

Rock Mechanics :-

It is the scientific study of the behaviour of rock mass under various forces either in situ state or mined state.

Scope of Rock Mechanics :-

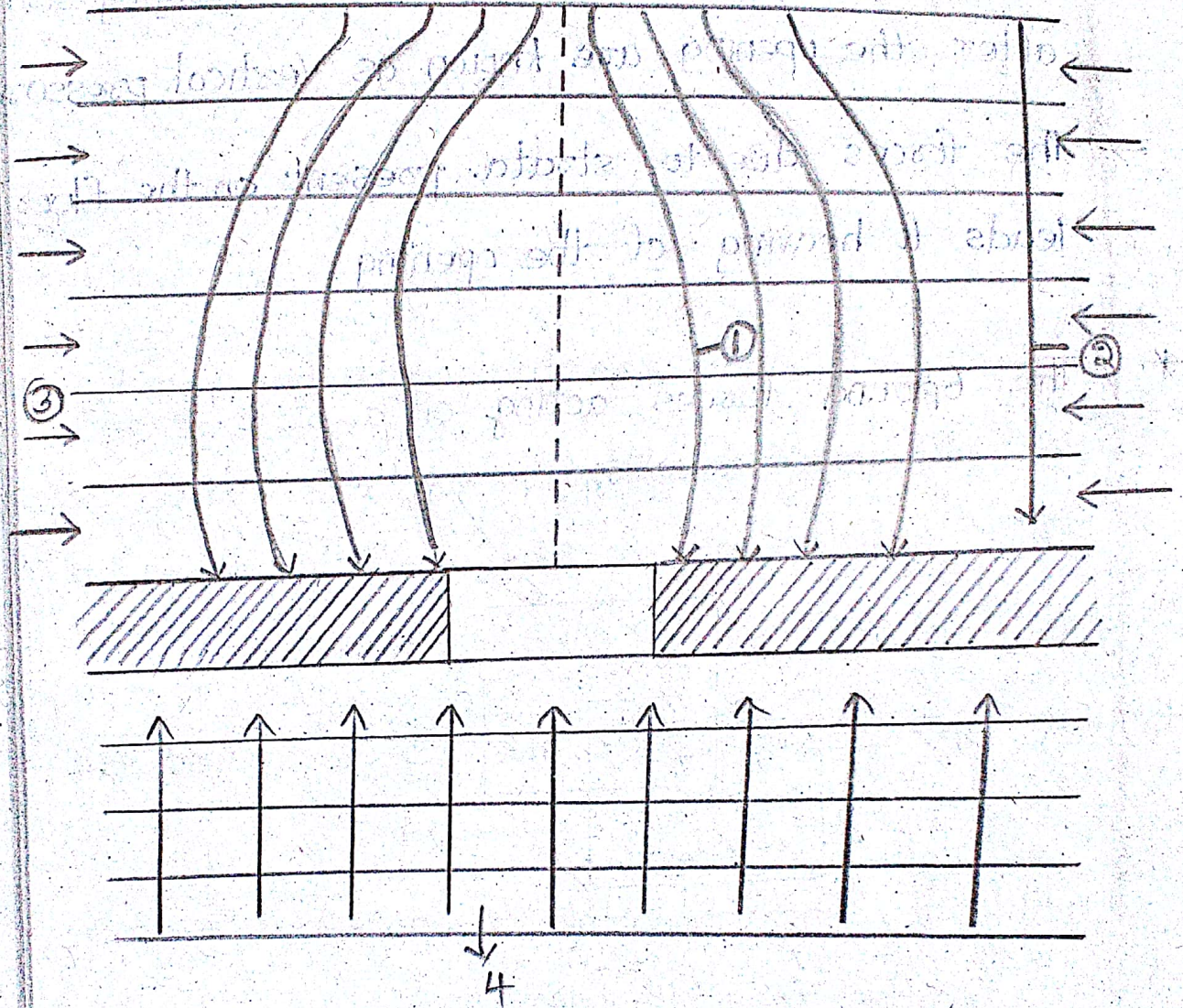
- The rock mechanics is used to measure the behaviour of rock mass while carrying out mining operations.
- The behaviour of rock mass is being measured by measuring its physico mechanical property.
- The mechanical properties such as
 - Compressive
 - Tensile
 - Shear strengthare to be computed to access the behaviour of rock mass.
- The physical properties of rock such as
 - Bulk density
 - Porosity
 - Void ratio and
 - Permeabilityare to be measured.

- The Scope of rock mechanics includes the
Computation of RQD (Rock Quality Designation)
→ RMR (Rock mass Rating)
→ Q-mass index

* Applications of Rock Mechanics in Mining :-

- To determine the type of Support required while carrying out mining activity.
- To determine the shape of opening (circular, square, rectangular).
- To determine the dimension of opening (width and height of opening).
- To determine the dimension of pillar
- To deduce the method of working
- For designing of roof span of the opening.
- To determine the amount of subsidence while carrying out the mining activity.
- To compute the support density

* state the forces due to weight of the strata.



1 - Abutment pressure

2 - Vertical pressure

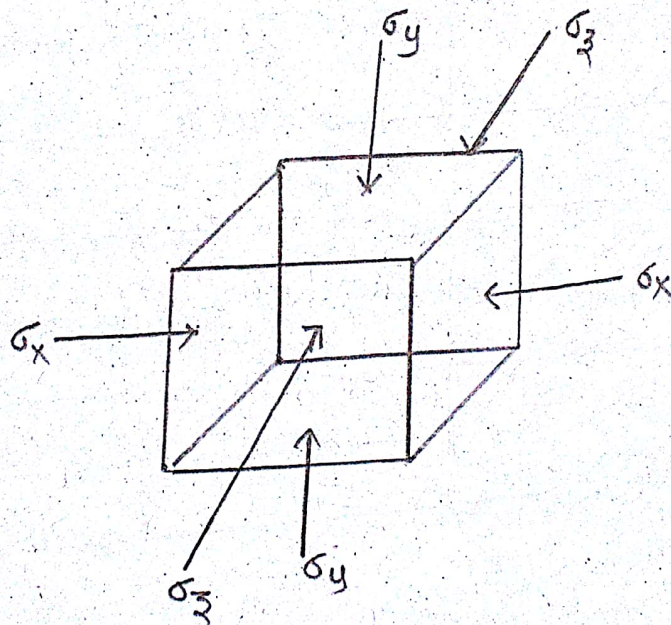
3 - Lateral pressure

4 - forces due to strata on the floor

→ When an opening is made into the ^{insitu rock mass} bed, the forces that were acting in its insitu forces gets redistributed.

- The redistributed forces acting on the edges of the opening is known as abutment pressure.
- The forces that are acting due to overlying strata after the opening are known as vertical pressure.
- The forces due to strata present on the floor leads to heaving of the opening.

* The Ground forces acting on a block of rock



- In case of insitu condition the forces acting on a block of rock mass are in Equilibrium and there will not be any displacement of rock mass.

→ Let σ_x , σ_y and σ_z are the forces acting along the x, y and z direction in insitu condition.

$$\sigma_x = \sigma_y = \sigma_z$$

- If an opening is made in to the insitu rock mass the equilibrium forces get distributed

Residual forces

The forces which are acting internal to the rock mass at various weak zones which are not exposed to outside are known as residual forces.

Tectonic and orogenic forces:-

- The forces that were acting between the tectonic movements of the plate of formation of earth in various regions are known as tectonic forces.
- The tectonic forces are responsible for the dislocation of plane tectonics.
- Due to movement of plate tectonics, the hilly terrains such as Himalayas, were formed

* Stress:-

The internal resisting force acting per unit area of a body is known as stress.

$$\text{Stress} = \frac{\text{force}}{\text{Area}}$$

It is denoted by " σ ".

* Strain:-

The ratio of change in dimension of the body to the original dimension of the body is called as strain.

$$\text{Strain} = \frac{\text{change in dimension of the body}}{\text{original dimension of the body}}$$

It is denoted by " e ".

* Poisson's Ratio:-

The Ratio of lateral strain to linear strain is called as Poisson's ratio. It is denoted by

" μ or $\frac{1}{m}$ "

$$\text{Poisson's ratio} = \frac{\text{Lateral strain}}{\text{Linear strain}}$$

* Young's Modulus:-

The ratio of tensile or compressive stress to the corresponding strain is called Young's modulus.

It is denoted by E

$$\text{Young's Modulus} = \frac{\text{Tensile stress or compressive stress}}{\text{Tensile strain or compressive strain}}$$

* Rigidity Modulus:-

The ratio of shear stress to the corresponding shear strain within elastic limit is known as Modulus of rigidity.

$$\text{Modulus of rigidity (C)} = \frac{\text{shear stress}}{\text{shear strain}}$$

* Bulk Modulus:-

The ratio of direct stress to the corresponding volumetric strain is known as Bulk modulus.

It is denoted by K .

$$\text{Bulk Modulus (K)} = \frac{\text{Direct stress}}{\text{Volumetric strain}}$$

* Relation between Young's Modulus and Rigidity Modulus

$$E = 2c(1 + \mu)$$

Where

E = Young's Modulus

c = Modulus of Rigidity

μ = Poisson's ratio.

* Relation between Young's Modulus and Bulk Modulus

$$E = 3k(1 - 2\mu)$$

Where

E = Young's modulus

k = Bulk modulus

μ = Poisson's ratio

* Relation between E , k and c .

$$E = \frac{9kc}{3k + c}$$

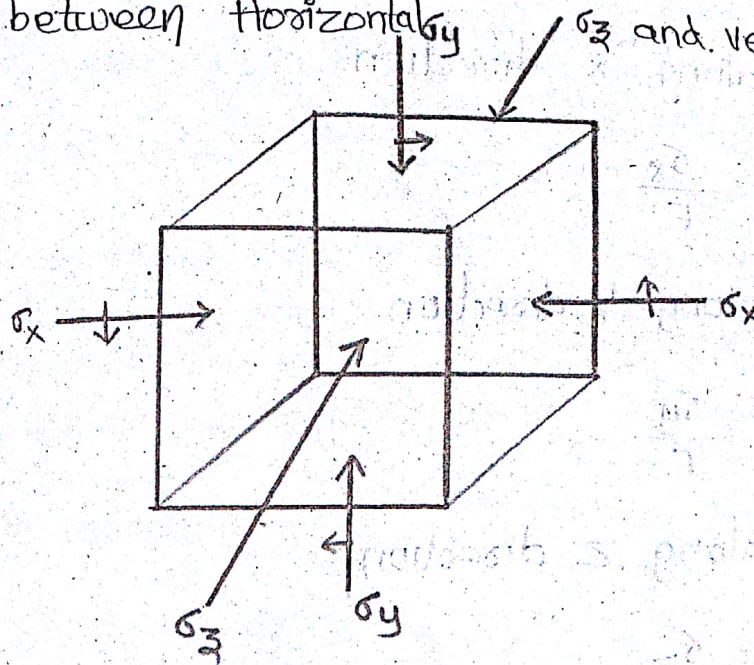
Where

E = Young's modulus

k = Bulk modulus

c = Rigidity Modulus.

Relation between Horizontal σ_y and σ_z and vertical stresses.



In a three dimensional block of rock mass the stresses acting along x, y and z direction are σ_x , σ_y and σ_z .

Due to application of linear force in one ^{direction} force, the forces acting in the lateral direction are tensile forces.

Relation between vertical and lateral stresses.

