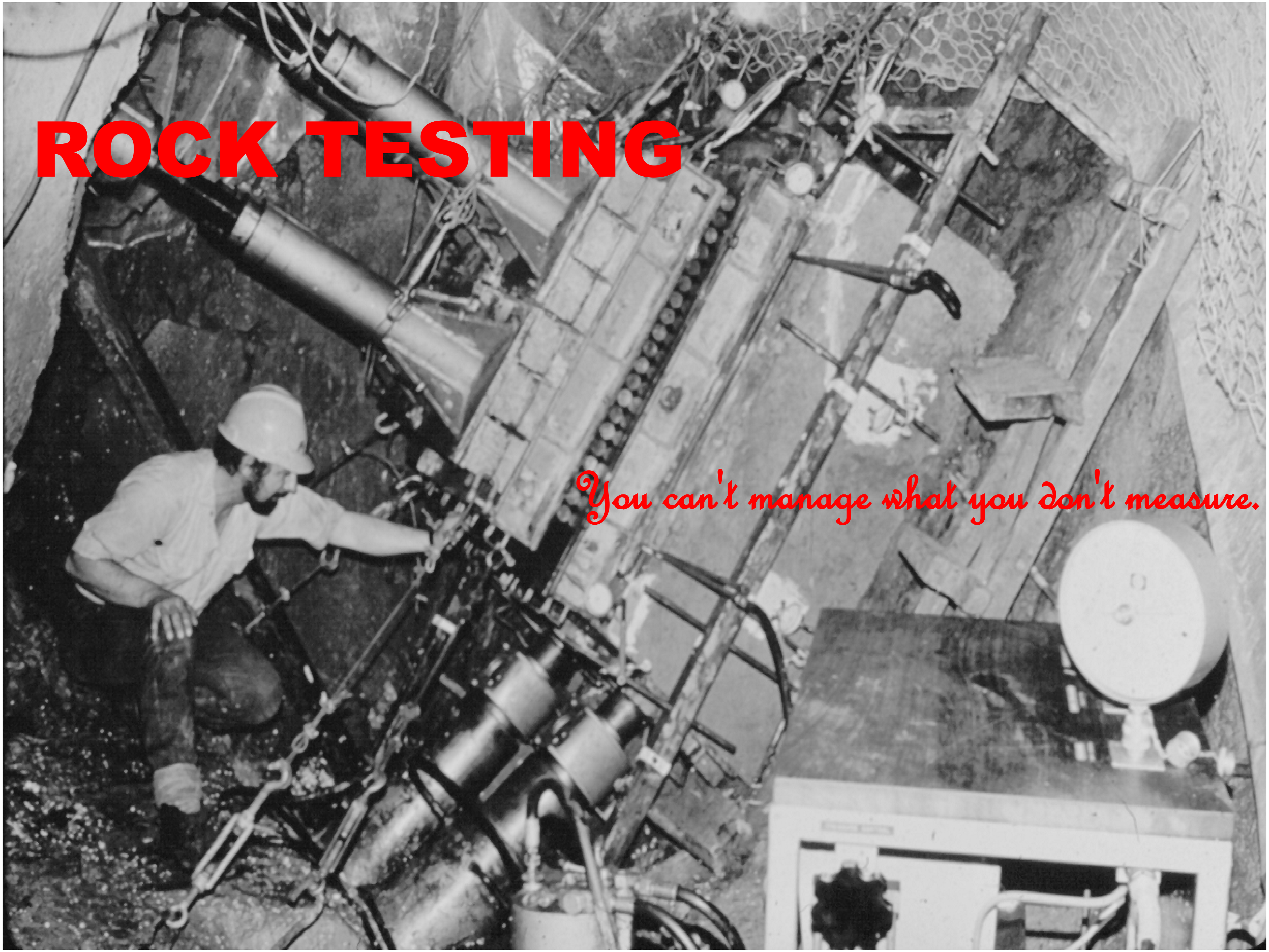
ROCK TESTING



You can't manage what you don't measure.

Physically or visually

Testing of rock

The most important and essential scope in Rock Mechanics is measuring & determination of rock properties & behaviour using recommended testing methods & procedures.

These include engineering characteristics of rock e.g. mode of deformation (bentuk canggaan), strength (kekuatan), mode of failure (bentuk kegagalan) & modulus of elasticity (keanjalan; E, G & *n*)

Testing of rock

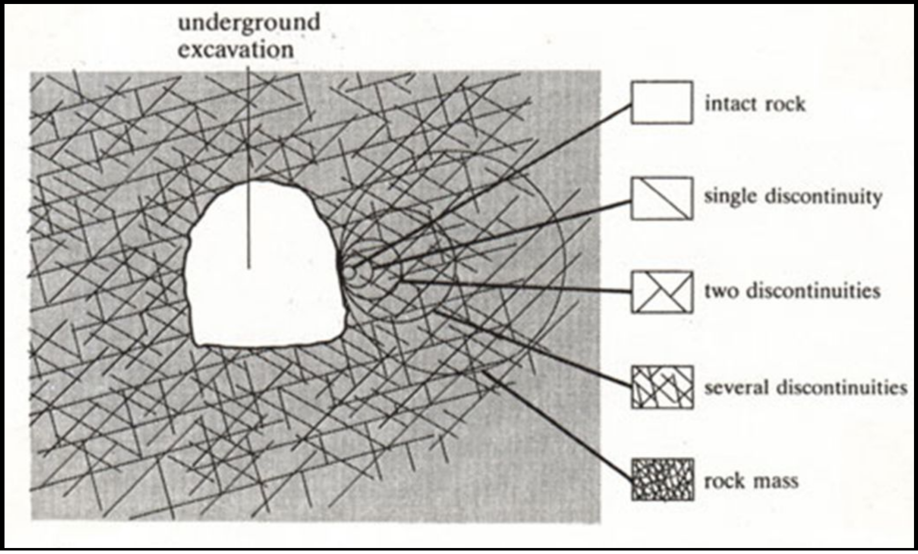
Specific testing methods can be used to evaluate & to determine the strength & characteristics of rocks numerically (in addition to the subjective description provided by geologists).

Standard test methods & procedures, laboratory & field are usually according to *International Society of Rock Mechanics* (ISRM).Other standards include S. African SRM, ASTM, NGI & BS.

Laboratory tests for testing of rock samples:

Rocks are naturally occurring material, they are inhomogeneous & anisotropic. Even rock of the same class, collected from the same location exhibit variation (kepelbagaian).

Testings are to measure & to evaluate change in rock properties & behaviour when acted upon by loading. The properties include physical, index & strength of rock materials. Behaviour include mode of deformation & failure.



Laboratory tests for testing of rock samples:

Are generally divided into 2 types:

[a] Index test & indirect strength test
(Ujikaji indeks & ujikaji secara tak lansung).

[b] Direct strength test
(Ujikaji kekuatan secara lansung)

The types are generally based on methods of testing & nature/type of data obtained.

[a] Index test & indirect strength test :

Index tests are relatively simple & rapid, but do not provide fundamental property. Data is just an indicator (petunjuk) on property being tested. Apparatus is generally simple and portable (allow test to be conducted on site).

Tests may not require detailed sample preparation. Certain tests are 'non-destructive' type & do not involve failure of samples (cost saving for sample can be reused).

[a] Index test & indirect strength test :

Data is not suitable for detailed design purpose but, it is valuable for preliminary / pre-feasibility assessments. Common tests include:

- Point-load index test,
- Schmidt / Rebound Hammer (surface hardness) test,
- Slake's durability index test,
- Sonic wave velocity test (PUNDIT),
- Brazilian / Indirect tensile strength test.

Brazilian test

large-
uities

Prof. Carniero, studying on the correlation between UCS and flexural tensile strength, developed **BRAZILIAN TEST** in 1943 in Brazil.

(Fairbain & Ulm, 2002)

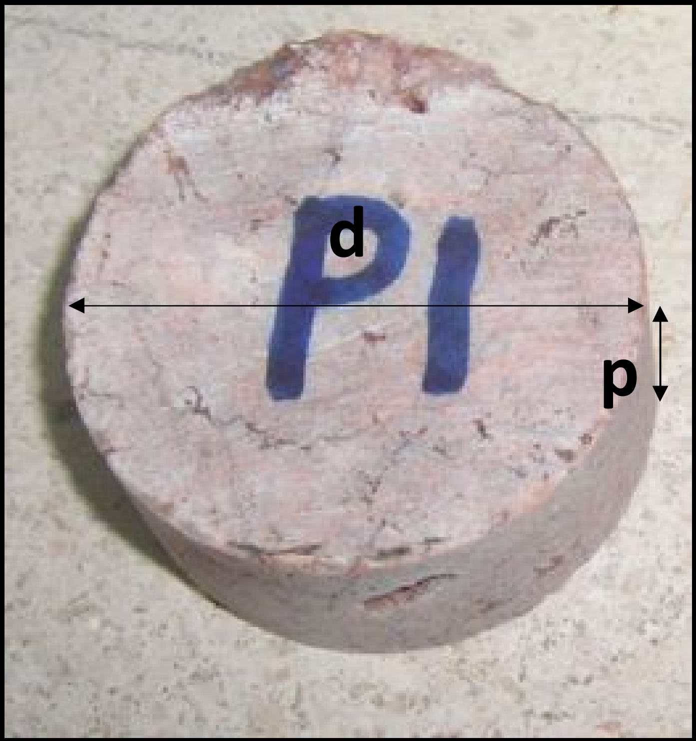
Prof. Carniero during Brazilian tensile strength test

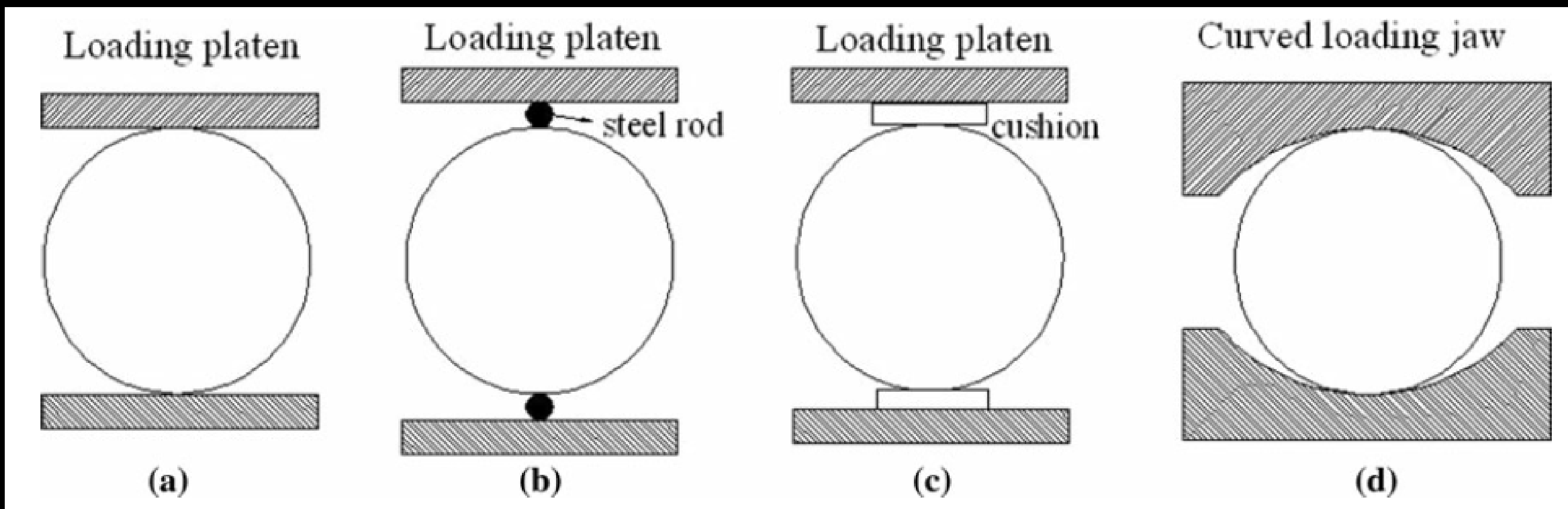
Brazilian or indirect tensile test

Test is to measure the uniaxial tensile strength of rock sample indirectly using Brazilian test. Equipment is similar to portable UCS test.

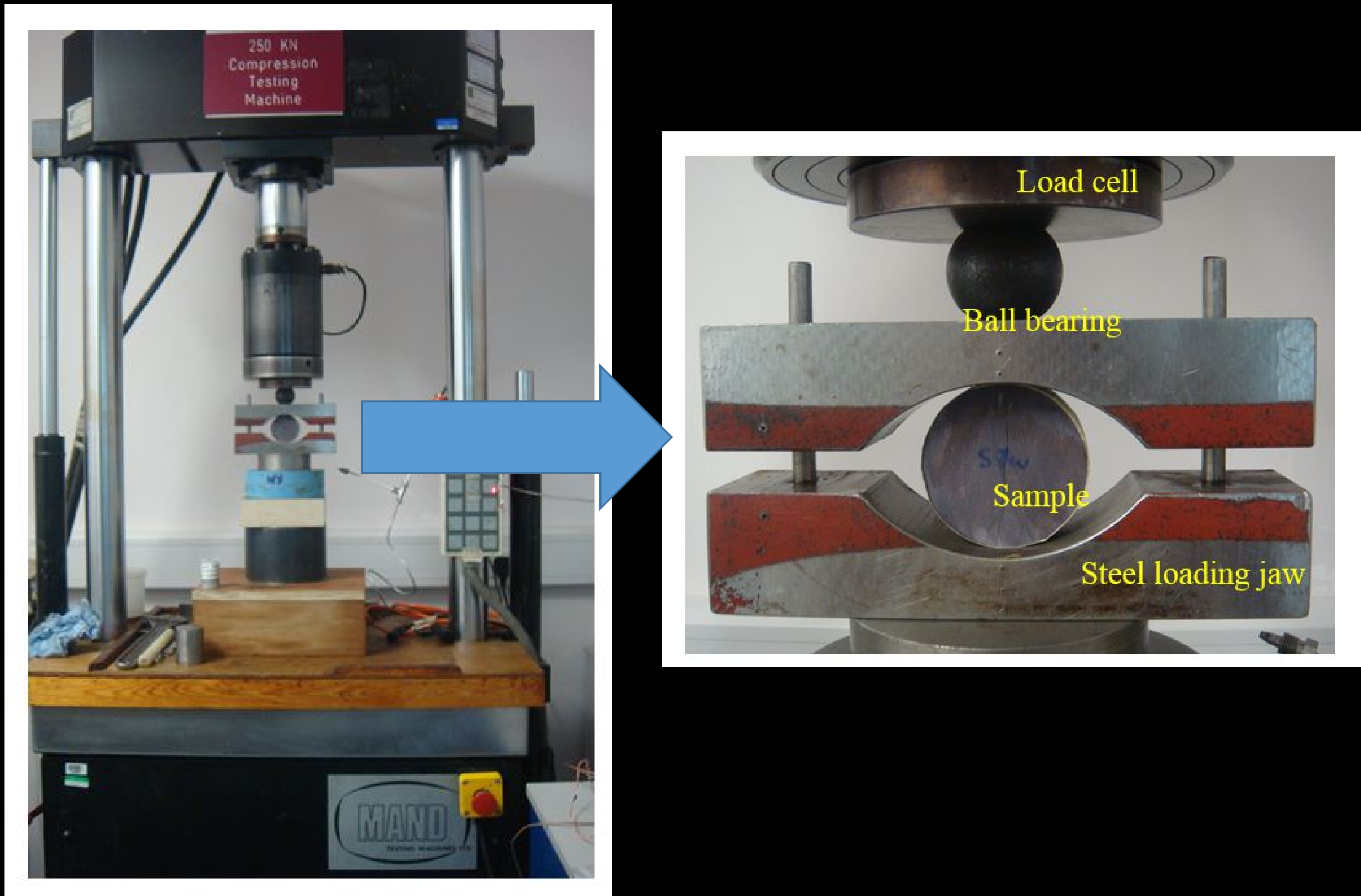
Sample is disc-shaped (thickness, t = 0.5 ×diameter, d). Load apply is compression. Sample fails with diametrical fracture.

Tensile strength, T = [0.636P / d t] where P is compressive load at failure.

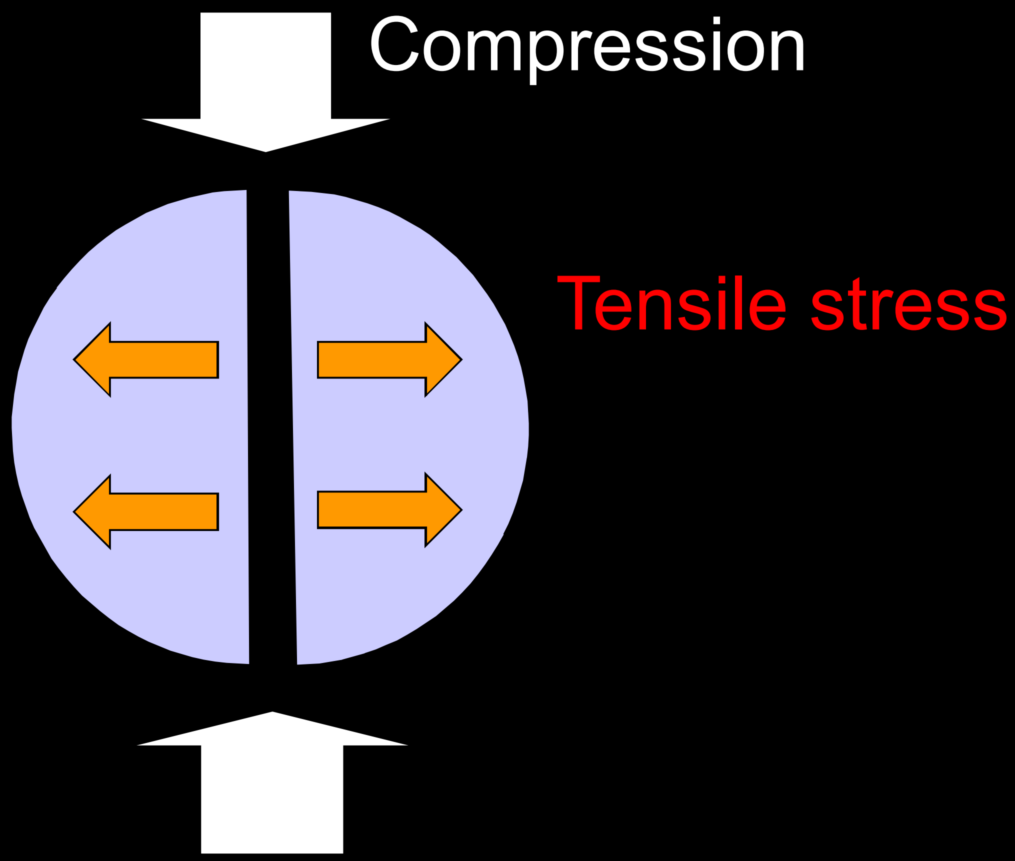




Typical Brazilian tensile test loading configurations: (a) flat loading platens, (b) flat loading platens with two small-diameter steel rods, (c) flat loading platens with cushion, and (d) curved loading jaws



Brazilian test (indirect tensile strength test) to obtain tensile strength of rock sample (note: the same equipment can be used for portable UCS test)

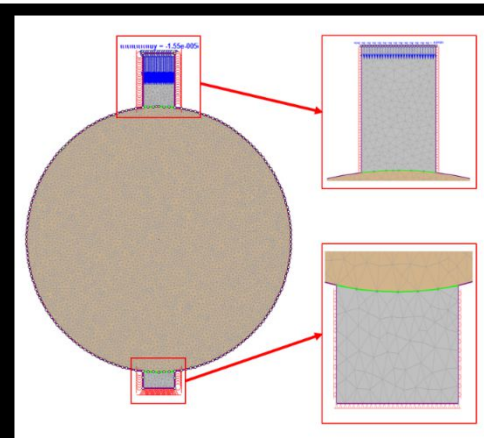


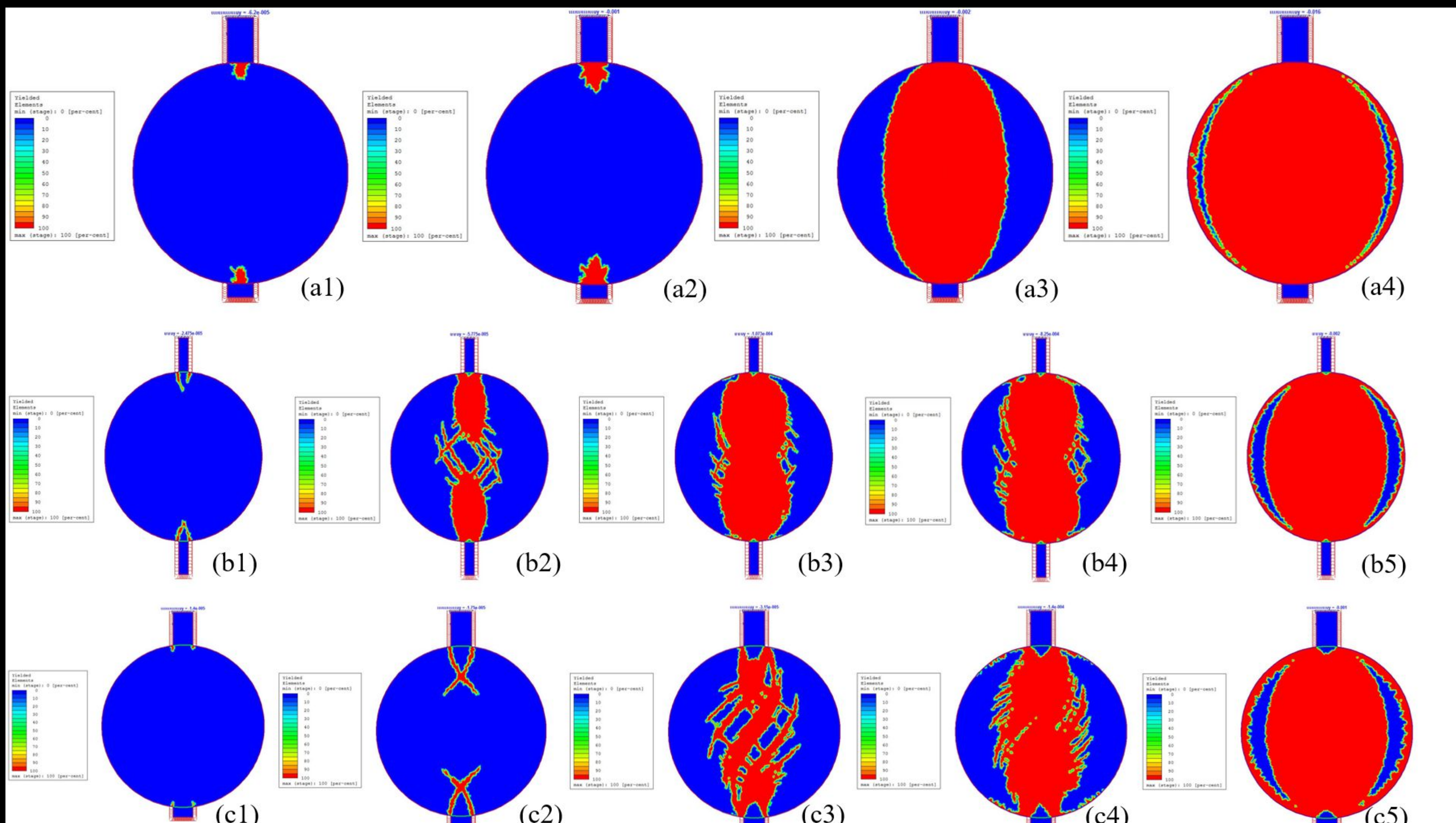
Mode of failure of sample – ‘diametrical fracture’ indicating failure is due to tensile stress

BEFORE TEST	AFTER TEST
	
	

BEFORE TEST	AFTER TEST
	
	

Numerical modelling of Brazilian test in RS2: (a) 0%, (b) 4% and © 8% contact area.





