1- Introduction

Rock Mechanics: the science concerning study of rock behavior, determining its physical and mechanical properties and study the outer effects on its strength and deformation.

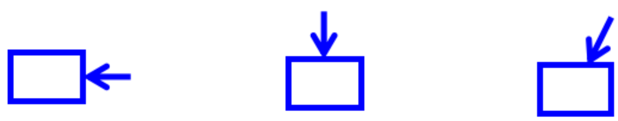
Types of rocks: Igneous, Sedimentary and Metamorphic. They differ according to their mineral composition, grain size and formation environment.

Mountains form as **rock masses** that contain:

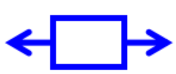
1- **Intact rock:** solid rock samples containing no cracks (on eye naked).
2- **Discontinuity surfaces:** cracks surfaces and joints.

Rock Mass: contains rock sample (Intact rock) and crack surfaces and joints visible by naked eye.
Discontinuity surfaces: crack surfaces and joints visible by naked eye, they vary with various rocks. They are:
Joints, Fractures, Bedding planes, Slate Cleavage, Schistosity, Shear zones.

Types of Forces:
1- **Static Force:** classified according to:
a- **Direction:** Horizontal Force, Vertical Force, Inclined Force.



b- **Action:** Tension Force, Compression Force, Shear Force



2- **Dynamic Force**

2- Types of Engineering Properties: divided into:

1- **Physical properties:** originated with the rock formation and controlled by geological factors like: rock type, color, grain size and weathering degree. Physical properties can be identified by knowing weight and size of the rocks.
2- **Mechanical properties:** influenced by outer circumference factors like forces and stresses. In this respect, it is demanded to break the rock samples to estimate their strength.

Mechanical properties of rocks can be determined through computing their strength versus forces and stresses, where:
Strength = Force/ Area

Types of Strength: Tension, Compression, and Shear

Strength: ability of rock sample to resist force, load or stress.
Strength value: amount of Stress (tension, compression or shear) at failure.

Types of Strength:

1- Tensile Strength

2- Compressive Strength

3- Shear Strength

The rock sample will break if the applied force is vertical and not associated with shear.

The rock sample will break if the applied compressive force surpasses the sample's strength.

Geological Factors Controlling the Engineering Properties of Rocks:

1- Rock Type
2- Degree of Weathering
3- Grain Size
4- Mineral Composition
5- Porosity and Intensity of fracturing
6- Anisotropy

3- Engineering Properties of Intact Rocks

A-Physical Properties for Intact Rocks:

Their values and characteristics were usually controlled by geological factors like: Rock Type, Grain size and Mineral composition.

The most important physical properties of rocks are:

1. Density, Specific Gravity, Unit Weight.
2. Porosity, **n**
3. Void ratio, **e**
4. Permeability, **k**
5. Absorption, **Abs**.

1- Density (ρ), Specific Gravity(Gs) & Unit weight(ɣ):

$$= \frac{Wheit}{Volume} = \frac{gm}{cm^3}, \frac{N}{mm^3}$$

Volume computation:

Regular Shapes:

Irregular Shape:

Regular Shapes: volume calculation via Mathematical formulas:

Volume of Cube = X * Y * Z

Volume of Cylinder = Area * L = πr^2 * L

Where: **πr^2 =** area of the circle

Irregular Shapes:

By submerging the irregular rock sample in a known volume water using a graded cylinder, where the excessive water represents the sample volume.

{1 mL = 1 cm^3}

1 L = 10^3 cm^3

Specific Gravity: **(Gs)**

Unit weight: (γ) = N/mm^3, $\frac{KN}{m^3}$, $\frac{Lb}{inch^3}$

2- Porosity:

$$n = \frac{Volume\ of\ Voids}{Total\ Volume} = \frac{V_v}{V_t} = \frac{V_v}{V_s+V_v}$$

3- Void Ratio:

$$e = \frac{V_v}{V_s}$$

4- Permeability:

Each permeable sample is porous, but not each porous sample is permeable.

Permeability is calculated with: 1- quantity 2- velocity 3- time

5- Saturation index:

$$\textbf{Absorption, (Abs)} = \frac{W_{sat.} - W_{dry}}{W_{dry}} * 100$$

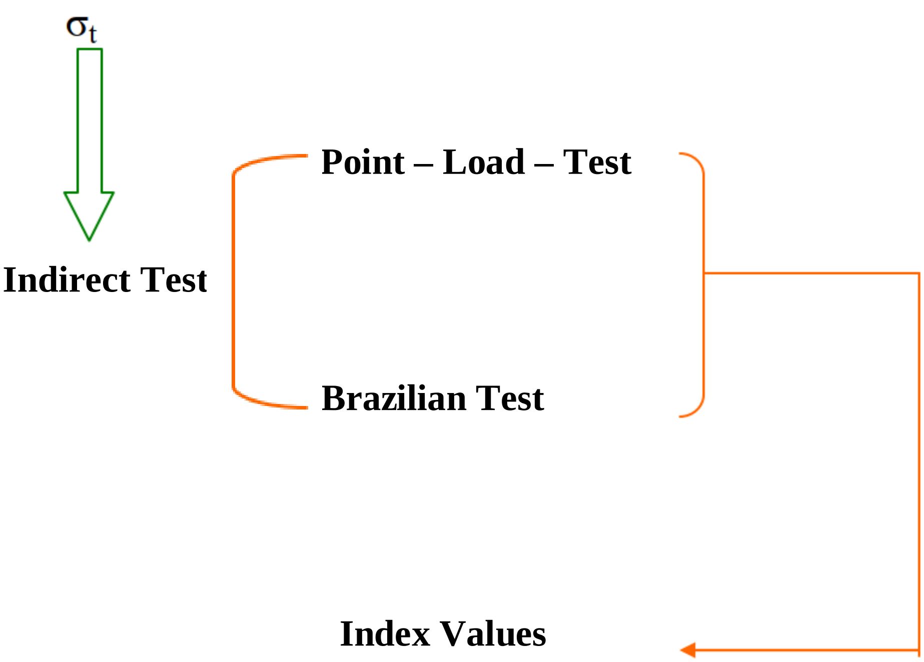
B- Mechanical Properties for Intact Rocks:

1- Strength **2- Deformation**

1- Strength:

1.1 Tensile Strength of Intact Rock:

Rock samples are weak in tension.



Indirect Test: non direct rock tests

1- **Point – Load Test**
2- **Brazilian Test**

The results are called **Index Values**

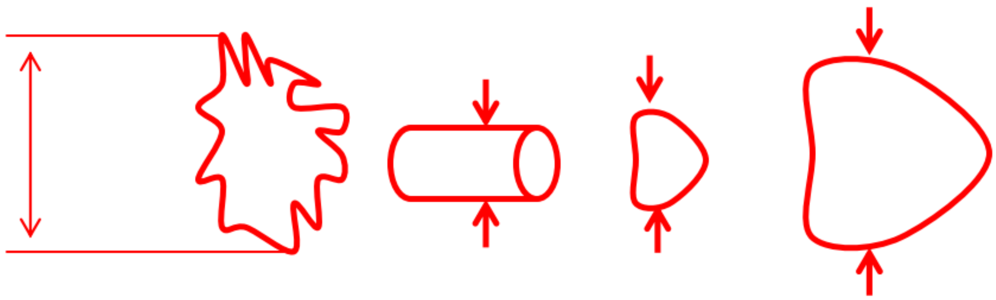
Tensile Strength, σ_t

Point-load test **Brazilian test**

The first test to determine **Tensile Strength** is the **Point-Load- Test**

I_s= Point- Load Index = $\frac{P}{D^2}$

D



ISRM: International Society for Rock Mechanics:

This society had unified **D** for sample

I_s (50) = Point-load index for sample of **50** mm Diameter:

D (mm)	**I_s (MPa)**	**I_s (50) (MPa)**
30	11	9.6
50	9.5	9.5
70	8	9.3

Tensile Strength, σ_t= (1~5) I_s(50) σ_t= (3) * I_s(50) (average)

This relationship between σ_t and I_s(50) is called Empirical Relationship (Linear Numerical).

σ_t= (1~5) * I_s (50) Range

σ_t= (3) * I_s (50) Average

Values from 1 to 5 depend on:

1- Rock strength 2- rock type 3- weathering degree

For example:

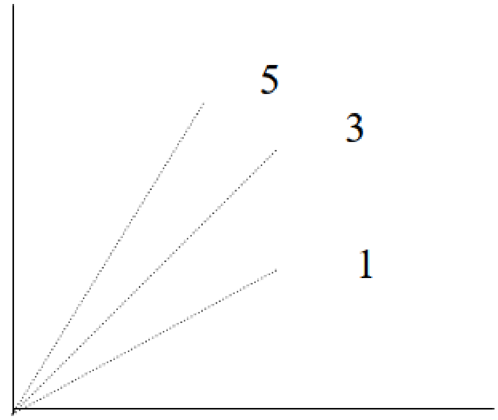
If the rock is highly weathered ⇒ **1* Is $_{(50)}$**

If the rock is moderately weathered ⇒ **3* Is $_{(50)}$**

If the rock is fresh ⇒ **5* Is $_{(50)}$**

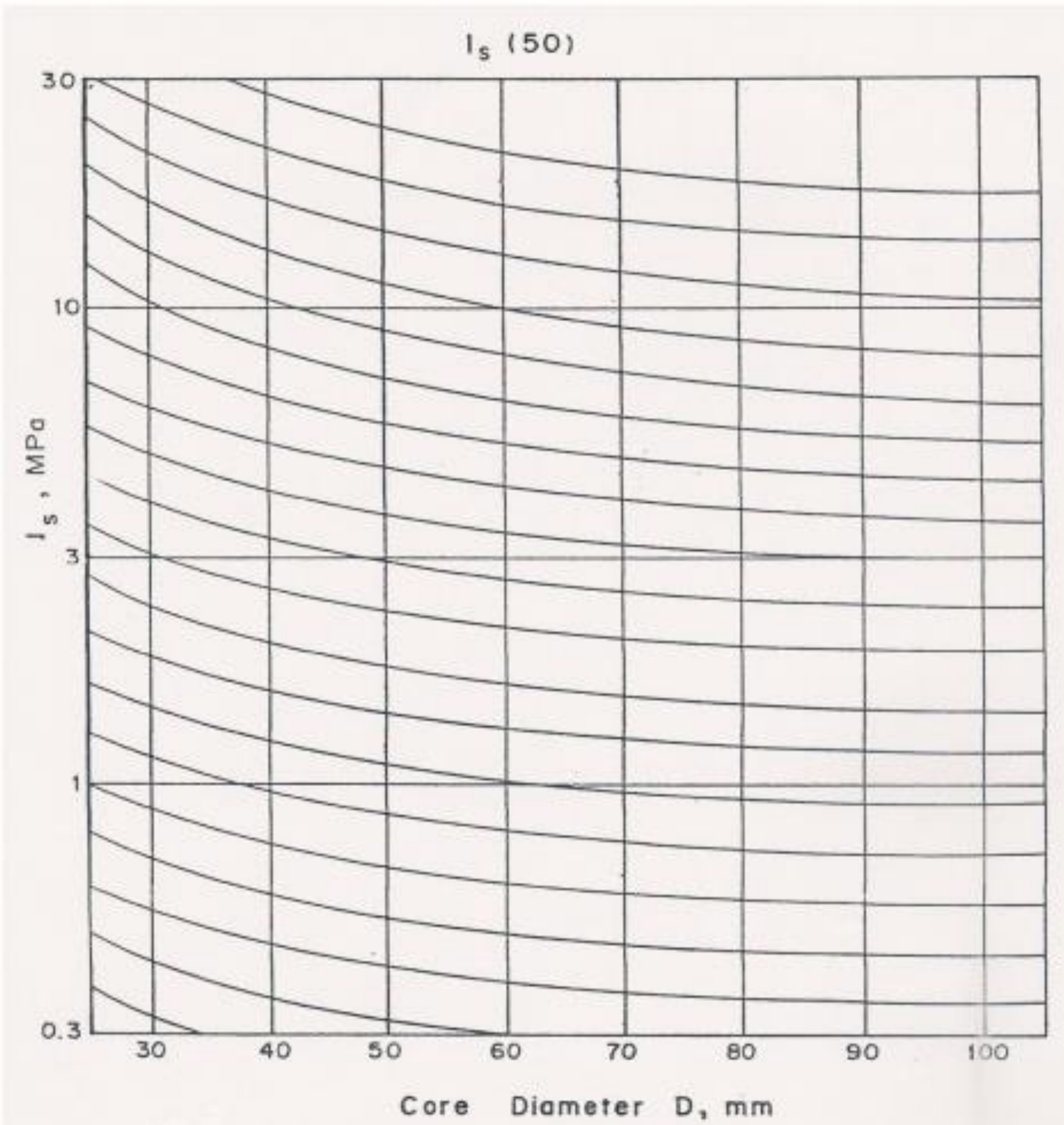
Where they are indirect values

σ_t **(Mpa)**



Is (50) (MPa)

