MODULE-2

- Determination of Physico-Mechanical properties of Rock and their Determination
- Rheological Properties of Rock and their Determination

Module -2 PHYSICAL AND MECHANICAL PROPERTIES OF ROCK

(i) The performance of a rock, under a particular condition, depends upon the physical and mechanical properties of the rock.

(ii) The physical properties also known as index property helps in describing the material of the rock and in classifying the rock.

(iii) The Mechanical property also known as strength property helps in describing the performance of the rock, when subjected to a particular loading system.

Note

physico-Mechanical properties of a same rock may vary drastically from place to place and even from time to time in a same geological formation.

Physical property	Mechanical Property
1. Density (kg/m³)	1. Modulous of Elasticity (E)
2. specific Gravity (Unitless)	2. Uniaxial Compressive strain (Mpas)
3. Porosity (Unitless)	3. Tensile strain (Mpa)
4. Void Ratio	4. shear strain
5. Moisture Content	5. point load strain
6. permeability	6. poission Ratio
7. swelling property	

* Dry density $(\rho_d) = \dfrac{\text{Mass of the solid}}{\text{Total Volume}} = \dfrac{Kg}{m^3}$

*. Unit weight of solid $= \dfrac{\text{Mass of dry solid}}{\text{True Volume}}$.

True Volume signifies the grains without pores and fissures.

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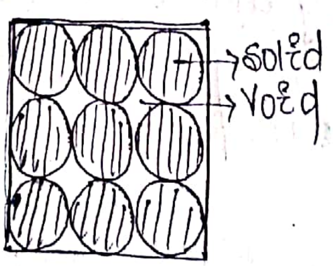
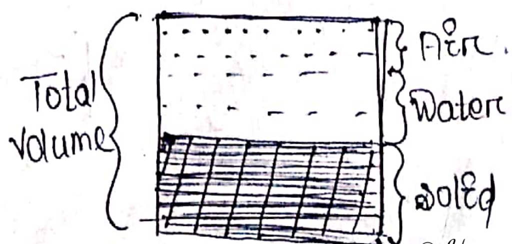




* Bulk unit Weight = $\frac{\text{Mass of a dry solid Rock}}{\text{Volume (including pores and fissures)}}$

* Dry density means mass per unit volume when the rock mass is dry i.e. void contains only air.

* Bulk density means mass per unit volume in normal condition i.e. void contain some liquid and some air.

* Wet density (or saturated) means mass per unit volume when the rock mass is fully saturated.

Relation between dry density and Bulk density

$$\boxed{\rho_d = \frac{\gamma}{1+m}}$$

where ρ_d = dry density
γ = Bulk density
m = Moisture content of the sample.

Moisture Content (m)

(i) Moisture content of a rock sample is defined as the ratio of weight of water in void to the weight of solid of the sample.

(ii) $\boxed{m = \frac{W_w}{W_s}}$ or $m = \frac{\text{Mass}_{wet} - \text{Mass}_{dry}}{\text{Mass}_{dry}}$.

$V_{Total} = V_{solid} + V_{water} + V_{air}$

When the rock is dry

$V_{Total} = V_{solid} + V_{air}$

Void Ratio (e)

$$e = \frac{V_{void}}{\text{Volume of solid}} \Rightarrow \boxed{e = \frac{V_v}{V_s}}$$

Porosity

$$\text{Porosity } (\eta) = \frac{\text{Volume of Void}}{\text{Total Volume}} = \frac{V_v}{V_s}, \Rightarrow \boxed{\eta = \frac{V_v}{V}} \times 100$$

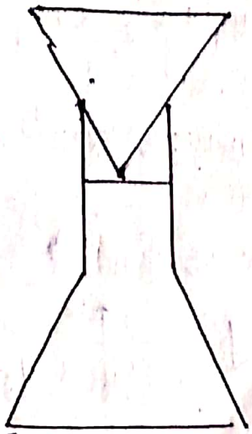
Relation between porosity and void Ratio

$$\eta = \frac{V_v}{V} = \frac{\frac{V_v}{V_s}}{\frac{V_v}{V_s} + \frac{V_s}{V_s}} \Rightarrow \boxed{\eta = \frac{e}{e+1}}$$

