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IIT(BHU) VARANASI

STUDENTS' NOTES

TOPIC-ROCK MECHANICS-I

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Rock Mechanics

Physical prop^s

1. Porosity
2. Density
3. Moisture Content
4. Degree of Saturation
5. Coeff. of permeability
6. Electrical props.
7. Thermal props.
8. Swelling props.
9. Anisiotropy
10. Durability.

Mechanical

1. Strength.
2. Deformability.
3. Elasticity & Plasticity
4. Hardness.

Porosity: → Porosity identifies the relative prop^s of solid and voids. Porosity of rock sample is defined as ratio of vol. of voids to the total volume of sample.

$$n = \frac{V_v}{V} \times 100\%$$

→ If the sample is completely dry, voids will contain only air where as in case of fully saturated sample, voids will contain only liquids such as water or oil.

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Porosity depends upon shape of mineral grains, their grading, orientation and degree of compaction and cementation.

When the rock forming particles are of diff. sizes, the space created by bigger particles will be filled by finer particles and thus rocks will be having dense compaction resulting into lesser porosity. On the other hand, grains of uniform size, the space inside the mass will be larger and thus rock has larger porosity.

Due to weathering in rocks, and microfractures, porosity may be a little high, porosity generally decreases with age of the rock, decreases with the depth also.

Sedimentary rocks have porosity variation to max. extent from 1% – 90%. It depends on age of formation.

Igneous rocks have least variation in porosity, only 1 to 2%. But due to weathering and micro fractures, it can go upto 20%.

→ Chalk is found to be most porous – As high as 50%

Porosity is measure of water holding capacity and sometimes used in calculating water yield of stratum.

More porous rocks may not be suitable for engg. works.

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Density:-

Density is defined as the mass/volume of rock. Depending upon the requirement, density can be expressed as:-

1. Dry density.
2. Bulk density
3. Saturated density.

Dry density refers to mass p.u. volume when the rock mass is completely dry. It means void contains only air..

Bulk density refers to M/vol. when the rock is in normal condⁿ. It means void contains liquid and air both.

Saturated density refers to ~~unit~~ mass per unit vol. when rock mass is fully saturated. Since rock mass is made of solid minerals, the sg. of the solid is ratio of its density and unit weight of water.

Similar to porosity, rocks also have wide range of density, which mainly depends upon the mineral constituents and degree of compaction, in addⁿ to that at which it is existing.

In general dry density of rock varies from 2.6 – 3 gm/cc.

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

γ_d → dry density

γ → bulk density.

m → moisture content

Moisture content: Moisture content of rock sample is defined as ratio of water weight in voids to the wt. of dry solids in sample.

