MECHANICAL PROPERTIES OF THE ROCK I

For the purpose of design and to evaluate the stability of underground structure, mechanical properties of the rock must be known. It provides the knowledge of material deform or fail, under the action of applied force. The mechanical properties are tensile strength, compressive strength, shear strength, creep or time properties and strain or deformation properties. The mechanical properties can be determined by static testing which includes uniaxial (unconfined) compressive, tensile, shear and flexural strength, triaxial compressive, shear strength etc. and also elastic constants, i.e., modulus of elasticity and Poisson's ratio obtained from uniaxial, triaxial stress-strain relationship.

Rate of stress application

The relationship between stress and strain is an extremely important characteristic of a material. It varies with the rate of application of stress (or load); we will consider four cases:

a) steadily increasing: zero to failure in a few minutes, e.g. as in a laboratory test.

b) permanent or static: constant with time, e.g. the self weight of the upper part of a structure acting on the lower part.

c) impact or dynamic: very fast, lasting a few microseconds, e.g. the impact of a vehicle on a crash barrier, or an explosion.

d) cyclic: variable with load reversals, e.g. earthquake loading – a few cycles in a few minutes, and wave loading on an offshore structure – many cycles over many years.

1 Uniaxial Compressive Strength

The uniaxial compressive strength of rock is measured by loading a cylindrical or cubical specimen to its failure in a compressive machine. Basically, there are four main factors which control the test results other than the intact rock properties itself.

- Friction between platen and the end surface
- Specimen geometry (shape, height to diameter ratio and size)
- Rate of loading
- Water content

A height to diameter ratio of 2 (54 mm in diameter and 108 mm in height) had been employed and testing procedure will strictly follow the Suggested Methods for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials (ISRM, 1981).

$$\sigma_c = \frac{P}{A}$$

where

σ_c is the uniaxial compressive strength (kN/m^2) or MPa

P is the load applied kN

A is the cross section area m^2

No.	Diameter (m)	Height (m)	Load (kN)	Uniaxial compressive strength (MPa)
1	0.05	0.1	48.446	24.67
2	0.05	0.1	50.566	25.75
3	0.05	0.1	52.746	26.86
Average				25.76

$$C_o = \frac{C_p}{0.778 + 0.222D/L}$$

Where,

Co is the compressive strength of a specimen of the same material having 1:1 length to diameter ratio.

Cp is compressive strength of specimen for which 2 > (L/D) > (1/3).

D is diameter of cylindrical samples and side length in case of a cubical sample.

L is length or height of sample.

The factors, such as, flatness of bearing surface, a specimen size and shape, moisture content in the specimen, the effect of friction between the bearing platens and the specimen, the alignment of swivel head and rate of loading affect the test conducted for determining the compressive strength of a material. The specimen generally must be cylindrical or cubical in shape. The cylindrical samples are cut to the size by a diamond saw and surface irregularities are smoothened by surface polishing machine. The length of the specimen is generally 2.5 times the diameter. The ends of the specimen should be parallel to each other and normal to the axes of specimen. In underground mining, pillars and columns

support the roof rock. For the stability of pillars and columns, the compressive strength of rock is a vital parameter.
The compressive strength of rock depends upon shape, surface quality of loading system, rock specimen surface, porosity and moisture content of the rock, rate of loading and specimen size. The compressive strength of the rock decreases with increase in its porosity. Water in rock pores reduces the magnitude of internal friction of rock thereby reducing the rock strength. Usually, wet sample has its strength 1/3 of that of a dry sample.

The axial stress σ is the controlled, independent variable, and the axial strain is the dependent variable. The longitudinal strain can be measured by a strain gauge glued to the lateral surface of the rock (Figure 1). Alternatively, the total shortening of the core in the direction of loading can be measured by an extensometer that monitors the change in the vertical distance between the platens. In this case, the longitudinal strain is calculated from the relative shortening of the core, that is, $\varepsilon = -\Delta L/L$. If the stress state were indeed uniaxial, then the Young's modulus of the rock could be estimated from $E = \sigma/\varepsilon$. The stress can be increased slowly until failure occurs. The stress at which the rock fails is known as the unconfined, or uniaxial, compressive strength of the rock.

