Engineering Geology

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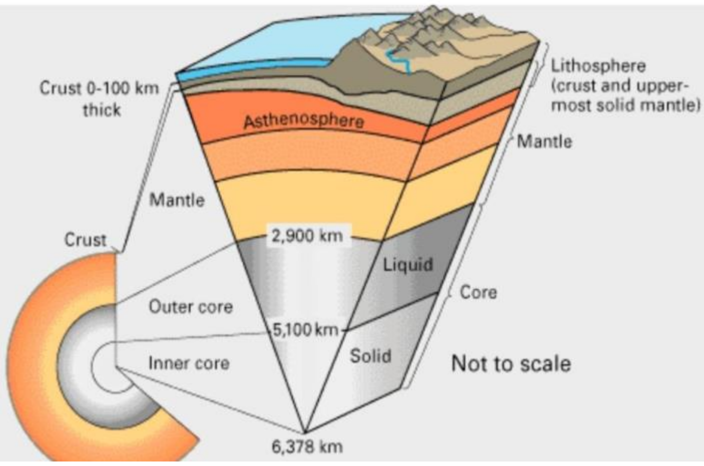
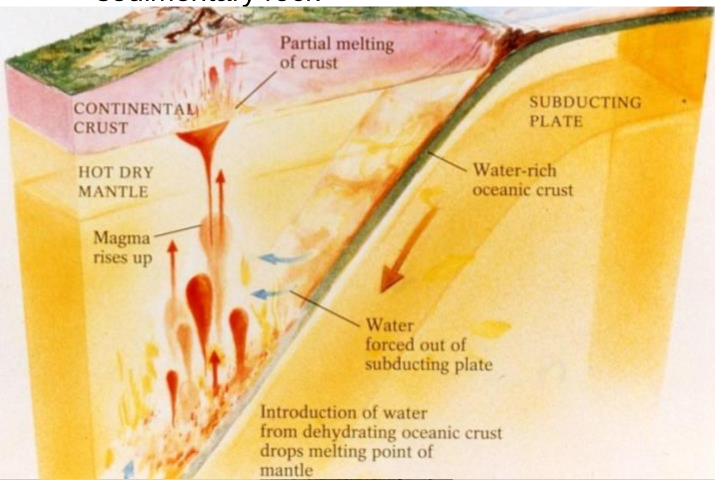
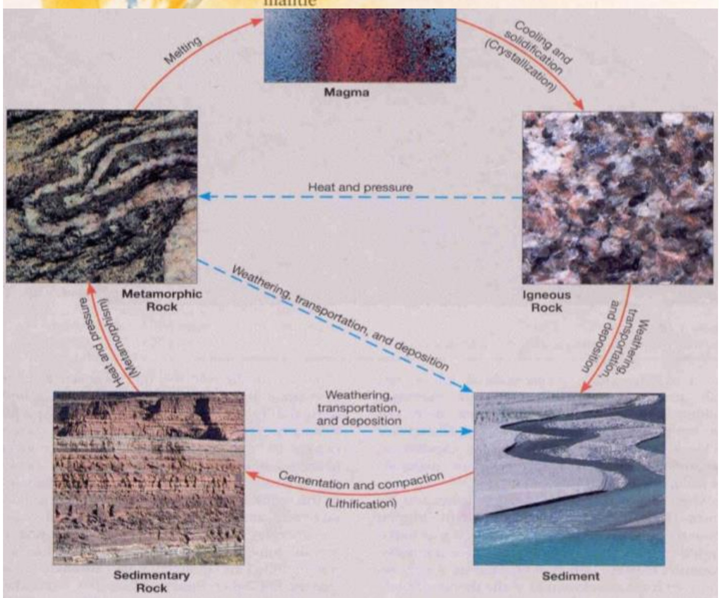
INTRODUCTION & REVIEW

- **Earth composition**: minerals & rocks
  - Rocks are formed of minerals
  - **Minerals**: natural & solid substance with certain chemical composition & physical properties, & Aggregates of minerals form the rocks



- **Earth interior processes**:
  1. **Formation of igneous rocks**: Intrusive (Plutonic) & Extrusive (Volcanic)
  2. **Plate tectonics** (general idea)
  3. **Exterior or surface processes**: weathering, erosion, mass wasting, sedimentation, soil, sedimentary rock





- **Civil engineering applications:**
  1. importance of geology in engineering
  2. factor controlling engineering property of rocks
  3. geological maps in civil engineering

IGNEOUS ROCKS

- **Igneous rocks**: formed when molten rock (magma) solidifies & classified as intrusive & extrusive

	Intrusive	Extrusive
Formation	beneath the earth's surface	at the earth's surface (Lava flow)
Texture	Coarse grained	Fine grained
Rate of cooling	slow	Fast

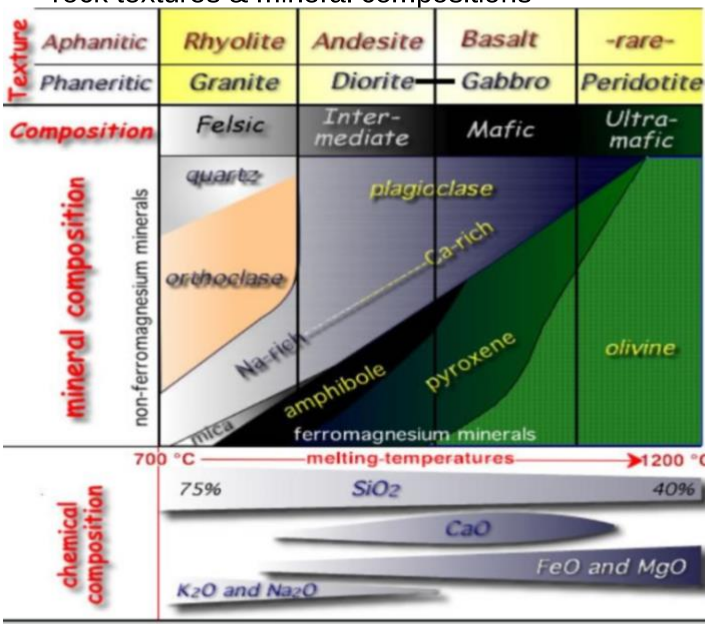
- **Magmas are developed** within the Earth's crust or beneath the Earth's crust (mantle)

Bowen's Reaction Series & Chemical Weathering

الكوارتز هو اكثر المعادن استقرارا لانه نشأ في بيئة قريبة من البيئة السائدة على سطح الارض (لانه اخر المعادن التي تكونت) واقصد بالبيئة الظروف الفيزيائية

Texture: controlled by the rate of crystallisation (cooling)	
Phaneritic	**Coarse**: visible grains, slow cooling
Aphanitic	**Fine**: grains are not visible, fast cooling
Porphyritic	**Mixed**: coarse grains surrounded by fine grains, slow cooling, & Magma erupted to surface suffering fast cooling
Vesicular	**Voided**: fine grained with vesicles formed by gas bubbles at the top of a lava flow
Glassy	**extra-fine**: due to rapid cooling

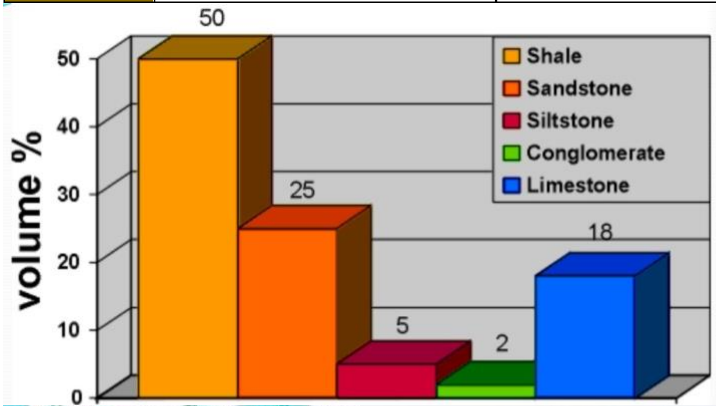
- **Identification of Igneous Rocks are based on:** rock textures & mineral compositions