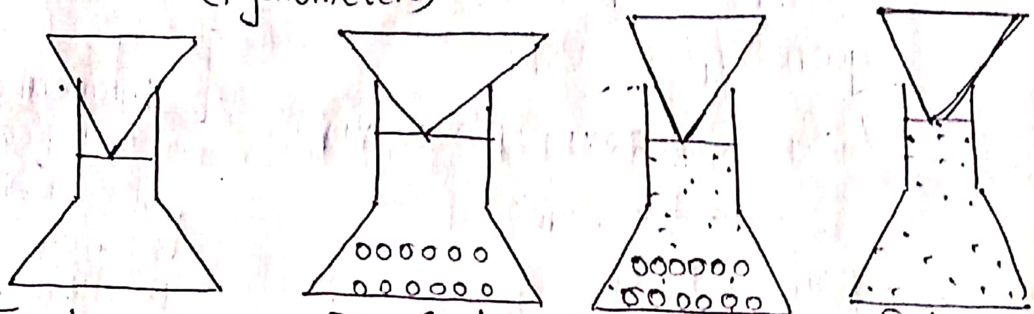
Specific Gravity (G)

$G = \frac{\rho_s}{\rho_w} \Rightarrow \boxed{G = \frac{M_s}{\rho_w \times V_s}}$

Where M_s = Mass of solid
ρ_w = density of water
V_s = Volume of solid



(Pycnometer)



W_1 = Weight of the pycnometer
W_2 = Weight of the pynometer + dry coal
W_3 = Weight of the pynometer + dry coal + water
W_4 = Weight of the pynomoter + water

Mass of the solid = $W_2 - W_1$

Volume of the solid = $\frac{(W_4 - W_1) - (W_3 - W_2)}{\rho_w}$

Q Dry sandstone sample of dia = 22mm and height 35mm. Weight 30 gm. The sample is crushed. Find the specific gravity having the following data. $W_3 = 91$ gm, $W_4 = 72$ gm and also find the porosity of the sample.

Ans Given =, d = 22 mm, h = 35 mm
$W_2 - W_1 = 30$ gm = Mass of the solid
$W_3 = 91$ gm, $W_4 = 72$ gm

We Know,

Volume of the sand $= \frac{(W_4 - W_1) - (W_3 - W_2)}{\rho_w}$

$= \frac{W_4 - W_3 + W_2 - W_1}{\rho_w}$

$= \frac{(72 - 91 + 30) \times 10^{-3}}{1000}$

$= 11 \times 10^{-6}\ m^3$

Now, specific gravity $= \frac{M_s}{\rho_w \times V_s} = \frac{30 \times 10^{-3}}{1000 \times 10^{-6} \times 11}$

$\Rightarrow \boxed{G = 2.72}$

Again $V_T = V_s + V_v$

$\Rightarrow V_T = \frac{\pi}{4} \times (22 \times 10^{-3})^2 \times 35 \times 10^{-3}$

$= 1.33 \times 10^{-5}\ m^3$

$V_s = 11 \times 10^{-6}\ m^3$

$\therefore V_v = V_T - V_s = 1.33 \times 10^{-5} - 11 \times 10^{-6} =$

$\Rightarrow \boxed{V_v = 2.3 \times 10^{-6}\ m^3}$

[Permeability is defined as the ability of a porous material to allow liquid to pass through it]

porosity $= \frac{V_v}{V_T} = \frac{2.3 \times 10^{-6}}{1.33 \times 10^{-5}} = 0.172$

Permeability

(i) permeability test is based on the Darcy's law.

