Rock Mechanics

Lecture 4

MECHANICAL PROPERTIES OF THE ROCK

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Introduction

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 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

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.

Uniaxial compressive test (UCS)

Universal testing machine (UTM)

Load

Before failure

After failure

Determination of the Uniaxial compressive strength of cylindrical intact rock specimens (load up 2000kN). The load rate is kept constant using a servo-hydraulic control unit.

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

What are the main factors that control the UCS?

Basically, there are four main factors that control the test results other than the intact rock properties themselves.

- **Friction between the 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 the testing procedure will strictly follow the Suggested Methods for Determining the Uniaxial Compressive Strength and Deformability of Rock Materials (ISRM, 1981).

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

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 the diameter of cylindrical samples.
L is the length or height of the sample.

Sample preparing

Uniaxial compressive test (UCS)

Rock sample coring

Rock sample cutting

Coring from rock mass sample

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

Laboratory test

Uniaxial compressive test (UCS)

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

(Failure load)

(Specimen cross sectional area)

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

Which factors affecting to the UCS test?

- The flatness of bearing surface,
- specimen size and shape,
- moisture content in the specimen,
- the effect of friction between the bearing platens and the specimen,
- the alignment of a swivel head and
- rate of loading

What are the characteristics of the specimen for UCS?

- 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 a surface polishing machine.
- The length of the specimen is generally <u>2.5</u> times the diameter.
- The ends of the specimen should be <u>parallel</u> to each other and <u>normal</u> to the axes of the specimen.

Why the compressive strength of rock is a vital parameter?

This character is useful in underground mining, pillars and columns support the roof rock. For the stability of pillars and columns.

Which parameters in UCS are dependent or independent?

The axial stress σ is the controlled, independent variable, and the axial strain is the dependent variable.

How many methods the engineers can test rocks to determine and estimate the UCS?

The direct method by testing a cylindrical or cubic rock specimen,
Point load test,
Schmidt hammer and
Geological hammer.

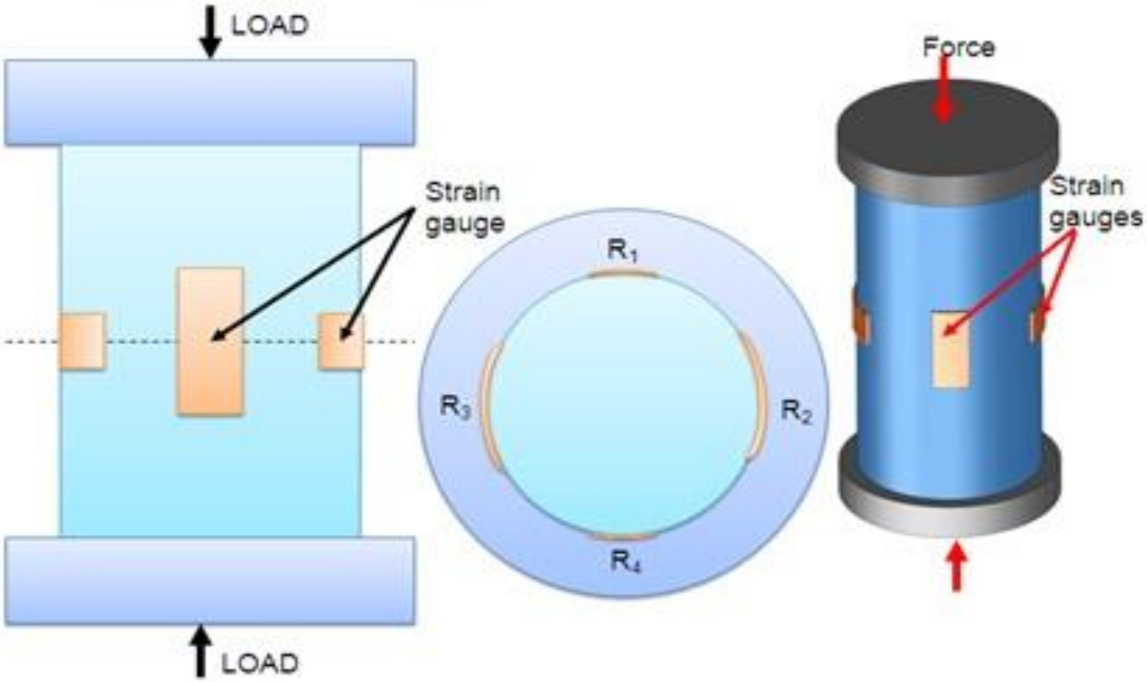
Describe the effects of porosity and water content on the compressive strength?

The compressive strength of the rock decreases with an increase in its porosity. Water in rock pores reduces the magnitude of internal friction of rock thereby reducing the rock strength. Usually, a wet sample has its strength 1/3 of that of dry one.

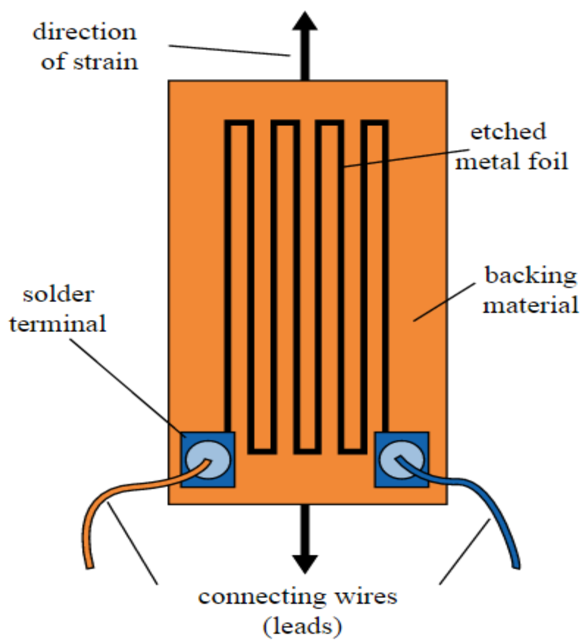
Explain how you can measure the strain, Young's modulus and UCS of the rock sample in the laboratory?

The longitudinal strain can be measured by a strain gauge glued to the lateral surface of the rock. 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 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.

Strain Gauge as force Sensor



Strain gauge glued to the lateral surface of the rock



The structure of the strain gauge

Laboratory test

Point load test

Point load testing machine

Determination of point load strength based on the application of axial load on rock specimens having a cylindrical or irregular shape.

Load

Before failure

After failure

Laboratory test

Point load test

Point load testing machine

Determination of point load strength based on the application of axial load on rock specimens having a cylindrical or irregular shape.