$$\boxed{m = \frac{W_w}{W_s}}$$

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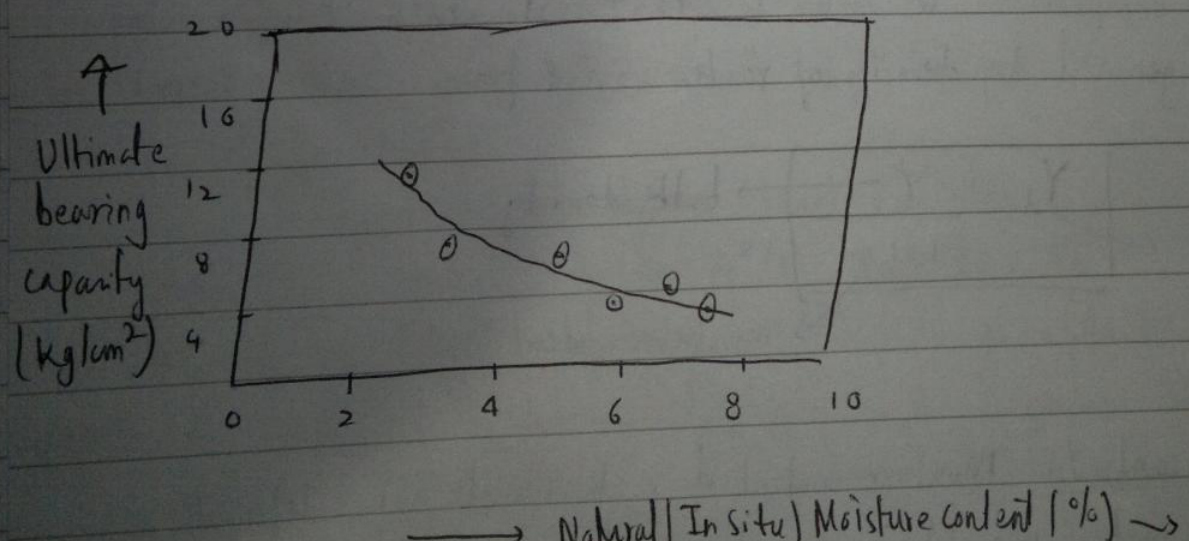
Natural moisture content of rock sample is Moisture content of it when taken from ground due to excavation or boring. Moisture content is determined by noting the loss of wt in sample after drying it for 24 hrs. at a temp. of 105°C – 110°C. An excess natural moisture content gives an indication that rock is more porous, hence of low strength.

When confining pressure is ↑sed around rock mass there is a ↓sed in moisture content making rock mass stronger and vice versa. That is why, due to an excavation near a rock mass, confining stress is ↓sed which may cause the natural moisture content to ↑se resulting in ↓se in strength.

Duncan (1969) has given a relation b/w moisture content and bearing capacity of the rock.



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degree of saturation.

$$S = \frac{V_w}{V_v}$$

V_w → Vol. of water
V_v → Vol. of void

D.O.S. is defined as vol. of water in void to the total vol. of voids in rock sample.

→ Rock mass having higher porosity has higher degree of saturation.

Permeability :- Permeability refers to ability of a porous material to allow a liquid to pass through its pores. Since the pores are connected with each other the flow of liquid takes place through pores. If there is diff in ~~header~~ head at the 2 ends of sample

Darcy's Relation :-

$$Q \propto i \cdot A$$

$$Q = k\, i\, A$$

k → constant of proportionality known as coeff. of permeability.

Q → discharge through area A

i → hydraulic gradient

$$\frac{Q}{A} = ki$$

$$\Rightarrow V = ki$$

Since 'i' ~~ho~~ is dimensionless.

k has units of velo.

$[L][T^{-1}]$

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K is generally expressed as cm/s or m/day.