(ii) He proposed that for Laminar and steady flow the discharge velocity (V) from the end discharge point is proportional to the hydraulic gradient. where,

$V \propto \frac{\Delta h}{\Delta L}$

$\Rightarrow V = K \frac{\Delta h}{\Delta L}$

$\Rightarrow V = KI$

$\Rightarrow \boxed{q = KAI}$

q = Rate of water flow (m^3/sec)

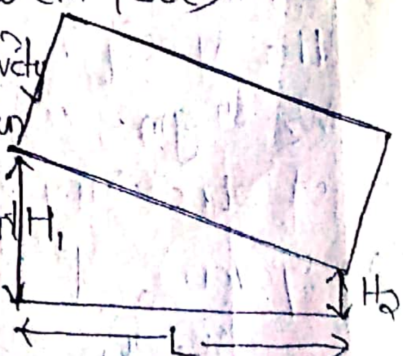
K = hydraulic Conductivity

A = Area of crossection of sample

I = hydraulic Gradient

H = Head of water (m)

L = length of specimen



Q.

Ans

Again $q = KAI = \frac{Q}{t}$

Where Q = Volume of Water Collected

t = Duration of Water Collected

K = Hydraulic Conductivity or Coefficient of permeability

There are two methods to find the value of K,

1. Constand head Method

We know,

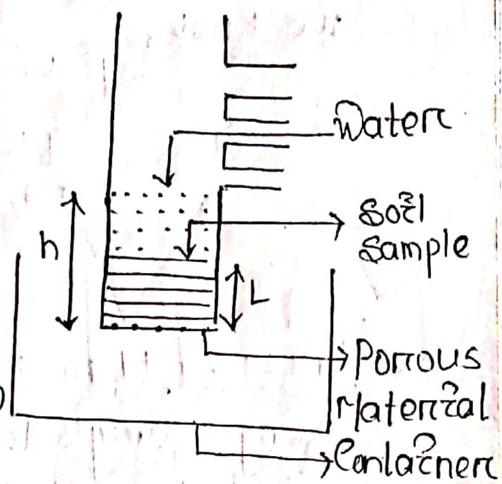
$q = KAI$

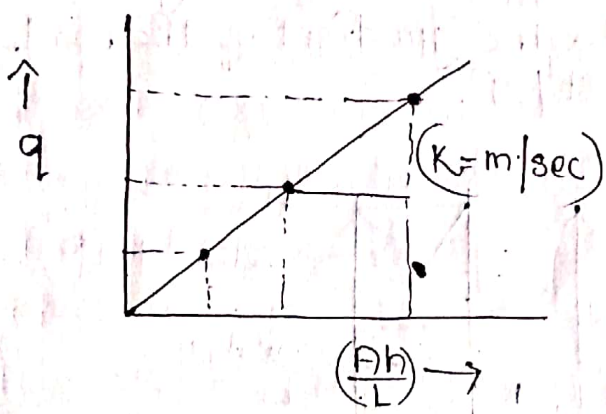
$\Rightarrow q = KA\frac{h}{L}$

$\Rightarrow q = K\left(\frac{Ah}{L}\right) \rightarrow (i)$

Again $y = mx \rightarrow (ii)$

Comparing equation (i) and (ii) we get





Q. A Constant head permeameter has a sample of medium grain sand 15 Cm in length and 25 Cm² Crossectional area with a head of 7 Cm. A total of 110 ml of Water is Collected in 12 minute. Find the hydraulic conductivity ?