SEDIMENTARY ROCKS

- **Sedimentary rocks**: formed by sediments, through lithification (commonly compaction & cementation

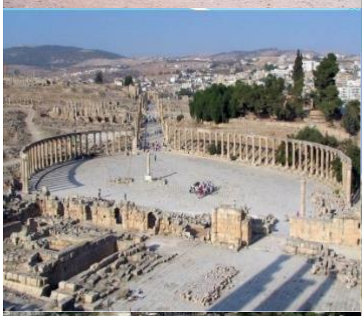
Divided into 2 groups: detrital (clastic) & chemical	
Detrital	Sediments are transported as solid particles
Chemical	Sediment dissolved & transported as solution

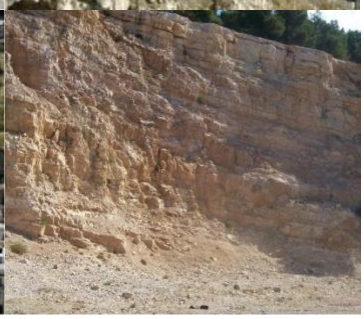










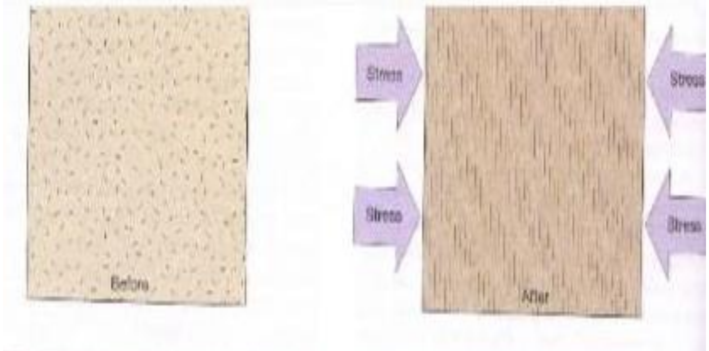



Sandstone is strong enough to hold a structure & weak enough to excavate

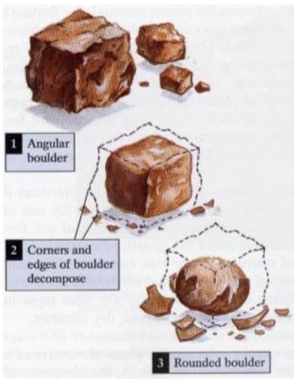
METAMORPHIC ROCKS

- **Metamorphism**: transformation of pre-existing rocks by heat, pressure, & chemically active fluids, & All types of rocks can undergo metamorphism
  - **Heat**: led to re-crystallisation
  - **Pressure**: led to re-orientation of crystals
  - **Chemicals**: led to chemical reaction

Classification of metamorphic rocks	
Regional	large scale, involving heat & pressure
Contact	Localized "baking" by igneous intrusion
Classification of metamorphic rocks textures	
Foliated	layered (banded) by mineral alignment
Non-foliated	Do not have foliated texture

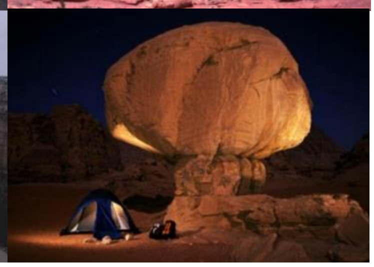


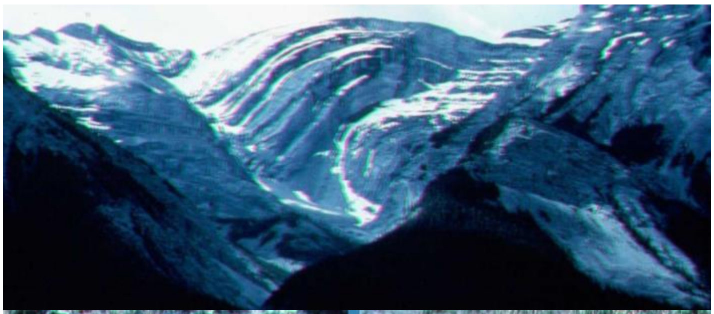
WEATHERING

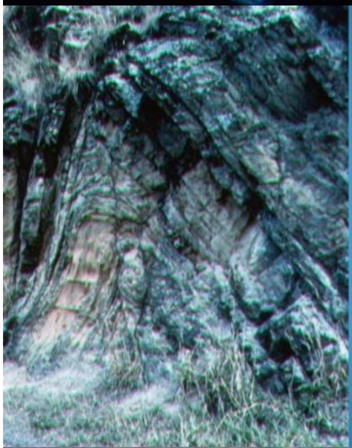


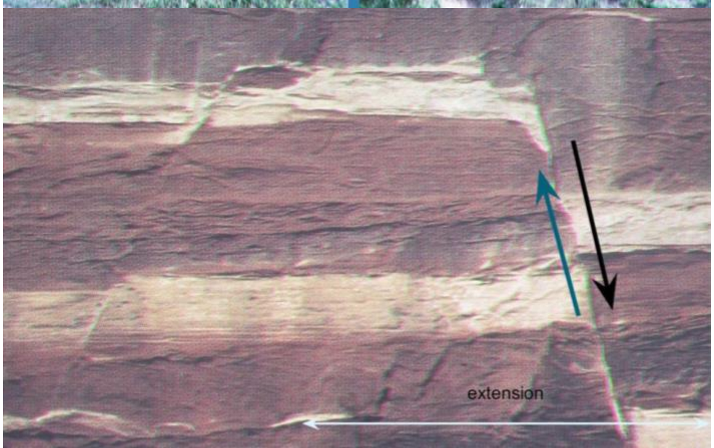


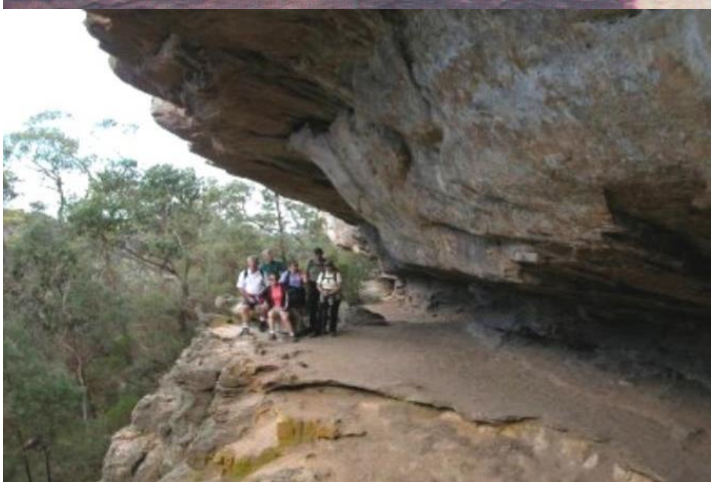


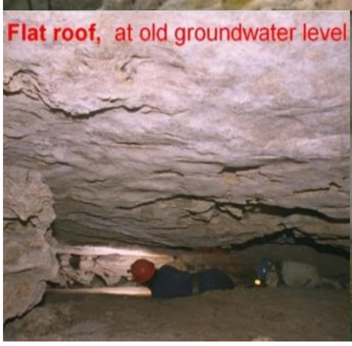












ENGINEERING APPLICATIONS

<table>
<tr><th colspan="2">Factors that controls engineering properties of rocks</th></tr>
<tr><td>Composition</td><td>High-strength mineral grains produce a higher-strength rock
Strong rock: Rocks composed of hard, stable, & strong minerals
<table>
<tr><td>Hard mineral</td><td>Qz, Fs, Amp</td></tr>
<tr><td>Medium hardness</td><td>Dol, Cal</td></tr>
<tr><td>Soft mineral</td><td>Gyp,Clay,Halide,Mica</td></tr>
</table></td></tr>
<tr><td>Rock texture</td><td>size, shape & interlocking or packing
Sorting & Rounding α^{-1} rock strength
Dense grain packing α rock strength
Dense grain packing α^{-1} total strain
<table>
<tr><td>Sed.</td><td>Most effective</td></tr>
<tr><td>Ign.</td><td>Fine Texture: Smaller interlocked crystal provides higher strength
Vesicles texture: more influential, weaker than granites or gabbros</td></tr>
<tr><td>Meta</td><td>Foliation texture: reduce strength (weak), like slate & schist
Gneiss is an exclusion</td></tr>
</table></td></tr>
<tr><td>Discontinuity</td><td>rock spacing, joint, crack, cave, fault, pores or vesicles, layering, foliation
<table>
<tr><th>Rock</th><th>Source of weakness</th></tr>
<tr><td>Sedimentary</td><td>Faults, Joints, & Layering</td></tr>
<tr><td>Igneous</td><td>Cracking</td></tr>
<tr><td>Limestone</td><td>Caving or Karstification</td></tr>
<tr><td>metamorphic</td><td>Foliation</td></tr>
</table></td></tr>
<tr><td>Weathering Degree</td><td>Physical, Chemical, & Biological disintegration or decomposition of rocks influences the strength of rocks
e.g. granite is very strong rock but weathering transfers it to a very weak
Strength reduction depends on the degree of weathering: Slightly, Intermediately, or Highly weathered</td></tr>
</table>