We know that

$$E = \frac{\text{stress}}{\text{strain}}$$

$$\text{strain} = \frac{\text{stress}}{E}$$

Strain along x direction

$$\epsilon_x = \frac{\sigma_x}{E}$$

Strain along y direction

$$\epsilon_y = \frac{\sigma_y}{E}$$

Strain along z direction

$$\epsilon_z = \frac{\sigma_z}{E}$$

When a compressive force is applied the forces that are acting in lateral direction are tensile.

$$\text{Poison's ratio } \left(\frac{1}{m}\right) = \frac{\text{lateral strain}}{\text{longitudinal or linear strain}}$$

$$\text{Lateral strain} = \text{linear strain} \times \frac{1}{m}$$

$$\text{Lateral strain along y direction} = \frac{\sigma_y}{E} \times \frac{1}{m}$$

$$\text{Lateral strain along z direction} = \frac{\sigma_z}{E} \times \frac{1}{m}$$

$$\text{Lateral strain along x direction} = \frac{\sigma_x}{E} \times \frac{1}{m}$$

The effective strain due to application of linear force along x direction.

$$\epsilon_x = \frac{\sigma_x}{E} - \frac{\sigma_y}{mE} - \frac{\sigma_z}{mE}$$

If the effective strain due to application of force along y direction.

$$\epsilon_y = \frac{\sigma_y}{E} - \frac{\sigma_x}{mE} - \frac{\sigma_z}{mE}$$

The effective strain due to application of force along z direction.

$$\epsilon_z = \frac{\sigma_z}{E} - \frac{\sigma_x}{mE} - \frac{\sigma_y}{mE}$$

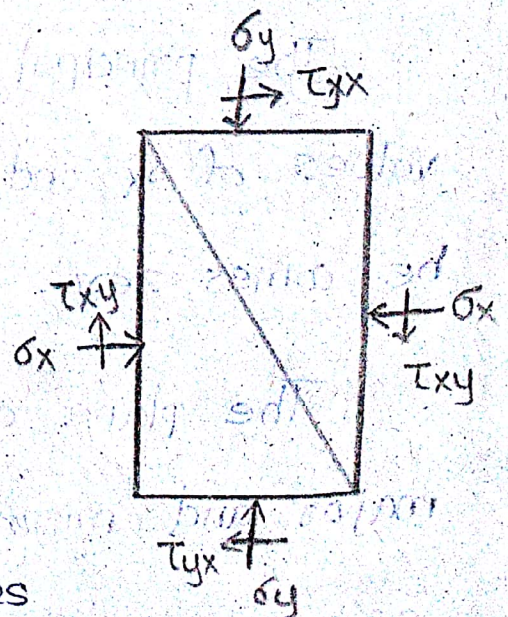
* plane stress and plane strain:-

The plane stress is acting on a two dimensional plane

Let σ_x , σ_y are the stresses acting along x and y direction

τ_{xy} , τ_{yx} are the shear stresses

acting x-plane along y direction, On y-plane along x direction respectively



Let the failure of the plane takes place along the plane of weakness makes an angle θ with the vertical.

Let σ_n , τ_n are the forces acting along the plane of failure

$$\sigma_n = \frac{(\sigma_x + \sigma_y)}{2} + \frac{(\sigma_x - \sigma_y)}{2} \cos 2\theta + \tau_{xy} \sin 2\theta$$

$$\tau_n = \tau_{xy} \cos 2\theta - \frac{(\sigma_x - \sigma_y)}{2} \sin 2\theta$$

* Principal stress:-

The stresses that are acting on a plane at which (σ_x, σ_y) the normal stress acting on a plane is maximum is known as principal stress.

The principal stress is also defined as at a given values of σ_x and σ_y the value of shear stress will be comes zero.

The plane along which principal stresses both major and minor principal stress are acting is known as principal plane

* Plane strain:-

The plane strain represents the change in dimensions of the specimen with the applied stress in a plane.

* Principal strain:-

It is the strain at which the shear strain value is maximum and is known as principal strain.

* Major Principal stress:-

It is the value of normal stress acting on a plane of failure is maximum and is known as major principal stress.

$$\sigma_{\max} = \frac{(\sigma_x + \sigma_y)}{2} + \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2 xy}$$

* Minor Principal stress:-

It is the value of normal stress acting on a plane of failure is minimum.

$$\sigma_{\min} = \frac{(\sigma_x + \sigma_y)}{2} - \frac{1}{2} \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau^2 xy}$$

* The Direction of Principal stress:-

$$\theta = \frac{1}{2} \tan^{-1} \frac{(\sigma_y - \sigma_x)}{2\tau xy}$$

* Mohr's circle to represent Principal stress, Principal strain

→ Mohr's circle is geometrical representation of the relation between the normal stress and shear stress.

→ The shear stress τ_{xy} is taken along y axis and normal stresses σ_x and σ_y are represented on the x-axis.

→ The shear stress is acting anti-clockwise direction it is taken above the axis.

→ The given set of values σ_x , σ_y , & τ_{xy} are plotted as shown in the figure.

→ Join the two points plotted with a straight line and it intersects the normal stress axes at a point O.

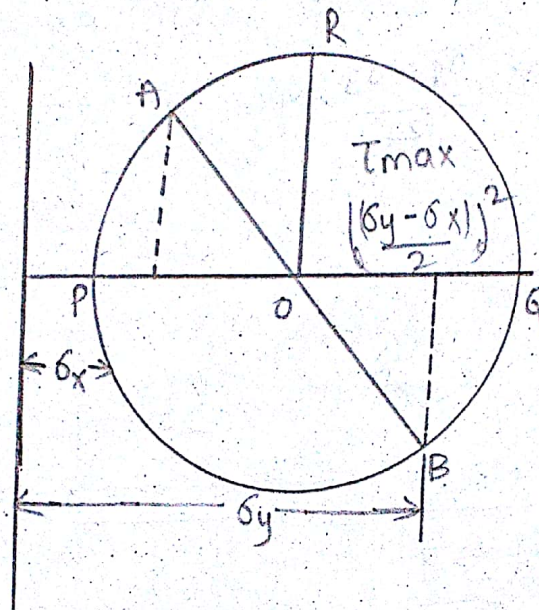
→ The line joining the two points intersects the normal stress axes at $\frac{\sigma_x + \sigma_y}{2}$.

→ Now draw the circle with O as centre and with OA as radius.

→ The circle now drawn is known as Mohr's circle

⇒ The Mohr circle intersects the normal stress axis at P, Q.

⇒ At Points P, Q the value of shear stress is equal to zero and they are known as principal stresses.



⇒ The maximum value of shear stress:

τ_{max} = The radius of Mohr circle.

$$\tau = \sqrt{\left(\frac{\sigma_y - \sigma_x}{2} \right)^2 + \tau_{xy}^2}$$

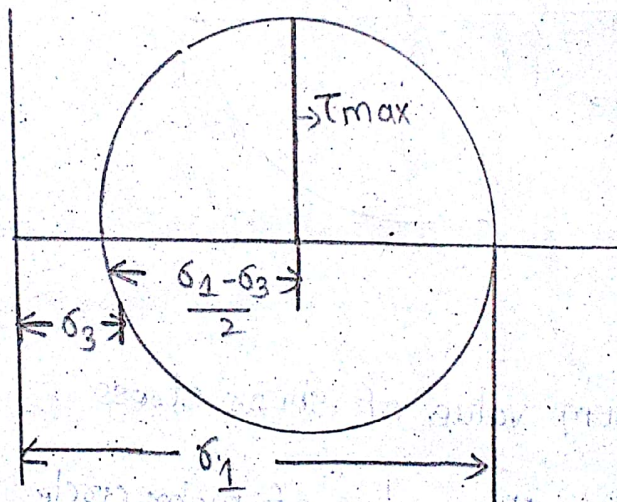
⇒ Let σ_1, σ_3 are the major and minor principal stresses.

→ The radius of Mohr circle in terms of principal stresses

$$r = \frac{\sigma_1 - \sigma_3}{2}$$

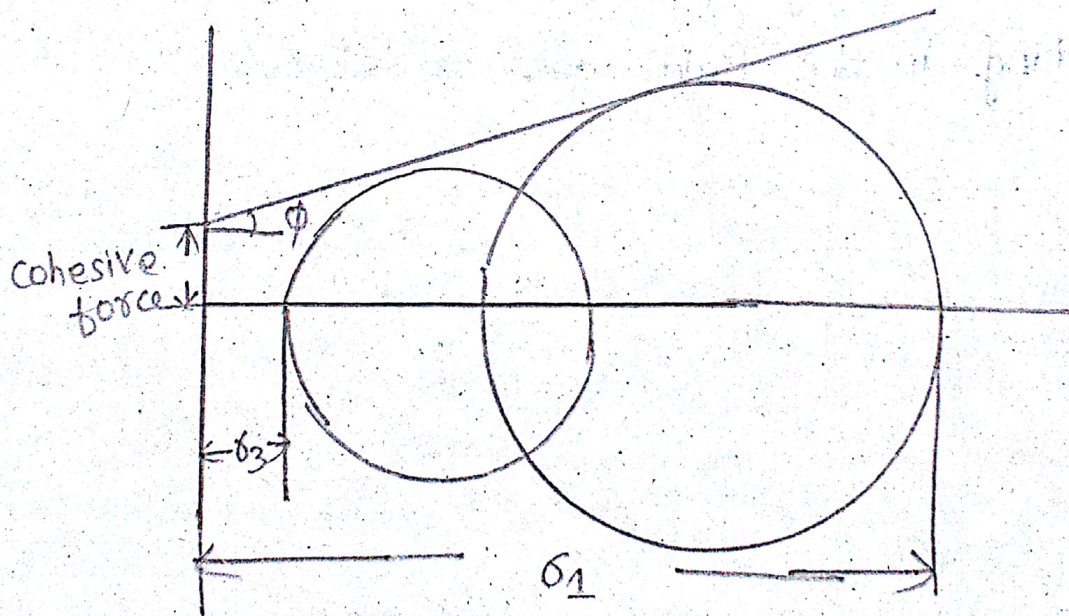
→ The value of maximum shear stress

$$\tau_{\max} = r = \frac{\sigma_1 - \sigma_3}{2}$$



Calculation of angle of internal friction and cohesive force of a sample from Mohr's circle

- ⇒ The angle of internal friction is calculated by drawing a tangent to the Mohr's circle.
- ⇒ The angle made by the tangent with the horizontal represents the angle of internal friction.



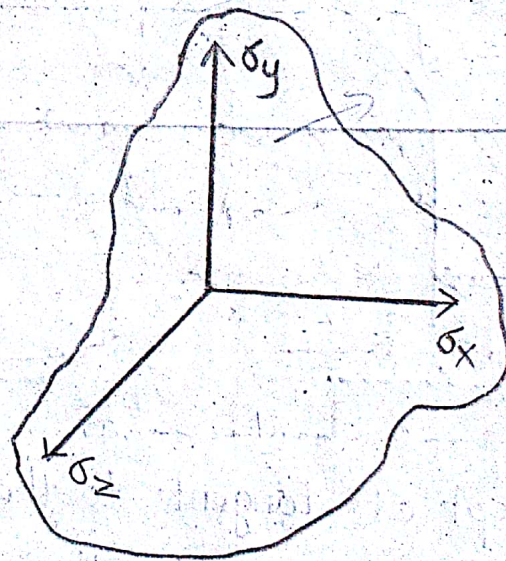
- ⇒ The intercept of tangent to the Mohr's circle on the y -axis represents the cohesive force acting along the plane of failure.

* Stress field:

In rock mechanics the stress field represents the place holder for acting of all normal stresses and corresponding shear stress.

In insitu condition the all the stresses in stress field are in Equilibrium.

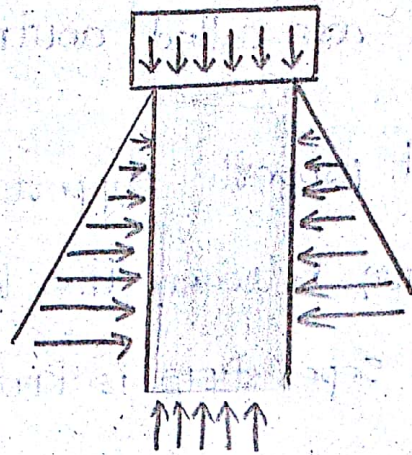
In the mining operations the insitu stresses acting in the field gets redistributed.