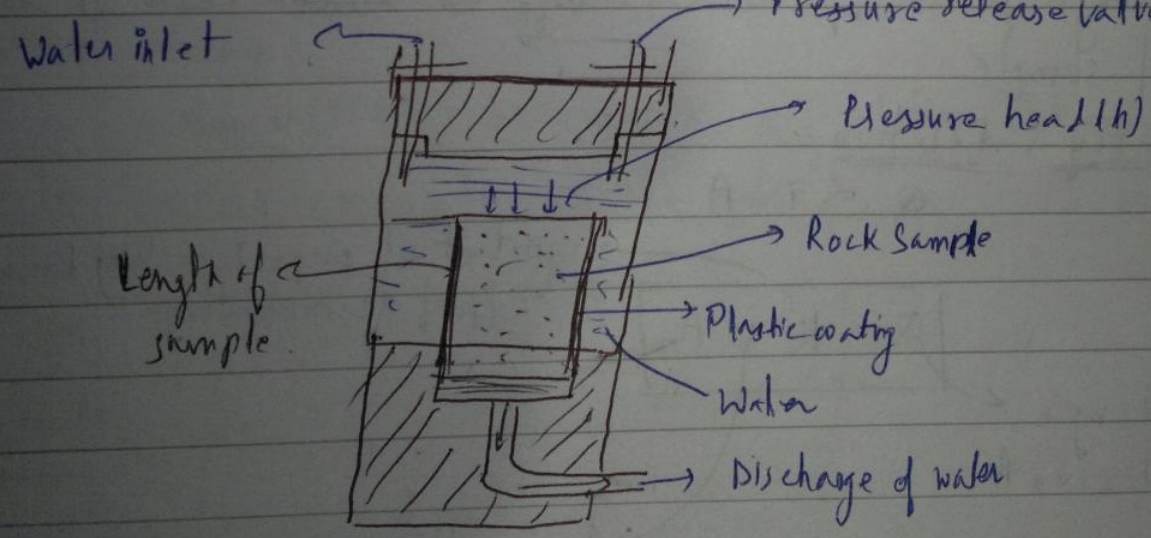
→ **K' depends upon :-**

1) Rock type 2) Pore size 3) Trapped Air in pore 4) Temp. of Rock Mass 5) Viscocity of liquid which in turns depends on temp. of flowing liquid.

→ Permeability — Longitudinal test / Radial test

$Q = kiA$, $k = \frac{Q}{iA}$

LONGITUDNAL TEST :-



Apparatus for permeability Test.

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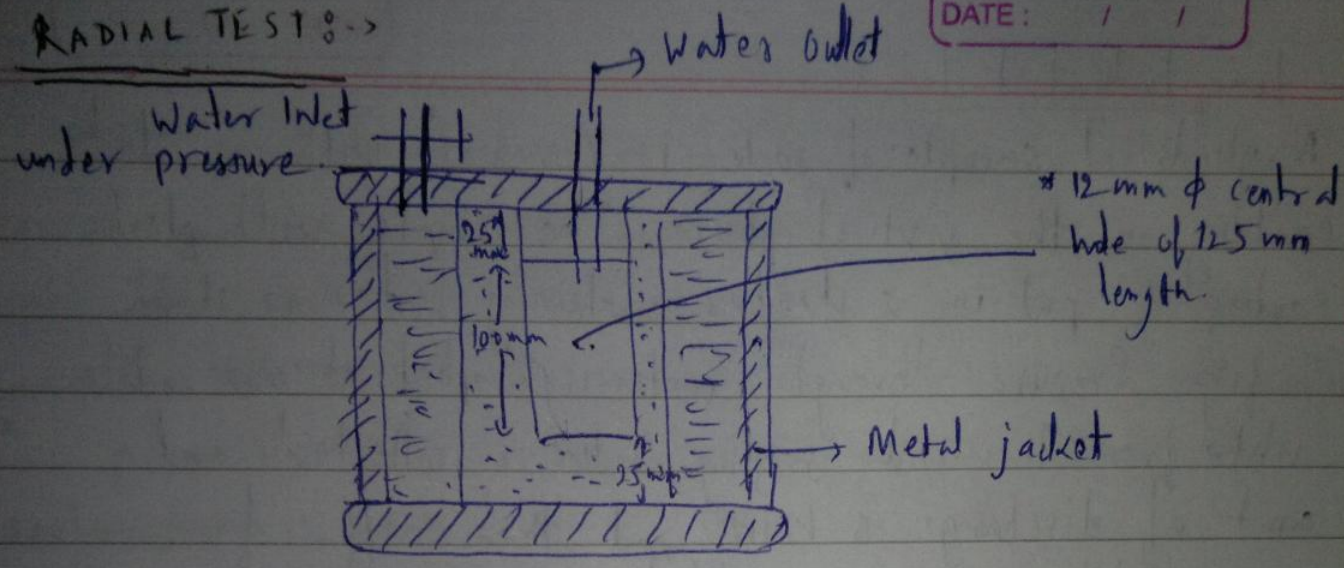
RADIAL TEST :->



