The water located beneath the earth's surface in soil pore spaces and in the fractures of rock formations is known as Ground Water.

Sources of Ground Water:

- The main source of ground water is the rainwater, snowmelt water and surface water that seep into the ground.
- Below the surface, ground water occurs within the loose soil and porous or fractured rocks.
- The saturated zone is a great natural subterranean reservoir of fresh water that absorbs and stores precipitation (rainfall) during the rainy season and releases it when required during dry periods.
- Sometimes ground water comes out in the form of natural springs and seepages.
- Ordinary open wells, bore wells and artesian wells are some of the common ways of exploiting ground water.
- In solving the water supply problem in the interior lands, one should relay on ground water and surface water only.
- Upon the surface, perennial rivers and lakes of considerable size and depth constitute important and dependable sources of water supply. While small lakes and rivers do not maintain an appreciable flow of water through out the year and hence indispensable. Storing water by constructing reservoirs, impoundments or dams is the only way in conserving this water in improving ground sources.
- It is the basic fact to remember that all natural sources of water supply upon or below the surface of the earth are, in turn, fed by and entirely dependent on rainfall or melting of ice. This means that humid countries having good rainfall, natural sources of water supply would be plentiful and in arid places, where the rainfall is scanty, the water supply would be inadequate.

Importance of Ground Water to a Civil Engineer:

The study of ground water is relevant from the civil engineering point of view from different angles as follows:

- Ground water contributes to the decomposition of rocks, making them incompetent and unsuitable for construction purpose.
- Formation of solution cavities or channels inside calcareous rocks, weathering, decomposition and corrosion of rocks are accelerated by the action of ground water.
- Groundwater conditions prevailed in some regions may seriously jeopardize the stability of structures like, reservoirs, tunnels and dams.

Advantages of using Ground Water:

1. Ground water is the only source of water supply in the regions where rivers, streams, ponds and lakes are not available.
2. Ground water is also good water supply source in the regions where the surface water supply is not constant. i.e surface waters flow in only seasons (during monsoons) and their flow would be dwindle during summers. Further during droughts when the surface water dries, naturally ground water will be the only source.
3. When compared to the stupendous task, in utilizing surface water by constructing dams or reservoirs or impoundments, it is easy and suitable well in digging a tube well or bore well completing the task easily and cheaply.
4. Exploiting ground water is also very useful in minimizing the national income. The amount spent on rehabilitation issues, land acquisition, huge constructions etc. all will be nullified by utilizing the ground water through tube wells.
5. While considering the leakage problems of reservoir constructions or impoundments also ground water utilization through tube wells is much economical than the surface water utilization.
6. In terms of water loss due to evaporation, the ground water is much benefitable than the surface water as they occupy large areas resulting in the huge evaporation losses.
7. In terms of contamination problems, the ground water is literally pure compared to all surface waters. (it should be noted that ground water contamination is possible due to anthropogenic activities, yet when compared to surface waters it will be nil naturally.)
8. The entire surface waters when stagnated or impounded, there will be serious problem of siltation. Which is not seen in the case of ground waters. Even after many years if siltation problem rises, it is easy to tackle or cleanup.
9. The fear of huge losses that occur when dams are constructed like RIS, land slides etc. and the damage that occur when a dam collapses due to natural calamities, cannot be seen in the case of ground water.
10. Above all, the distribution and occurrence of ground water is more at a particular place of the world. Its really a reliable resource, yet one must not folly in over exploiting this resource.

Factors influencing the source of ground water:

The main source of the ground water “rainfall” is relatively distributed into runoff, fly-off and delayed runoff is often influenced by

Topography: If the surface has a steep slope, most of the rainfall quickly flows as streams, i.e. runoff will be very high and only very little water undergoes either evaporation or percolation. On the other hand, if rainfall occurs in depressed areas the reverse will be true, i.e., runoff will be negligible, while the other two processes will occur to a greater extent.

Climate: In the humid regions, there shall be less evaporation, whereas percolation and/or runoff will be considerable. But in hot and dry (arid) areas, if rainfall occurs, evaporation will be considerable and the others will be less.

Lithology: Depending on the mode of formation, cementation, compaction, etc., different rock types have different degrees of porosity and permeability characters. Highly porous and permeable formations like some sandstones, conglomerates and unconsolidated sediments will allow rapid percolation and the other two fraction will be less. If the rainfall occurs over rocks that are neither porous nor permeable, all water both flows as runoff and undergoes evaporation.

Geological Structures: If the rocks are inherently porous and permeable or not, if they have suitably interconnected fractures, cracks, joints, crushed zones or solution cavities, rain water can easily percolate through them and contribute to ground water. Their absence naturally results in less percolation that means the other two i.e., fly-off and runoff will be more.

Porosity: Porosity is the mount of openings or empty spaces present in the rock. Technically it is defined as the "ratio of the volume of voids (i.e., openings) in a rock mass to the total volume of the rock expressed in percentage".

Porosity can be of primary or secondary. Primary porosity is that which is present in the rock right from its formation. Secondary porosity is that which is present in the rock after the concerned rock is formed.

Occurrence of primary porosity: In igneous rocks, it is due to the vesicular structures, if present. To be use for ground water these should be interconnected. The interconnections or ground water intrusion may be due to the factures that occur in the igneous rocks. If the openings or fractures are quiet enough for the water saturation, its called effective porosity. If not non-effective porosity.

In sedimentary rocks, the porosity is the inter-granular space. It depends on the size shape, arrangement of sediments, degree of compaction and cementation of sediments.

In metamorphic rocks, foliation and lineation are responsible for little primary porosity that occurs in slates, phyllites and schists etc.

Occurrence of secondary porosity: Secondary porosity in rocks is mainly due to the joints, faults, shear zones, irregular cracks etc. In calcareous rocks, solution cavities and channels also may develop, contributing to additional secondary porosity. In the hard rocks the secondary porosity is due to weathering. The natural weathering process decomposes and disintegrates all rocks exposed on the surface and produces soil, which is highly porous.

Factors influencing porosity:

- Porosity decreases with depth as the pressure exerted by overburden. The overburden also decrease the number of joints, cracks etc. The overburden also influence the weathering, as the depth increases the inner layers are protected by compacted or cemented upper layers on which the weathering impact will be less.
- The porosity of rocks and unconsolidated material may also vary considerably. It may be less than 1% or more than 50%. A porosity ore than 20% is considered as large and porosity less than 5% is considered as small, medium porosity is between 5 and 20%. The average porosity values for some common geological formations are as follows; granite, quartzite = 1.5%; slate, shale = 4%; limestone = 5% to 10%; sandstones = 10 to 15%; sand with gravel = 20 to 30%; only gravel = 25%; only sand = 35%; clay = 45%.

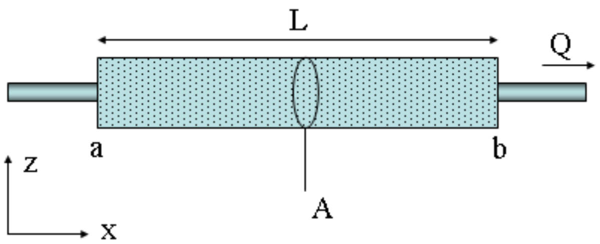
Permeability:

It is the ability of the rock to transmit water through it. It is due to the interconnected voids (i.e. porosity) present in the rock. In other words porosity is the main cause of permeability yet some exceptions are there like, shales are highly porous but less permeable because of their narrow inter-granular space. Similarly, some vesicular basalts that are too porous are little permeable because of the vesicles in them are not interconnected.

Permeability rate: As the ground water has to move through minute pores or narrow factures, its flow will naturally be slow. The flow rates of ground water vary form a few centimeters per year in rocks of low permeability to several centimeters per second in the large passages of some caves. The dracy's law defines the permeability rate. In simple terms the flow of water through a porous medium is proportional to the factor known as hydraulic conductivity or coefficient of permeability, k, which is the characteristic of the porous medium. And expressed as $Q=kiA$, where Q is the volume of water flowing per unit time through a cross-sectional area A under a hydraulic gradient i. when i and A are the same, the k is defined as the coefficient of permeability. The volume of the flow of water is dependent on k. As $Q/A = V$ &When $i=1$, $V=k$ which is known as unit hydraulic gradient.

Dracy's Law (explained):

Darcy's law is a phenomenological derived constitutive equation that describes the flow of a fluid through a porous medium. The law was formulated by Henry Darcy based on the results of experiments on the flow of water through beds of sand. It also forms the scientific basis of fluid permeability used in the earth sciences, particularly in hydrogeology.