Mode of failure of sample – ‘diametrical fracture’
indicating the association of tensile stress

Solid vs hollow sample

Sandstone

Granite

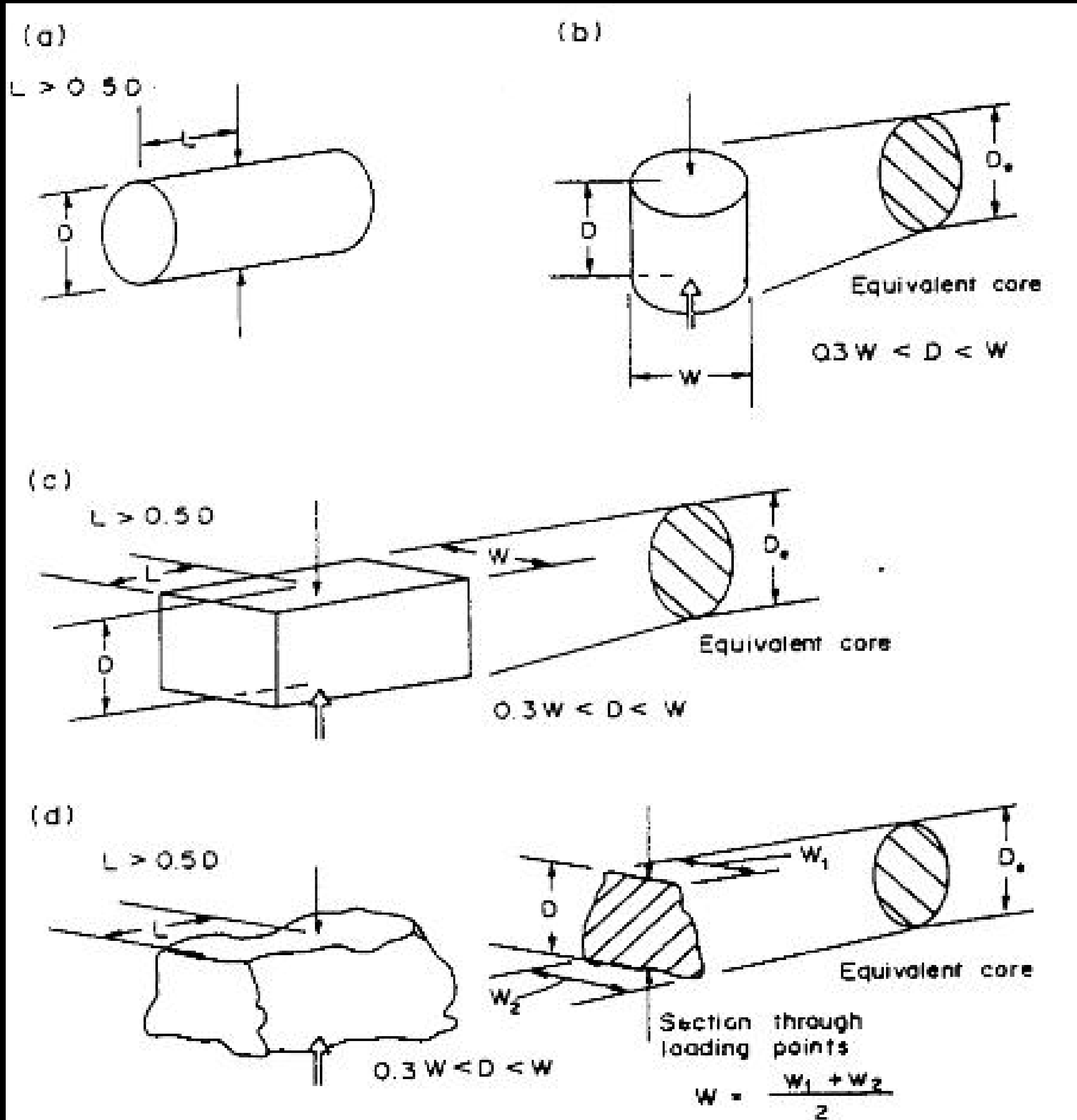
Point Load Test

Point-load Index test:
Is a quick & simple test to undertake. Sample can be core (teras) or irregular block. Equipment is easy to handle and portable. Test can be undertaken on site. Data obtained is an index (indicator) for strength of sample tested.
A simple test & therefore, no constraint on number of test.

Index value obtained (I_s) can be converted to UCS:

$$I_s = P/D_e^2$$

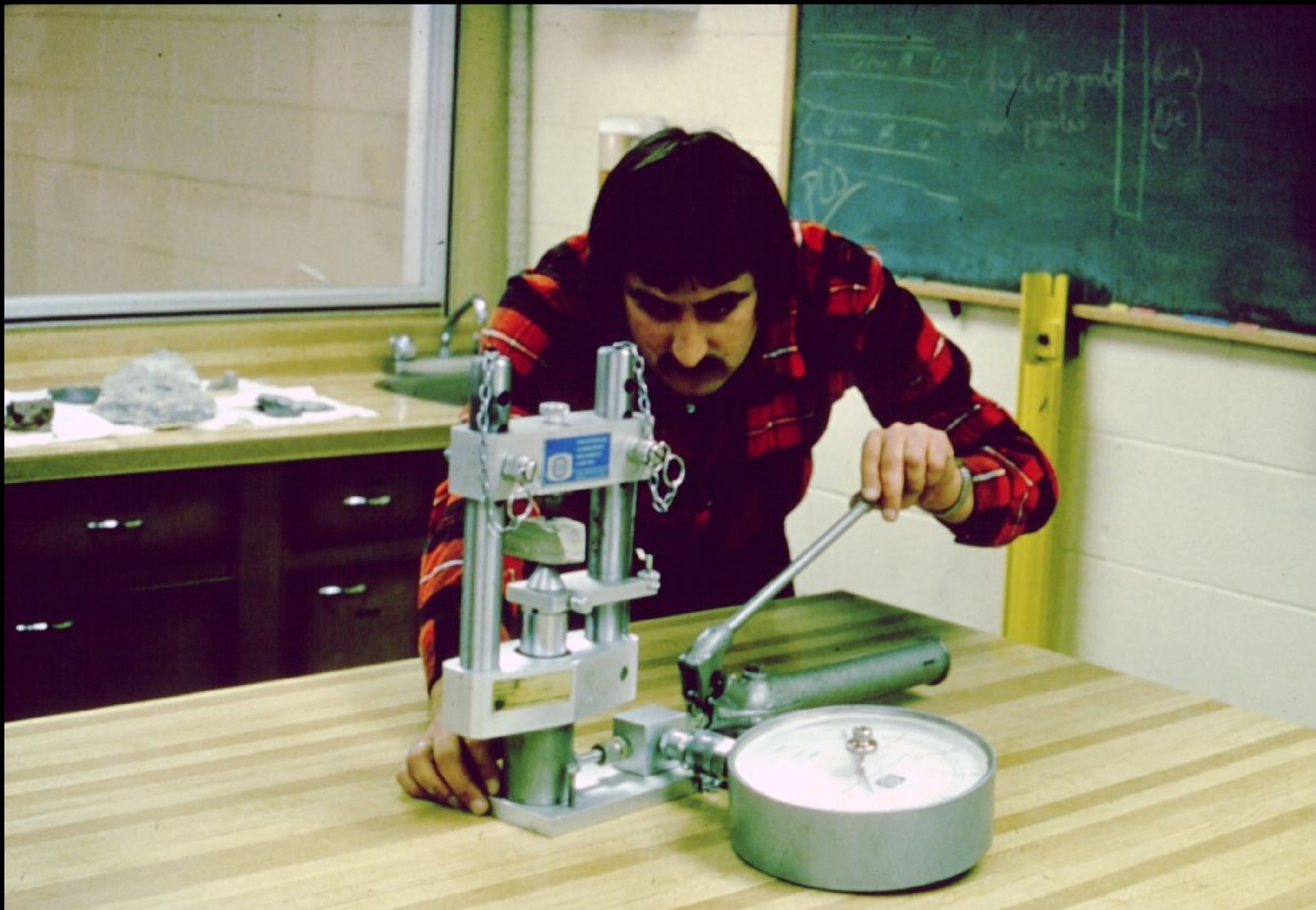
$$UCS \approx 24\ I_s$$ (Broch & Franklin, 1972).



(a)
L > 0.5D
L
D
(b)
D
W
De
Equivalent core
0.3W < D < W
(c)
L > 0.5D
L
W
D
De
Equivalent core
0.3W < D < W
(d)
L > 0.5D
L
W1
D
De
W2
Equivalent core
Section through loading points
0.3W < D < W
W = (W1 + W2)/2

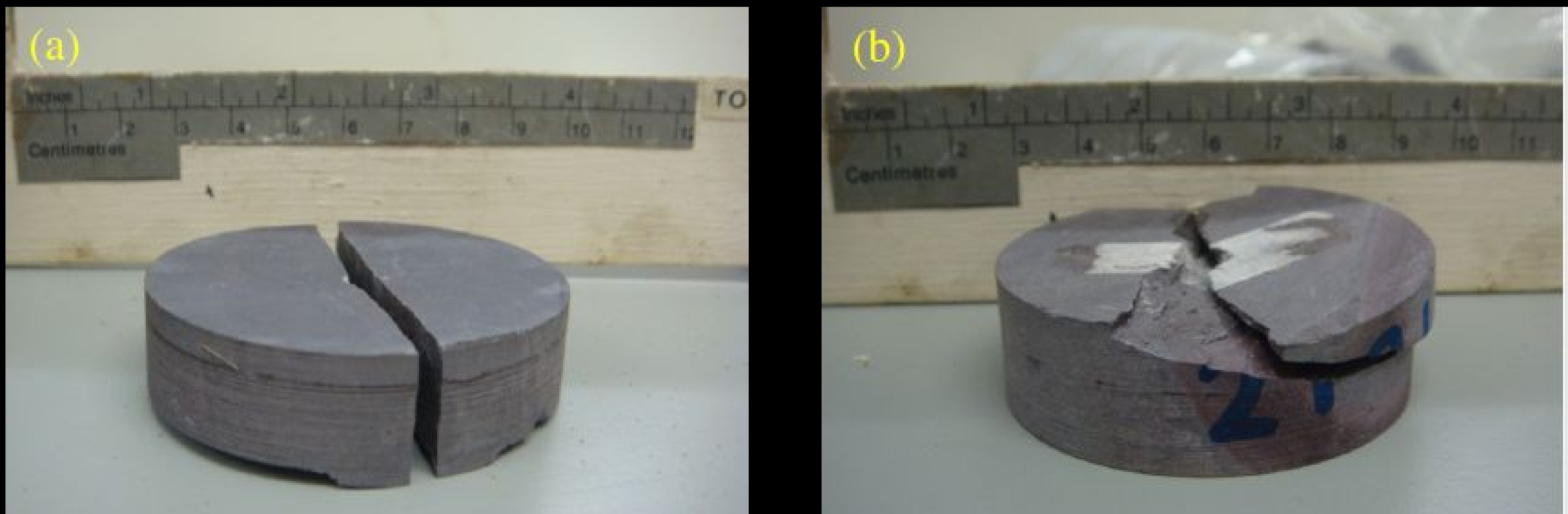
Point-load test on irregular block sample

Irregular block sample placed in between pointed loading platens



Core sample obtained rock drilling

Core sample obtained rock drilling



Mode of failure for (a) valid and (b) invalid PLT

Schmidt Hammer

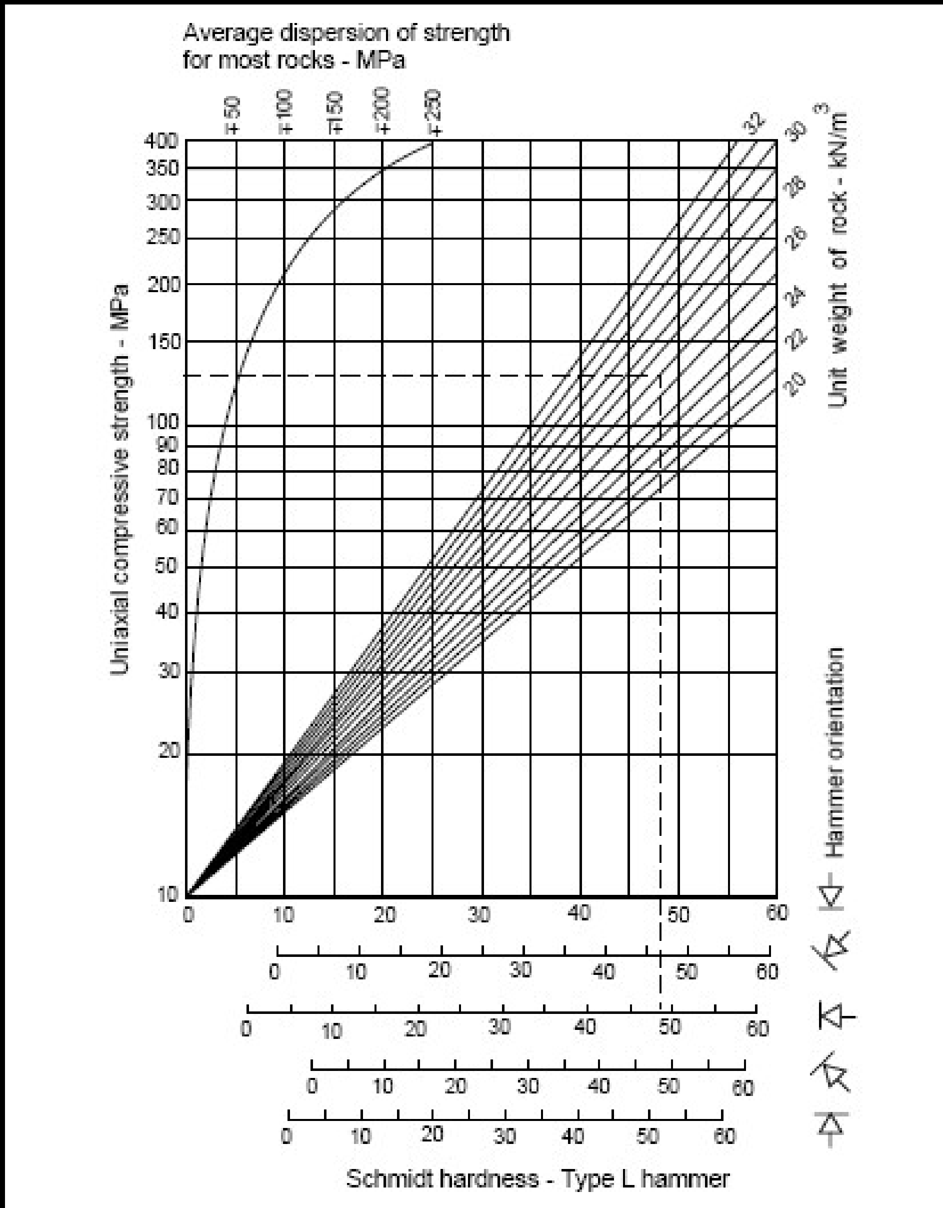
Schmidt / Rebound Hammer test

Test on surface hardness of rock sample using Schmidt hammer (L-type), a portable & simple equipment to handle. Sample can be core or block. Test is non-destructive & sample can be re-used.

Index data obtained is rebound number (R). The stronger is the surface the higher is the R value.
R is related to the surface strength (JCS) of rock sample tested:

Log_{10} JCS = 0.00088 (g) (R) + 1.01
(Broch & Franklin, 1972).

Schmidt hammer test on irregular block sample



Correction factor to the hammer orientation

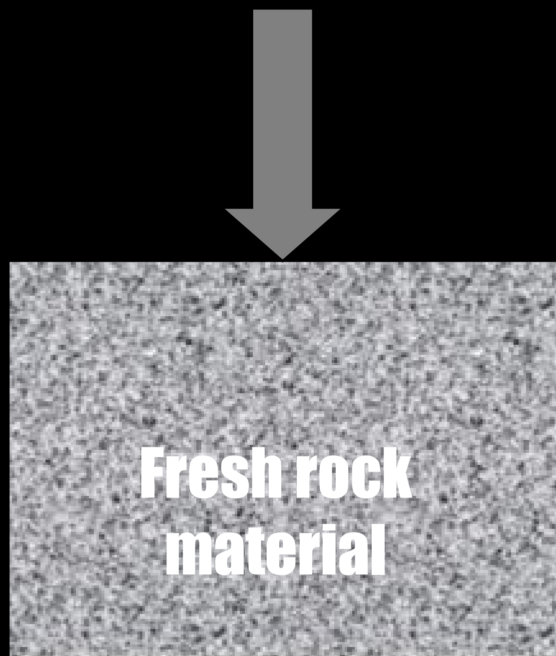
Schmidt / Rebound Hammer test

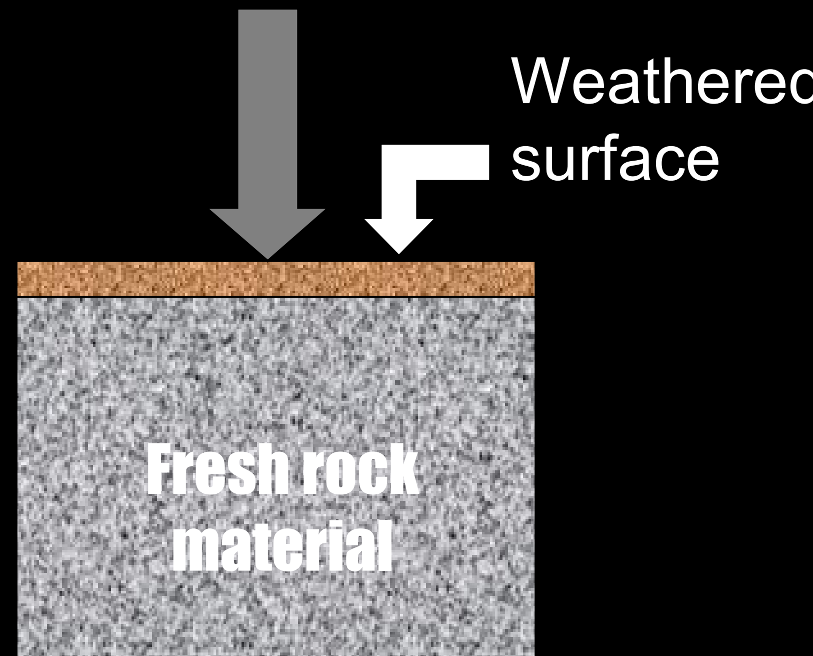
$Log_{10}JCS = 0.00088\ (g)\ (R) + 1.01$

JCS: Joint compressive strength, or surface compressive strength of sample

If rebound test is conducted on Fresh (Grade I) rock sample, value of R (i.e. surface compressive strength) is approximately equals to the UCS value of the sample surface.

However if the surface of rock sample being tested displays some weathering effect (e.g. iron staining), the above does not apply.





Test on fresh rock block: Rebound indicates UCS of surface ≈ UCS of rock internal material.

Test on rock blocks with weathered surface (interior is still fresh): Rebound indicates UCS of the surface but does not represent the UCS of internal materials.

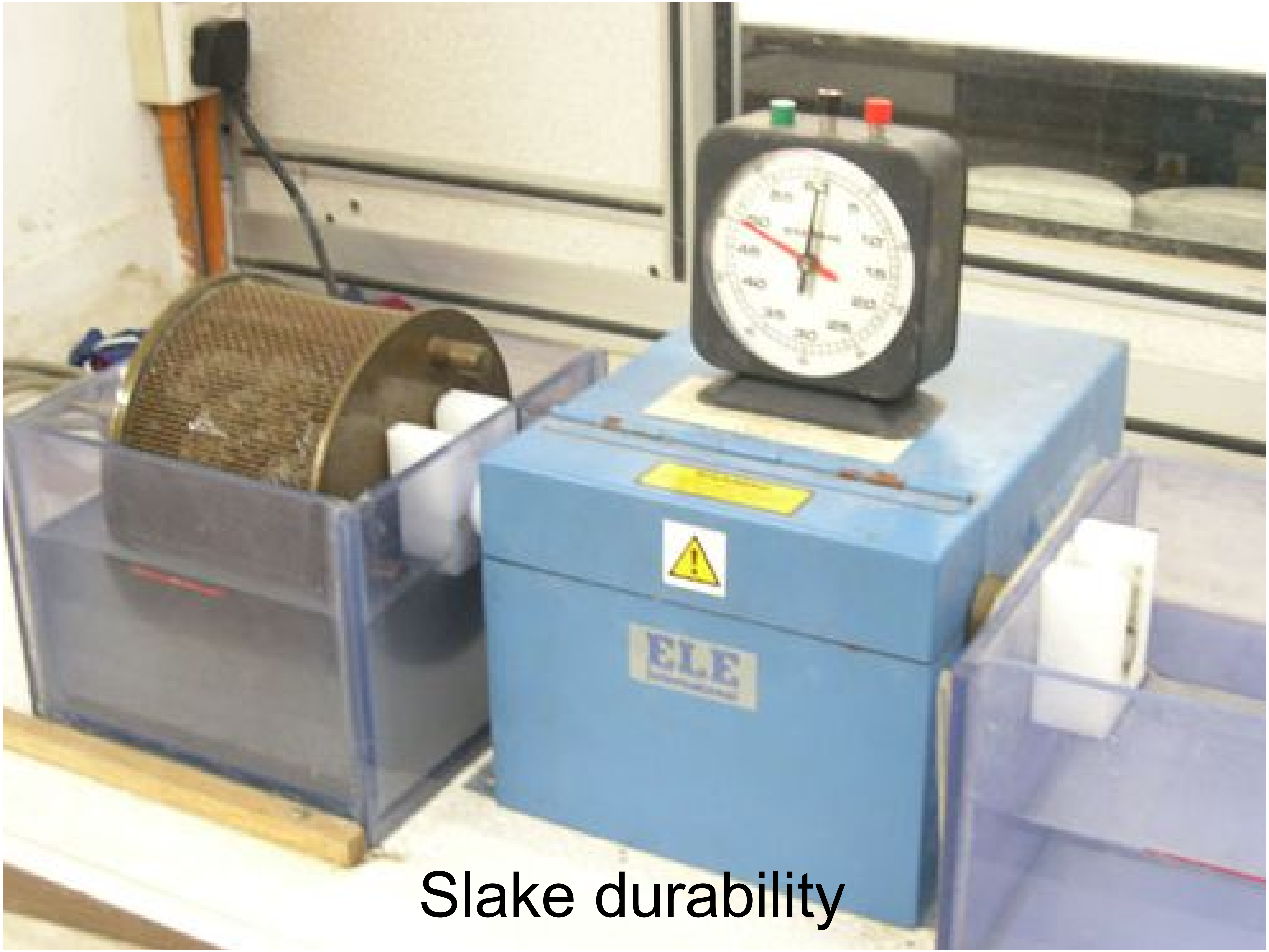
Fresh sample (Grade I):
R = JCS $\approx$ UCS

Weathered sample (Grade II to III):
R = JCS $\neq$ UCS

Weathered rock
(Grade II to III):
R = JCS $\neq$ UCS

Fresh rock
(Grade I):
R = JCS $\approx$ UCS

Effect of rebound no. R on weathered rock surface



Slake durability

Slake durability test

Test is to assess the resistance of rock sample to weakening & disintegration when subjected to drying & wetting (weathering process). The stronger the rock the higher is SDI.

Sample is soaked in water and cycled for a given time. Cycling process can be repeated up to 2 sets. Slake durability index I_{sd} for hard rock can be as high as 100% and soils usually exhibit very low index of less than 30%.

Slake durability index test apparatus

Aggregate sample for Slake durability test

Aggregate sample for Slake durability test

Slaking (disintegration) of rock sample after test

Ultrasonic velocity test

Ultrasonic velocity test

Test is non-destructive & equipment is portable & simple.

Test involves transmitting Primary-wave through core sample, and data obtained is wave propagation velocity (V_p).

The denser the specimen (less voids) the higher is the V_p. Rocks display a higher V_p compared to soils.
(note: denser means stronger)

Sonic velocity test on core sample (non-destructive test, sample can be used for other test)

Type Of Rocks	P-wave velocity m/s
Dry, loose topsoils and silts.	180-370
Dry sands, loams; slightly sandy or gravely soft clays.	300-490
Dry gravels, moist sandy and gravely soils; dry heavy silts and clays; moist silty and clayey soils.	460-910
Dry, heavy, gravely clay; moist, heavy clays; cobbly materials with considerable sands and fines; soft shales; soft or weak sandstones	910-1460
Water, saturated silts or clays, wet gravels.	1460-1520
Compacted, moist clays; saturated sands and gravels; soils below water table; dry medium shales, moderately soft sandstones, weathered, moist shales and schists.	1460-1830
Hardpan; cemented gravels; hard clay; boulder till; compact, cobbly and bouldery materials; medium to moderately hard shales and sandstones, partially decomposed granites, jointed and fractured hard rocks.	1680-2440
Hard shales and sandstones, interbedded shales and sandstones, slightly fractured hardrocks.	2440-3660
Unweathered limestones, granites, gneiss, other dense rocks.	3660-6100

Index test, data obtained & indication.

Name of test	Data obtained and indication
Uniaxial compressive test (UCT).	**Uniaxial compressive strength (UCS). Indication on strength and resistance against loading and fracturing.**
Point-load index strength.	**I_s (can be converted to UCS). Indication is similar to UCS**
Slake durability index test.	**I_{sd} (Slake durability Index). Indication on resistance against slaking (pemeroian) and degree of bonding between mineral grains. Resistance against weathering.**
Schmidt / Rebound hammer test.	**R (Rebound Number). Indication on surface hardness (strength) and resistance against impact and abrasion. R is related to UCS**
Tensile strength	**Tensile strength (T). Indication on resistance against fracturing and degree of bonding mineral grains.**
Ultrasonic Veolcity Test	**Vp (P-wave velocity). Indication on denseness and compactness.**

[b] Direct strength test:

Test procedure requires detailed preparation of sample (standard shape & finishing). Sample preparation process is equipment related & it is costly.

The testing itself involving sophisticated & large equipment, thus detailed testing procedures. May require complex analysis, again it is costly.

However data obtained is fundamental property & direct presentation of property being evaluated.

[b] Direct strength test:

Expensive tests to conduct therefore, limited number of tests.

Since data is direct fundamental property, it can be used for detailed design. Tests include:

Permeability of rock.

Modulus of deformation – elastic modulus (E) & Poisson ratio (n).

Uniaxial & Triaxial compressive strength test (Kekuatan mampatan satu-paksi (UCS) & tiga-paksi).

Shear strength test on weakness planes (joint & foliation).

Preparation of rock core sample using laboratory coring machine (tungsten carbide coring bit)

Coring of rock block in laboratory – to obtain cylindrical sample 54 mm diameter & 108 mm height

Coring of rock block in laboratory – to obtain cylindrical sample 54 mm diameter & 108 mm height

Trimming of core sample to the required height or length using diamond disc cutter.

