Chapter 4

Geological structures and engineering consideration

- **Structural geology** can be defined as the branch of geology concerned with the shapes, arrangement, and interrelation of the bed rock units and the forces that cause them.
- **Tectonic forces** move and deform parts of the earth crust, particularly along plate margins. When studying deformed rocks, structural geologists typically refer to stress, a force per unit area.
- Where stress can be measured, it is expressed as the force per unit area at a particular point. However, it is difficult to measure stress in rocks that are currently buried.
- We can observe the effect of past stress (caused by tectonic forces and confining pressure from burial) when the bed rock is exposed after uplift and erosion. It is possible to observe in exposed bed rock the effect of forces on the rock that was stressed.

- ❖ **Stress** is the amount of force that acts on a rock unit to change its shape and/or its volume. Strain is the change in size (volume) shape, or both, while an object is under going stress.
- ✓ Some of the geologic structures (strain) associated with crustal deformation (stress) include folds, faults, joints or fractures.
- ❖ **Compressive stress** is common along convergent plate boundaries and typically results in rocks being deformed by shortening strain. Rocks subjected to compressive stresses, particularly along convergent plate boundaries, behave in the same way and are typically shortened in the horizontal direction and elongated in the vertical direction.
- ❖ **A tensional stress** is caused by force by pulling away from one another in opposite directions and results in a stretching or extensional strain. Tensional stresses are quite rare in the crust.
- ❖ **shear stress** that is due to movement parallel to but in opposite directions along a fault or other boundary. A shear stress results in a shear strain parallel to the direction of the stresses .

Deformation

- ✓ Rocks behave as elastic, ductile, or other brittle materials depending ***on the amount and rate of stress applied, the type of rock, and the temperature and pressure*** under which the rock is strained.
- ✓ Depending on the nature of the rocks and the rate or frequency of the movements, it can be **Brittle** and **Ductile** deformations.
- ❖ **Ductile deformations;** A rock that behaves in a ductile or plastic manner will bend while under stress and doesn't return to its original shape after relaxation of the stress.
- ✓ Ductile behavior results in rocks that are permanently deformed mainly by folding or bending of rocks**(**changes their shape without breaking or fracturing)**.e g**. Folds and associated structures
- ❖ **Brittle deformation;.** A rock exhibiting brittle behavior will break or fracture at stresses higher than its elastic limit. Rocks typically exhibit brittle behavior at or near the earth's surface where pressure and temperature are low. Under these conditions, rocks favor breaking rather than bending.
- Faults and joints are examples of structures that form by brittle behavior of the crust.

FOLDS ;Folds are geologic structures resulted from ductile deformations.

- **Folds:** are bends or buckles in layered bed rock caused by compressive forces applied parallel to the bedding plane resulting in the ductile deformations.
- ***Compressive forces slowly deform*** the rock but after removal of this load by uplift and erosion, the rock still remains the folded shape.

(a) Anticline: an up arched fold in which the two limbs diverge (dip) away from each other. The rocks forming the core are the oldest.

(b) Syncline: a down-arched fold in which the two limbs converge (dip) towards each other. The rocks forming the core are the youngest.

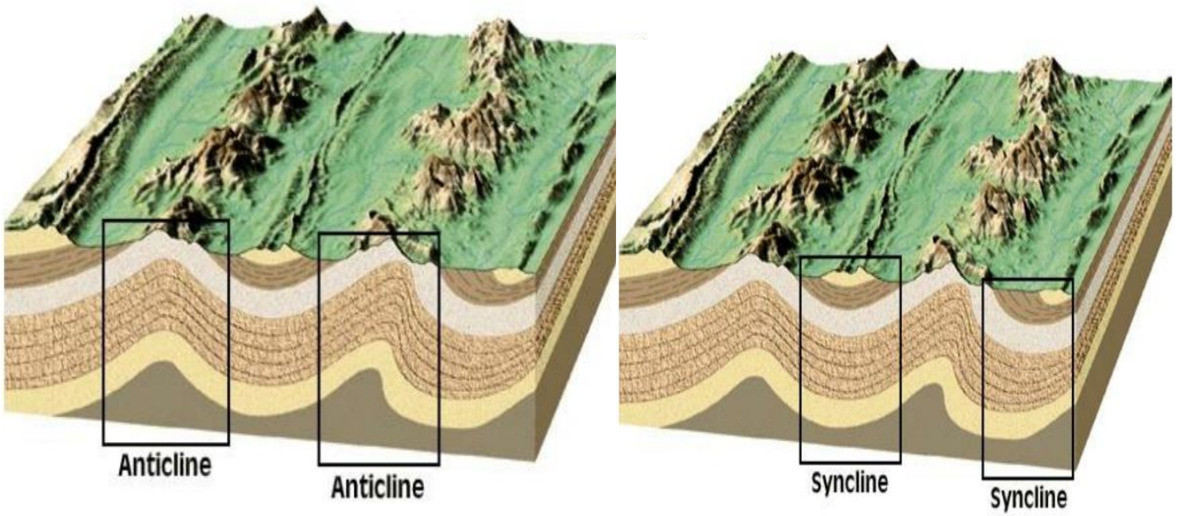


fig .Fold in outcrop photo

Engineering considerations

- ❖ Folds in the rocks are important for engineers-in that this makes their work more complicated. If these structures are not thoroughly investigated and properly interpreted any engineering project driven through folded rocks may prove un safe and uneconomical in the ultimate analysis.

- ➢ The general effects of folds on the engineering structures are given below.

(a) Change in the attitude: Folding of any type would cause a change in the attitude (dip and strike) of the same strata in its extent and also in depth. Hence, same layers may be repeated along an alignment or different layers may be encountered.