Darcy's law is a simple proportional relationship between the instantaneous discharge rate through a porous medium, the viscosity of the fluid and the pressure drop over a given distance.

$$Q = \frac{-kA}{\mu}\frac{P_b - P_a}{L}$$

The total discharge, Q (units of volume per time, e.g., m^3/s) is equal to the product of the intrinsic permeability of the medium, k (m^2), the cross-sectional area to flow, A (units of area, e.g., m^2), and the pressure drop (P_b - P_a), all divided by the viscosity, μ (Pa·s) and the length over which the pressure drop is taking place (m). The negative sign is needed because fluid flows from high pressure to low pressure. If the change in pressure is negative (where $P_a > P_b$), then the flow will be in the positive 'x' direction. Dividing both sides of the equation by the area and using more general notation leads

$$Q = \frac{-k}{\mu}\nabla P$$

where q is the flux (discharge per unit area, with units of length per time, m/s) and ∇P is the pressure gradient vector (Pa/m). This value of flux, often referred to as the Darcy flux, is not the velocity, which the fluid traveling through the pores is experiencing. The fluid velocity (v) is related to the Darcy flux (q) by the porosity (n). The flux is divided by porosity to account for the fact that only a fraction of the total formation volume is available for flow. The fluid velocity would be the velocity a conservative tracer would experience if carried by the fluid through the formation.

Factors influencing the permeability rate:

- The movement of ground water depends on the prevailing effects of gravity, velocity and pressure of the water.
- Size and shape of constituent grains: A uniformly coarse-grained gravel is highly permeable, but when the same material consists of fractions of different sizes, there is a tendency for the smaller sediments to fill up the interstices, rendering the rock less porous and permeable. Rounded sediments will be highly permeable than the angular sediments.
- Sorting of grains: Well-sorted materials are highly permeable than ill-sorted or unsorted grains in the rocks.

- Continuity and nature of interstices: These are particularly relevant in the case of secondary porosity. Mere presence of cracks or cavities or joints does not make a rock permeable. The permeability will increase or becomes more when all the openings are interconnected.

Transmissibility: Literally it is permeability. Technically it is measured with coefficient of transmissibility (T). And expressed in terms of specific yield and specific retention.

Coefficient of Transmissibility: It is the rate of flow of water through a vertical strip of permeable layer of unit width and depth (d) under a unit hydraulic gradient. The relation; between T and k is: T=kd.

Specific yield: Ground water yield is the volume of ground water extracted by gravity drainage from a permeable layer. When this is expressed a ratio of the volume of total material drained, it is known as specific yield.

$$specific\ yield = \frac{volume\ of\ water\ obtained\ by\ gravity\ drinage}{total\ volume\ of\ the\ material\ drained}$$

Specific retention: The quantity of water retained by the material against the pull of gravity is termed as specific retention. This is expressed as percentage of total volume of material drained, i.e.,

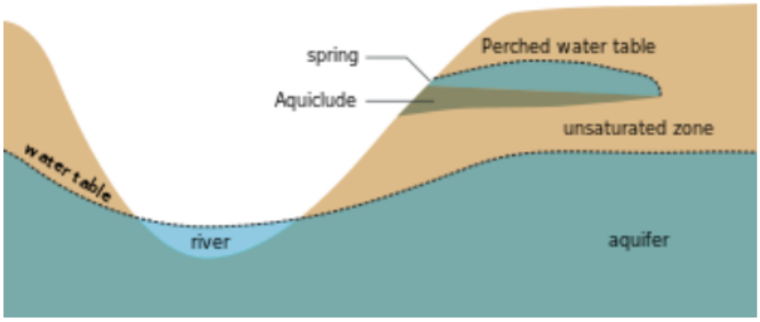
$$specific\ retention = \frac{volume\ of\ the\ water\ held\ against\ gravity\ drinage}{total\ volume\ of\ the\ material\ drained} x100$$

Generally, Porosity of the rock = specific yield + specific retention

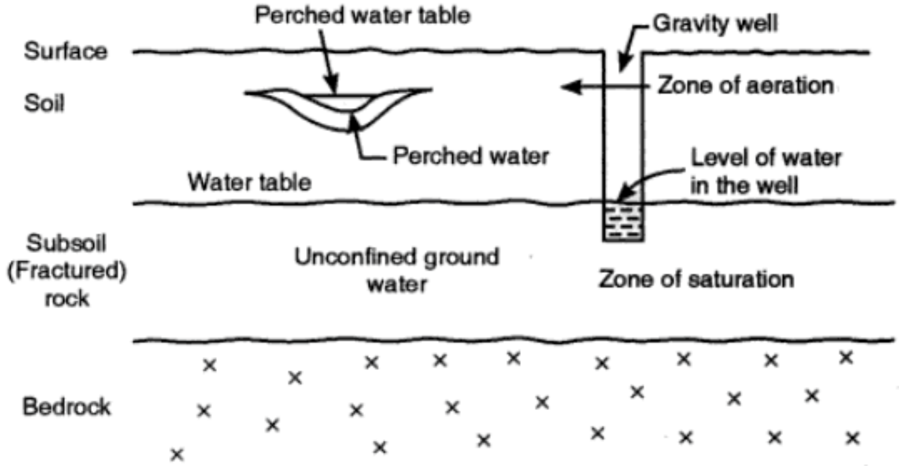
Rocks based on porosity and permeability:
Aquifers: All the rocks that is porous and permeable. These are suitable for groundwater occurrence and exploitation. Ex. Sandstones.
Aquifuges: These are the rocks neither porous nor permeable. These are not suitable for ground water occurrences. Ex. Granites and quartzite.
Aquicludes: These are the rocks that are porous but not permeable. Such rocks may bear water but do not yield the same as they are impermeable. Ex. Shale and clay.
Aquitards: These are the aquifuges and aquicludes that have sufficient interconnected fractures.

Water Table:

The upper layers of the crust will be loose i.e. soil due to the effect of the weathering. As the depth increases, weathering impact decreases and the fractured zone of rocks exist below the soil zone. Further, below will be the bedrock which is free form fractures. Thus, an area that contains vertical section of area consisting of top loose, permeable soil, below fractured layer and bottom compact bedrock will hold water.



When rainfall occurs in any area, an appreciable percentage of water moves downwards through fractures, under the influence of gravity until it reaches the bedrock. Then, all openings lying above the bedrock will begin to be filled up by percolated water. Thus, the percolation of rainwater leads to the development of a zone of saturation above the bedrock, in which all openings are filled with water. Such water is ground water, in true sense. The upper surface of this zone of saturation is called "water table" as shown below.



Above the zone of saturation and below the ground surface is the zone of aeration, in which water fills only a portion of the pore space.

Ground water types that occur in the zone of aeration:

- Soil water: The water that occurs in the soil and is available to the roots of plants or vegetation existing on the surface.
- Pellicular water: The water which sticks to the sides of fractures or the surface of openings in rocks, while percolating, will not move down under the influence of gravity. Such water is called pellicular water.
- Vadose water: This is also called gravity water. It is actually that fraction of rainfall which percolates downwards under the influence of gravity and reaches the water table and joins the zone of saturation.
- Perched water: The water that occurs above a suitable aquiclude or aquifuge with in the zone of aeration is called perched water.
- Capillary water: The water that exist within very fine openings, just above, and in contact with, the water table is called capillary water.

Ground water types that occur in the zone of saturation are:

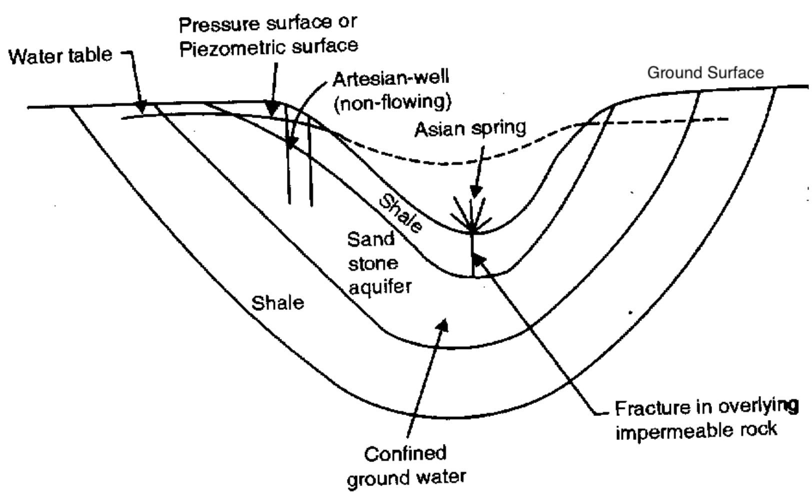
- Unconfined or free ground water: The water that lies below the water table and under atmospheric pressure only is called unconfined ground water. This water can move freely upwards or downwards with in the aquifer.
- Confined water: The water occurs below the water table and is confined between aquicludes or aquifuges. Unlike free water, this type of ground water occurs under some hydrostatic pressure.
- Fixed ground water: The water that exists within extremely small openings in aquicludes and cannot move under gravity.
- Connate water: The water, which is held within the rocks right from the beginning of their formation, is called connate water.
- Internal water: The underground water that occurs at very great depths within the zone of disconnected openings is known as internal water.
- Juvenile water: The water from the magmatic source is called juvenile water.