Ans Given $L = 15\,Cm = 15 \times 10^{-2}\,m$

$A = 25\,Cm^2 = 25 \times 10^{-4}\,m$

$H = 7\,Cm = 7 \times 10^{-2}\,m$

$q = 110\,ml / 12\,min$

Now, q = 110 ml / 12 minute

$\Rightarrow$ 12 min = 110 ml

$\Rightarrow$ 1 min = $\frac{110 \times 10^{-3} \, l}{12}$

$\Rightarrow$ 1 sec = $\frac{110 \times 10^{-3}}{12 \times 60}$ = 0.0001527

$\therefore$ q = 0.0001527 l/sec

= $0.0001527 \times 10^{-3} \, m^3/sec$

We know,

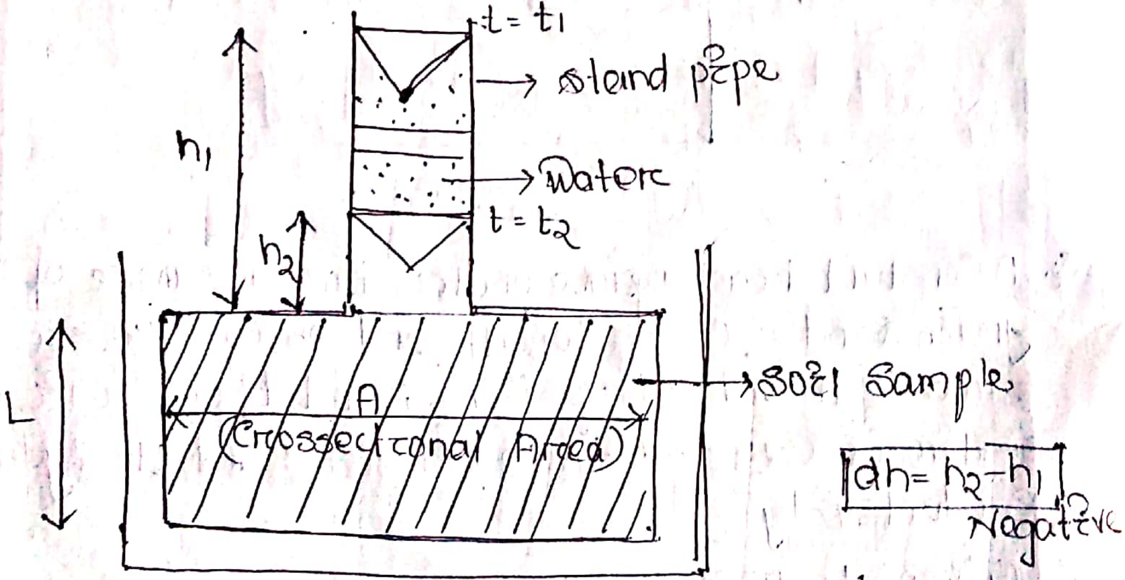
$$q = KA\frac{h}{L}$$

$$\Rightarrow K = \frac{qL}{Ah} = \frac{0.0001527 \times 10^{-3} \times 15 \times 10^{-2}}{25 \times 10^{-4} \times 7 \times 10^{-2}}$$

= 0.00013 m/sec (Ans)

2. FALLING HEAD METHOD

Using Darcy's law, we can state that quantity flowing through the sample length L at time t is related to the gradient of the head with respect to time dt/dh.



dh = $h_2 - h_1$
Negative

Now, $q = KAV$

$\Rightarrow q = A_p \times V$

$\Rightarrow KA\frac{dh}{dt} = A_p \times V$

$\Rightarrow$ K $\Rightarrow$ $dt = K \times \frac{A}{A_p} \times dh$

$q = -AV$

$\Rightarrow KA \times \frac{h}{L} = -A_p \times \frac{dh}{dt}$

$\Rightarrow dt = \frac{-A_p}{A} \times \frac{L}{K} \times \frac{dh}{h}$

$\Rightarrow \int_{t_1}^{t_2} dt = \frac{-A_p L}{AK} \int_{h}^{h} \frac{dh}{h}$

$$\Rightarrow (t_2 - t_1) = \frac{-A_p L}{AK} \ln(h_2/h_1)$$

$$\Rightarrow \boxed{K = \frac{A_p L}{(t_2 - t_1) A} \ln \frac{h_1}{h_2}}$$

$$\Rightarrow \boxed{K = 2.303 \frac{A_p L}{(t_2 - t_1) A} \log \frac{h_1}{h_2}}$$

Q. A falling head permeameter containing a fine sand has a falling head tube (standing tube) of dia 4 cm. A sample dia 12 cm and flow length is 15 cm. The initial head is 5 cm and it fall to 0.5 cm with time 528 min. Find K?