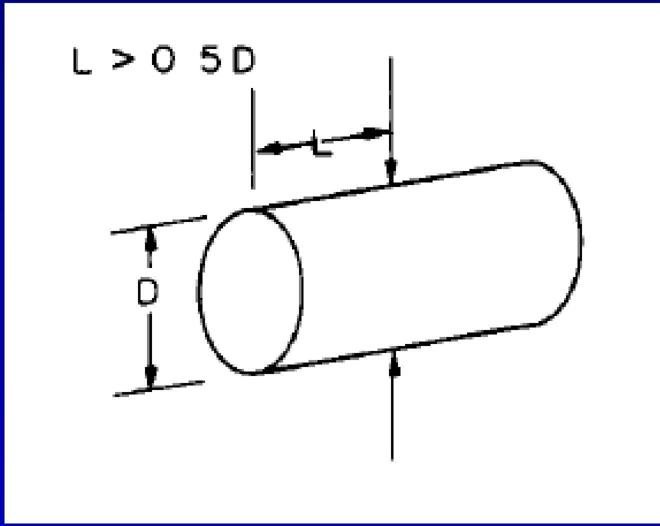
Load

Before failure

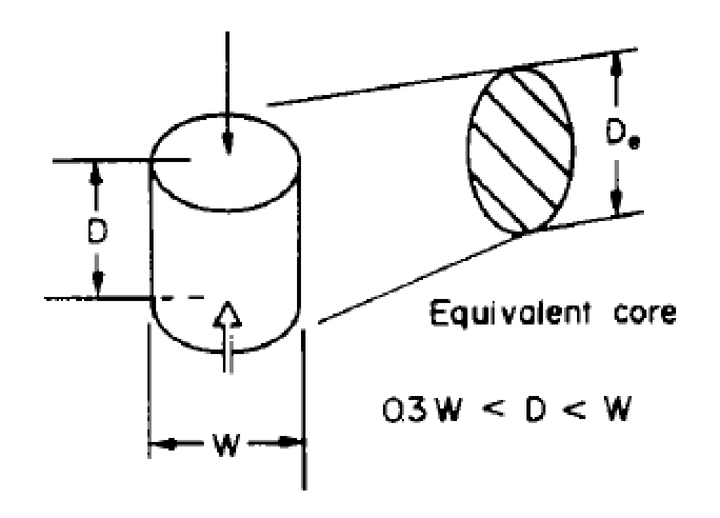
After failure

Laboratory test

Point load test – shape requirements



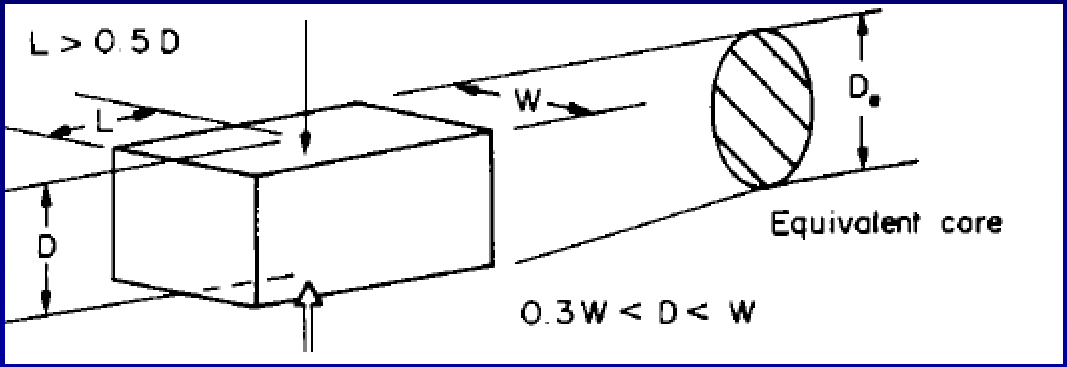
Diametric test



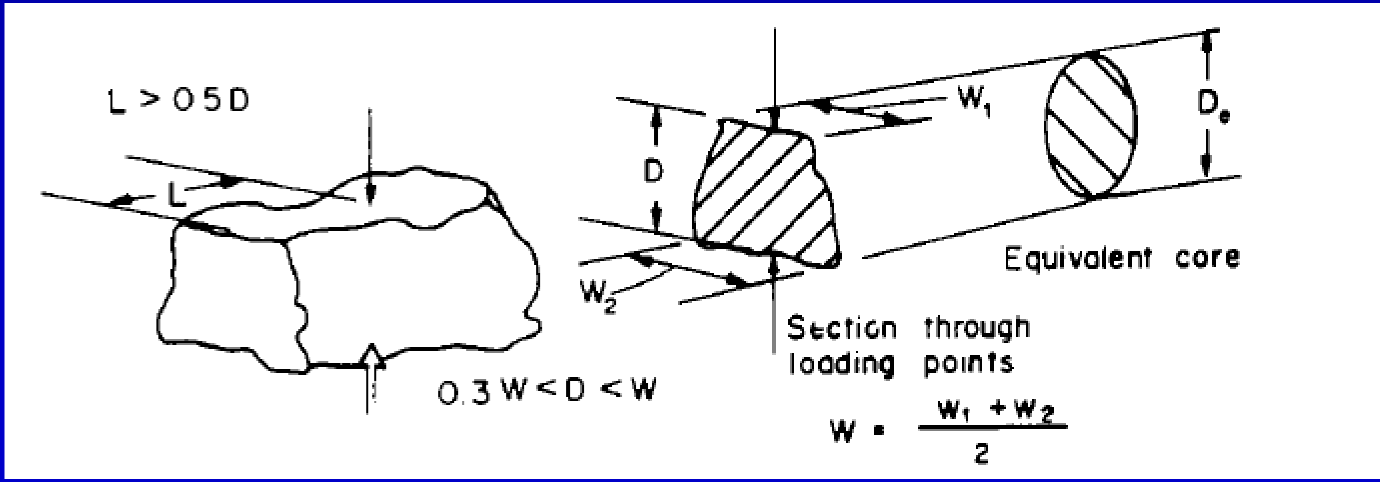
Axial test

Laboratory test

Point load test – shape requirements



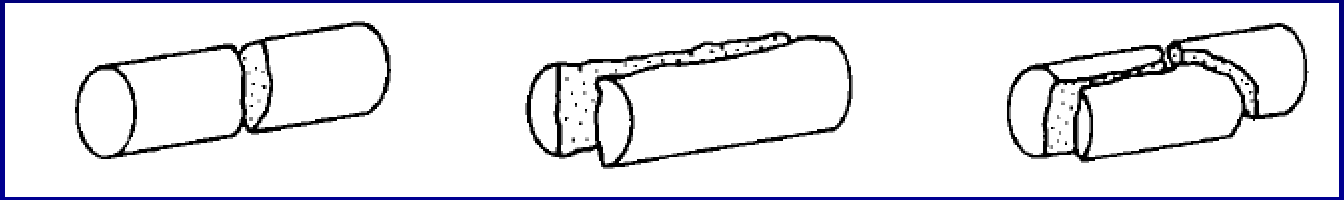
Block test



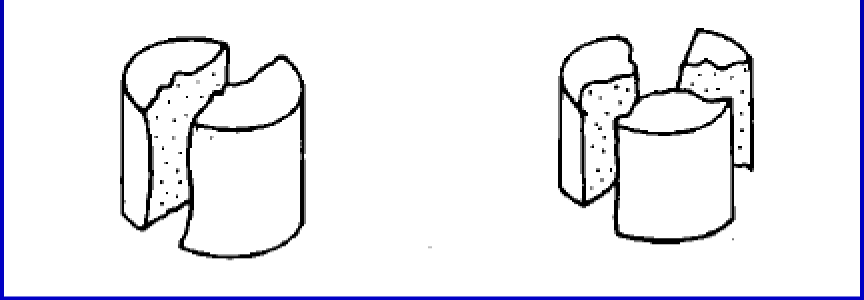
Irregular lump test

Laboratory test

Point load test – shape requirements



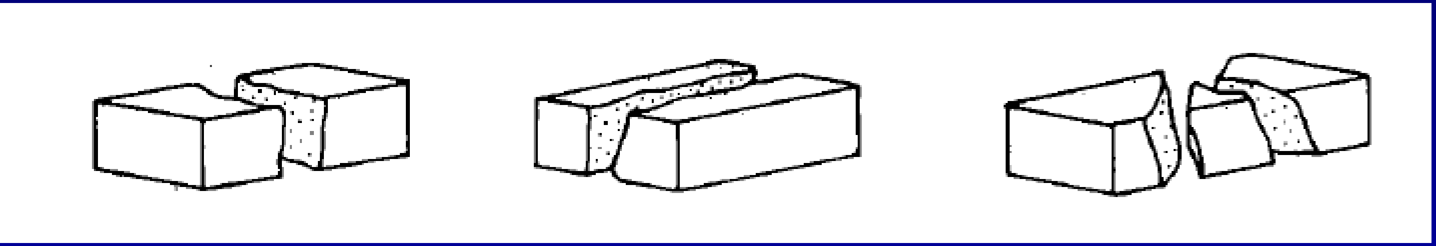
Valid diametric test



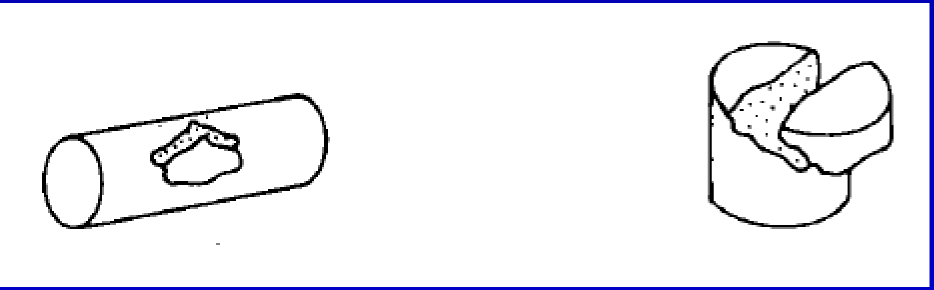
Valid axial test

Laboratory test

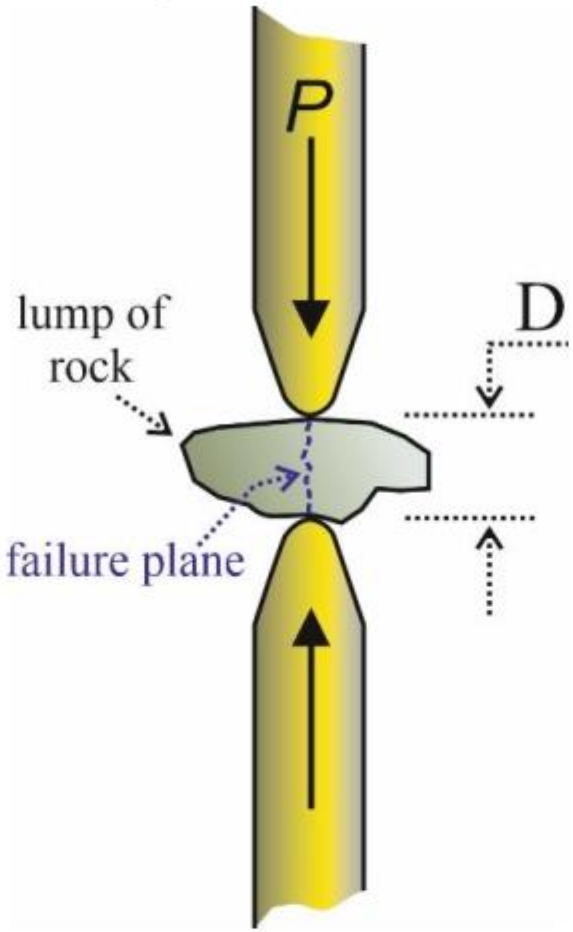
Point load test – mode of failure



Valid block test



Invalid core and axial test


P
lump of
rock
D
failure plane

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

Laboratory test

Point load test

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.

$$I_s = \frac{P}{D^2}$$

(Failure load)

(Equivalent core diameter)

No.	Diameter (m)	Height (m)	Load (kN)	$Is_{(50)}$ (MPa)
1	0.05	0.075	2.685	1.07
2	0.05	0.075	2.680	1.07
3	0.05	0.075	3.185	1.27
Average				1.14

$UCS = 24I_{s(50)}$ $\sigma_c = \frac{P}{A}$

Correlation between UCS and PL