Relation between **Is (50)** and $\boldsymbol{\sigma_t}$

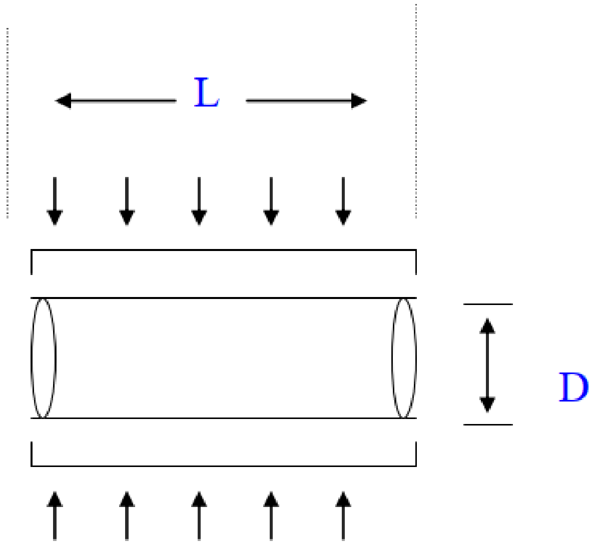


Size correction chart for point load test (After Broch and Franklin, 1972)

The second test to determine **Tensile Strength** is the **Brazilian Test**:

Brazilian Test provides tensile strength values closer to reality than **Point Load Test**.

In **Brazilian Test,** the stress loading is on sample line which must be regular cylindrical. Whereas the sample must not be regular cylindrical in **Point Load Test**.



$$\boxed{\boldsymbol{\sigma_t} = \frac{2P}{\pi * L * D}}$$

1.2- Compressive Strength of Intact Rock, σ_c

Uniaxial Compressive Strength

σuc = UCS

Considered of the best tests and gives real strength value and be assigned in two ways:

Uniaxial Compressive Strength

In direct Test

Used in laboratory and in field

Gives approximate values

With two tests:

a) **Point Load Test**

Specification:

Is (50)

$$\boxed{\mathbf{UCS = 24 * Is_{(50)}}}$$

Where 24 ranges between 10 ~ 40

Direct Test

Used only in laboratory

Gives real values

Only one test:

Uniaxial Compression

Instrument:

Uniaxial Compression Machine

Instrument Specification

Cylinder Shape

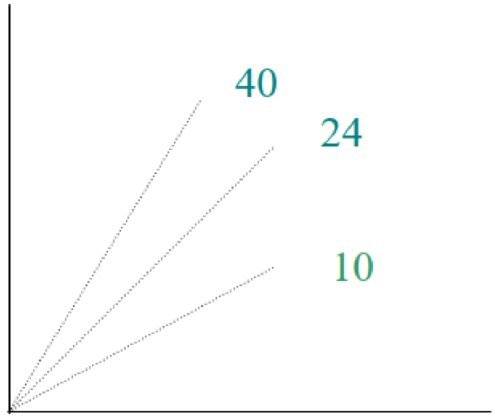
D = 54mm (NX- Size)

L/D (2~2.5)

L= 108 mm - 135 mm

σ_{uc}

(MPa)



Is $_{(50)}$ (MPa)

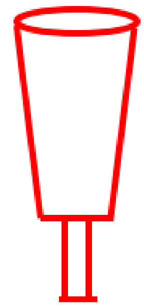
The relation between **Is $_{(50)}$** and **σ_{uc}**

b) Schmidt Hammer Test: gives indirect values for **strength**

b) Schmidt Hammer Test: gives indirect values for **strength**

Schmidt Hammer Test: specified for civil engineering to test concrete strength. There are two types: **N**-type for concrete and **L-**type for rocks.

Using conditions:



1- The surface must be clean.
2- Faraway from cracks.
3- Knowing the direction during measuring.
4- Hammer type and number must be recorded.
5- Measuring must be on hard surface.

How to use:

R= Rebound No.

Taking 15 measurements. Neglecting higher and lower abnormal values.

The most use of Hammer:

1- Knowing the direction.
2- Recording Hammer type and number.
3- Measuring must be on hard surface.
4- Taking at least **five** measurements for each surface of the same rock

Example: The following values were measured using **Schmidt Hammer:**

R = 62,59,63,62,43, 61,59,58,60,60,60,76, 62,63,64

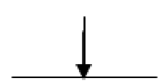
Neglecting the larger and smaller values

Average R = $\frac{\textit{Readings Sum}}{\textit{Number of measurements}}$

Average R =$\frac{793}{13} = 61$

Example:

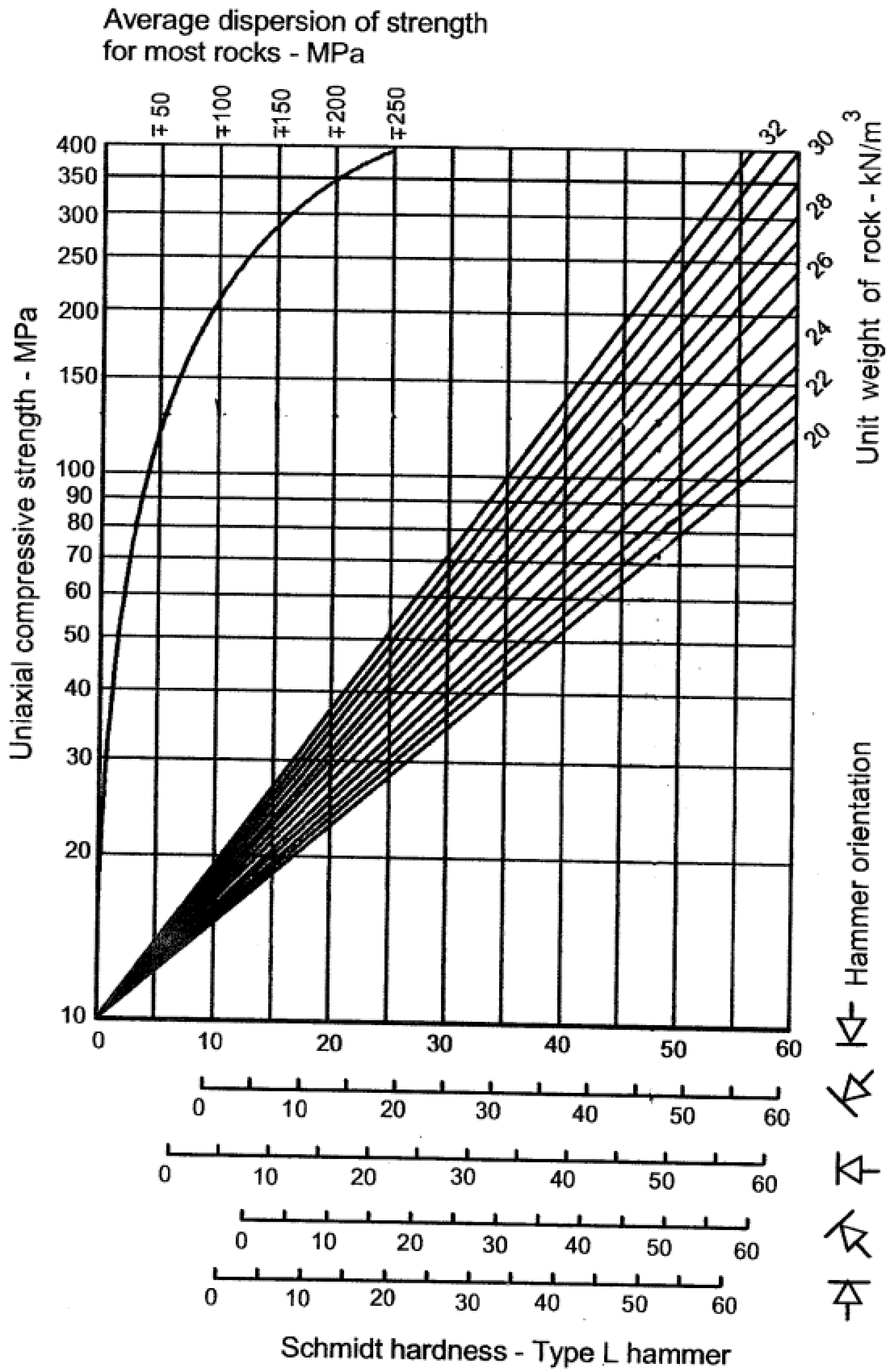
Computing **UCS** from **Schmidt Hammer** using the attached figure:



Average = 55 **γ= 26 KN/m³**

UCS (For Schmidt hammer test) = 185 MPa (+ -) 80 MPa

$$\boxed{\textbf{UCS = 105 – 265 MPa}}$$


Average dispersion of strength
for most rocks - MPa
∓50
∓100
∓150
∓200
∓250
Uniaxial compressive strength - MPa
400
350
300
250
200
150
100
90
80
70
60
50
40
30
20
10
Unit weight of rock - kN/m3
32
30
28
26
24
22
20
Hammer orientation
0 10 20 30 40 50 60
Schmidt hardness - Type L hammer

1.3- Shear Strength of Intact Rock:

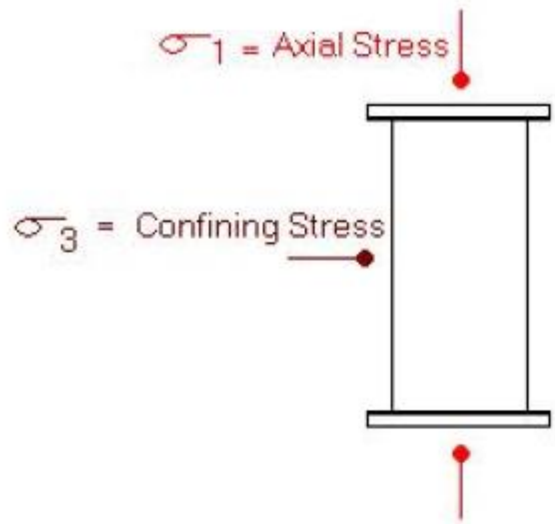
Shear Strength values of Intact Rocks determined with two characteristics:

1- **Internal Cohesion, C_i**
2- **Internal Friction Angle, φ_i**

In Soil cohesion, C = zero

Shear strength of intact rocks determined by **Triaxial Compression Test**:

$$\boxed{\tau = C + \sigma n}$$



To compute shear strength value of an intact rock we must know the followings:

1- **C** (**Cohesion**)
2- **φ** (**Friction Angle**)
3- **σ_n** (Normal **Stress)**

Shear Strength Parameters for Intact Rocks: C_i & φ_i

Since failure occurs inside the intact rock, the formula will be:

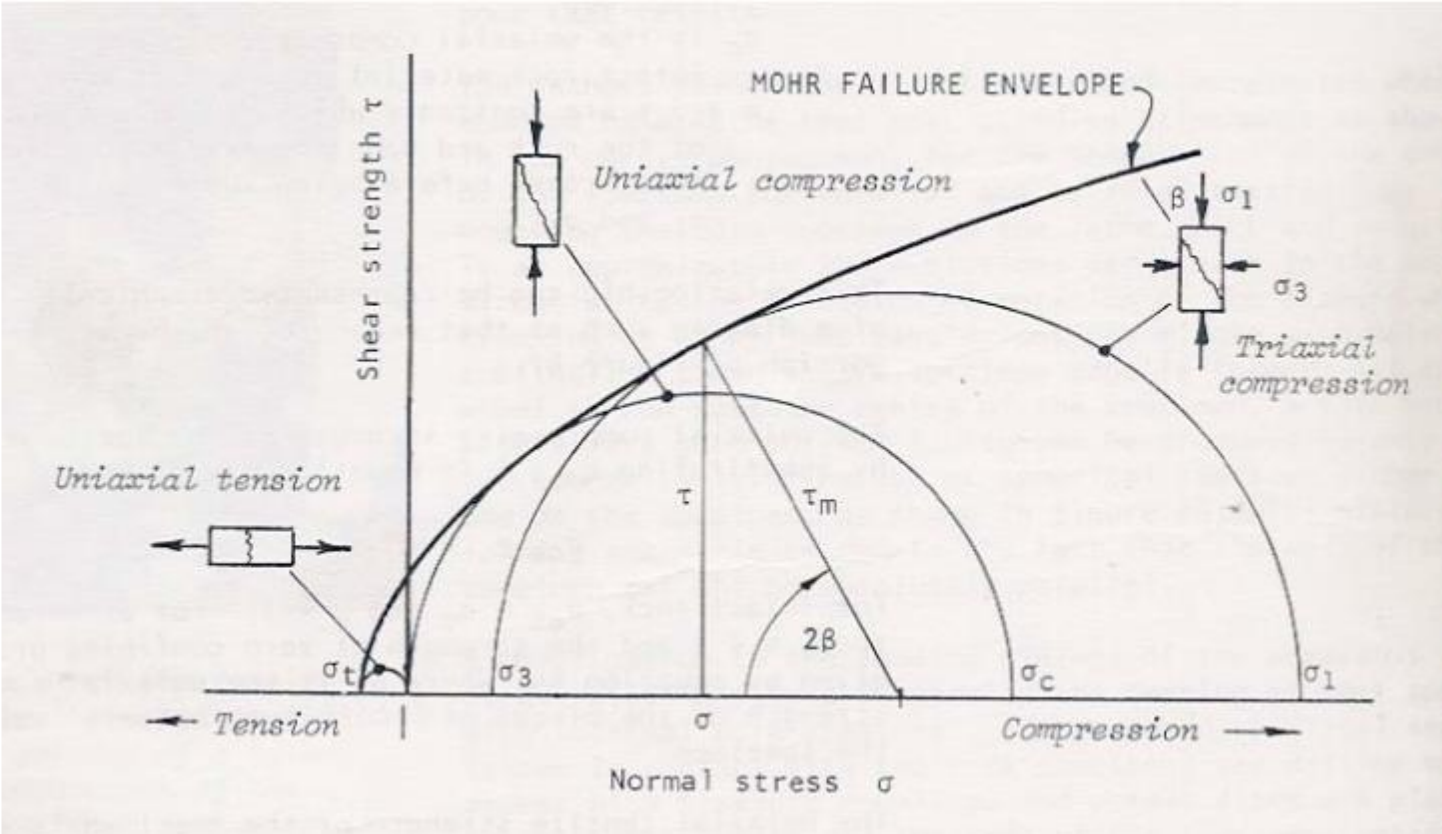
$$\boxed{\tau = C_i + \sigma_n * Tan(\emptyset_i)}$$

Shear Strength Parameters: -

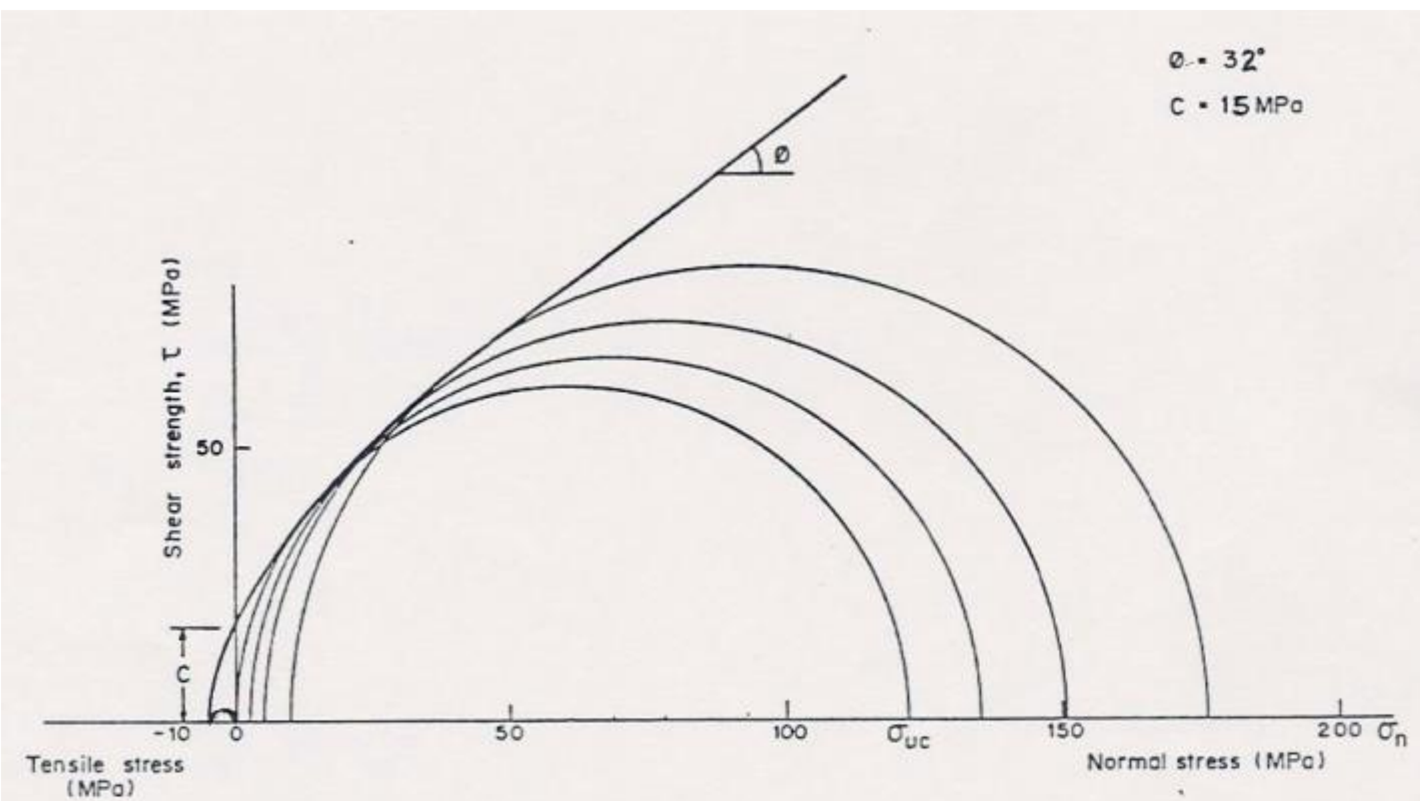
C_i (Internal Cohesion) & $\emptyset_i$ (Internal Friction Angle)

Shear Strength Parameters determined with the Triaxial Compression Tests.

Five tests must be done for five intact rock samples: 3 **Triaxial** tests, 1 **Uniaxial** test and 1 **Tension** test, to draw the relationship between **σ_n** and **τ** using **Mohr Diagram** to find **Shear Strength Parameters C_i & ∅I** and computing shear **τ** from the previous formula with known pressure **σ_n.**



The required tests and Mohr circles plotting



Determination of **C_i** and **φ_i** from Mohr curve

2. Deformation of Intact Rock

All deformations of intact rocks are due to applied pressure, thus two following factors must be identified:

Deformation Parameters ⇨

- **Modulus of Elasticity, E**
- **Poisson's Ration, ν**

Deformation Parameters:

2.1- Modulus of Elasticity, E

2.2- Poisson's Ratio, V

The following factors control the shape of **Elasticity Modulus** curve:

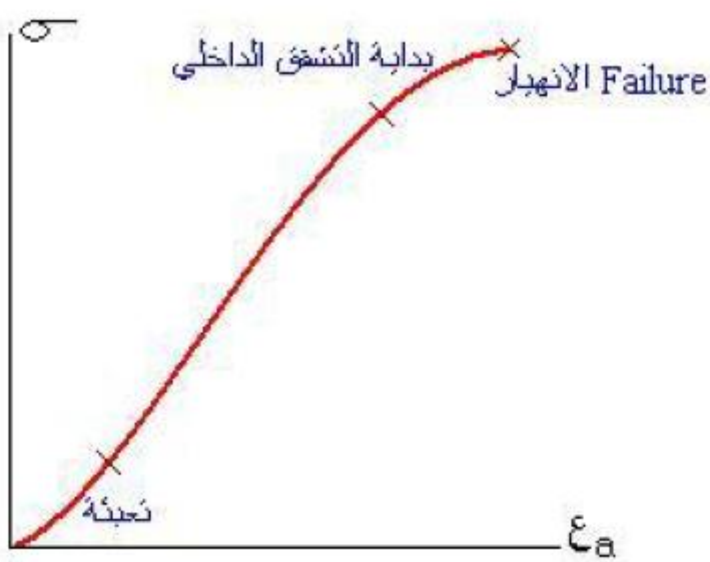
1- Rock type 2- Grain size 3- Voids ratio 4- Weathering

Uniaxial Compression Test with Strain gauge:

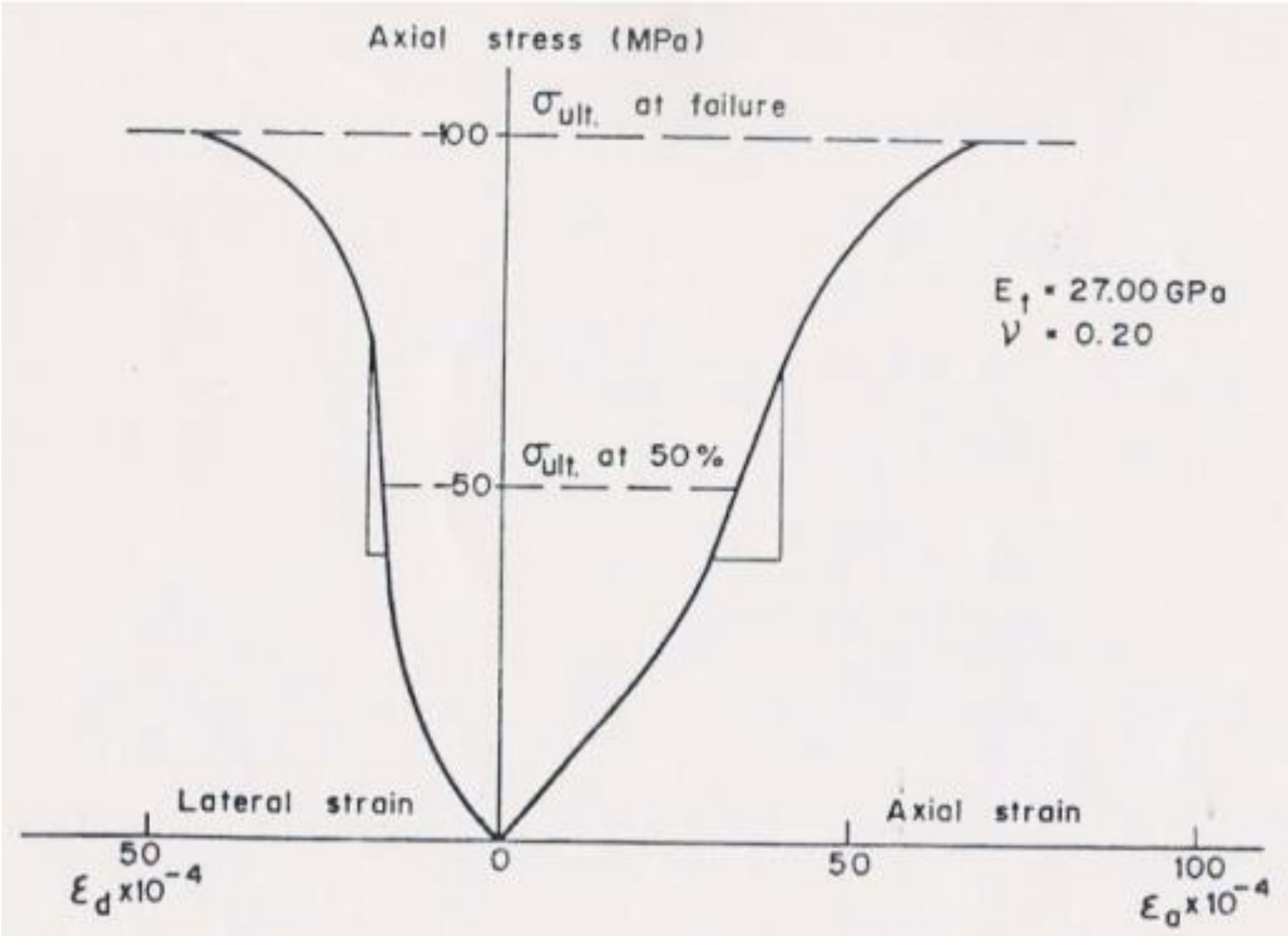
Strain gauge: measures variation ratio between length and width.