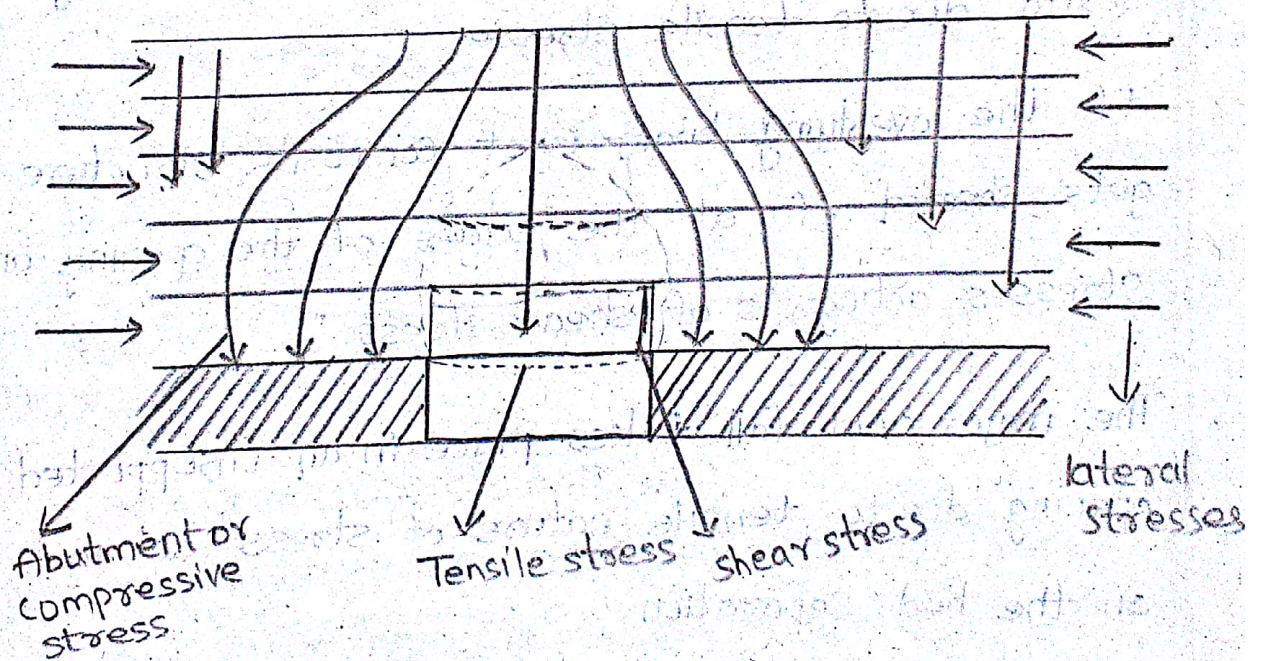
Hydrostatic state of rock:-

The hydrostatic state of rock represents the insitu condition of the stresses acting on a rock mass.

In this state, the forces are acting in 3 dimensional



* Various induced stresses due to mining activities



→ When an opening is made in to the mineral deposit the stresses acting which over the opening, which were in equilibrium state are get distributed.

- The vertical stresses which are of compressive nature gets redistributed over ~~of~~ the abutment of the opening. These stresses are called abutment stresses.
- When the opening is not properly supported it leads to development of separation between the layers of the overlying strata. This separation is known as bed separation.
- The bed separation leads to failure of overlying strata due to tensile stresses.
- If the overlying beam is of composite structure gets sheared off at the edges of the opening and stresses acting is of shear stress.
- The major roof fall takes place in an unsupported opening due to tensile nature of stress acting on the bed separation.
- The horizontal forces that are acting on a in situ rock mass are also get disturbed and are known as lateral stresses.
- The lateral stresses are always trying to close the opening.

* Various physico-mechanical properties of rock.

The following are the various physical properties of rock.

- Specific gravity
- Bulk Density
- Porosity
- Void Ratio
- Thermal Conductivity
- Permeability
- Electrical Conductivity
- Corrosion
- Density

The following are the various Mechanical Properties of rock.

→ Compressive strength.

a) Unconfined Compressive strength

b) Confined Compressive strength

or

Tri-axial strength

→ Shear strength

→ Tensile strength

→ Point load strength index

→ Slack durability index

→ Protodyakonov strength index

→ Elasticity

→ plasticity

→ Malleability

* Rock Quality Designation (RQD)

The RQD represents Rock Quality Designation and is computed based on the size of the core recovered.

The RQD is used to determine the length of the roof span, type of the support used.

The RQD is defined as the ratio of length of the core sample whose size is greater than 10cm to the total length of core sample.

$$RQD = \frac{\text{Length of core sample} > 10\text{cm}}{\text{Total length of core sample}}$$

* classification of RQD:-

Based on the RQD Percentage the quality of rock is classified into following types.

RQD	Rock Quality
< 25	Very Poor
25 to 50	Poor
50 to 75	Fair
75 to 90	Good
90 to 100	Very good.

Rock Mass:-

- In rock engineering the rock mass is defined by general form discontinuity.
- Discontinuity is a collection of joints, weak bedding planes, weak shear zones, faults.
- Depending on the different types of joint parameters material parameters the rock mass are classified into the following system
 - RQD (Rock Quality Designation)
 - RMR (Rock Mass Rating)
 - Q-system (used in tunneling)
 - GSI (Geological strength Index)
 - CMRR (Coal Mine roof Rating)
 -

* Rock Mass Rating:-

- The RMR is a geomechanical classification system developed for determination of rock mass rating.
- "It is extensively used for determination of various types of supports in underground coal mines."
- The Rock Mass Rating depends on the following 6 parameters.
 - Uni-axial compressive strength
 - RQD
 - Joint spacing
 - Condition of discontinuities
 - Ground water condition
 - Orientation of discontinuities

* Q-System (Rock Quality Index).

Rock Quality Index is used for determination of rock mass characteristics and tunnel support requirement.

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF}$$

Where

RQD = Rock Quality Designation

J_n = Joint set number

J_r = Joint roughness number

J_a = Joint alteration number

J_w = Joint water reduction factor

SRF = Stress Reduction factor.

From the above formula it is clear that the tunnel quality index (Q-system) is based on the joints present in the rock mass.

The Relation between RMR and Q index.

$$RMR = 9 \log_e Q + 44$$

Classification of RMR rating:-

RMR Rate	Description
100 - 80	Very good
80 - 60	good
60 - 40	fair
40 - 20	poor
< 20	Very poor

classification of Q - system

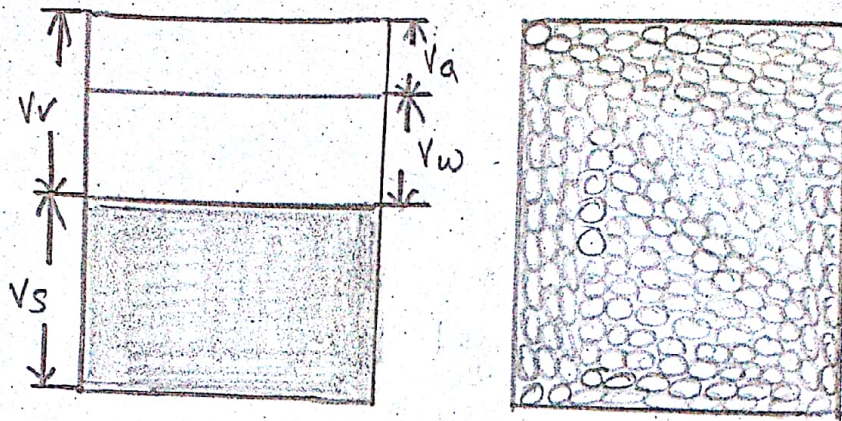
1000 - 400	Exceptionally good
400 - 100	Extremely good
100 - 40	Very good
40 - 10	good
10 - 4	fair
4 - 1	poor
1 to 0.1	Very poor
0.1 - 0.01	Extremely poor
0.01 - 0.001	Exceptionally poor

* classification of rock mass based on Moh's scale of hardness :-

* The God can feed an Orphan Quicker than a cow Does

- Talc - 1
- Gypsum - 2
- Calcite - 3
- Fluorite - 4
- Apatite - 5
- Orthoclase - 6
- Quartz - 7
- Topaz - 8
- Corundum - 9
- Diamond - 10

physical Properties of rocks:-



Where

V = Total volume of the sample

V_v = Volume of void

V_s = volume of solid

V_a = volume of air

V_w = volume of water.

Porosity:-

It is the ratio of the volume of void to the total volume of the sample.

$$\text{Porosity} = \frac{V_v}{V}$$

Void ratio:-

It is the ratio of volume of void to the volume of solid

$$\text{Void ratio (m)} = \frac{V_v}{V_s}$$

$$e \text{ (porosity)} = \frac{V_v}{V}$$

But

$$V = V_s + V_v$$

$$e = \frac{V_v}{V_s + V_v}$$

Dividing with V_s we get

$$e = \frac{V_v/V_s}{V_s/V_s + V_v/V_s}$$

$$e = \frac{m}{1+m} \quad \left[\because \frac{V_v}{V_s} = m \right]$$

* Degree of Saturation:-

It is the ratio of the water to the volume of void.

$$\text{Degree of Saturation} = \frac{V_w}{V_v} \times 100$$

for

fully saturated sample $V_w = V_v$.

Then the degree of saturation = 100%.

* Water Content or Moisture Content:-

It is the ratio of the weight of water to the weight of solid.

$$\text{Water Content} = \frac{W_w}{W_s}$$

* Bulk Density:-

It is the ratio of the mass of the sample per unit volume.

$$\text{Bulk Density } (\rho) = \frac{M}{V} \text{ kg/m}^3$$

* Specific gravity:-

It is the ratio of weight of solid in water to the volume of water displaced

$$\text{Specific gravity } (s) = \frac{W_s}{V_w}$$

* Permeability:-

It represents the rate of flow of water through the rock mass.

The permeability of rock mass depends on its porosity

$$Q = K \times i \times A$$

Where

K is the coefficient of conductivity of rock mass.

i is hydraulic gradient.

A is cross-sectional area

Q is the quantity of water flowing through the rock mass.

* Thermal Conductivity:-

→ The thermal conductivity represents the transformation of heat through the rock mass.

→ It also represents geo-thermal gradient of particular location.

* Electric Conductivity:-

It represents the conductivity of electricity through the rock mass.

* Compressive strength:-

The Compressive strength of rock mass is used to represent the strength of the rock mass when the load is applied on it.

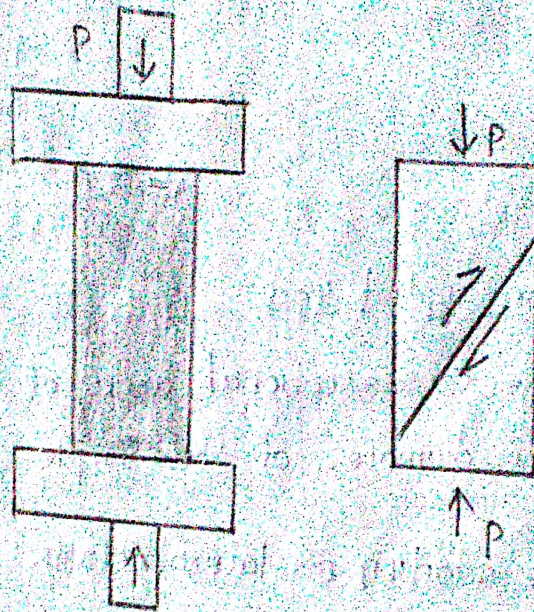
The compressive strength is calculated by anyone of the following methods based on the type of load applied on the sample.

→ Uni-axial Compressive strength

→ Tri-axial Compressive strength.

In order to compute the compressive strength of rock mass the rock sample prepared must meet ISRM standards having slenderness ratio (40)

* Unconfined compressive strength (or)
Uni-axial compressive strength



- ⇒ In case of determination of uni-axial compressive strength the load is applied in uni-directional.
- ⇒ The rock sample prepared is placed between the platens of universal testing Machine UTM
- ⇒ Now the load is applied gradually in a regular time interval and readings are taken
- ⇒ The load at which the rock sample fails is noted carefully.

The uni-axial compressive strength is determined by the following formula.

Uni-axial compressive strength is determined by the following formula.

$$\text{Uni-axial compressive strength} = \frac{P}{A}$$

$$= \frac{P}{\frac{\pi d^2}{4}} = \frac{4P}{\pi d^2}$$

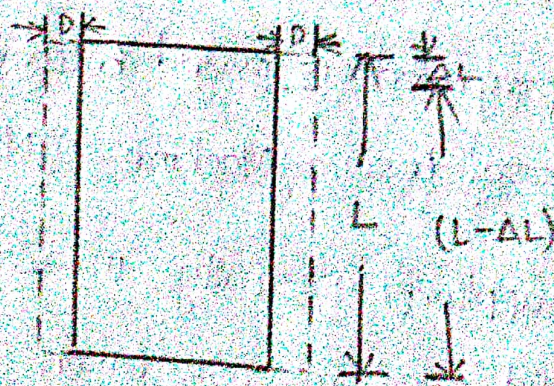
Where

P is the applied load

A is the cross-sectional area of sample

D is the diameter of the sample.