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

Sample	Point load index	UCS Estimated	USC value
1	1.07	25.68	24.67
2	1.07	25.68	25.75
3	1.27	30.48	26.86
Average		27.28	25.76

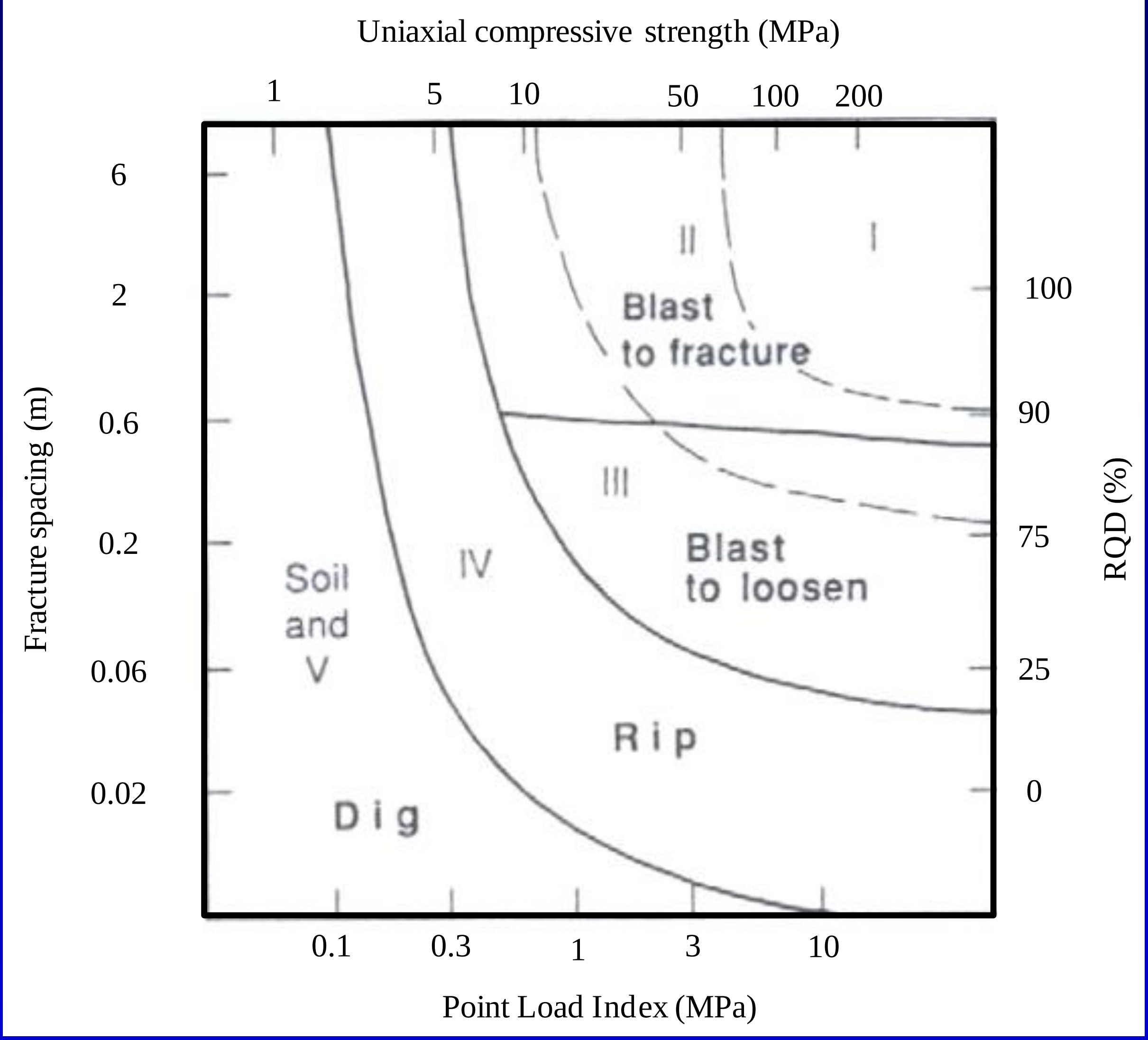
What is the meaning of the *Is(50)*?

This test method is performed to determine the point load strength index *Is(50)* of rock specimens, and the point load strength anisotropy index *Ia(50)* that is the ratio of point load strengths on different axes that result in the greatest and least values.

$UCS = 24 I_{s(50)}$ $\sigma_c = \frac{P}{A}$

Correlation between UCS and PL

Classes of rock excavatability



$UCS = 24I_{s(50)}$ $\sigma_c = \frac{P}{A}$

Correlation between UCS and PL

Field estimates of intact rock based on Uniaxial compressive strength and point load index

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		ammer	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite, rhyolite, tuff
R4	Strong	50-100		ogical	Limestone, marble, sandstone, schist
R3	Medium strong	25-50		m a	Concrete, phyllite, schist, siltstone
R2	Weak	5-25		, oint of	Chalk, claystone, potash, marl, siltstone, shale, rocksalt
R1	Very weak	1-5	**	eological 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