Types of Aquifers:

Unconfined Aquifers: The aquifers which do not have any impermeable beds above them and the water table is under atmospheric pressure only are called unconfined aquifers. According to recharging rate, the water table will fall or rise uniformly throughout the rock. Wells dug in such an aquifer will have the water level equal to the level of the water table. Such wells are called as gravity wells or unconfined wells.

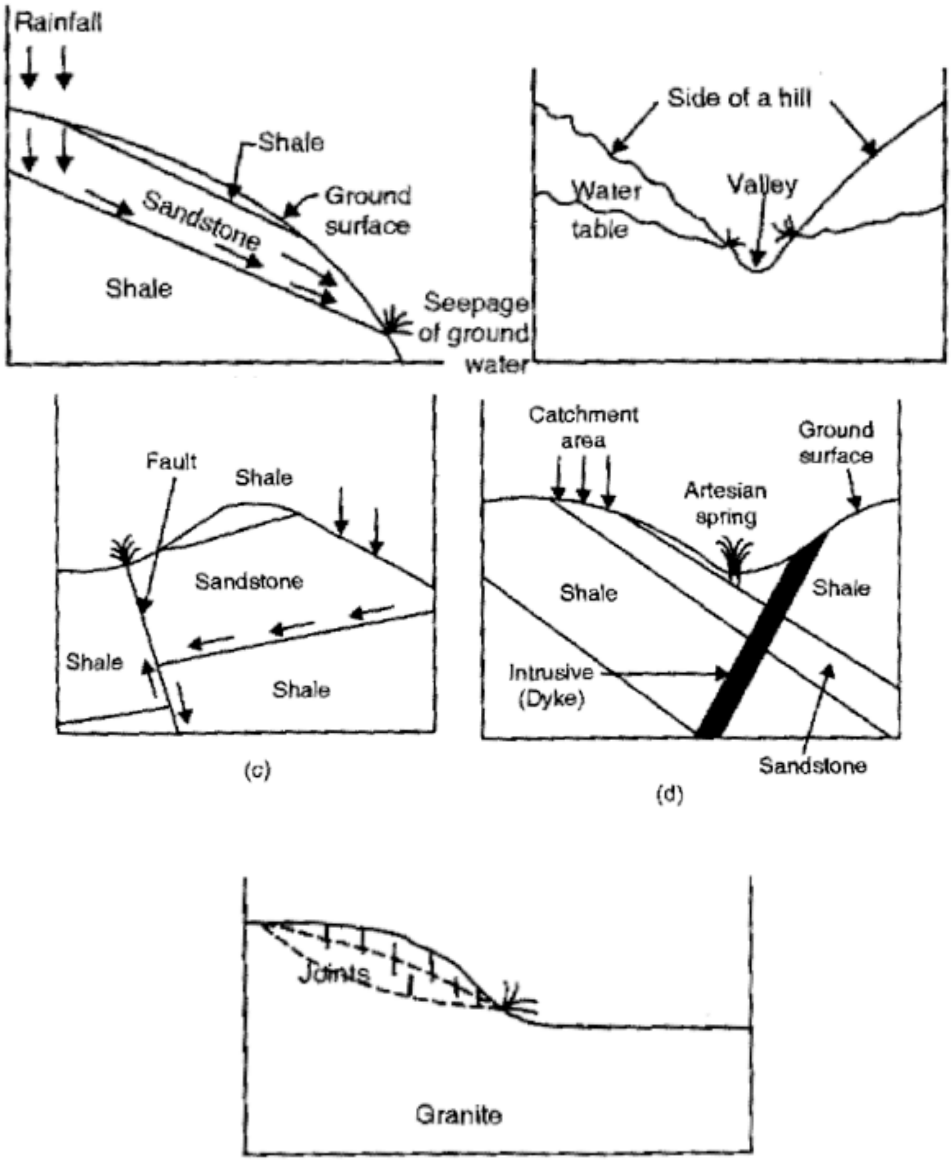
Confined Aquifers: These are also called as artesian aquifers. The requirements and the conditions prevailing in the case of confined aquifers are as follows:

1. An aquifer should be sandwiched between two impermeable formation.
2. Such an aquifer should have suitable structural conditions so that the confined water occurs in it under some hydrostatic pressure.



3. The aquifer should outcrop on the surface at a higher level to serve as a catchment area and facilitate percolation of rainwater through it.

4. In the preceding set-up, if the overlying impermeable formation is punctured, depending on the surface height at that point and the level of the pressure surface* existing there, the water may gush out under pressure in the form of a spring or may rise to some height below the ground level. Such wells are called artesian springs or wells.



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Geological Controls on Ground water movement:

In the zone of aeration the ground water movement occurs due to the influence of gravity. But in the zone of saturation, various factors will influence the ground water movement.

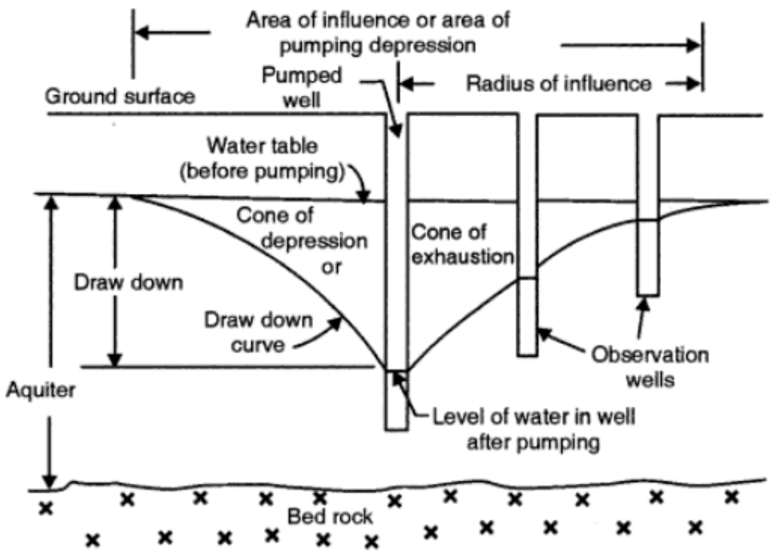
1. Permeability of the rocks is most influential factor in the zone of saturation.
2. Secondary porosity is the other most influential factor that controls the ground water movement in the zone of saturation.

3. Well-developed joints will influence the ground water movement in the zone of saturation. If joints are present they facilitate the ground water movement along the alignments lot. Among the joints sheet joints will influence a lot.
4. The presence of faults will also influence the ground water movement along them. This is the important factor that should be checked in the alignment of springs.
5. The other factors that influence the ground water movement in the zone of saturation is attitude of bedding. If the beds are inclined or folded, the percolated water moves along the bedding planes only. This is the way that the artesian conditions occur.
6. The buried river channels and unconformities also influence the ground water movement, as they are more porous and permeable.
7. The occurrence of perched water bodies due the prevention of movement of vadose water by local impermeable formations also influences the occurrence of ground water in the zone of saturation.
8. The vertical or steep inclined dykes or veins that occur in impermeable layers will also help in ground water movement on one side.
9. Finally hydraulic gradient is the influence ground water in the zone of saturation.

FLUCTUATION OF THE WATER TABLE LEVEL IN UNCONFINED AQUIFERS:

Water level in unconfined aquifers is governed by seasonal factor and cone of depression. Seasonal fluctuation: During rainy seasons the water flow will be more which allows more water to percolate allowing increase of water table level. During dry seasons the water table level decreased due to decrease of percolation.

Cone of depression: In the gravity well, the static level of water coincides with the water table level of the surrounding aquifer. When water is pumped out in considerable measure from such a well, the level of water in ti goes down, leading to the depression in the water table around the well in the form of an inverted cone. This phenomenon is called cone of depression or cone of exhaustion.

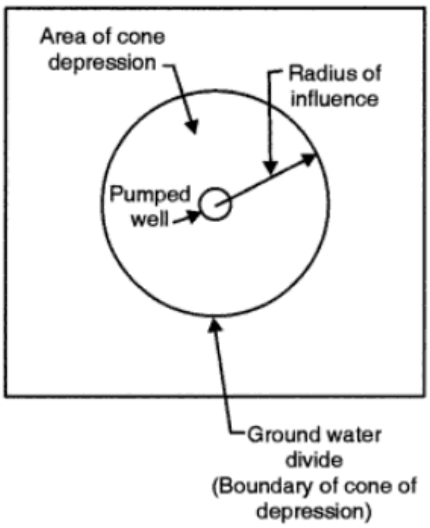


The phenomenon of cone of depression or exhaustion is a temporary fluctuation in the level of water table. This is because the original position is restored within a short period due the seepage of ground water from the sides of the well.

