes and rivers) or underground water. Surface water resources are fairly amenable for definite assessment and exploitation. Among the surface water resources, rivers provide copious supplies of water which can be stored in man-made reservoirs by constructing dams across the rivers.

A dam is a prestigious civil engineering structure which blocks a river channel and compels the running water to accumulate within the reservoir. In other words dams are constructed for impounding water.

Dams are the costliest *multipurpose* civil engineering constructions. They deliver beneficial results for a long time to mankind. But the same dams, if they fail, create a heavy toll of life and property through lightning floods. They may even cause the failure of other dams built along the downstream course. Each dam consumes millions of tons of building materials including cement, aggregates, sand and steel and other items.

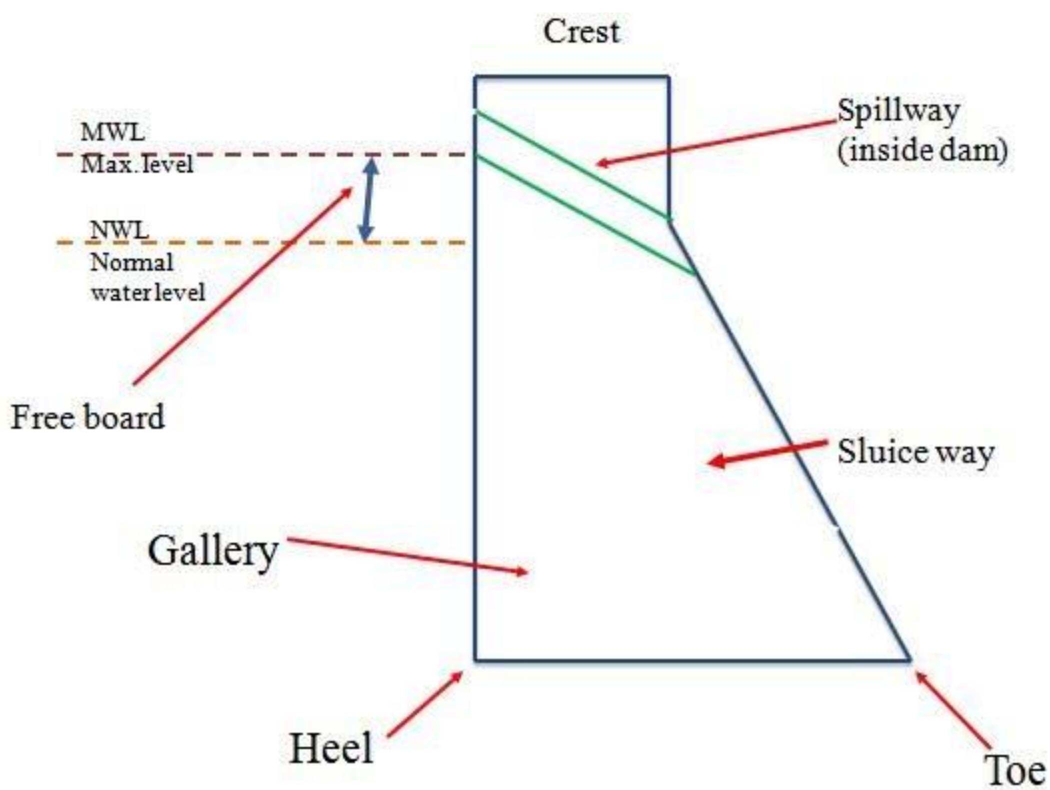
Whenever this accumulation of water exceeds the desired limit of storage in reservoir, the surplus water is allowed to flow downstream. The openings which control the discharge of surplus water from reservoir together constitute the SPILLWAY. The Spillway is commonly placed on a sound foundation within or outside the body of the dam and the openings are controlled by suitably designed gates.

Among various constructions, dams throw the toughest challenge to the civil engineer. Barrages are similar to dams and are mainly meant to raise the level of water along the course of a river to reap certain advantages.

The location of a dam or the selection of a dam site is mainly based on the Geology of the site because the stability or success and the cost of dam are dependent on different geological conditions of the site.

In India, more than 90% of the dams operating are primarily for irrigation. Various purposes of dam construction are:

- To generate hydro-electric power
- For flood control
- For water supply to meet domestic, industrial ..



Parts of a Dam: The chief parts of a dam are as follows:

Heel: It is the 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

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.

Spillway: An arrangement is made in a dam near the top or inside to allow 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.

Abutment: These are the sides of the valley on which the dam structure rests.

TYPES OF DAMS & BEARING OF GEOLOGY OF SITE IN THEIR SELECTION

Dams are of different types. Either they can be totally of reinforced concrete or totally of earth materials or a combination of both.

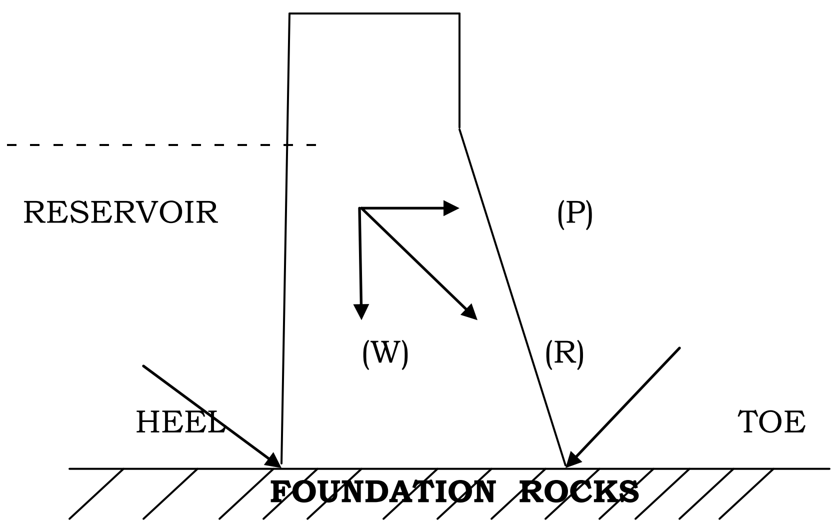
Based on the construction material used, dams are grouped into **concrete dams**, (masonry dams) and **earth dams.**

Based on design, the concrete dams may be further grouped in to Gravity dams, Buttress dams and Arch dams.

Similarly, Earth dams too are grouped in to Earth Fill dams and Rock Fill dams (based on the kind of material used.)

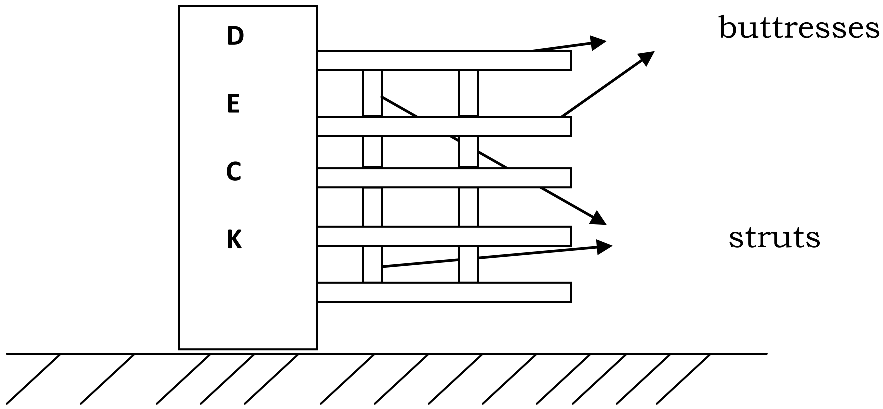
Gravity dams: It is a heavy concrete structure. The weight of the dam acts vertically (whole weight acts vertically downwards) and plays an important part in its stability. The stability of a gravity dam depends on the pressure distribution. This type of dam is to be selected only in such places where competent and stable rocks occur.