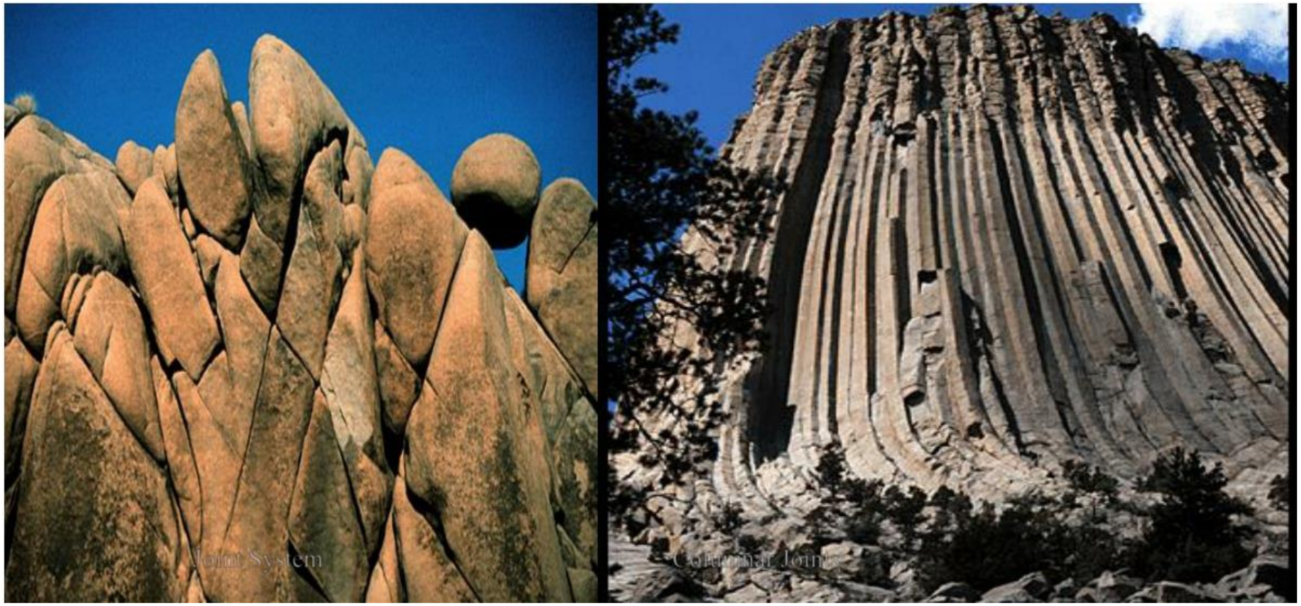
(b) Shattering of rocks; The stresses are often strong enough to break or shatter or develop cracks in the rocks, essentially at the points of maximum concentration. Hence, in folded rocks, axial regions are likely to be areas of fractured zones. This effect is of utmost importance because shattered rocks become.

- Weaker in strength
- Porous and pervious in character

2 . Fractures in rock

- **Fractures** are cracks within different rocks formed due to different rocks formed due to shearing of brittle materials.
- ✓ If a rock is brittle, or if the strain rate is too great for deformation to be accommodated by plastic behavior, the rock fractures.
- ✓ Commonly there is some movement or displacement.
- ✓ If essentially no displacement occurs, a fracture or a crack in bed rock is called ***joints.***
- ✓ If the rock in either side of the fracture moves, the fracture is ***a fault.***

Fig. joint in rock (columnar joints)



1. Joints; Fractures with no measurable shear displacement

- During volcanism there is a development of columnar jointing, in which hexagonal columns form as the result of tension and contraction of cooling, solidified lava flow.

- ***Columnar and sheet joints*** are examples of fractures that form from non tectonic stresses and are therefore referred as primary joints.
- Joints are one of the most commonly observed structures in rocks.
- Joints are regular or irregular fractures where the rocks on either side suffered no relative displacements.
- Joints may occur in any types of rocks in either vertical, horizontal or any other orientation.

Discontinuity description and characterization

✓ The following information concerning joints are needed for determining the behavior of rock masses:

- Sets and systems
- Orientation
- Joint Spacing
- Space between joint surfaces/aperture
- Continuity/persistence
- Surface roughness/features on the surface/wall
- Joint wall strength
- Surface weathering
- Presence of filling material, nature, thickness
- Presence of water or not
- RQD

- ✓ **Joint Spacing**: average perpendicular distance between fractures. Spacing tends to be consistent and depends on ***rock type and bed thickness*** (thick layers form greater spacing)
- ✓ Relation to rock type and bed thickness
- Stronger, "stiffer", or more brittle rocks have more closely spaced joints.
  - **Bed thickness-** -Joints closely spaced in thinner beds
  - **Lithology-** Stiffer lithologies ~ closer spacing

    -Less stiff rocks ~wide joint spacing.
  - **Tensile strength of the rock-** Lower tensile strength ~ more joint
- ❖ The Rock Quality Designation (RQD) was devised by Deere (Deere etal.1967) to provide quantitative estimate of rock mass quality from drill core logs. RQD is important parameter to describe the engineering properties of rock mass. RQD is defined as the percentage of intact core pieces longer than 10cm in the total run.

Correlation between RQD and rock mass quality

RQD (%)	Rock Quality
< 25	Very Poor
25-50	Poor
50-75	Fair
75-90	Good
90-100	Excellent

RQD is calculated with the following procedure

$$RQD = \frac{\sum \text{Length of core pieces} > 10\,\text{cm}}{\text{total core length}} \cdot 100\ (\%).$$

Engineering Considerations

- **Joints** influence many engineering operations. The selection of sites for dams and reservoir and alignment for highways and tunnels through rocks will require very careful investigations for arriving at safe and economic designs.
  - Joints are always to be considered as a source of weakness of the rock and as the pathways for the leakage of water through the rock. Both these properties of joints destroy the inherent soundness of the rock to a great extent.
  - If a rock forming the foundation for a dam or reservoir happens to be heavily jointed and the region is one of low water table, the risk of leakage of water from under the dam or from the reservoir may be of substantial magnitude demanding very heavy cost for treatment of the rocks.
  - If the roof or side rocks in the case of tunnel are much fractured, slippage of rocks along these fractures and leakage of water may become real troubles, often insurmountable by ordinary methods of treatment

B. Fault ; faults are well-defined cracks along which appreciable movement has taken place where the movement may be in any direction; vertically up or down, laterally to the right or left, obliquely.

- **Throw -** the vertical displacement of the fault,
- **Fault plane -** a fracture plane along which displacement takes place,
- **Foot wall -** the block below the fault plane,
- **Hanging wall -** the block above the fault plane,
- **Up-thrown side -** the block which relatively moves up wards along the fault plane,
- **Down-thrown side;** the block which relatively move down wards along the fault plane.