With the addition of lateral strain gauges the deformation along lateral and longitudinal direction are being measured.



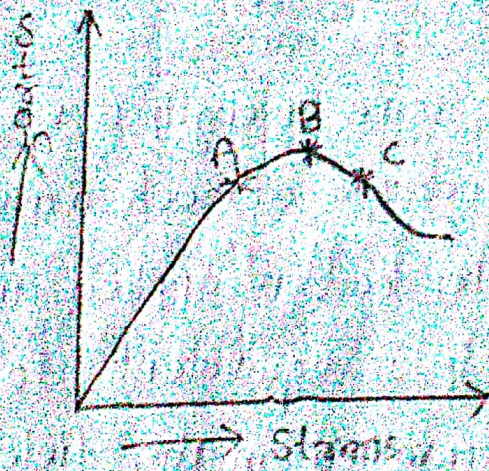
By measuring the lateral and longitudinal ratio of the sample its poisson's ratio is calculated.

$$\text{Poisson's ratio} = \frac{\text{Lateral strain}}{\text{longitudinal or linear strain}}$$

$$\mu \text{ or } \frac{1}{m} = \frac{\frac{\Delta D}{D}}{\frac{\Delta L}{L}}$$

Stress Vs strain graph

Graph is also plotted from the readings noted



- A → stress within elastic limit
- B → ultimate stress
- C → stress at failure

* Precautions:-

The following precautions are to be taken while calculating uni-axial compressive strength.

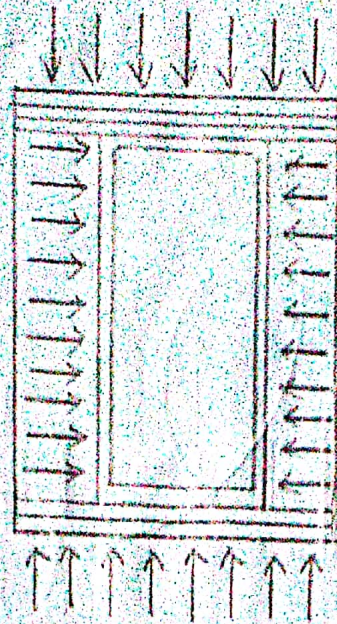
- The rock sample has to be prepared as per ISRM standards.
- The uni-axial load has to be applied gradually.
- The readings have to be taken carefully while performing the experiment.

Tri-axial Compressive strength :-
(or)

Confined Compressive strength :-

- The tri-axial compressive strength is used to know the insitu conditions of rock mass.
- In this method the load is applied in all the directions which is equivalent to the stress conditions prevailing in the field.
- The rock sample prepared is placed inside a tri-axial rubber tube.
- The tri-axial casing of rock sample is placed inside the tri-axial container.

The tri-axial cell containing the rock sample is placed between the platforms of UTM



The lateral force is applied by means of hydraulic fluid at required pressure (σ_3).

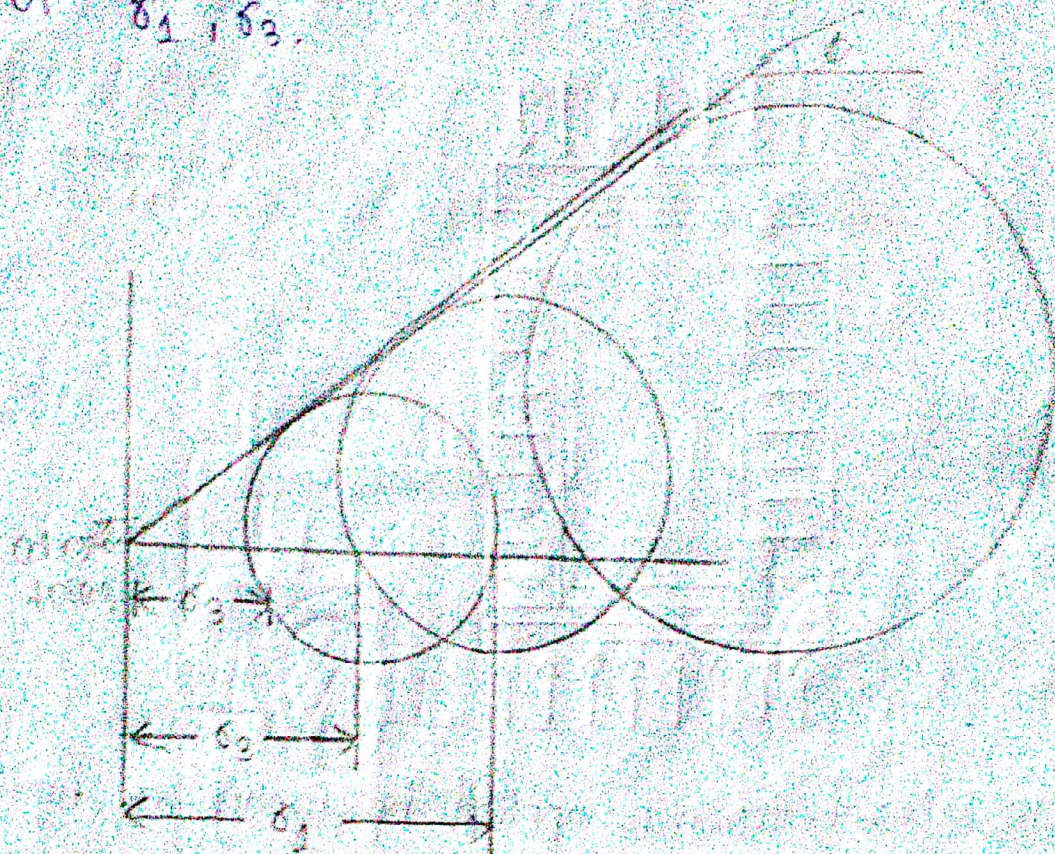
The longitudinal force is applied by Universal Testing Machine gradually (σ_1)

The longitudinal and lateral forces are applied at regular time intervals till the rock sample fails.

The readings are noted in the following tabular form

S.No	σ_1 longitudinal stress	σ_3 lateral stress
1		
2		
3		
4		
5		

The mohr's circle is plotted for various values of σ_1, σ_3 .



A tangent is drawn to all the mohr's circle and is known as mohr's envelope.

The tangent makes an intercept on τ -axis which represents the cohesion along the plane of radius failure.

The angle made by the tangent with the horizontal represents the angle of friction (ϕ).

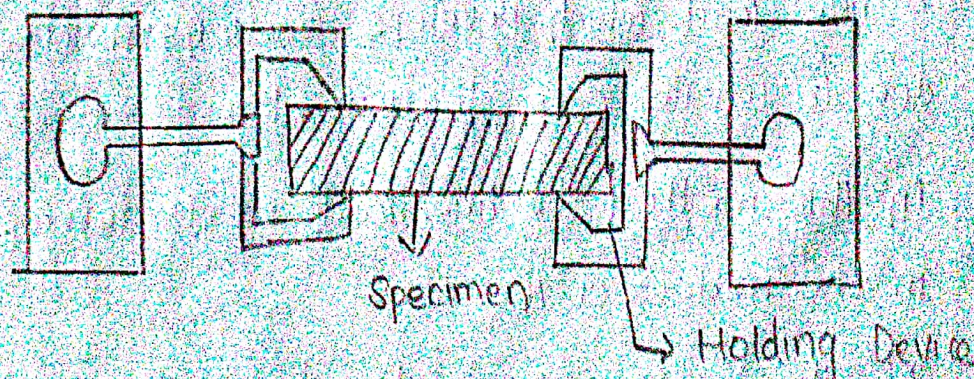
Precautions:

The following precautions are to be taken while calculating tri-axial compressive strength.

- The rock sample prepared must meet ISRM standards.
- Care must be taken to see that the load is applied in all directions.

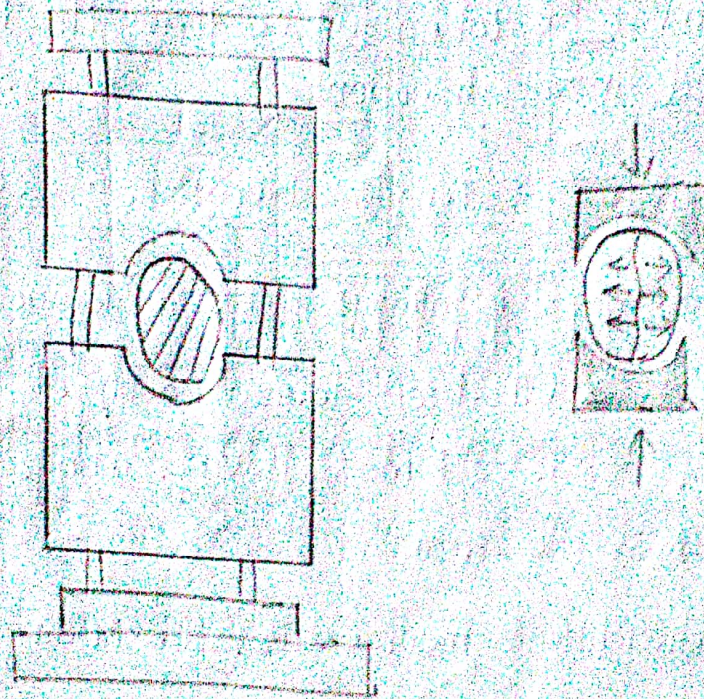
* Determination of Tensile strength of rock mass

- The rock mass is always weak in tension.
- The direct method of determination of tensile strength of a rock mass having many difficulties to perform the test.
- It is difficult to manufacture the holding devices to perform the test.



- Since it is difficult to perform this tensile strength test by direct method it will be carried out in the laboratory by indirect method.

- The indirect method of tensile strength is also known as Brazilian test.
- The Brazilian test is performed by using core sample of size $n \times$



- In this method, the cylindrical disc is subjected to a line load which develops fracture in the middle due to tensile force towards lateral direction.
- In this method the line load must develop fracture in the middle of the disc.
- If the fracture is developed at the ends of the disc that particular specimen must be discarded.

The tensile strength of the specimen is calculated by following formula

$$\sigma_t = \frac{2P}{\pi DL}$$



Where

P = is the load applied along the uni-axial direction

D = Diameter of the specimen

L = length of the thickness of the disc.

Precautions:

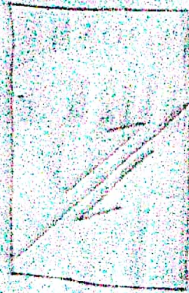
The following precautions are taken while calculating the tensile strength of rock mass. They are

- ⇒ The rock specimen should be of nx size
- ⇒ The slenderness ratio of the specimen is equal to 1
- ⇒ The load has to be applied gradually by performing test
- ⇒ The plane of failure must be in the middle of the specimen as it fails at the edges the specimen must be discarded

* Determination of shear strength of specimen

* Tensile < shear < compressive

→ The shear strength, if the strength of the specimen along its plane of failure gets sheared off



→ The shear strength of the specimen along the plane of failure depends on cohesion and angle of internal friction and the normal force acting along the failure plane

$$\sigma_{\text{shear}} = \sigma_n + c \tan \phi$$

Where σ_n is the normal stress acting on a failure plane

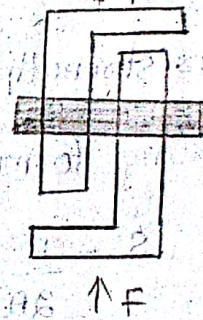
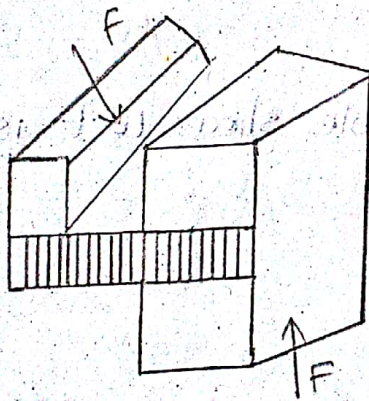
c is the cohesion or cohesive force

ϕ is the angle of internal friction

The shear test of a specimen as determined by following methods:-

- Simple shear test
- Double shear test
- Punch shear test
- Torsional shear test
- Oblique shear test

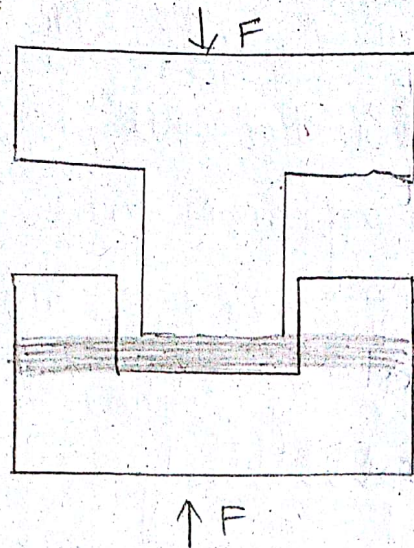
Single shear test:-



- In case of single shear test the shearing of the specimen takes place in single direction or (location)
- The shear strength can be calculated by the formula

$$S = \frac{F}{A}$$

Double shear strength :-



→ In case of Double shear test the specimen will fail two location.