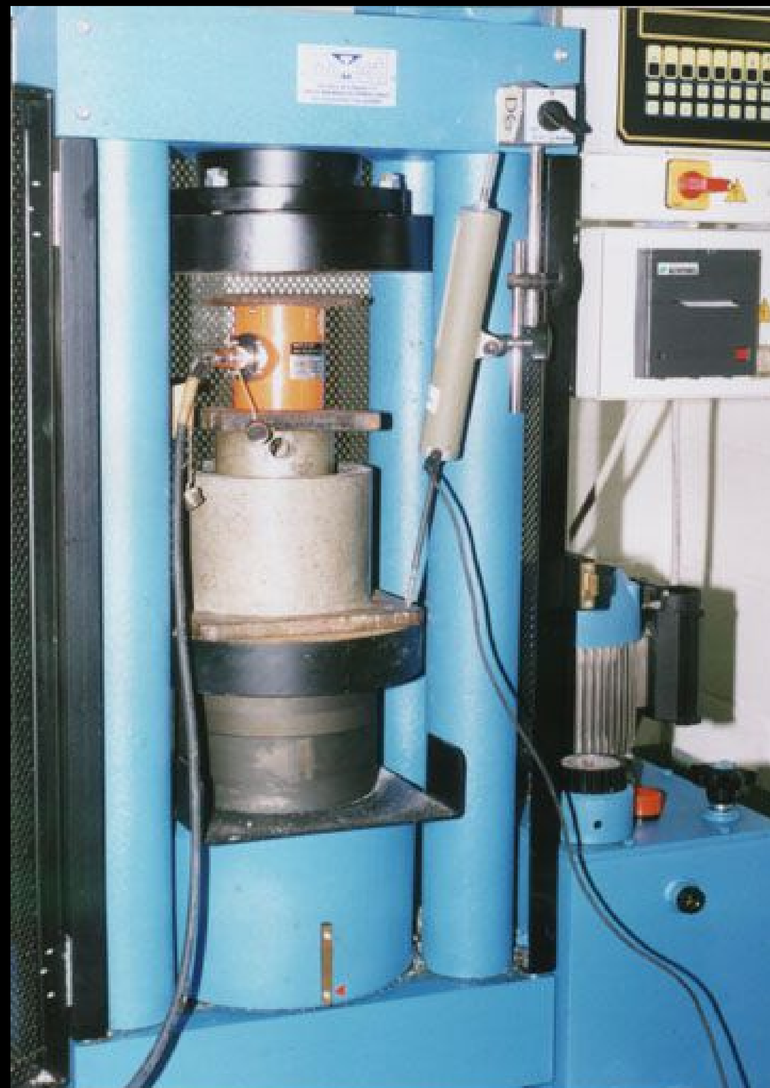
Trimming of core sample to the required height or length using diamond disc cutter.

Lapping of core sample to ensure end surfaces are smooth and perpendicular to core axis.

Prepared core samples – 54mm dia. & 108mm height.

Prepared core samples – 54mm dia. & 108mm ht.

Prepared core samples – 54mm dia. & 108mm ht.



Universal compression machine for uniaxial & triaxial strength test (500 kN capacity)

Universal compression machine, equipped with closed-circuit servo-controlled unit (3000 kN capacity)

Uniaxial compression test

Uniaxial compression test:

Requires preparation of sample, as per ISRM. Cylindrical shape (H : D = 2) & specific finishing of sample surface.
UCS of rock material & deformation behaviour under loading is verify by applying compressive load until failure using high capacity universal testing machine.
If UCT is conducted with measurement on vertical & horizontal strain, a number of rock properties can be determined – UCS, strain at failure, E & n.
Plotted Curve – Stress (MPa) versus Strain (%) in Figure 7.5.
Value of E & n for various rock type is as Table 7.1.

2 sets of gauges placed at vertical position (axial strain) and horizontal position (radial strain)

Electric foil strain gauges (20 - 30 mm gauge length)
to measure strains

Core samples for UCS test with axial (vertical) and radial (horizontal) strain measurements

TESTING EQUIPMENT & FACILITY

Servo-controlled 3000 kN compression machine – allows loading under strain-controlled

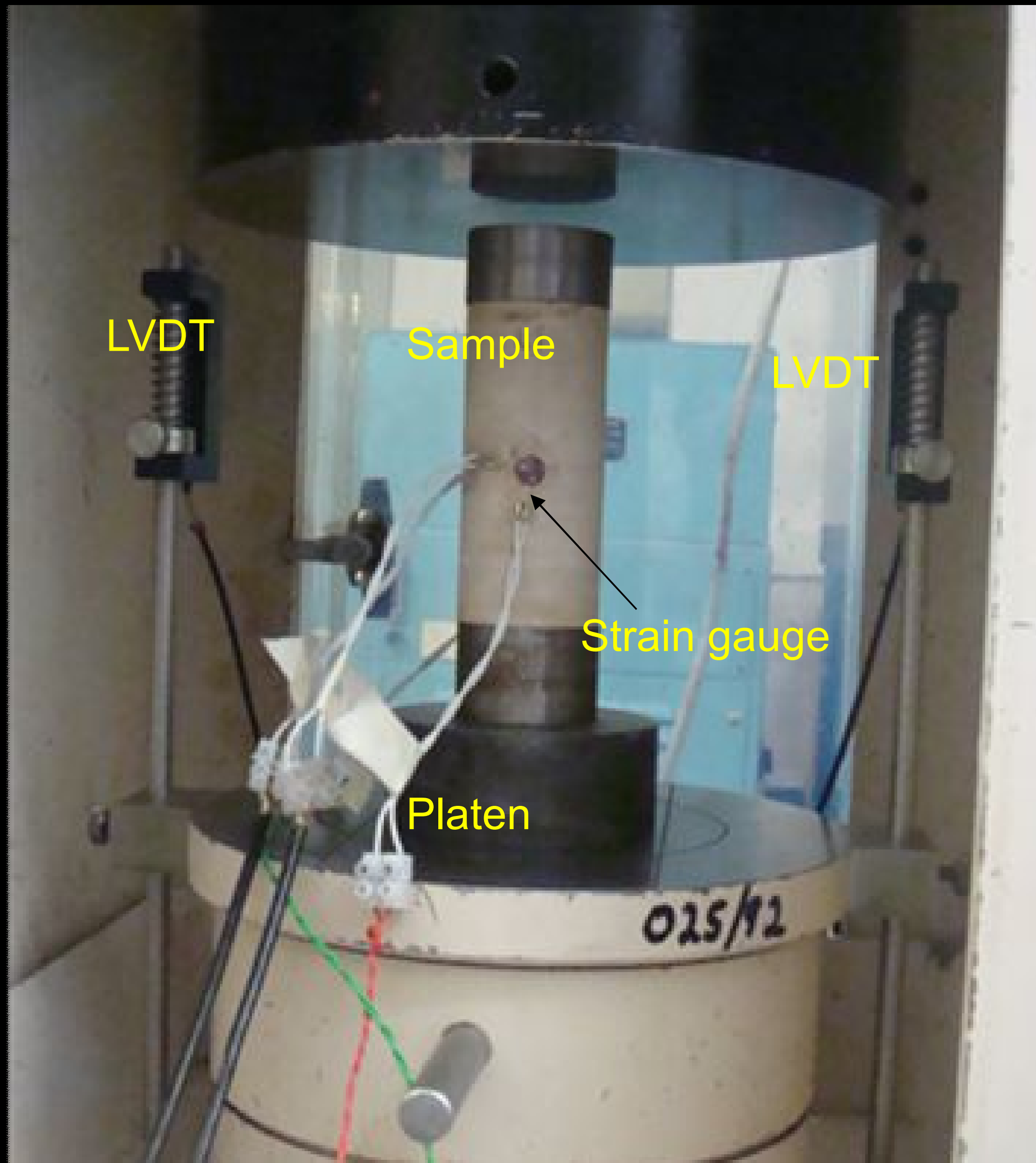
Load-cell & displc. transducer (LVDT)

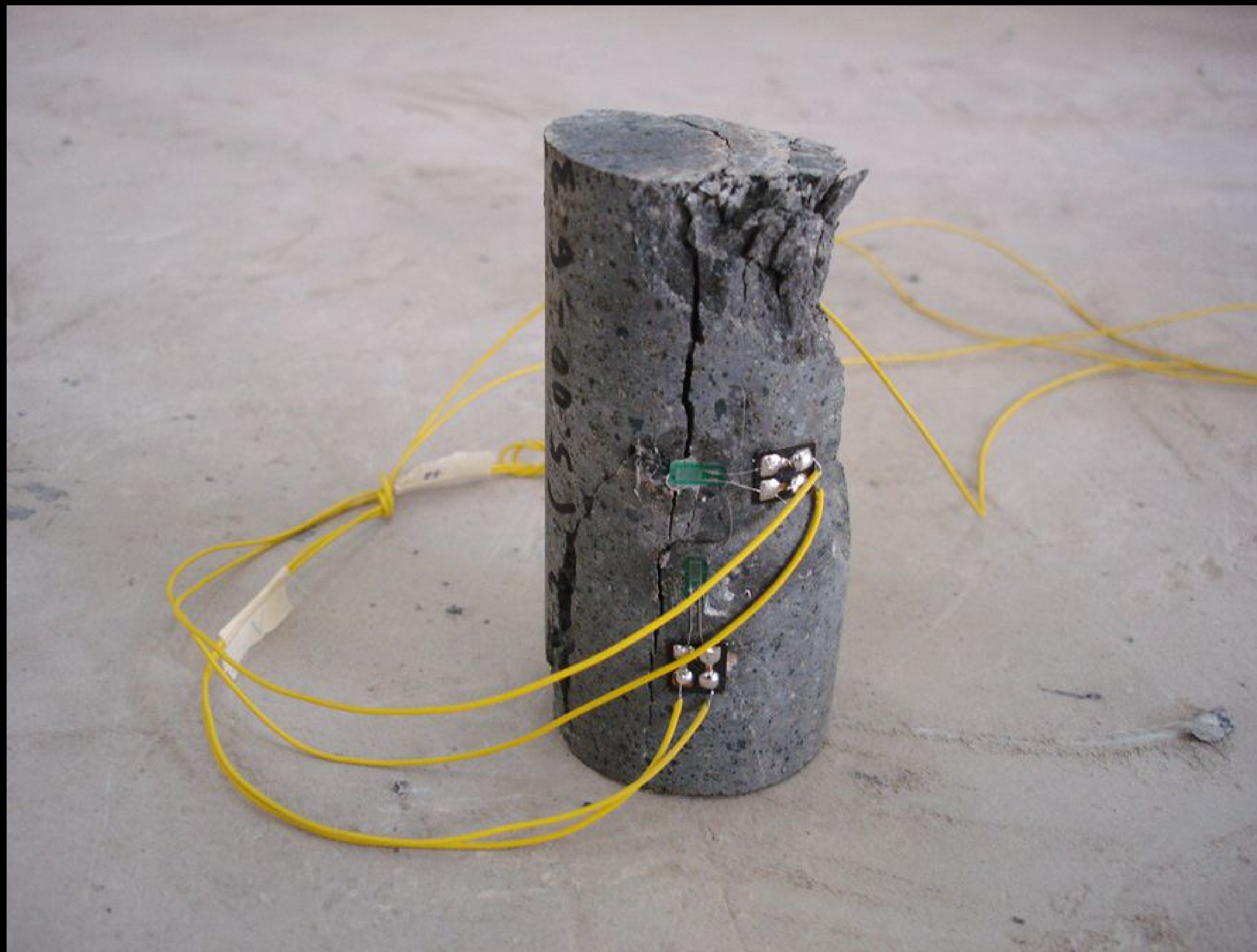
Data scanner & logger

Universal compression machine, equipped with closed-circuit servo-controlled unit (3000 kN capacity)

Digital controller for input of test parameters into testing program e.g. strain-rate & maximum load etc.

Servo-controlled (power pack) unit - for complex testing program e.g. compression under strain-controlled (complete stress-strain curve) & cyclic loading. Essential for study on deformation behaviour of rock.


LVDT
Sample
LVDT
Strain gauge
Platen



Fracture planes in failed rock (basalt) sample

Uniaxial compression test:

From Fig 7.2, elastic modulus of rock (E) is the gradient of the graph at 50% ultimate stress (UCS):

E = stress / strain = (σ) / (ε)

unit σ is MPa; ε is % & E is GPa

Poisson ratio n is the ratio of radial (lateral) strain to axial (vertical) strain taken at 50% UCS:

$$n = \varepsilon_r / \varepsilon_a$$

Axial strain at failure is ε_a at ultimate UCS. Strain at failure indicate the brittleness & ductility of sample.

Table1: Stress and strains data obtained from UCT

Normal stress (MPa)	Vertical strain (%)	Horizontal strain (%)
0.0	0.000	0.000
0.5	0.001	0.000
8.0	0.011	-0.001
18.8	0.029	-0.004
32.0	0.054	-0.008
38.1	0.066	-0.010
44.7	0.081	-0.012
51.8	0.096	-0.014
59.8	0.113	-0.017
67.8	0.128	-0.021

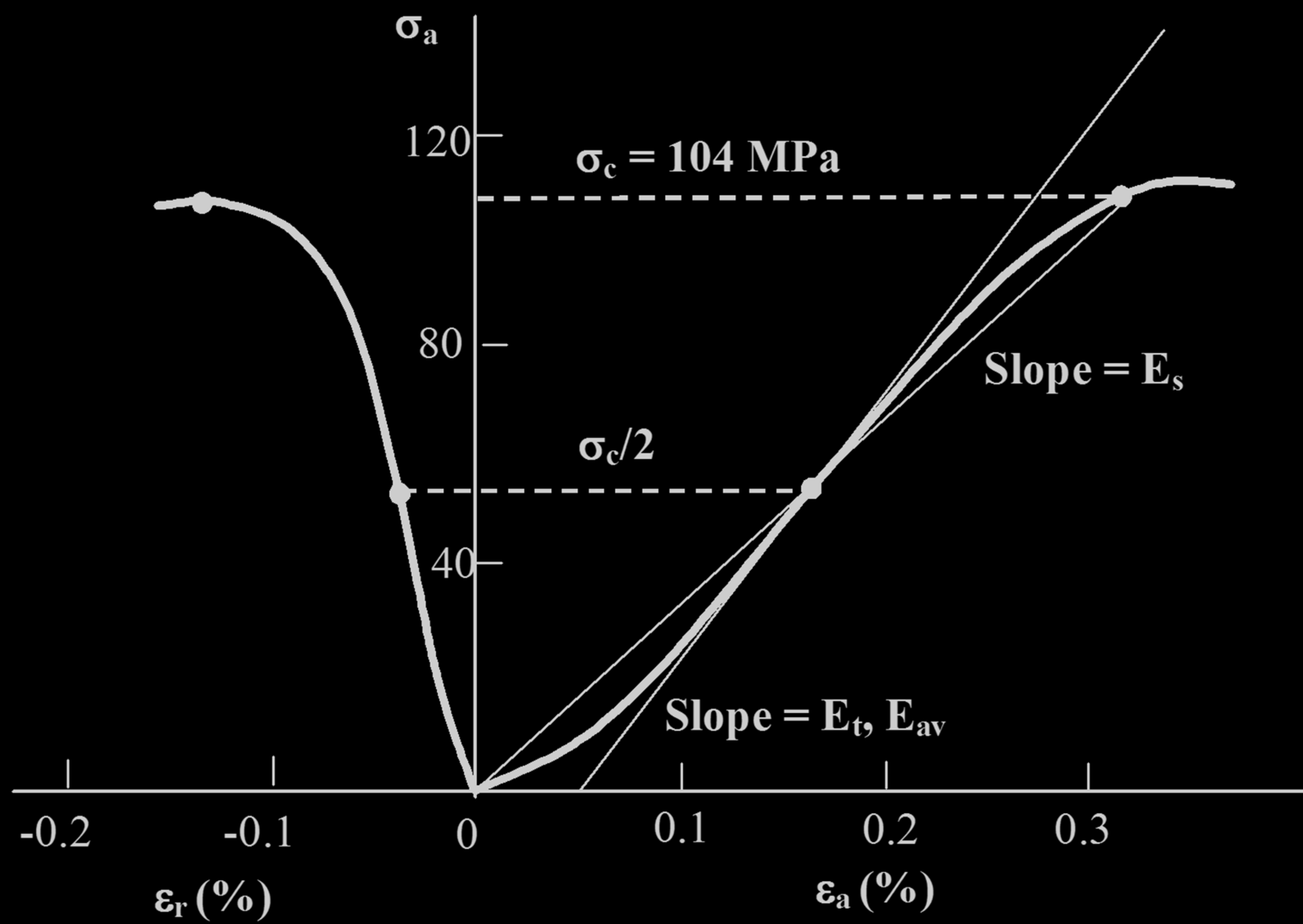
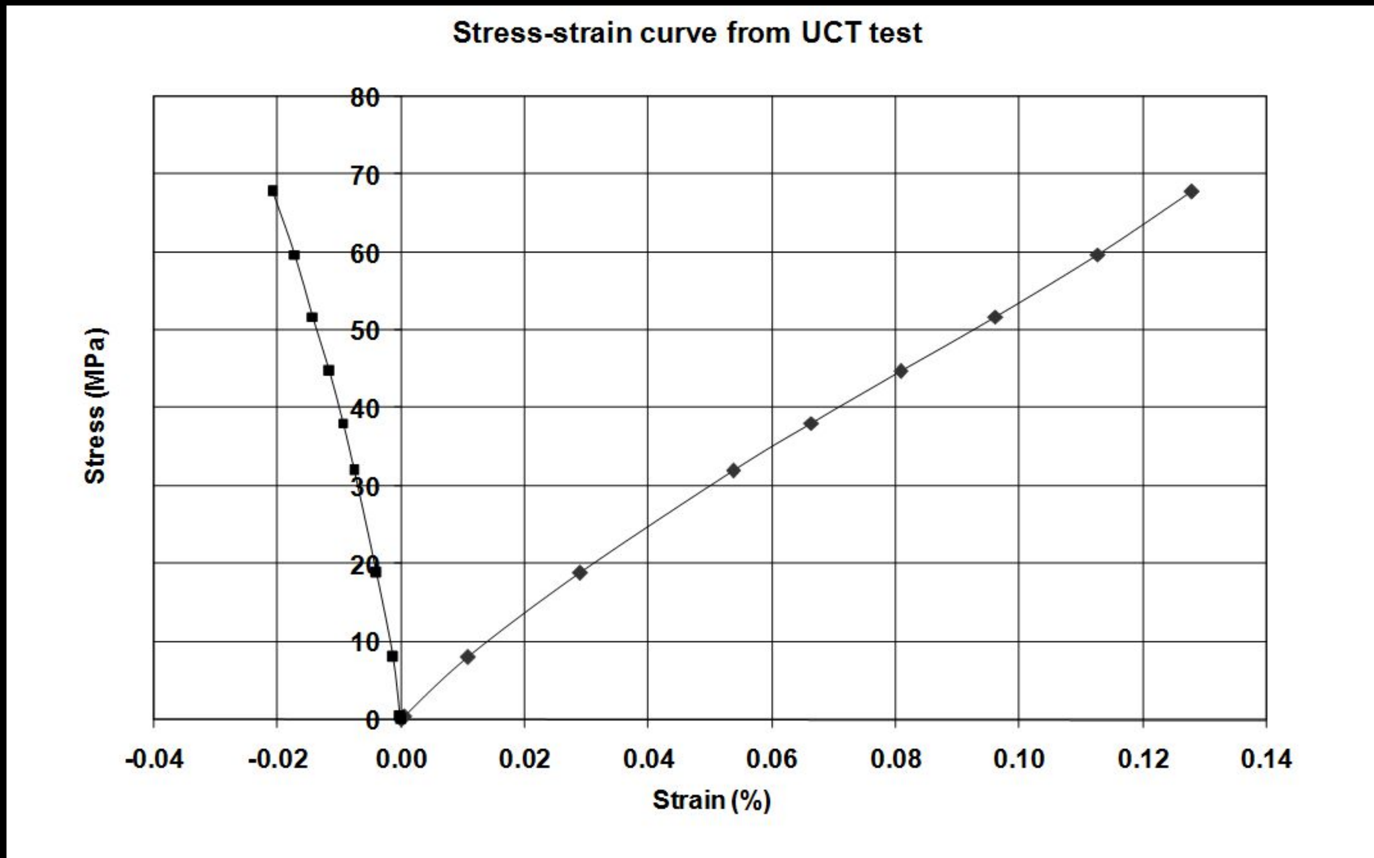


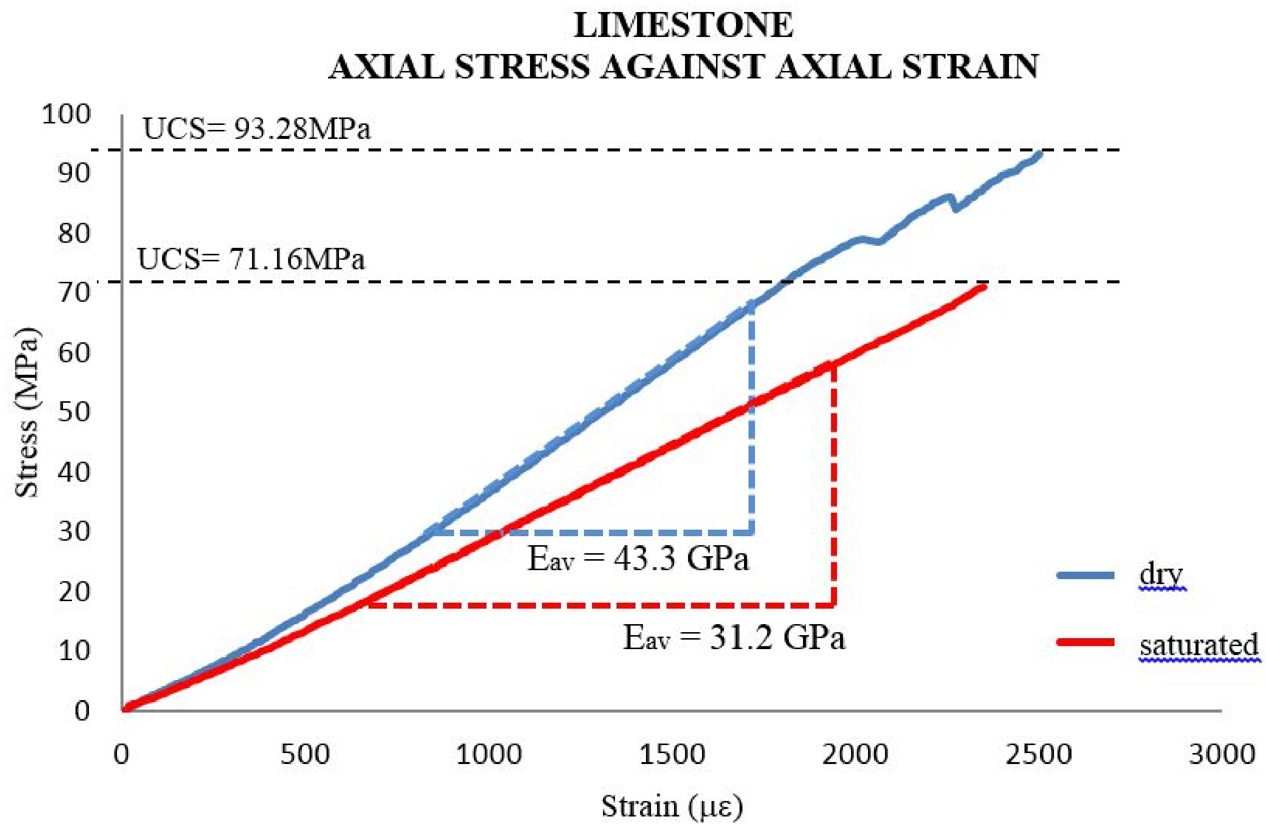
Figure 7.5: Stress versus strain (ε_a & ε_r) curve



E $= (\delta\sigma / \delta\varepsilon)$ @ 50 % UCS
$= (33 \times 10^6)/(0.06/100)$
$=$ 55 GPa

υ $= (\varepsilon_h / \varepsilon_v)$ @ 50 % UCS
$= (0.009)/(0.06)$
$= 0.15$

Summary of various methods of calculation for Young's modulus.



Sample	Young's modulus (GPa)		
	Average	Tangent	Secant
Limestone	43.3	43.6	37.9

Rock type	Elastic modulus, E (GPa)	Poisson's ratio, ν
Andesite, Basalt	60	0.20
Gabbro, Dolerite	90	0.20
Coal	3	0.42
Dolomite	70	0.15
Gneiss	60	0.24
Granite	60	0.22
Limestone	70	0.30
Quartzite	80	0.17
Sandstone	20	0.15
Shale	12	0.10

Typical values of E & ν for various types of fresh rock

Safe Bearing Pressure versus UCS and RQD

Safe bearing pressure (SBP): load that may safely be imposed upon rock in the ground.

UCS (MPa)	**100**	**4**	**8**	**12**	**Safe Bearing Pressure, SBP (MPa)**
	25	**1**	**3**	**5**	
	10	**0.2**	**1**	**2**	
	RQD (%)	**25**	**70**	**90**	

Failure under uniaxial compression test:

Types and modes of failure of sample during testing indicate the degree of hardness & brittleness (kerapuhan) of rock. A number of characteristics can be interpreted about the sample tested.

Under uniaxial compression, rock sample fails in a sudden manner & fracture planes (satah kegagalan) are distinctive. For strong rock like gabbro (igneous), crushed material (dust) and fragmentations is very minimal.

Failure under uniaxial compression test:

For softer rock like shale (sedimentary rock), failure is gradual and fragmentation & powdered rock is more obvious. Fracture planes is less significant.

Brittle (rapuh) & hard materials like rocks – the strain at failure is relatively smaller & the stress at failure is higher.