For the dam to be stable, the resultant R of the force, [W (weight of the dam) and the lateral thrust of the reservoir water (P)] must be within the middle of the dam. Foundation treatment like grouting is adopted in case of any incompetent foundation material present.



Buttress dams: These are concrete structures in which there is a DECK sloping upstream, supported by <u>BUTTRESSESS</u> (or walls) placed at right angles to the dam axis. These buttresses are further strengthened by cross-walls known as <u>STRUTS</u>.

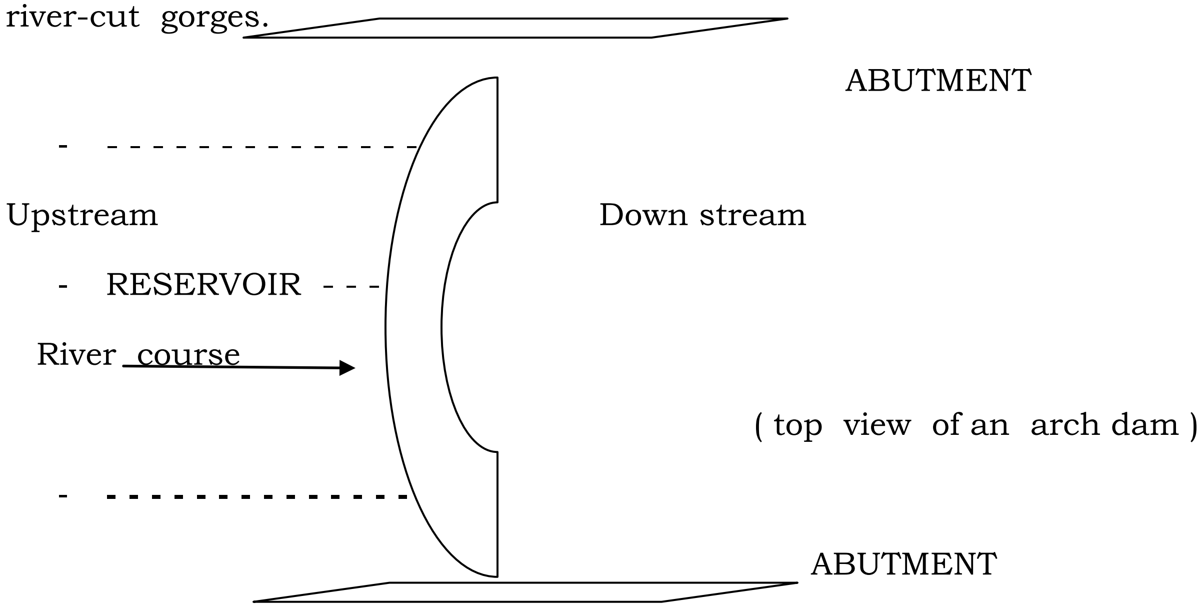
The entire system with all these components distributes the load over the foundation. Since the load distribution is over a wide area, even formations relatively weak are considered.



FOUNDATION ROCKS (top view of buttress dam)

Arch dams: This type of dam is preferred for narrow and deep river gorges. The arch is convex to the upstream side. It can be a single arch dam or multiple arches. The design of an arch dam is such that the whole part of the load is transformed to the abutments.

Since a substantial part of the load is transmitted to the abutments, the formations constituting the abutments must be very competent. Arch dams need better monitoring. Arch dams are best suited to narrow, deep, river-cut gorges.



(top view of an arch dam)

NOTE: Masonry dams are suitable where the geological formations at the dam site are very strong and stable, so as to withstand heavy loads associated with the dams.

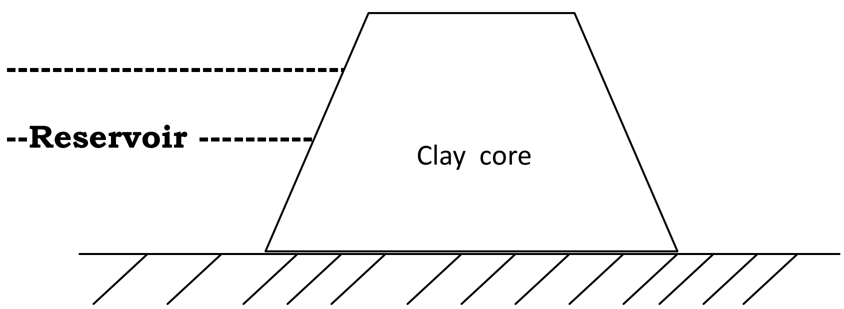
EARTH DAMS: These structures are large in size and trapezoidal in shape. These are preferred in broad valleys and where the foundation material is weak or where suitable competent rocks occur at a great depth.

The earth dams, relatively of smaller height are lighter structures and broad based. Because of the broad nature of the dams, the weight of the dam is distributed over a wide base and the force per unit area is consequently less.

The earth materials used in the construction are gravel, sand, silt and clay is called an <u>Earth Fill Dam</u> and if the material used is rock, it is called a <u>Rock Fill Dam.</u>

The side slopes are maintained at 1 in 2.5 and an impervious clay core is provided to arrest seepage across the structure.

E.g.: Ft. Peck, Wyoming dam.... It is $4\frac{1}{2}$ miles long, 4000 feet thick at the base and 250 feet high.



FOUNDATION ROCKS

LOCATION OF A DAM: The ideal site for location of a dam should satisfy the following requirements:

- A narrow river valley along with steeper side slopes
- Stable slopes both at the dam location and along the reservoir sides
- Absence of weathered formations
- Competent geological formations devoid of weak zones
- Absence of clay and fractured material
- Absence of fault zones
- Stability of formations below the dam and reservoir area
- Easy access and supply of materials for construction of the structure

It may be mentioned here that all these attributes never exist in any one particular site. Consequently, appropriate foundation treatments are resorted for making the dam site and reservoir area most suitable.

GEOLOGICAL CONSIDERATIONS for selection of a dam site:

(A) Topography and geomorphology of the site: At the proposed dam site, if the valley is narrow, only a small dam is required, which means the cost of dam construction will be less. On the other hand, if the valley is wide, a bigger dam is necessary which means the construction cost will be very high.

Therefore, it is preferable, from the economy point of view, to select such a site along the river valley which has the narrowest part of the river. However, narrow river valley may have severe defects which may lead to leakages.

Quite often the valleys have TALUS and flood deposits along the slopes, thus giving a narrow appearance to the valley but in fact it may be a wider river valley.

(B) Impact of Geological structures (occurrence of rock formations at shallow depths) :

The rock formations at the dam site should be dipping towards upstream or horizontal. This will counter the seepage, compared to the situation where the formations dip in the downstream direction.

To ensure the safety and stability of a dam, it should necessarily rest the dam on strong (physically) and very stable rocks (structurally).

- Usually the foundations will have greater stability when the load is normal in case of horizontal formations or with low dip formations.
- Fault zones present in the formations result weakness in the rock formations.
- Extensive joints in the rocks threaten the safety of the structures by means of seepage.
- Presence of Anticlinal or Synclinal structures in the rocks also contribute to the seepage.

To know the bedrock profile (i.e. the depths at which bedrock occurs at different places) in the river valley along the axis of a proposed dam, geophysical investigations such as '*Electrical Resistivity* " or "*Seismic Refraction*" methods are to be carried out.

Following examples reveal the impact on dams where the cost was high as well as the presence of structures in the rock formations:

1. Bhakra Nangal dam on sutlez river, the bed rocks were at a great depth caused more excavation for foundation .

2. Koyna dam is located on an excellent competent basalts with 6 to 7 meters thick but followed by weak volcanic breccia up to 20 mts below the ground level. This naturally rise in the construction cost of the dam.