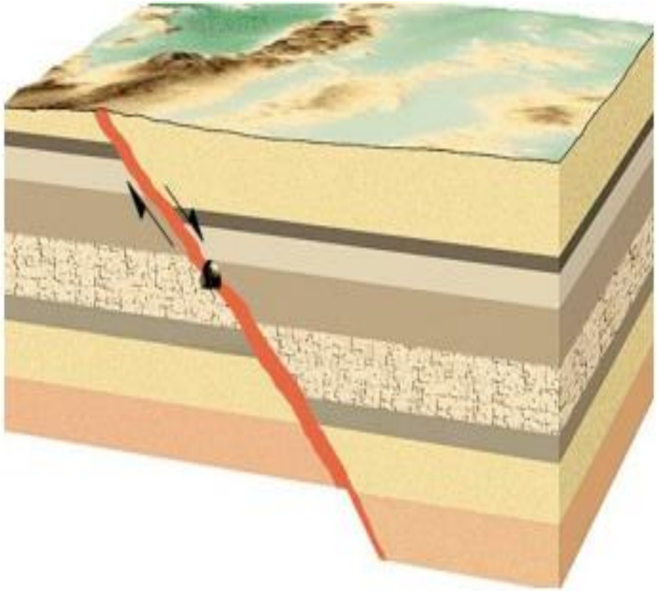
Fig. normal fault in sedimentary layer

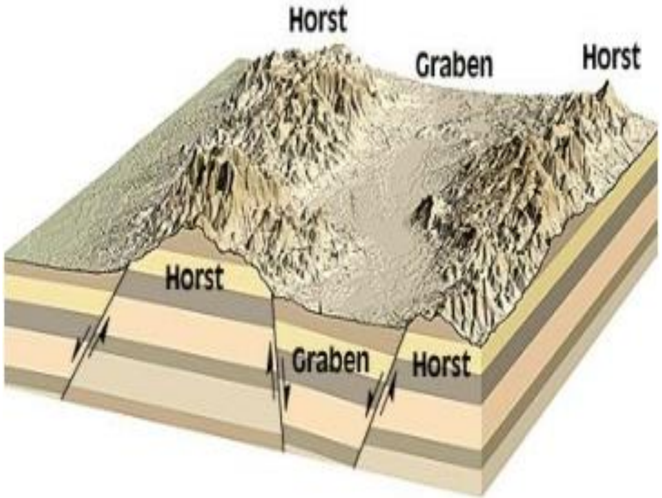
1. **Dip-Slip Faults**: Faults in which the movement is primarily parallel to the dip or inclination of the fault surface are called dip- slip faults. Two types of dip-slip faults:

(a) Normal fault; when the hanging wall block moves downward relative to the foot wall.

- ✓ Normal faults result from horizontal tensional forces applied to brittle rock masses.
- ✓ Normal faulting may also result in a central block called a **Graben** that is bounded by uplifted structures called **Horsts.**

Fig . Normal dip- slip fault

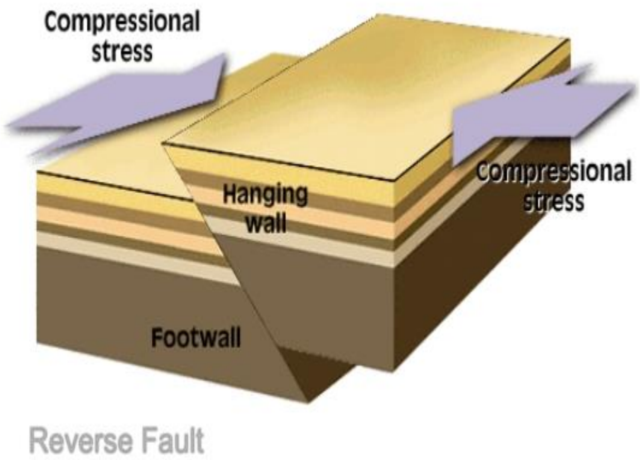


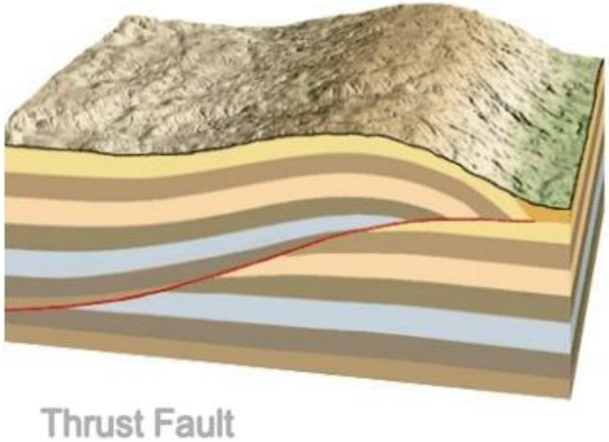


(b) Reverse fault; where the hanging wall moves up relative to the foot wall.

- ✓ Reverse faults result from horizontal compressive forces.
- ✓ **Thrust fault;** is a special type of reverse fault with a very small dip angle which is close to the horizontal.
- Reverse faults (dips greater than 45^0) and thrust faults (dips less than 45^0) occur in compressional environments.

Fig. reverse fault





Fault Related Structures

- **Graben -** a block depressed b/n two normal faults which are either parallel or dipping towards each other.
- **Rift Valley** a large scale structure formed by successive faults forming successive grabens.
- **Horst -** a block raised b/n two normal faults which are parallel or dipping away from each other.

Engineering considerations of fault

- What has been the effect of faulting on the rocks of the region under investigation and how far such rocks will be suitable, from strength point of view, as foundations or abutments or roofs for an engineering project as the case may be?
- ***If there is the effect of past faulting , such that the rocks have not been designed on them without some treatment, if did these structures safe in the future?***

- **Faults ;** make the rocks weak and unstable on the one hand and permeable on the other hand. Thus, The faulted rocks as such will form very weak foundations and abutment for dams and reservoirs, their original character not with standing;

- The shear zone and fault zones serve as easy path way for water; these can cause leakage when left untreated in dams and reservoir and may become source of great trouble when encountered along or across highway and tunnel alignment.