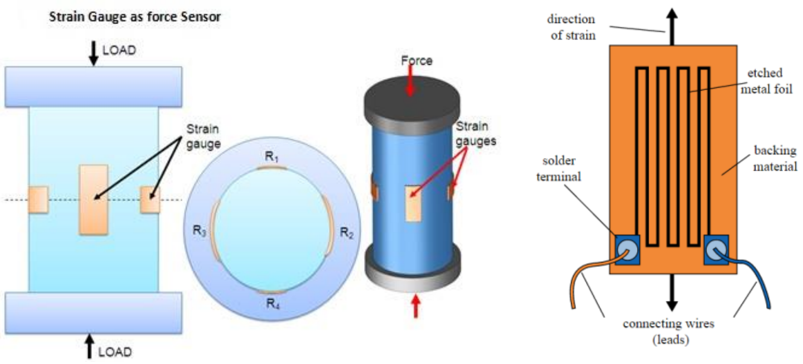


Figure 1: Strain gauge glued to the lateral surface of the rock and the structure of the strain gauge.

There are several methods <u>to estimate</u> the UCS in the field or laboratory:

- Point load test, to determine point load strength based on the application of axial load on rock specimens having a cylindrical or irregular shape. A rock core is loaded diametrically between the tips of two hardened steel cones, causing failure through the development of tensile cracks parallel to the loading direction.

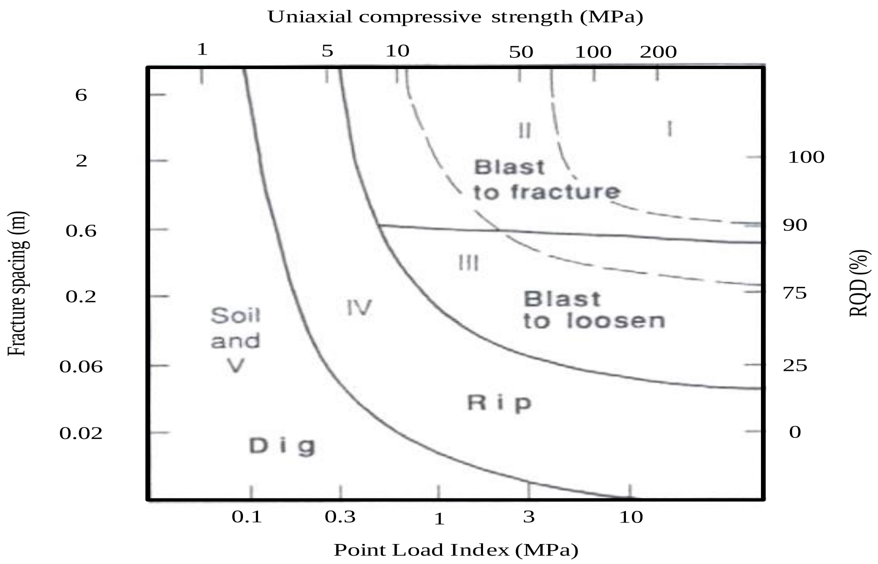
$$I_s = \frac{P}{D^2} \quad \begin{matrix} \textit{(Failure load)} \\ \textit{(Equivalent core diameter)} \end{matrix}$$

The relation between the point load and the UCS is:

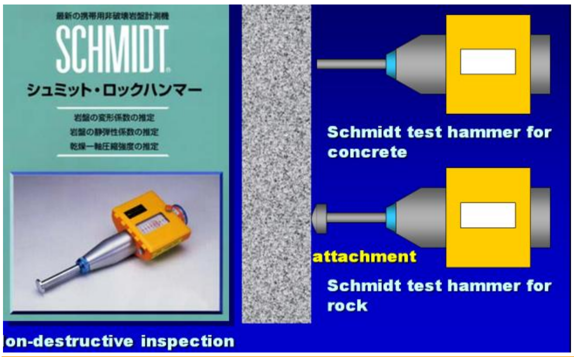
UCS= $24I_{s(50)}$

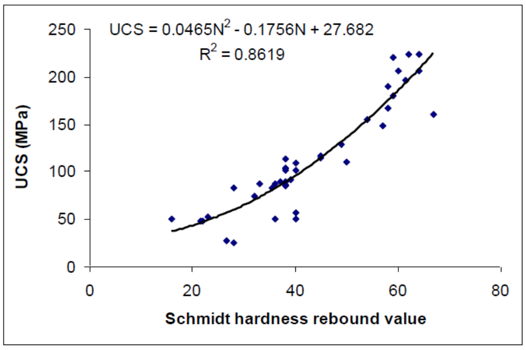
Using of regular samples, the test may done axial or diametric in the cylindrical specimen. The diametric test done on the sample has length as double of diameter in the midpoint of axis. The axial test done on the sample has length equal diameter to 0.3 of diameter in the midpoint of cross section. In a block specimen, L, W and D represent the length, width and height of the block respectively, the test done in the midpoint of the LW plane.

Using PL index with UCS, fracture spacing and RQD to classes of rock excavatability.

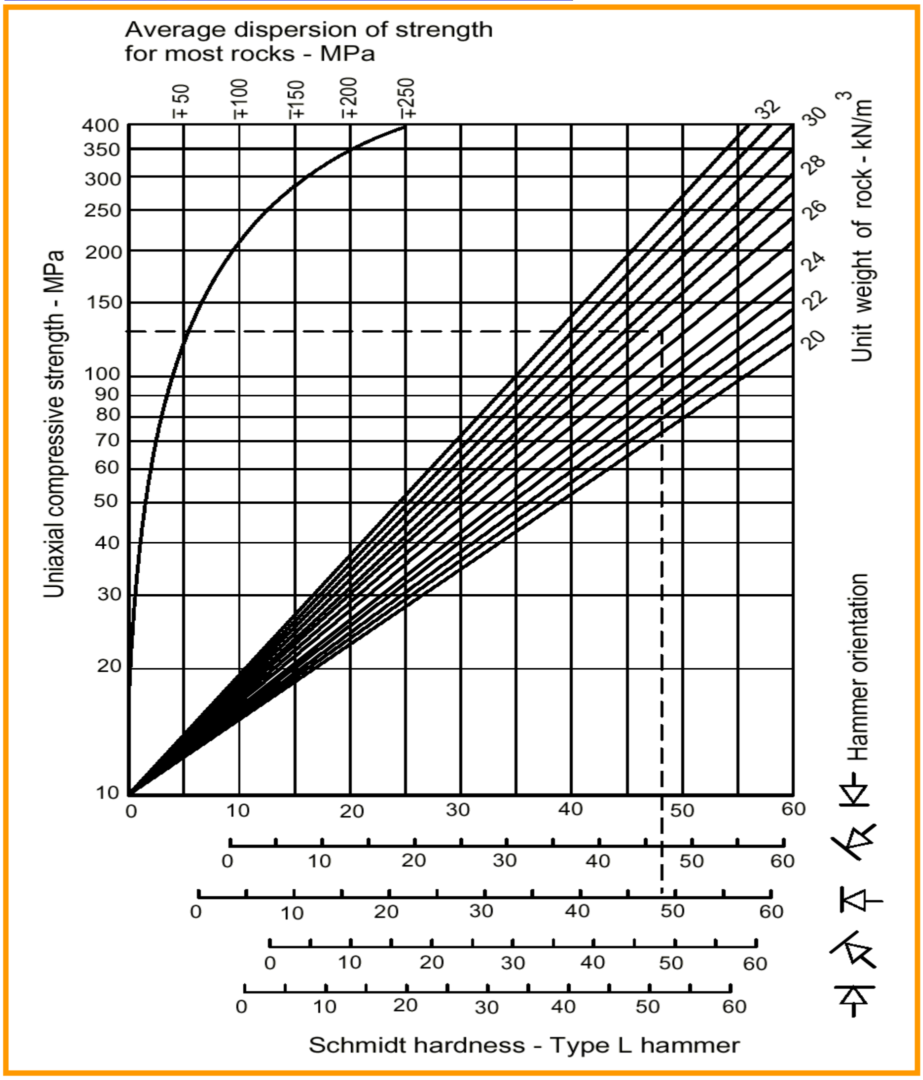


- Schmidt hammer: is a simple index test, cheep, simple operation in a short time, easy to get, anyone can do it many times even a naive engineer. Schmidt hammer can predict the approximated rock property with small cost in a wide region.





Relationship between Schmidt number and UCS for the roof rock of North-Eastern collieries of Iran.