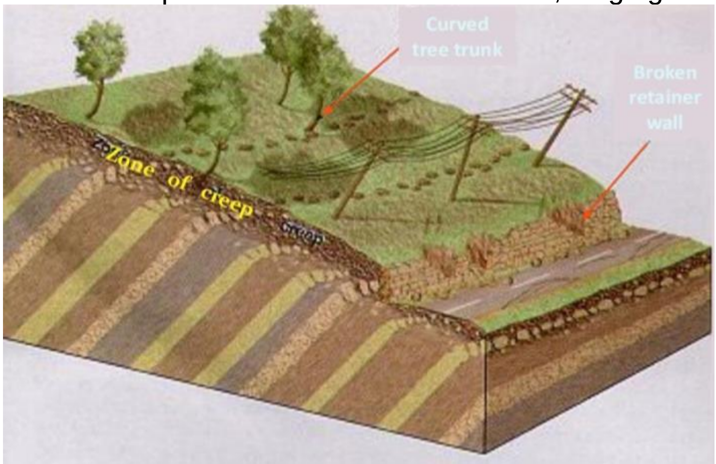
Ep = f (C, T, D, W)

Ep: Engineering Properties, f: Function, (C, T, D, W): Factors

- **Coral or algal reefs & masses**: medium to high strength, depending on the properties of the mass
- **Very fine-grained chemical limestone:** have high to very high strengths
- **The chemistry & mineralogy of evaporates** indicate that they are low-strength materials
  - ➢ **Evaporates**: lack voids & have initial elastic phase of very limited range
  - ➢ Low strength & creep property of evaporate minerals produce extended plastic phase prior to failure
- **In clastic limestone** the strength is controlled by the strength of the limestone particles (fossils or broken aggregates of other limestone bodies)
- **Rock Strength decrease by:**
  1. Dissolution of the rock mass that produces cavities & zones of weakness
  2. Densification on loading or Preferential orientation of crystal lattice forms plastic phase
  3. Densification upon loading vesicular or porous produces early plastic deformation
  4. Grain interlocking produces elastic deformation
- **Rock Strength increases by:**
  1. Void filling (decreases sorting) & cementation
  2. As crystals or grain size decreases
  3. High-strength cements produce higher-strength rocks

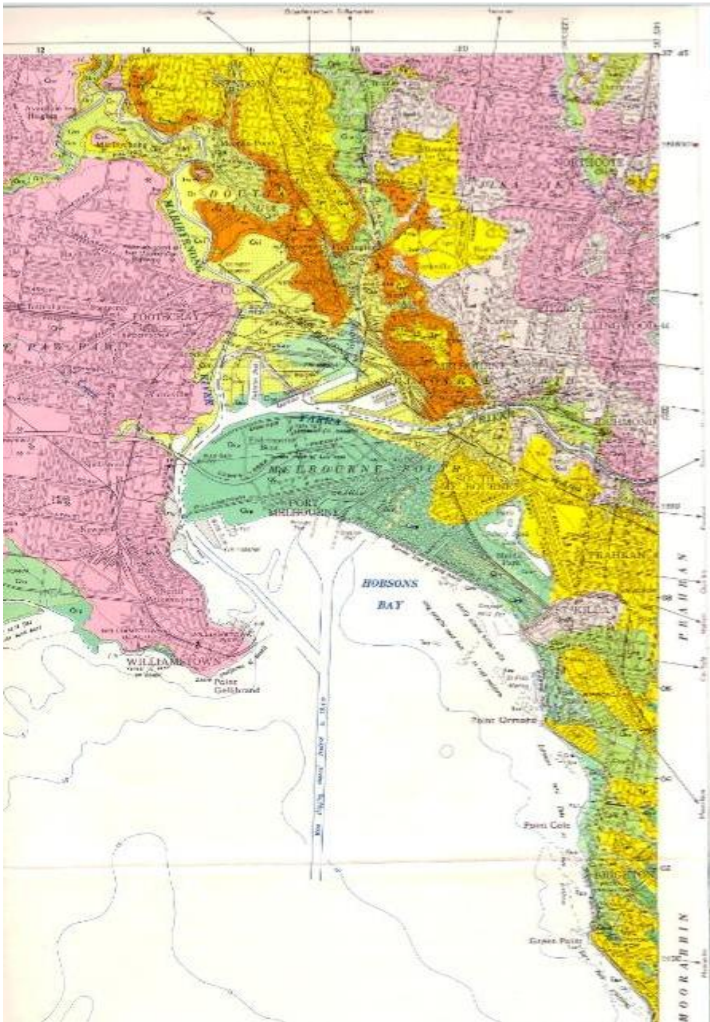
LANDSLIDES

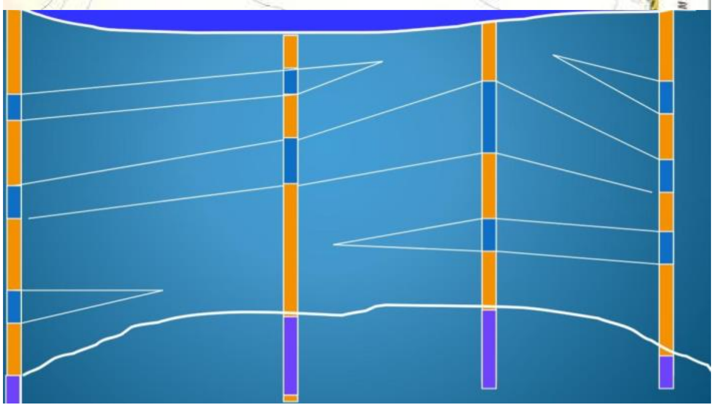
- **Landslides**: mass of material that maintains coherence while moving along slide plane
- **Slide Planes:** often arc shaped
  1. joint or bedding planes in solid rock
  2. clay layer or water saturated soil
- **Slump:** material coherence lost near toe, moves as a flow & produces arcuate scar at head, bulging toe



GEOLOGICAL MAPS

- **Kay Words**: Plan or Cross-sectional view, Rock Type, Scales, Location (relative to most significant feature in the area), Date, Publisher, Projection System, Ages, Groups, Formations, Symbol, Color, Unconformity, Topography (Contour), Water courses, Man-made features & N-points
- **Geological information on the maps**
  1. **Materials**: Boundary of rock types at the earth's surface, dykes, sills…etc
  2. **Structure**: fault, bedding plane, joint, fold…etc
  3. Geological maps are an essential aid to the planning of Civil Engineering projects.
- **Importance of maps in engineering applications**
  1. Understand the geological setting
  2. Plan for further investigation work to obtain maximum information at minimum cost