- ✓ Once the fault planes, shear zones or fault zones become lubricated with water, further slippage of the rocks is highly facilitated, especially if these have to withstand some loads as below the dams or under some high ways or beneath the tunnel.

- ✓ Zones of higher susceptibility to weathering.

- ✓ Weaker in strength ---Zones of higher deformability and instability.

Geological hazards

Outline;

- Landslide
- Earthquake

Mass movement/mass wasting

- ❖ Mass movement is the down slope movement of rock and/or surfacial material in mass under the influence of gravity.
- ✓ The term landslide is used in alternative with the mass movement/mass wasting.
- ❖ Mass movement:
  - Occur in terrain ranging from vertical cliff to slopes as gentle as one or two degrees.
  - Velocity range from extremely slow to extremely rapid.
  - In completely dry to completely wetted states of earth’s material
- ✓ Materials include natural rock, soil, artificial fills, or combination these.

Controlling factors in mass wasting

- ❖ Why land slide occurred and why it moved so rapidly ??

When the slopes are steep;

Water and ice not only added **weight** to the mass of debris but also acted as **lubricants**;

- ✓ abundant **loose rock** and debris were available in the course of the slide; where the slide begin, there was no **plant roots** to anchor loose material on the slope and the area is earthquake prone.

- ❖ Mass wasting is mostly triggered by:

  Earthquakes

  Weight added to the upper part of a slope

  Undercutting of bottom of slope

Classification of mass wasting

- Mass wasting is classified according to:
  - the rate of movement,
  - type of material and
  - nature of movement

Rate of movement:

- ✓ A landslide clearly involves **rapid** movement. Just as clearly, movement of soil at a rate of less than a centimeter a year is **slow** movement.

Types of material:

- ✓ Mass wasting processes are usually distinguished on the base of whether the descending mass started as bed **rock** (as in a rock slide) or **debris**.

Types of movement:

- ❖ In general, the type of movement can be classified as mainly; creep, flow, slide, or fall.

✓ **Creep;** □ is very slow, down slope movement of soil or unconsolidated debris

□ shear forces, over time, are only slightly greater than shear strengths.

□ the rate of movement is usually is less than a centimeter

✓ **Earth flows;**

□ the process can be slow or rapid

□ debris moves down slope as a viscous fluid

□ usually occur on hill sides that have thick cover of debris, often after heavy rains have saturated the soil

□ Like other kinds of landslides, it can be triggered by undercutting at the base.

- **Rock fall**
  - When a block of bed rock breaks off and falls freely or bounces down a cliff, detachment of rock.
  - Rapid sliding of a mass of bed rock along an inclined surface of weakness - **discontinuities**.
  - Caused by undercutting at the base of the slope from erosion or construction
- **Rockslide**
  - Rapid sliding of a mass of bed rock along an inclined surface of weakness
  - Caused by undercutting at the base of the slope from erosion or construction
  - Blocks of rocks will break off along the plane of weakness Rockslide

Triggering factors for mass wasting /land slides

- Construction generally makes a slope more susceptible to mass wasting of debris in several ways:

(1). The base of the slope is undercut, removing the natural support for the upper part of the slope;

(2). Vegetation is removed during construction;

(3). Buildings constructed on the upper part of the slope add weight to the potential slide; and

(4). Extra water may be allowed to seep into the debris.

Some preventive mechanisms can be taken during construction.

- A retaining wall is usually built where cut has been made in the slope
- water can percolate through **drain** way rather than collecting in the debris behind the wall.
- Another practical preventive measure is to avoid **overstepping** the slope. The hillside can be cut back in series of **terraces** rather than **single steep** cut.

Earthquake and Seismic Design

- **Earthquake** :‘’vibrations induced in the earth’s crust due to internal or external causes that virtually shake up a part of the crust”.
- An earthquake is caused by release of energy stored in the rock within the earth’s crust.

- ***The sudden release of stress is in turn caused by*** : Fracturing of rock during faulting, Sudden blow from an explosion (volcanic eruption, atomic bomb, and quarry blast).
- The immediate cause of an earth quake is the sudden movement of rock mass that has been distorted beyond the limit of their strength .
- The energy stored is released and spread in all direction in the form of elastic waves called **seismic waves.**

Classification of Earthquakes:

- Earthquakes are classified on a number of basis such as depth of focus, the intensity and the amplitude (magnitude)

1). Depth of as the basis: Three classes of earthquakes are recognized on the basis of depth of focus: shallow, intermediate and deep seated.

A. **Shallow** earthquakes, depth of focus lies anywhere up to **60km** below the surface.

B. **The intermediate** earthquakes, originate between **60** and **300km** below the surface. These are rare in occurrence but their effects are felt over large area.

C. **The deep** seated earthquakes are originate between **300** and **700km** and are very rare phenomena.

A seismograph is an instrument that records seismic waves (vibrations) onto a tracing called a seismogram.

1. **Surface Waves:** Travel on surface of earth .

2 . **Body Wave;** Travel within the earth (p-wave and s-wave) .