$$\boldsymbol{E = \frac{stress}{strain} = \frac{\Delta\sigma}{\Delta\varepsilon_a}}$$

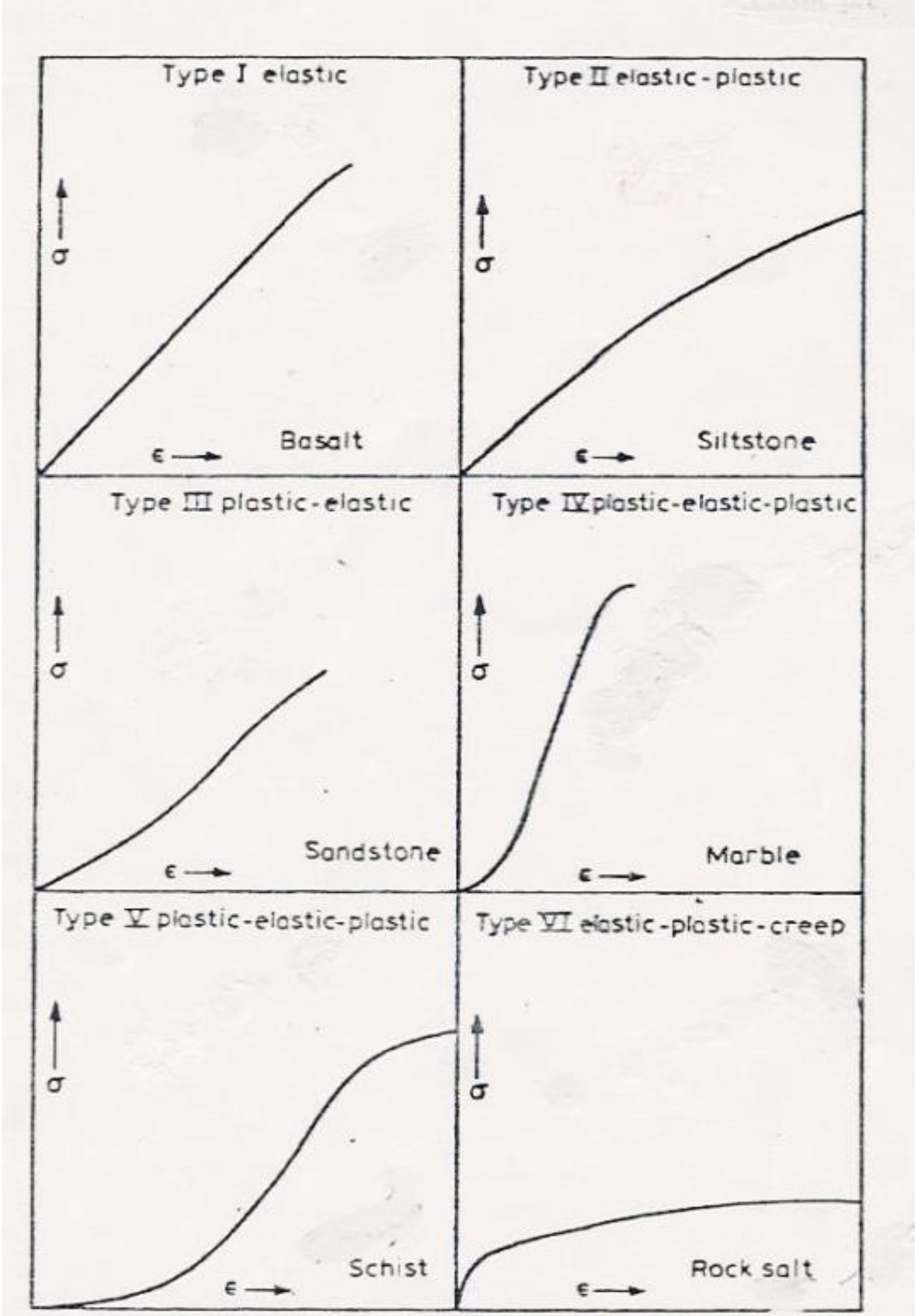
$$\boldsymbol{v = \frac{\Delta\varepsilon_l}{\Delta\varepsilon_a} = \frac{Transversal\ strain}{Longitudinal\ strain}}$$



Name : plastic , Elastic , plastic



Method of computing ***E*** and ***v***

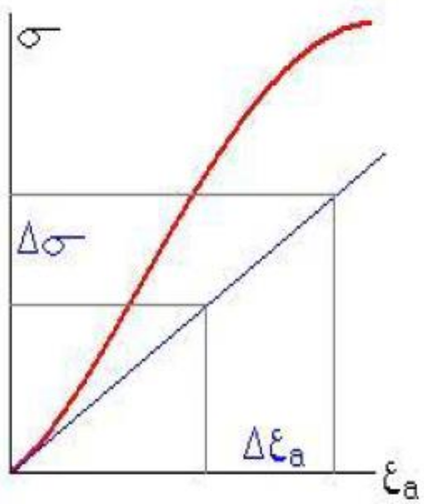


Types of deformation of some rocks

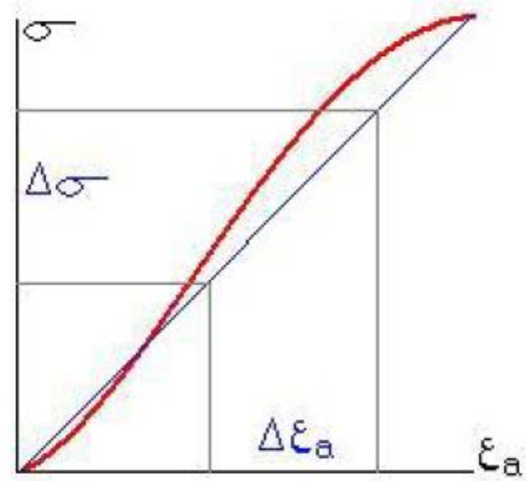
Types of E:

1- E_i = Initial
2- E_{sec} = Secant
3- E_{tang} = Tangent
4- E_{AV} = Average

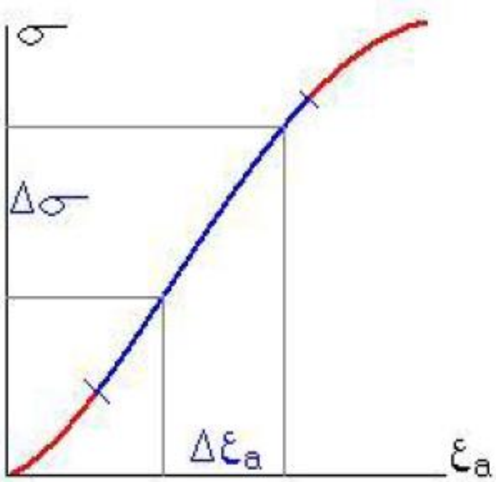
1. E_i



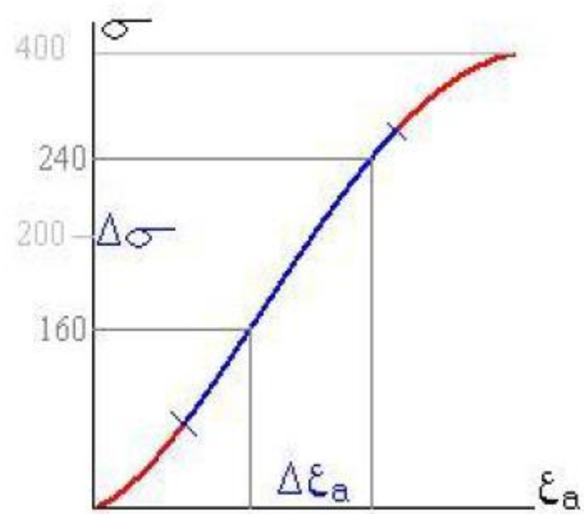
2. E_{sec}



3. E_{tang}



4. E_{Av}



Intact Rock Classification

Intact Rock Classification System

Compressive Strength (UCS) | **UCS & E** | **UCS & E &υ**

The best methods of classification

By Equation | **From A chart**

There are three methods for intact rock classification:

1. **Strength System:**

According to **STRENGTH** (**Uniaxial Compressive strength (UCS**))

2. **Modulus Ratio System** (By Deere and Miller,1966):

According to **STRENGTH** and **MODULUS OF ELASTICITY** (**Modulus Ratio MR**).

3. **Strength – Deformation System** (By Turk and Dearmann,1983):

According to **STRENGHT** and **DEFORMABILITY**

Uniaxial Compressive Strength (UCS), **Modulus of Elasticity (E)**, **Possion's Ratio (υ)**

1. **Strength System:**

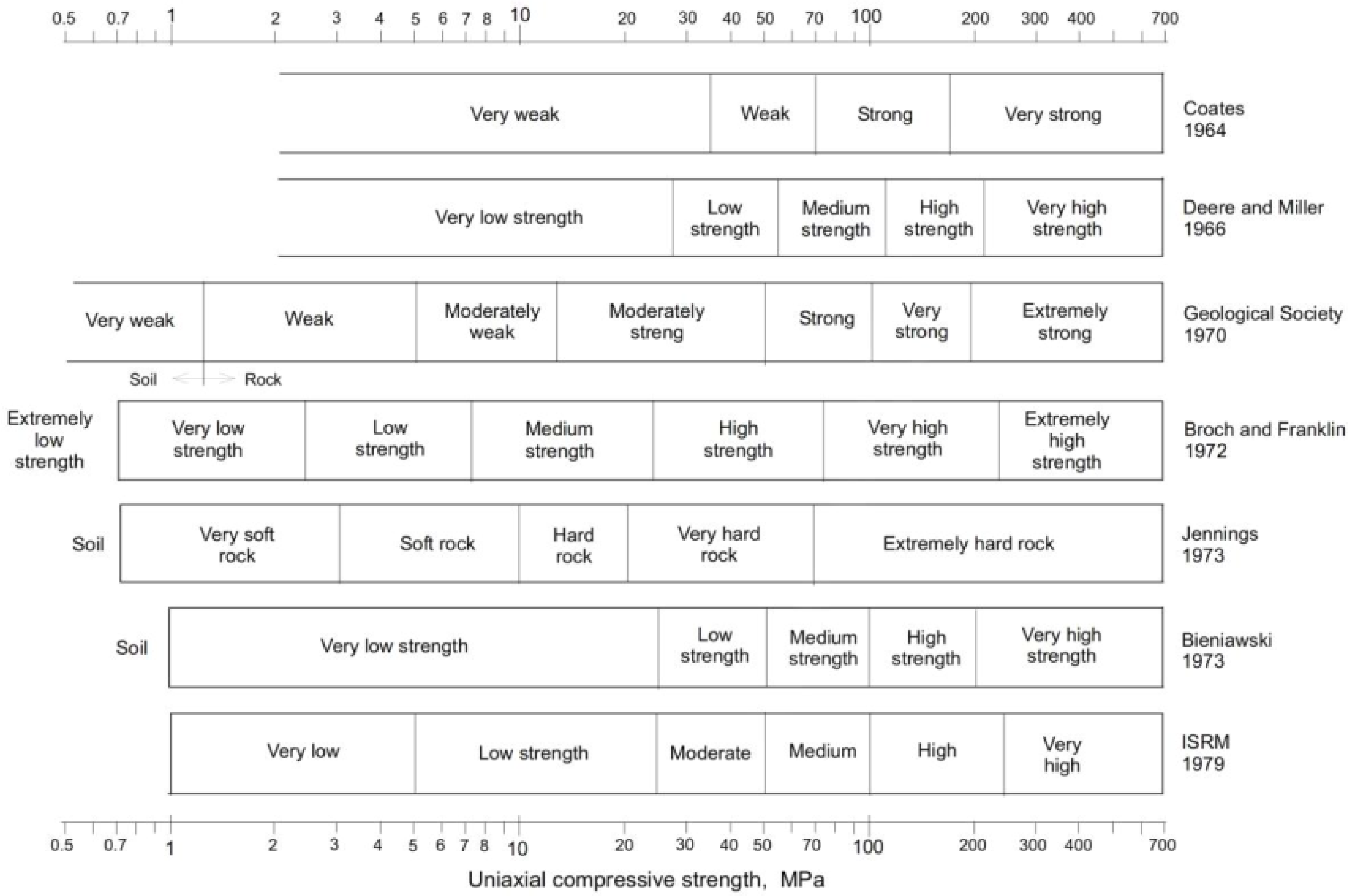
According to Compressive Strength (UCS):