The shape of this cone of depression on the water table around the pumped well depends on the permeability nature of the aquifer body. In case of highly permeable materials like gravels, the cone of depression is nearly flat, while in less permeable aquifers, it is very steep.

Some technical terms:

- Ground water divide: The boundary of the cone of depression is known as groundwater divide.
- Area of pumping depression or area of cone depression: The areas enclosed by the groundwater divide.
- Radius of influence: The distance between the well and the ground water divide is known as radius of influence.



- Drawdown: the difference between the original level of water in the well and the level after pumping is called drawdown.

Ground water exploration:

1. Geological investigations: These investigations are the most important among all the ground water explorations, since the other two will give more supplementary information. These investigations comprises of study of given area from different angles as followed to predict the ground water occurrence.
   a. Study of rocks: This study include the rock types, structure and factors like rock thickness, attitude (i.e., strike and dip), porosity and permeability characters.
   b. Study of topography: The study of topography will give good information in determining the occurrence of ground water level. At normal conditions ground water occur parallel to the surface, so occurrence of high lands (hills)

or low lands (valleys) will be very useful, as the depth of actual occurrence of the water table will be relatively less than in hilly regions.

c. Study of weathering: In hard rock areas, surface occurrence of insitu rocks as bare boulders without soil and subsoil zones is not suitable for tapping ground water because they not only lack weathered zones but also joints and fractures which may occur on the surface shall become less prominent zones and disappear at a depth.
d. Study of geological structures: The geological structures like trend or attitude of joints, cracks, faults, shear zones, folds, etc., will contribute to the secondary porosity, so their study will help in predicting the ground water occurrence. During structural exploration, synclinal folding accompanying suitable lithological leads to artesian conditions which are very much sought as thy generally yield a copious supply of water.
e. Study of intrusive rocks: The study of geological structures like trend, dykes, veins, will help in study of flow of ground water movement as these structures act as barriers to the normal flow. This study will help in prediction of ground water well as, on occurrence of the geological structures will allow accumulation of water on only one side leading to plenty of water in one are and scarce water in the near by area.
f. Geological mapping: Having the idea of mapping will give high information while studying the geological maps showing the attitudes and geological structures of an area. This information will be very useful in prediction of ground water occurrences.

2. Geophysical investigations: Generally the geophysical investigations are incomplete, yet these will be very useful in making predictions of ground water by simple instruments. The incompleteness of geophysical investigations is due to
    a. The out crops of insitu rocks may be absent or few present that too scattered widely.
    b. The surface is covered with soil, sediments etc.
    c. The rapidly expanding agricultural fields.

   All the above said causes may hide the actual rock type ad geological structures lying beneath resulting in not accurate data for ground water prediction.
   Yet some of the geophysical investigations like “electrical resistive method” is mostly employed in remaining cases the “seismic refraction method” is employed. Some times gravity methods will give potential results in predicting the ground water occurrence and depth.

   Electrical resistivity method: This is the most popularly used method, which helps in determining the aquifer zone but also helpful in knowing fresh and saltwater contacts in the shore zones.
   The principle involved is that subsurface resistivity is influenced by the rock type, fracturing (porosity), moisture content and salinity of moisture. The subsurface

resistivity is studied by profiling and sounding. When current is passed between the two metallic electrodes kept at unit distance and if the potential difference is measured, the electric lines of force will be diverging away while equipotential lines will be converging at the resistive body.

Seismic investigation: This is the investigation based on the principle that the velocity of shock waves depends on the fracturing of the medium. Elastic property of the rocks is the controlling factor of seismic investigation.
Natural seismic waves produced due to the earth's instability under the subsurface layers are studied and the deflective patters are mapped to find the geological structures present underneath. For this geophones are used. When natural seismic waves are not enough for study purpose, artificial seismicity is created with explosions in the shallow holes and the resulting seismicity is used for exploration purpose.

Gravity methods: Study of gravitation differences on the surface will give potential outcomes. Gravimeter, which is a loaded spring commonly employed and used to measure relative gravity on the surface is very useful in determining the ground water occurrence. i.e. if the subsurface is heavier with the occurrence of any geological structure, the gravity pull is more i.e. +g and if the subsurface is lighter like water the gravity pull is less i.e. –g.

Geophysical investigations are most useful methods in locating dolerite dike, buried river valleys, etc. which have significant bearing on ground water movement.

3. Hydrological investigations: These are very simple and effective methods in assessing the ground water potential or occurrence in any region. The hydrological investigations can be done in the following ways:
    a. Study of water table: The study or observation of static water in the number of wells or bore wells in an area will give the valuable information about water table, its relative position, the nature of the slope, probable direction of flow of ground water etc. If more details is available and if the historic data of water table occurrences in particular are is available, it will be very useful in predicting the ground water occurrences.
    b. Study of surface water bodies: The knowledge of streams, rivers, ponds, lakes, reservoirs etc. in any region will be very useful in finding the recharging aquifers and thus the ground water occurrences.
    c. Study of springs and seepages: If any natural seepages or springs are available in any area, this indicates a high water table position and rich ground water conditions.
    d. Quality of water: Quality of water can also be the factor of study in knowing the water table properties. This is very useful to know if even the ground water occurrence is there, is it potable or not. As water drawn from granites tastes good normally, but that of from dolerite is brackish. The ground water

occurrences along with rock type like pegmatite will be of high mineral content posing serious health hazards like fluorosis.

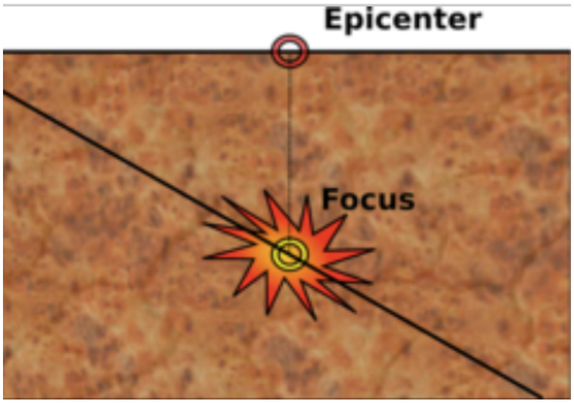
e. Study of climate: The micro climatic conditions of the particular area and rainfall pattern will also be very useful in predicting the ground water potential and depth. Ex. Anantapur district of Andhra Pradesh has a low ground water potential.

Earthquakes:

An earthquake is a sudden vibration or jerk or jolt or tremble or shiver of the earth surface. It can also be described as sudden shaking phenomenon of the earth's surface for some reason. Most of the earthquakes are insignificant but some are catastrophic. As per physical geology, an earthquake is a natural force that originates below the earth surface, works randomly and creates irregularities on the earth surface. The study of earthquakes is called seismology. And the instruments called seismographs used to record the intensity of the earthquakes. The records of intensities are called seismograms.

Certain Terminology:

- Origin: The place of occurrence of the earthquake in the interior of the earth. It is also called focus or center or hypocenter.
- Epicenter: The area on the earth's surface that lies above exactly on the center or origin of earthquake.



In the case of earthquakes, the epicenter is directly above the point where the fault begins to rupture, and in most cases, it is the area of greatest damage. However, in larger events, the length of the fault rupture is much longer, and damage can be spread across the rupture zone. For example, in the magnitude 7.9, 2002 Denali earthquake in Alaska, the epicenter was at the western end of the rupture, but the greatest damage occurred about 330 km away at the eastern end of the rupture zone.

- Anticenter: The point on earth's surface diametrically opposite to the epicenter is anticenter.
- Seismic vertical: The imaginary line that joins the center and epicenter is called seismic vertical. It represents the minimum distance that the earthquake has traveled to reach the surface.

- Isoseismal lines: The imaginary lines joining the points of same intensity of earthquake are called isoseismal lines. On the map or on plans these are shown as concentric circles.
- Coseismal lines: The imaginary lines which join the points where the earthquake has reached the surface are called coseismal lines. In the homogeneous grounds isoseismal and coseismal will coincide, yet in many cases due to the surface and subsurface irregularities, the coincidence may not occur.
- Seismic waves: The waves that originate and transmit in all the directions from the focus due to the enormous energy released at the time of earthquake are called seismic waves.

TYPES OF EARTHQUAKES:

Earthquakes are grouped on the basis of depth and cause.

Earthquakes based on depth are normally called as shallow, intermediate and deep.