3. Presence of a fault and incompetent rocks of conglomerate in St. Francis dam of California caused for enormous leakage of water through the conglomerates and failed

4. Similarly the presence of cavernous limestones in the foundations caused for the collapse of Hales bar dam on the Tennessee river.

(C) Competent rocks to offer a stable foundation (Lithology of the formations):

Among the Igneous rocks, (either plutonic or hypabyssal rocks) Granites, Syenites, Diorites, Gabbro's, and volcanic rocks viz., Basalts (fine grained) are most desirable at the dam site. However, adverse effects will be noticed in basalts only when they are highly vesicular and permeable.

In case of sedimentary rocks, particularly shales, poorly cemented sandstones and cavernous limestones shall be undesirable to serve as foundation rocks. However, well cemented siliceous sandstones have good compressive strength and suitable for the dam foundation.

Laterites and conglomerates are undesirable at dam site. Clay, if present in any of sedimentary rocks is totally to be excavated since it swells on saturation with water.

Among the **metamorphic rocks**; gneisses are generally competent whereas schists are undesirable due to their well developed cleavages and foliation.

Quartzites are very hard and highly resistant to weathering and suitable for foundation of dam sites.

Slates bear a typical slaty cleavage and soft nature are undesirable at dam sites.

Khondalites which are feldspar rich and contain soft graphite, and are usually weathered and hence unsuitable at dam sites

Much attention is needed in case where the contact of igneous intrusive (for example dolerite) with the host rocks often are fractured and jointed.

- E.g.: (1) In the Ukai dam site in Gujarat, the contacts of basalts and the dolerite dyke were the weak zones.

- E.g.: (2) Similarly, at the contacts of a dolerite dyke with the host granite gneisses in the Nagarjuna sagar dam area, shear zone with heavily crushed rock was found. Of course, back filling with grouting was adopted.

(D)Influence and Effects of various factors:

1. The extent of weathering should be carefully assessed (through trial pits) to ascertain whether a rock is suitable or unsuitable for the required purpose.

2. Study of intrusive such as dolerites and quartz veins is important factor. If they are present they contribute to the heterogeneity at the dam site causing leakage.

3. Fracturing is a common phenomenon observed in all kinds of rocks and represents a reduction in the cohesion or compactness of the rock. Suitable remedial measures taken up to make the site rocks fit for the location of the dam.

4. Alternating soft and hard beds when inclined are bad and the situation leads to a variety of problems including slipping of hard beds over softer ones at the time of excavation.

In civil Engineering point of view, the following cases of geological structures at dam site are important:

I. Case of undisturbed strata.

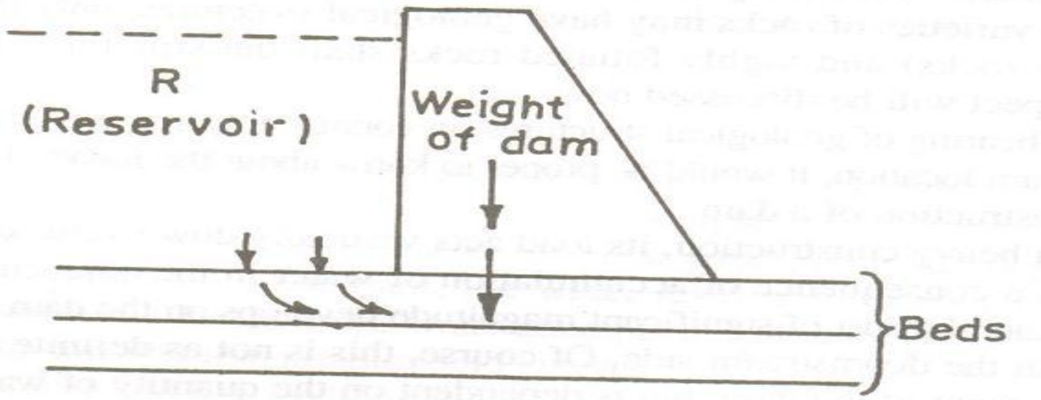


Fig. 18.8 A gravity dam over horizontal beds

Horizontal Strata: This geological situation is good at the dam site because the load of the dam acts perpendicular to the dam site.

II. Beds Dipping towards Upstream Side

a. Gently Inclined beds:

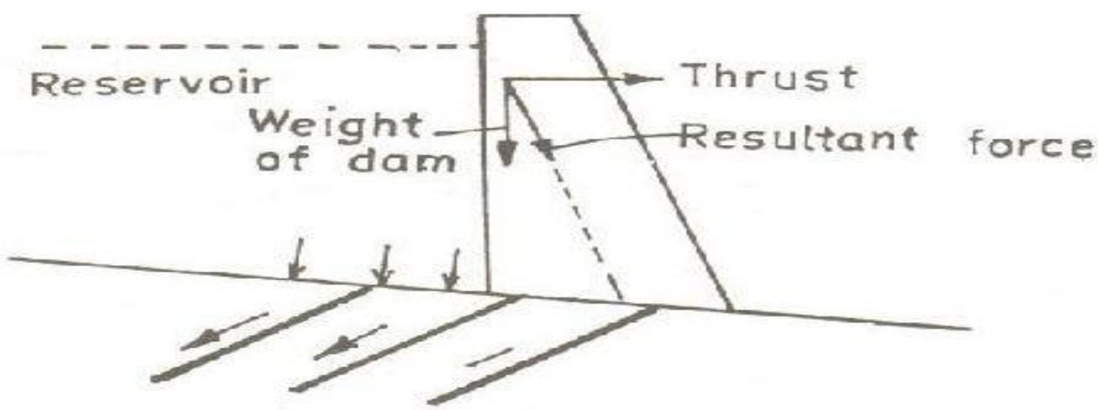


Fig. 18.9 Dam over gently inclined beds in upstream direction

In this case, rocks are best positioned to take the loads of dam because the resultant force and the bedding planes are not in the same direction. No uplift force on the dam and percolated water is returned to the upstream side only, so this is doubly advantageous.

b. Steep beds:

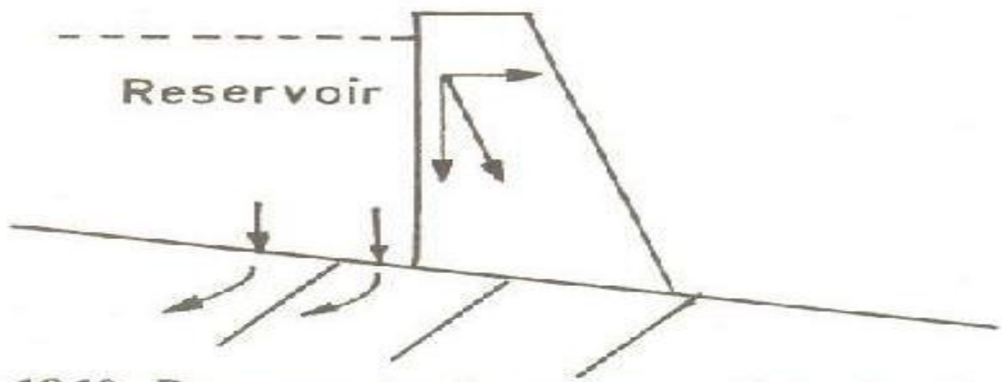


Fig. 18.10 Dam over steeply upstream side inclined beds

This situation is not bad but not that competent to take up the dam loads as compared to gently inclined beds. This may not cause uplift force on the dam and percolated water is returned to the upstream side only.