Example: Limestone, UCS = 120 MPa (Coates, 1964)

The intact rock of limestone is classified as a strong rock according to coates Classification (1964).

Example: Basalt, UCS = 210 MPa (Deere & Miller, 1966)

The intact rock of Basalt is classified as high strength to very high strength rock according to Deere & Miller (1966).



Various strength classifications for intact rock (from Bieniawski, 1984)

2. Modulus Ratio System:

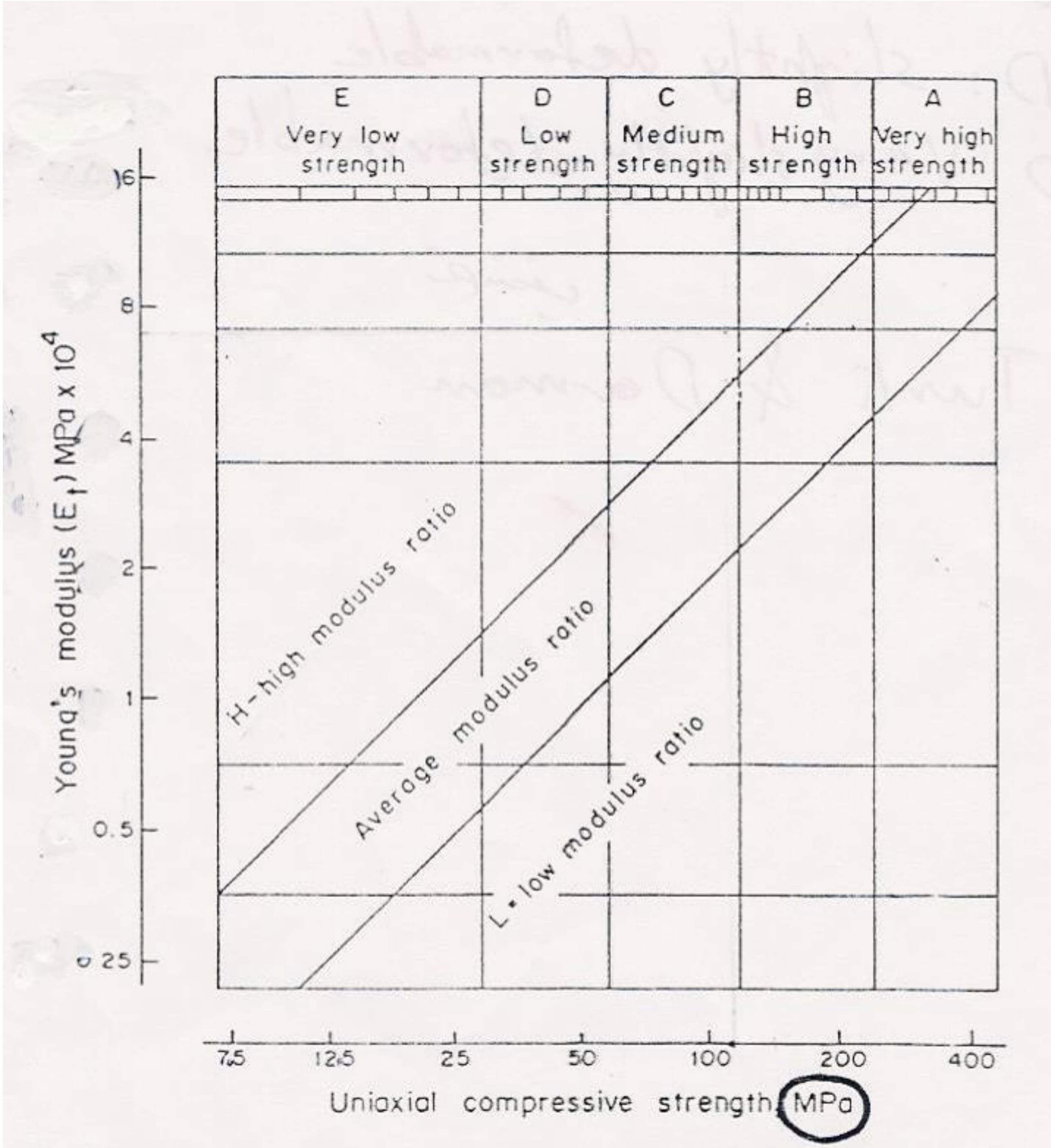
According to strength and Modulus of Elasticity (UCS & E Values), By Deere & Miller (1966). The classification can be made using either of the two methods:

(1) By Equation: $M_R = \dfrac{E}{ucs}$

Engineering classification of intact rock on base of modulus ratio

Class	Description	Modulus ratio
H	**High modulus ratio**	**Over 500**
M	**Average (medium) ratio**	**200-500**
L	**Low modulus ratio**	**Less than 200**

(2) From Chart:



.: Engineering classification of intact rock.
(after Deere and Miller, 1966)

Example: (Granite) UCS = 150 MPa, E = 60 GPa

$$M_R = \frac{E\ (Mpa)}{ucs\ (Mpa)} = \frac{60000}{150} = 400$$

$\therefore$ MR = 400 (Medium Ratio)

The intact rock of granite has a medium ratio according to Deere and Miller classification (1966).

3- Strength – Deformation System:

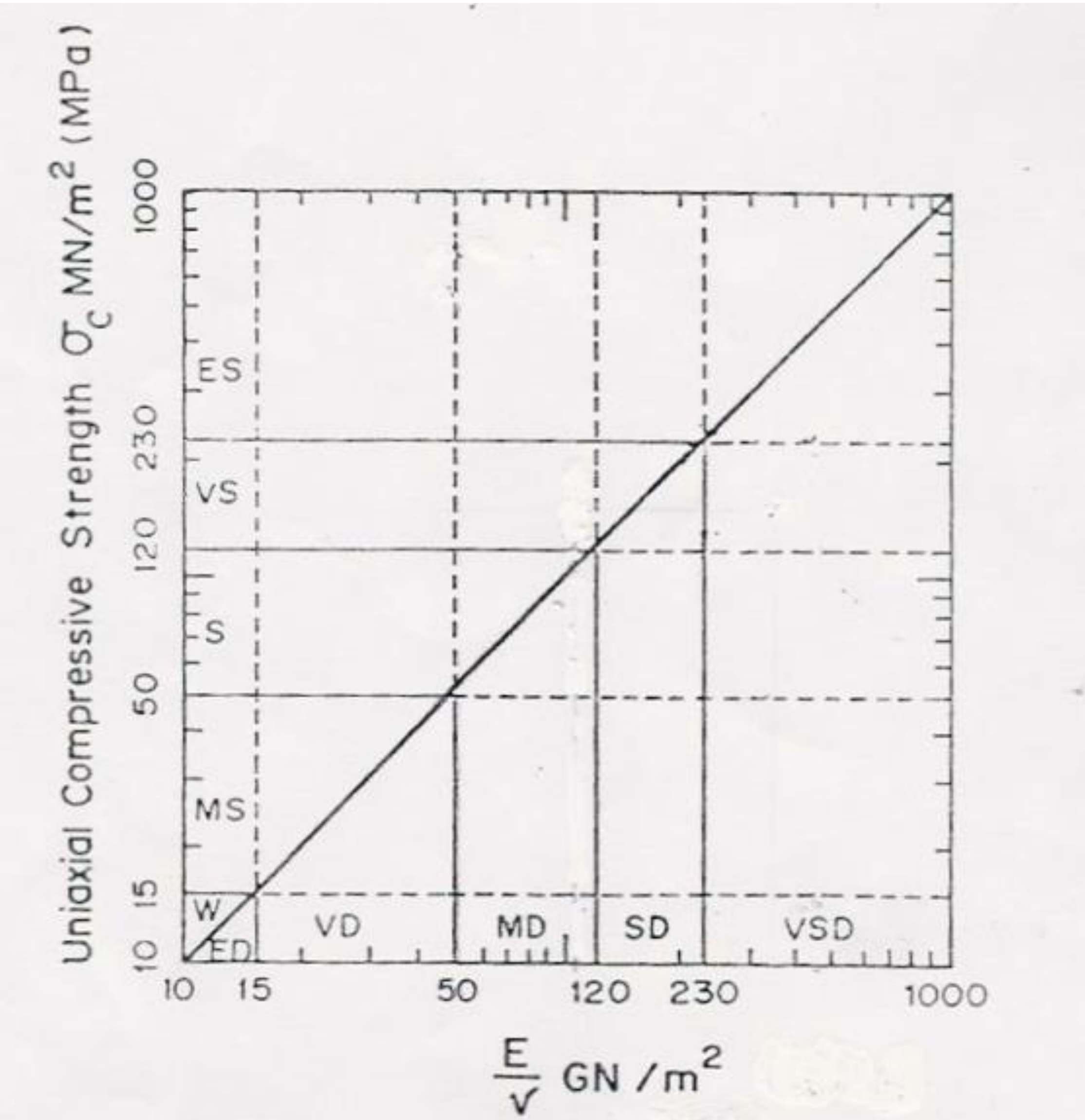
According to Strength, Modulus of Elasticity & Poisson's Ratio (UCS, E &υ values). By Turk and Dearman (1983). It is of the best and appropriate classification methods, since it is including the three engineering parameters.

Example: Diorite, UCS = 180 MPa, E = 60000 MPa, υ = 0.2

$$\frac{E}{\upsilon} = \frac{60000\ MPa}{0.2} = 300000\ MPa = 300\ GPa$$

From the attached chart:

The intact rock of Diorite is classified as a very strong (VS) and very slightly deformable (VSD) rock according to Turk and Dearmann classification (1983).