SNO	DEPTH	NAME OF EARTHQUAKE
1	< 60 km	Shallow
2	> 60 km & < 300 km	Intermediate
3	> 300 km	Deep

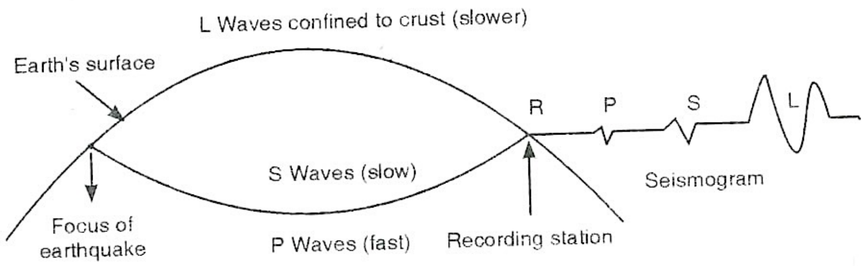
* Deep earthquakes are rarely observed.

Earthquakes based on cause are named as tectonic or non-tectonic.

- Tectonic earthquakes: These earthquakes are exclusively due to internal causes like, disturbances or adjustments occurring in geological formations or due to plate tectonic movements. These earthquakes are normally major earthquakes.
- Non-tectonic: These earthquakes are generally due to surface causes like impoundments or RIS (reservoir induced seismicity). They can be also due to volcanic activity. These earthquakes may range from minor to major. The cause for the non-tectonic earthquakes can be listed as,
  - When huge quantities of water pound to a particular place like huge waterfalls, tremors develop in the ground resulting in the mechanical disturbances that cause the earthquakes.
  - They can be due to avalanches. Avalanche is the movement of glacier mass due to gravity along the slope due to certain conditions like near by explosions or due to huge mass gatherings. While the mass rolling down, gains considerable momentum and when it hits the ground forcefully, minor tremors occur at the place of hit.
  - Due to meteorites: Meteors are the chunks of rocks or other heavenly masses that enter the atmosphere and burn. Every second or usually this type of events will be occurring. Some of the masses will be huge enough that even after burning will reach the earth surface with sufficient mass and the hit the ground causing tremors. Very huge masses called asteroid can create violent earthquakes.

- Due to landslides: Mostly in hilly regions the rock masses on the cliffs or cliffs themselves move along the slope due to gravitational pull. There will be considerable strain, which will be resisting the movement. But when a disturbance will be caused due to instability of earth crust or due to near by explosions or when the water seeps between the fractures resulting the sliding motions landslides occur. The occurrence of land slides causes tremors at the area where they hit the ground.
- Volcanic activity: Any active volcano will be creating disturbances in the surrounding crust layers, which is responsible for minor seismicity. But some times when they erupt violently causing huge earthquakes.
- Tsunamis: Tsunamis are giant earthquakes occurring in the sea or ocean. The impact of tsunami causing violent and huge waves cause earthquakes at the coast where they hit.
- Anthropogenic causes: Man made causes like explosions, under ground explosion testing, nuclear testing, blasting for mining or other activities are normally result in minor to major tremors.
- RIS: Reservoir induced seismicity, it is strange phenomenon seen in the recent years. The huge water stored in the dams or reservoirs is causing enough pressure on the surface of the earth causing tremors in the down stream areas resulting in minor to major earthquakes.

Seismology:
The study of seismicity or earthquake waves or intensity is called seismology.
The vibrations that occur during earthquake traveling in all directions can be classified as P Waves, S Waves and L Waves.
P Waves: These waves are called primary waves or push-pull waves or preliminary waves or longitudinal waves or compressional waves. These are the fastest seismic waves that travel as fast as 8 km to 13 km per second. As these are the first vibrations that occur these are the waves that are recorded first. The P waves resemble sound waves hence they will travel like compressional and longitudinal waves. They can travel in any medium (solid, liquid or gas).



S Waves: These waves are called shear waves, secondary waves, transverse waves etc. These waves travel at a rate of 5 to 7 km per second. These waves are recorded after P waves. These waves travel perpendicular to the direction of propagation hence, transverse particle motion characteristic waves are observed. These waves travel only through solids.

These waves sometime show polarization phenomenon. If the particle motion is parallel to prominent planes in the medium they are called SH waves. On the other hand, if the particles motion is vertical, they are called SV waves.

L Waves: These are called surface waves. These are the slowest among all the seismic waves, so these are the last to record in the seismographs. They travel at the rate of 4 or 5 km per second. These waves show characteristic complex and elliptical motion. These waves travel in solids and liquids. The destruction on the surface is by these waves only. These waves travel only in surface they won't travel towards focus.

Intensity of earthquakes:
The intensity of the earthquake is the degree of destruction caused by it. In other words it is the measure of severity of the shaking of ground and damage it causes. Yet the intensity depends on various factors like:

- Distance from the epicenter: The destruction decrease with the increase of distance from the epicenter.
- Compactness of underlying ground: If the underlying ground is loose, the destruction is less as the loose ground will absorb the shock waves dissipating the energy travelling in concerned direction. On the other hand if the ground compact and hard the destruction is huge.
- Type of construction: If all the factors are proportionate, the destruction of the construction is more if not properly reinforced.
- Magnitude: Greater magnitude the greater will be destruction.
- Duration: The duration of the earthquake also plays an important role in the destruction caused by earthquake. Even if the magnitude is small, if it lasts for more time like 30 sec or more the destruction will be more.
- Depth of focus: The extent of destruction will be more with the increase of depth of focus. The destruction will be local or less if the focus is very shallow.

Measurement of Earthquake (intensity/magnitude):
The magnitude is defined as the rating of an earthquake based on the total amount of energy released when the earthquake occurs. The energy released (E) will be in the form of seismic waves through the subsurface geological formations. In doing so, part of energy is absorbed by the medium and only a part of it is recorded during recording. So by considering this fact the Energy released during earthquake is given by linking ground acceleration (a) using equation:

$$\mathrm{Log}_{10}E=4.4 + 2.1M - 0.0054M^2$$

Generally equation $\log10E=4.4+1.5Ms$ is used for earthquake less than 5.0 magnitude and $\log10E=5.24+1.44Ms$ for earthquake greater than 5.0 magnitude. Where, E=Energy of the earthquake in Joules and Ms=surface wave magnitude
In the above equation E is obtained for the formula

$$\sqrt{E} = C(\frac{a}{h})(D^2 + h^2)$$

Where E = the total amount of energy released, in erg.

a = the ground acceleration.

h = depth of focus in km.

D = distance of the recording station from the epicenter, in km.

C = a constant, equal to 0.625.

Earthquake intensity or magnitude is measured on Richter scale or Mercalli scale (modified Richter scale).

The Richter scale is the most familiar scale as it is mostly reported in newspapers. The Richter magnitude scale (often shortened to Richter scale) was developed to assign a single number to quantify the energy released during an earthquake. Charles Richter of California Institute of Technology proposed this scale. A massive earthquake can give surface wave readings 10,000 to 100,000 times larger than a just perceptible earthquake and so Richter numbered his scale in steps logarithmically with each step representing an earthquake record 10 times larger than the previous step.

The scale is a base-10 logarithmic scale. The magnitude is defined as the logarithm of the ratio of the amplitude of waves measured by a seismograph to arbitrary small amplitude. An earthquake that measures 5.0 on the Richter scale has a shaking amplitude 10 times larger than one that measures 4.0, and corresponds to a 31.6 times larger release of energy.

The Richter scale can be listed as followed in comparison with Mercalli scale:

Richter Magnitude	**Description**	**Mercalli intensity**	**Average earthquake effects**	**Average frequency of occurrence (estimated)**
Less than 2.0	Micro	I	Micro-earthquakes, not felt, or felt rarely by sensitive people. Recorded by seismographs.	Continual/several million per year
2.0–2.9	Minor	I to II	Felt slightly by some people. No damage to buildings.	Over one million per year
3.0–3.9		II to IV	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.	Over 100,000 per year
4.0–4.9	Light	IV to VI	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely. Some objects may fall off shelves or be knocked over.	10,000 to 15,000 per year
5.0–5.9	Moderate	VI to VIII	Can cause damage of varying severity to poorly constructed	1,000 to 1,500 per

			buildings. At most, none to slight damage to all other buildings. Felt by everyone. Casualties range from none to a few.	year
6.0–6.9	Strong	VII to X	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometers from the epicenter. Strong to violent shaking in epicentral area. Death toll ranges from none to 25,000.	100 to 150 per year
7.0–7.9	Major	VIII or greater	Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicenter. Death toll ranges from none to 250,000.	10 to 20 per year
8.0–8.9	Great		Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions. Death toll ranges from 1,000 to 1 million.	One per year
9.0 and greater			Near or at total destruction - severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography. Death toll usually over 50,000.	One per 10 to 50 years

The Mercalli intensity scale is a seismic scale used for measuring the intensity of an earthquake. It measures the effects of an earthquake, and is distinct from the moment magnitude M_ω usually reported for an earthquake (sometimes misreported as the Richter magnitude), which is a measure of the energy released. The intensity of an earthquake is not totally determined by its magnitude.