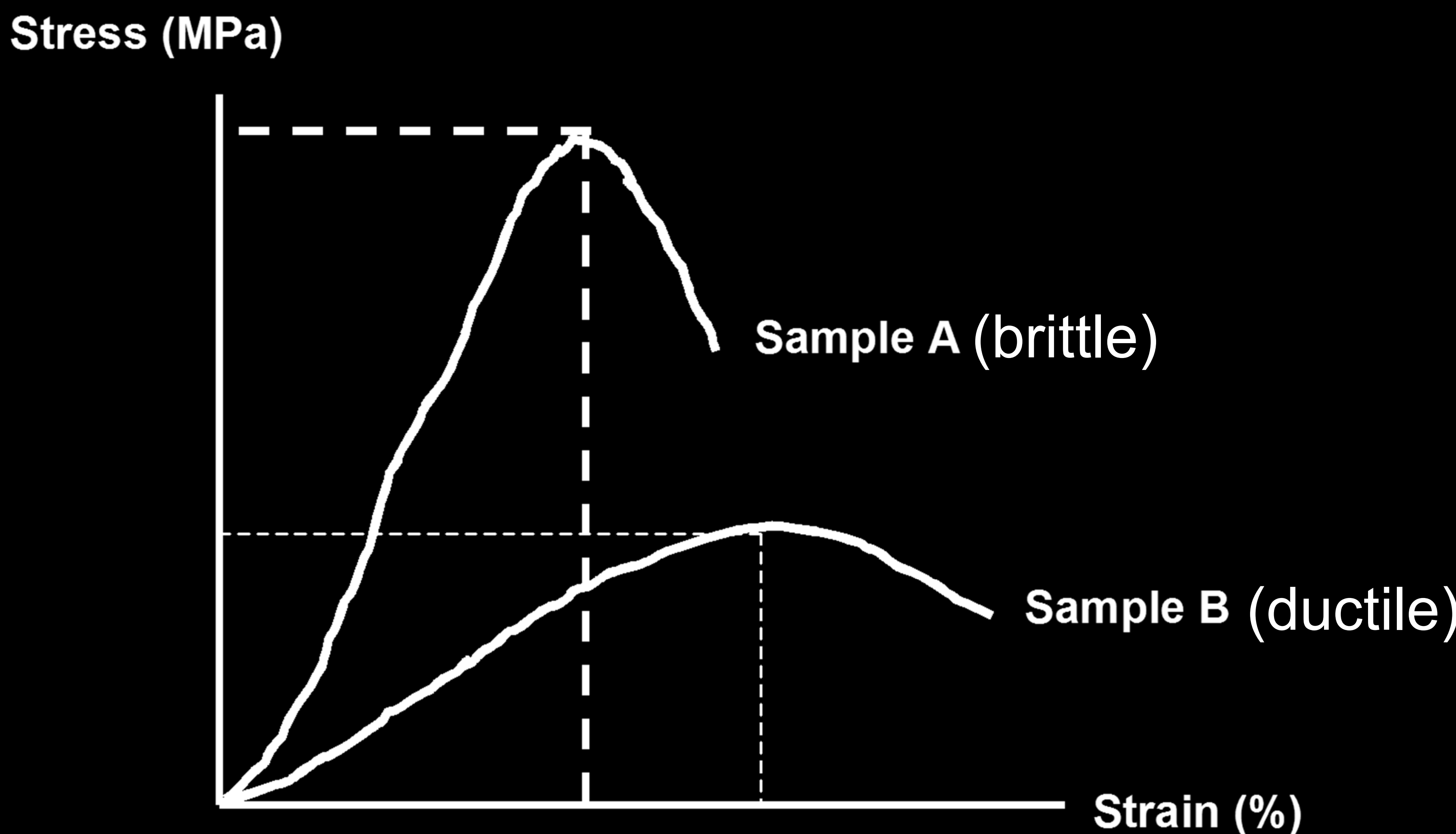
Mode and shape of failure are shown in Figure 7.6

Modes of failure of rock sample under loading

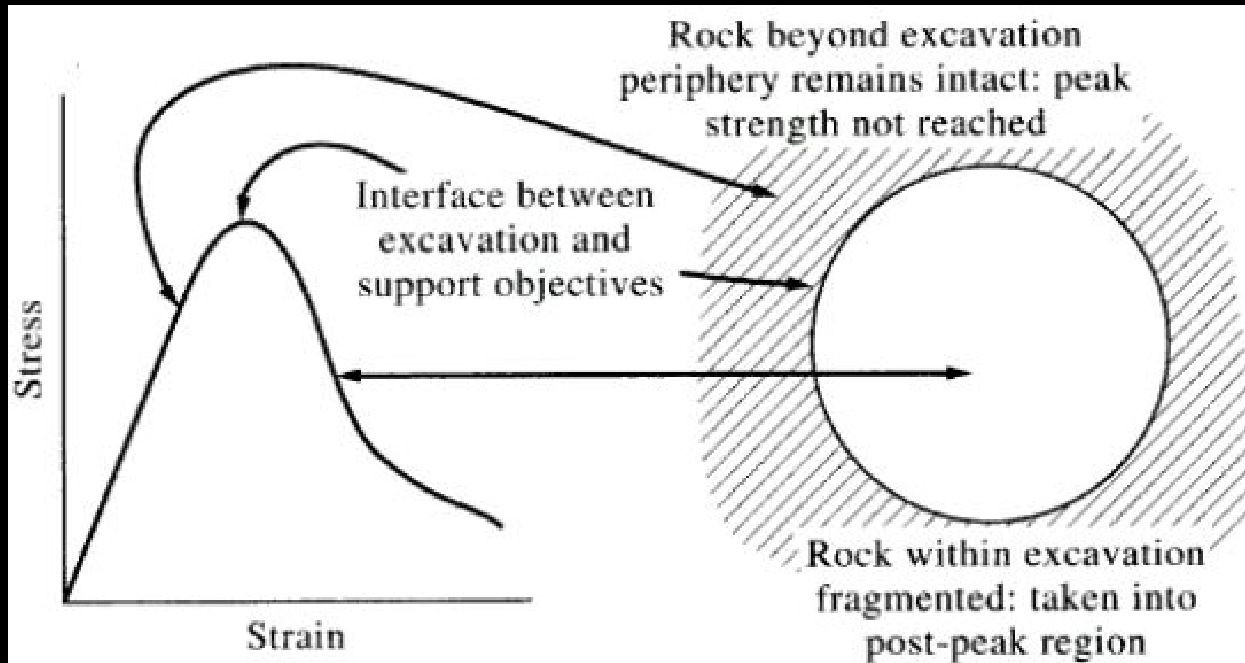
Fracture planes in failed rock sample

Fracture planes in failed rock sample (UCT)

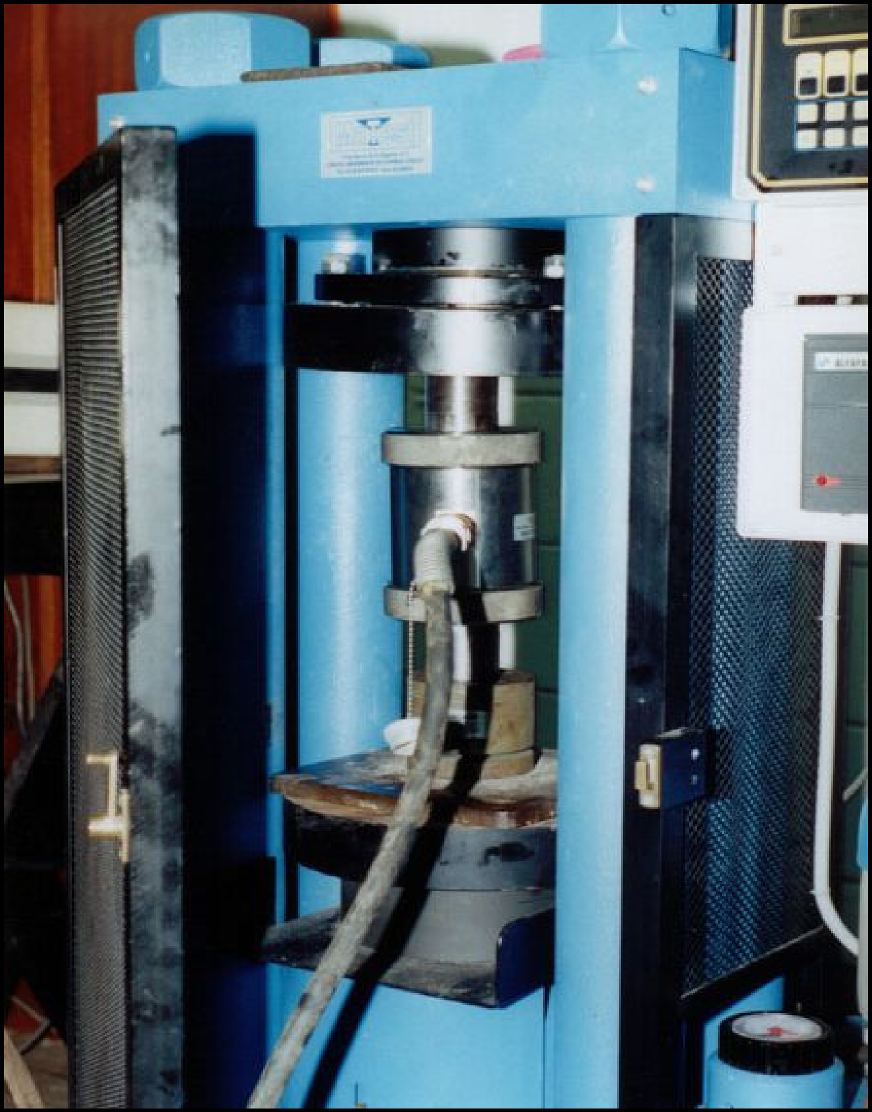
Fracture planes in failed rock sample



Stress-strain curve for rock samples of different hardness: ductile and brittle


Rock beyond excavation periphery remains intact: peak strength not reached
Interface between excavation and support objectives
Stress
Strain
Rock within excavation fragmented: taken into post-peak region

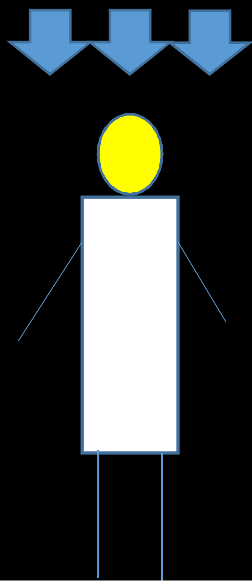
Triaxial compression test

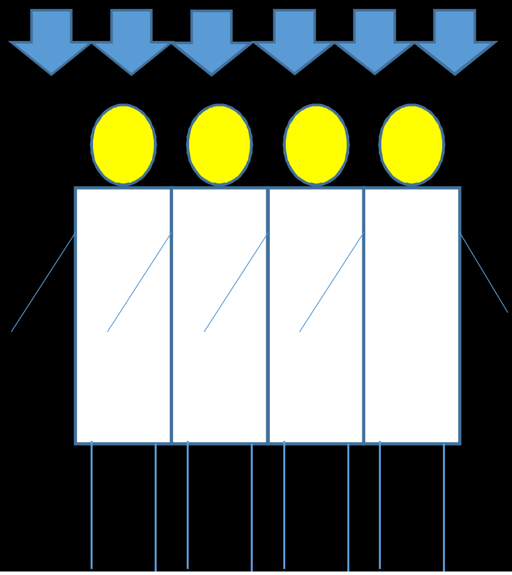


Triaxial Compression test:

Triaxial compression test (mampatan 3-paksi) is to evaluate the strength of rock under confinement (terkurung), e.g. rock samples obtained from deep seated rock mass (effect of hydrostatic pressure $P = \rho g h$, due to weight of overburden).

Rock displays a higher strength when confined and deformation behaviour becomes ductile / strain-hardening).

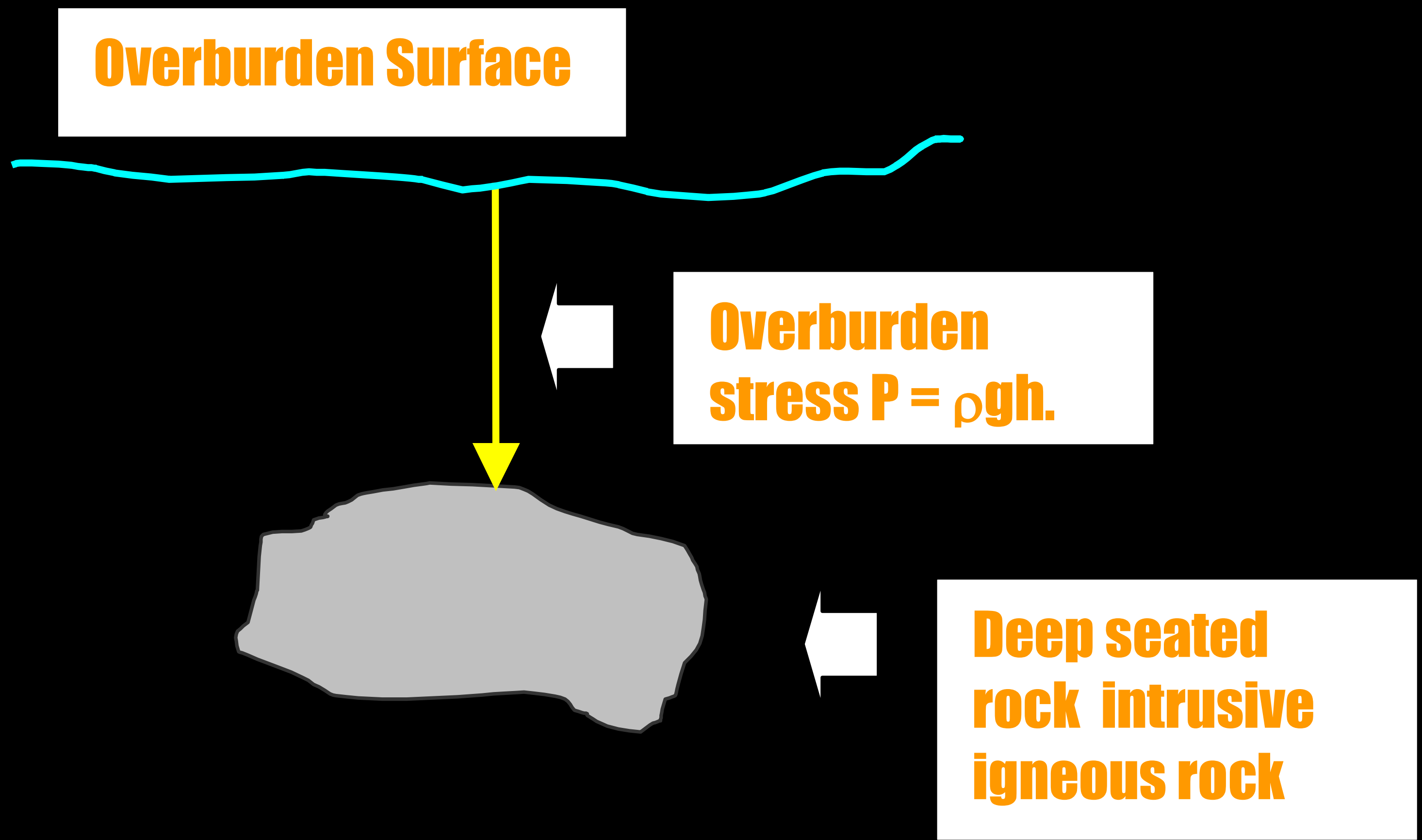




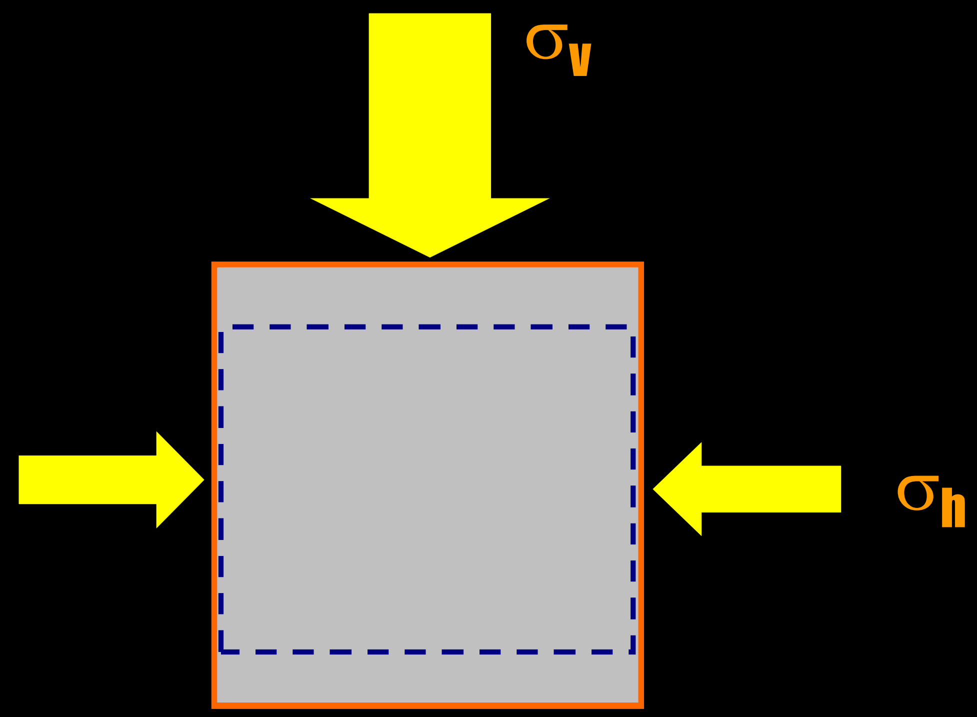
Triaxial Compression test:

The test is used to assess load bearing capability of rock at depth (20 m from surface). Example the bedrock (batu dasar) where a large structure is to be founded & strength of rock surrounding a deep tunnel.

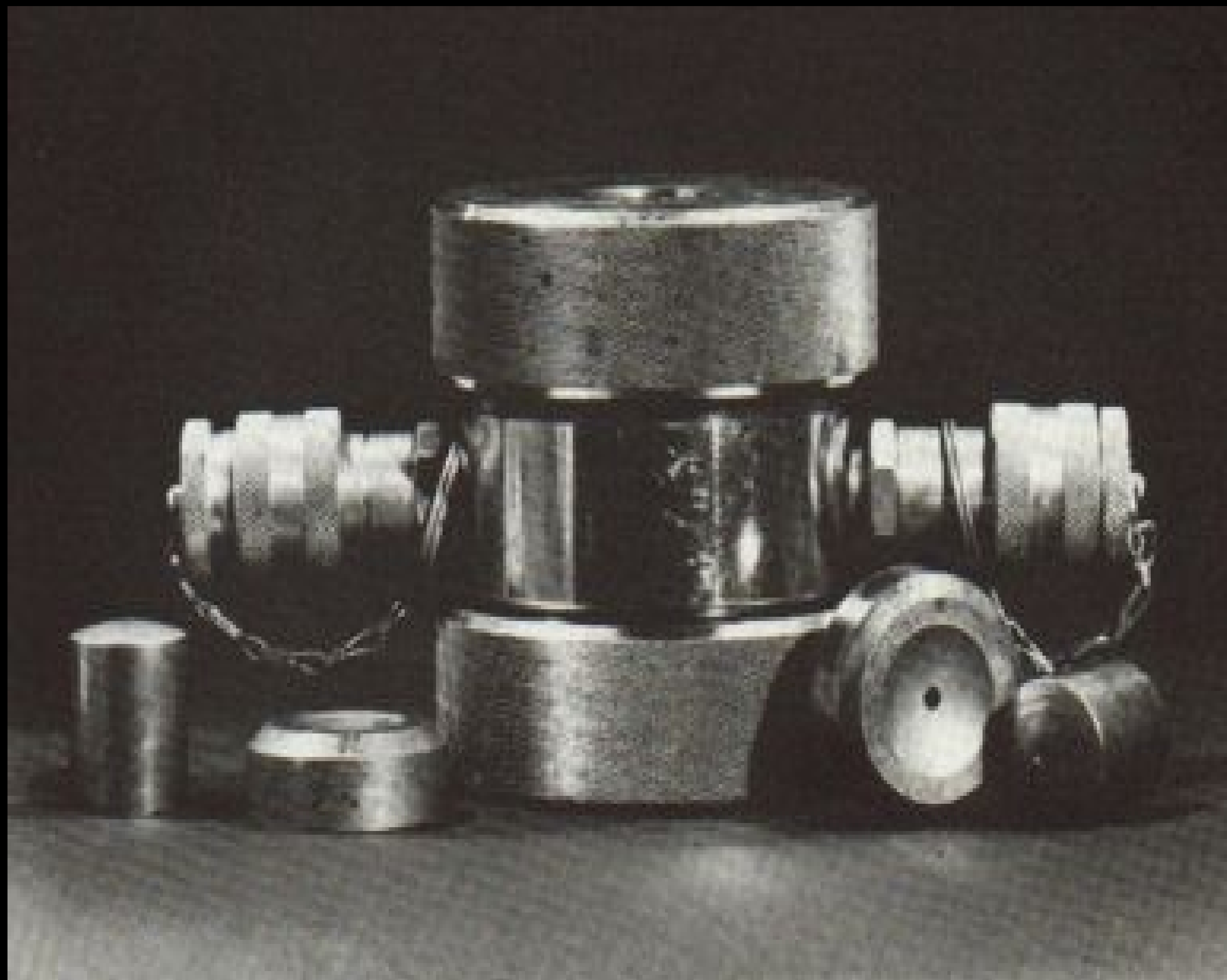
Test requires high capacity compression machine, Hoek's cell & confining pressure generator.



Rock body at depth is subjected to confining pressure, due to overburden stress & surrounding material


σv
σh

Hoek’s Cell & sample sleeve for triaxial compression test on core sample of 54 mm D & 108 mm H



Hoek’s Cell for use in triaxial compression test

Hoek’s Cell for use in triaxial compression test

Test set-up for triaxial compression test

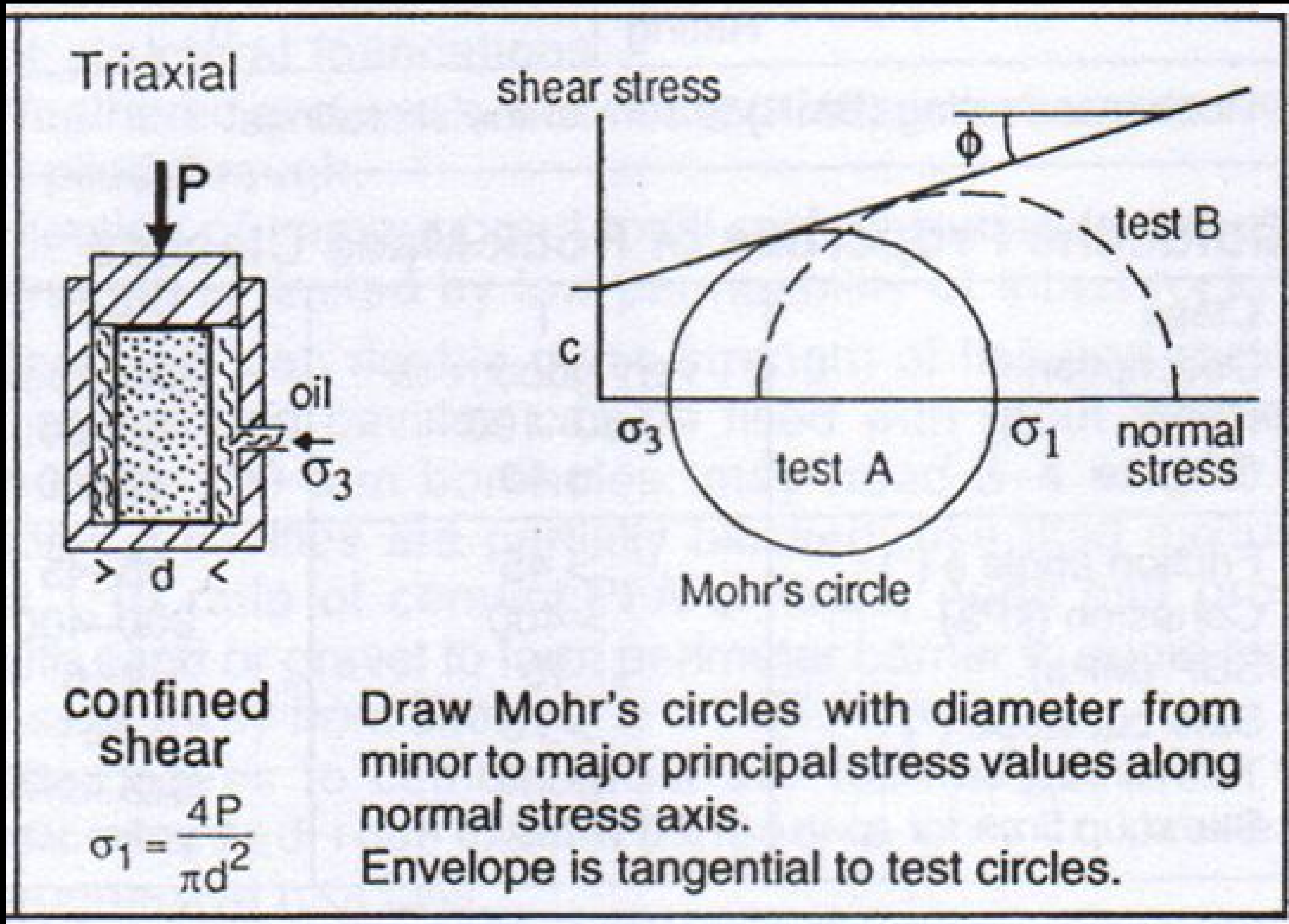
Compression machine

Spherical seat

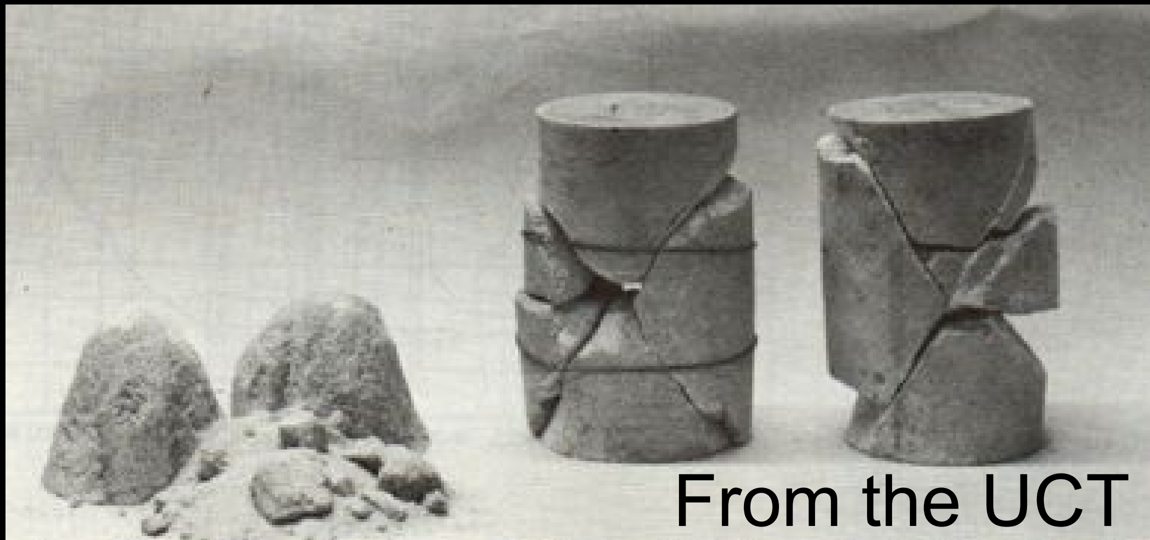
Hoek's cell with core sample

Constant pressure pump unit with pressure accumulator

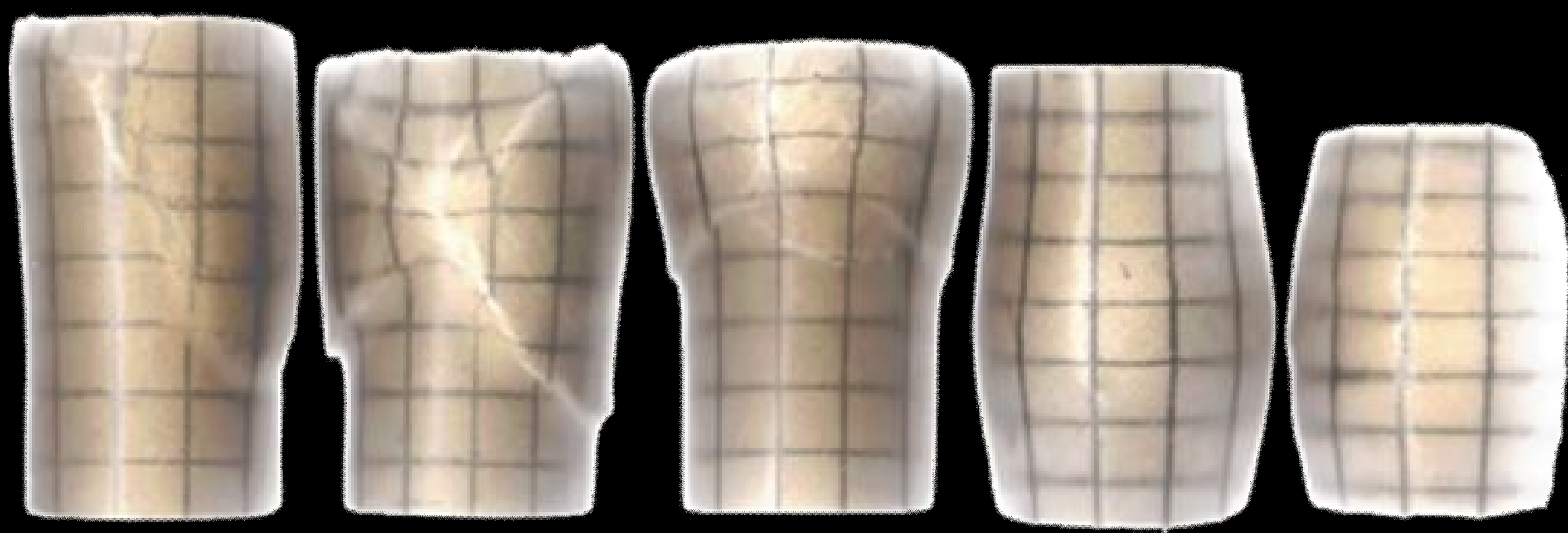
Test set-up for triaxial compression test