III. Beds Dipping towards Downstream

c. Gently Inclined beds:

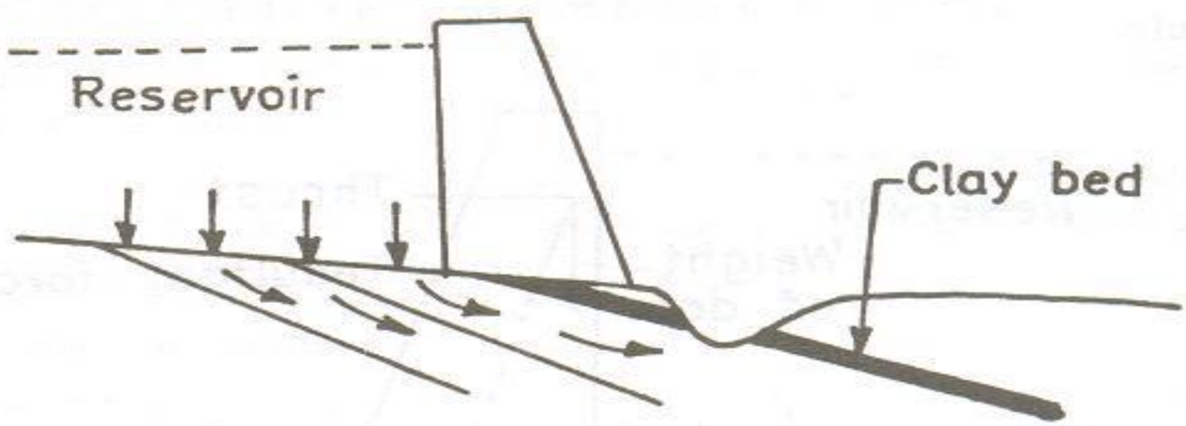


Fig. 18.11 Dam over downstream side inclined beds

It is disadvantageous, because the resultant force and the bedding planes are in the same direction. Percolated water to down stream side cause uplift force on the dam and percolated water goes out and cause significant water loss.

d. Steep beds: This situation is similar to the above situation and further dangerous because the resultant force and the bedding planes are almost parallel.

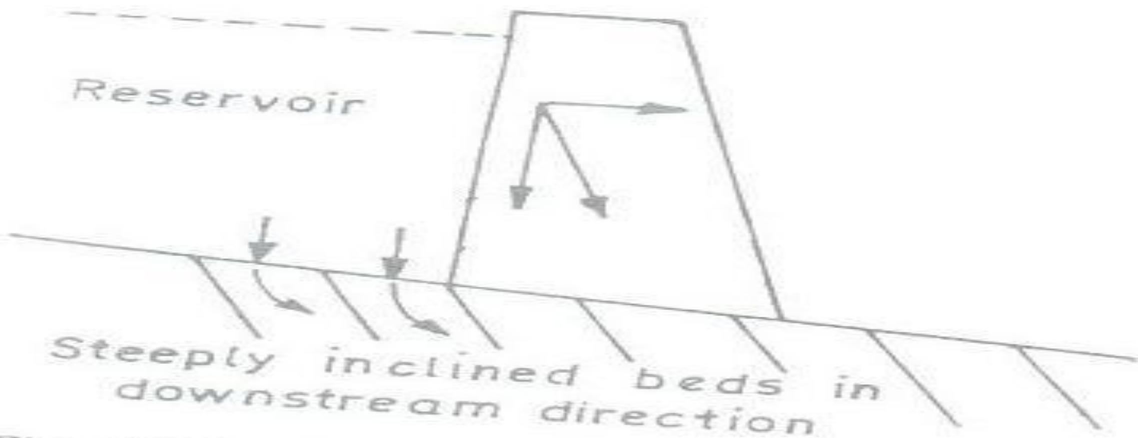


Fig. 18.12 Dam over steeply inclined beds in downstream side

IV. Beds dipping vertically

e. Dam Over Vertical Beds:

Fig. 18.13 Dam over vertical beds

Occurrence of this situation is rare. It will not pose problems of uplift force or leakage below the dam. However, it shall not have any advantage in terms of competence of rocks.

V. Beds which are Folded

Dam Over Folded Beds: Folding of beds, are generally less dangerous than the faulting, unless the folds are of a complex nature. The folded rocks are not only under strain but also physically fractured along the crests. Hence grouting and other precautions may have to be taken, depending upon the context, to improve the stability and competence of rocks at the site.

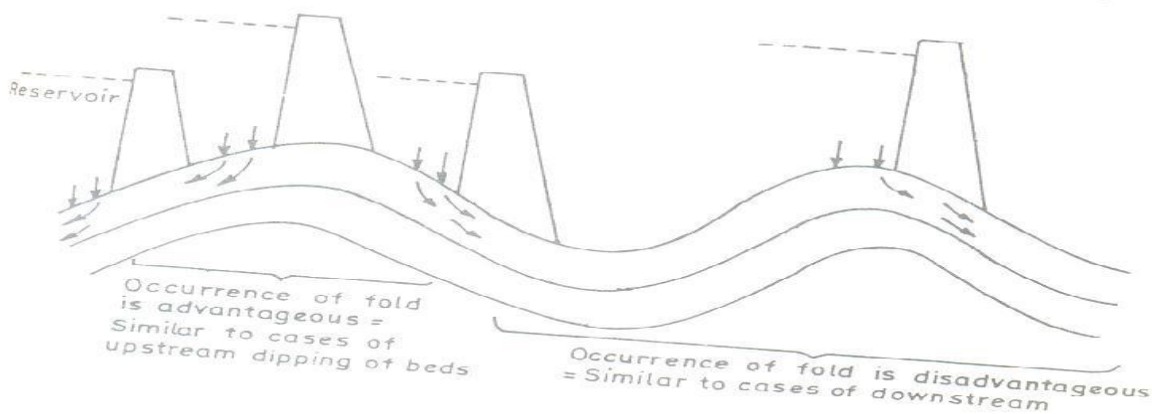


Fig. 18.14 Dam over folded beds

VI. Beds which are Faulted

Dam over Faulted Beds: Occurrence of faulting at the dam site is most undesirable. If the faults are active, under no circumstances, dam construction can be taken up there. This is due to relative movement of bed and also possible occurrence of an earthquake.

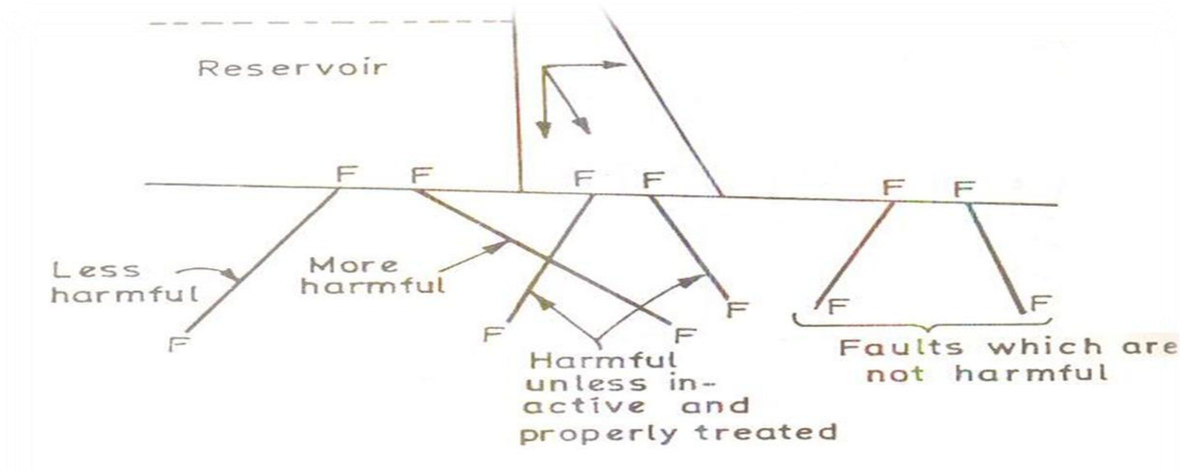


Fig. 18.15 Dam over faulted beds

1. If the faults occur in the downstream side, they will not be much harmful directly.

2. If the faults occur in the upstream side, the downstream dipping faults are dangerous because they have all the disadvantages of a case with bedding planes of such attitude (i.e., risk of uplift pressure, heavy leakage water), but if the faults dip in the upstream side they need to be sealed to avoid possible leakage.