$$q = kiA$$
$$= k \cdot 2\pi r L \cdot \left(\frac{dp}{dr}\right)$$

If Q is total discharge :-

$$\int q = \int k \cdot 2\pi r \cdot L \left(\frac{dp}{dr}\right)$$

$$\Rightarrow \int \frac{dr}{r} = \int \frac{k \cdot 2\pi L}{q} dp$$

$$\Rightarrow \log_e \frac{R_2}{R_1} = \frac{K \cdot 2\pi L \cdot P}{Q}$$

$$\Rightarrow K = \frac{Q}{2\pi L P} \log_e \frac{R_2}{R_1}$$

$$\Rightarrow = \frac{2.3\, Q}{2\pi L P} \log_{10}\left(\frac{R_2}{R_1}\right)$$

if divided by time 't'

$$\boxed{K = \frac{2.3\, Q}{2\pi L P t} \log_{10}\left(\frac{R_2}{R_1}\right)}$$

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Longitudinal test:

A cylindrical sample of rock is covered with a plastic coating on the vertical phase. The sample with plastic coating is put in a chamber containing water as shown in fig. Pressure through water is applied at one end while from other end, seeping water is collected and amt of discharge is known and the coeff. of permeability can be calculated as

$$\boxed{K = \frac{QL}{Ah't}}$$

Radial test: In core sample of dia. 60 mm and length 150 mm dia, a hole is made at centre of specimen of dia. 12 mm and length 125 mm and sample is enclosed in a metal cylinder. Pressure from outside periphery of cylinder is applied due to which a flow takes place and collected in sample ~~core~~ hole, where pressure is atmospheric.

Let L be length of inside hole and outside and inside radii of hole be r_2 and r_1 respectively.

∴ flow through a cylinder surface with a radius can be calculated by following derivation:-

Previous page derivation

It should be noted to get the permeability in cm/s, the Q should be in cc, length in cm and pressure head in cm too.

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While conducting test, care should be taken that applied pressure should not be too high or too low.

These two tests given value of permeability of lab. samples, but an engineer is not interested only in permeability, ∴, permeability is further defined as primary and secondary ~~perforation~~ percolation.

Electrical properties :-

Electrical prop^s are of interest in geological prospecting where electrical resistivity methods are used.

Most of the rocks are dielectric and measurement of dielectric constants are done for interpretation of data. This prop is also ~~known as~~ of importance in prospecting of water resources. bcoz due to presence of of in coarse of rocks, the dielectric prop^s of rock change sharply and hence interpretion of data is done for location of ground water reservoir.

Thermal prop^s. → Thermal prop^s are of more importance to the engineers especially for tunnels and other U/G openings such as U/G Power House etc., As in temp. of rock or a frequent change in rock temp. makes it weaker due to the formation of cracks in rock mass, hence a knowledge of thermal conductivity & coeff. of thermal expansion and contraction of rock mass is essential.

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Thermal conductivity (K) is given by following formulae :-

Q = Amount of heat transfer in perpendicular dir^n through an area 'A'.

$T_2 - T_1$ = temp. diff. in °C b/w 2 points at differe distance x.

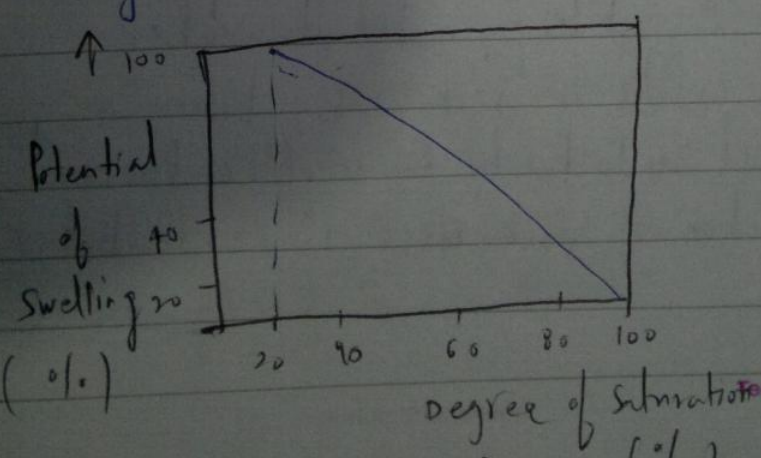
$$K = \frac{Q\,x}{A\,t\,(T_2 - T_1)}$$

$$\Delta L = \alpha L \Delta T$$

α = Coeff. of linear thermal expansion.
L = length of specimen.
ΔT = changes in temp.