• Geological hammer: depends on the experience of the geologist or engineer to estimate the strength of the rocks. The classification of test ranged between extremely strong to extremely weak.

G	Term	UCS (MPa)	PLI (MPa)	Field estimate of strength	Examples
R6	Extremely strong	>250	>10	Specimen can only be chipped with a geological hammer	Fresh basalt, chert, diabase, gneiss, granite, quartzite
R5	Very strong	100-250	4-10	Specimens requires many blows of a geological hammer to fracture it	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite, rhyolite, tuff
R4	Strong	50-100	2-4	Specimen requires more than one blow of a geological hammer to fracture it	Limestone, marble, sandstone, schist
R3	Medium strong	25-50	1-2	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer	Concrete, phyllite, schist, siltstone
R2	Weak	5-25	**	Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of geological hammer	Chalk, claystone, potash, marl, siltstone, shale, rocksalt
R1	Very weak	1-5	**	Crumbles under firm blows with point of a geological hammer, can be peeled by a pocket knife	Highly weathered or altered rock, shale
R0	Extremely weak	0.25-1	**	Indented by thumbnail	Stiff fault gouge

2 Tensile Strength of Rock

The tensile strength is measured directly by loading a cylindrical specimen in tension to its failure. The indirect methods such as Brazilian test and flexural strength or bending test are also used to measure tensile strength.

a) Brazilian Test

The specimen is cut out of a cylindrical core by a diamond saw. The length to the diameter ratio is usually 0.5. The periphery of the specimen should be smooth. The specimen is placed under compression testing machine. Compressive load (normally 220 kgf/s or 2.16 kN/s) is applied slowly till failure take place (Figure 2a).

$$T_o = \frac{2F_c}{\pi DL}$$

Fc = applied failure load in kg along the length of the specimen
D = diameter of specimen in cm
L = length of the specimen in cm
T_o = uniform tensile strength in kg/cm^2

b) Flexural Strength or Bending Test (Modulus of Rupture)

The flexural strength or modulus of rupture is a measure of the outer fiber tensile strength of a material. This can be determined by loading a cylindrical specimen in a three point loading device to fracture (Figure 2b)

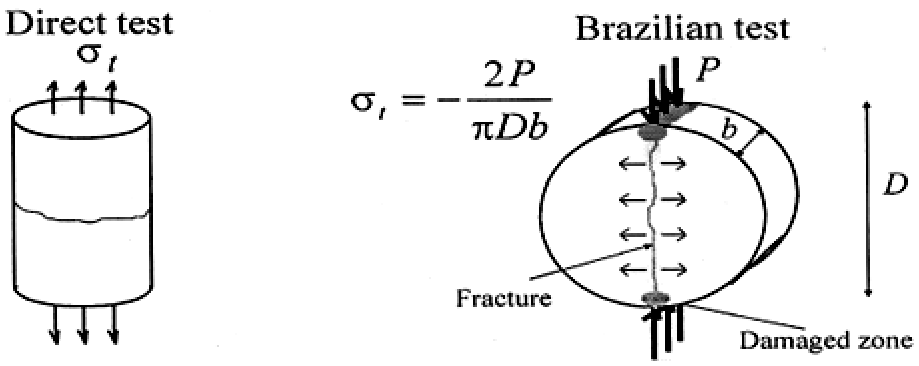


Figure 2a**:** Direct and Brazilian Test for Tensile Strength of Rock

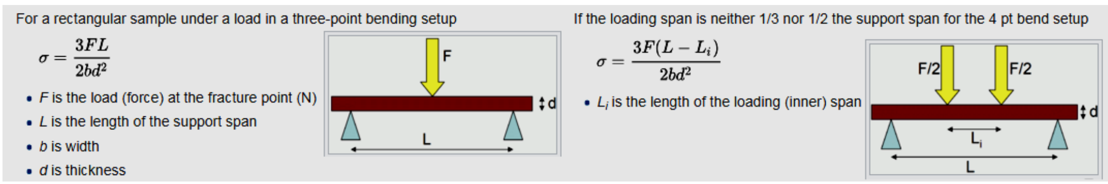


Figure 2b: Flexural Strength Test (Modulus of Rupture)

3 Unconfined Shear Strength

Indirect shear test is properly known as punch shear test. Usually, shear test are single shear test, double shear test, punch shear test, torsion shear test [Figures 4 (a), 3 (b) & 5 (a), 4 (b)]. Usually, the measured shear strength is not inversely proportional to the cross-sectional area.