Geological Model

SOIL MECHANICS

- **Definitions of a soil**
  - **H.Jenny**: Soil is a function of climate, organism, relief (landscape), parent material, & time
  - **Ollier & Pain**: Regolith is all surficial materials above fresh bedrock
  - **Pedologically**: soil profile & soil horizons, soil physics, soil chemistry, soil biology
  - **In Agriculture**: soil as a resource, soil fertility, soil health, & topsoil, & subsoil
  - **Geomorphology**: series, transported, residual
  - **In Engineering:** is a natural aggregate of mineral grains that can be separated by such gentle mechanical means as agitation in water.
- **Engineering Rock**: natural aggregation of mineral connected by strong & permanent cohesive forces
  - The boundary between rock & soil in engineering is necessarily an arbitrary one

	Elasticity	Strength	Compaction	Forms
Soil	Inelastic	Low	Loose	Aggregated
Rock	elastic	High	Compact	Solid

- **Mechanical properties of soil controlled by:** Mineralogy, Particle Size & Shape, Fabric, & Moisture (water) & Organic Content

Soil mineralogy: clay minerals have the most influence	
Kaolonite	1:1, Low CEC, water absorption, & Plasticity
Illite	2:1, Intermediate CEC, absorption, plasticity
Montmo-rillonite	2:1 sheets, High CEC, High water absorption, & High plasticity

The ratio is for (silica:gibbsite), & CEC: cation elastic capacity

SOIL CLASSIFICATION

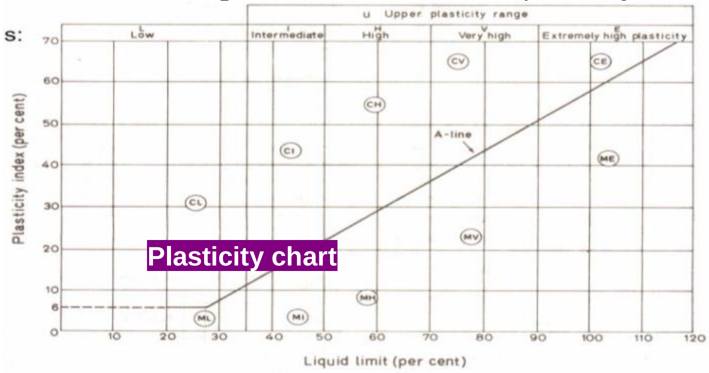
Classification of soil based on their origin	
Residual	Formed by weathering of underlying rock
Transported	Transported from their place of origin

Classification of soil based on their particle size					
Boulder		>200mm	Silt		60-2μm
Cobble		60-200mm	Clay		<2μm
Gravel 2-60m	C	20-60mm	Sand 2m-60μ	C	2mm-600μm
	M	6-20mm		M	600-200μm
	F	2-6mm		F	200-60μm

- **International unified soil classification (USC)**: developed for use in airfield & dam constructions, provides a common terminology for soils based on their mechanical behaviour
  - **The primary division is made between:**
    1. **Coarse grained:** >50% of soil is >75μm
    2. **Fine grained:** >50% of soil is <75 μm

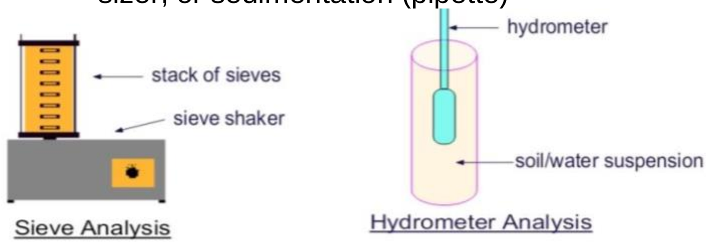
Component	Qualifier	Com.	Qualifier
Gravel (G)	Well-graded(W)	Sand(S)	Poor-graded(P)
Organic (O)	Low-plasticity(L)	Clay (C)	Clayey (C)
Peat (Pt)	Highplasticity(H)	Silt (M)	Silty (M)

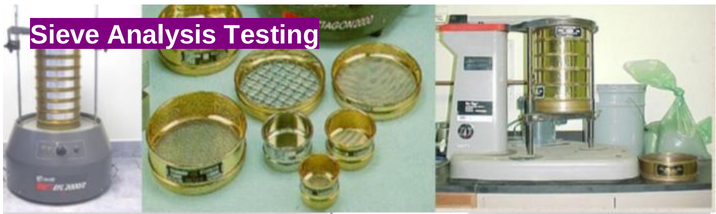
  - **For coarse grained soils**:
    1. **If ≤5% is <75 μm:** GW, GP or SW, SP
    2. **If 5%<75μm≤12%:** dual classification
    3. **If > 12%<75μm**: GM, GC or SM, SC
  - **For fine grained soils**: Use the plasticity chart

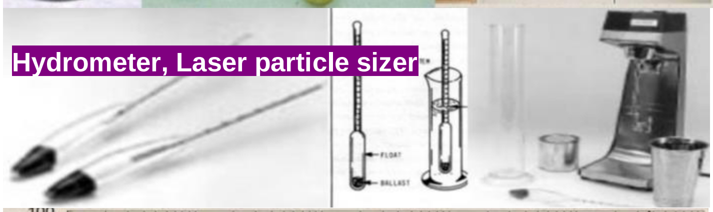


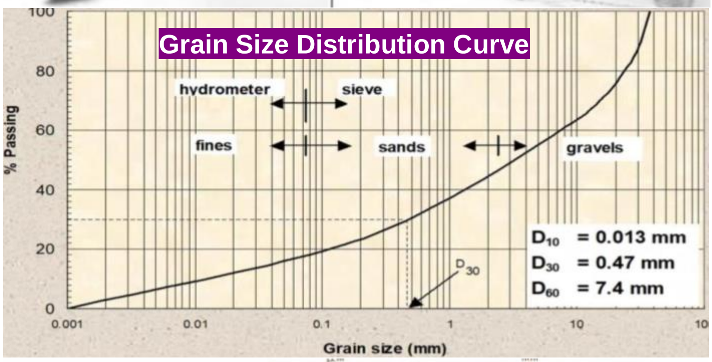
PARTICLE SIZE DISTRIBUTION

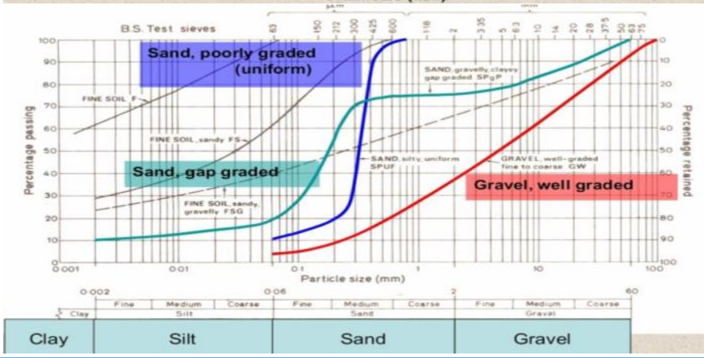
- **Technics to determination the particle size:**
  1. **For coarse grain:** sieve analysis
  2. **For fine grain**: hydrometer analysis, particle sizer, or sedimentation (pipette)











SOIL BEHAVIOR

- **Color**: is unimportant (not mechanical property)
  - Stick to primary colours (red, yellow, grey…)
  - Useful to indicate: Organic & Deleterious matter, Saturation, Filled ground (imported soil)
- **Consistency:** Cohesiveness

Cohesive	Sticks together, contains clay minerals
Non-cohesive	Friable, flows like sand
Apparent	Can stick together when wet

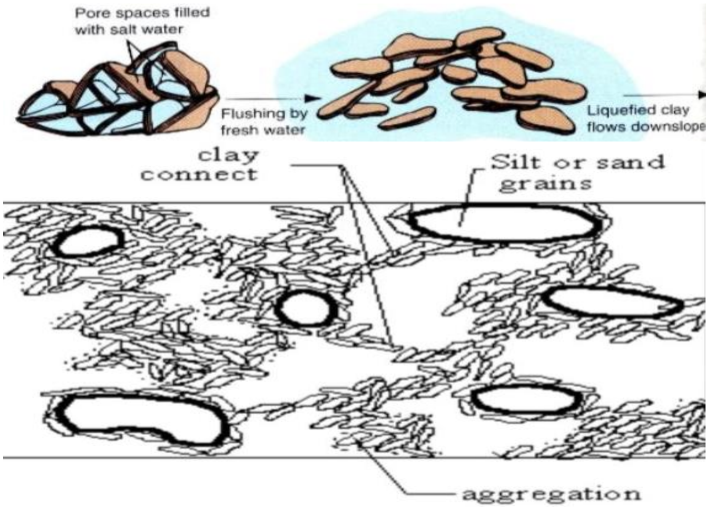
Cohesive soil	UCS	Tactile Test
Very soft (VS)	<25	Easily penetrated 5cm by fist
Soft (S)	25-50	Easily penetrated 5cm by thumb
Firm (F)	50-100	Can be penetrated 5cm by thumb with moderate effort
Stiff (S)	100-200	Readily indented by thumb but penetrated only with great effort
Very Stiff (VS)	200-400	Readily indented by thumb nail
Hard (H)	≥400	Indented with difficulty by thumb