**Point load tests on rocks with Uniaxial compressive strength below 25 MPa are likely to yield highly ambiguous results

Index test

Objective investigation → **Simple index test**
Ex) Schmidt test hammer

cheap	simple operation	short time
easy to get	anyone	many times

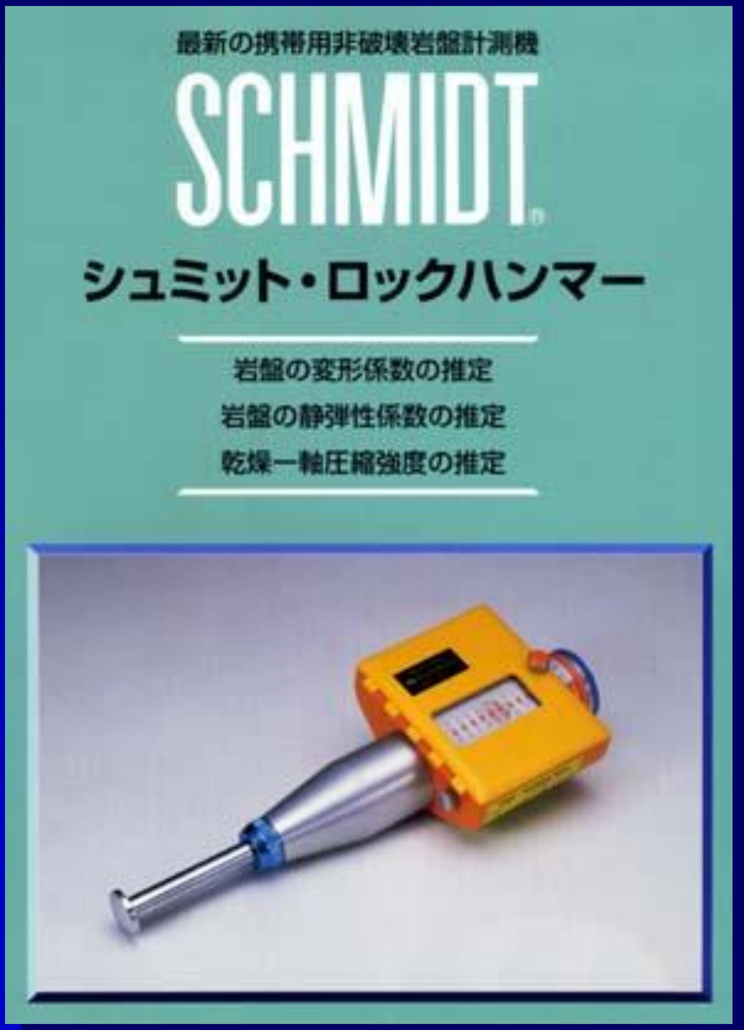
Even a naive engineer

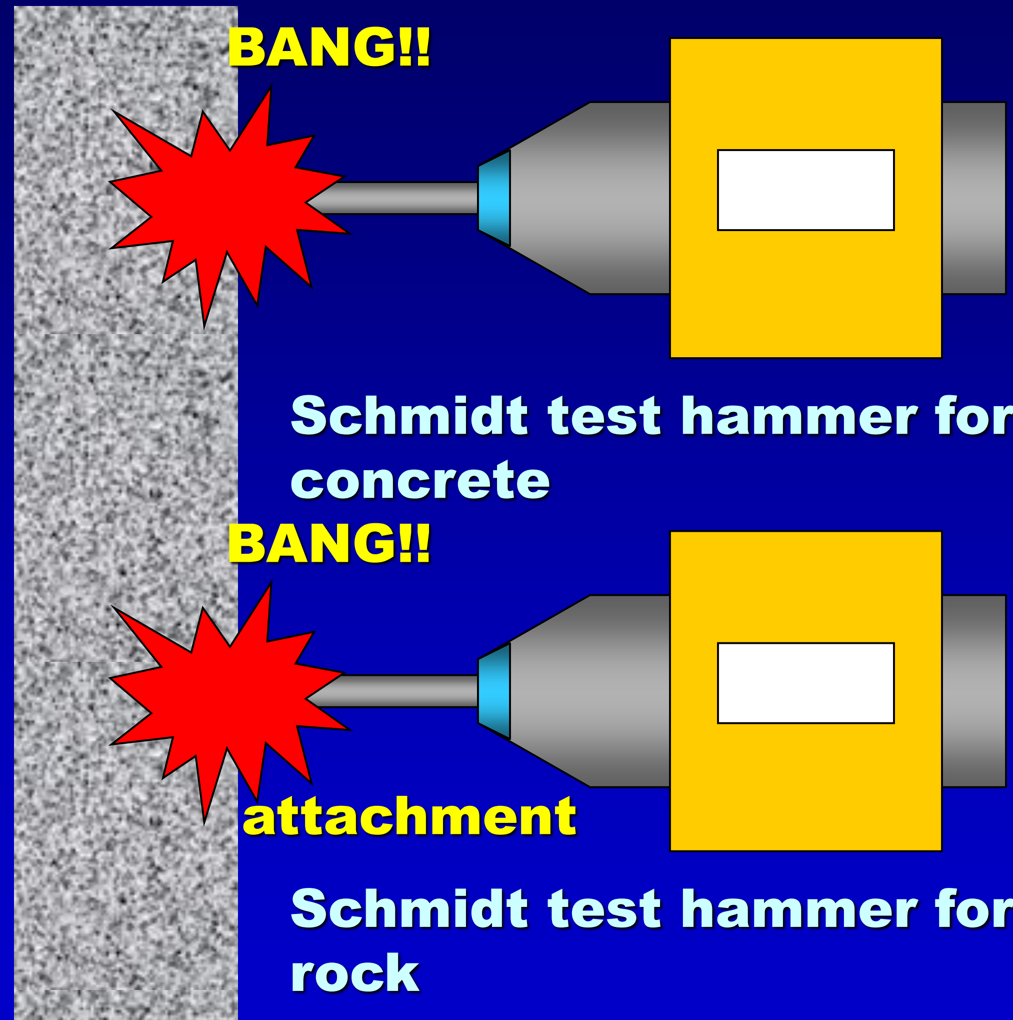
with small cost

can predict the approximated rock property

in a wide region

Schmidt test hammer





Schmidt test hammer for concrete