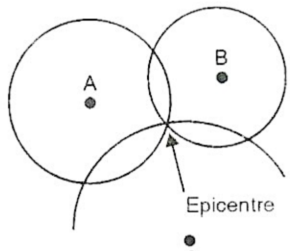
The scale quantifies the effects of an earthquake on the Earth's surface, humans, objects of nature, and man-made structures on a scale from I (not felt) to XII (total destruction). Values depend upon the distance to the earthquake, with the highest intensities being around the epicentral area. Data gathered from people who have experienced the quake are used to determine an intensity value for their location.

I. Instrumental	Generally not felt by people unless in favorable conditions.
II. Weak	Felt only by a couple people that are sensitive, especially on the upper floors of buildings. Delicately suspended objects (including chandeliers) may swing slightly.
III. Slight	Felt quite noticeably by people indoors, especially on the upper floors of buildings. Many do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration similar to the passing of a truck. Duration can be estimated. Indoor objects (including chandeliers) may shake.
IV. Moderate	Felt indoors by many to all people, and outdoors by few people. Some awakened. Dishes, windows, and doors disturbed, and walls make cracking sounds. Chandeliers and indoor objects shake noticeably. The sensation is more like a heavy truck striking building. Standing automobiles rock noticeably. Dishes and windows rattle alarmingly. Damage none.
V. Rather Strong	Felt inside by most or all, and outside. Dishes and windows may break and bells will ring. Vibrations are more like a large train passing close to a house. Possible slight damage to buildings. Liquids may spill out of glasses or open containers. None to a few people are frightened and run outdoors.
VI. Strong	Felt by everyone, outside or inside; many frightened and run outdoors, walk unsteadily. Windows, dishes, glassware broken; books fall off shelves; some heavy furniture moved or overturned; a few instances of fallen plaster. Damage slight to moderate to poorly designed buildings, all others receive none to slight damage.
VII. Very Strong	Difficult to stand. Furniture broken. Damage light in building of good design and construction; slight to moderate in ordinarily built structures; considerable damage in poorly built or badly designed structures; some chimneys broken or heavily damaged. Noticed by people driving automobiles.
VIII. Destructive	Damage slight in structures of good design, considerable in normal buildings with a possible partial collapse. Damage great in poorly built structures. Brick buildings easily receive moderate to extremely heavy damage. Possible fall of chimneys, factory stacks, columns, monuments, walls, etc. Heavy furniture moved.
IX. Violent	General panic. Damage slight to moderate (possibly heavy) in well-designed structures. Well-designed structures thrown out of plumb. Damage moderate to great in substantial buildings, with a possible partial collapse. Some buildings may be shifted off foundations. Walls can fall down or collapse.
X. Intense	Many well-built structures destroyed, collapsed, or moderately to

	severely damaged. Most other structures destroyed, possibly shifted off foundation. Large landslides.
XI. Extreme	Few, if any structures remain standing. Numerous landslides, cracks and deformation of the ground.
XII. Catastrophic	Total destruction – everything is destroyed. Lines of sight and level distorted. Objects thrown into the air. The ground moves in waves or ripples. Large amounts of rock move position. Landscape altered, or leveled by several meters. Even the routes of rivers can be changed.

Identifying the Epicenter:

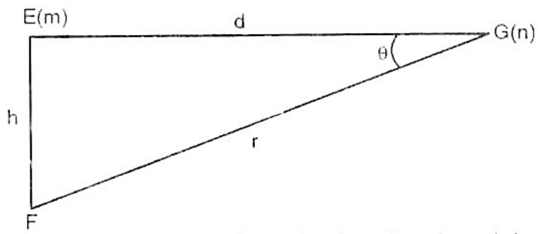
The epicenter is the point on the earth's surface vertically above the focus. So this point can be located easily by taking advantage of the time lag noticed between the P and S waves. When the earthquake waves are recorded at different places, there will be increase in time lag between the arrival of P and S waves as the distance from the epicenter increases. This factor fives the measure of the distance between the epicenter and the seismic place. Therefore if the recordings are made at different places with wider space, and circles are drawn (as shown in fig. as A, B, C) with the measure of distance for the focus as radius, the circles intersect at a common point which will be epicenter.



Epicentre location

Depth of the focus:

The depth of the focus can be estimated by comparing the intensities at the epicenter and at a distance place as shown in the fig. This estimation is suggested by Oldham.



Determination of depth of earthquake origin

Where E = epicenter.

G = a place at a distance d where the intensity is known.

m = intensity at the epicenter.

n = intensity at G.

h = depth of focus.

First, **θ** can be calculated by $\frac{n}{m} = \frac{h^2}{r^2} = sin^2\theta$, based on the θ value, h is known by h=d tan θ

Civil Engineering Considerations in Seismic Areas:
If the Civil Engineering constructions are made strong and earthquake proof, they can with stand the earthquakes in any seismic areas. For this suitable precautions should be taken keeping the economical aspects in mind. The difficulties in achieving this objective arise due to the fact that earthquakes are unpredictable and certain factors as followed will influence the constructions.

- Epicenter: The knowledge of probable epicenters in the active seismic zone is required as those are the regions, which will be affected most and need maximum protection.
- Magnitude: The unpredictable magnitudes also influence the civil engineering constructions as the magnitude increases, the destruction will be more. So much emphasis should be given to shock absorbers or other methods in the active zones to prevent damage to constructions.
- Duration: The duration of the earthquake also influences the damage caused to constructions. As the duration increases the damage caused to construction also increases. So this factor should also be considered while planning constructions in active zones.
- Ground movement: The Ground movement direction happening at the time of earthquake also influences the constructions. This could be cause for additional faults or geological deformities that may cause further damage.

Safety factor: In active zones, a structure is assumed to be subjected to lateral stresses during an earthquake, which would depend on the ground acceleration due to an expected shock, the weight of the structure and the nature of the structure. The horizontal force acting at the base of the structure during an earthquake is assumed to be same as acting on the ground beneath.
This force is called the base shear force, F is calculated by the formula $F = \frac{a}{g} w$,
where a is the acceleration due to the expected earthquake
g is the acceleration due to gravity and
W is the weight of the structure.
The ratio a/g is called seismic factor, which varies from 0.1g to 0.001g.
After knowing F, the overturning moment M of the structure is obtained by the formula M=FY, where Y is the vertical distance of the Centre of gravity of the structure above the horizontal section. Based on M, the safety factor is incorporated into the design.

For suitable constructions in active zones, IS Codes 1893-1970 guidelines are followed.

Precautionary measures to be taken for constructions in seismic zones:

- Building Constructions: The following precautionary measures are considered during building constructions in active zones.

- The buildings should be founded on hard bedrock only and never on loose soils or fractured rocks. This is so because loose ground settles due to earthquake vibrations. Further, the foundation should be of same depth throughout for continuity.
- The phenomenon of sliding is common in active zones, so if the foundation and the superstructure[1] are thoroughly tied up by incorporating keys or reinforcements, sliding can be prevented.
- The places like cuttings on hillsides, steep slopes, undulating ground or marshy ground etc. should be avoided for constructions as they are incompetent and suffer more damage during earthquake.
- In active zones, the large buildings should have raft[2] type foundations and normally square type foundations are more stable.
- Buildings should have light walls.
- Different parts of building should be well tied together so that the whole structure behaves like a single unit to the vibrations.
- Only rich cement mortar and reinforced concrete 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 like parapets, cantilevers, domes and arches are undesirable.
- Building with irregular shapes with wings, protruding verandas, porches, etc. should be avoided.
- Buildings should have flat RCC roofs; they should be designed not to yield to lateral stress.
- Slates, tiles and corrugated sheets are unsuitable as roofing material.
- Projections above the roof are undesirable.
- Resonance factor is most important that can influence during earthquake. If the vibration period of structure coincides with the vibration period of foundations rock, the entire structure will collapse. Hence it is very necessary to avoid resonance.