→ The shear strength by double shear test is computed by following formula.

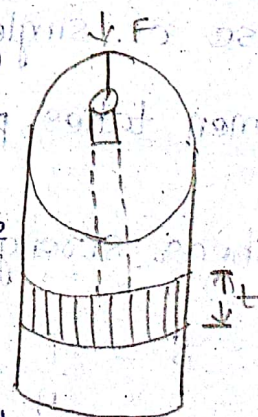
$$S = \frac{F}{2A}$$

Punch shear test :-

→ A punch of hole having dia (d) is created into the rock

specimen placed inside the device having thickness (t).

→ The rock specimen gets sheared off at the punch hole location.



↑ F is the punch shear test

- The shear strength is determined by the following formula.

$$S = \frac{F}{\pi dt}$$

Where

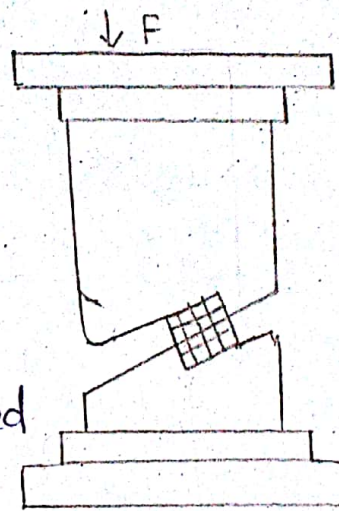
F is the force applied

d is the dia of the punch

t is the thickness of the specimen.

Oblique shear test:-

- In oblique shear test the shear specimen is placed at an oblique angle of 45° .



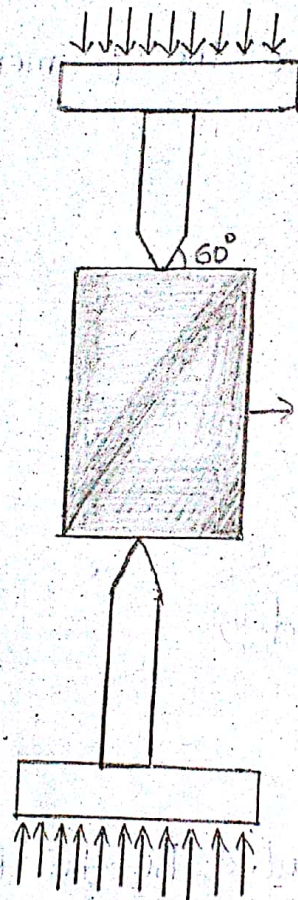
- When the load is applied the specimen gets sheared off along the

shear strength is computed by the formula

$$S = \frac{F}{A \cos 45^\circ}$$

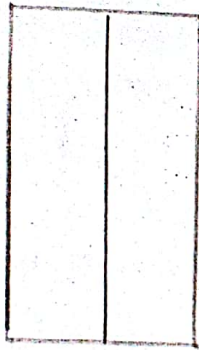
Point load strength index:-

The various strength indices of rock mass used to access the behaviour of rock under various geo-environmental conditions, such as Temperature, pressure, permeability and Watery conditions of rock mass.

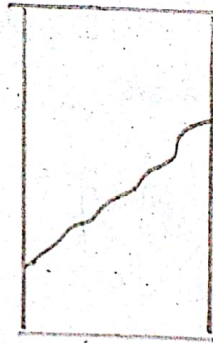


- In determination of point load strength index, the sample is prepared as per ISRM standards
- The rock sample is placed between the conical portion of point load strength index machine

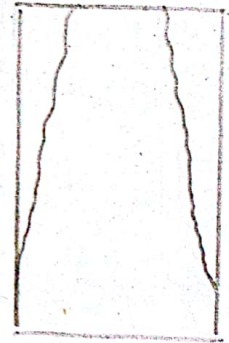
- The conical part of machine will make an angle of 60° with the horizontal.
- The load P is applied gradually using point load machine and the failure of rock sample with applied load has to be monitored carefully.
- The failure of different rock samples is observed carefully to access the behaviour of the rock sample under applied load.



Central failure



Cross-sectional failure



Spurt failure

- The following formula is used to calculate point load strength index.

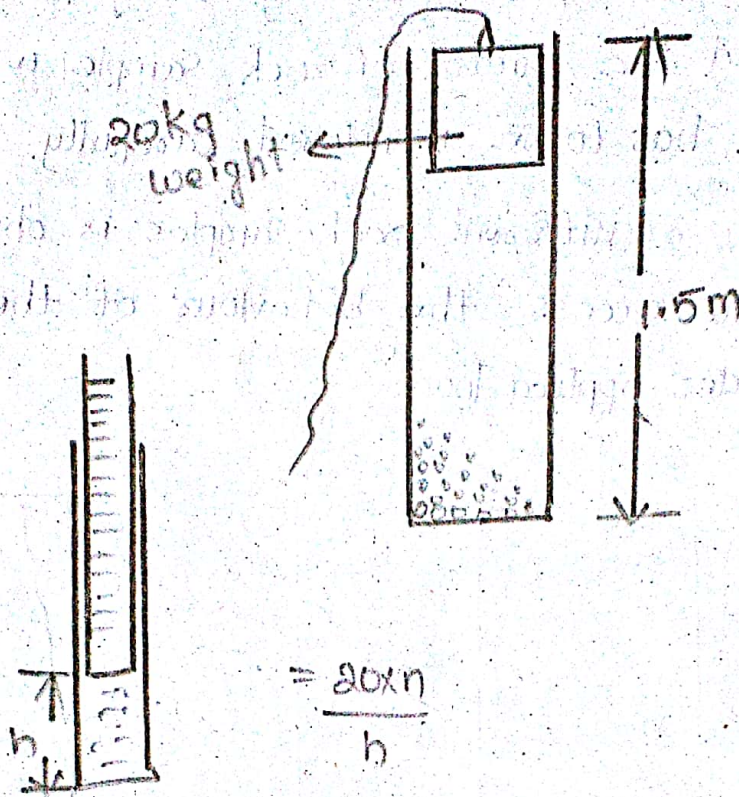
$$I_{\text{index}} = \frac{P}{D^2}$$

* Where,

→ P is the applied load

→ D is the diameter of the sample.

Proto Dyaknov Strength Index :-



The Proto dyaknov strength index is used to measure the crushing strength of the rock mass.

It consists of a hollow cylinder, made of cast iron having length of 1.5m.

A 20kg weight is attached with a nylon thread to give number of blows on the sample.

A sample of 100 grams each whose crushing strength is to be measured is placed at the bottom of the hollow cylinder.

by using a weight of 20 kg and is dropped from a height of 1.5 m.

Number of blows are given.

This total number of blows given for each sample should be equal to 5.

After subjecting number of blows, the crushed sample is taken out and allowed to pass through 10 mm sieve.

The above procedure is repeated for a total of 4 samples of each 100 grams.

The volume of the crushed sample which passes through the 10 mm sieve is placed in a volumeter.

The Volumeter is used to measure the length of the crushed sample by placing the measuring spindle inside the Volumeter.

The Protodykno's strength index is calculated of the sample by using the following formula.

$$\text{Protodykno's strength index} = \frac{20 \times n}{h}$$

Where

n = Total number of blows

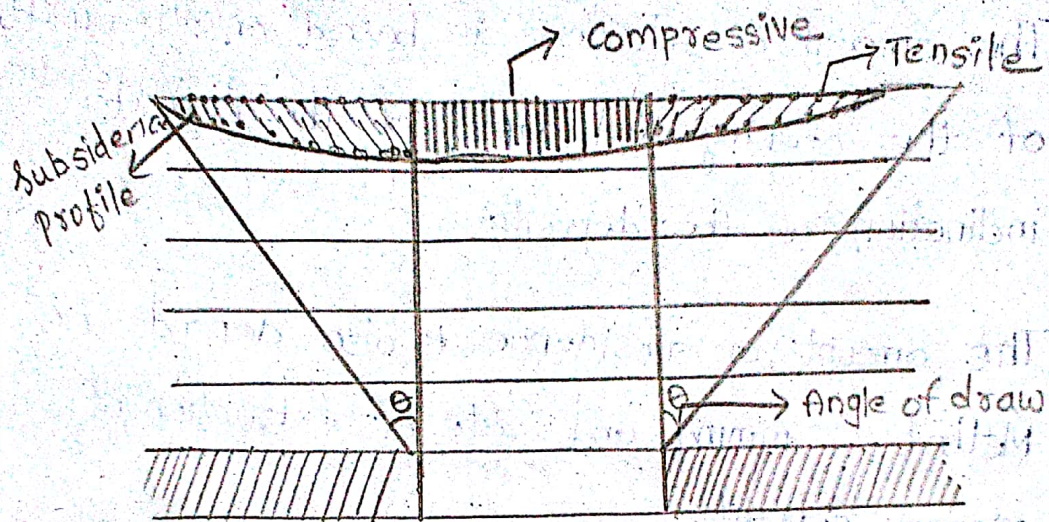
h = Length of the crushed sample in Volumometer