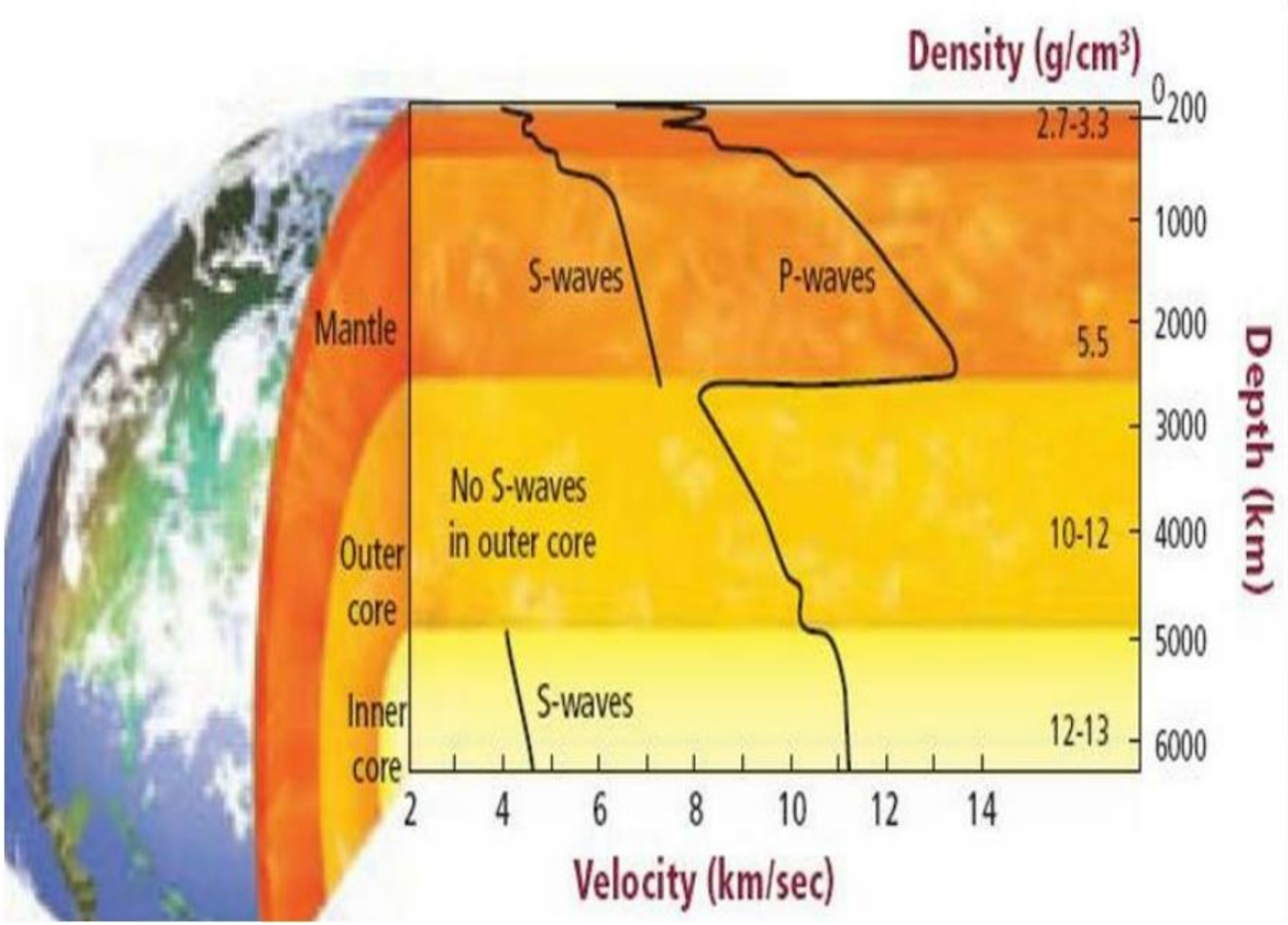
- ✓ **Love and Rayleigh** (surface waves) are responsible for a lot of damage that takes place during earthquakes. They are not as basic as P and S waves, but create a lot of problems anyway.
- ✓ **Love waves** produce motion that is perpendicular to the direction of wave travel in a horizontal orientation only. This is the type of horizontal shearing that wipes out building foundations.
- ✓ **Rayleigh** waves produce a rolling motion like the waves on the sea. An object like a building on the surface will experience both an up-and-down, bobbing motion transverse to and a back-and- forth motion parallel to, the Rayleigh wave direction of travel.
- ✓ The two movements combine to create a rolling, elliptical action that is extremely difficult for buildings (**more damaging effects).**

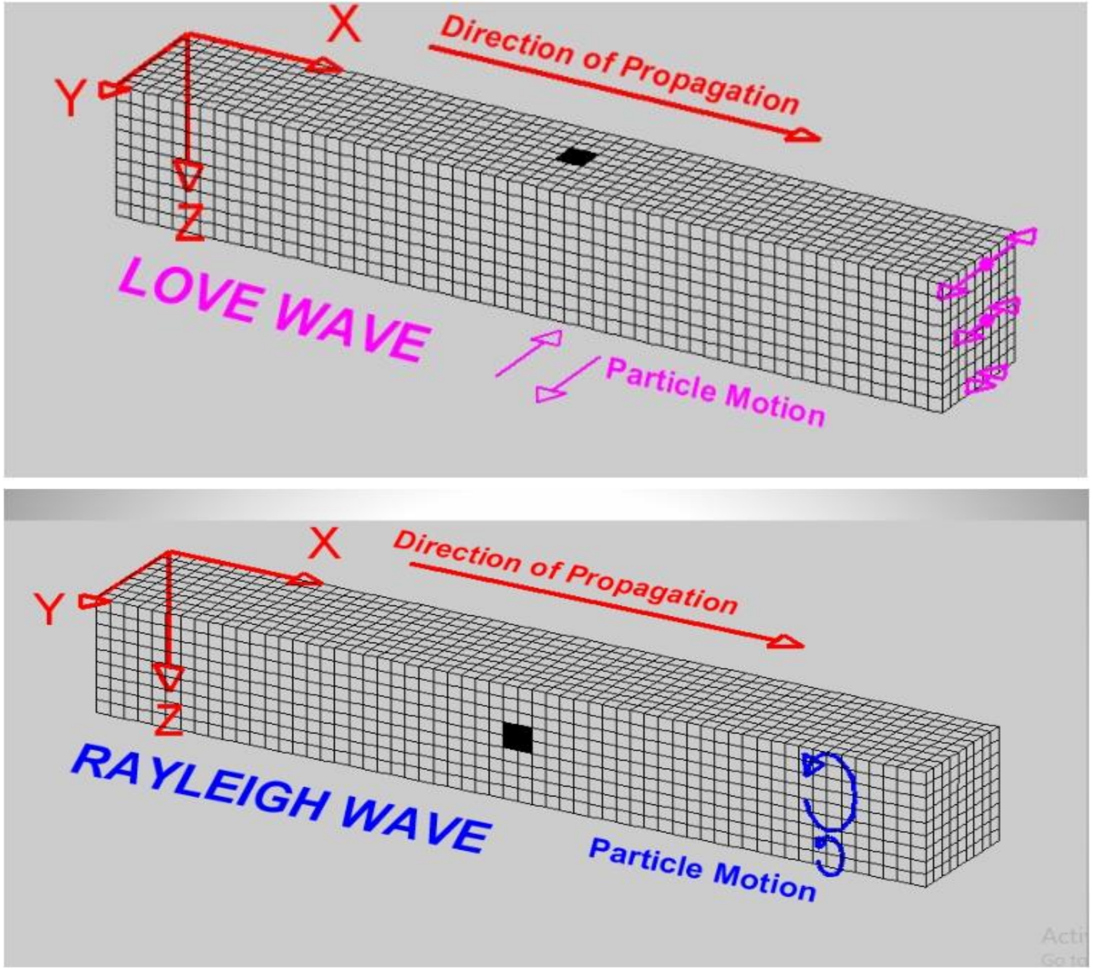
Primary waves; P-waves are the fastest seismic waves and the first to arrive at any monitoring station.