1. for single shear test, the shear strength S_o is

$$S_o = \frac{F_c}{A}$$

Where,

F_c is the force in the direction of the plane ‘A’ necessary to cause failure.
A = cross-sectional area of specimen

2. For Double Shear test, the shear strength S_o is

$$S_o = \frac{F_c}{2A}$$

3. For Punch Shear test, the shear strength S_o is

$$S_o = \frac{F_c}{2\pi ra}$$

Where,
a = thickness of the specimen and
r = radius of punch

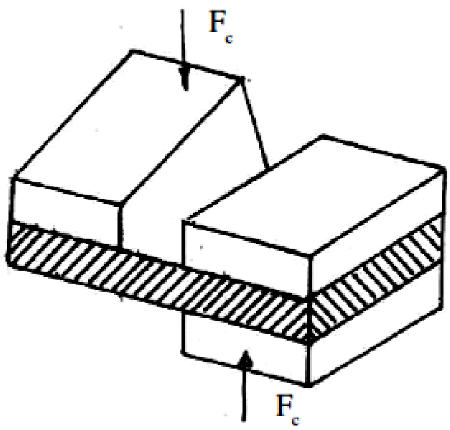


Figure 4 (a): Single Shear Test

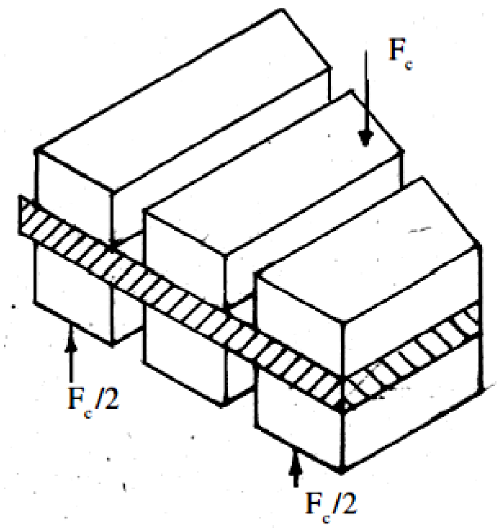


Figure 3 (b): Double Shear Test

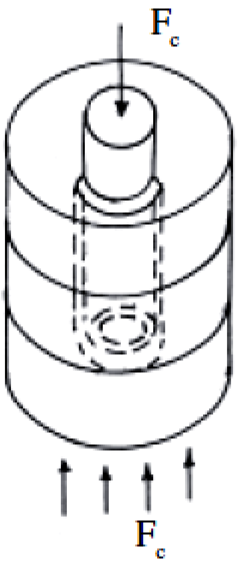


Figure 4 (a): Punch Shear Test

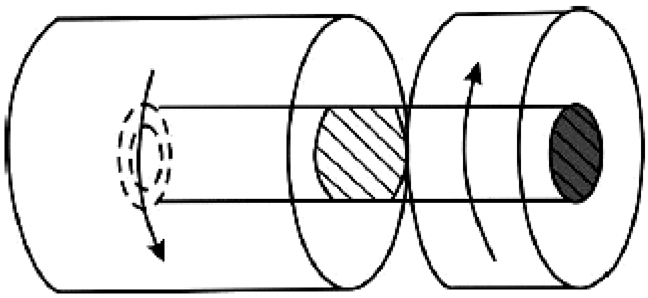


Figure 4 (b): Torsional Shear Test

4. For Torsional shear test, the shear strength S_o is

$$S_o = \frac{16\,M_c}{\pi D^3}$$

Where,
M_c = applied torque at the failure
D = Diameter of the cylinder

4 Triaxial Compressive and Shear Strength

The triaxial compressive and shear strength is required for calculating the bearing capacity of foundation rock for surface structure and in determining the strength of mine pillar and other parts of underground structure (Figure 5).