Ans $d_p = 4$ cm

$A_p = \frac{\pi}{4} \times (4 \times 10^{-2})^2$

$d = 12$ cm

$A = \frac{\pi}{4} \times (12 \times 10^{-2})^2$

$L = 15$ cm $= 15 \times 10^{-2}$

$h_1 = 5$ cm $= 5 \times 10^{-2}$ m

$h_2 = 0.5$ cm $= 0.5 \times 10^{-2}$ m

$t = 528$ min.

$$K = \frac{A_p L}{(t_2 - t_1) A} \ln \frac{h_1}{h_2}$$

$$= \frac{\frac{\pi}{4} \times (4 \times 10^{-2})^2 \times 15 \times 10^{-2}}{528 \times 60 \times \frac{\pi}{4} \times (12 \times 10^{-2})^2} \ln\left(\frac{5 \times 10^{-2}}{0.5 \times 10^{-2}}\right)$$

$$= 1.211 \times 10^{-6} \text{ m/sec}$$

Slake durability (Index I_d)

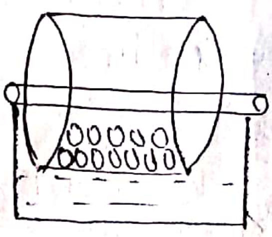
Rock sample after set of drying and wetting cycle.

A = Initial Mass of the drum + dry rock sample.

B = Mass of the drum + Mass of the rock after first cycle.

C = Mass of the drum + Mass of the rock after second cycle

D = Mass of the drum



$$I_{d_1} = \frac{B - D}{A - D} \times 100 \quad \text{(First Cycle)}$$

$$I_{d_2} = \frac{C - D}{A - D} \times 100 \quad \text{(Second Cycle)}$$

	Id_1	Id_2
Very high durability =	>99	>98
⋮	⋮	⋮
Very low durability =	<60	<30

Strength

(i) The ability of a material to resist an external applied load is called strength.

(ii) Rock strength depends upon the following factor.

1. Size of the rock specimen
2. Type of test
3. Duration of test
4. loading condition
5. Cycle of loading
6. Degree of saturation
7. Confining pressure

Tensile strength
Ability of a material to resist max^m tensile stress

Shear strength
Ability of a material to resist max^m shear stress.

(iii) Strength is of three types

1. Tensile strength
2. Compressive strength
3. Shear strength.

Compressive strength

It is again of two types

a) Uniaxial or Unconfined Compressive strength
b) Triaxial Compressive strength.

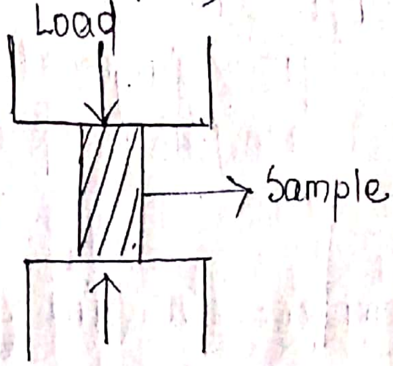
a) UNIAXIAL / UNCONFINED COMPRESSIVE STRENGTH

(i) Uniaxial / Unconfined Compressive strength is the strength of the rock when a load on the rock acts in one direction only.

(ii) There is no load along an axis perpendicular to the loading axis.

(iii) The uniaxial compressive strength is the value of compressive strength at which the specimen or sample break or fail.

(iv) This str test is conducted in straight, circular cylinder having height to dia ratio ($\frac{h}{d}$ = 2.0 – 3.0) and diameter preferably not less than Nx core diameter (54mm).



Test of UCS

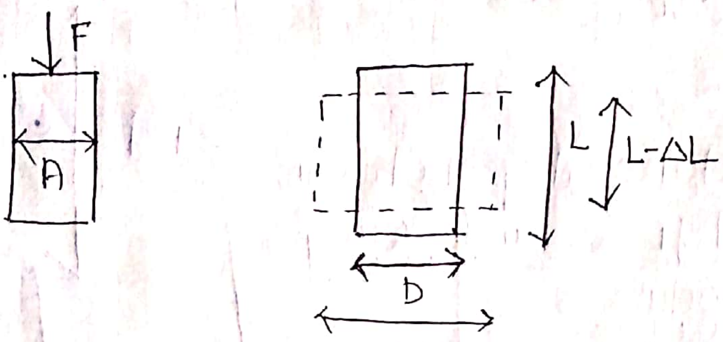
(i) Coring

(ii) Policing

(iii) Testing

*. stress = $\frac{\text{Force}}{\text{Area}} \Rightarrow$ $\boxed{\sigma = \frac{N}{m^2} = Mpa}$

*.