Schmidt test hammer for rock

Non-destructive inspection

Rebound number & rock properties

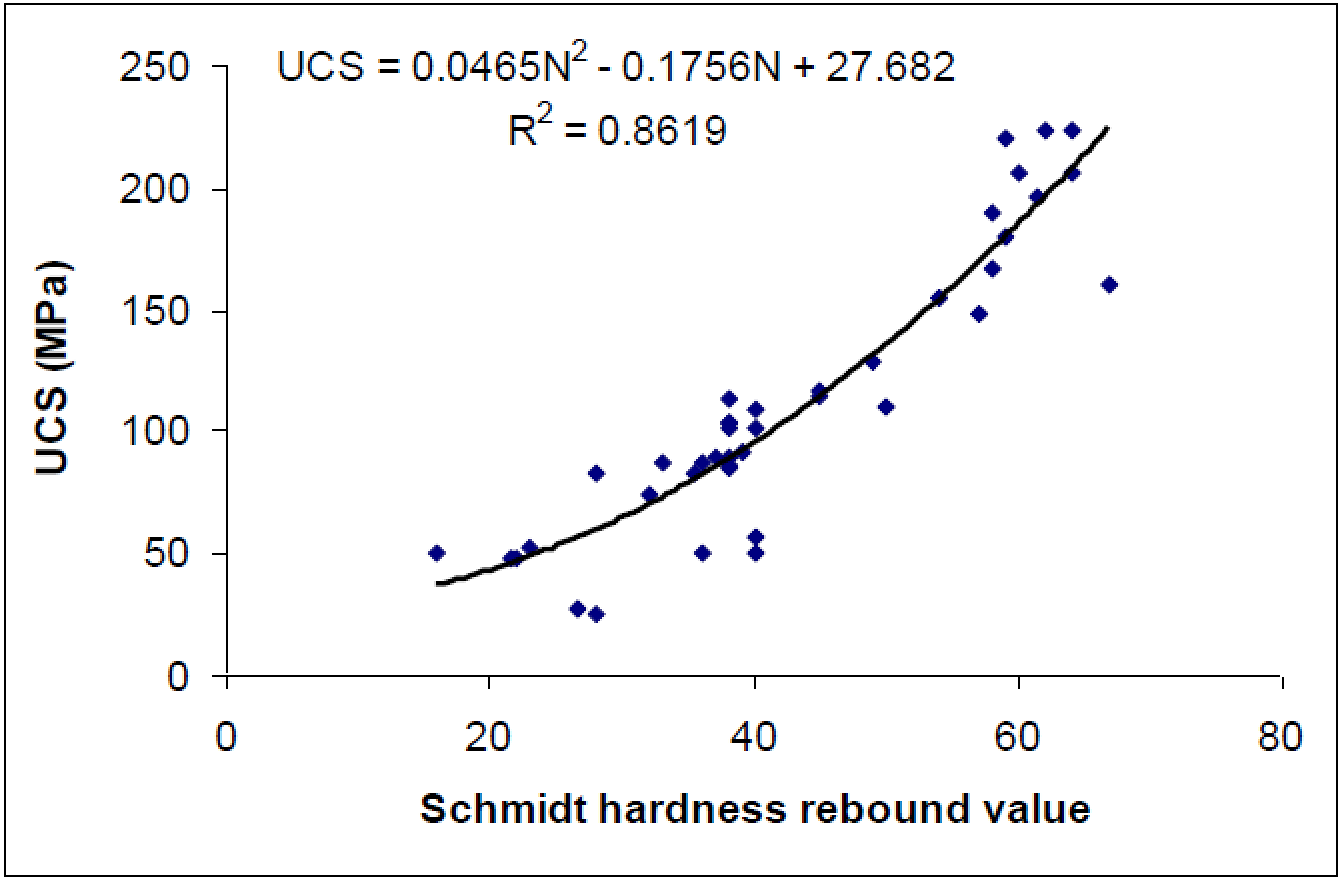
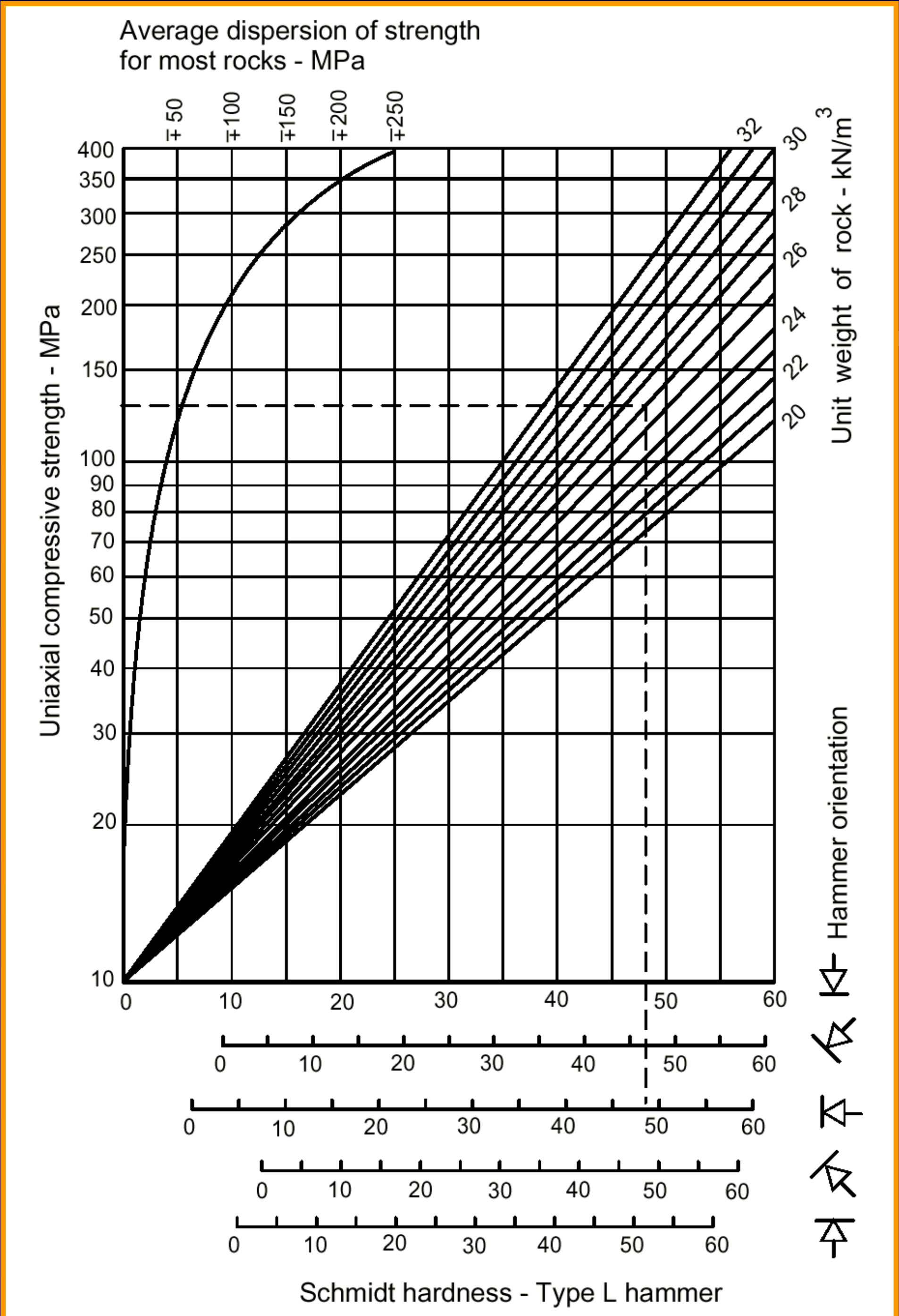
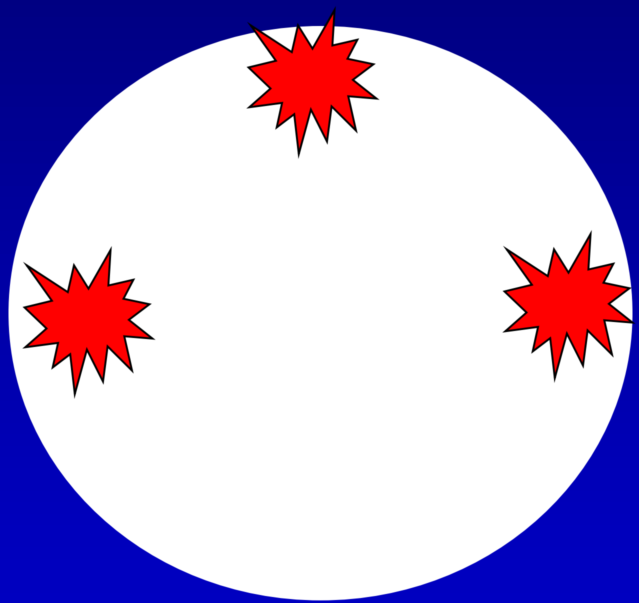


Figure2.Relationship between Schmidt number and UCS for the roof rock of North-Eastern collieries of Iran.

Rebound number & rock properties

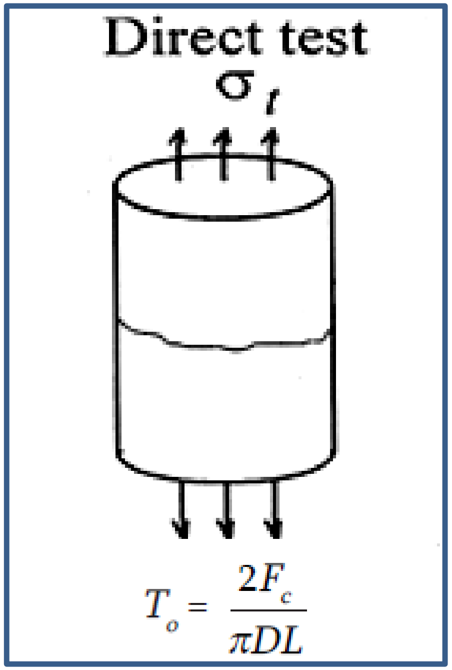




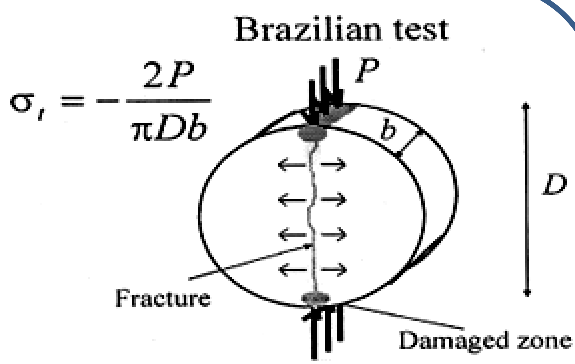
Schmidt test hammer measurement in tunnel