Swelling :-

Swelling is defined as ~~ase~~ in mass/volume of rock due to suction of water or due to contact of water for a longer time.



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When there is an excavation in the rock mass, the confining stresses reduces at that site which causes an ↑se in suction of water pressure at that site and this causes entry of water into pores causing an ↑se in volume. This ↑se in volume sometimes causes cracks in rock mass. Again, a suction pressure causes sometimes splitting of bedding planes in sedimentary rocks. If cementing force is not sufficient ∴ swelling ↑ses upto 50%. Swelling is more in weaker type of rocks ∴ it can be related with unconfined compressive strength. with ↑sing value of unconfined compressive strength, swelling reduces.

Relationship b/w degree of saturation and potential of swelling is shown in fig. by Duncan (1969)

If the sample remains as a coherent block with no significant swelling on absorption of water, it is known as 'cemented'.

If it remains as coherent block with significant swelling on absorption of water, sample will be known as 'compacted'. The degree of cementation governs the ability of individual grains to reorient under tensile stresses due to water, clay, shales, mudstones have the greatest tendency of swelling.

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Anisotropy :- Due to sequence in formation, a rock mass may not be isotropic. It may be anisotropic due to existence of bedding planes and diff. constituting minerals. An isotropic material like steel / concrete, has the same property in all dir^n but anisotropic material has some weaknesses in a particular dir^n or axis. specially in sedimentary rocks, degree of anisotropy is more. Due to anisotropy, a rock mass has diff. property along plane of weakness, hence it is necessary to know the plane of weaknesses.

This can be easily done in labs by taking samples in all 3 dir^ns.

Durability :- It may be defined as resistance to destruction. If a rock mass is more durable, it will last for a longer period when put to use. Durability of rock mass will depend upon nature of environment against which it is to be used. In other words, durability depends on climate & atmosphere and amt of exposure of rock mass. Agencies which reduces durability of rock mass are hydration, slaking, solution, oxidation, attrassion etc. These may act alone or in combination. In some cases rock mass starts changing as soon as a fresh surface is exposed to atmosphere

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The process of decay retards with time. Hence, before using a rock mass its degree of decay or its durability has to be ascertained. To describe ranking of rock durability an index of ~~abrassion~~ alteration is commonly used known as "Slack Durability Index".

31/03/13

Mechanical Properties :->

Mechanical prop^s are also big described as mechanical prop^s. these are prop^s which help an engineer to fix the design parameters for construction. Therefore the most imp. prop. is 'strength'. Strength is a general term, the ability of a material to resist an externally applied load, is known as its strength. But, in rock mechanics, strength may be defined as $\frac{\text{Force}}{\text{Area}}$ reqd. to bring about rupture in a rock mass at given environmental cond^n.

A cylindrical rock sample when tested in unconfined compression i.e w/o lateral restraint will behave as a brittle material and will fall at comparatively lesser strain where as with lateral restraint material will behave as a ductile material and will fall at A sed strain.

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Rock strength depends on following factors:

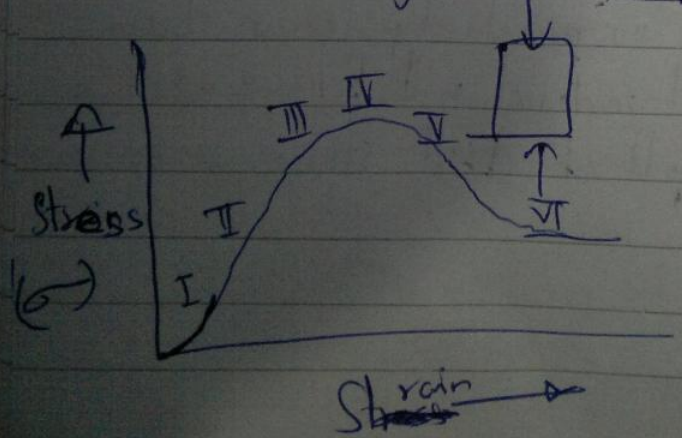
1) Size of rock specimen.
2) Type of test
3) Duration of test
4) Loading condⁿ.
5) Cycle of loading
6) Confining pressure
7) Degree of saturation.