- ✓ **P-waves** travel at about 5 km/s (14 times faster than sound waves travel through air). For this reason, they are called primary waves or P waves of an earthquake.
- ✓ P-waves are longitudinal compressional waves. Like sound waves, they travel through rock or buildings causing squeezing and expanding, parallel to the direction of transmission.
- *The speed that P waves travel depends on* the types of matter through which they move. Generally, in the case of P waves, the denser the matter, the faster the wave travels.
- ✓ Because P waves are the first seismic waves to reach any given location after an earthquake takes place, their arrival can easily be identified on a seismogram. The tracing is flat during zero or background vibration,

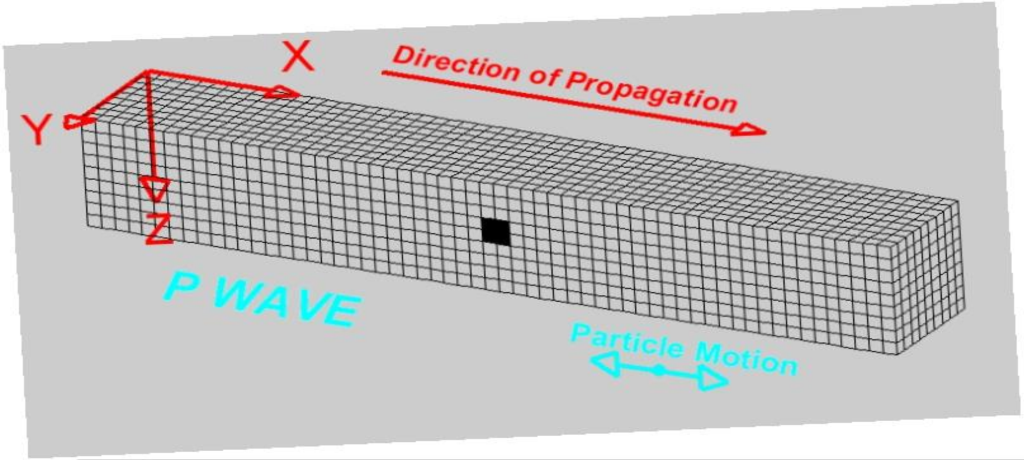
Secondary waves; S-waves arrive at a monitoring location second, since they only travel around ***60% of the speed of P waves.***

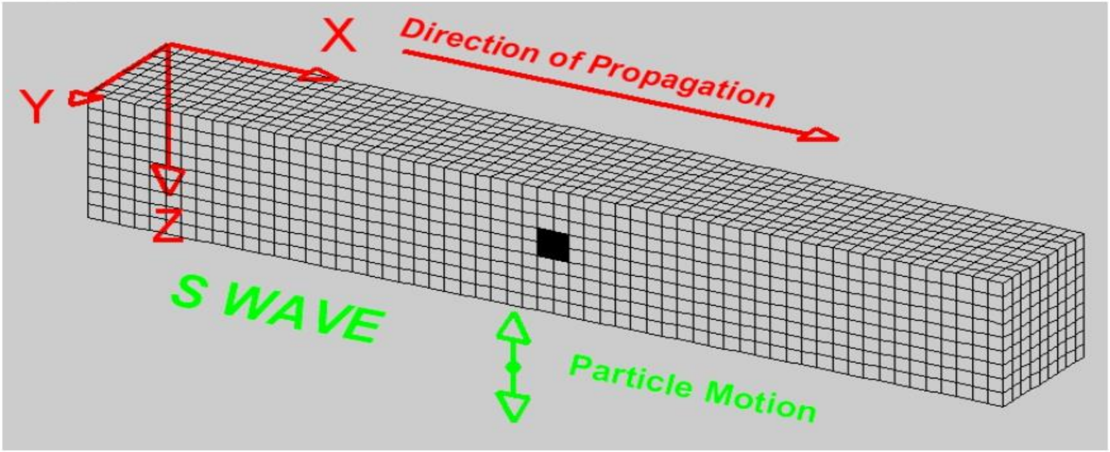
- ✓ For this reason, they are called secondary or S waves.
- ✓ *S waves are transverse shear waves*. They cause a shearing, side-to-side motion transverse (perpendicular) to their direction of travel.
- ✓ Because of this, they can only travel through a substance like rock that has **shear strength**. Liquids and gases have no shear strength and S waves cannot travel through water, air, or even molten rock.
- Since the seismogram is already jumping wildly with the action of the P waves, it can be tricky to figure out when S waves arrive. However, seismologists study the amplitude and wavelength of a seismic recording. S waves are often lower in frequency and velocity.


Density (g/cm³)
0
200
2.7-3.3
1000
S-waves
P-waves
Mantle
2000
5.5
3000
Depth (km)
No S-waves
in outer core
Outer
core
10-12
4000
5000
Inner
core
S-waves
12-13
6000
2
4
6
8
10
12
14
Velocity (km/sec)



Surface wave


X
Y
Z
Direction of Propagation
P WAVE
Particle Motion


X
Y
Z
Direction of Propagation
S WAVE
Particle Motion

Body wave

Earthquake measurements

- The vibrations caused by earthquakes are recorded by **seismographs** where the vibrations are registered in the form of oscillations.

- ✓ **Focus** is the point in the earth's crust from which an earthquake disturbance emanates.
- ✓ **Epicenter** is the point on the earth's surface immediately above the point of the disturbance. **i.e**. it is the vertical surfacial projection of the focus.