UCS: Unconfined Compressive in kPa

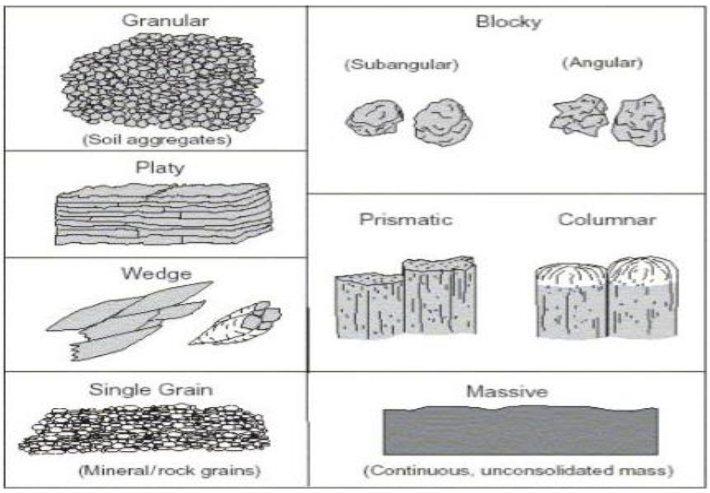
Non-cohesive soils	Relative density (RD%)
Very loose VL	<15
Loose L	15 – 35
Medium dense MD	35 – 65
Dense D	65 – 85
Very dense VD	>85

*__RD%:__ to max dry ρ achieved in a standard soil compaction test

- **Soil Fabric:** card house fabric



- **Soil Structures**:

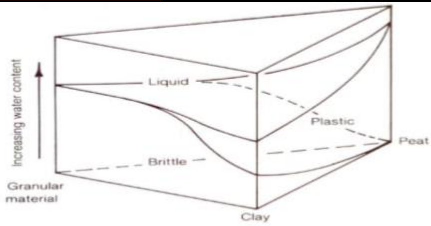


- **Thixotrop:** looses strength under vibration

Sensitivity	UCS in situ
Insensitive	< 2
Medium Sensitive	2 – 4
Sensitive	4 – 8
Very Sensitive	8- 16
Quick	> 16

- **Sensitivity:** Ratio of undrained shear strength of undisturbed soil to the undrained shear strength of remoulded soil at same water content

Soil	Saturation Behavior
Slaking	• the breakdown of aggregates into smaller aggregates or single particles • occur when dry clay soil becomes wet
Dispersive	break down to fine particles & wash away
Moisture	**Tactile**
Dry D	Looks & feels dry
Moist M	Feels & looks moist, but no water on hands
Wet W	Feels & looks wet, free water on hands
Limit	**Consistency indices: Atterberg Limits**
Liquid	Moisture(ω) above liquid behavior
Plastic	ω below which the soil behaving as plastic
Shrink	ω below which no further volume change
Sticky	ω below which soil loos adhesive quality
Cohesive	ω below which particles no stick together



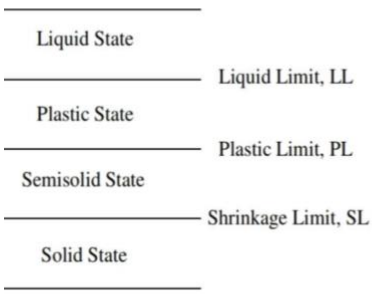
PI = LL - PL

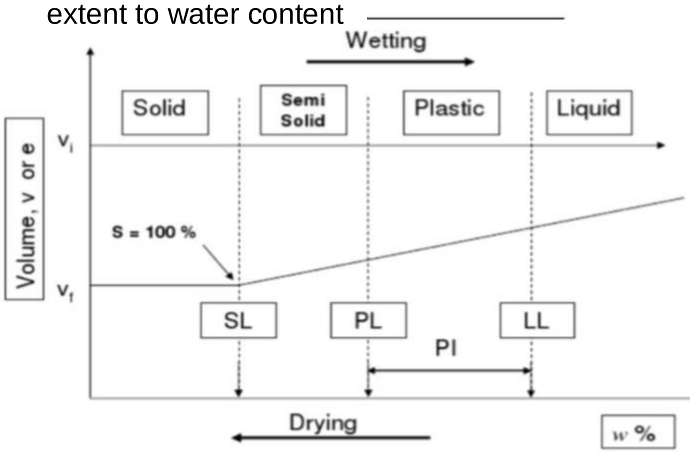
Plasticity index (PI)
Liquid Limit (LL)
Plastic Limit (PL)

Liquid limit testing devices

STATE OF CONSISTENCY

- **Consistency**: relative ease with which soil mass can be deformed & used to describe the degree of firmness of fine-grained soils for which consistency relates to a large extent to water content





- **Volume change accompanying in water content**
  - **Solid state**: no change in volume of soil mass
  - **Other states:** directly proportional
- **Mass of soil behavior under stress**
  - **Liquid state:** behaves like a liquid possessing very less sheer strength
  - **Plastic state** deformed without cracking
  - **Semi-solid state:** deformed with cracking
- **Consistency or Atterbag limits**: water contents, which define the boundary between states

Liquid Limit	water context at which a groove, cut with a standard grooving tool, in soil pat taken in cup of standard liquid limit device closes for a distance 13mm when cup imparted 25 blows • Denoted by WL & is the boundary between plastic & liquid states • It is the minimum water content at which the soil mass still flows like a liquid.
Plastic limit	Is the water context at which the soil mass can be rolled into a threat of 3mm diameter & the thread first shows signs of cracking • denoted by WP & is the boundary between semi-solid & plastic • It is the minimum water content at which the soil mass deformed without cracking
Shrinkage limit	the maximum water content at which there is no reduction in volume of soil mass • denoted by WS & is the boundary between solid & semi-solid

MAJOR EQUATIONS RELATED TO THE SOIL'S PHYSICAL BEHAVIOR

	Mass	Volume
Solid	Ms	Vs
Liquid	Mw	Vw
Air	0	Va
Total	Mt = (Ms+Mw)	Vt =(Vs+Vw+Va)
Void	Mv = Mw	Vv = (Vw + Va)
Saturated	Msat=(Ms+Mw+Va)	V_{sat} = Vt
Dry	Md = Ms	Vd = (Vs + Va)
Wet	Mwet = (Ms + Mw)	Vwet = Vt

- **Specific Volume (V):** the total volume of the soil
- **Bulk density:** $\rho = \frac{M_t}{V_t}$
- **Dry density** when (Sr = 0): $\rho_d = \frac{M_s}{V_t}$
- **Wet density:** $\rho_{wet} = \frac{M_{wet}}{V_t} = \frac{M_s+M_w}{Vt}$
- **Saturated density** (when Sr = 1): $\rho_{sat} = \frac{M_{sat}}{V_{sat}} = \frac{M_s+M_w+V_a}{V_t}$
- **Specific Gravity or Relative Density (Gs)**

$$G_s = \frac{\rho_s}{\rho_{water}} = \rho_{Particle}$$

- **Particle density:** $\rho_p = \frac{M_s}{V_s}$

Materials	Gs	Materials	Gs
Basalt	2.7-3.0	**Kaolinite**	2.4
Silty, Sandy clay	2.75-2.7	**Silt**	2.67
Peat	1.5-2.15	**Quartz**	2.65