Precautions:-

The following precautions are to be taken while

* SUBSIDENCE *

Subsidence :-

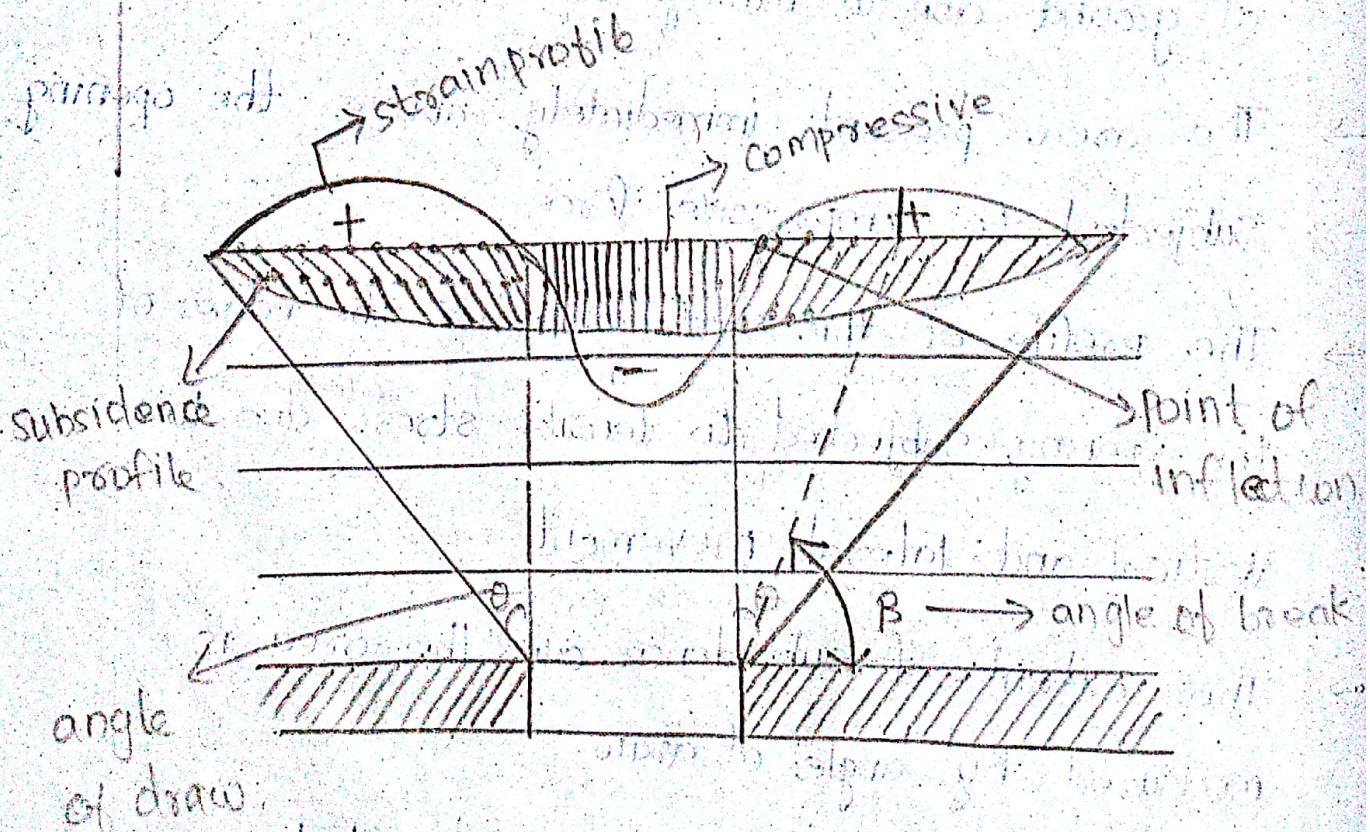


- It Subsidence is measure of change in profile of ground due to mining activity.
- The area present immediately above the opening subjected to compressive force
- The profile of the surface after the edges of the opening subjected to tensile stress due to vertical and lateral movement
- The extent of subsidence over the area is measured by angle of draw.
- An angle of draw is the angle between

vertical line at the edges of the opening and the line joining the edge of the opening and the point of zero subsidence

- The amount of subsidence is based on the width of the opening and depth of the deposits inclination of the deposits.
- The amount of subsidence is also depends on Method of mining and rate of extraction of mineral deposits.

* Various terms related to Subsidence:-

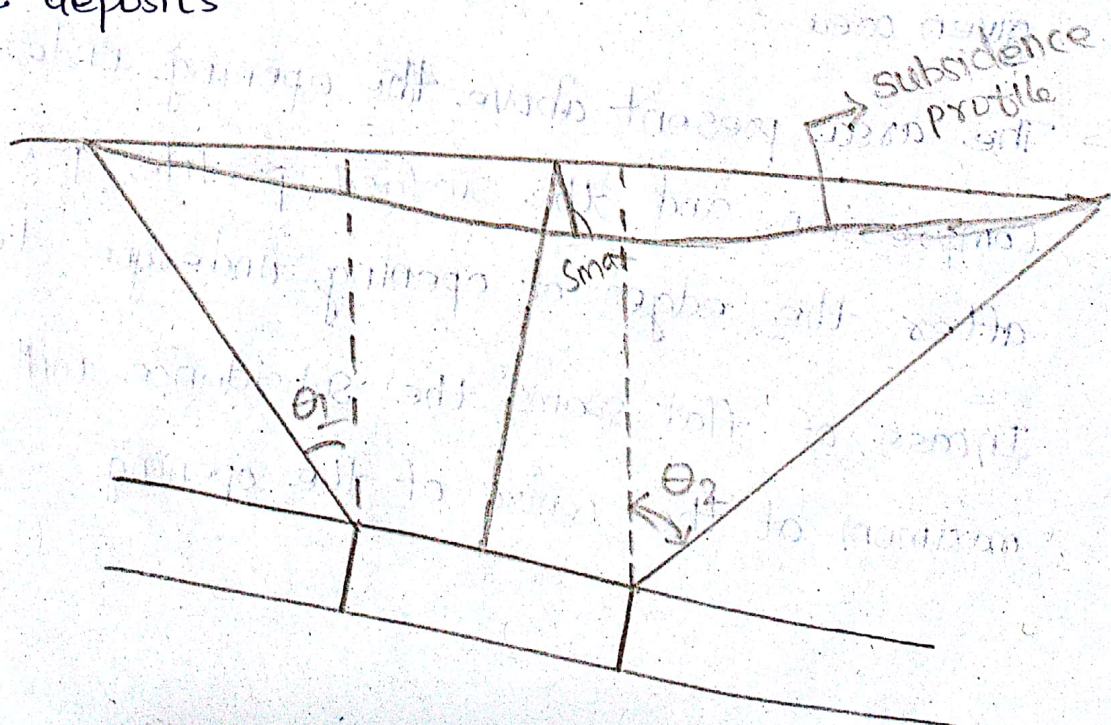


The following are various terms related to subsidence

- 1) Angle of draw.
- 2) Subsidence profile
- 3) strain profile
- 4) point of inflection
- 5) Angle of Break

* Angle of Draw:-

- It is the angle made with the vertical and the line joining edge of the opening to the point of zero subsidence.
- The angle of draw represents the extent of subsidence over a given area.
- The angle of draw depends on the inclination of the deposits

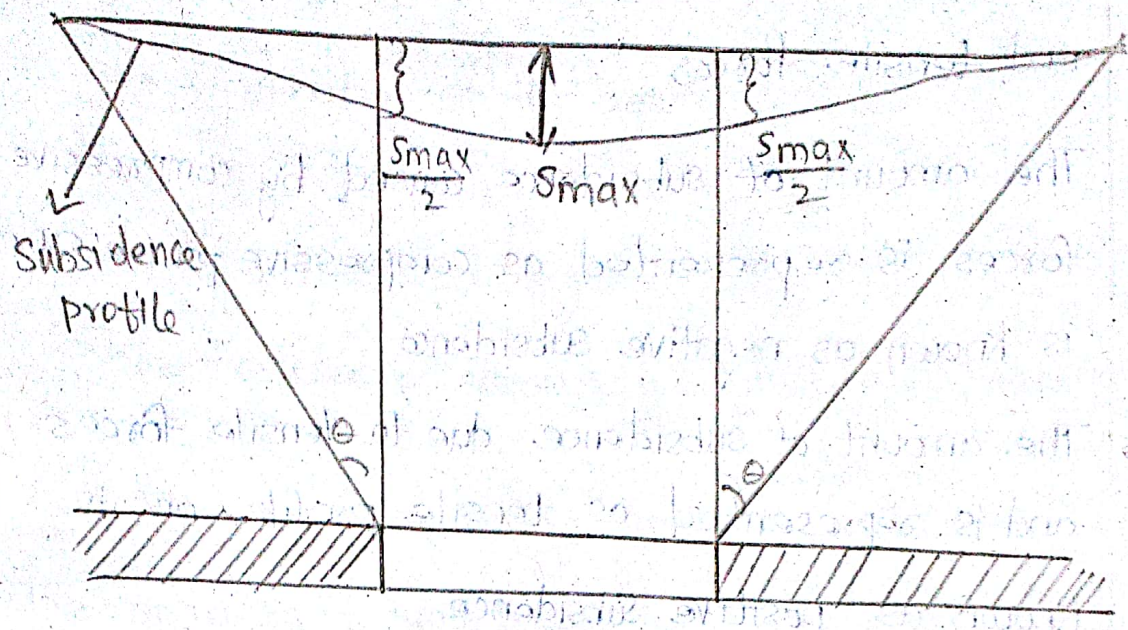


- The angle of draw which represents the extent of subsidence over the area varies with the inclination of the seam.
- The angle of draw decreases towards rise side and is known as negative angle of draw.
- The angle of draw increases towards the dip side of the seam and is known as positive angle of draw.
- In case of inclined seams the subsidence will be maximum at a point a line normal to the opening and its projection on the surface.

Subsidence Profile

- It represents the amount of subsidence over a given area.
- The area present above the opening undergoes compression and the surface profile present after the edges of opening undergoes tensile.
- In case of flat seams the subsidence will be maximum at the centre of the opening.

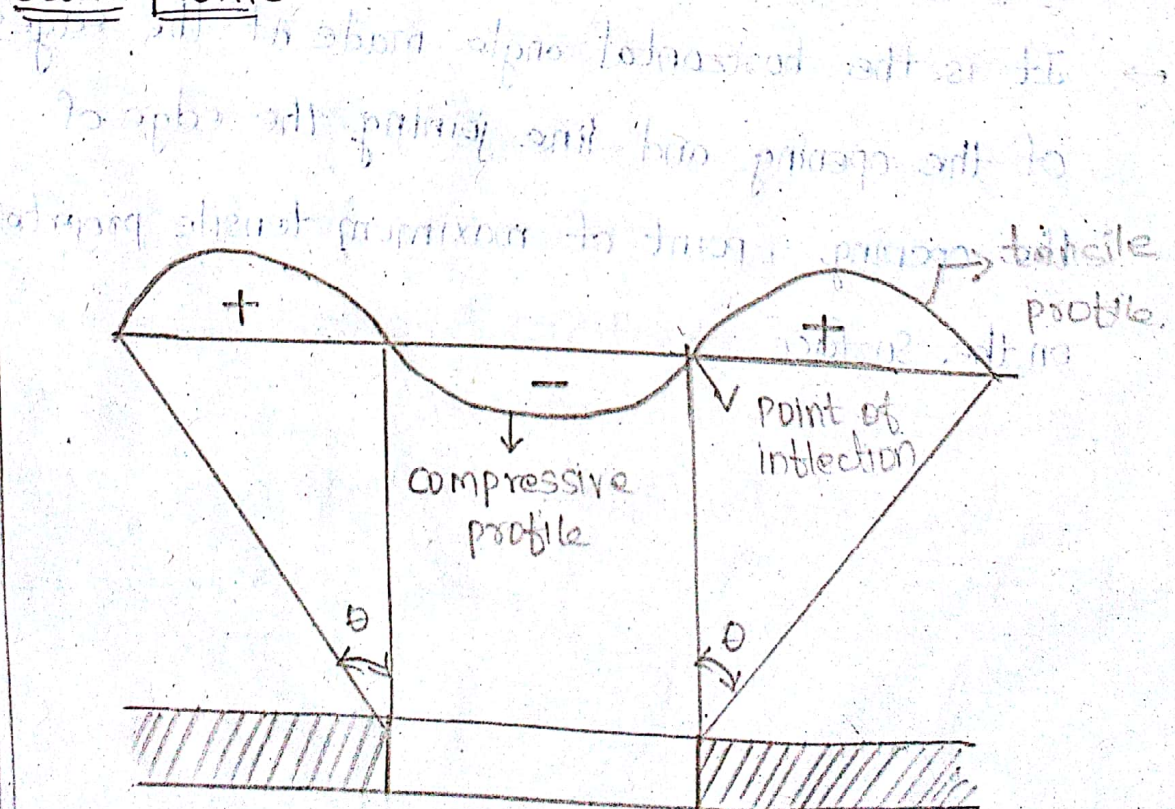
at points with a horizontal distance x from the center of the opening, the subsidence is given by



→ The subsidence at the edges of the opening is equal to half of the maximum subsidence

$$\frac{S_{max}}{2}$$

Strain profile



- The strain profile represents the change in displacement of surface profile due to compressive and tensile forces
- The amount of subsidence caused by compressive forces is represented as compressive profile and is known as negative subsidence
- The amount of subsidence due to tensile forces and is represented as tensile profile and is known as positive subsidence
- The point on the strain profile, where the compression changes to tensile and vice versa and is known as point of inflection

* Angle of Break

- It is the horizontal angle made at the edges of the opening and line joining the edge of the opening, point of maximum tensile projection on the surface

* Various factors influencing angle of draw:-

The angle of draw depends on the following factors:

- Inclination of the seam
- Width of the extraction
- Depth of the deposit
- Presence of various geological disturbances

* Factors influencing Subsidence:-

The amount of subsidence in a given area depends on the following factors.