* Longitudinal strain = $\frac{\text{change in length}}{\text{Original length}} = -\frac{\Delta L}{L}$

*. Lateral strain = $\frac{\text{change in diameter}}{\text{Original diameter}} = \frac{\Delta D}{D}$

*. Poisson's Ratio = $-\frac{\text{Lateral strain}}{\text{Longitudinal strain}}$

$$= -\frac{\frac{\Delta D}{D}}{\frac{\Delta L}{L}}$$

Poisson's Ratio = (0 – 0.5)

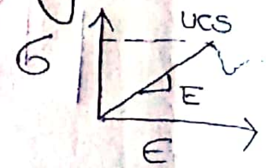
Hooke's law

Within elastic limit, stress is directly proportional to strain.

$\sigma \propto \epsilon$ — E = Young's Modulous or Modulous of elasticity.

$\Rightarrow \sigma = E\epsilon$

$\Rightarrow \boxed{E = \frac{\sigma}{\epsilon}}$

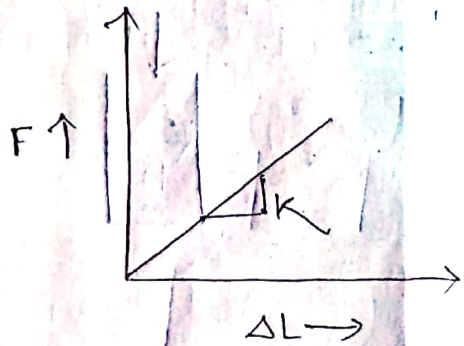


Triaxial Compressive strength

When a rock mass is subjected to an all around pressure and further it is subjected to an additional vertical pressure than the strength exhibited by the rock mass is known as triaxial compressive strength.

Stifness (K)

$K = \frac{F}{\Delta L}$



Relationship between stifness and Young's Modulous

$$E = \frac{\sigma}{\epsilon} = \frac{\frac{F}{A}}{\frac{\Delta L}{L}} = \frac{F}{A} \times \frac{L}{\Delta L} = \frac{F}{\Delta L} \times \frac{L}{A} = \frac{KL}{A}$$

$\Rightarrow \boxed{E = \frac{KL}{A}}$

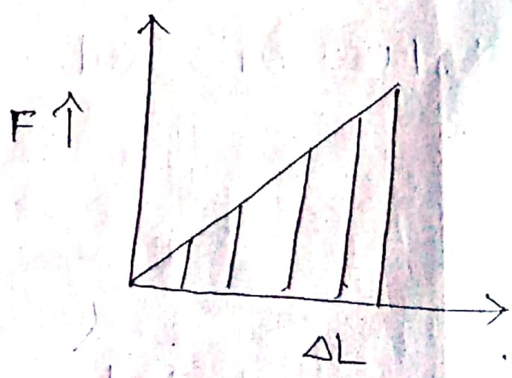
$\boxed{\text{Resilence} = \frac{\sigma^2}{2E} \times \text{Volume}}$