Tensile Strength of Rock

Direct Method



Indirect Methods



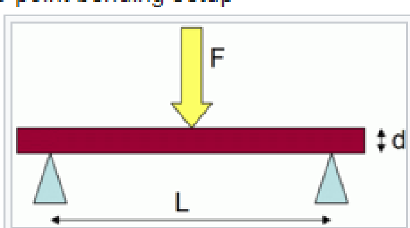
P = applied failure load in kg along the length of the specimen
D = diameter of specimen in cm
b = length of the specimen in cm
σt = uniform tensile strength in kg/cm^2

flexural strength or bending test

For a rectangular sample under a load in a three-point bending setup

$$\sigma = \frac{3FL}{2bd^2}$$

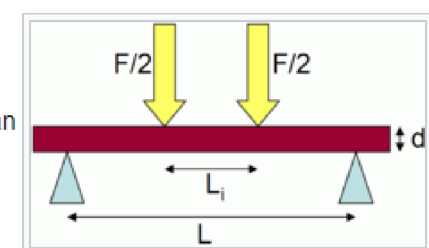
- *F* is the load (force) at the fracture point (N)
- *L* is the length of the support span
- *b* is width
- *d* is thickness



If the loading span is neither 1/3 nor 1/2 the support span for the 4 pt bend setup

$$\sigma = \frac{3F(L - L_i)}{2bd^2}$$

- L_i is the length of the loading (inner) span



Laboratory test

Splitting tension test (Brazilian test)

Brazilian test machine

Load

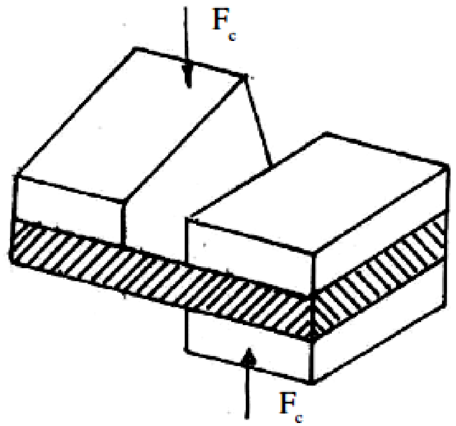
Brazilian test apparatus are used for indirect measurement of tensile strength of rocks

flexural strength or bending test

3 Unconfined Shear Strength

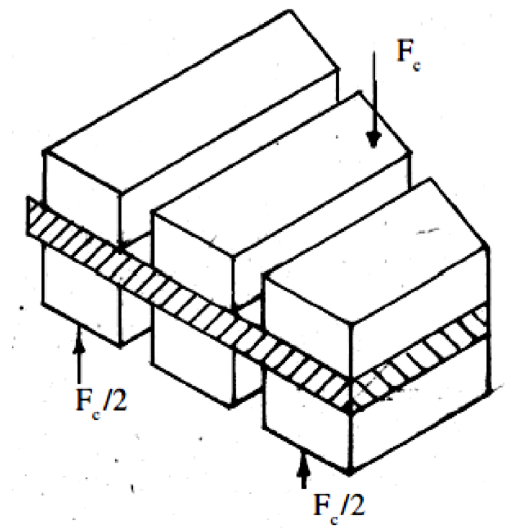
1. For single shear test, the shear strength So is

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

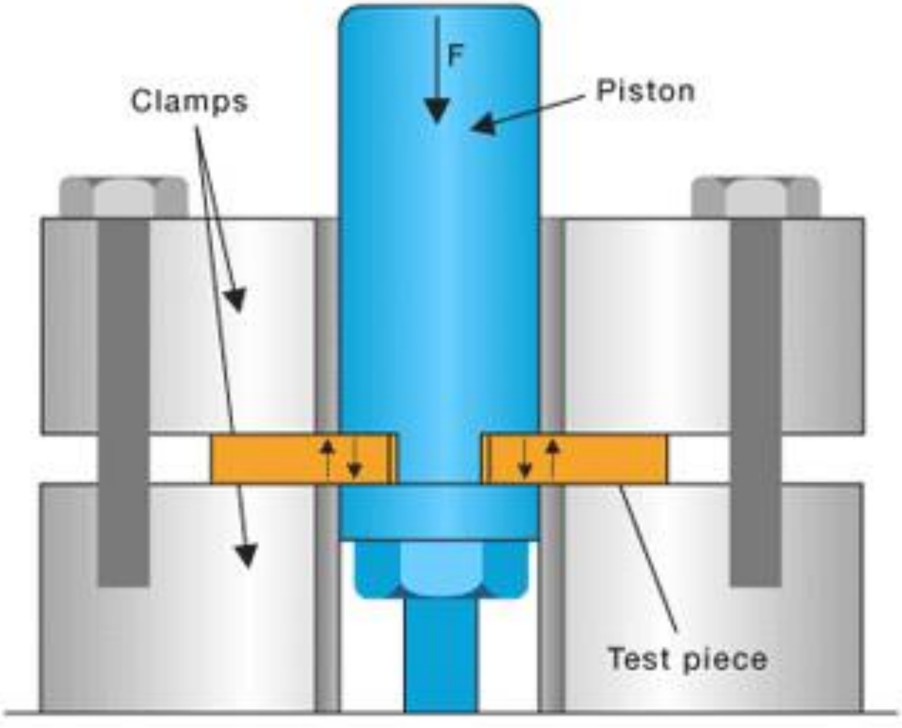


2. For Double Shear test, the shear strength S_o is

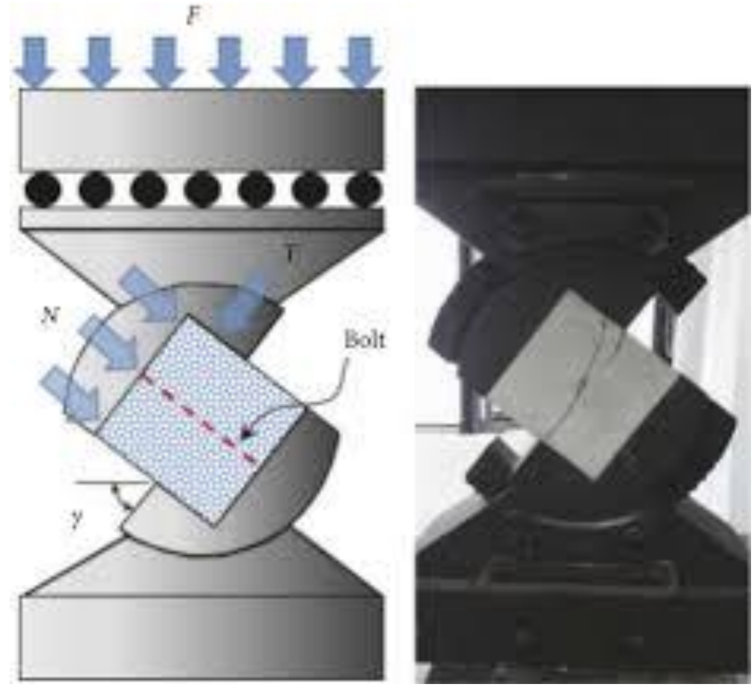
$$S_o = \frac{F_c}{2A}$$



Fc is the force in the direction of the plane 'A' necessary to cause failure.
A = cross-sectional area of specimen