- **Porosity:** $n = \frac{V_v}{V_t} = \frac{V_v}{V_t}x100\%$
- **Void Ratio :** $e = \frac{V_v}{V_s}x100\% = \frac{n}{1-n}x100\%$
- **Air content:** $A = \frac{V_a}{V_t}x100\%$
- **Moisture (water content):** $w\% = \frac{W_t-W_s}{W_s} = \frac{M_w}{M_s}x100\%$
- **Degree of Saturation:** $S = \frac{V_w}{V_v}x100\%$
  - If only air is present, the soil is dry: S = 0
  - If the voids are only filled with water: S = 100%
- **Unit weight:** $wighte\ (\gamma) = \frac{W}{V} = \frac{gM}{V}$
- **Dry Unit weight:** $wighte\ (\gamma_d) = \frac{gM_d}{V_d}$
- **Submerged Unit Weight:** $\gamma_{sub} = |\gamma_{sat} - \gamma_{water}|$

EXAMPLE in the 100cc soil sample, the mass of solid is 150g, specific gravity is 2.5, & volume of water in the voids is 25cc. Calculate the following:

1. Volume of solid, Volume of air, & Void volume
2. Porosity, & Void ratio
3. Dry density, & Wet density
4. Particle density, & Saturated density
5. Air content & Moisture
6. Degree of saturation
7. Bulk unit weight, & Dry unit weight
8. Submerged Unit Weight

1. Volume of solid & volume of air

$$G_s = \frac{\rho_s}{\rho_{water}} = \rho_s = 2.5 \rightarrow \rho_s = \frac{M_s}{V_s} = 2.5g/cc$$

$$\rho_s = \frac{150g}{V_s} = \frac{2.5g}{cc} \rightarrow V_s = \frac{150g.cc}{2.5g} = 60cc$$

$$V_t = V_s + V_w + V_a \rightarrow V_a = V_t - (V_s + V_w)$$

$$V_a = 100cc - (60cc + 25cc) = 15cc$$

$$V_v = V_w + V_a = 15 + 25 = 40cc$$

2. Porosity, & Void ratio

$$n = \frac{V_v}{V_t} = \frac{100-60}{100} = 0.4$$

$$e = \frac{0.4}{1-0.4}x100\% = 66\%$$

3. Dry density, & Wet density

$$\rho_{dry} = \frac{M_s}{V_t} = \frac{150}{100} = 1.50g/cc$$

$$\rho_{wet} = \frac{M_{wet}}{V_t} = \frac{M_s + M_w}{Vt} = \frac{150+25}{100} = 1.75g/cc$$

4. Particle density, & Saturated density

$$\rho_p = \frac{M_s}{V_s} = Gs = 2.5g/cc$$

$$\rho_{sat} = \frac{M_{sat}}{V_{sat}} = \frac{M_s + M_w + V_a}{V_t} = \frac{150+25+15}{100} = 1.9$$

5. Air content & Moisture

$$A\% = \frac{V_a}{V_t}x100\% = \frac{15}{100}x100\% = 15\%$$

$$w\% = \frac{M_t - M_s}{M_s}x100\% = \frac{25}{150}x100 = 16.7\%$$

6. Degree of saturation

$$S = \frac{V_w}{V_v}x100\% = \frac{25}{40} = 62.5$$

7. Bulk unit weight, & Dry unit weight

$$\gamma = \frac{W_t}{V_t} = \frac{gM_t}{V_t} = \frac{9.8x175N}{100} = 17.2Ng/cc$$

$$\gamma_{dry} = \frac{gM_d}{V_d} = \frac{gM_s}{V_s + V_a} = \frac{9.8x150}{60+15} = 19.6Ng/cc$$

8. Submerged Unit Weight

$$\gamma_{water} = \frac{gM_w}{V_w} = 9.8Ng/cc$$

$$\gamma_{sat} = \frac{gM_{sat}}{V_{sat}} = \frac{9.8x190}{100} = 18.62Ng/cc$$

$$\gamma_{sub} = |\gamma_{sat} - \gamma_{water}|$$

$$\gamma_{sub} = |18.62 - 9.8| = |8.82| = +8.82$$

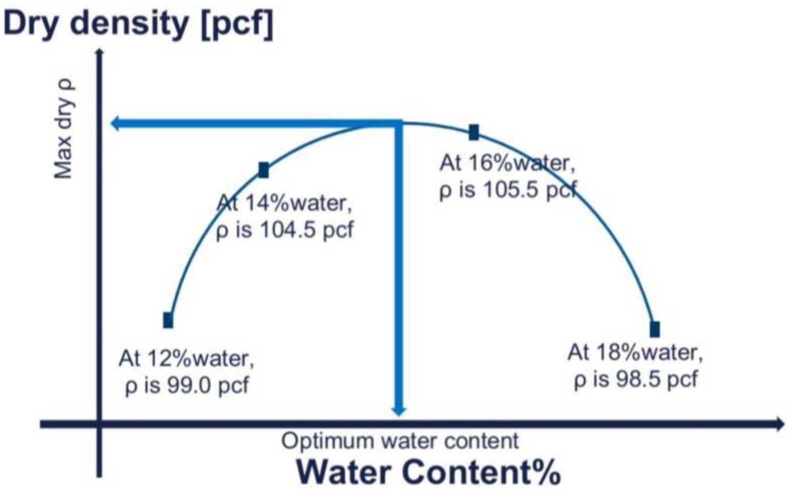
COMPACTION PRINCIPLES

- **Compaction Tests**
  - ➢ are not suitable for soils with >30%wt of the sample being larger than ¾" sieve
  - ➢ aren't performed on soil with 12% or fewer fines
- **Relative Density testing:** for clean sand & gravels
  - ➢ Standard Procedures for testing available for soil with some gravel (< Max allowable content)
- **Proctor Developed Principle**: is a principle of compaction & is a theory developed by Proctor (1930, California), that 3 factors or variables determine density that results from soil compaction
  1. The energy used in compaction
  2. The water content of the soil
  3. The properties of the soil

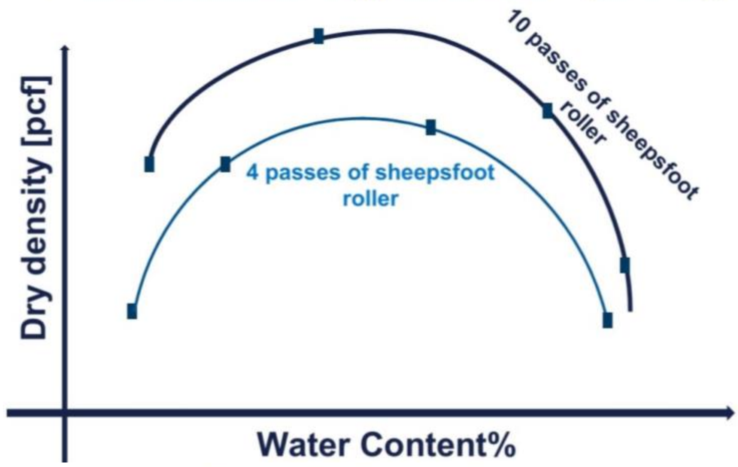
- **Proctor Compaction Test**

1. Prepare 4-5 specimens at increasing moistures about 2% apart (e.g. 14, 16, 18, & 20 %) Use range of moistures based on feel & experience
2. compact each sample into steel mold with standard procedures
3. strike off excess soil so mold has a known volume of soil
4. For each sample, measure the weight & the water content of the soil in the mold
5. The mold volume & weight are Pre-measured (Don't assume nominal volume 1/30 or 1/13.33 ft³)
6. Calculate moist density (wet density) & dry density
7. Plot dry density & water content for each point