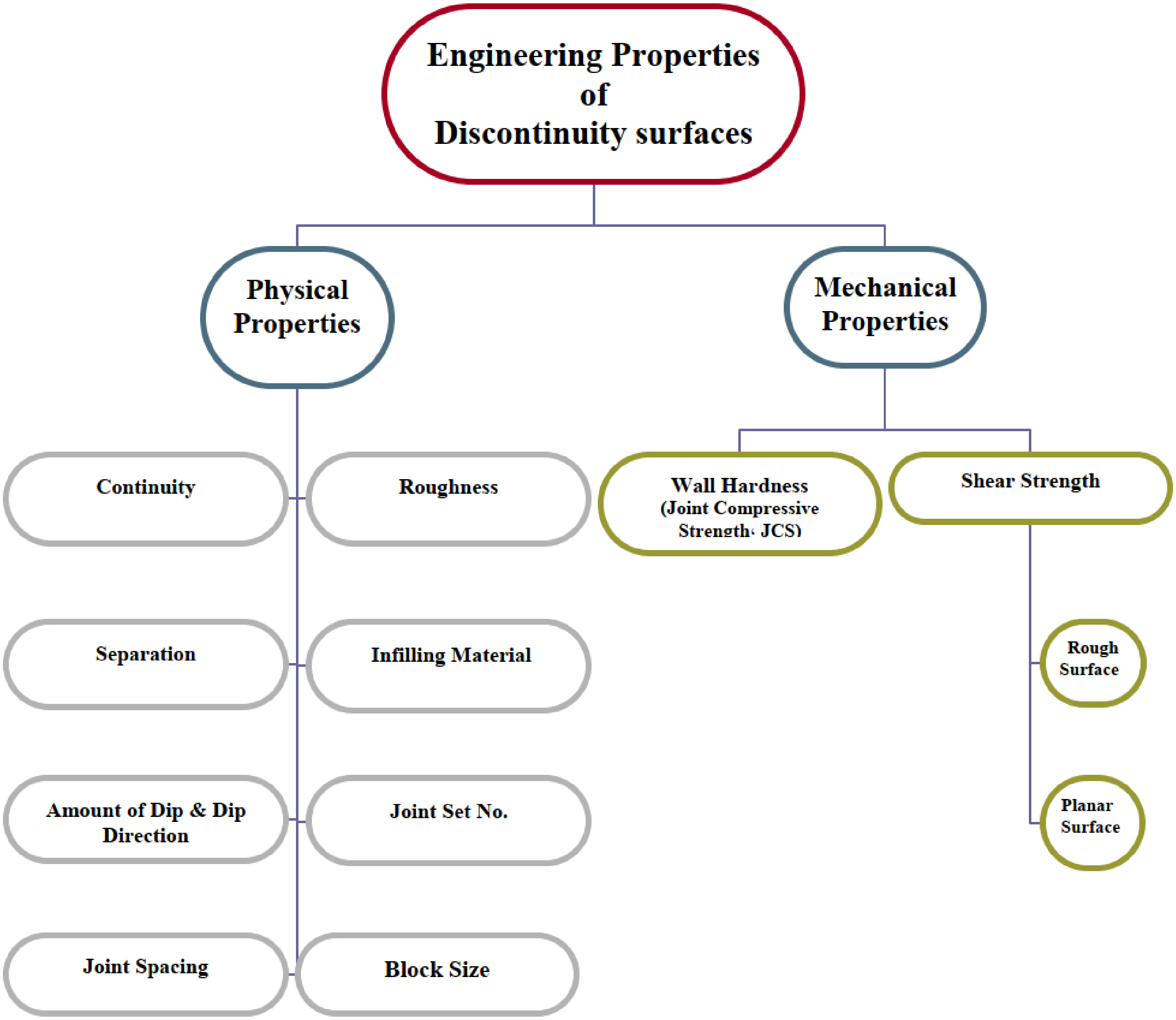


Engineering classification of intact rock (Turk and Dearman, 1983) (W: weak; MS: moderately strong; S: strong; VS: very strong; ES: extremely strong; ED: extremely deformable; VD: very deformable; MD: moderately deformable; SD: slightly deformable; VSD: very slightly deformable.

Engineering Properties for discontinuity surfaces

Engineering Properties for discontinuity surfaces divided into:

1- Physical properties
2- Mechanical properties

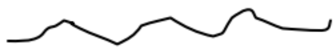


A-Physical Properties for discontinuity surfaces

1- Roughness
2- Continuity
3- Separation (Aperture)
4- Infilling materials
5- Amount of Dip & Dip Direction
6- Joint Set No.
7- Joint Spacing or Fracture Intercept
8- Block Size

1- **Roughness:** the shape of discontinuity surface measured with **Profile Roughness gauge**. Its description depends on the origin of discontinuity surface, is it formed by **tension** or **shear** or **compression** action. There are originally three types:

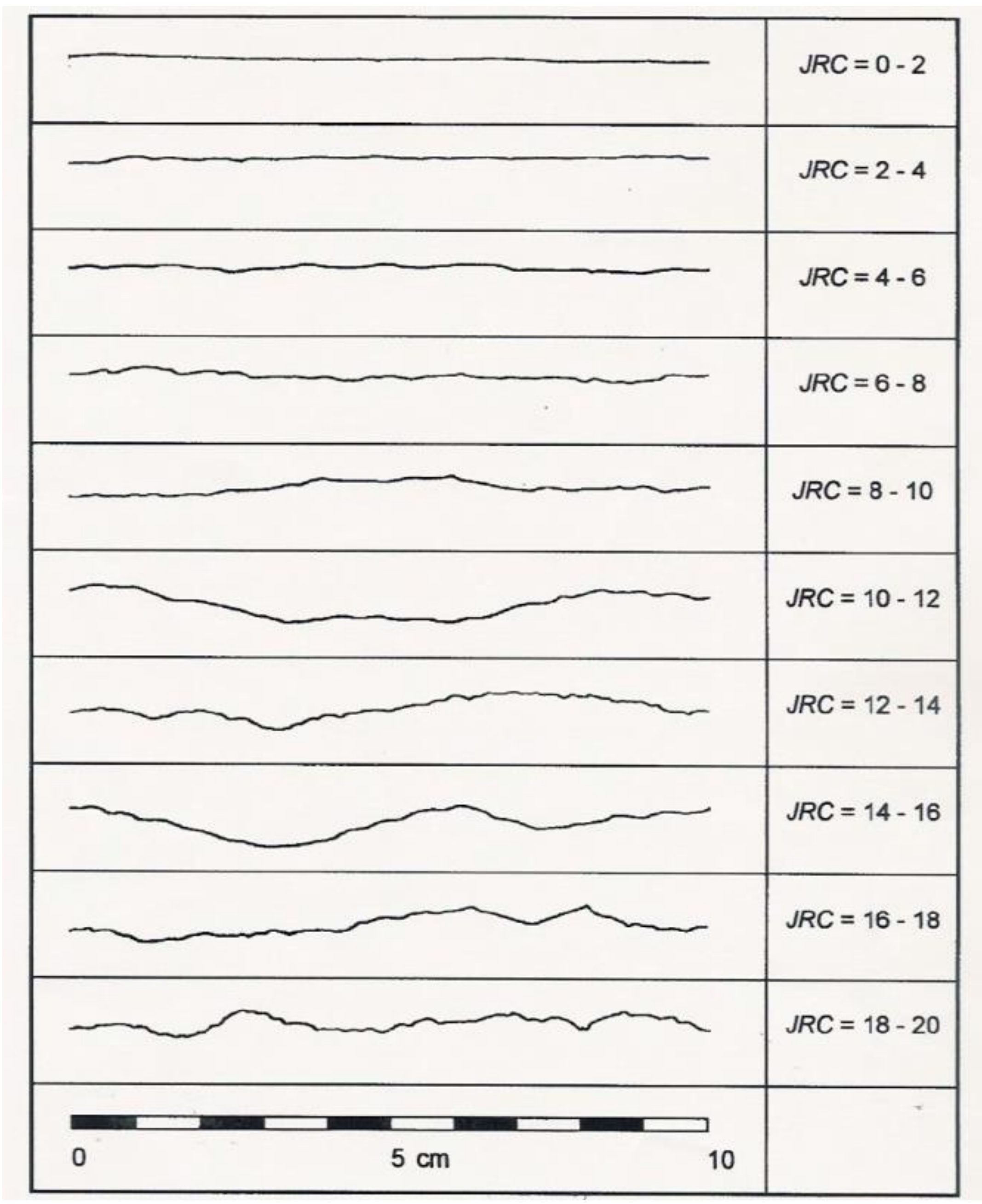
1- Smooth

2- Very Rough 

3- Rough 

As more the surface is rough its strength for slipping increases.

Roughness Types



Roughness profiles and corresponding JRC values (After Barton and Choubey,1977)

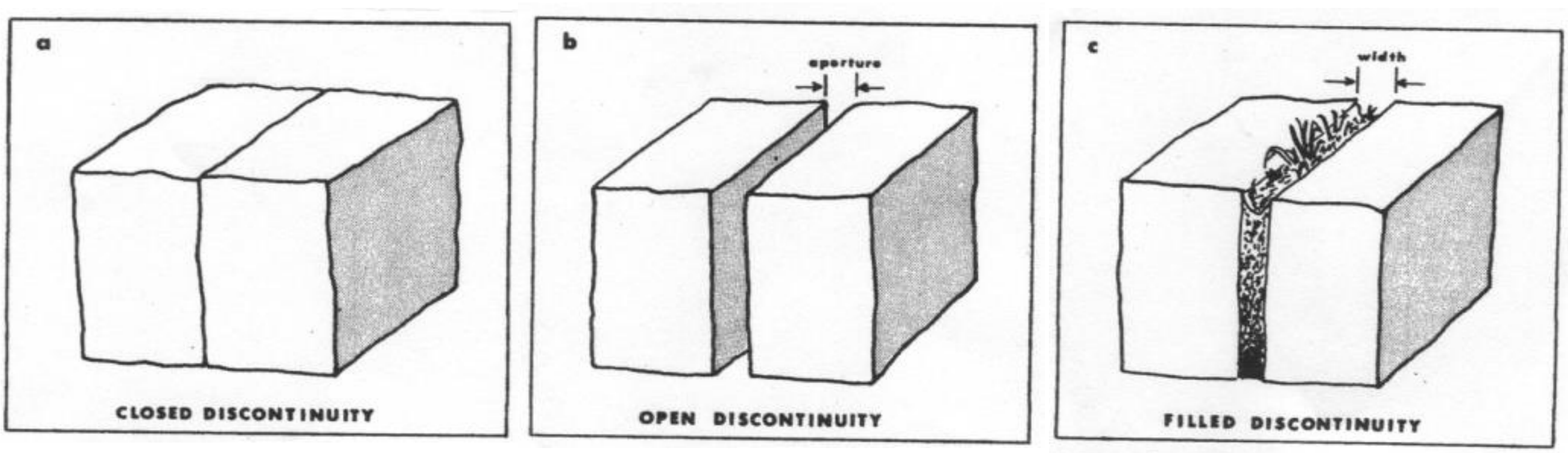
2- **Continuity:** deepening of crack surface in the rock mass. Deepening increase weakens the rock mass and increases its permeability and consequently increases the effect of weathering and roughness.

3- **Separation (Aperture):** the magnitude of separation of a rock piece from a neighbored one and measured in millimeter unit (mm). The limits are described in the table below:

Aperture of discontinuity surfaces (After Geological Society of London 1977)

Aperture	**Term**
>200 mm	Wide
60 – 200 mm	Moderately wide
30 – 60 mm	Moderately narrow
6 – 20 mm	Narrow
2 – 6 mm	Very narrow
0 – 2 mm	Extremely narrow
< 2 mm	Tight

As the separation increase as the rock mass will crash.



4- **Infilling materials:** materials filling the separation between the two rock pieces. They composed mostly of the following clastic materials: sand, silt or clay according to the mineral composition of the rock mass, its weathered amount and decomposition of the overlying layer. As the infilling materials are coarse the resistance parameter of the rock for sliding increases.

5- **Amount of Dip & Dip Direction:** measured with Clar Compass as illustrated below, where the Compass measures the dip amount and dip direction of the surface immediately. It is required to measure more than 100 readings for crack surfaces in the rock mass.

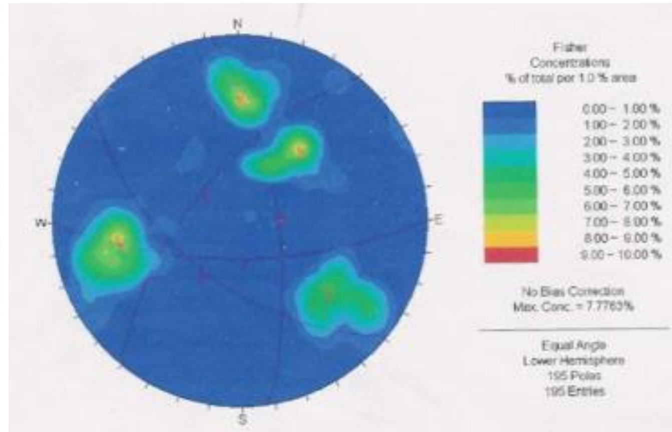
6- **Joint Set No.:** can be identified throughout projecting the measured readings (in previous paragraph) onto Schmidt Net, the set groups appear in green and yellow as illustrated in the figure below. The figure shows four sets of cracks in the rock mass, their dip amounts and directions are concentrated in yellow color. The average value of each set is calculated arithmetically as well.