VII. Beds Which have Joints

Joints are nothing but gaps of different magnitude that are common in rocks. They

contribute to the physical weakness of the rock and also more porous and permeability. These physical features are undesirable for the dam construction. Hence, by adopting grouting technique, these weaknesses can be avoided.

VIII. Cases where beds lie parallel to the length of the valley

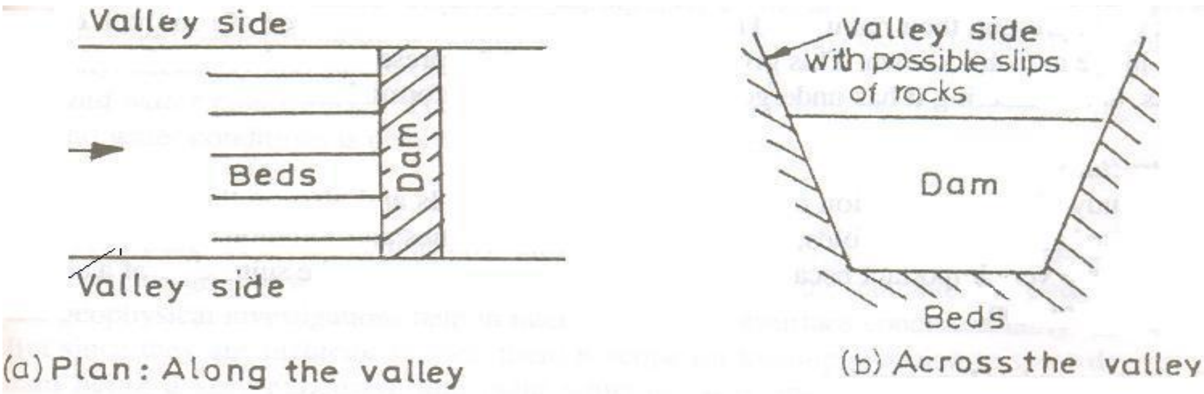


Fig. 18.16 Dam over beds striking parallel to valley

This is the case where the dam is aligned across the strike, i.e., in the dip direction of the beds. In this case the danger will almost always be present as the slope of valley sides are very steep at the dam sites and are very likely to be steeper than the dip of rocks and causes instability at the site and slipping of rocks at one side

DAM FAILURES OF THE PAST:

1. The **St. Francis Dam** was a concrete gravity-arch dam, designed to create The dam was built between 1924 and 1926 under the supervision of William M

The dam Height is 195 feet (59 m) & its l**ength is** 608 feet (185 m). The dam was constructed on the foundation of Schists and conglomerates and in turn, separated by a distinct fault. In addition, conglomerates also had veins of gypsum, a soluble mineral and hence both Schists and conglomerates are unsuitable to serve as a foundation to such a dam.

Several temperature and contraction cracks appeared in the dam when the reservoir had reached full capacity. Enormous leakage of stored water occurred through the conglomerate and the dam failed by sliding in 1928 resulting more than killing of 450 people.

Huge concrete block from the west abutment of the dam . The block is approximately 63 feet long, 30 feet high, and 54 feet wide. It was concluded that the disaster was primarily caused by the landslide on which the eastern abutment of the dam was built.

2. **Hales Bar Dam** was a hydroelectric dam located on the Tennessee River in Marion Country, Tennessee, USA. **The Hales Bar Dam** was constructed on the foundation of cavernous limestones. Such rocks are naturally weak both physically and chemically. To improve the site conditions and to reduce the seepage, the large openings were filled up by using more than 3000 tons of cement and 1100 barrels of asphalt. The height of the dam is 113 feet with a length of 2315 feet

The dam was planned to complete in 1909, but numerous difficulties brought by the soft bedrock i.e. limestone upon which the dam was built.

Leaks began to appear almost immediately after completion. However. in 1919, engineers attempted to minimize the leakage by pumping hot asphalt into the dam's foundation. This was temporarily successful, but by 1931, a study leaking at a rate of 1,000 cubic feet per second was noticed .

In the late 1950s, however, the water below Hales Bar Dam, was again leaking, this time at an alarming 2,000 cubic feet per second. **Dye tests** carried out in 1960 suggested that many of the leakage channels had interconnected, increasing the possibility of a future dam failure.

GEO HAZARDS : Geological hazards such as Earthquakes; volcanoes ; landslides etc.. pose a threat to the earth's stability. All these geological hazards cause considerable destruction in many ways.

During earthquake, the ground motion results in damaging buildings, dams, dislocating the roads and railway tracks; alter the course of surface water and groundwater flow etc..

Volcanic activity brings devastation on large scale due to emission of a number of gases.. Thick forests are denuded, vast areas are buried under thick volcanic debris.

Land slides are common phenomena during earthquakes. Huge flow of pyroclastic materials mix with water flows and cause damage to whatever lies in its path.

Thus, earthquakes, volcanic activity and land slides are all inter-related.

1. Earthquakes & earthquake hazards : The earth's crust is broken into 13 major plates which are in constant movement (1 to 2 cm / year on average) due to the **convection currents** in the interior of the earth. These plates are called as Tectonic Plates .

The pate boundaries move away from each other at some places while they converge and collide against each other at some places.

An earthquake is a sudden motion of the ground. In the Earth's crust, at different places , stresses accumulate causing slow and continuous deformation of rocks. As the stress exceed its elastic limit, the rocks break . Due to this sudden breakage, the strain energy is released in the form of shock waves.

The focus is the place where this slippage has initially taken place. Vertically above the focus, the location on the ground surface is known as epicenter of the earth quake.

Recording of the shock waves is done with the help of an instrument known as Seismograph. The record (chart) is known as a seismogram. These records for an earthquakes are useful in locating the epicenter of the earthquake and also to define the size of the earthquake.

The size of an earthquake is defined by its **intensity and magnitude**.

The intensity at a place depends on several factors such as distance from the epicenter, depth of focus, geological formations and the type of a civil structure.

The magnitude of an earthquake does not vary from place to place. Magnitude is a function of the energy released in an earthquake and is common ly expresses as Richter's magnitude . Richter's scale has magnitude numbers up to 10 but the maximum known magnitude is around 9.6 only.

In civil engineering practice, earthquake resistant designs have been needed for all civil structures.

Earthquake Hazards:

- Destruction of buildings e.g.: Bhuj earthquake (7.5) on 26-01-2001

- Dislocation of transportation routes (highways, bridges, railway tracks).

E.g.: (1) California earthquake of 1994, caused subsidence and landslides.

(2) Alaska earthquake (8.7) on 27-03-1964 causing the displacement of a road bridge.

- Generation of Tsunamis for e.g.: Mexico, Chile , Indonesia (Tsunami means the rapid displacement on the sea floor during the earthquake. These waves travel several thousands of kilometers.

- Power lines breakdown and cause for fires

2. Volcanic and volcanic hazards: The earth's crust is highly fractured and these fractures extending to certain depths and facilitate migration of magma upwards . The rate of travel of magma depends on its composition (i.e. silica rich magma) granitic magma ; Basaltic magma (Fe - Mg rich with deficiency of silica).
The molten rock material emerges on to the surface as Lava. Volcanic activity involves eruptions with ejection of lava along with several volcanic gases.

Volcanic Hazards: Volcanic eruptions are hazardous and occur in many forms. The details are as follows:

<u>Volcanic gases:</u> When a volcano erupts, gases (water vapour; CO_2; SO_2; HCl; HF; CO; H_2S) spreads into the atmosphere.