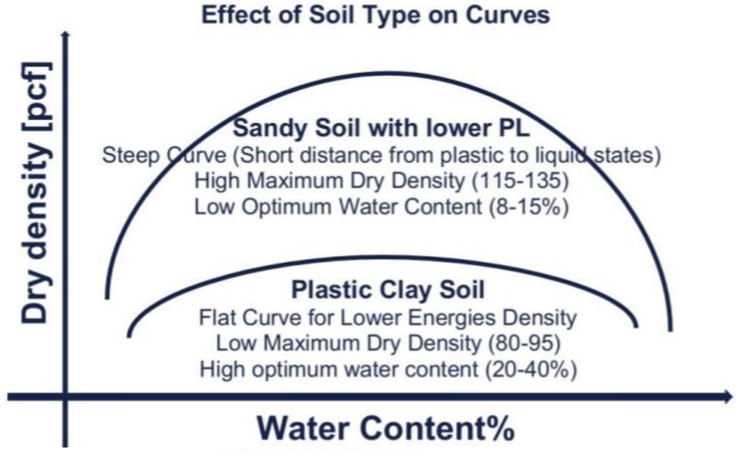
- **Effect of Water Content**
  - ➢ **At low water contents**: insufficient water is available to lubricate the particles & allow them to be rearranged into a dense structure, & The frictional resistance of dry particles is high
  - ➢ Using standard energy, if a series of specimens of soil compacted at increasing water contents, the resultant dry density of the specimens will vary, the ρ increase to a peak & then decrease
  - ➢ A plot of dry density versus water content from a compaction test will be parabolic in shape
  - ➢ The peak of the curve is termed the ***maximum dry density***, & the water content at which the peak occurs is the ***optimum water content***
- **Zero Air Voids Curve:** The 100% saturation curve is used to judge the reliability of the compaction curve & of field measurements of compacted soil density & water content
- Compacted soils for NRCS specifications are usually at a degree of saturation of 75-95%

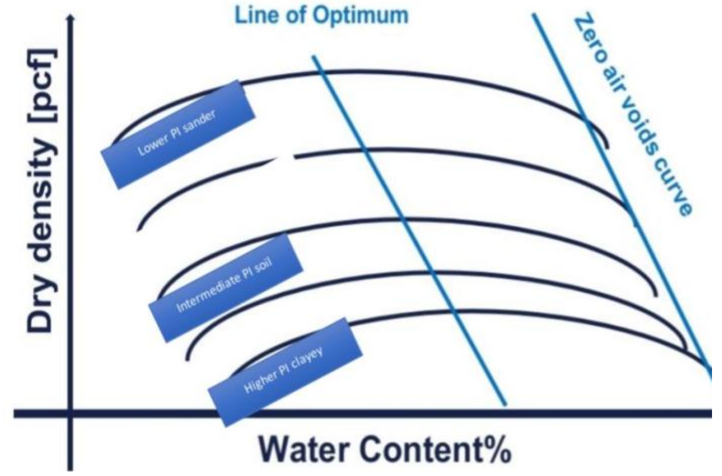


Affect of moisture & energy, Curve 2 is for higher energy



Effect of Soil Type on Curves





EXAMPLE for sample with mold wt 4.26#, & Mold Vol 0.03314 ft³, the following data were obtained, what is the optimum moisture & max. dry density

Point	Mold & Soil	Moist Soil	Water%
1	8.04	3.78	17.5
2	8.30	4.04	19.6
3	8.38	4.12	21.7
4	8.29	4.03	24.4

$$\rho_{moist} = \frac{M_{moist}}{V_t}$$

$$\rho_{moist_1} = \frac{3.78}{0.03314} = 114.1"/ft^3$$

$$\rho_{moist_2} = \frac{4.04}{0.03314} = 121.9"/ft^3$$

$$\rho_{moist_3} = \frac{4.12}{0.03314} = 124.3"/ft^3$$

$$\rho_{moist_4} = \frac{4.12}{0.03314} = 121.6"/ft^3$$

…

$$\rho_{dry} = \frac{\rho_{moist}}{1 + w\%}$$

$$\rho_{dry_1} = \frac{114.1}{1 + 0.175} = 97.1"/ft^3$$

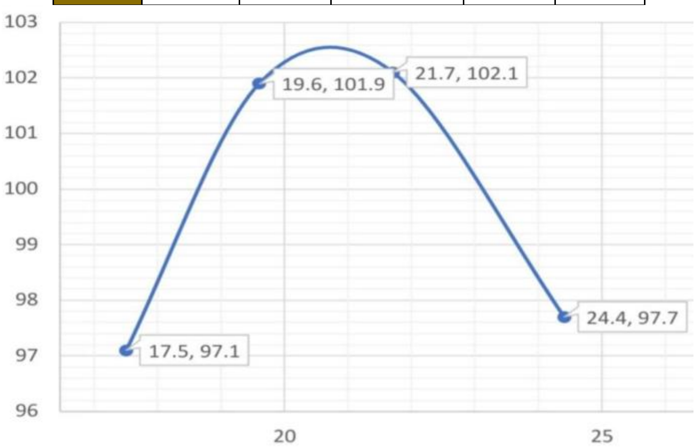
$$\rho_{dry_2} = \frac{121.9}{1 + 0.196} = 101.9"/ft^3$$

$$\rho_{dry_3} = \frac{124.3}{1 + 0.217} = 102.1"/ft^3$$

$$\rho_{dry_4} = \frac{121.6}{1 + 0.244} = 97.7"/ft^3$$

…

Point	Mold & Soil	Moist Soil	Water Contents	Moist ρ	Dry ρ
1	8.04	3.78	17.5	114.1	97.1
2	8.30	4.04	19.6	121.9	101.9
3	8.38	4.12	21.7	124.3	102.1
4	8.29	4.03	24.4	121.6	97.7



Maximum Dry Density = 102.3
Optimum Water Content = 20.7

Standard Proctor Energies for compaction test		
Standard	• Hammer: 5.5 pound • Dropped: 12 inches • mold filled in 3 lifts • hammer per lift: 25 blows • TotalEnergy 12,400 ft-lbs/ft³	
Modified	• Hammer: 10 pound • Dropped: 18 inches • mold filled in 5 lifts • hammer per lift: 25 blows • Total Energy 56,000 ft-lbs/ft³	
California	• Total energy ≈ 20,300 ft-lbs/ft³	

Standard molds (depending on max particle size)	
4"diameter mold (1/30 ft³)	• used for soils with ***low gravel contents*** • **Method A:** for soils with < 20 % gravel • **Method B:** for soils with > 20% gravel & <20% larger than 3/8"
6"diameter mold (1/13.33 ft³)	• for soil with ***significant gravel content*** • >20 % gravel larger than 3/8" • Must have <30% larger than ¾"

- Standardized tests are not available for soils with >30%wt being larger than ¾"in diameter gravels
- **ASTM Compaction Test Methods are:** D698A, D1557A, D698B, D1557B, D698C, & D1557C
- **Purposes of compaction:** Improve engineering properties that are affected by ρ & water content
- **Process that depends on compaction tests: determine suitability, Permeability**
- **A Permeability Test**: measures an acceptably low permeability, performed at 95% of Max Standard Proctor Dry Density, The sample is remolded at 2% wet of optimum (for this sample, 85% saturated)
  - ➢ A recommendation is given to the field office that compaction to this combination of ρ & water content results in acceptably low permeability
  - ➢ If the degree of compaction & saturation % are equal to or better than specified, the liner is judged to have a low permeability & is considered acceptable
- **For construction**: measurements of dry ρ & water content are made during construction
- **Problems:** The measured data appears to have problems (errors) such as dry ρ, moisture, & Gs

EXAMPLE A compaction test measures a maximum dry density = 104.0 pcf & optimum water% = 18.0, the soil has an estimated Gs = 2.68. A contract requires compaction to 95% of maximum dry density at a water content of optimum or greater & a field test measures a moist density = 126.3 pcf & a water content = 23.4%

1. Use ρ_{moist} & water% to calculate the dry density
2. Does the compacted fill meet the contract requirement

SOLUTION

compaction test: ρ_{DRYmax} = 104.0 pcf & $w\%_{opt}$ = 18.0

Gs = 2.68, requires compaction to 95% ρ_{DRYmax}

field test: ρ_{moist} = 126.3 pcf & w% = 23.4%

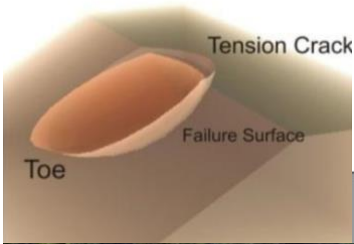
$$\rho_{dry} = \frac{\rho_{moist}}{1 + w\%} = \frac{126.3pcf}{1.234} = 102.4pcf$$