Energy

$\boxed{E = \frac{1}{2} \times \Delta L \times F} \rightarrow (i)$

= potential energy / strain energy

$\Rightarrow E = \frac{1}{2} \times \sigma \times \epsilon \times A \times L$



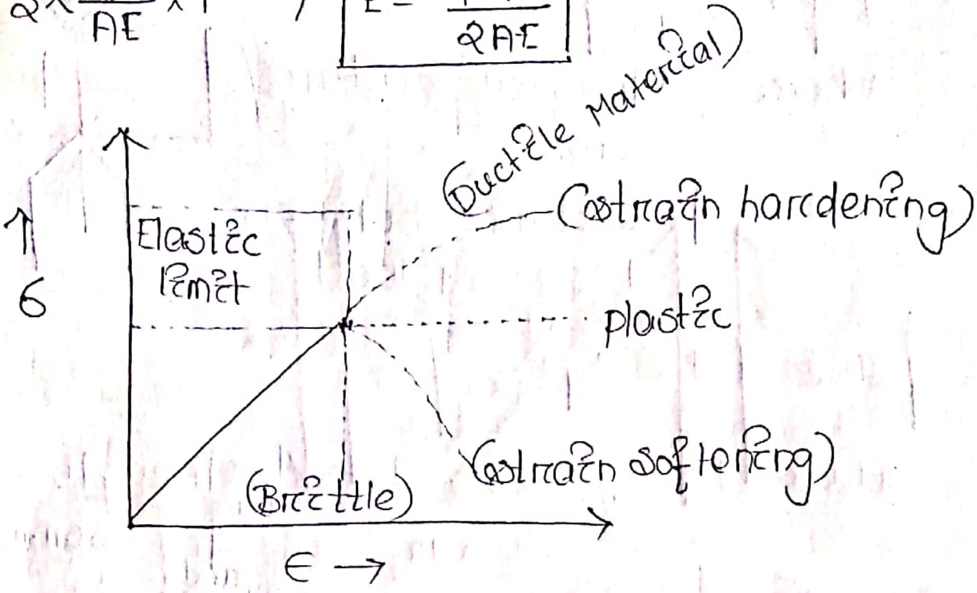
We know, $E = \frac{\sigma}{\epsilon}$

$= \frac{F}{A} \times \frac{L}{\Delta L}$

$\Rightarrow \boxed{\Delta L = \frac{FL}{AE}}$

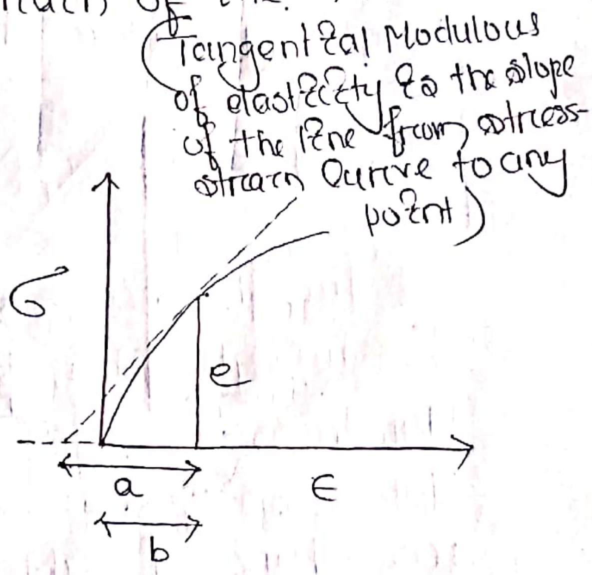
putting the value of ΔL in eqn (E),

$$E = \frac{1}{2} \times \frac{FL}{AE} \times F \Rightarrow \boxed{E = \frac{F^2 L}{2AE}}$$



* strain hardening = After confinement the material becomes too hard.
* strain softening = strain of the material releases slowly.

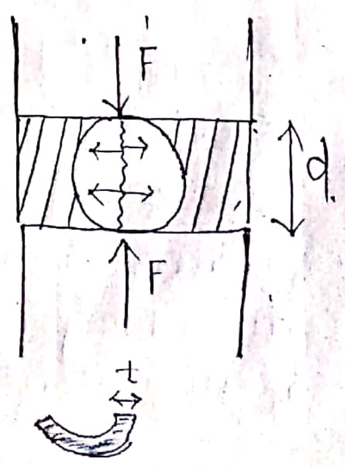
* Tangential Modulous of elasticity $= \frac{e}{a}$
* Secant Modulous of elasticity $= \frac{e}{b}$



TENSILE STRENGTH

* Indirect tensile strength test / Brazilian tensile strength test.
* $\frac{L}{D} = 0.5 = \frac{1}{2} = 1:2$
* $\boxed{\sigma_t = \frac{2F}{\pi d t}}$

F = Load acting on the sample
d = dia of sample
t = thickness of sample.