SO_2 contributes acid rain and CO_2 causes depletion of Ozone layer. Fluoride and Chloride gases contaminate water and may also cause skin irritation.

<u>Lava flows</u>: Lava flows, being hot, are very disastrous. Volcanic flows vary in their temperature between 200°C and 1000°C causing extensive burning of all the material they encounter. The volcanic flows follow stream valleys resulting floods in case of snow or ice terrains.

<u>Volcanic Fragments / ash</u> is also called as TEPHRA. If the fragments are < 2 mm, it will be called as VOLCANIC ASH whereas the large fragments are known as LAPILLI.

The volcanic ash spreads as a cloud covering enormous areas following the wind direction. The fine particles sometimes gets electrically charged causing for lightning. Volcanic ash causes breathing problems.

Lahars: Volcanic material mixed with water forms a slurry, similar to wet concrete mix. Lahars containing around 80% of the volcanic materials and destroy bridges and buildings.

Ground Subsidence: Movement of material vertically down is known as subsidence (or) Ground subsidence involves vertical collapse of ground. Sinking of the ground takes place due to underground presence of open spaces. Subsidence can be slow or relatively fast depending upon the type. Subsidence can be caused by natural or through human activities. Carbonate dissolution in the subsurface; underground mining; ground water withdrawal etc. are some of the examples for subsidence.

Carbonate dissolution in the subsurface: This is common to limestone terrains. If the ground water is slightly acidic, it reacts with $CaCO_3$. In this reaction, the bicarbonate formed is soluble and is carried away by the underground circulating water.

Cavities or caverns are common in limestone formations. In the caves, the evidences of solution and the enrichment of carbonate ions in water can be seen from the formation of stalactites (hanging carbonate precipitate) from the leaking water on the cave roofs and also the growth of these deposits from the leaked water falling on the floor of the cave (stalagmites).

Underground mining: in coalmines, the subsidence of the ground is common due to collapse of the roof of the mine. During the mining, inadequate supports or excessive mining of coal results the roof collapse. In addition, underground fires taking place in some coal fields due ground subsidence. E.g.: Jharia coal fields.

Groundwater withdrawal in the subsurface: Excessive withdrawal of groundwater from the subsurface results in subsidence. This process is known as hydro-compaction, usually which takes place by dewatering from the geological formations.

In oil and gas fields, withdrawal of the fluids (crude oil) also results in subsidence.

ARCH DAM in India (Idukki Dam): The 'Idukki Dam' - Asia's biggest Arch Dam of 555 feet height proudly standing between the two mountains - 'Kuravanmala' (839 meters) and 'Kurathimala' (925 meters) in Idukki district in Kerala. . This prestigeous project power House is located at Moolamattom which is about 43 kms away from Idukki.

The Idukki Dam was commissioned in 1976. This is India's first & only Arch Dam. This is also the second highest concrete dam in India. It has a thickness of 19.81 m, at the deepest foundation & 7.62 m at top.

The shape and the quality of rock at the deep gorge where this dam was built was immensely suitable to adopt the arch shape of the dam. The double curvature arch shape has resulted in an saving in concrete volume by 60 % as compared to a gravity dam of this height.

Reservoir

Principal sources of natural recharge include precipitation, stream flows, lakes etc. whereas artificial recharge include excess irrigation water, seepage from canals. Reservoirs are the results of human attempts to make effective use of the run-off water which is otherwise going waste i.e., flowing into the sea. However, the reservoir basin should be of adequate water capacity to hold a large and desirable quantity of water to derive optimum benefit.

Geological investigations are carried out in advance to study the suitability of the site to serve as the reservoir. In addition, non- geological aspects such as

- Water tightness of the reservoir site
- The life of the reservoir (rate of silting)
- The capacity of the reservoir
- The area covered by the reservoir
- The effect of evaporation
- Possible submerge of economic minerals
- Submerge of fertile land, forests.
- Submerge of places of interest like temples and historical monuments.

Considerations for successful reservoir: In general, a reservoir can be claimed to be successful if it is **watertight** (<u>doesn't suffer from any serious leakage of water</u>) and if it has a very low rate of silting (long life of reservoir) in the reservoir basin. Of course, the reservoirs capacity is very important and it depends on the existing topography and the proposed top water level (TWL) of the reservoir.

(A) **Water- tightness and influencing factors:** As a consequence of weathering (due to natural process), the surface is covered by loose and below it lies the fractured rock and massive rock occurs further below. When a river flows over such loose soil or fractured ground, it is natural that some river water percolates into underground through cracks and may even cause for leakages. .

Before the construction of a reservoir, priority for leakage shall be considered as less or limited to some extent. When a dam is constructed, the accumulated water occupy in large quantities in a reservoir which cover a very large area. Due to the considerable height of the water in the reservoir, significant hydrostatic pressure develops which will make the leakage more effective on the sides and the floor of the reservoir through the cracks. .

Buried river channels which are more frequent in glaciated regions are a serious source of leakage when they occur at the reservoir site. E.g.: A buried channel noticed in Tapoban dam site of river Dhauli Ganga which is a tributary of the river Alaknanda (U.P)

Water tightness of a reservoir basin is very much influenced by the kind of rocks that occur at the reservoir site. If the rocks are porous and permeable (i.e., aquifers) they will cause the leakage of water and hence such rocks are undesirable at the reservoir site.

The Influence of commonly occurring rock types at the reservoir site play also a major role:

Granite: will not cause leakage unless the presence of joints/faults.

Basalts: Not desirable because of presence of vesicles, cracks, fractures, joints etc.... except if it is compact in nature .

Shales: shall not cause leakage due to fine grained and non permeable if compact

Sandstone: well cemented and compact sandstones will naturally be less porous and less permeable and hence cause less leakage.

Limestone: Undesirable but not so always. Compact limestone have negligible porosity may be suitable.

Conglomerate and Breccia cause leakage at the reservoir site.

Gneiss: will not cause.

Schists: Cause leakages due to the presence of soft and cleavage bearing minerals.

Quartzite: will not cause.

Marble: though compact not advisable by virtue of $CaCO_3$ composition.

Slate: Cause leakage due to cleavages.

<u>Influence of Geological structures</u> such as folds, faults, joints, fractures have a significant influence in increasing the leakage through the rocks at the reservoir. Among the different structures, the bedding planes and fault planes are also represent planes of weakness and provide scope for leakage. Of course this depends on their attitude i.e., their Strike and Dip.

(B) **Reservoir Silting (Life of Reservoir):** The streams flowing through the catchment area into the reservoir carry sediments and in turn the sediments deposit in the reservoir. Silting of a reservoir is harmful and can cause the failure of the reservoir and the quantity of water stored gets reduced. Of course, the life of the reservoir is based on the siltation rate.

If the rate of silting is very low, the life of the reservoir will be long and useful for a long period and proves worthy. The total volume of the silt likely to be deposited during the designed period of life of the reservoir /dam is therefore estimated and approximately that much volume is left unused to allow for silting and is known as **dead storage**.

TUNNELS

Tunnels are underground passages through hills or mountains used for several operations. Tunnels are made by excavation of rocks below the surface or through the hills.

Like other engineering structures, tunnels too need favorable geological conditions at their sites for achieving success. In case of tunnels also, success means safety, stability and economy.

To achieve these objectives, careful geological examinations should be made with reference to the rock types occurring at the site (lithology of rock-formations), structures associated with them and the prevailing ground water conditions.

The construction of underground tunnels, shafts and passageways are of course essential but these are dangerous activities. Working under reduced light conditions, limited access; the exposure to air contaminants and the hazards of fire and explosion, underground construction workers face many dangers.

PURPOSES OF TUNNELLING: Tunnels are constructed for several operations:

- **In mining practice**: Adits and shafts for reaching the work spots and for the transport of workers and materials.