- Width of the opening
- Depth of the deposits
- Method of Mining
- Rate of extraction
- Angle of draw
- Angle of break
- Geological conditions

(presence of various geological disturbances)

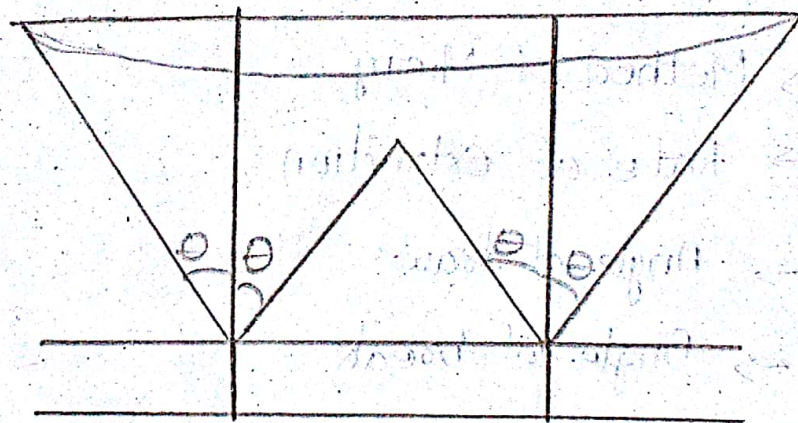
- physicommechanical properties of rock
- Time effect

* Types of subsidence :-

➔ Depending on the amount of subsidence on the surface, the subsidence over a area are categorised into three types.

- ➔ subcritical width of extraction
- ➔ Critical width of extraction
- ➔ Supercritical width of extraction.

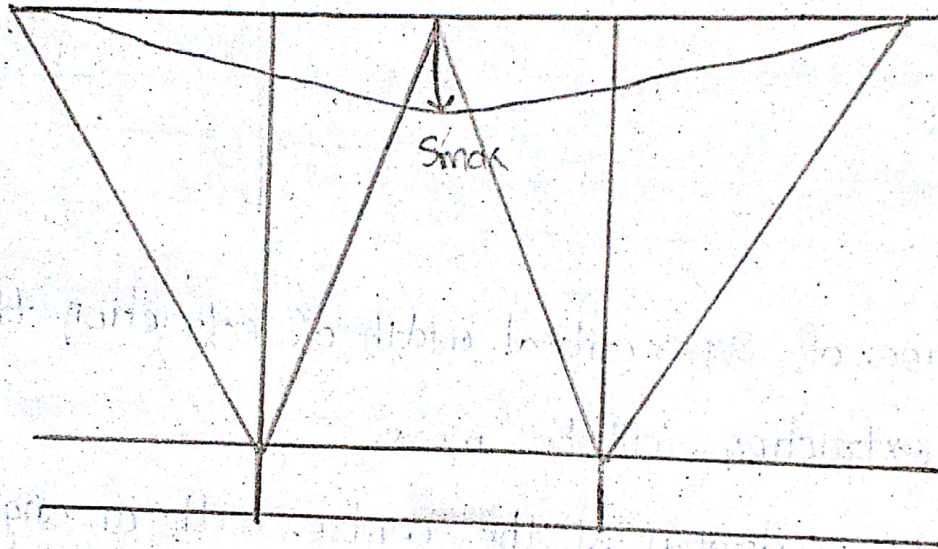
* Subcritical width of extraction :-



In case of subcritical width of extraction since the width of extraction is small, there is no maximum subsidence on the surface.

→ The lines joining with an angle equals to angle of draw will meet below the surface hence there will not be any maximum subsidence on the surface

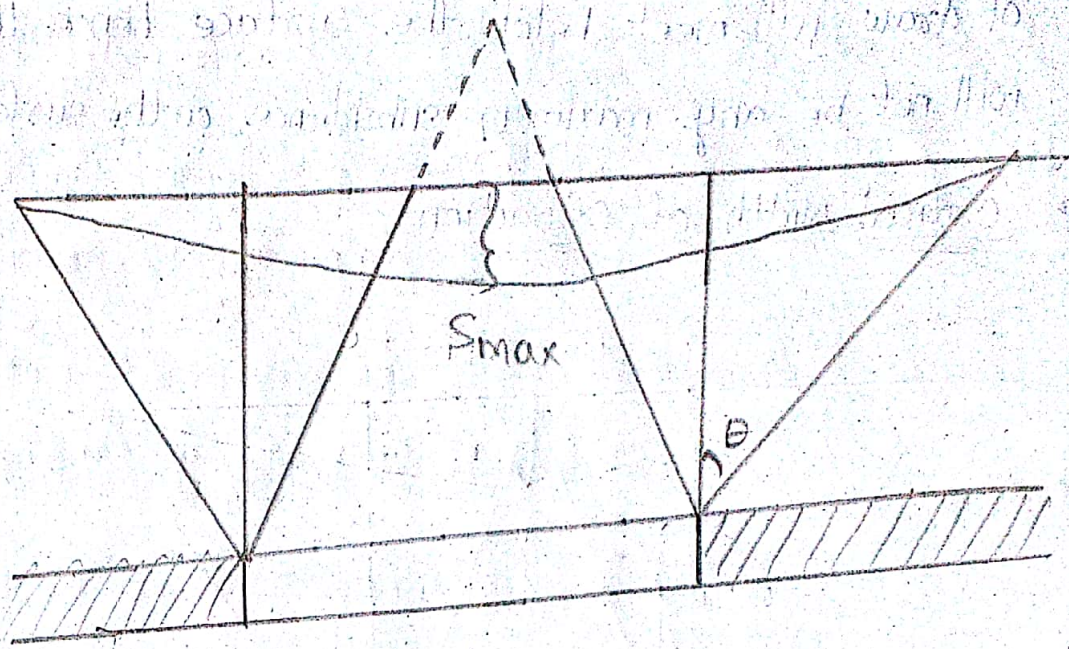
* Critical width of extraction:



→ In case of critical width of extraction, the maximum subsidence will be at single location

→ The lines joining at the centre with an angle equal to angle of draw will meet with a single location on the surface, hence the maximum subsidence is at single location

* Super critical width of extraction



- In case of super critical width of extraction the width of extraction will be more.
- The lines drawn at the centre with an angle equal to angle of draw will meet above the surface.
- The amount of subsidence will be maximum over an area.
- If W is the width of the opening and D is equal to depth of the deposit

$$\text{if } \frac{W}{D} \text{ is } < 1$$

$$\frac{W}{D} < 1$$

$$W < D$$

It indicates subcritical width of extraction

$$\text{If } \frac{W}{D} = 1$$

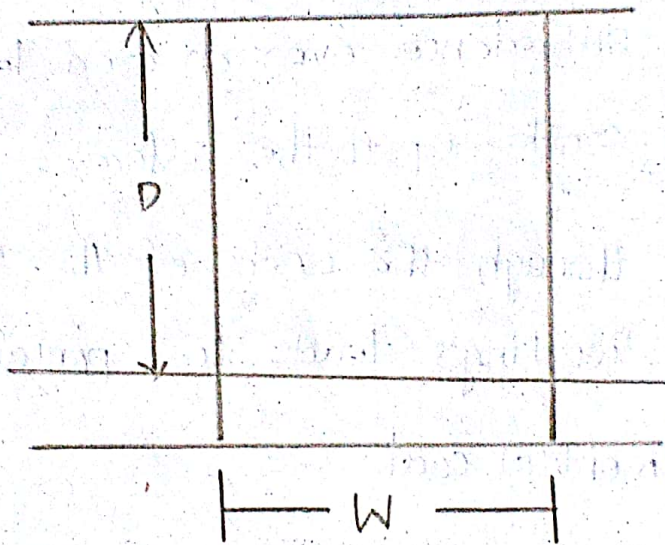
$$W = D$$

⇒ It indicates critical width of extraction.

$$\text{If } \frac{W}{D} > 1$$

$$W > D$$

⇒ It indicates supercritical width of extraction.



* Effects of subsidence:-

The following are the effects of subsidence.

- The Surface Topology of subsided area gets disturbed.
- The surface over the subsided area will get undulated.

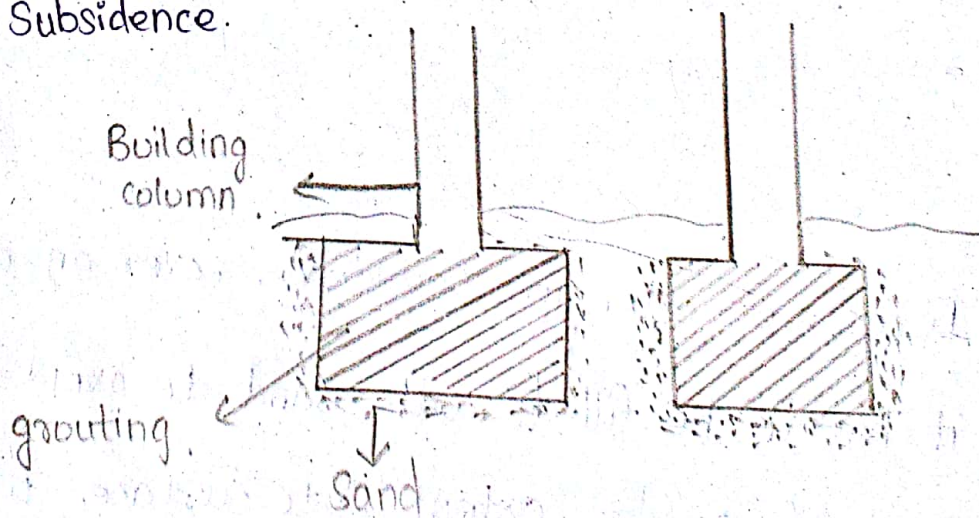
- ⇒ The important surface structures such as building, roadways, railways gets damaged.
- ⇒ The Subsided land cannot be used for any other purpose.
- ⇒ Any Sewerage pipeline passes through subsided area gets damaged due to development of cracks.
- ⇒ The excess of subsidence over an area leads to development of cracks up to the surface.
- ⇒ The air passes through the cracks of the subsidence into the mine workings leads to spontaneous heating development of coal.
- ⇒ The subsidence over the area changes the profile of surface drainage system.

* Protective Measures On the Surface and Underground to minimize the damages due to subsidence.

→ Protective measures against subsidence on the surface:

→ While constructing the important surface structures over the subsiding area, the foundation has to be laid in such a way that it will absorb or nullify the displacement strains created by ground movement due to subsidence.

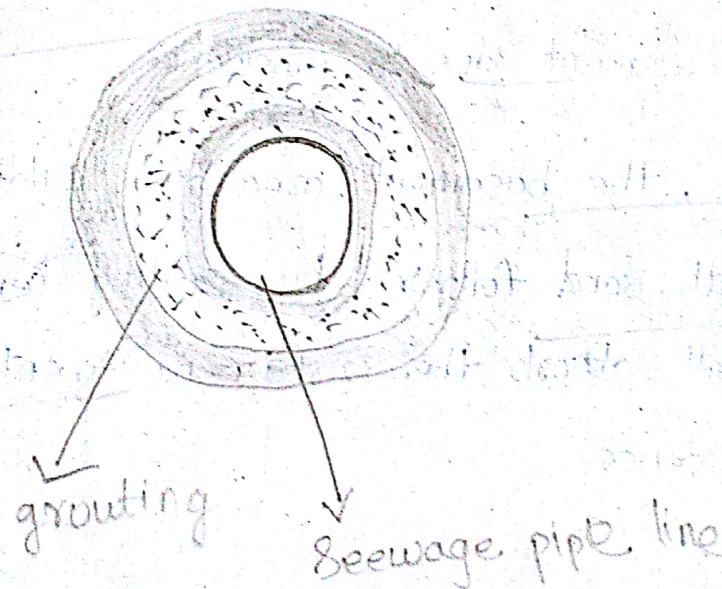
→ Generally, the basement area of a building is filled with sand followed by grouting cement which will absorb the surface movement caused by subsidence.



In case of any sewage pipe passes over the subsided area special grouting has to be provided to the pipeline.

→ The Grouting will absorb the ground movements created by subsidence and prevents the damage of the pipeline

→ The pipeline has to be laid at certain depth below ground.