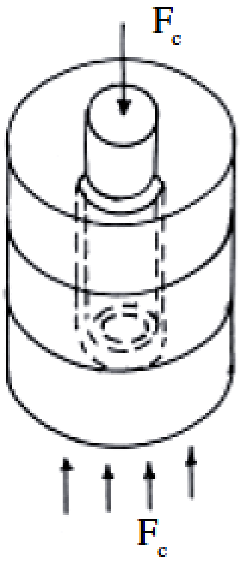


Double Shear test



Single shear test

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

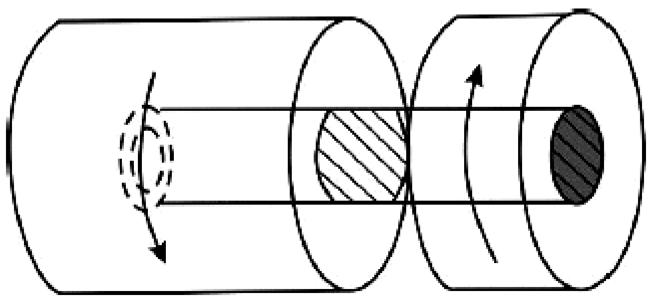


$$S_o = \frac{F_c}{2\pi ra}$$

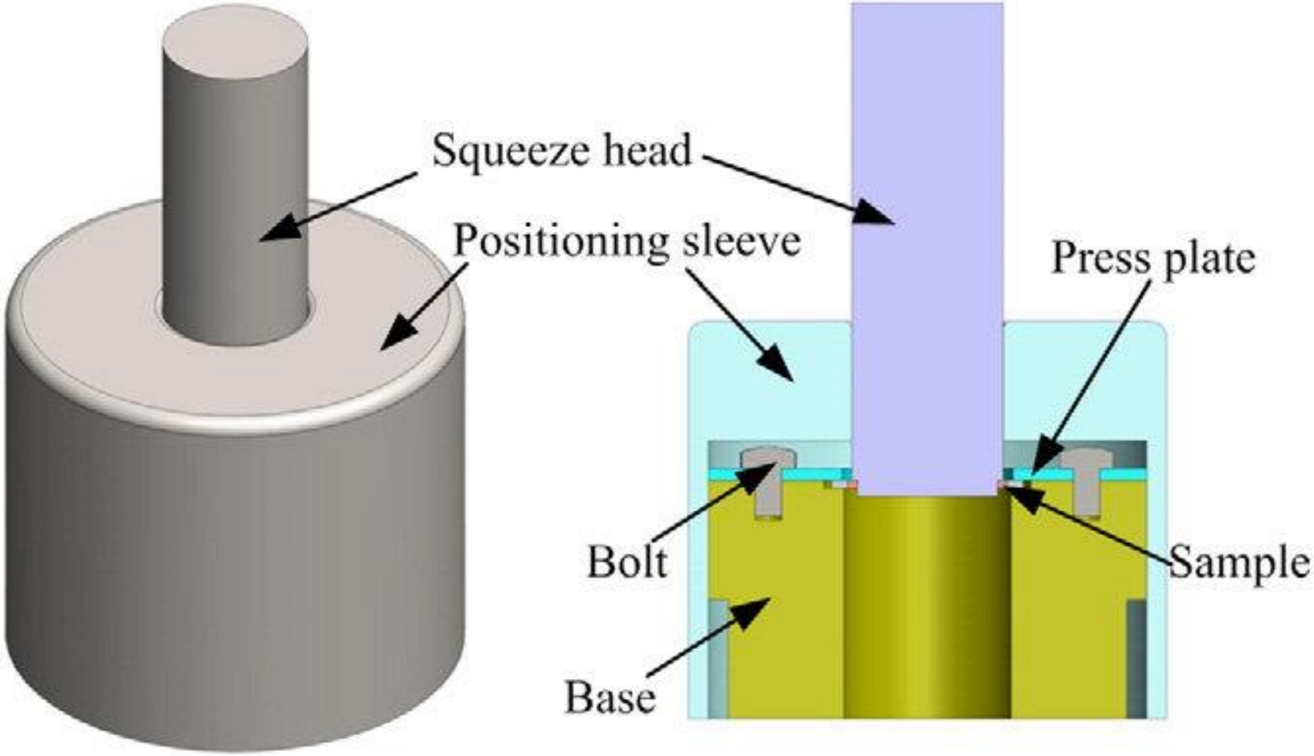
a = thickness of the specimen and
r = radius of punch

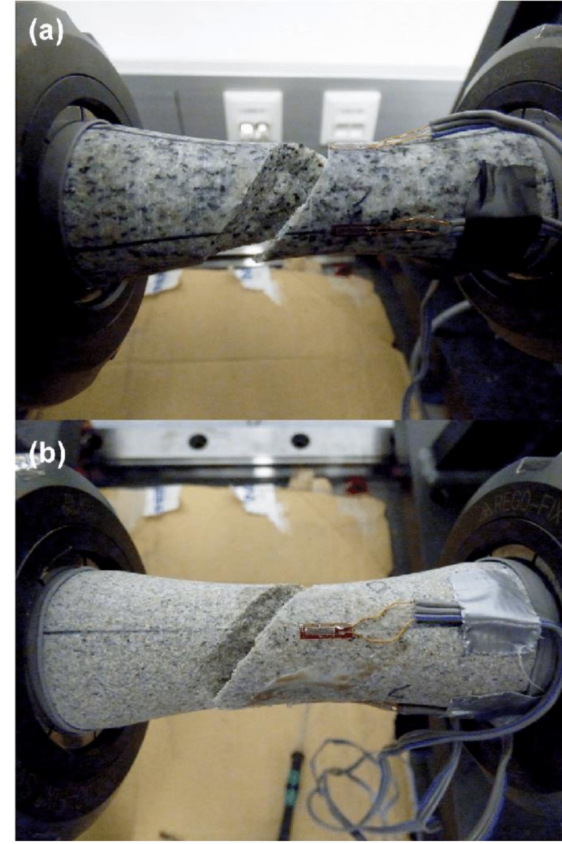
4. For Torsional Shear test, the shear strength S_o is