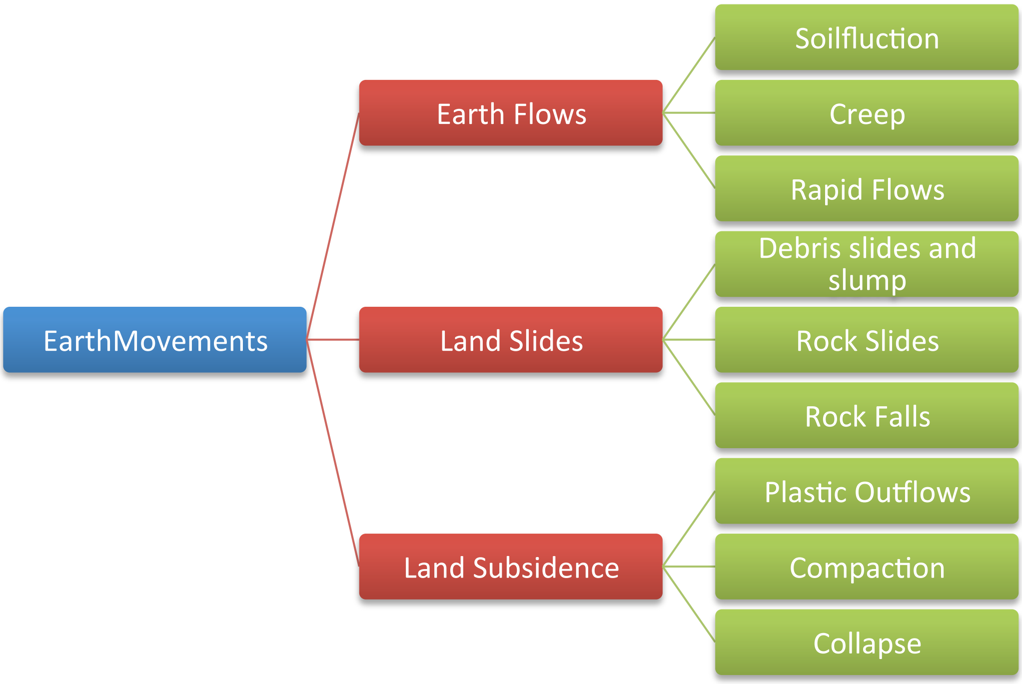
* Dam Construction: Dams being a costly construction, their construction in seismic zones is a very risky factor. Under unavoidable circumstances, various factors should be considered and studied in very detailed to ensure the safety of the dam. Following precautionary measures can assure dam safety in seismic zones:
  - Dams should be designed in such a way that during an earthquake they move along with the foundations below.
  - Dams should not be built along or across the faults because of possible slippage along these planes during earthquakes will introduce additional complications.
  - The resonance factor should be considered and much care should be taken.

1 - A **superstructure** is an upward extension of an existing structure above a baseline. 2 - A **raft** is any flat structure for support or transportation over water. It is the most basic of boat design, characterized by the absence of a hull.

- The other factors that influence the dam construction in an active zone are the forces that act after dam construction. These forces are the ones' created by the dam and the other created by the reservoir water.
  - Forces of the dam: These are the forces that are created due to the horizontal and vertical ground acceleration on the weight of the dam. The ***horizontal inertia force***, Ve, of the concrete dam to the horizontal acceleration. (This is given by the formula Ve=w.c where w is the concrete load and c is the seismic factor) This force acts in the direction opposite to the earthquake acceleration and develops an overturning effect so it must be counter balanced by introducing additional stress in the design of the dam, in all the directions in which overturning is most likely to happen.
  - Forces due to Reservoir water: When the dam is vertical on the upstream face, at the time of earthquake, the effect of water immediate to the wall will also be in the horizontal direction and will rise an additional force on the dam, which, when sufficiently strong, may lead to sliding or overturning of the dam. This is called ***hydrodynamic force***. (The hydrodynamic force is calculated by Pe = Ca.w.h, where Pe=pressure at depth y; C is the coefficient for the shape of the dam at various depths, a is the seismic factor, w is the unit weight of water and h is maximum depth of the reservoir). If the dam is sloping on the upstream face, then the water load will have a vertical effect in addition to the horizontal component. A change in the vertical component will also be caused during an earthquake, which is undesirable. So this factor is also considered in construction to overcome risk.
- The design of earth dam is the most incompetent design in active zones. This is because most of the earth dams fail during the earthquake due to the vibration effect or due to shearing forces or both. Due to the vibrations effect, the material of the dam or its foundation gets compacted due to the repeated vibrations. Further such compacted dams may slump or may be overtopped by the reservoir water. In the case of shear failure, it may slide along its base or it may be separated form its abutments. In all such cases it is very essential to provide a clay core within the structure, which makes the dam impermeable and stable.
- In the case of reservoirs the above factors may be considered according to the design of reservoir. Yet for the remaining factors they should be filled to a limited safety level and draining the water from the weak zone reduces the pore pressure. However, it is also noticed that after reaching the maximum, when the reservoir is full, these shocks tend to become not only weak but also less frequent.

Landslides:
Landslide is referred to downward sliding of huge quantities of landmasses along the slope due to gravitational pull.
These are important to a civil engineer as they create great destruction or cause of tremors when they stuck the ground. If they active or occur in uninhabited places they are not of much concern. They are very much concerned when they occur in inhabited places, which result in huge human loss & economical loss. They also become matter of concern when occur near inhabitants, which may cause tremors in the direction of inhabitants.

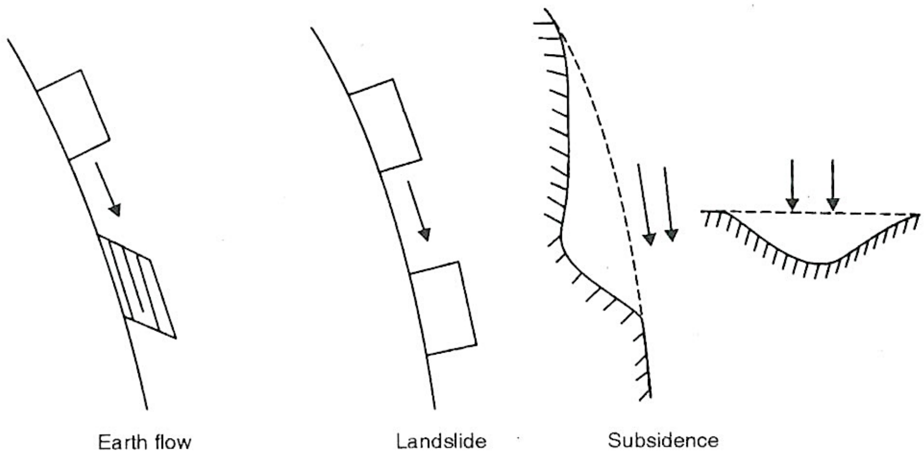
Types:
Any landmass movements can be called as landslide. Yet technically some times some of the landmass movements won't come under landslides can't come under landslides. So normally certain types of earth movements are considered as landslides, explained as followed.



The classification is based on the type of movement by which the displaced mass has suffered.

- Earthflow: The earth movement, which is distributed throughout the displaced mass, is known as earthflow.
- Landslide: If the earth movement is confined to a definite shearing plane or zone, it is called landslide.
- Land Subsidence: If the earth movement is vertically downwards it is called land subsidence.

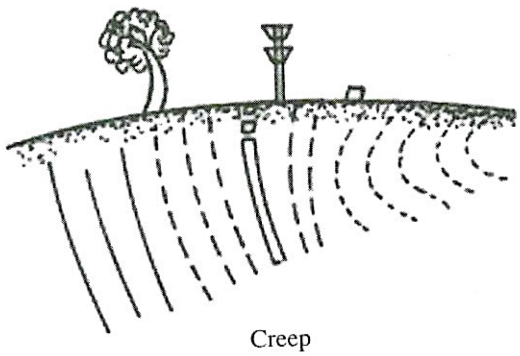
Considering the rate of movement and types of materials involved makes the subdivisions among the aforementioned divisions. The complete classification of the earth movements according to C.F.S shape is as said above.



Types of earth movements

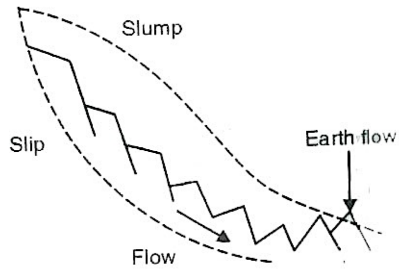
Subtypes:

1. Soilfluction: This refers to the downward movement of wet soil along the slopes under the influence of gravity.
2. Creep: Creep refers to the extremely slow downward movement of dry surficial matter. This is very important from the civil engineering point of view because the rate of movement is so slow that it may not be detected until its effects on engineering structures call attention to it. Thus, railway tracks, highways, retaining walls or tunnels built in or on creeping slopes may be thrown out of line or destroyed.



Creep

3. Rapid flows: This is similar to creep but differ with respect to the speed and depth of the material involved. These are rapid earth flows and involve considerable depth. These generally accompany heavy rains.
4. Debris slide: These are the failures of unconsolidated material on a surface of rupture. In a majority of the cases, debris slides represent readjustment of the slope of the ground. Debris slides of small magnitude are called slumps. Complementary bulges at the toe often accompany slump.