Mohr's circle is obtained from series of triaxal compression tests undertaken at different confining pressure (σ_3); data obtained is cohesion c & friction angle ϕ

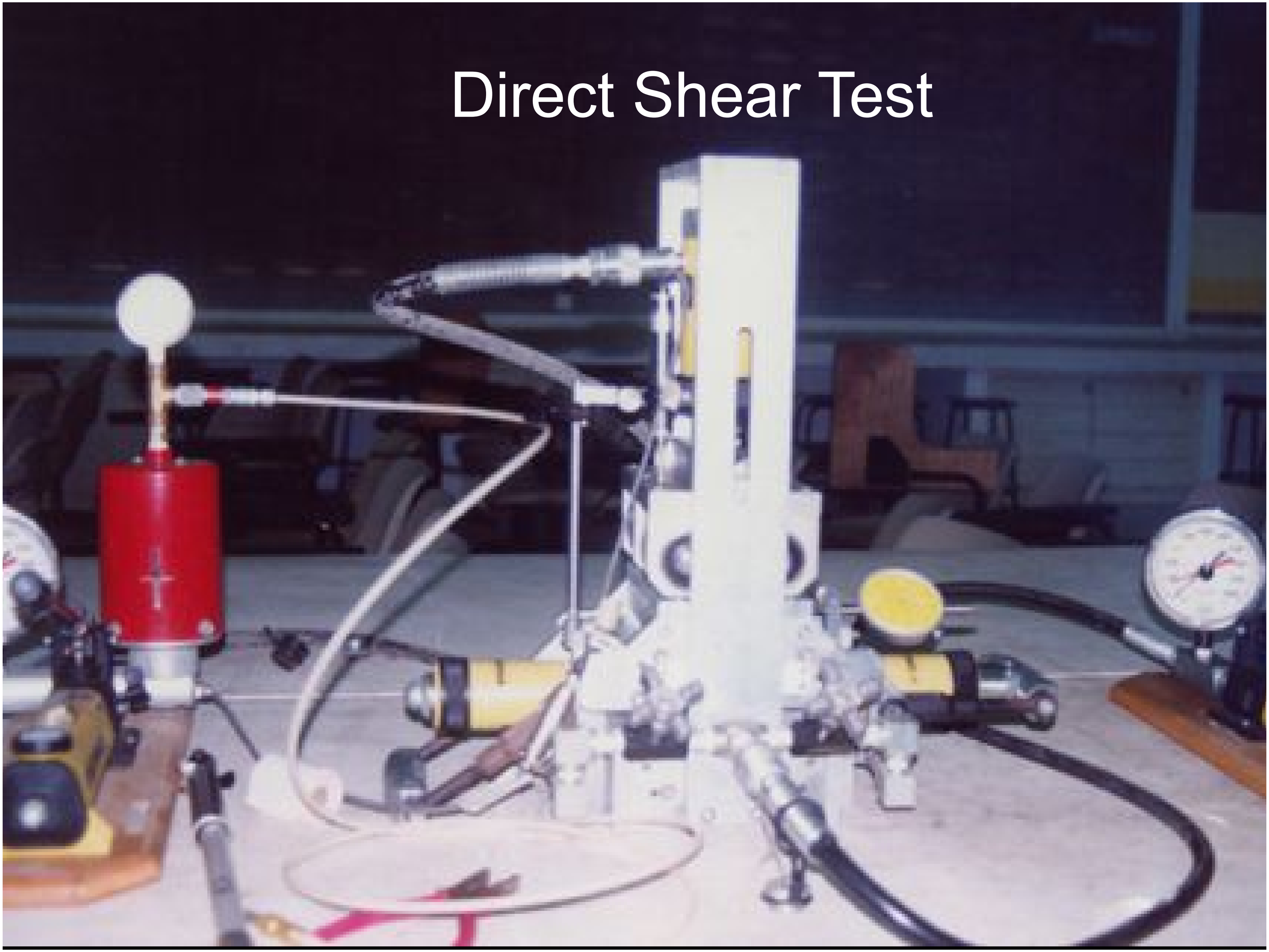


Modes of failure of rock sample under loading



Triaxial tests on Indiana Limestone, showing transition from brittle fracture (at the low pressures) to ductile flow

Direct Shear Test



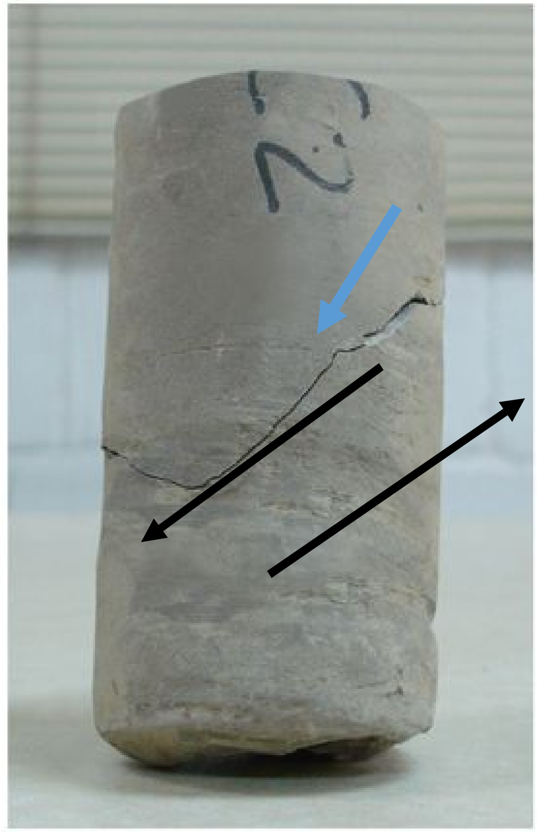
Direct shear test:
Shear test is to evaluate shear strength & shear behaviour of weakness plane in rock (not shearing of the intact rock material)

This is the most expensive laboratory strength tests, for it requires special method for acquiring of samples from site (fracture plane to be tested) & relatively complex testing procedures.

Shear strength of the weakness planes (fractures & joint) in rock mass is important for project involving excavation in rock e.g. slope & tunnel.

Joint is the weakest point in this core sample, sliding or shearing is likely to occur along this fracture

BH13/C2



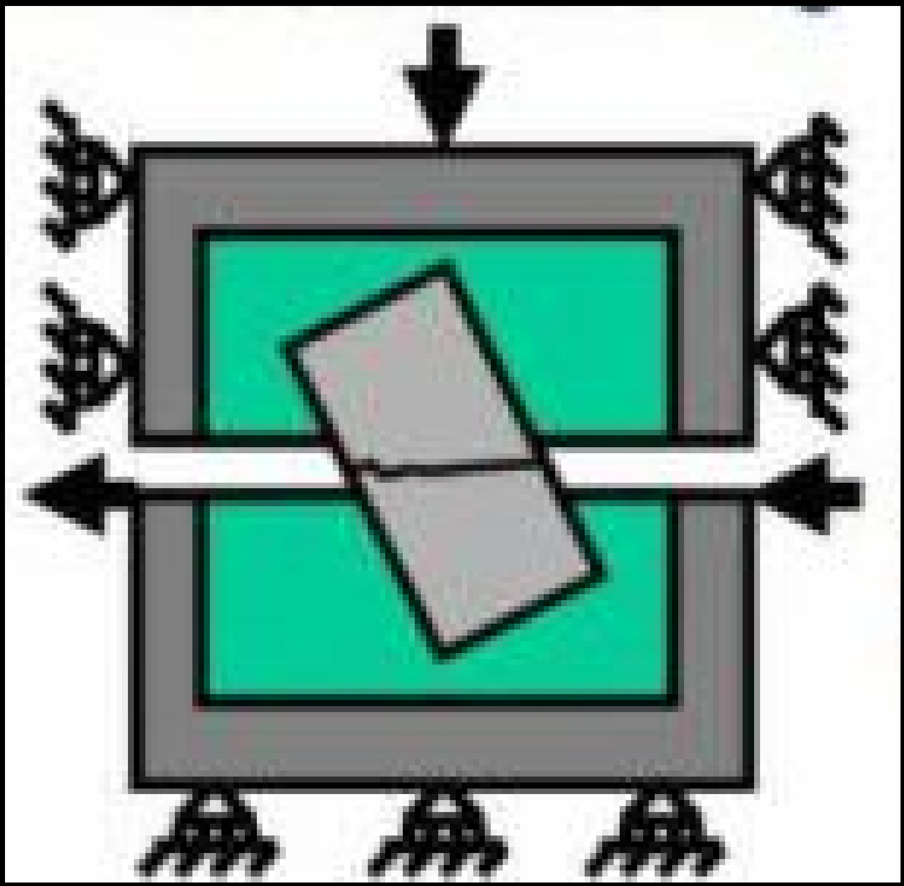
BH17/C2

BH19/C2

Joint is the weakest point in this core sample, sliding or shearing is likely to occur along this fracture


(a)
(b)
(c)
(d)
(e)
BOTTOM
(f)

NORMAL LOAD



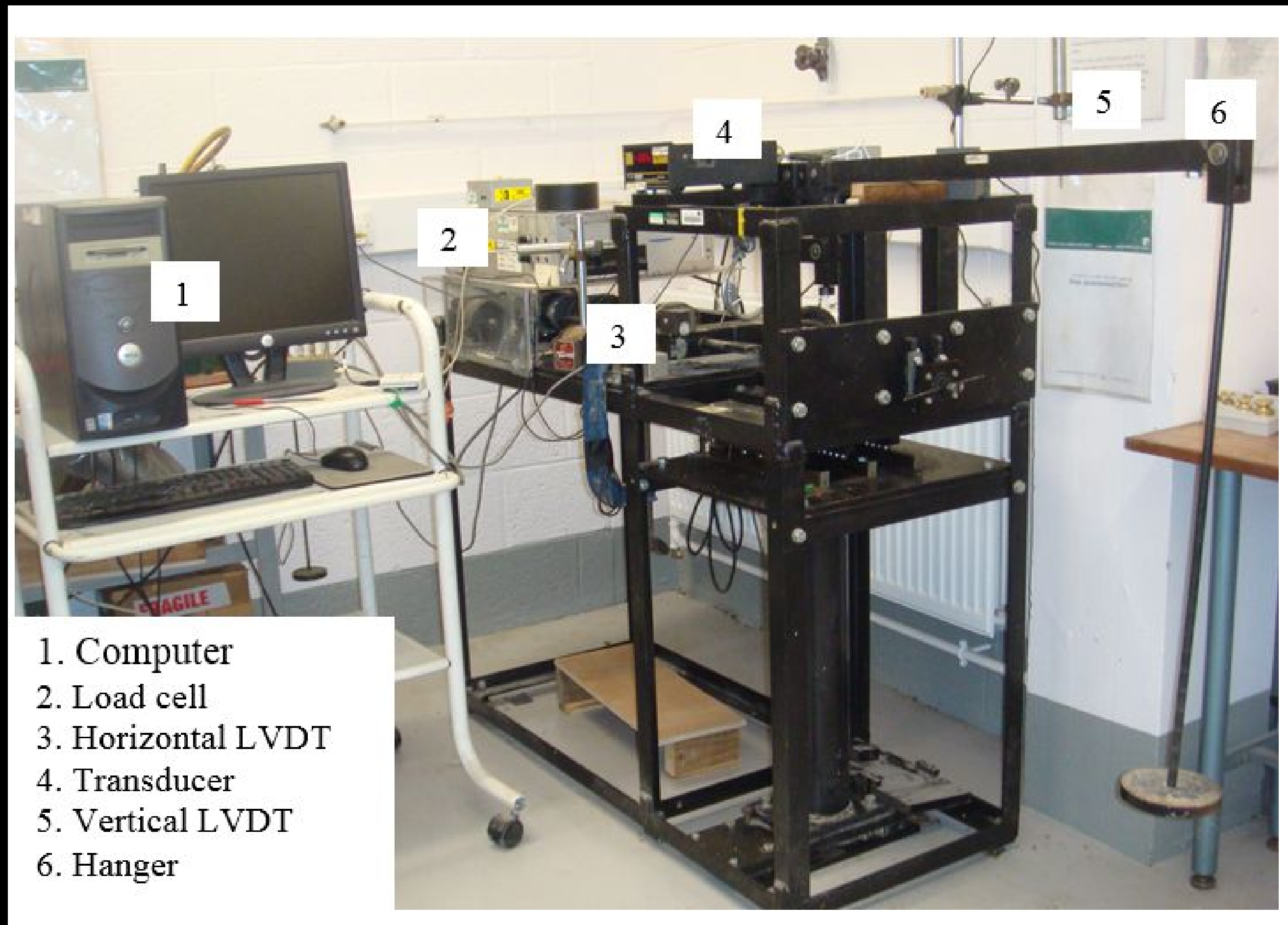
SHEAR LOAD

Direct shear test:

Shear test is to obtain shear strength parameters : cohesion (c), basic friction angle (ϕ), & shear strength (τ).

These parameters are greatly depending on the texture, roughness & degree of weathering of fracture surface being tested.

Value of ϕ (dry) is between 30^0 (siltstone & slate) & 40^0 (limestone & basalt).

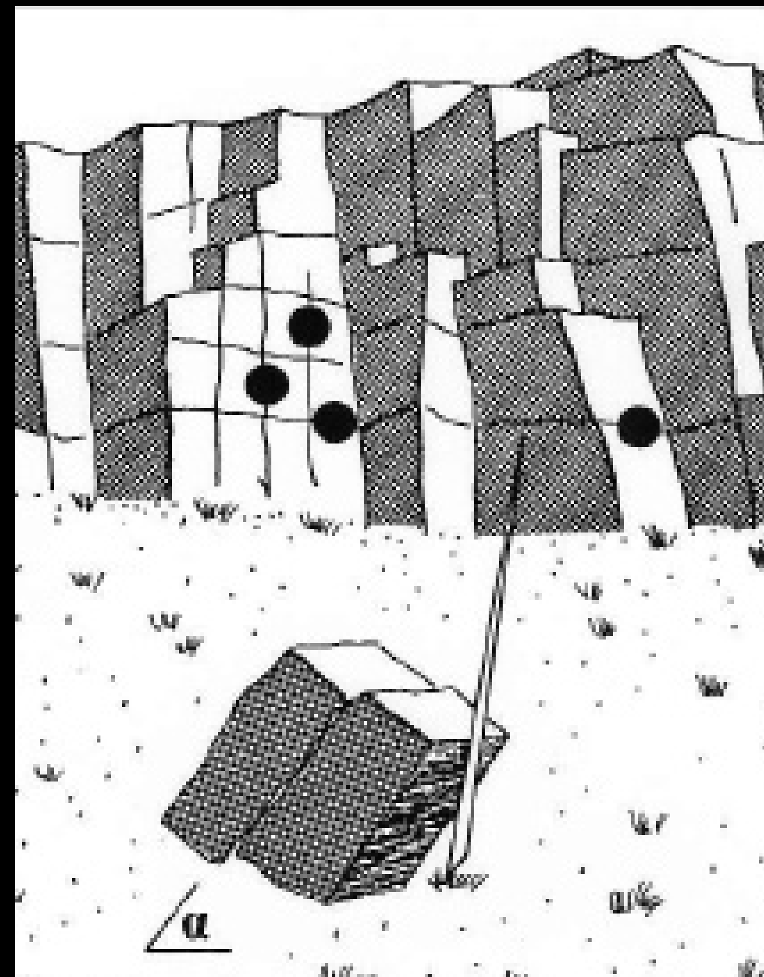

1
2
3
4
5
6
1. Computer
2. Load cell
3. Horizontal LVDT
4. Transducer
5. Vertical LVDT
6. Hanger

Portable shear box apparatus suitable for test on core sample (Roctest Phi – 10)

Large shear box apparatus

Shear box section for rectangular sample size 150 × 220 × 220 mm (H × L × B)

Shear box section for rectangular sample size 150 × 220 × 220 mm (H × L × B)



TILT TEST

Estimation of joint shear strength:

- The shear joints will affect the stability of excavation face created in jointed rock mass.
- If sufficient information is available to allow realistic analysis of stability, then some quantitative assessment of joint strength is possible.
- The shear strength can be estimated perfectly adequately from the following formula, provided that exposed joint surfaces are available *in situ*, or at least in core samples.

$$\tau = \sigma_n \tan \{ JRC \log_{10} (JCS / \sigma_n) + \phi_b \}$$

Estimation of joint shear strength:

$$\tau = \sigma_n \tan \{ JRC \log_{10} (JCS / \sigma_n) + \phi_b \}$$

τ : peak shear strength

σ_n : effective normal stress

JRC: joint roughness coefficient

JCS: joint wall compressive strength (obtained Rebound Hammer test on joint surface).

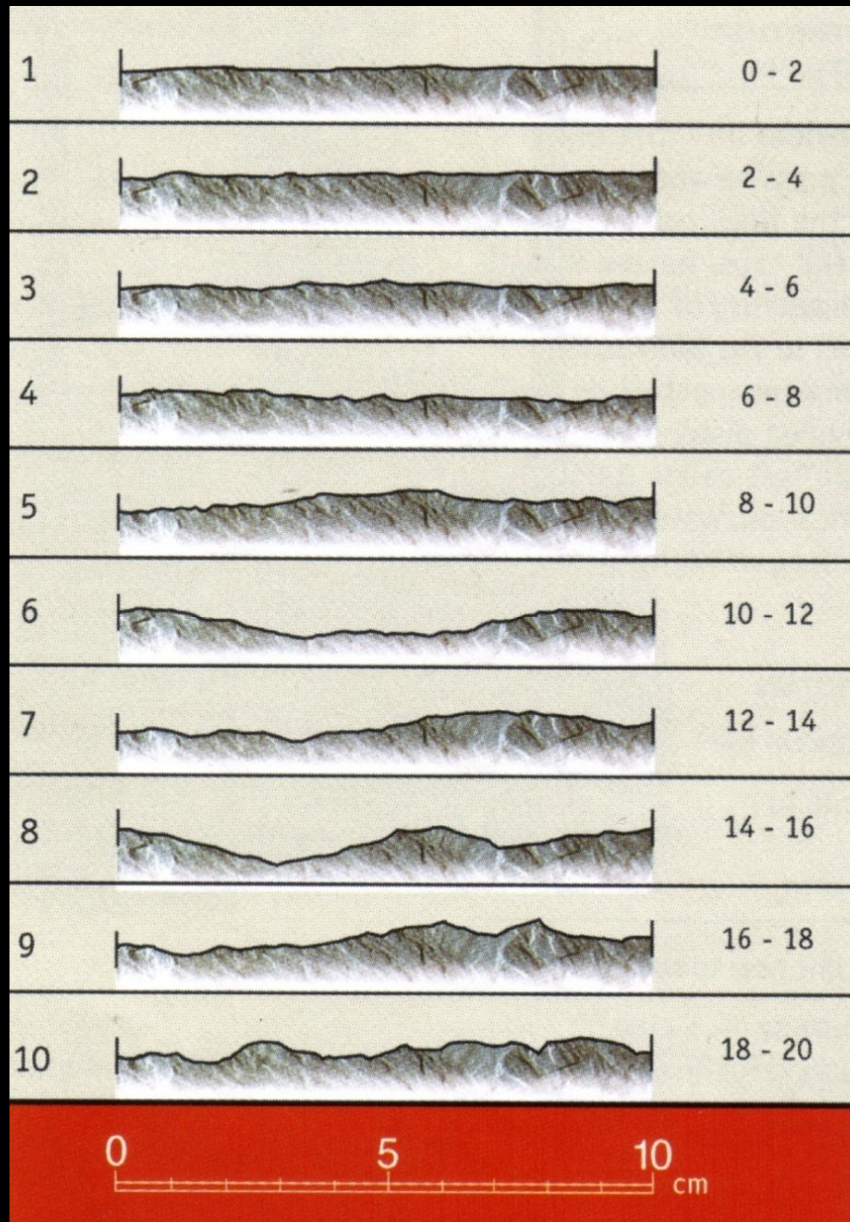
ϕ_b : is the basic friction angle (obtained from residual shear test on flat unweathered surfaces

- The shear strength estimated using the above formula includes apparent cohesion of the joint

Estimation of joint shear strength:

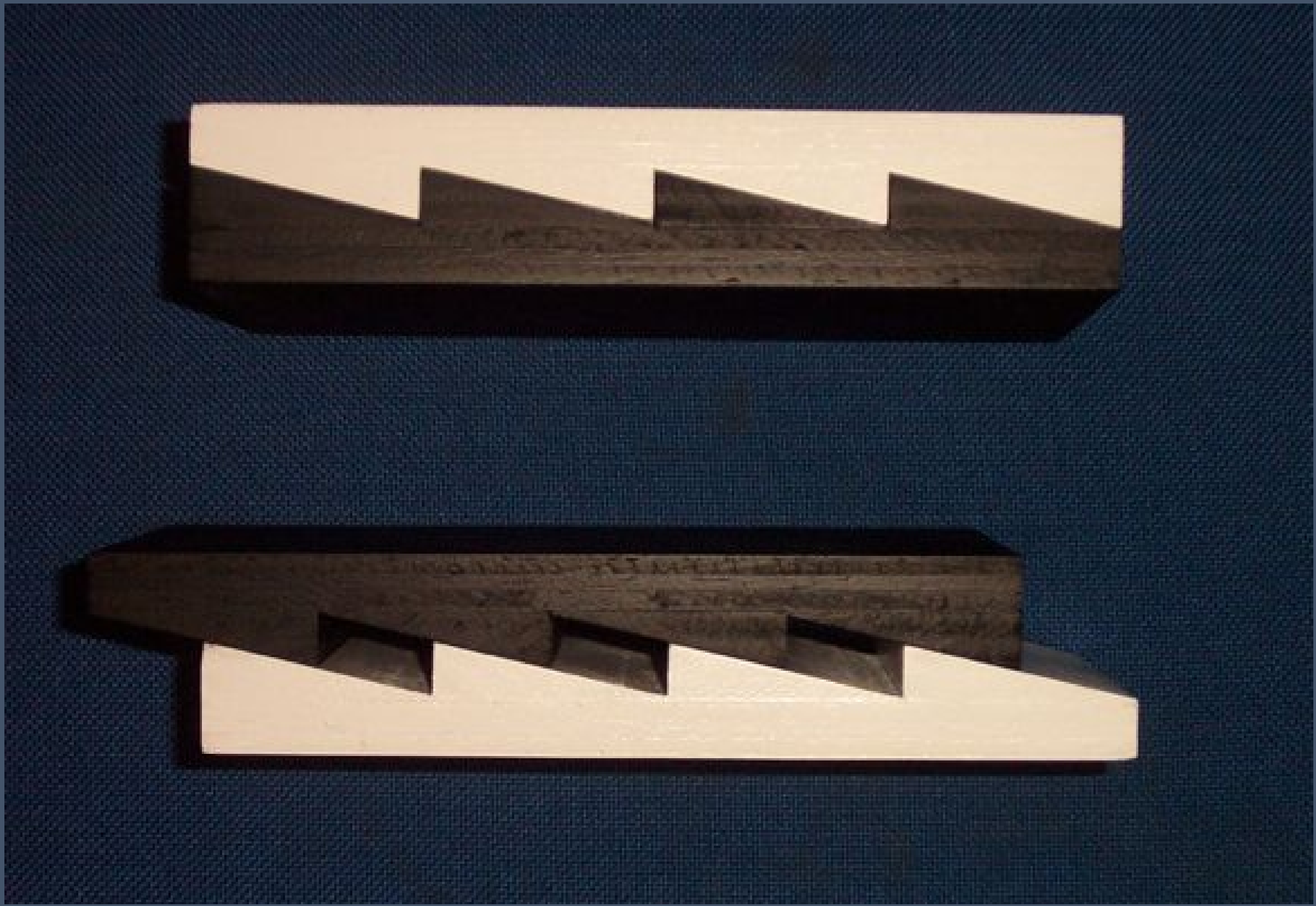
- In practice ϕ_b may vary between 25^0 and 35^0, and the assumption of 30^0 will be adequate.
- JCS is obtained from Rebound Hammer test on joint surface and R is converted to JCS using formula:

  Log_{10} JCS = 0.00088 (g) (R) + 1.01 (Broch & Franklin, 1972).
- JRC can be interpolated from roughness profile.
- A simpler, but more approximate means of estimating frictional shear strength (excluding apparent cohesion) is to take into account of the roughness using description given in the following table and add the basic friction angle.