- **In certain mines:** tunnels are made to extract coal from coal seams

- **In hydroelectric projects**: Diversion tunnels for channel diversion (by diverting the normal flow of river water through the tunnels) and for power generation.

- **For water supply and sewage disposal:** For supply of drinking water or sewage disposal purposes, tunnels are made.

- **Transportation**: to lay roads or railway tracks to regularize the traffic and transportation of goods.

- **For laying cables and service lines:** These are utility tunnels for laying cables and for transport of oil/gas through pipelines.

- **To reduce the distance:** To reduce the distance between places of interest across natural obstacles like hills, to save time and to provide conveyance.

  E.g. (1) In Bihar, between Hazaribagh and Gaya the eastern railway passes through a number of tunnels across the hills of the Chota Nagapur Plateau.

  E.g. (2) A number of tunnels of 1 km in length or less were driven in the Deccan Traps between Bombay and Pune railway line.

E.g. (3) In Jammu and Kashmir, 2 parallel tunnels of 2440 mts long were made between Jammu and Srinagar in the Pir Panjal mountain range.

E.g. (4): the under sea tunnels made between France and England and between some islands of Japan.

CLASSIFICATION OF TUNNELS:

Depending on the nature & competency of the ground, tunnels are classified as:

Hard rock tunnels: The tunnel alignment is essentially through competent rock mass with little or no ground water seepage.

Soft rock tunnels: The tunnel alignment is through unconsolidated or highly weathered material which always encounter the groundwater problems.

EFFECTS OF TUNNELLING: When tunnels are made through weak or unconsolidated formations, they are provided with suitable lining for safety and stability. Lining may be in the form of steel structures or concrete.

- Due to heavy and repeated blasting during excavation of a tunnel, numerous cracks and fractures develop which reduces the compactness in rocks. In addition, rock become loose/more fractured which allow water movement .
- Lining of the tunnel helps in checking the leakage of groundwater into the tunnel.
- Fault zones and shear zones are naturally weak and tunneling through them further deteriorates and cause stability problem.
- Fall of rocks takes place even in hard rocks like granite though devoid of bedding or foliation and this process is known as **Popping.**
- Roof may collapse due to stress and strain of the region due to overburden.
- Poisonous gases encountered during the excavation of tunnels, sometimes.

ROAD TUNNELS IN INDIA:

Tunnel	Length	State	Notes

Rohtang	8 820 m	HP	Under the 3978 above msl high Rohtang pass on Manali - Leh road
Banihal	2 576 m	JK	Jammu - Kashmir road. 2209 m above sea level
Jawarhar	2 500 m	JK	Srinagar - Jammu
Kamshet-I	1 843 m	MH	Mumbai - Pune Expressway.
Bhatan	1 658 m	MH	Mumbai - Pune Expressway
Gokhale Nagar	1 000 m	MH	
Khambatki - Ghat	890 m	MH	
Madap	646 m	MH	Mumbai - Pune Expressway
Kamshet-II	359 m	MH	Mumbai - Pune Expressway
Khandala	330 m	MH	Mumbai - Pune Expressway.
Aodoshi	? m	MH	Mumbai - Pune Expressway. Only for Mumbai bound traffic

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

The main purposes of lining are to resist the pressures from the surroundings (from the roof or the sides or the floor) and to protect the shape of the tunnel. Lining also helps in the leakage of ground water into the tunnel . Thus lining is a an effective remedial measure to overcome the various drawbacks resulting from underground tunneling either geologically or non-geologically.

Lining provides a regular shape to the tunnel as the excessive excavated portions (i.e. over break) are filled by concrete. Lining being a very expensive treatment, needs to be provided only at such places where the rocks are not capable of supporting themselves,., where the rocks are weak and likely to collapse.

Lining is also provided in such places where the seepage of water into the tunnel occurs and creates problems. The zones of faulting or shearing also need suitable lining to impart strength to them. Strong and complete lining is required in hydropower tunnels which carry water under great pressure and even minor leakages can prove hazardous.

GEOLOGICAL CONSIDERATIONS: Geological considerations of tunneling depend on various geological factors prevailing at the site. The geological considerations in a civil engineering project (i.e. tunneling) include

Lithology of rock formations;

Geological Structures and

Groundwater conditions.

1. LITHOLOGY OF ROCK FORMATIONS : Massive **Igneous rocks** (i.e. plutonic and hypabyssal rocks) are in general compact and competent and no lining is required for the tunnels designed. Volcanic igneous rocks being often vesicular, porous and permeable posses a threat of water seepage in the tunnel. However, sometimes, the vesicular character is also competent and suitable for tunneling.

E.g.: 20 tunnels were excavated for Bombay–Delhi railway line through amygdaloidal / vesicular basalts.

Sedimentary rocks are less competent. However, sandstones with siliceous matrix may be considered . If the sandstones have carbonate or iron oxide as cementing material (poorly cemented), the tunnel lining needs reinforcement otherwise they are undesirable.

E.g.: In the Himalayan Ramganga diversion tunnel, a poorly cemented sandstone formation, had caused a roof fall.

Limestones may expect seepage problems. Among limestones, dolomitic limestones are harder and more durable. On the other hand, calcareous limestones or porous limestones are naturally weaker, softer and are unsuitable for tunneling by virtue of their tendency to corrode. Shales are the lest competent because of the clay content. The presence of Clay layers are troublesome as they have low strength.

Among the **metamorphic rocks**, Quartzites and gneisses are massive and competent. Phyllites and Schists are problematic due to the presence of foliation and presence of susceptible minerals like mica and clay. Depending the orientation of cleavage of minerals in case of slates may be considered. Marbles are reasonably competent by virtue of their high compactness and granulose structure.. But their susceptibility to corrosion and softness necessitates lining.

GEOLOGICAL CONSIDERATIONS FOR EFFECTIVE TUNNELLING

Importance of Rock Types

SUITABILITY OF IGNEOUS ROCKS: Massive igneous rocks, i.e., the plutonic and hypabyssal varieties, are very competent but difficult to work. They do not need any lining or any special maintenance. This is so because they are very strong, tough, hard, rigid, durable, impervious and, after tunneling, do not succumb to collapse, or to any other deformation.

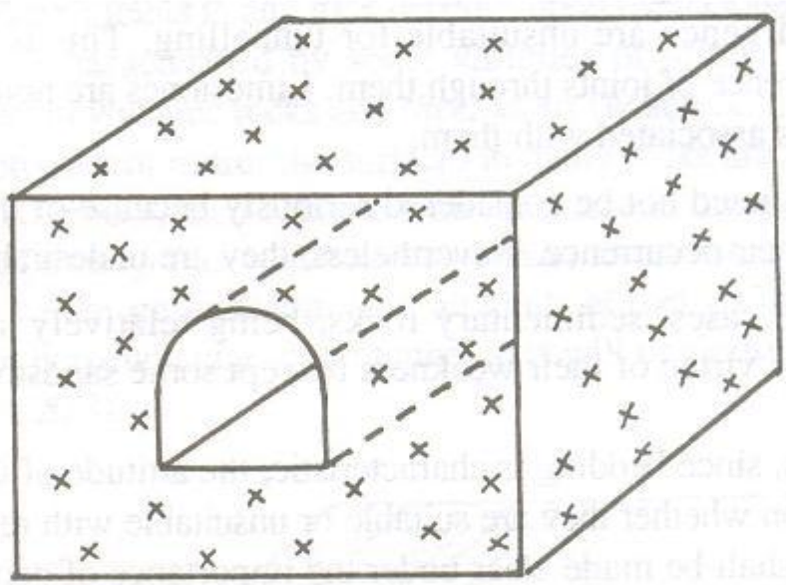


Fig. 20.1 Tunnel in igneous rocks

SUITABILITY OF SEDIMENTARY ROCKS: Thick bedded, well-cemented and siliceous or ferruginous sandstones are more competent and better suited for tunneling. They will be strong, easily workable and, moreover, do not require any lining. Thus they possess all the desirable qualities for tunneling, provided they are not affected adversely by any geological structures and ground water conditions.