- Earthquake vibrations are measured in two ways:

1.Magnitude: it is the actual amount of energy released from earthquakes at the respective focus. It is measured using **Richter** scale ranging 1 to10.

$$M = \log 10\ (a/T) + B$$

Where 'a' is maximum ground motion, a/T=Amplitude (A) of ground motion at a distance of 100km measured in microns,

T is duration of one oscillation or period of the seismic wave

B is the attenuation factor (distance correction),B measured in mm.

2. Intensity; It refers to the amount of surface damage or the degree of the hazard due to the earthquake.

- ✓ It is given by the **Mercalli Scale** of numbers ranging from I to XII.
- ✓ Intensity is not strictly dependent on the magnitude but also depends on the nature and type of construction, population density, etc.

- An earthquake of the same magnitude may have different intensities.

Note; Any structure should be design far from the focus, and fault area as well as volcano lands. The task of an engineer is:

- To know the seismic history of the area ,to assess the magnitude and probable loss or damage, in quantity and quality, due to ‘expected 'seismic shocks in the life period of the structures.
- To introduce suitable factor of safety in the new construction.

Quarry types and building material

- **Quarrying** is a place where different types of stones are extracted. The stone industry is broadly classed in to the uses for which the stone is intended:

(1) dimension stone, for building purposes, paving blocks, curbstones, switchboards, blackboards,

(2) crushed stone, for concrete aggregate, road metal, ballast, and riprap

(3) manufacturing stone, for Portland cement, line, refractories, and various chemical and metallurgical uses. Granitic rocks, limestone, marbles, slates, sandstones, and other types are used. Selection of a quarry site will depend on the need for a particular kind of stone and on the use for which it is intended.

Applications for rock fill

- The properties required of rock fill are directly related to its function in a particular application. Rock fill may be used in a variety of engineering structures including the following:

  ! Highway embankments

  !! Embankment dams

  !!! Foundations for buildings

!!!!. Gabions ; are steel wire or plastic mesh baskets filled with rock and they are usually used in situations where land is at a premium or soil protection is required. They have many applications in civil engineering, particularly on highways where soil retention is necessary.

- High-quality rock fill is usually quarried at depth and there may be considerable quantities of overlying weathered overburden.
- There are obvious economic and environmental advantages if such weathered material can be used in the fill operation.

- Low grade rock fill, or soft rock fill as it is sometimes called, can be considered a transition between earth fill and rock fill and has found increasing use. In a soft rock fill the fines fill the voids between the coarser particles and a maximum density is obtained after compaction.

- **Coastal structures** may be;

  1. Rubble mound breakwaters and reefs
  2. Shoreline protection and sea walls
  3. Artificial beaches (and beach nourishment)

  Although there are many examples of artificial materials such as concrete and asphalt forming all or part of these structures, natural rock is commonly the major component used in the construction of structures in the first three groups listed above.

- Rock facings and armouring are being used increasingly at the present time as a consequence of economic, practical and environmental considerations in the design.
- Rubble mound structures are widely used as breakwaters for harbour and coastal protection, and in modified form for coastal defence structures.
- The principal advantage of an open textured rubble mound structure is that the wave energies are dissipated to a considerable extent by turbulence generated within the voids between adjacent blocks.
- Thus, wave energies are largely dissipated as turbulence and heat rather than reflected back, The effect is to reduce wave run-up and overtopping of the structure. Consequently, size, shape, packing of blocks on the face of the structure, and slope angle of the face are all key factors which control the effectiveness of energy dissipation.

Material quality evaluation in armourstone

- ✓ Rock selected for use in a coastal structure such as a breakwater may be subject to severe conditions, particularly during storms. The rock must be able to withstand rapidly fluctuating and severe hydraulic pressure changes, impact due to movement, abrasion and attrition, wetting and drying, thermal cycling, and possibly freeze/thaw, salt and solution damage.
- ✓ Many of the tests to evaluate armourstone quality have been modified from appropriate National Standard tests that were originally designed for aggregates, while others have been specifically designed to determine armourstone quality.
- ✓ The objective of all these test procedures is to ensure that a rock selected for a marine structure will be strong enough to withstand breakage, both during handling from quarry to structure and during its service life on the structure and will also be sufficiently durable to avoid significant wear or degradation in-service.

- ***Dimension stone*** is defined as any rock that is cut and worked to a specific size or shape for use in building and that the stone should be free from fractures, tough and devoid of minerals that can break down chemically or by weathering. The surfaces of the finished blocks may be dressed by one or more mechanical treatments.

for example honing, or flame texturing

Index and classification tests

- With the difficulty and expense of carrying out strength and compressibility tests, there is much interest in correlating index and classification test results with engineering behaviours.
- ***Particle strength, hardness and durability;*** The properties of the individual fragments of rock will have a significant influence on the behaviour of the rock fill. Particle strength and hardness will control the amount of particle breakdown and crushing of points of contact which occur during compaction and subsequent loading. Long-term performance of the fill will be affected by the durability of the rock. Rocks are affected by wetting and drying; the strength of saturated rock fragments may be much less than the strength of the fragments when dry. shale will swell or disintegrate when exposed to atmospheric

Properties of strength and durability can be measured in several ways:

- The uniaxial compressive strength (q,) of cylindrical specimens of rock can be measured but considerable time and effort is required to prepare the cylindrical sample of rock for this standard test.
- In the point load strength test cylindrical specimens or irregular lumps of rock are loaded to failure between the conical platens of a portable tester.
- In the slake durability test the resistance of a rock to wetting and drying cycles is assessed by immersing samples in water and noting the rate of disintegration; this test is useful for relatively weak rocks which are sensitive to the test
- The aggregate crushing test has been used to assess the suitability of a material to form a rock fill.
- The saturation moisture content or water absorption can give an indication of the weathering potential.

Types of quarry

I . **Boulder quarries;** it is the splitting or blasting of boulders, Those boulders are sourced from glacier deposit that is taken from mountians.The smaller stones were used as while the larger one is split.

II. **Surface edge quarries;** it is a place were exposed bedrock usually on hillsides was quarried for usable bars of rock. The exposed bed rock many times had well defined fractures that allow the rock to split easily.