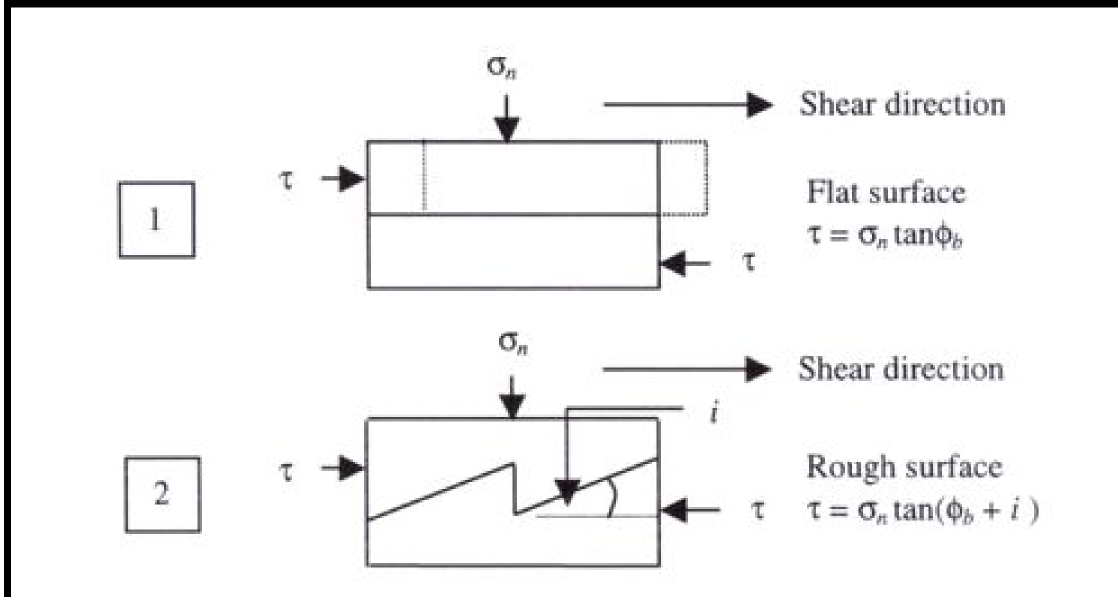


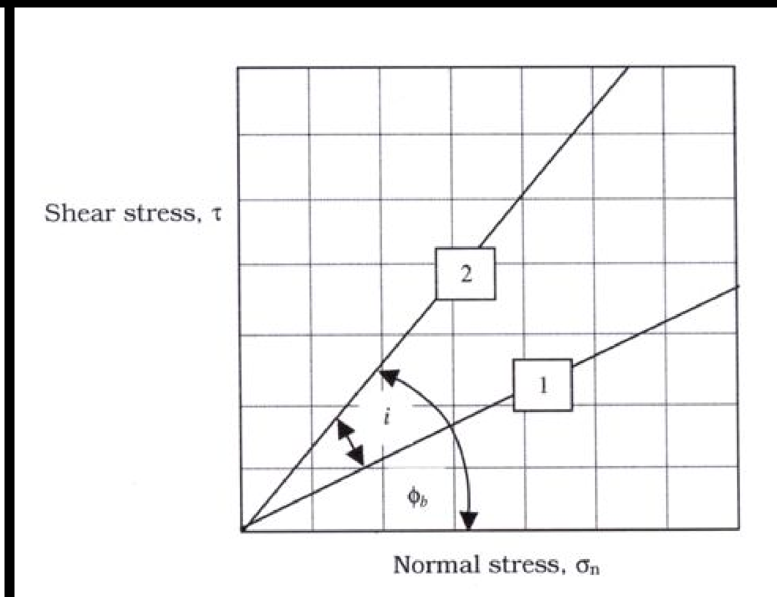
Typical roughness profiles and JRC number

Sample of rectangular joint size 150 × 220 × 220 mm (H × L × B)



Roughness of joint surface may induce <u>dilation</u> during shearing of joint blocks. Dilation is the vertical displacement that leads to joint opening.





Effect of surface texture (roughness) on shear strength

Roughness and frictional strength of joint

Description of roughness	Friction angle
Smooth	Basic + 2^0
Defined ridges	Basic + 6^0
Small steps	Basic + 10^0
Very rough	Basic + 14^0

Note: Slickenside on joint surfaces will reduce the angle of friction very considerably, and the presence of gouge or other infilling in the joint aperture may totally control the joint strength. In such cases, take the angle of friction to be 15^0.

Strength Classification	Is (MN/m^2)	Equivalent UCS (MN/m^2)
Very strong	>6.7	>100
Strong	3.35-6.7	50-100
Moderately strong	0.85-3.35	12.5-50
Moderately weak	0.4-0.85	5-12.5
Weak	0.12-0.4	1.25-5
Very weak rock or hard soil	0.05-0.12	0.6-1.25

Is ≈ 24 UCS

Strength classification of rocks based on point load index strength (Broch & Franklin, 1972)

Group name and description	% retained after one 10 min. cycle, Id_1 (dry weight basis)	% retained after two 10 min. cycle, Id_2 (dry weight basis)
Very high durability	>99	>98
High durability	98-99	95-98
Medium High durability	95-98	85-95
Medium durability	85-95	60-85
Low durability	60-85	30-60
Very Low durability	<60	<30

Durability Classification (Gamble, 1971)

Rock Type	Uniaxial Compress. Strength (MPa)	Uniaxial Tensile Strength (MPa)
Granite	100-250	7-25
Dolerite	200-350	15-35
Basalt	150-300	10-30
Sandstones	20-170	4-25
Mudrocks	10-100	2-10
Limestones	30-250	5-25
Gneisses	50-200	5-20

Uniaxial compressive and tensile strengths of rocks
(Pitts, 1984)

Typical static mechanical properties of some common rock types (Bengt Stillborg, 1985)

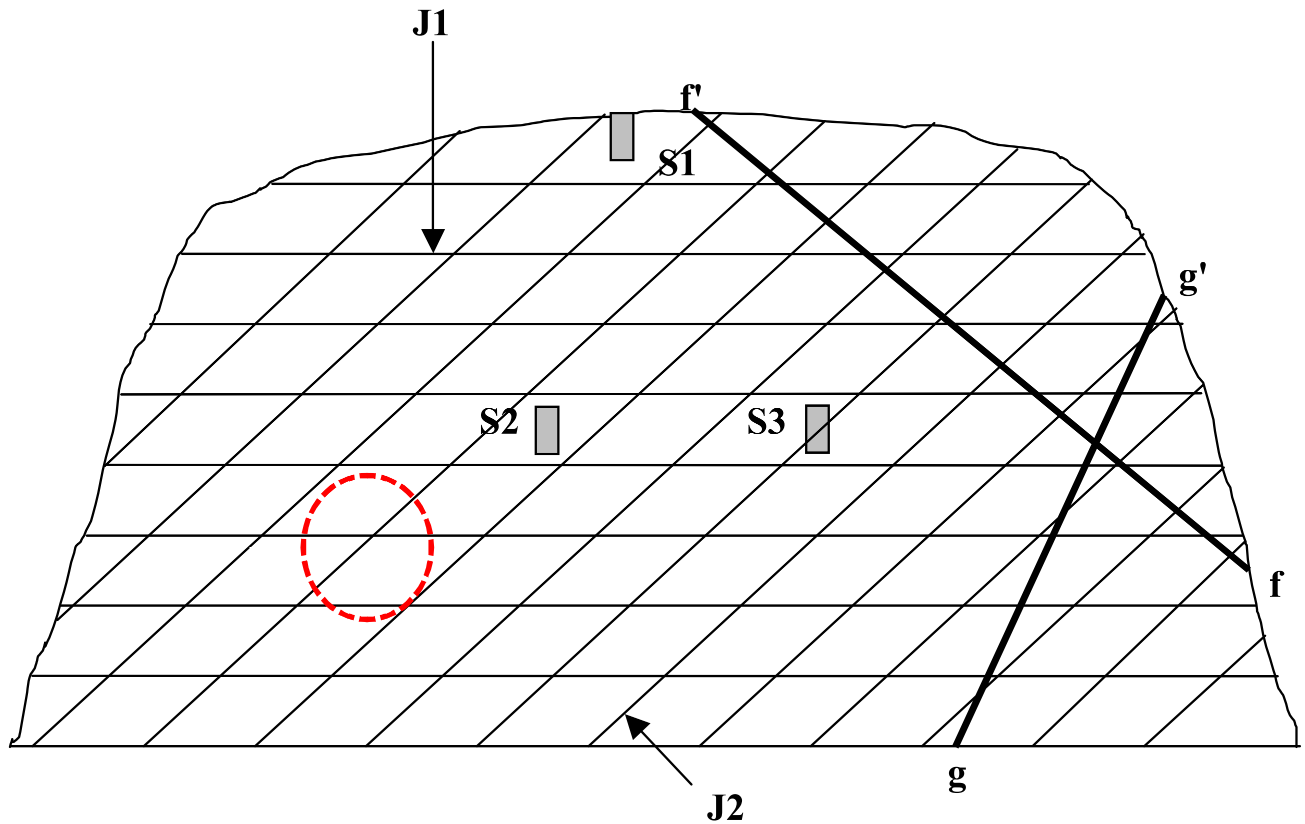
Rock class	Rock type	Unconfined compress. strength σ_c [MPa]	Tensile Strength σ_t [MPa]	Point load Index $I_{s(50)}$ [MPa]
Sedimentary rock	Limestone	50 - 200	5 - 20	0.5 - 7
	Mudstone	5 - 15	–	0.1 - 6
	Sandstone	50 - 150	5 -15	0.2 - 7
	Siltstone	5 - 200	2 - 20	6 - 10
	Shale	50 - 100	2 - 10	–
Metamorphic rock	Gneiss	100 - 200	5 - 20	2 - 11
	Marble	100 - 200	5 - 20	2 - 12
	Quartz	200 - 400	25 - 30	5 - 15
Igneous rock	Basalt	100 - 300	10 - 15	9 - 14
	Gabbro	100 - 300	10 - 15	6 - 15
	Granite	100 - 200	5 - 20	5 - 10

Rock class	Rock type	Unconfined compressive strength σ_c [MPa]	Tensile Strength σ_t [MPa]	Modulus of elasticity E [GPa]	Point load Index $I_{s(50)}$ [MPa]	Angle of Friction, ϕ^0
Sedimentary rock	Limestone	50 - 200	5 - 20	20 - 70	0.5 - 7	33 - 40
	Mudstone	5 - 15	–	–	0.1 - 6	–
	Sandstone	50 - 150	5 -15	15 - 50	0.2 - 7	25 - 35
	Siltstone	5 - 200	2 - 20	20 - 50	6 - 10	27 - 31
	Shale	50 - 100	2 - 10	5 - 30	–	27
Metamorphic rock	Gneiss	100 - 200	5 - 20	30 - 70	2 - 11	23 - 29
	Marble	100 - 200	5 - 20	30 - 70	2 - 12	25 - 35
	Quartz	200 - 400	25 - 30	50 - 90	5 - 15	48
Igneous rock	Basalt	100 - 300	10 - 15	40 - 80	9 - 14	31 - 38
	Gabbro	100 - 300	10 - 15	40 - 100	6 - 15	–
	Granite	100 - 200	5 - 20	30 - 70	5 - 10	29 - 35

Typical engineering properties of rock

Classification of rock types based on unconfined compressive strength (McLean & Gribble, 1980)

Descriptive terms	UCS (MPa)	Rock types
Very weak rock. Weak rock. Moderately weak rock	< 1.25 1.25 – 5.0. 5.0 – 12.5	Some weakly compacted sedimentary rocks, some very highly weathered igneous or metamorphic rocks, boulder-clays.
Moderately strong rock	12.5 – 50.0	Some sedimentary rocks, some foliated metamorphic rocks, highly weathered igneous and metamorphic rocks.
Strong rock.	50 – 100	Some low-grade metamorphic rocks, marbles, some strongly cemented sandstones (silica cement), some weathered and metamorphic igneous rocks.
Very strong rock.	100 – 200	Mainly plutonic, hypabyssal and extrusive igneous rocks (medium to coarse grained), sedimentary quartzites, strong slate, gneisses.
Extremely strong rock.	> 200	Fine-grained igneous rock, metamorphic quartzites, some hornfelses.



Core samples are obtained from rock drilling during SI. Cores are used to estimate RQD & suitable samples (core with fractures) are selected for laboratory shear tests

ROCK DYNAMICS

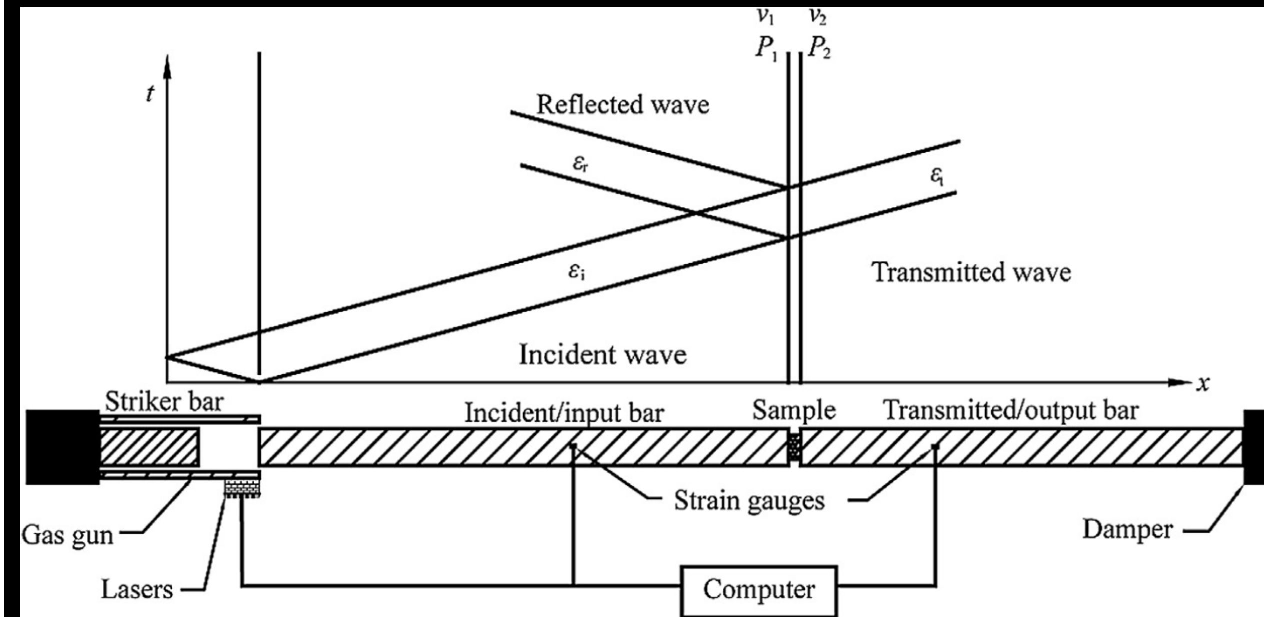
As a branch of rock mechanics, **Rock Dynamics** deals with the responses of rock under dynamic stress fields, where an increased rate of loading (or impulsive loading) induces a change in the mechanical behavior of the rock materials and rock masses.

Rock specimens after failure under static and dynamic loads

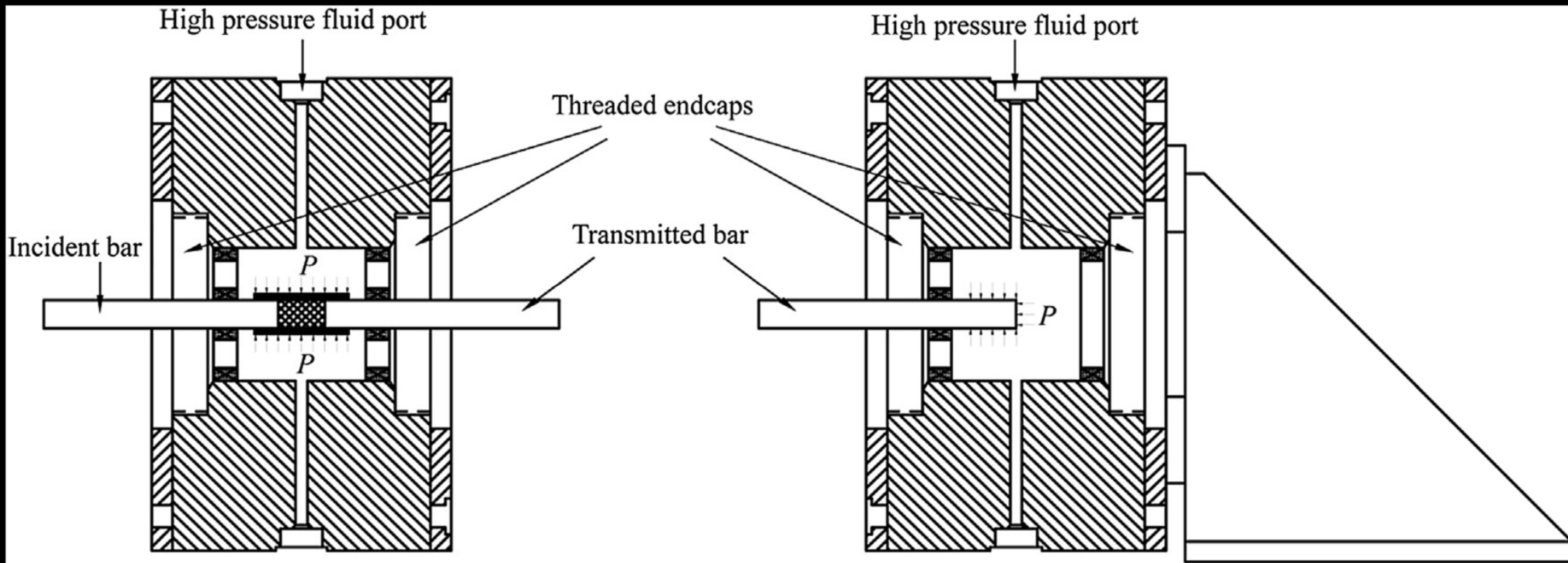
(Zhou & Zaho, 2011)

Due to the additional 4th dimension of time, **dynamics has been a more challenging topic** to understand and to apply. **ROCK DYNAMICS** remains, at least in the discipline of rock mechanics, a relatively virgin territory, where research and knowledge are limited.

Split Hopkinson Pressure Bar (SHPB)



- SHPB consists of three bars: a striker bar, an incident bar, and a transmitted bar.
- The impact of the striker bar on the free end of the incident bar induces a longitudinal compressive wave propagating in both directions. The left propagating wave is fully released at the free end of the striker bar and forms the trailing edge of the incident compressive pulse εi.
- Strain gauges are used to record the stress wave pulse on both incident bar and transmitted bar.



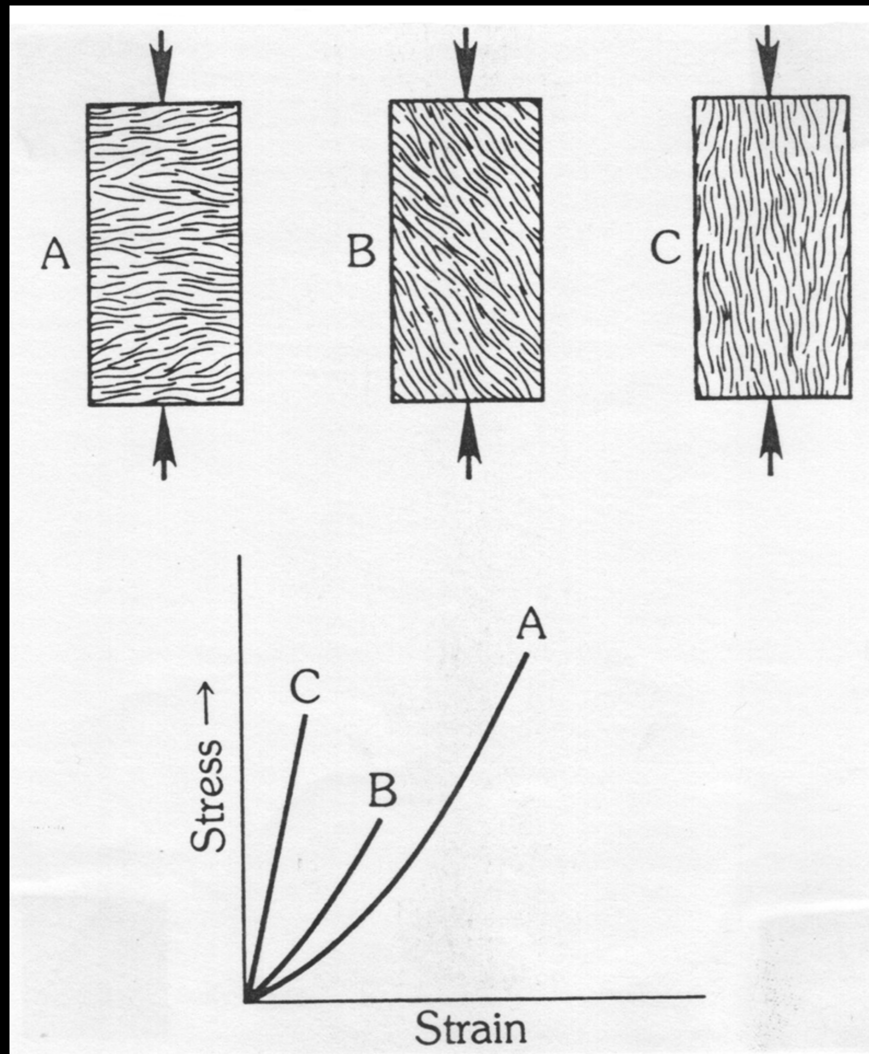
Schematics of confined SHPB system for testing rocks (Frew et al., 2010).

One of the objectives of an SHPB test is to determine the material dynamic stress-strain curve, from which the mechanical properties can be derived, e.g. dynamic failure strength, dynamic failure strain and dynamic Young's modulus.