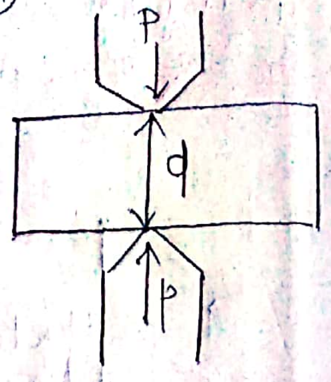


Point load strength Index (I)

$$I = \frac{P}{d^2}$$

Where P = load at rupture/ break

d = Distance between two point load.

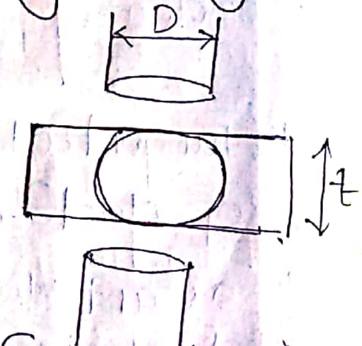


$$\sigma_{UCS} = 24 \times I_{d=50mm}$$

Where $I_{d=50mm}$ = point load strength index of sample of core dia 50mm

* Relationship between computed and ultimate compressive strength and having of sample having $\frac{L}{D}$ ratio equals to 1 and sample having length greater than dia is given by

$$\sigma_D = \frac{\sigma_C}{0.778 + 0.222\left(\frac{D}{L}\right)}$$



σ_D = strength when $\frac{L}{D} = 1$

σ_C = strength when $\frac{D}{L} > 1$ $\frac{L}{D} > 1$

Hardness

Hardness of a rock is defined as the resistance to abrasion.

Punch shear strength

$$S = \frac{P}{\pi d t}$$

Swelling

Swelling of a rock is defined as the increase in volume of the rock mass after absorbing water or remain in contact with water for long period.

MODULE-02

The most important properties for application of elastic theories are

a) Modulous of elasticity (E)
b) Modulous of Regidity (G)
c) Poission's Ratio (γ)

MODULOUS OF ELASTICITY (E)

(i) When a test specement is loaded within in compression or tension within the elastic range, then the ratio of stress to the strain in the direction of stress is known as young's modulous or Modulous of elasticity (E).

Modulous of Regidity (G)

(i) When a test specimen is loaded in shear, then the ratio of shear stress to shear strain is known as modulous of regidity (G)

Poission's Ratio (γ)

(i) The ratio of lateral strain to the longitudinal strain is called poission's Ratio.

Relation between E, G and γ

$$E = 2G(1+\gamma)$$

$$E = 3K(1-2\gamma)$$

$$E = \frac{9KG}{3K+G}$$

Seismic Velocity

(i) The seismic velocity is the propagation of elastic wave through a particular rock.

(ii) The seismic velocity of a material property are of two types.

SEISMIC VELOCITY

- Body wave
  - P-wave (primary wave)
  - S-wave (secondary wave)
- Surface wave
  - Rayleigh wave
  - Love wave

BODY WAVES

(i) Body waves are those which passes through the interior of mass.

(ii) These are again of two types.
a). P-waves (primary / longitudinal waves)
b) S-waves (secondary / shear waves)

a). P-waves are
(i) P-waves are longitudinal waves / are compressive waves in solid.
(ii) These waves travel twice the speed of S-waves.

b). S-waves
(i) S-waves are traverse or shear waves which means the ground is displaced perpendicular to the propagation of traverse

SURFACE WAVE

(i) Surface wave are those waves which passes ~~through~~ along the surface
(ii) These are again of two types
a) Ray leigh wave
b) Love wave

Ray-Leigh Wave
(i) These are also called surface wave and ~~the~~ travel very similar to those wave on the surface of water.

Love Wave
(i) Love wave are those surface wave that cause horizontal sharing of ground.
(ii) They usually travel slightly faster than the railway wave.

$$V_p = \sqrt{\frac{\frac{4}{3}G + K}{\rho}}$$

$$V_s = \sqrt{\frac{G}{\rho}}$$

where G = shear Modulous
K = Bulk Modulous
ρ = Density of Rock.