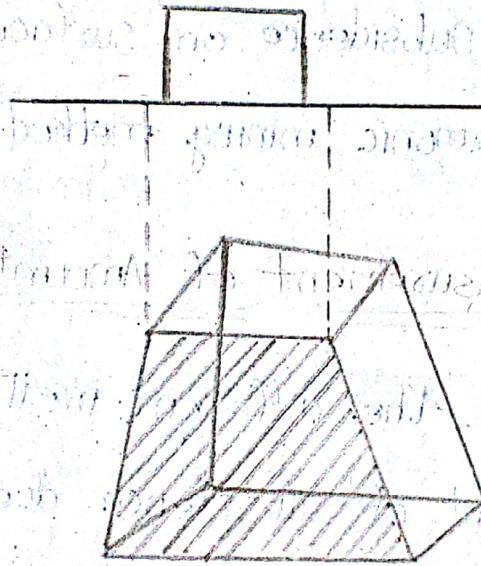


→ In case of extensive subsidence, over an area it has to be filled with sand to avoid development of cracks extent upto surface, which causes the leakage of air and water seepage into the workings

Underground

Protective Measures against Subsidence below ground

- In order to protect any important surface structures over the area suitable size of pillars has to be left in original condition without mining activities.



- The mining activity has to be carried out as per DGMS norms to protect important surface structures.
- By adopting mining activity along with stowing which reduces the amount of subsidence on the surface.
- In order to minimize the damage to the surface structures, the mining activity should be carried out at a faster rate as the amount of

Subsidence depends on the Time period.
The faster rate of extraction will provide uniform amount of subsidence on the surface which will not cause damage to the surface structure.

→ The amount of subsidence on surface can be reduced by "harmonic mining method".

* Methods of Measurement of Amount of Subsidence

The following are the different methods of measuring amount of subsidence due to mining on the surface.

→ Graphical Method

→ Analytical Method

→ Profile function

→ Physical Models

→ Numerical Method

→ Differential levelling Method

* Method of subsidence Measurement :-

* Instruments Required to carry out subsidence survey :-

→ Electronic Dumpy level.

→ Total station

→ LVDT instrument.

Procedure :-

The measurement of surface subsidence is being carried out by performing accurate level survey over the mining area.

The bench mark which is used as reference for levelling should be placed outside the mining boundary. Before carrying out the mining activity the surveying station at a regular interval has to be laid with cement grouting by digging a pit up to a smaller depth.

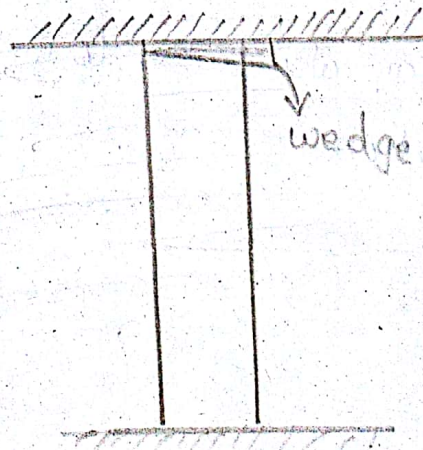
The reduced levels of surveying stations are calculated accurately using total station.

As the mining activity progresses below ground the reduced levels of surveying stations are calculated periodically to know the change in profile of ground due to mining.

- The above levelling operation is repeated periodically with the progress of mining activity and change in reduced levels of various surveying stations are measured.
- The Reduced levels of surveying stations are given as input to the DTM (Digital Terrain Model) Software.
- Based on the the reduced levels of surveying stations the DTM software will provide surface Topology view.
- The DTM software is also used to know the cross-section of surface profile ; which is used to measure the amount of subsidence.

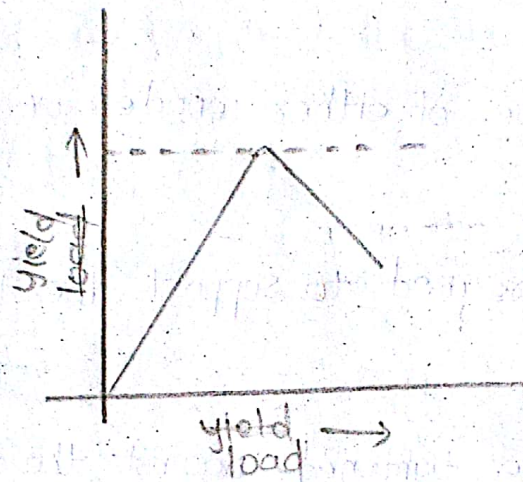
* Rigid Props:-

- While doing mining activity there are different types of supports used for effective strata control.
- The supporting system is used to avoid separation between the layers of strata known as bed separation.
- The Rigid prop are of either wooden or steel/iron props.
- The Rigid props are used to support the immediate roof quickly.
- The Rigid props are tightened against the roof by means of wedges. (triangular).

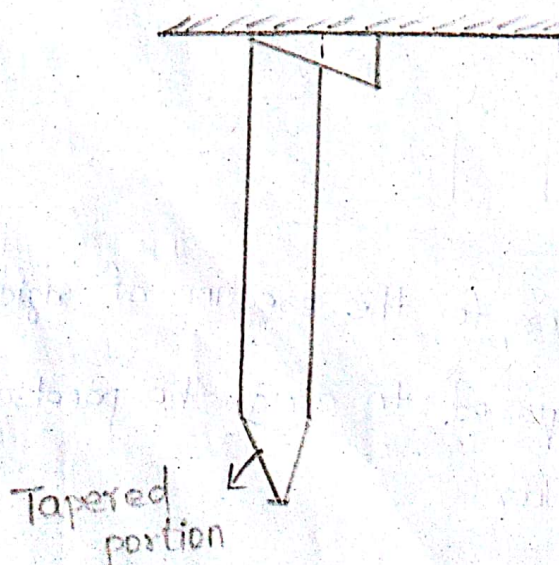


- In case of soft floor, for the erection of rigid prop a base plate is required to avoid the penetration of rock into the floor.

- The rigid prop can bear a load of maximum of its capacity.
- When the load acting on the prop exceeds its capacity it leads to failure of the prop which releases its load bearing capacity.

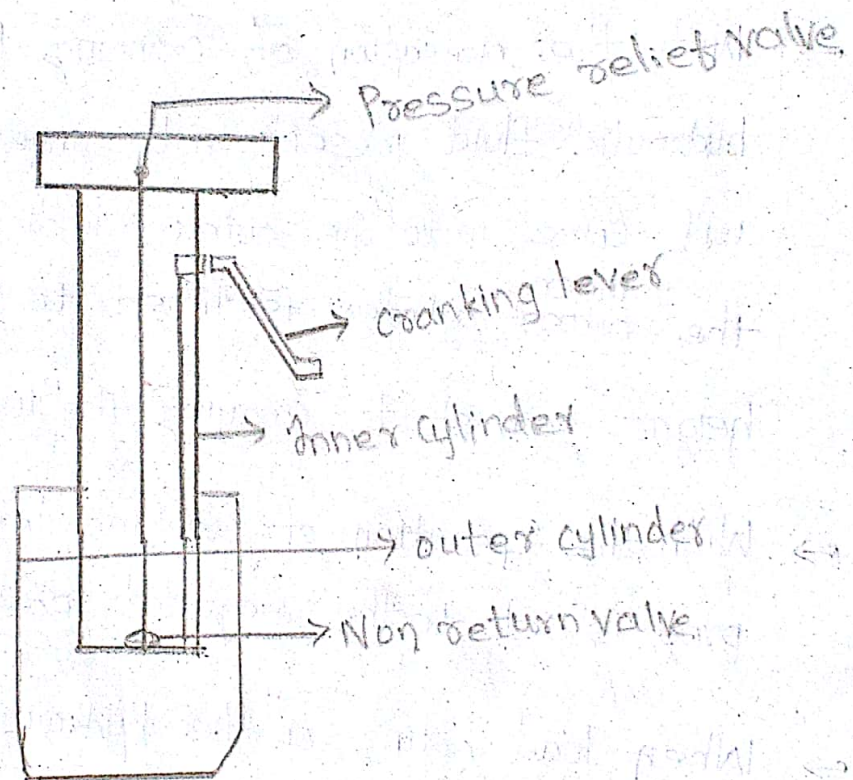


- The load yield characteristics of rigid prop is shown in the above figure.
- The rigid prop can also make to yield by tapering its bottom portion



→ The rigid prop with bottom tapered provides yield behaviour; When load acting on the prop exceeds its capacity it will penetrate into the floor which provides yield behaviour without failure of prop.

* Yield Prop or Hydraulic Prop :-



→ The hydraulic prop is an early load bearing prop which will carry the load immediately after setting the prop

→ It consists of two cylinders, namely

- outer cylinder
- inner cylinder

which are operated telescopically.

→ It consists of a non-return valve at the bottom part of inner cylinder, which will allow the flow of hydraulic fluid in one direction.

→ The hydraulic prop is provided with cranking lever which is used to set the hydraulic prop

→ With the operation of cranking lever, the hydraulic fluid present in the inner cylinder will come into the outer cylinder, as a result the ^{inner} outer cylinder is lifted to the required height and start carrying the load.

→ With the operation of cranking lever, the hydraulic prop is set to the required load.

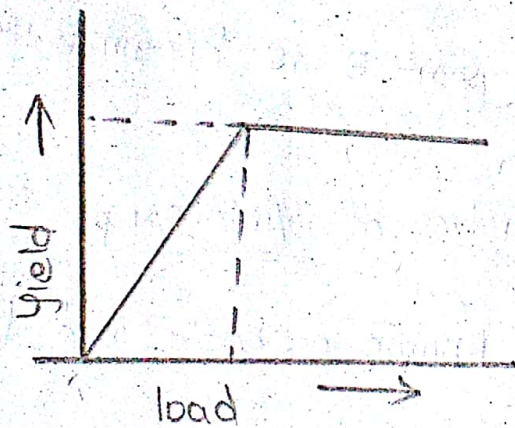
→ When load acting on the hydraulic prop exceeds its capacity it operates pressure relief valve and starts yielding

→ With the operation of pressure relief valve, the hydraulic fluid present in the outer cylinder will enter into inner cylinder, which, lowers

the inner cylinder of hydraulic prop carrying the same load.

→ The property of hydraulic prop starts lowering at by bearing yield load (maximum capacity without failure) is known as yielding

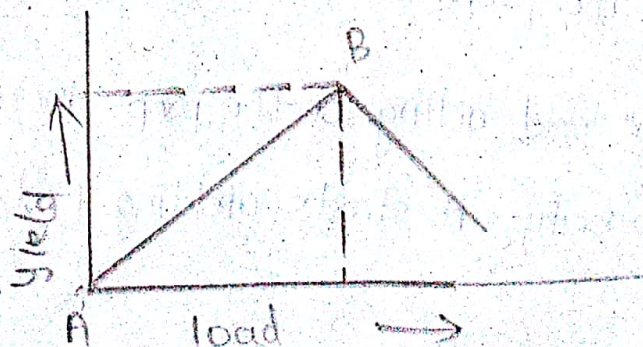
→ The load yield characteristics are represented by the following figure



* Load Yield characteristics of friction prop:-

→ The friction or rigid prop is known as non-yielding prop

→ When the prop is set against the roof it starts carrying the load.

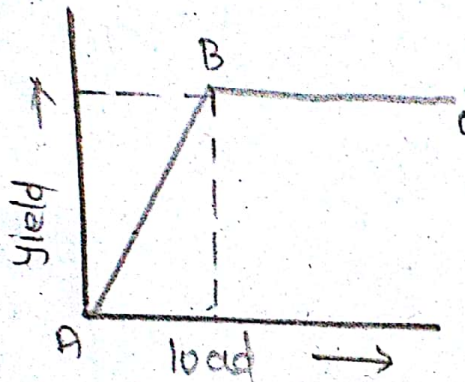


- When the load acting on the prop increases as the face advances and reaches the maximum Capacity AB.
- The load acting on the prop further decreases it leads to failure of prop with the release of load acting on it, It is represented as 'BC' in the above figure.
- The load acting at point B is known as yield load.

Load Yield characteristics of Yield prop:

- The hydraulic prop is known as early load bearing Capacity prop.
- When hydraulic prop is set against the roof by operating cranking lever it starts carrying the load.
- As the advancement of face takes place the load acting on the prop increases.
- When the load acting on the prop increases, maximum of its capacity it starts yielding without failure.

- At the yielding position, the prop. will continue carrying the load without failure. by lowering its position.
- At the yield load the pressure relief valve operates which lowers hydraulic prop.



Roof Bolting:-