III. Commercial deep pit quarry

- ✓ Modern types of quarry type to exploited the superior grades of stones found deeper in the bed rock.

Selection of site for quarrying of stones

- ❖ Engineers and contractors have to keep following factors in to consideration while deciding about the location of quarry site.

I. **Availability of sound rock**: A quarry can be opened up only where a sound rock that can yield good quality building stones exists in the considerable area.

- ✓ The rock must be available in large quantity and must be uniform quality.

II. Distance from the areas of construction

- ✓ The quarry must not be located far away from the area where constructional activities are going on. It should be located far from town since it is a full of hazards.

III. Distance from main road

- ✓ The quarry should be near to main road to minimize cost of haulage of the stone to towns.
- ✓ Availability of water and dumping water is an important necessity for the work force. it must be enough water in the quarry site similarly, quarrying operations involve a lot of breaking of different types of rocks which are not useful for building construction.

Properties of building materials and their importance in construction

- ✓ For a material to be considered as building material, should have required engineering properties suitable for construction works.
- ✓ ***Chemical resistance*** is the ability of a material to withstand the action of acids, alkalis, sea water and gases.
- ✓ The chemical resistance of natural stone is particularly important for stones that are to be exposed to polluted atmospheres where acidic gases are present, for example industrial areas. Other sources of chemical attack include, amongst others, spray from roads treated with de-icing salts, some cleaning agents, particularly those used for stone cleaning.
- The types of stone that are particularly affected by acidic gases are limestone, calcareous sandstones and metamorphic slates containing significant amounts of calcium carbonate.
- Chemical weathering can affect igneous rocks, for example granites, but the timescale over which the weathering takes place is usually much longer than the expected life of a building.

Frost resistance

- The ability of a water-saturate material to endure repeated freezing and thawing with considerable decrease of mechanical strength. Under such conditions the water contained by the pores increases in volume even up to 9 per cent on freezing. Thus the walls of the pore experience considerable stresses and may even fail.
- Frost or freeze-thaw resistance is important for stones used in locations where temperatures will drop below freezing for extended periods. The effect of freeze-thaw on a stone will depend on the temperature the stone is exposed to, the porosity and pore size distribution and the amount of water present in the stone at the time of freezing . Stone with a low porosity, such as marble, or stones that are dry will have little water within their pore structure and therefore ice will not form when freezing occurs.

Abrasion resistance

- The abrasion and wear of stone occurs in areas subjected to high levels of pedestrian traffic. Wear is defined as the. progressive loss of substance from the surface of a body brought about by mechanical action.

- **Porosity(n)**" is the degree to which volume of the material is interspaced with pores. It is expressed as a ratio of the volume of pores to that of the specimen.

$$n = V_v / V$$

- ✓ Porosity is indicative of other major properties of material, such as bulk density, heat conductivity, durability, etc.
- ✓ Dense materials, which have low porosity, are used for constructions requiring high mechanical strength on other hand, walls of buildings are commonly built of materials, featuring considerable porosity.
- ✓ Following inter relationship exists between void ratio and the porosity.

$$n = e/1+e ,$$

Void ratio is defined as the ratio of volume of voids (Vv) to the volume of solids (Vs),

$$e = V_v / V_s$$

- ***Water absorption*** denotes the ability of the material to absorb and retain water. It is expressed as percentage in weight or of the volume of dry material:
- ***Weathering resistance (Durability)*** is the ability of a material to endure alternate wet and dry conditions for a long period without considerable deformation and loss of mechanical strength.

Mechanical properties

- The important mechanical properties considered for building materials are: strength, compressive, tensile, bending, impact, hardness, plasticity, elasticity and abrasion resistance.
- ***Strength*** is the ability of the material to resist failure under the action of stresses caused by loads, the most common being compression, tension, bending and impact.
- The importance of studying the various strengths will be highlighted from the fact that materials such as rock and concrete have high compressive strength but a low (1/5 to 1/50) tensile, bending and impact strengths.

- **Hardness** is the ability of a material to resist penetration by a harder body. Moh's scale is used to find the hardness of materials. It is a list of ten minerals arranged in the order of increasing hardness.
- **Elasticity** is the ability of a material to restore its initial form and dimensions after the load is removed. Within the limits of elasticity of solid bodies, the deformation is proportional to the stress. A large value of it represents a material with very small deformation.
- **Plasticity** is the ability of a material to change its shape under load without cracking and to retain this shape after the load is removed.

Common building stone

- ✓ Those are naturally occurring massive dense rock which can be cut or shaped into slabs for use in wall or roofing materials.
- Be it igneous, metamorphic, or sedimentary a building stone is chosen for its use, durability, attractiveness, and economy as desired.
- **1. Granite**
- classification: igneous, siliceous variety
- composition: quartz, feldspar, and mica
- characteristics: specific gravity:2.64

  crushing strength:110 to 140MN/M2

  colour: depends on feldspar pink or white
- **use**: for construction of sea walls, bridge piers, building blocks

2. Basalt

- **Classification**: igneous, siliceous variety
- **Composition**: silica alumina and feldspar
- **Characteristics**:
  - Crushing strength :70 to 80 MN/M2
  - Specific gravity:2.96
  - it is rough and black in color
  - it is alkali resistant.

uses; suitable for paving sets d as road metal

. used for manufacture of artificial stones

. used as aggregates

3. Slate

- **classification:** metamorphic rock formed from shale
- **composition:** alumina mixed with sand
- **characteristics**:
  - specific gravity:2.8
  - it can split in to thin sheets
  - crushing strength:60 to 70 MN/m2
  - it is non absorbant
  - ideal good roof covering since it is impervious

4. Limestone

- **Classification**: sedimentary rock of calcareous variety
- **Composition**: calcium carbonate
  - specific gravity:2.6
  - crushing strength,52MN/m2
  - for stone masonry, for walls and paving floors
  - for manufacturing of lime cement, and road metal

5. Sandstone

- **Classfication**: sedimentary rock
- **Compostion**: quartz or feldspar cemented by lime
- **Characteristics**: specific gravity:2.25
  - crushing strength 35 to 40 MN/m2
  - it is weak in abrasion and hold water
  - dimension stone and for riprap purpose