Gekom - Small Stratum Compass

Cocla – Geological Stratum compass

Tectronic 4000 – Geological data collector

Figure 1.4: Geological compasses manufactured by F.W. Breihapt & Sohn, P.O. Box 10 05 69, D-3500 Kassel. W. Germany.



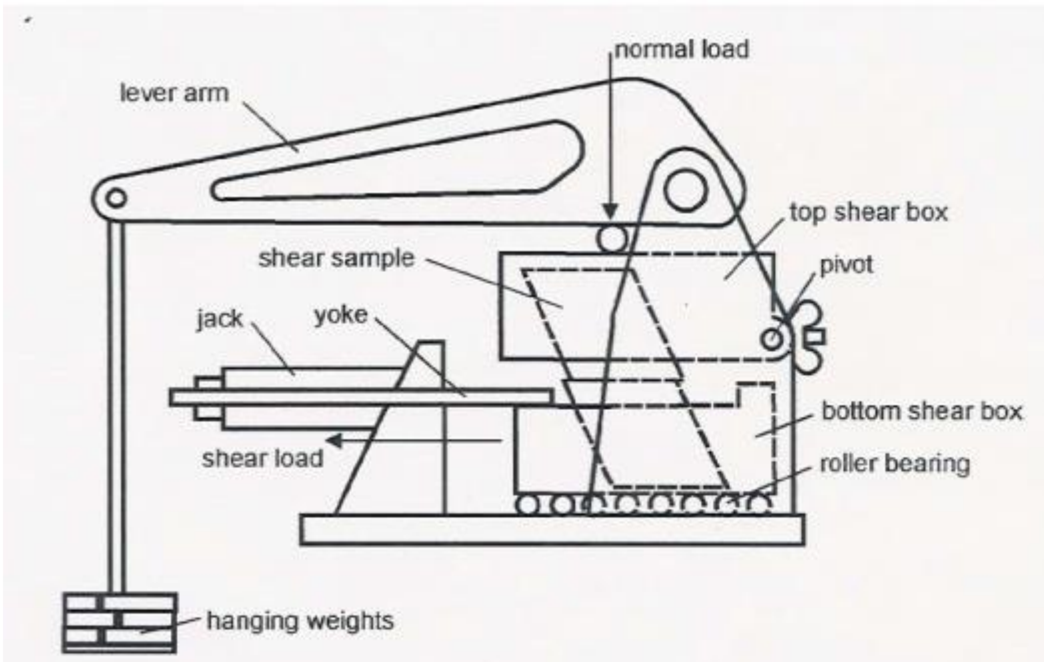
7- **Joint Spacing or Fracture Intercept:** the distance in centimeters between two successive cracks of the same set. Joint spacing is the distance between joints without regard to irregular fractures. Whereas the measured distances between irregular fractures are called Fracture Intercept.

8- **Block size:** measuring the dimensions of the rock mass (block) in three directions which related with the distances between cracks

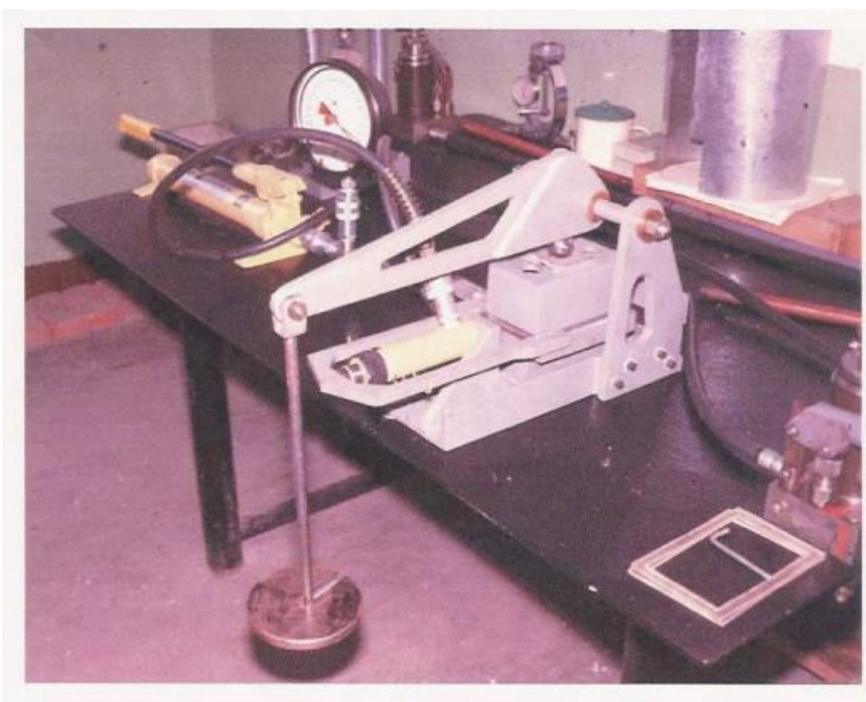
B. Mechanical Properties for discontinuity surfaces

Mechanical Properties of discontinuity surfaces can be expressed by two characteristics:

1- **Joint Wall Hardness: Schmidt Hammer Test** gives indirect value for joint surface strength.
2- **Shear Strength of Discontinuity surfaces:** friction value for crack surfaces can be determined by two characteristics: **Cohesion** (**C**) of the surface and **Friction Angle** (**φ**) between the two surfaces. These two characteristics can be specified with **Direct Shear Test**.



Diagrammatic section through shear machine by Hencher and Richards (1982)



Shear machine of the type used by Hencher and Richards (1982) for measurement of the shear strength of sheet joints in Hong Kong granite.

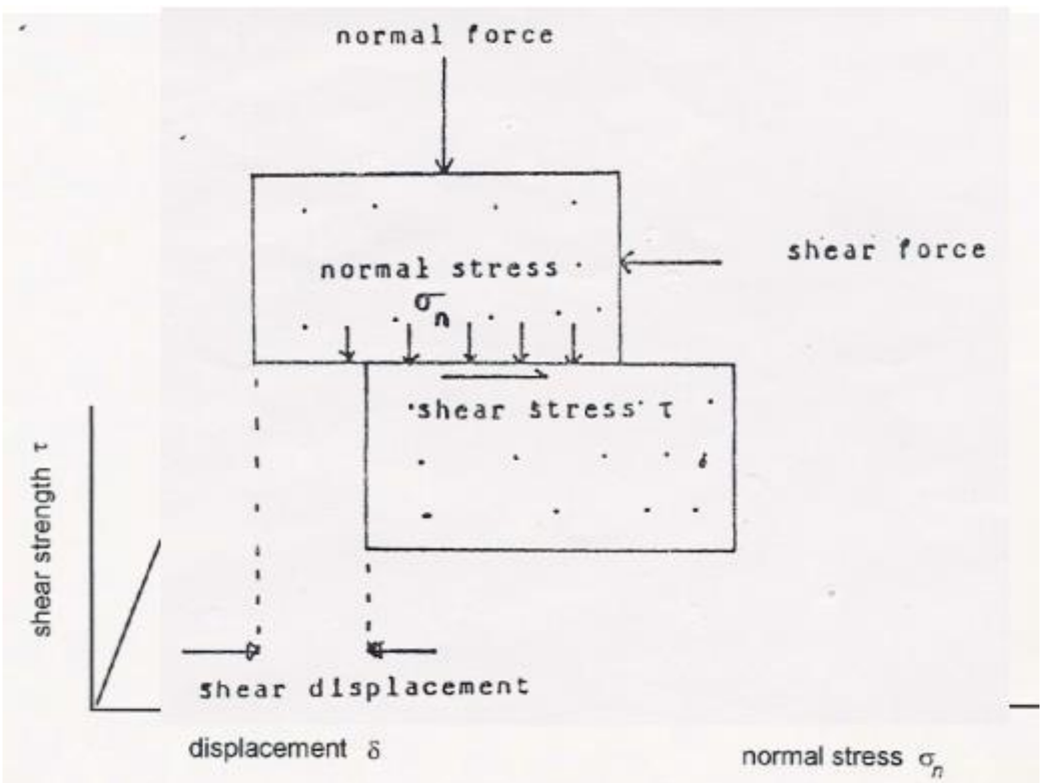
The friction strength value of the discontinuity surface is computed by the following general formula:

$$\tau = C + \sigma_n * \tan(\varphi)$$

To compute friction value, the following parameters must be known:

1. **C (Cohesion)**
2. **φ (Friction Angle)**
3. **σ_n (Normal Stress)**

Five tests must be executed on the same surface with different normal stress (**σ_n**) values and measuring the displacement with the pressure. The linear relation between **σ_n** and **τ** is plotted to find shear strength parameters (**C** & **φ**) and to calculate friction strength **τ** from aforementioned formula with known normal stress (**σ_n**).



Shear testing of discontinuities

To find Shear Strength Parameters (**C** & **φ**) for crack surfaces, there are two types of surfaces:

1- **Smooth Surface:** there is no cohesion, **C**=Zero. Whereas the friction angle between surfaces is called (**φ_b** basic).

The value of shear strength for smooth surface is computed using the following formula:

$$\tau_b = \sigma_n * \tan(\varphi_b)$$

2- Rough Surface: at beginning there is no Cohesion, **C**=Zero because the pressure on the surface is low. Whereas the friction angle between the surfaces is high and denoted φ_p Peak due to ascending of the ripples over each other.

The strength value of rippled surface for friction with low overhead pressure, can be computed using the following formula:

$$\tau_p = \sigma_n * \tan(\varphi_p)$$

$$\tau_p = \sigma_n * \tan(\varphi_b + i)$$

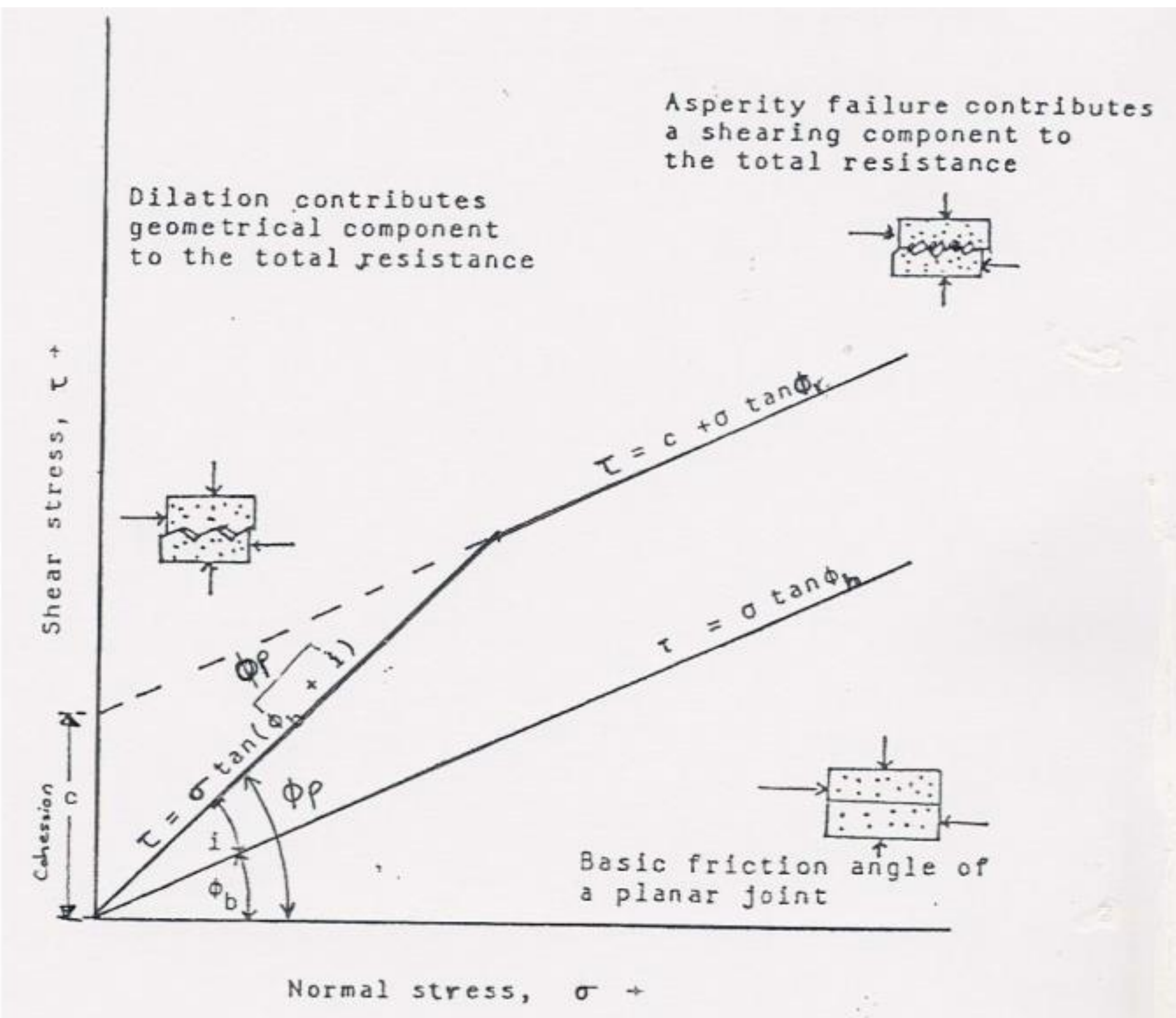
Where φ_p Peak equals the original planar surface friction angle φ_b basic plus the rippled surface angle (**i**)

If the overhead pressure on the surface is large, the friction of the original rippled surface will increase and with time the rippled surface of the specimen becomes planar, and results Cohesion, **C** between the two surfaces.

The friction angle between the two surfaces is called φ_r residual, because during the test the teeth of the rippled surface have broken and the originally rough surface of the specimen has been smoothed. Thus the φ_r residual values equals the φ_b basic values.

The strength value of the rippled and then smoothed surface for friction with large overhead pressure can be computed using the formula below:

$$\tau_r = c + \sigma_n * \tan(\varphi_r)$$



C.Classification Systems of Discontinuity Surfaces

RQD - System

Rock Quality Designation, RQD (1964)

Js, FI

Joint Spacing

(Fracture Intercept)

1- Joint Spacing, (Js) OR Fracture Intercept, (FI):

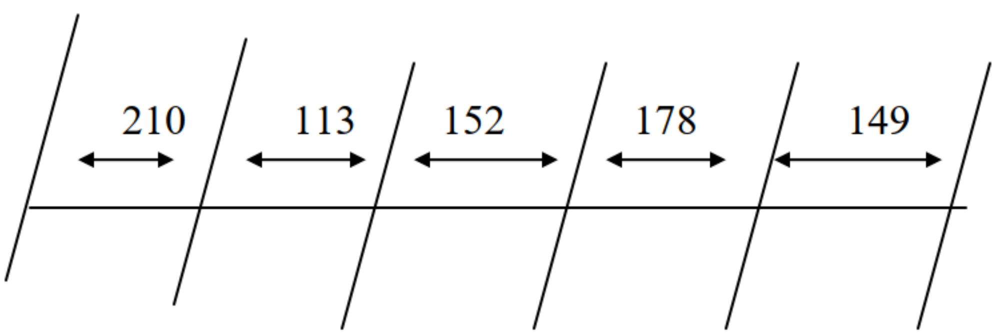
Joint System: nearly parallel system with approximately same distances between individual joints and nearly with the same dip amount and direction.

The practical method to compute **Js**, **FI** is **Scan-Line.**

Descriptive terms for joints spacing (After Geological Society of London, 1977)

Intervals (cm)	Symbols	Description
>200	F_1	Extremely wide spaced
60 – 200	F_2	Widely spaced
20 – 60	F_3	Moderately wide spaced
6 – 20	F_4	Closely spaced
2 – 6	F_5	Very closely spaced
< 2	F_6	Extremely closed spaced

Example:



There are two methods to compute **Joint Spacing:**

1- $Av.J.s = \frac{distance\ between\ joints}{number\ of\ specimens\ between\ joints}$

2- $Av.J.s = \frac{length\ of\ scan\ line}{number\ of\ \ joints}$

Solution:

First method:

$$Av.J.s = \frac{149+178+152+113+210}{5} = \frac{802}{5}$$

$\therefore$ Av. J.s = 160.4 cm

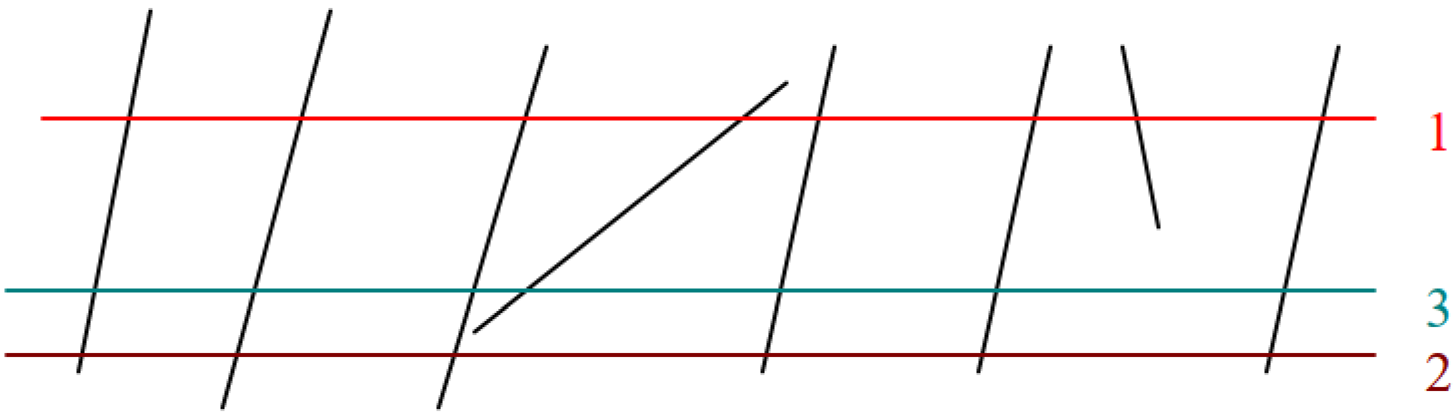
Second method:

$$Av.J.s = \frac{800}{5} = 160\ cm$$

Classification: according the previous table, these joints classified as Widely spaced (F_2).

Computing Fracture Intercept:

Compute Fracture Intercept for **8** meter if:



1. $Av.FI = \frac{800}{8} = 100\ cm$
2. $Av.FI = \frac{800}{6} = 133.3\ cm$
3. $Av.FI = \frac{800}{7} = 114.3\ cm$

$$\therefore Av.FI = \frac{100+133.3+114.3}{3} = 115.87\ cm$$

Classification: according the previous table, these joints classified as Widely spaced (F_2).

2- RQD-System

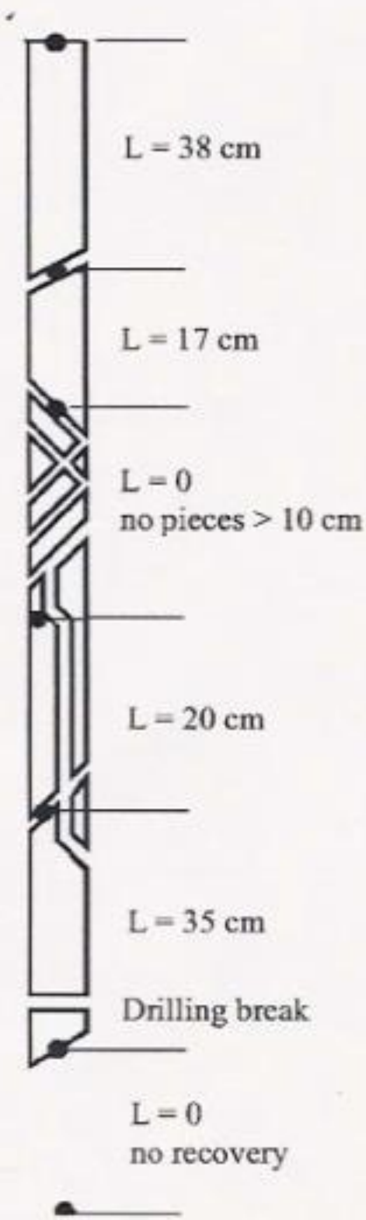
By Deere and Miller (1964)

2-1 Computing RQD value using the Formula below:

$$\boxed{\boldsymbol{RQD}\ (\%) = \frac{\sum Samples \geq 10cm, \geq 4inch}{TotalRun}}$$

Descriptive terms for Rock Quality Designation (After Deere and Miller, 1966)

Descriptive Term	RQD %	Symbols
Very Good	90 – 100	R_1
Good	75 – 90	R_2
Fair	50 – 75	R_3
Poor	25 – 50	R_4
Very Poor	<25	R_5



Total length of core run = 200 cms

$$RQD = \frac{\Sigma \text{ Length of core pieces} > 10 \text{ cm length}}{\text{Total length of core run}} \times 100$$

$$RQD = \frac{38 + 17 + 20 + 35}{200} \times 100 = 55\ \%$$

Example:

Total Run 300 cm

Total Sum of solid samples:

18, 32, 8, 22, 54, 10, 9, 4, 40, 14, 50, 26, 12 cm = 299 cm

$$\therefore Tcr = \frac{299}{300} * 100 = 99.7\%$$

$$RQD = \frac{278}{300} * 100 = 93\%$$

2-2 At mountainous areas, **Palmstrom (1982)** introduced the equation below to compute **RQD**:

$$\boxed{\boldsymbol{RQD = 115 - 3.3 * (J_v)}}$$

J_v (Volumetric Joints) = No. of Joints in $1m^3$

Table Block size expressed in terms of **J_v** (Joints/m^3) (After Barton, 1978)

J_v (Joints/m^3)	**Descriptive Terms**
< 1	Very Large Blocks
1-3	Large Blocks
3-10	Medium-sized Blocks
10-30	Small Blocks
> 30	Very Small Blocks

Example:

Calculate **RQD** value for 12 joints in a sector of 4 m length.

$\boxed{\mathbf{RQD = 115 - 3.3\ (J_v)}}$

Face 1 = 12 Joints/4m = 3 Joints/1m

Face 2 = 3 Joints/1m

Face 3 = 3 Joints/ 1m

$\therefore J_v = 3+3+3 = 9$ Joints/ $1m^3$

RQD = 115 –3.3 (9)

RQD = 115 – 29.7

RQD = 85 %

Class: (R2) Good Quality

RQD calculation from Joint Spacing, (**J_s**) & **Fracture Intercept**, (**FI**)

Example:

Calculate RQD value with classification for all the following data:

The first face of Granitic rock masses:

First face: 25 joints in 5m

Second face: **J. S** = 25cm

Third face: **FI** = 20cm

Solution:

RQD = 115 – 3.3 (J_v)

∴ Face 1 = 25 Joints/ 5m = 5 Joints/1m

Face 2 = 25 cm $\Longrightarrow$ 4 Joints/ 1m

Face 3 = 20 cm $\Longrightarrow$ 5 Joints/ 1m

∴ J_v= 5+4+5 = 14 Joints/1m^3

RQD = 115 – 3.3 (14) = 69 %

The rock mass of Granite has a **fair quality (R3)** according to **RQD** system by Palmstrom (1982) and the fracture is **moderately wide to closely spaced (F3 – F4)** according to Geological Society (1977) and has a **small blocks** based on **Jv system** according to Barton (1978).