Parameters affecting laboratory tests

Factors affecting variations in test data include:

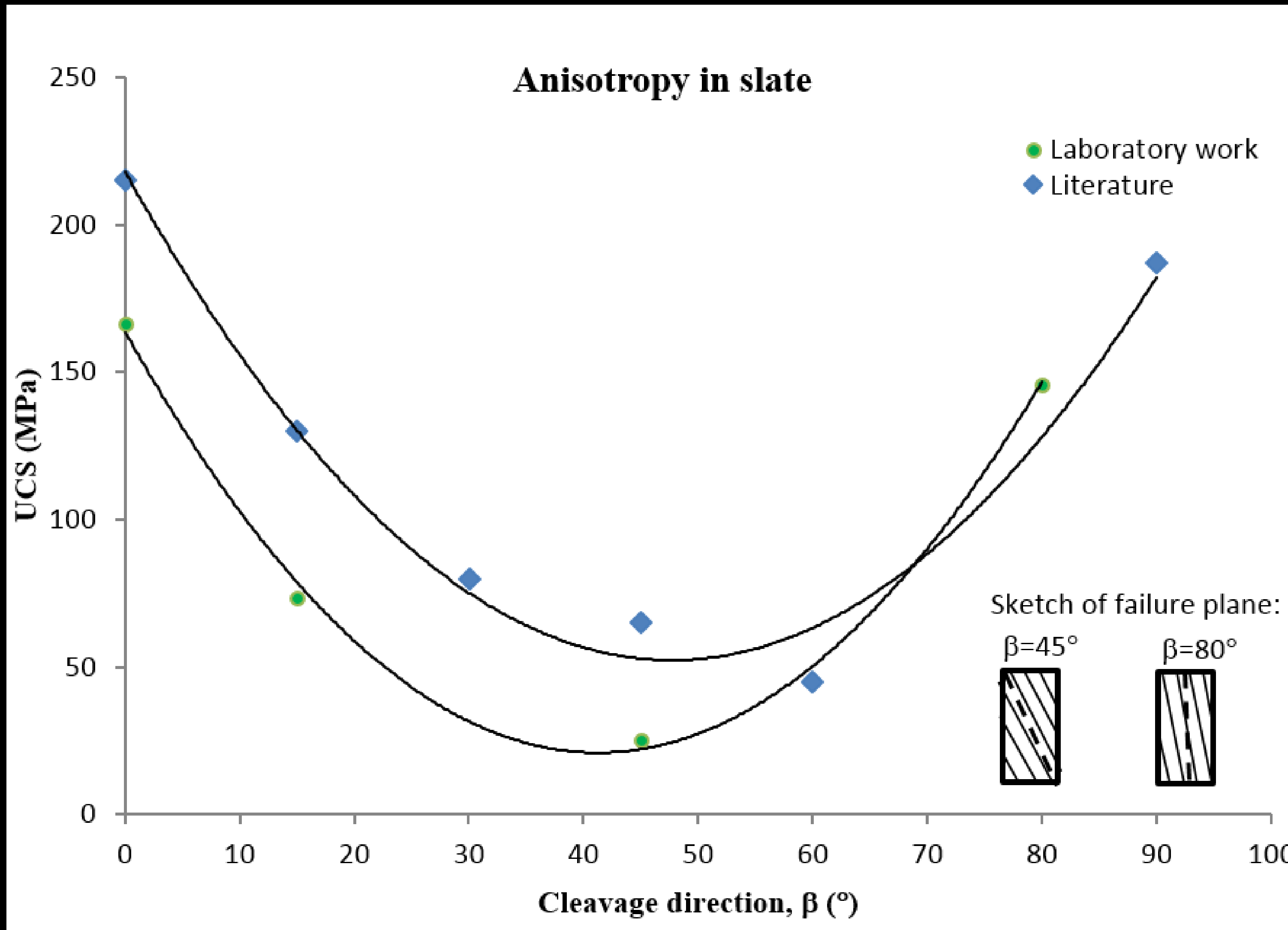
- Testing procedures – used standard methods.
- Condition of sample – sampling & preparations.
- Environment (lab test) – temperature & humidity.
- Specimen size – when small-scale discontinuities are present in sample (sedimentary & metamorphic rock).



Effect of loading orientation on UCS of sample displaying lamination (metamorphic rock e.g. schist)

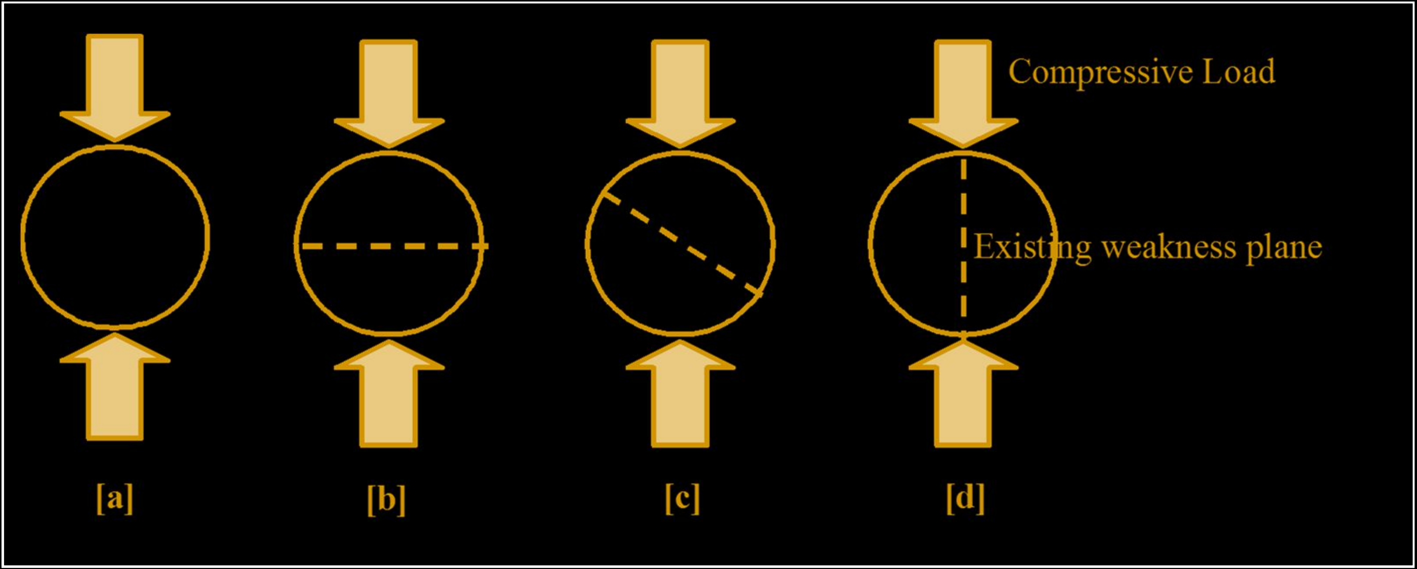
Minerals arrangements due to sedimentation (lamination) and due to metamorphism (foliation) are is small scale discontinuities rock (e.g. shale, sandstone slate & schist)

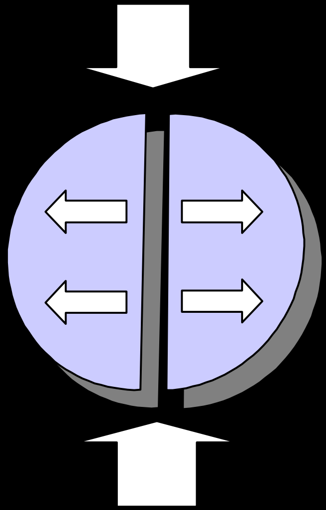
Being small scale discontinuities, they occur in laboratory rock sample. Fracture/failure can be easily induced along the lamination/foliation, but not perpendicular to it. Thus rock sample displaying lamination/foliation may display different strength when loaded at different direction



Effect of compressive strength due to anisotropy in Penrhyn slate

EXISTING FRACTURE AFECT FAILURE LOAD

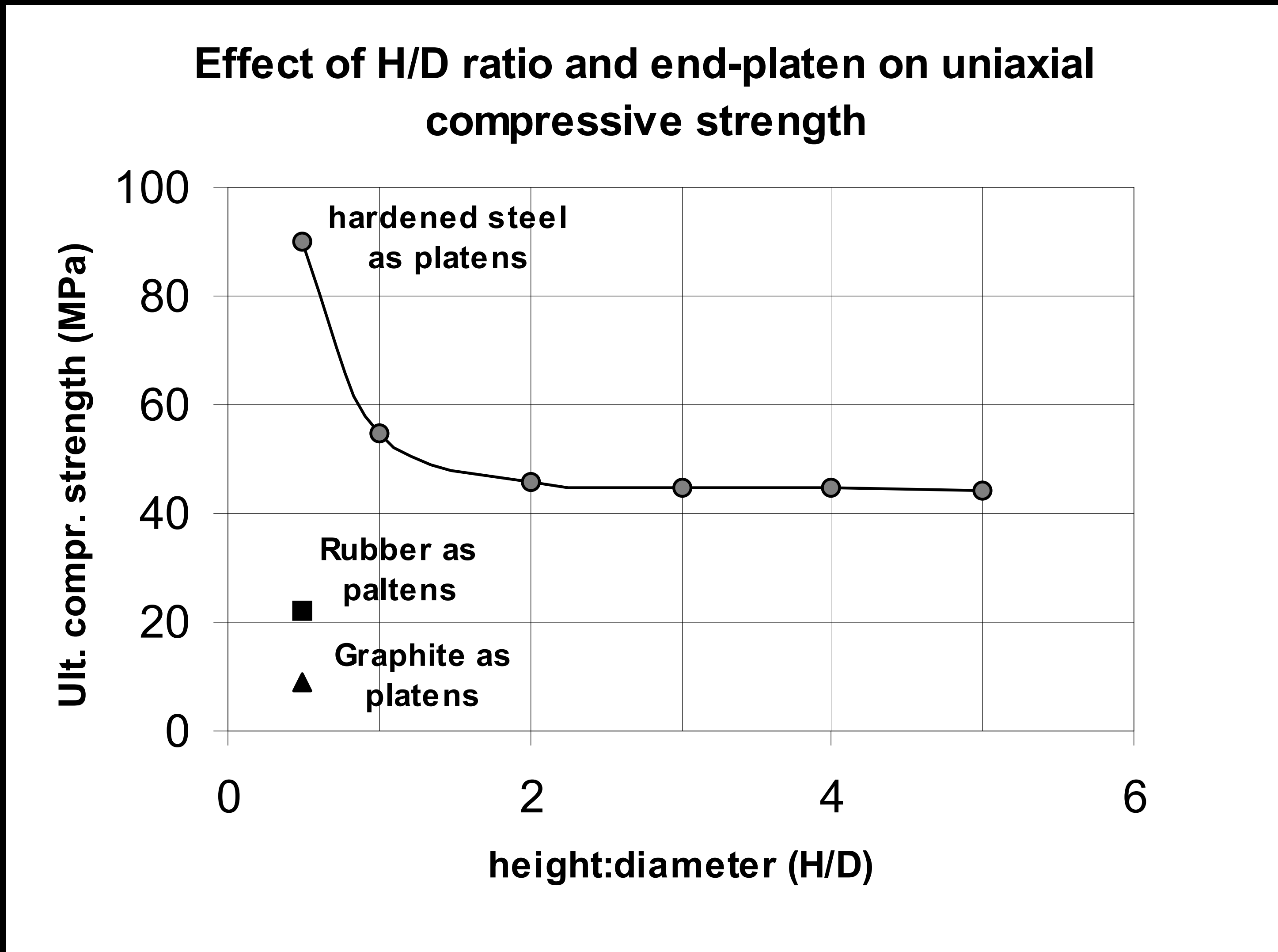




Effect of orientation of existing fracture on test data is more significant for Brazilian & Point-load test

Parameters affecting laboratory testing:

- Loading rate (kN/s), straining rate (%/s) & shearing rate (mm/s) – higher loading rate, lower strength.
- Flatness & smoothness of specimen surfaces – bending & flexural effect, cracks may initiate failure.
- For H/D greater than 2.0, UCS remains constant, thus the recommended H/D > 2 to eliminate size effect.
- End-conditions affect UCS. The stronger the end platens (e.g. steel vs. graphite) the higher is the UCS (note: an important aspect in designing a pillars size in underground coal mining).

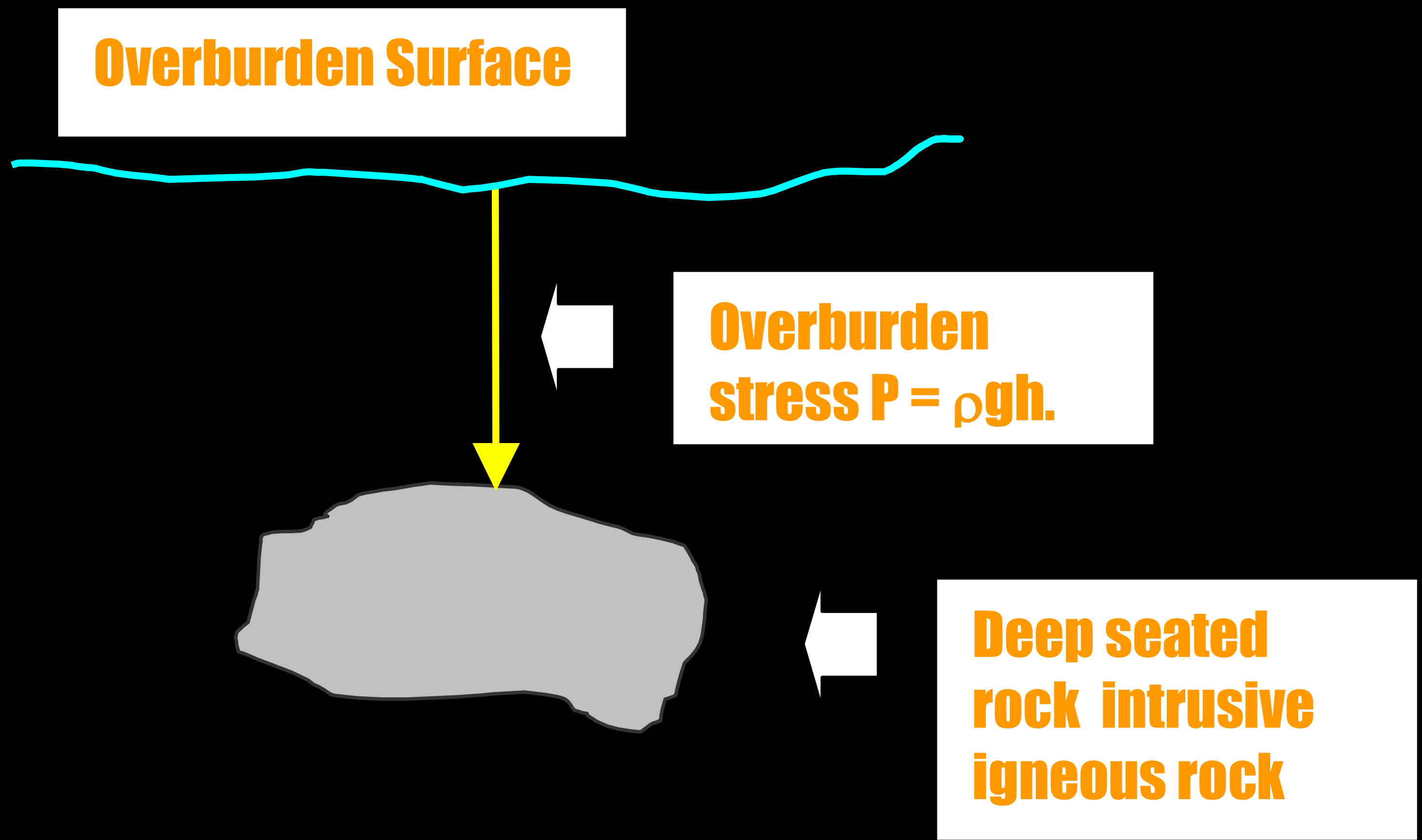


Effect of H/D ratio and end-conditions

Parameters affecting laboratory testing:

- Stiffness of compression machine – stiff loading column or machine equipped with closed-loop servo-controlled loading system to reduce sudden/violent post failure mode (violent failure is not inherent properties of rock).

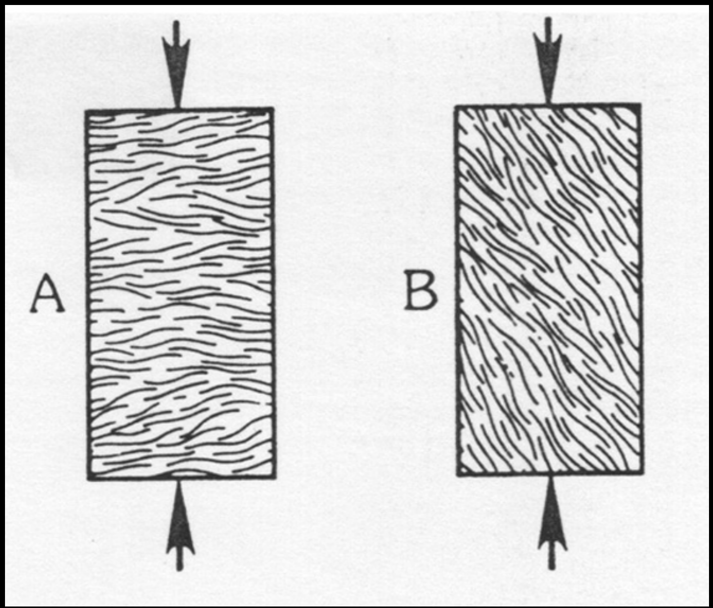
- The state of stress – remnant stress in rock mass may affect strength of rock sample obtained for laboratory test (cores obtained in folded rock strata) and deep-seated rock body.

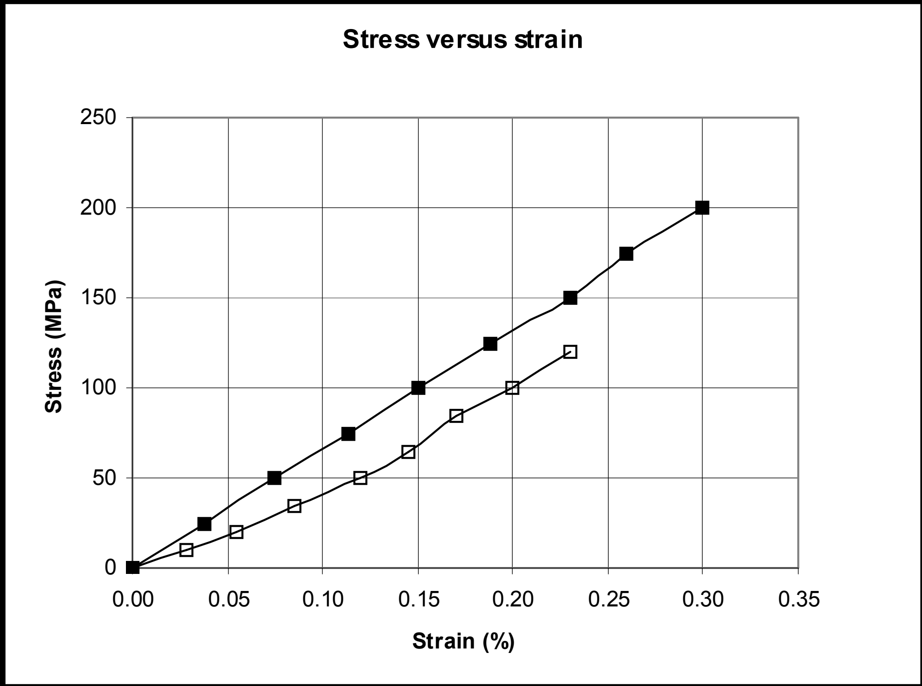


Rock sample obtained from a deep-seated rock body (intrusive igneous rock) need to be test in a manner similar to its in-situ condition.

Discontinuities in rock & their effect on rock properties:

- Attached figure shows effect of single & multiple joint-sets at different orientations, on compressive strength of rock. Rock normally exhibits multiple joint sets hence, it is weakened in all directions of loading.
- When the number of joint sets in a rock body approaches an infinite number (similar to soil body) the strength approaches that of soil strength (3rd curve). Highly fractured rock displays a strength much lower than intact and unweathered rock.

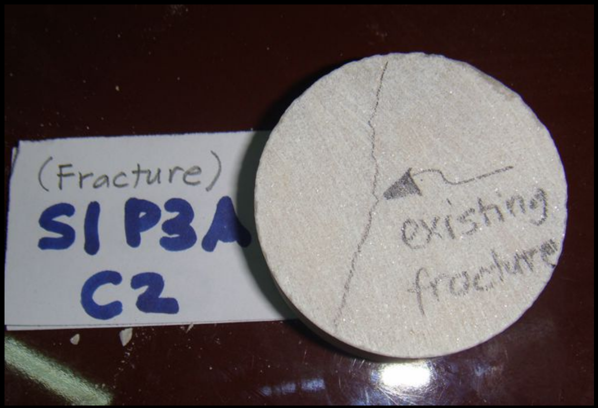




Effect of loading orientation on UCS of sample displaying lamination (metamorphic rock e.g. schist)

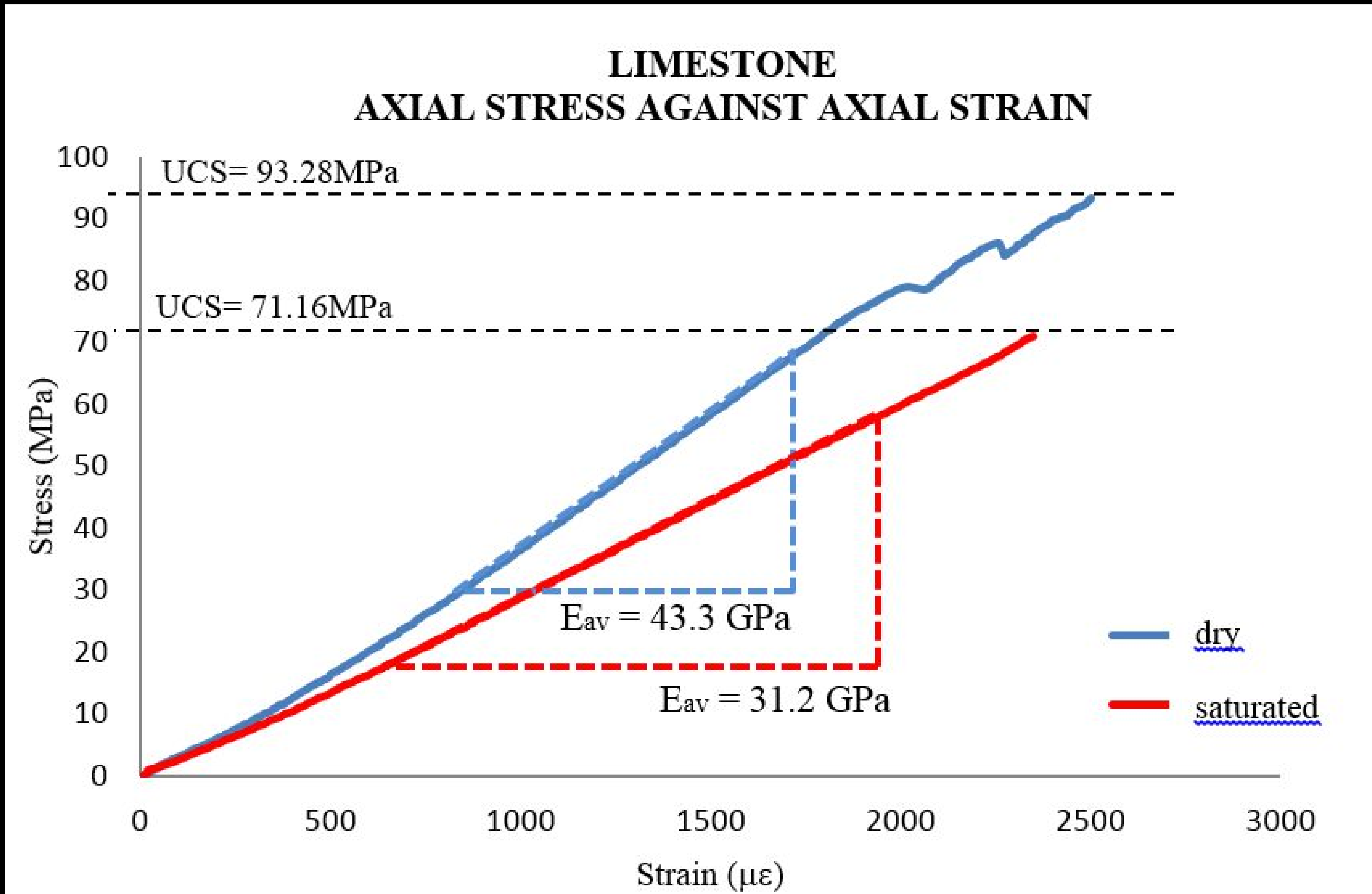
VARIATIONS ON ROCK PROPERTIES

- Samples variation: rock is inhomogeneous & anisotropic (contributes 10 - 20 % error on lab data (Waltham, 2002)
- Machine accuracy: typically at 500 kN max. capacity, accuracy is ± 3 to 5 % (Jaeger & Cook, 1979)
- Existing fractures: leads to premature failure in some samples



Effect of water on rock strength:

- Sample saturation – test at natural saturation (or either 100% saturation or dry).
- The presence of water & any increased pore water pressure (pwp) reduces rock strength.
- Water interrupts the bonding between minerals, and allows the break-up of clay cements in some sedimentary rocks. Water also acts as lubricant on fracture planes.
- PWP acts in opposition to confining stress; this reduces effective normal stress in triaxial situation, and therefore reduces confined shear strength.
- Water greatly reduces strength of weak, porous sedimentary rocks but has minimal effect on strong rock with low porosity.


LIMESTONE
AXIAL STRESS AGAINST AXIAL STRAIN
UCS= 93.28MPa
UCS= 71.16MPa
Eav = 43.3 GPa
Eav = 31.2 GPa
dry
saturated
Stress (MPa)
Strain (με)
0
10
20
30
40
50
60
70
80
90
100
0
500
1000
1500
2000
2500
3000

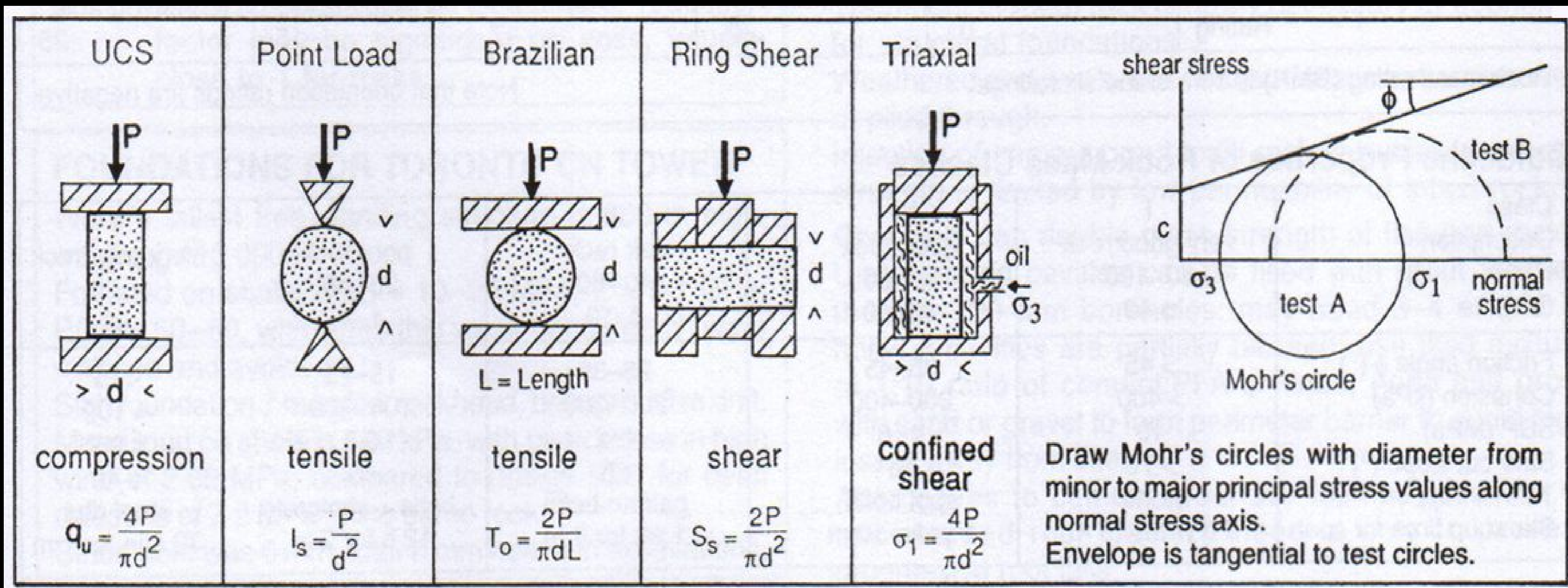
Frequently asked questions

Why joint is susceptible to weathering?