In addⁿ to these, rock strength also depends on physical propˢ of rock mass.

Depending on type of loading and the stresses the strength may be classified as:

a) Compressive strength
b) Tensile strength
c) Shear strength

Compressive strength :→ It is capacity of a material to withstand axially directed compressive forces, so the most common type of compressive strength is Uniaxial compressive strength OR Unconfined Compressive Strength.



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For Stage (I) : Rock is initially stressed, pre-existing microcracks or pores oriented at large ∠ to the applied stress is closing in addⁿ to deformation. This causes initial non-linearity of the axial stress - strain curve. The initial non-linearity is more in weaker & porous rocks.

St. (II) : Rock basically has a linearly elastic behaviour with linear stress - strain curve, both axially + laterally.

St. (III) : Rock behaves non-linear elastic. The axial stress-strain curve is nearly linear and is linearly recoverable. There is a slight ↑se in lateral strain due to dialation. Microcrack propogation occur in a stable manner during this stage & that micro~~break~~crack ing events occurs independently of each other and are distributed throughout specimen. In this zone, strength depicts up to 80% of peak strength.

St. (IV) :

Rock undergoes a rapid accⁿ of micro-cracking events, and Vol. ↑ses. The spreading of microcracks is no longer independent and cluster of cracks in the zone of highest stress tends to ~~coalas~~ coelase and start to form tensile fractures or shear planes depending on strength of rock.

St. (V) : Rock has passed peak stress but is still intact. Even though the internal str. is highly disrupted. In this stage, the crack arrays fork and ~~coalese~~ coalease into microcracks or fractures. This is called strain softening deformation i.e. at peak stress, test

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Thus, further strain will be concentrated on weaker elements of the specimen which have already been subjected to strain, This in turn will lead to zones of concentrated strain or shear plains.

St. 6 VI

Rock has essentially parted to form a series of blocks rather than an intact structure. These block slide accross each other and the predominant deformation mechanism is friction b/w these sliding blocks. And, sec. fractures may occur due to differential shearing. The axial stress or force acting on specimen tends to fall to a constant residual strength value, equivalent to the frictional resistance of sliding blocks.

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There is a slight increase in lateral strain due to dilation, micro crack propagation occurs in a stable manner, during this stage & that micro-cracking event occurs independently of each other & are distributed throughout the specimen. In this zone strength depicts upto 80% of peak strength.

Stage IV]: The rock undergoes a rapid acceleration of micro cracking events & volume increases. The spreading of microcracks is no-longer independent & clusters of cracks in the zone of highest stress tends to collaps coalesce & start to form tensile fractures or shear planes depending upon the strength of the rock.

Stage V]: The rock has passed peak stress but is still intact, even though the internal structure is highly disrupted. In this stage, the crack arrays forks & coalesce into micro cracks or fractures. This is called strain softening deformation. i.e. at peak stress, the test specimen start to become weaker with increasing strain. Thus further strain will be concentrated on weaker elements of the specimen which have already been subjected to

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strain. This in turn will lead to zones of concentrated strain or shear planes.

Stage VI: The rock has essentially parted to form a series of blocks rather than a intact structure. These blocks slide across each other ← the predominant deformation mechanism is friction the friction b/w the sliding blocks & secondary fractures may occur due to differential shearing. The axial stress or force acting on the specimen tends to fall to a constant strength value equivalent to the frictional resistance of the sliding blocks.