In triaxial test, a constant hydraulic pressure –p may be applied on the curved surface of cylindrical specimen together with applying compressive axial load to the end of specimen till the specimen fails. To prevent the penetration of hydraulic fluid into the pore space in specimen, rubber jacket may be provided to specimen. If F_c is axial load at failure, the principal stresses in specimen at the failure are:

$$\sigma_3 = \frac{F_c}{A} \quad \text{and} \quad \sigma_1 = -p$$

Where,
A is the end area of the specimen.

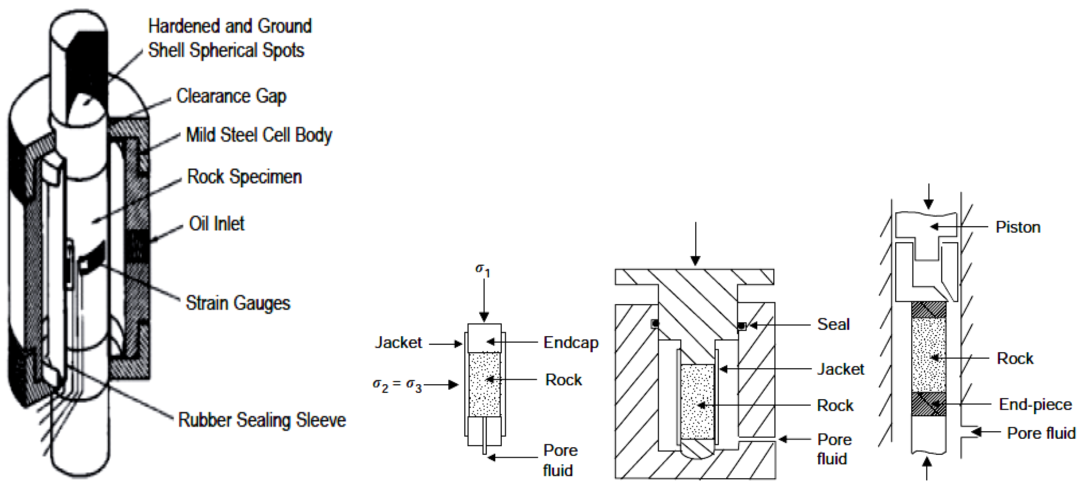


Figure 5: Triaxial Compressive and Shear Strength

To determine the triaxial compressive strength of a given material, usually six specimens are tested under the triaxial machine. The resulting different value of radial pressure σ_1 & σ_3 gives the functional relationship $\sigma_3 = f(\sigma_1)$. For each σ1 and σ3 values, Mohr's circle can be constructed.

Envelop curves tangent to the circle $\tau_0 = f(\sigma_0)$. The intercept of envelop with the τ axis is the triaxial shear strength S_0 of the material (Figure 6). A decrease in modulus of elasticity with increasing tensile stress is the characteristics of most rocks.

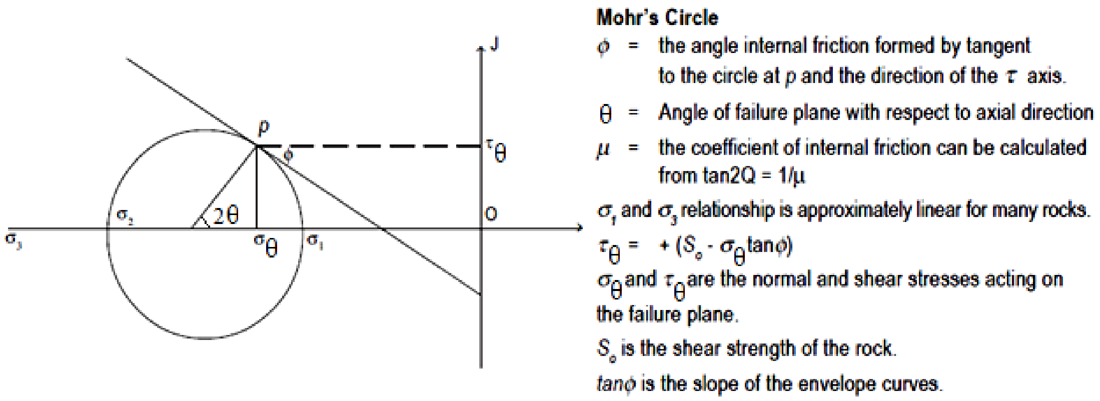


Figure 6: Mohr’s Envelope