If the surface of joint A is weathered to grade III, and joint B is grade I, which joint exhibits higher shear strength?

If the surface roughness of joint A and B are of similar roughness, how weathering affects the shear strength of joint A ?

What test is used to measure the compressive strength of joint surface ?



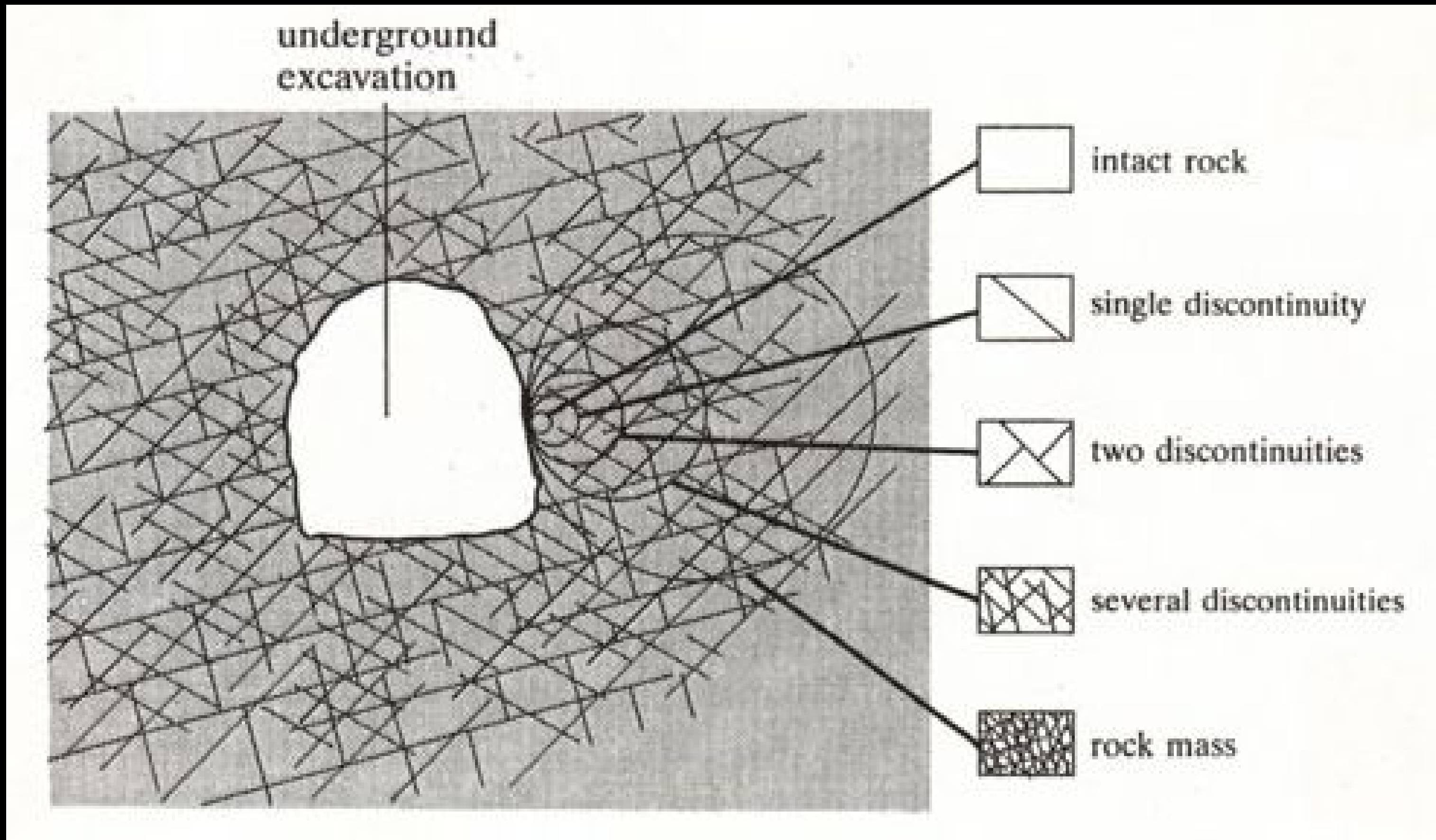
Typical loading configuration in rock testing

Discontinuities in rock & their effect on strength:

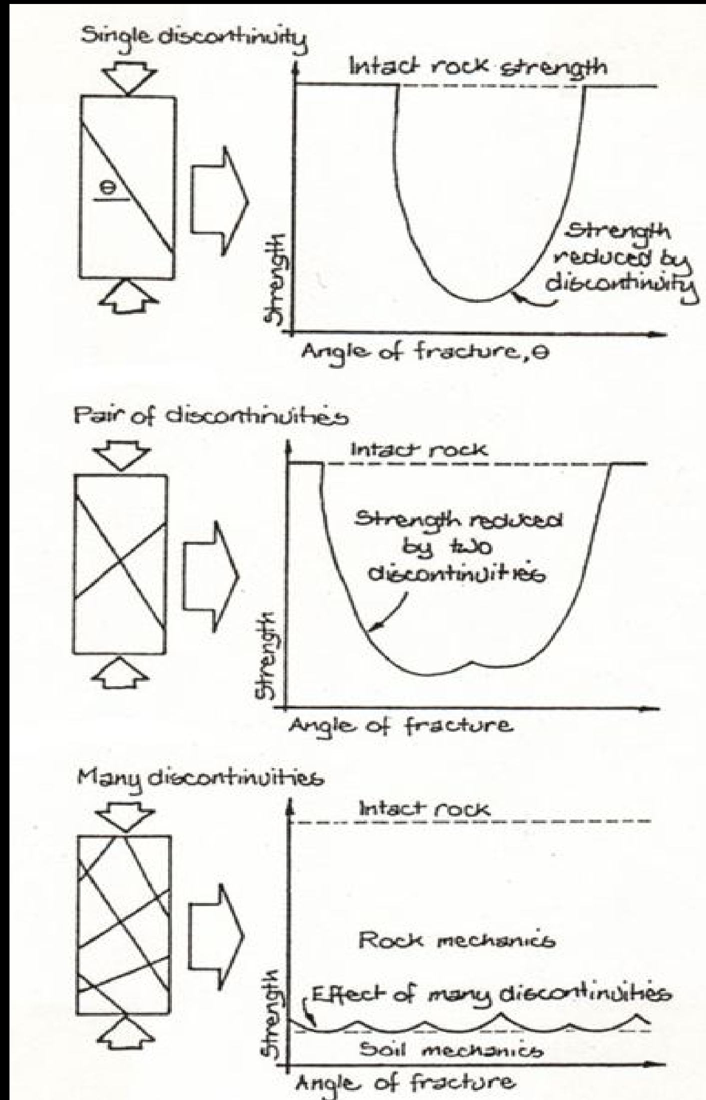
- Strength in rock refers to INTACT or material strength & MASS strength.
- Intact strength of rock depends on component mineral strength & the way they are bound together – by interlocking or cementation.
- Strength normally determined in laboratory using small and fresh sample.

Discontinuities in rock & their effect on strength:

- Mass strength applies to a mass (or body) of fractured rock on site, hence also referred to as *in situ* strength.
- Mass strength largely relates to discontinuity (weakness) planes in rock. Mass strength also include effect of weathering (mass strength = intact strength + discontinuities + weathering + water condition).
- Strength normally determined in the field using *in situ* large-scale test.
- Strength data is affected by large-scale & small-scale discontinuities in sample.



Differences between rock mass (*in situ*) & rock material (intact) properties – variation in properties due to the presence of discontinuities in rock



The influence of weakness planes on strength – joint orientation with respect to loading axis

In situ or field test:

Field or *in situ* tests are to assess properties of rock at location where they are found.

Simple laboratory index tests (e.g. point-load & Rebound hammer) can also be undertaken on site as to save time & minimise disturbance of samples.

Field test include large-scale direct strength tests undertaken on site. Tests require elaborate preparation & equipments & hence very expensive, complex & time consuming.

Texture of joint surface – roughness (kekasaran)

Texture of joint surface (roughness)

Joint orientation that may contribute to rock sliding, note the typical profile of the joint

- In lab tests it is important to note the direction of loading with respect to rock anisotropy.
- Strength of rock mass that exhibits small & large-scale discontinuities is best assessed using large-scale *in-situ* tests.
- Weathering also affects strength of rock. Degree of weathering is usually evaluated on site.
- In design, suitable FOS is used to cater for any uncertainty in design parameters (e.g. strength & E). Typical value of FOS is between 1.5 & 2.5. The higher the FOS, the more conservative is the design & subsequently, higher construction cost.

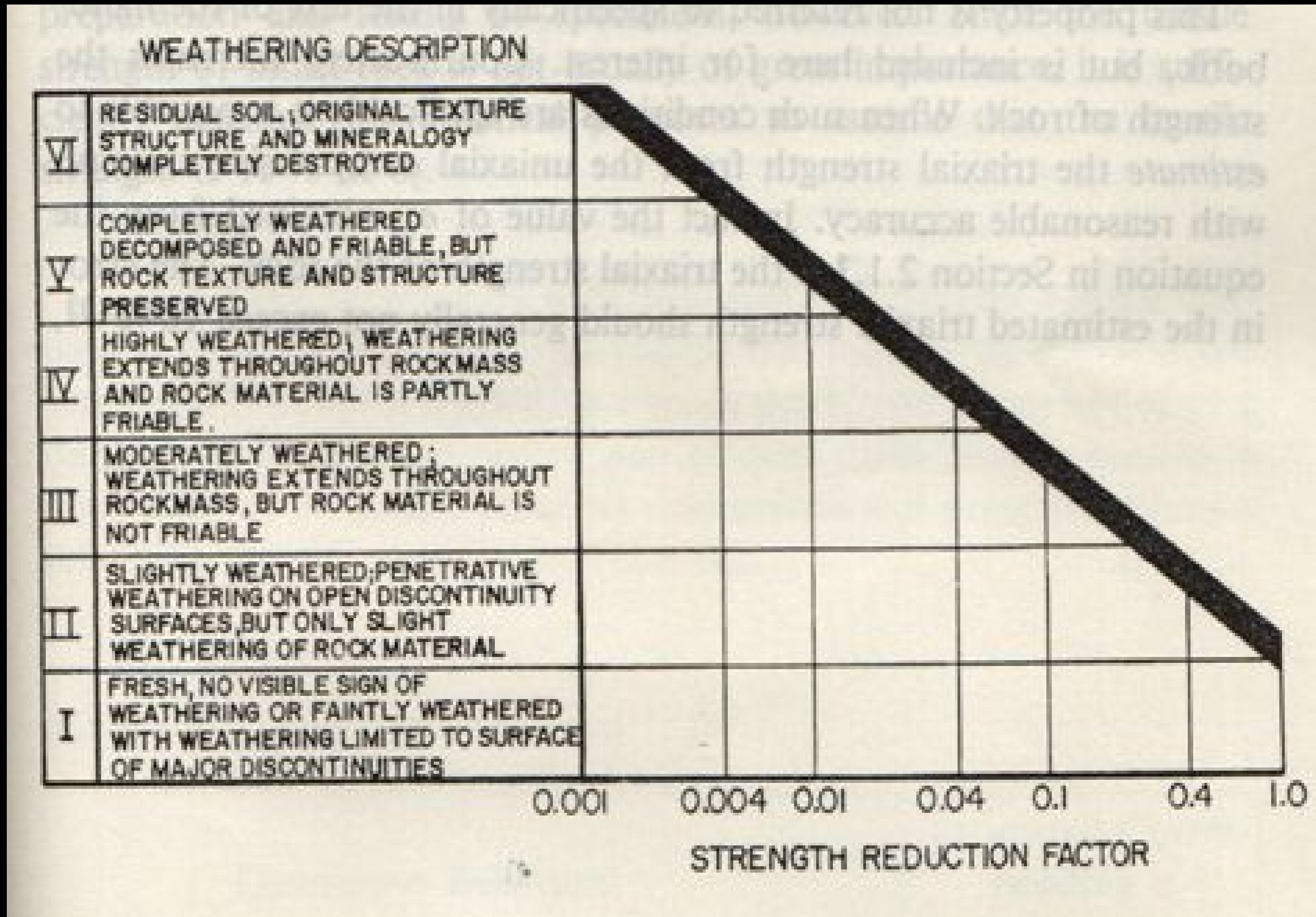
Fresh rock (weathering grade I)

Weathered rock (Gred V)

Properties of rock determined in laboratory & field:

Take for example the effect of weathering, a difficult parameter to be accommodated and considered in designing a structure although its effect on rock properties is paramount.

Sample use in laboratory strength test is usually fresh (grade I). On site, the rock body may be weathered. Therefore, a reduction factor must be imposed on to the laboratory data. This is similar to the use of F.O.S. in design, to cater for the uncertainty aspects & parameters that are difficult to measure.



Strength Reduction Factor (SRF): Effect of different weathering grades (I to V) on strength of rock. Grade VI is soils

In situ or field test:

In situ strength tests are undertaken when properties of rock is very critical to the design and detailed assessment under actual environment is essential.
Most importantly, the cost justifies the importance of the data.

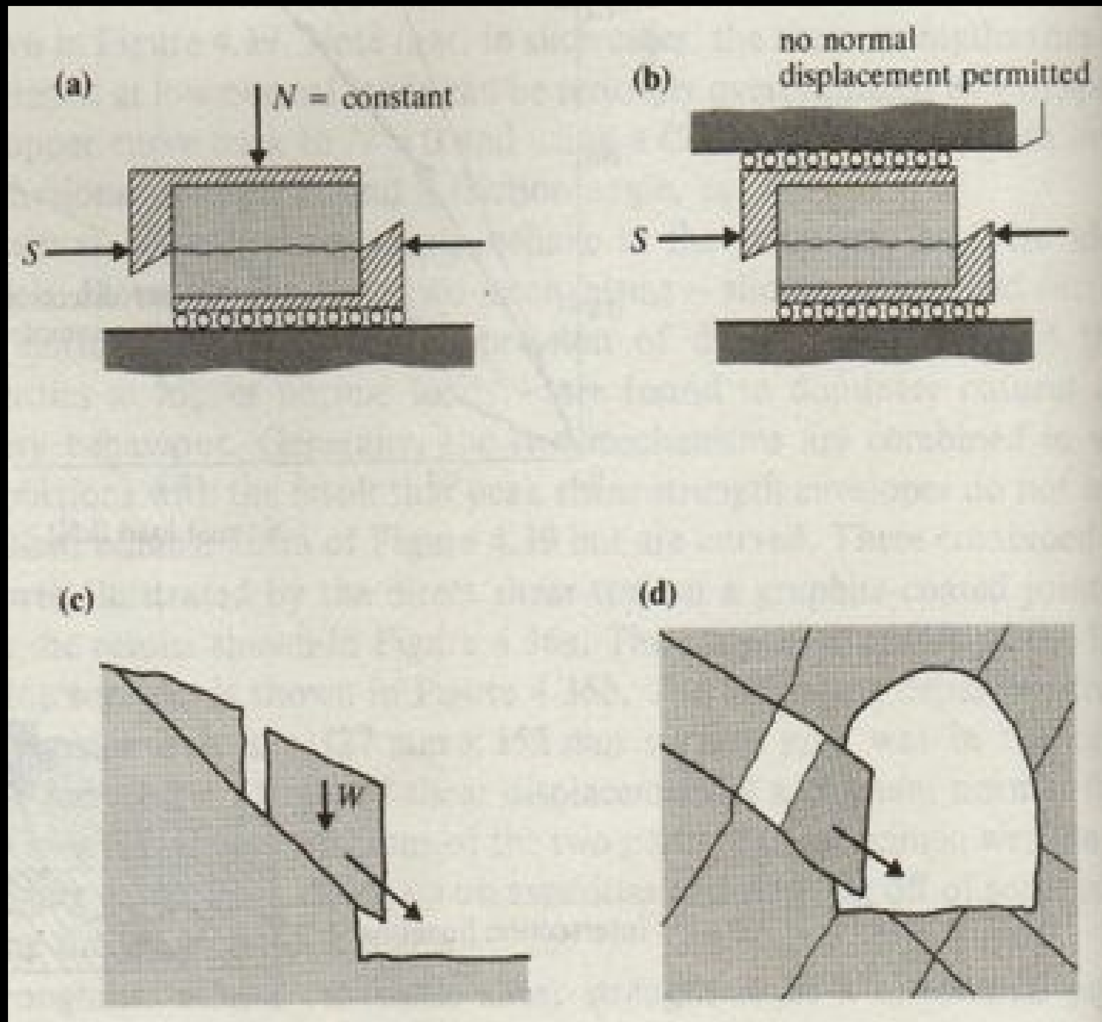
The main advantages of field full-scale test are:
1) it involves a larger size of sample (inclusive of large-scale discontinuities
2) *in situ* sample is therefore undisturbed & more *representative* of field conditions.

In situ or field test:

Among the common field tests are plate-bearing test & direct shear test.

The complexity & elaborate preparation required to assess the shear behaviour of a rock block in slope & tunnel.

The cost involved in undertaking the test can be seen in the anticipated behaviour of the unstable block with regard to nature of the project and surrounding rock mass.



[a] & [b] shear test configuration; loading & displacement.
[c] & [d] type of shearing behaviour for unstable rock block in different situations.

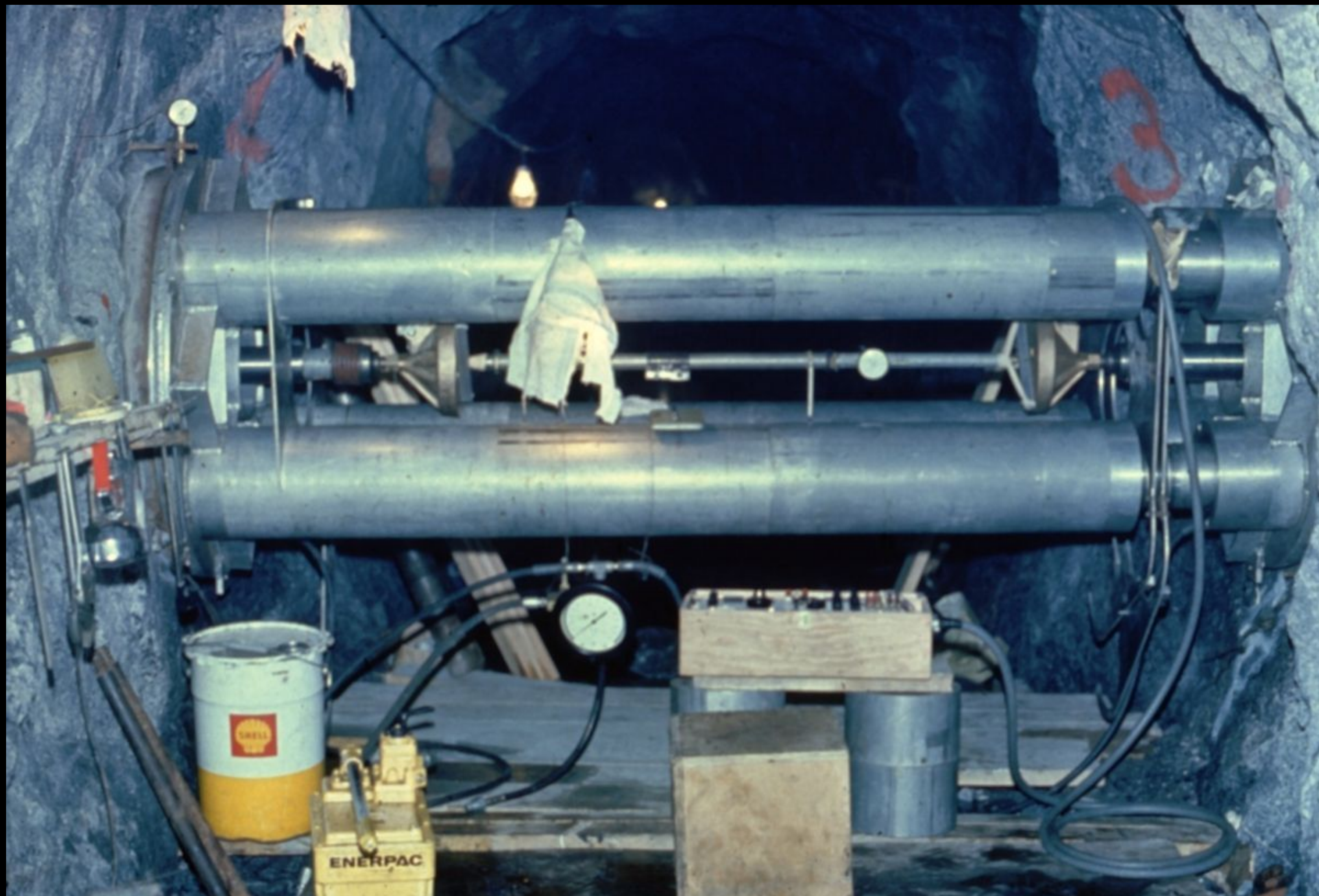
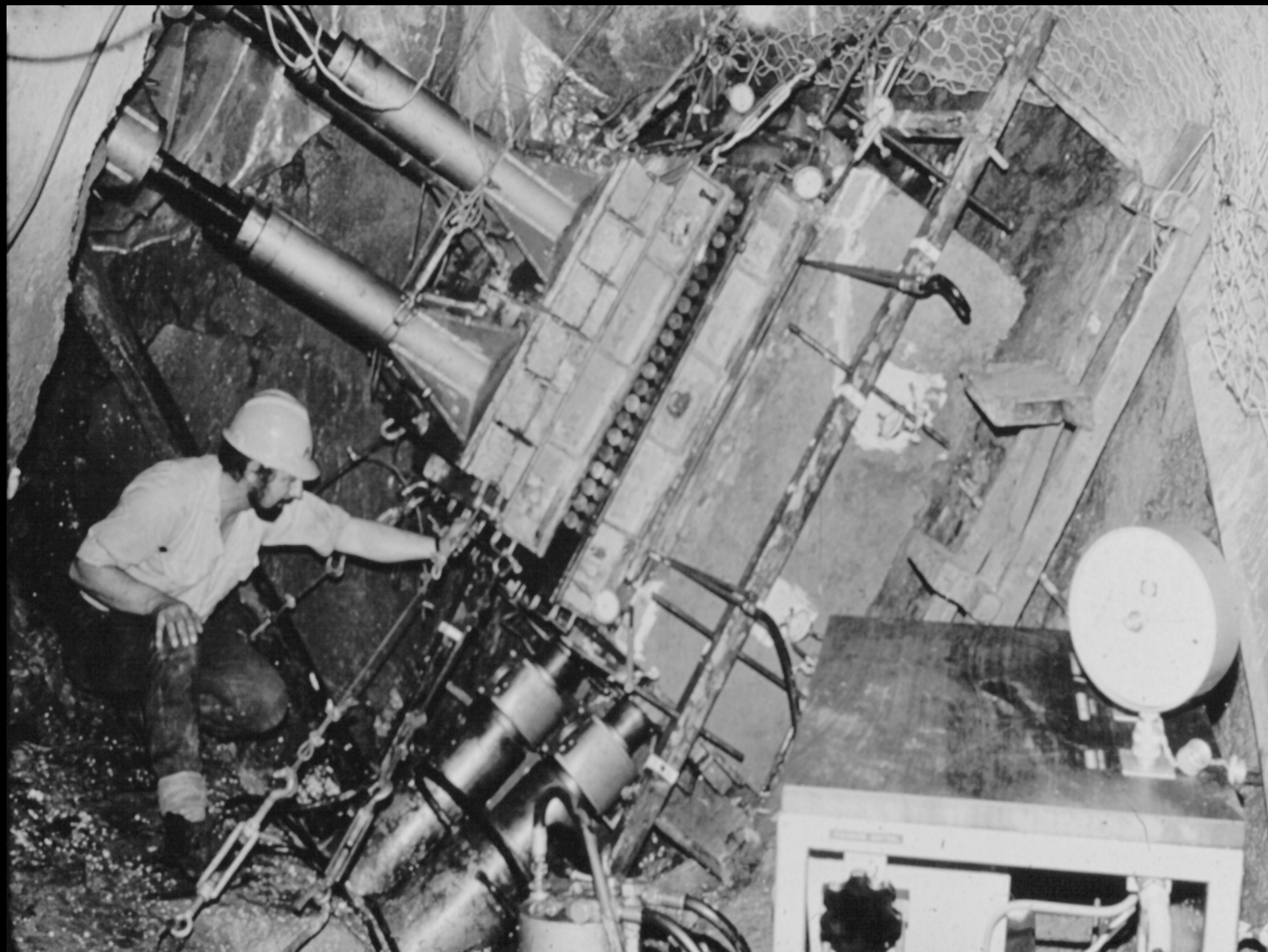


Plate load test



Direct shear test.