5/2/13

Uniaxial or unconfined compressive strength is the strength of the rock when the load on the rock acts in one direction only. There is no load along an axis perpendicular to the loading axis. The loading condition, simulate the condition of pillars supporting the mine roof in case of U/G mines.

END Effects & influence of L/D ratio.
(L → length, D → Diameter)

It should be the objective of test that boundary conditions with uniform, uniaxial

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stress and a uniform displacement feild being produced throughout the specimen. But due to the friction b/w the specimen & platens & differences b/w the elastic properties of rock & steel. The specimen will be restrained near it's ends & prevented from deforming uniformely. Becoz of this shear stresses are set up at the specimen platen contact. This means that the axial stress is not a principle stress & that the stresses in the specimen are not always uniaxial. As a consequence of these end effects, the stress distribution varies throughout the specimen as a function of specimen geometry. As the L/D ratio increases, a greater proportion of sample volume is subjected to an approximately uniform state of uniaxial stress. It is for this essential reason, a L/D ratio atleast 2:1 should be used in laboratory compression testing of rock. A 51 mm dia. specimen is a good measure of it.

The strength is derived by the simple formula F/A. The strength is also effected by the rate of loading.

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Triaxial compressive stress (T.C.S)

When a rock mass is subjected to an all round pressure & further it is subjected to an additional vertical pressure, then the strength exhibited by the rock mass is known as triaxial compressive strength. The lateral pressure acting on the rock mass is also sometimes known as Hydrostatic pressure. And additional pressure which causes the failure in the mass is known as Deviatric stress. A sample of L/D ratio varying from 2 – 2.5 is kept in a chamber in which fluid pressure is applied in all three directions. Through plunger, vertical load is applied which causes failure in the sample. The lateral fluid pressure corresponds to all round pressure existing in the rock mass in the feild. This test also helps in determination of shear strength parameters of rock material.

Three cylindrical sample or more samples of same rock material is subjected to three diff. chamber pressure and test is done. Thus major & minor principle stresses are known. Using major & minor principle stresses Mohr's circle are drawn. Mohr's angular ~~value~~ envelop gives the value of C - cohesion & the

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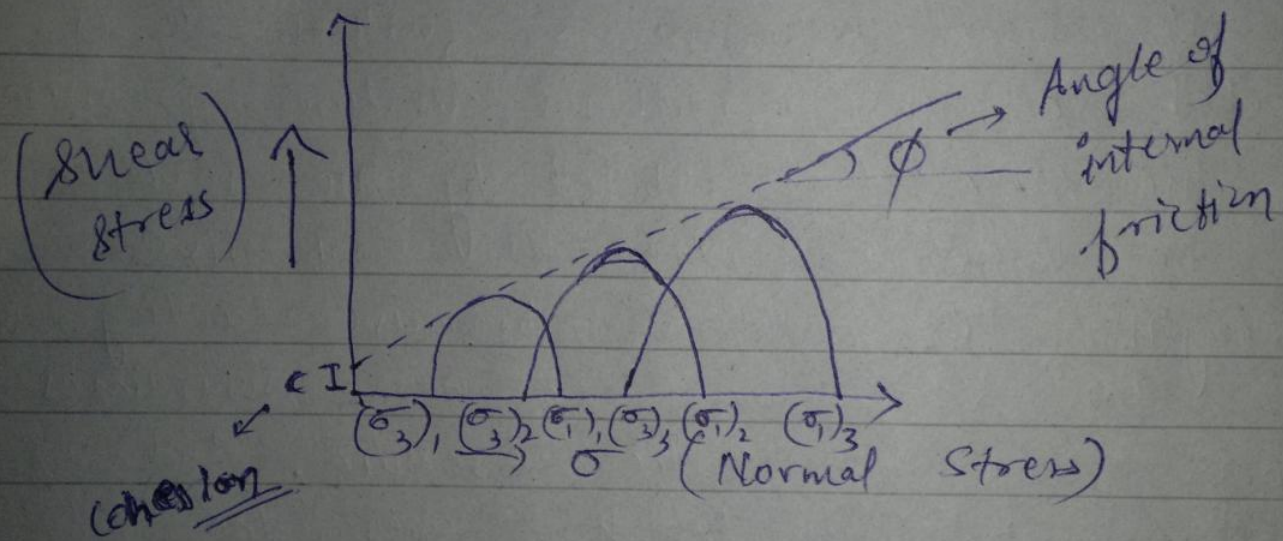
angle of internal friction.