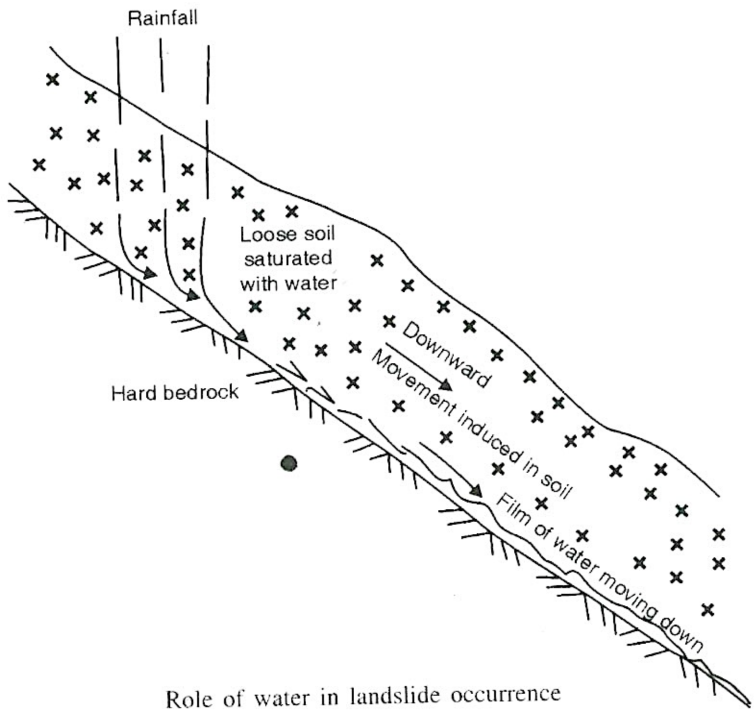
Debris slide grading into earth flow

5. Rock slides: These are the movements of essentially consolidated material, which mainly consists of recently detached bedrock.
6. Rock falls: These are the blocks of rocks of varying sizes suddenly crashing downwards (from cliffs) along steep slopes.
7. Plastic outflow: This land subsidence that occur when heavy loads of the lower layers will become plastic due to disturbance that may be squeezed outwards, allowing surface settlement or subsidence.
8. Compaction: sediments often become compact because of load, by pumping out water or due to withdrawal of oil from the ground also cause subsidence, locally.
9. 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. It may also happen when underground formations are leached by subsurface water.

Causes:

Inherent Causes (internal causes):

- Effect of slope: This is most important factor that contributes favorable condition for the landslide occurrence. Steeper slopes are prone to land slips of loose overburdens due to greater gravity influence, whereas gentle slopes are not prone to such landslips because, in such cases, loose overburden encounters greater frictional resistance; hence any possible slip is stalled. However hard consolidated and fresh rocks remain stable even against any slope, unless they are adversely affected by other lithological structural factors.
- Effect of water: This is another most important factor, which is mainly responsible for landslide occurrence. This is so because it adversely affect the stability of the loose ground in following ways:
  - The presence of water greatly reduces the inter-granular cohesion of the particles of loose ground. This weakens the ground inherently and, therefore, makes it prone to landslide occurrence.
  - On hill slopes, water on percolation through the overlying soil zone may flow down as a film or thin sheet of water above the underlying hard rocks. This not only acts as lubricating medium between the two but also induces the movement in the overlying loose material along its own direction of flow.

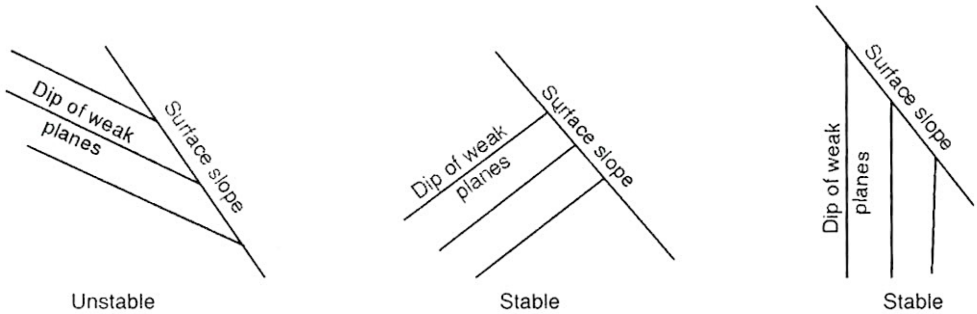


Role of water in landslide occurrence

- Along hill slopes, rainwater, while percolating down, carries with it fine clay and silt material which may form a thin band at the interface of loose overlying material and underlying hard bedrock. In the presence of water the clayey matter becomes very plastic forming slippery base enhancing the chances of loose overburden slipping downwards.
- Along steep slopes, the water in the inter-granular spaces of loose unconsolidated or weathered material adds weight and increases the influence of gravity, contributing to landslide.
- Water being a powerful solvent, causes decomposition of minerals and enhances the leeching out of soluble matter of the rocks. This reduces the compaction or cohesion of the rock body and makes it weak mass contributing to landslide.
- At the glaciers, near the snow line, frequent change in state of ice to liquid either by climatic condition or due to excess pressure. This phenomenon contributing to avalanches (landslide in glaciers).

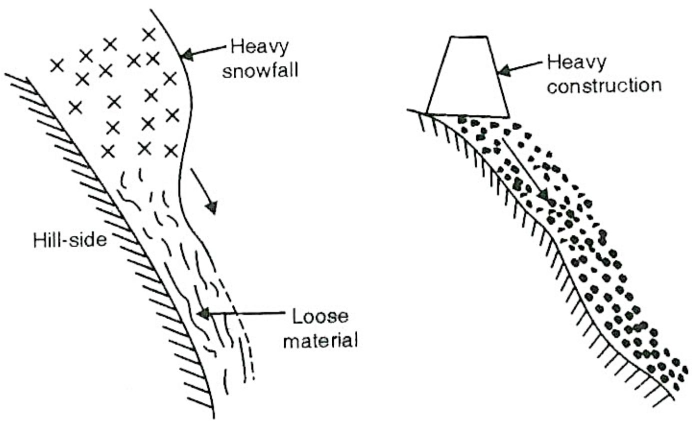
- Effect of lithology: The nature of rock types influences the landslides in the following ways;
  - Rocks which are heavily fractured, porous and permeable contribute more to landslides, as they give more scope to water accumulation.
  - Rocks made of constituents like clay, mica, calcite, gypsum and calcareous material are more prone to landslide as they can be easily leached out by water.
  - Thinner strata are prone to landslide than thicker strata.
  - A sequence of strata having thin, soft and weak beds lying in between hard and thick beds provide a congenial set-up for landslide occurrence.

- Effect of associated geological structures: The geological structures like inclined bedding planes, joints, faults or shear zones can increase the chances of landslides. The influence of geological structures can be explained as followed;
  - All the planes which are inclined or jointed or faulted or under shear zones are very weak and contribute weakness to the lying areas.
  - When the surface slope of a landmass is dipping it may contribute to stability or instability, which is explained as followed.



Natural, stable and unstable slopes

  - Joints and folds not only contribute to instability but also they are the active zones of percolation of water leading to landslides.
  - If thin clay beds are underlying the inclined beds or folds or joints, the percolated water will add overburden leading to landslides.
- Effect of humans: In the recent time, the interference of humans with nature by their activities is the major cause for landslides. For example due the under cuttings made along the hill slope for laying roads or railway tracks, the lateral support is lost and the gravity is more effective contributing to landslides.



Some causes of landslide occurrence

When construction works are carried on hilltops, they will act a heavy loads on the loose zone of overburden and create scope for sliding the underlying loose ground. Similar situation is seen when a heavy snowfall occur on the top of mountain. The massive piled snow will have the same effect as heavy load on the hilltop.

Immediate Causes: In reality these can be attributed as external causes. They may not be actually creating landslide. In certain areas the slope or the structures are delicate or unstable due to weak resistive forces. In such areas a sudden jerk or jolt caused by near by landslide or an explosion or an earthquake or avalanche or meteorite hit or volcanic activity or blasting activities for mining, road construction etc. will lead to landslides.

Preventive measures:

1. Counter effect to Slope: Retaining walls are constructed against the slopes, to prevent the rolling down of the material to prevent further fall. This also reduces slope and increases stability. Terracing is another effective measure.
2. Counter effect to Water: Proper drainage system is an effective measure. This decreases the percolation effect and further actions contributing to landslides. Constructing suitable ditches or waterways along the slopes will help in reduction of percolation. Drainage tunnels are also effective measures in preventing landslides.
3. Counter effect to structural defects: The different structural defects like, planes and zones are covered or grouted suitably to seal off. This will not only prevent percolation but increases compaction or cohesion of the material leading to stability.
4. Not to resort the existing slope: The undercutting or construction activities will reduce the stability of slope. So, such activities should not be undertaken.
5. Counter effect to loose nature of overburden: Growing vegetation, plants and shrubs on the loose ground helps in compacting the soil and increasing stability.
6. Reduction of human activities: Near hills or slopes, blasting, heavy traffic operations should be minimized or avoided to decrease the landslides.