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



Mc = applied torque at the failure
D = Diameter of the cylinder



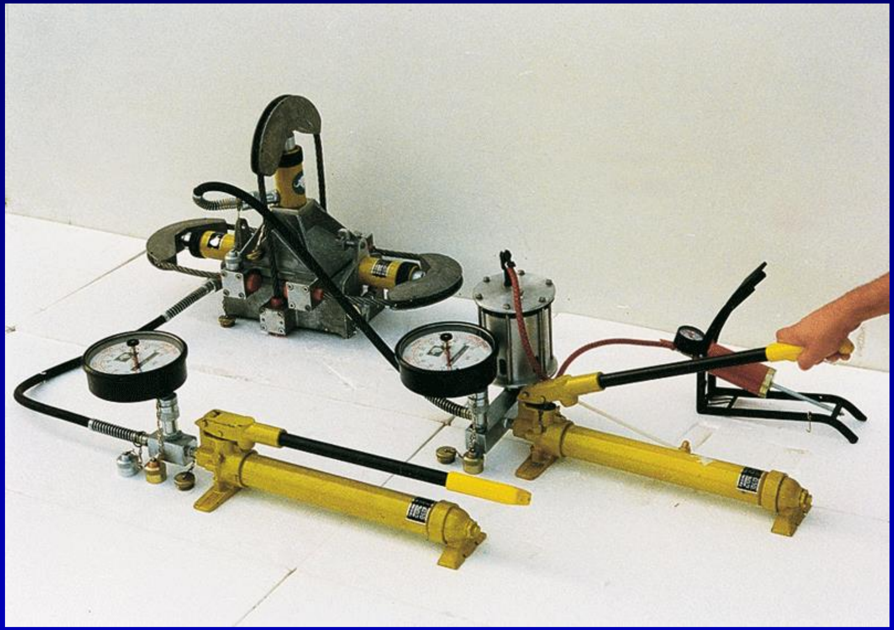


Punch Shear test

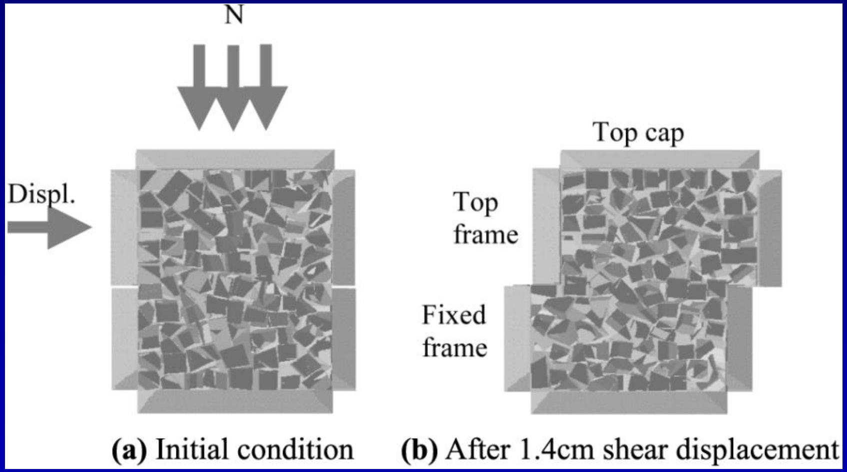
Torsional Shear test

Laboratory test

Portable direct shear test



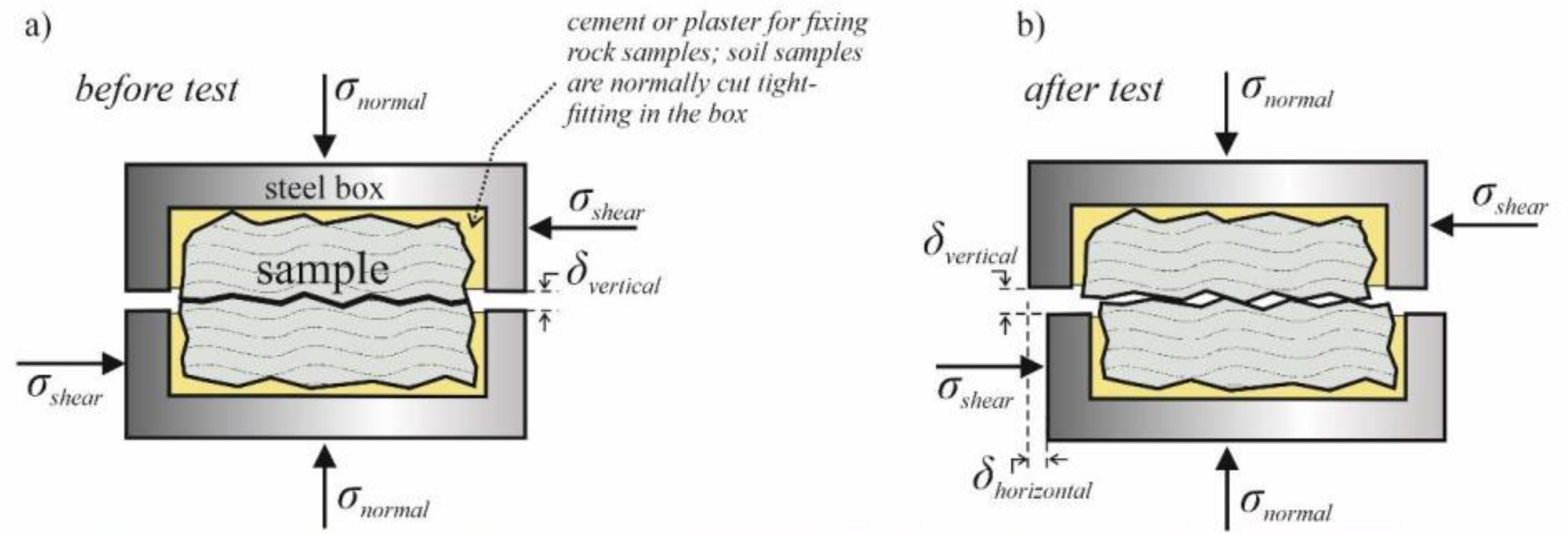
Shear test on rock discontinuities



Shear of rock discontinuity

Determination of the shear strength of natural and artificial rock discontinuities.

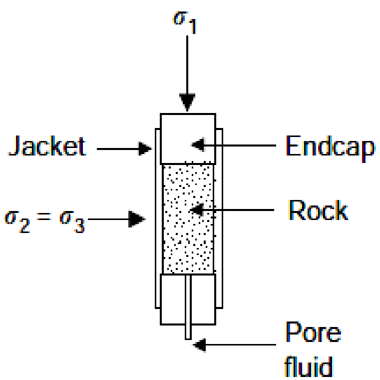
Direct single shear test

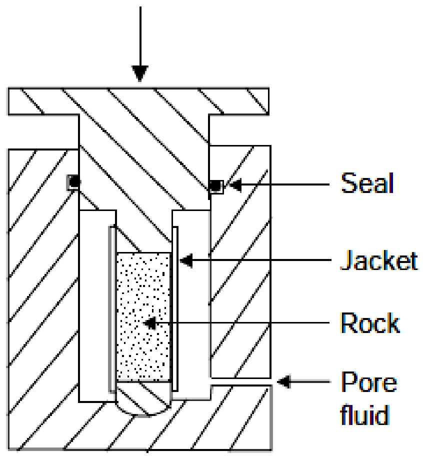


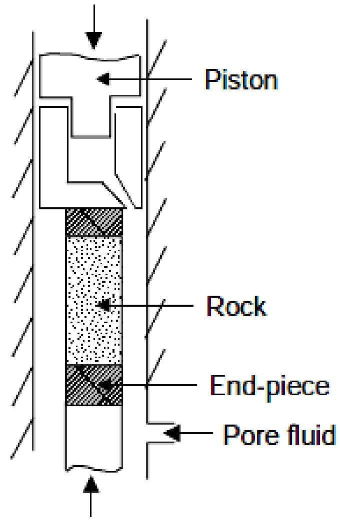
4 Triaxial Compressive and Shear Strength

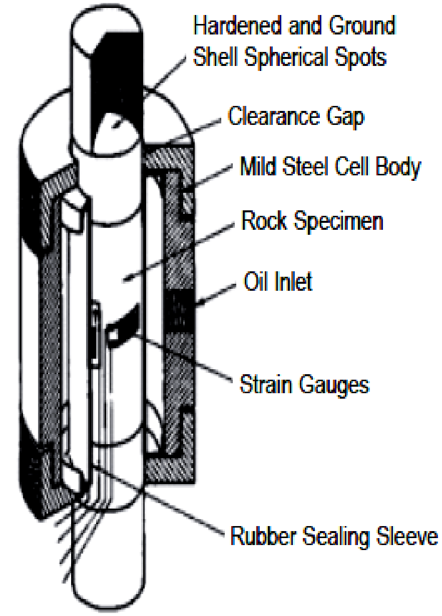
$$\sigma_3 = \frac{F_c}{A} \quad \text{and} \quad \sigma_1 = -p$$

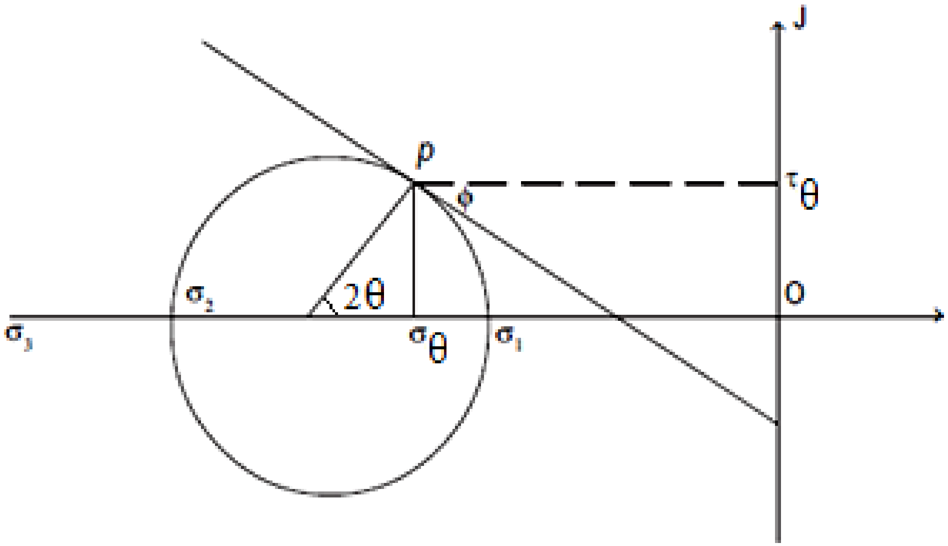
A is the end area of the specimen











Mohr's Circle

ϕ = the angle internal friction formed by tangent to the circle at p and the direction of the τ axis.

θ = Angle of failure plane with respect to axial direction

μ = the coefficient of internal friction can be calculated from tan2Q = 1/μ

σ_1 and σ_3 relationship is approximately linear for many rocks.

$\tau_\theta = +(S_o - \sigma_\theta \tan\phi)$

σ_θ and τ_θ are the normal and shear stresses acting on the failure plane.

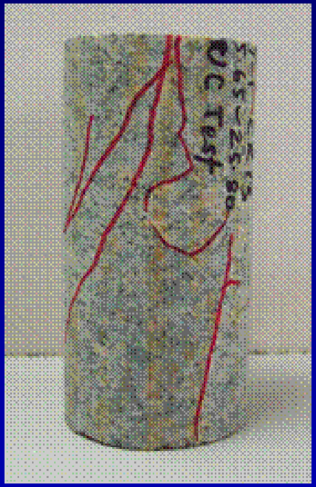
S_o is the shear strength of the rock.

$\tan\phi$ is the slope of the envelope curves.

Laboratory test

Triaxial test

Triaxial rock testing system



Before failure

After failure

Determination of the compressive strength of intact rock specimens with simultaneous application of confining pressure (up to 70MPa) using the Hoek cell.


SP3
Thank You