Effective stress = Total stress − Pore water pressure

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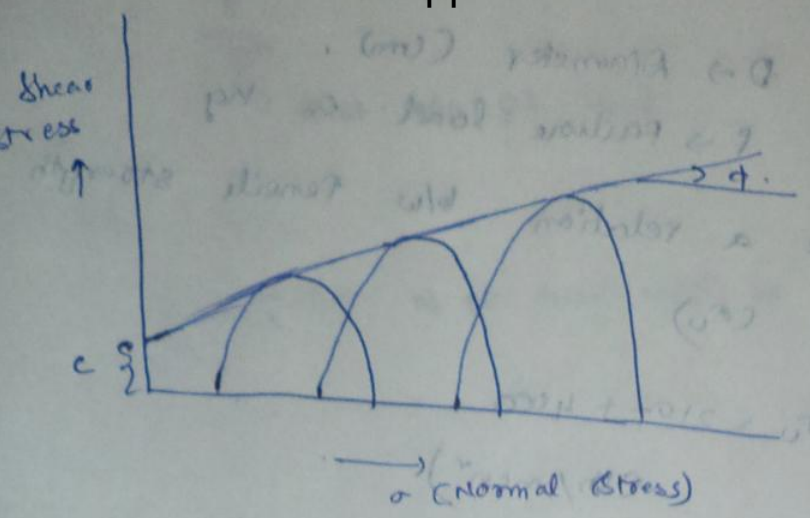

Effective stress = Total Stress - pore water pressure

Tensile Strength :

It is defined as the max. Tensile stress which a material is capable of developing. In nature the rock mass is rarely subjected to direct tension, but it is subjected to Tensile strength

→ In the roofs & domns of u/g openings Tension is developed in the Tensile zone of the rock mass. Tensile stresses also develops on the underside of a rock slag or a beam subjected to bending. Rocks are weak in tension

→ Reichmath described a point load stress for the determination of tensile stress of rock sample

→ Cylindrical pore specimen is kept such that its axis is horizontal, comp. curve loads are applied on curved surface of specimen by a comp. testing m/c. thro' small diameter Hard steel loders at rt. angles to the axis of the specimen. This loading produces tensile stresses ⊥ to axis of loading & Tensile strength (σt) is given by following

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$$\sigma_T = 0.0675 \frac{P}{D^2}$$

D → Diameter (cm).

P → Failure load in kg

→ Miller (1965) gave a relation b/w Tensile strength (σ_T) & comp. strength (σ_U)

$$\sigma_U = 21\sigma_T + 4000$$

(lb/inch²)

Shear strength:-

It may be defined as the capacity of rock mass to take a shear stress. Shear strength may also be defined as max. resistance to deformation due to shear disp. caused by shear stress. Shear strength in a rock mass is derived from the surface frictional resistance along the sliding plane, interlocking b/w the ind. rock grains & cohesion in the sliding surface of the rock. The pattern of joints, shear zones and faults in a rock mass reduces the defective shear strength of the rock mass. Therefore shear strength of insitu rock is highly anisotropic. Shear strength in a disc'n' l'n' to discont. are much less than the intact rock mass. When a rock mass is supporting the complete foundation which is likely to exp. sliding force at the base due to excessive water pressure. It is necessary to check sliding resistance & shear resistance of rock mass along the disc'n' in which max. stress expected to develop.

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