Poorly cemented or argillaceous sandstones, however, are weak and undesirable, particularly if they get saturated with water or are thin bedded. Shales, by virtue of their inherent weakness and lamination, may get badly shattered during blasting. Mudstones are weaker than shales as they are less compacted.

Among limestones, dolomitic limestones are harder and more durable. They are better than other varieties. On the other hand, calcareous limestones or porous limestones are naturally weaker and softer. Conglomerates need not be considered seriously due to the presence of pebbles and consolidation.

SUITABILITY OF METAMORPHICROCKS: Metamorphic rocks such as gneisses are nearly similar to granites in terms of their competence, durability and workability. Schists, Phyllites, etc., which are highly foliated and generally soft, are easily workable but necessarily require good lining.

Quartzites are very hard and hence very difficult to work. Marbles are reasonably competent by virtue of their high compactness and granulose structure. Slates are rather soft and possess slaty cleavage. Hence they are weak and require lining.

(1) GEOLOGICAL STRUCTURES :

Strike and Dip orientation; Joints, Faults, Folds etc. are the most common structural features associated with rocks.

If the tunnel alignment coincides with the strike of the formations, is acceptable if the formations are competent but in the case of less competent formations, the tunnel alignment should be a short span.

(A) Joints at the tunnel site: Closely spaced joints in all kinds of rocks are harmful (e.g. Koyna third stage tail tunnel has been excavated through a closely jointed basalt causing roof fall with heavy copious leakage of water). Joints which strike parallel to the tunnel axis for long distances are undesirable whereas the joints which are perpendicular to the tunnel axis have a limited effect.

In sedimentary rocks, the presence of joints may be due to folding (occur along crests and troughs) or faulting is undesirable.

In metamorphic rocks, such as granite gneisses and quartzites are competent even if the joints present due to their competent nature. Schists and Slates with joints will become very incompetent and require lining.

(B) Tunnels in Faulted Strata: Faults are harmful and undesirable because of the following problems:

Fault zones are places where the displacement of rocks occur and lead to discontinuity in the tunnel alignment. The fault zones are places of intense fracturing which means physical weakness in rock masses. Fault zones allow percolation of groundwater which may cause for collapse of walls. E.g.: Koyna (Maharashtra state) third stage tunnel collapsed about 15 mts along a fault zone.

Fault zones are normally avoided along tunnel alignments. However, if they cannot be avoided, the fault zone has to be extensively treated with concrete grout and a strong lining has to be provided.

Problems are severe if the tunnel alignment coincides with the strike of the fault. If the tunnel is located in the foot wall of a fault, the roof portion of the tunnel becomes instability and needs reinforcement. In case of Hanging wall, less effect can be observed.

(C) Tunnels in Folded Strata: Folded rocks are always under considerable strain. When excavation for tunnels are made in folded rocks, such rocks get the opportunity to release the strain (stored energy). Such energy cause the rock falls or bulging. In folded regions, the tunnel alignment may be advisable to have the tunnel located on the limbs than at the core if possible.

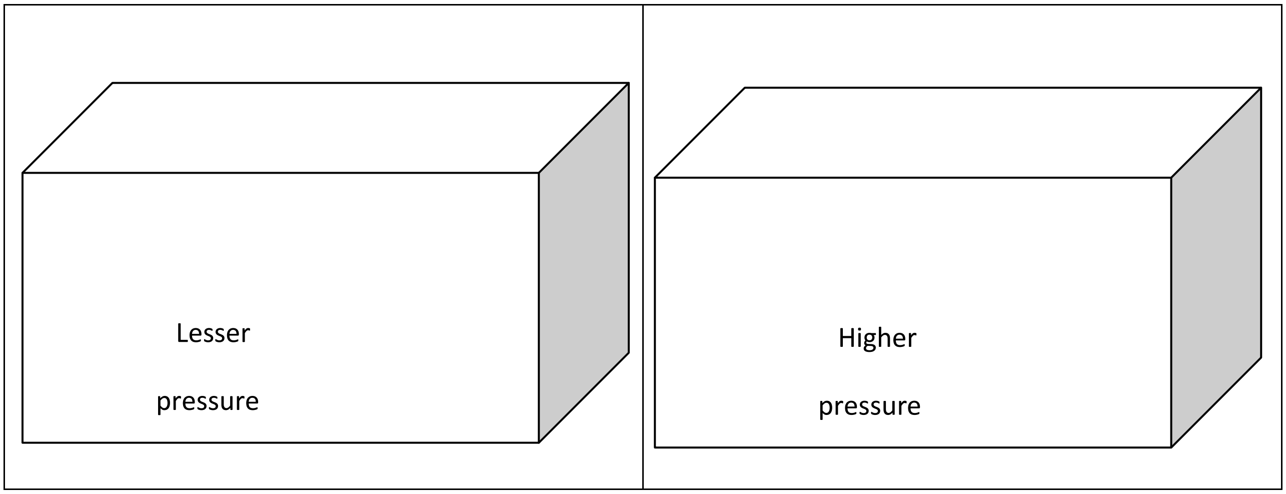
Tunnel alignment parallel to the axis of a fold: This is desirable when tunneling along limbs is considered. Rock masses may be in a highly fractured condition along crests, hence there may be frequent fall of rocks from the roof. Tunnels along troughs encounter harder formations and difficult to excavate. If bedding planes are inclined, groundwater percolates and these aquifers are punctured during the process of tunneling.

Tunnel alignment perpendicular to the axis of a fold: This is undesirable because different rock formations are encountered along the length of the tunnel due to heterogeneity in physical properties of rock.

In anticlinal fold, the central region will be under lesser pressure when compared to synclinal fold where the central region will be under higher pressure in addition to the occurrence of ground water.

However, anticlinal fold is to be considered for tunneling with proper precautions.

TUNNELS PERPENDICULAR TO THE AXIS OF FOLD



(2) GROUNDWATER CONDITIONS: Ground water problem in the tunneling is the most serious one. If ground water encountered in case of tunneling, the entire water is to be pumped out to keep the working area dry and adds the expenditure on tunneling project.

If the water table lies below the level of the tunnel, no severe ground water problem can be anticipated. But if the tunnel lies below the position of the water table , then the ground water problem is inevitable. .

TUNNEL SUPPORTS : Supports are used for keeping the tunnel walls and the roof in safety condition. Several support alternatives are available for use in tunnels. Following are the types of supports:

Shotcrete : Shotcrete is mortar or concrete pneumatically sprayed at high velocity through a hose. The process can be a dry process (Guniting) or a wet process.

Rock Bolts: These are steel bolts designed for holding weak formations together. The bolts are driven into the formations without causing any disturbance. These are used in tunneling for anchoring the tunnel walls to sold rock.

Wire mesh; Concrete lining; Pre-stressed anchor cables; Steel ribs etc. are also used wherever is necessary.

Some of these types are used in combination also.

OVERBREAK: Excavations through hard rocks involves the removal of some of the rocks outside the proposed perimeter of the tunnel.

The quantity of rock removed, in excess of what is required by the perimeter of the proposed tunnel, is known as the over break.

The geological factors which govern the amount of over break are:

The nature of the rocks

The orientation and spacing of joints or weak zones

The orientation of the bedding planes in case sedimentary rocks.

In general, tunnels which pass through a single homogeneous formation without structural defects produce little over break, whereas tunnels which pass through a variety of rocks with structural defects (like fault zones) have more over break.

The factor of over break is important because it adds to the cost of tunneling, particularly if lining is required. Hence, it is desirable that over break should be as minimum as possible.