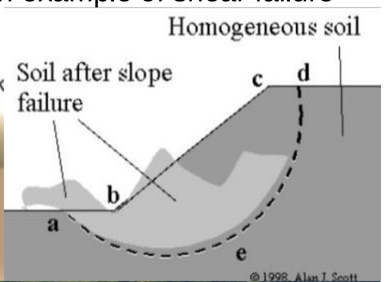
$$CR = \frac{\rho_{dry}\,meatured}{\rho_{dry}calculated} = \frac{102.4pcf}{104.0pcf} x100\% = 98.5\%$$

Yes, the compacted fill meet the contract requirement, because maximum dry density matured 98.5% of maximum dry density calculated & the requirements is 95%, & also optimum water content matured is 23.4% is higher than optimum water content calculated which is 18% (the requirements: optimum water content meatured is equal to or higher than calculated)

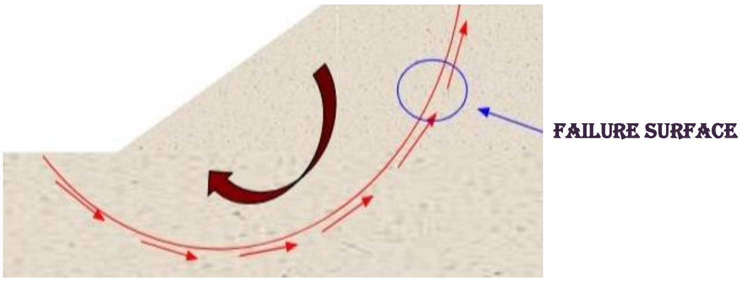
SHEAR STRENGTH

- **Shear strength**: resistance to movement between particles due to physical bonds (stress at failure)
  - ➢ Shear strength is a soils' ability to resist sliding along internal surfaces within the soil mass
- **Shear strength is a result of**
  1. Particle interlocking
  2. Atoms sharing e- at surface contact points
  3. Chemical bonds (cementation) such as crystallized calcium carbonate
- The strength of soil is a function of **friction & cohesion** (shear strength is directly related to friction, cohesion, angular grains, grading, low w%, compaction, particle interlocking, max dry density)
- **Influencing factors on Shear Strength (affected by)**
  1. **Soil composition**: mineralogy, grain size, grain size distribution, shape of particles, pore fluid type & content, ions on grain & in pore fluid
  2. **Initial state**: loose, dense, over-consolidated, normally consolidated, stiff, soft…
  3. **Structure**: arrangement of particles, the manner in which particles are packed or distributed (structure include layers, voids, pockets, cementation…)
- **Laboratory tests for shear strength**
  1. Direct Shear Test
  2. Unconfined Compression Testing
- **Soil failure**: structural strength occurs in the form of shearing along internal surface within the soil
  - ➢ Is a function of shear strength
  - ➢ Failure is an example of shearing along internal surface (slope stability)
  - ➢ **Mass wasting** is an example of shear failure

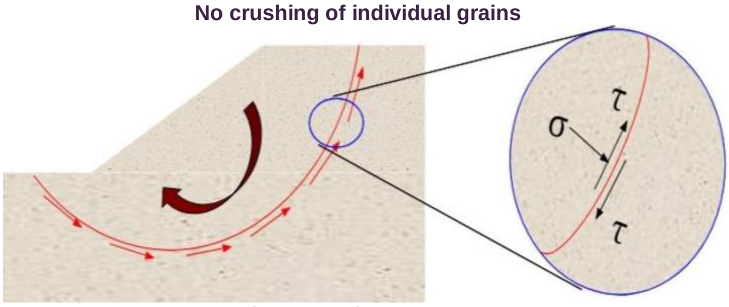




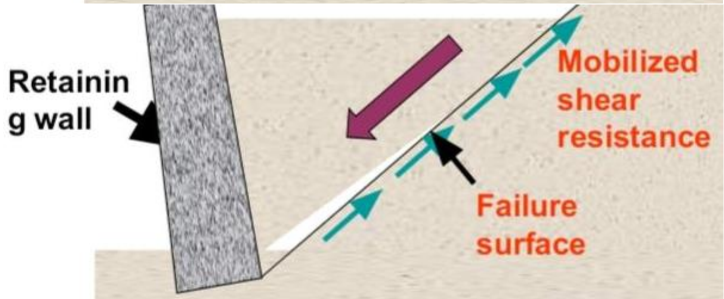
SHEAR FAILURE MECHANISM



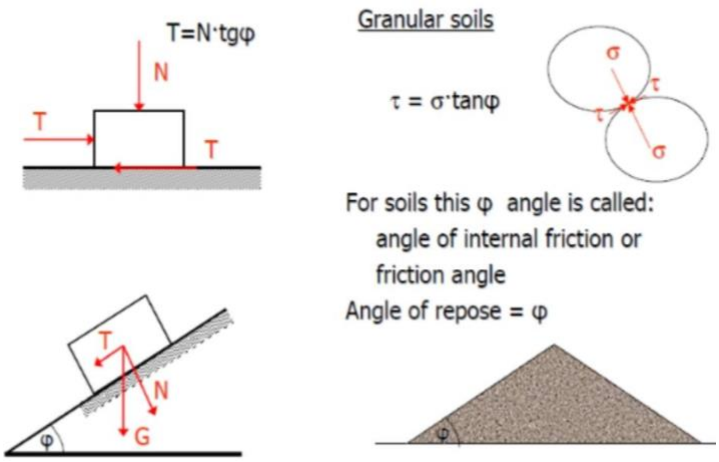
The soil grains slide over each other along the failure surface
No crushing of individual grains



shear stress along the failure surface (τ) reaches shear strength (τ_f)
σ : resistance force, τ : friction force



shear stress along the failure surface (mobilized shear resistance) reaches the shear strength



Wight Concept
Weight analyzes into x- & Y-components because the force is described as a magnitude & direction

SHEAR STRENGTH PARAMETERS

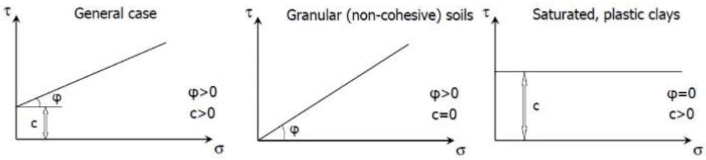
- **Shear strength parameters**:
  1. **Cohesion (c) or effective cohesion (c')**: directly proportional to the shear strength, & inversely to water or clay particles contents
  2. **Internal fraction angle (φ) or effective fraction angle (φ')**: directly proportional to the shear strength
- In fine grained soils the strength is apart from friction due to internal forces holding particles together & this property is called ***COHESION*** & soil possessing it are ***COHESIVE SOIL***

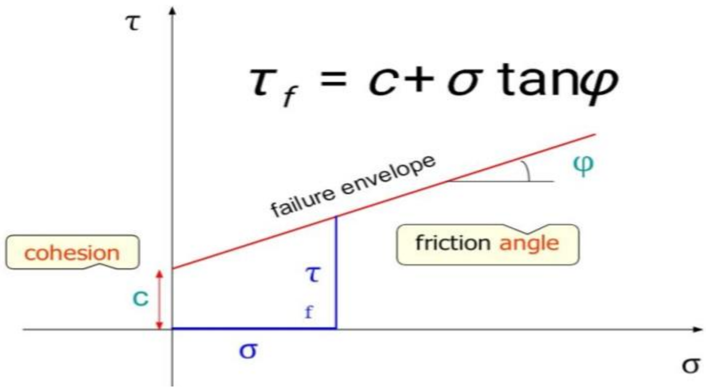
Coulomb's law for cohesive soils

$$\tau_f = c + \sigma \tan(\varphi)$$

Coulomb's law for saturated soils

$$\tau_f = c + (\sigma - u)\tan(\varphi)$$

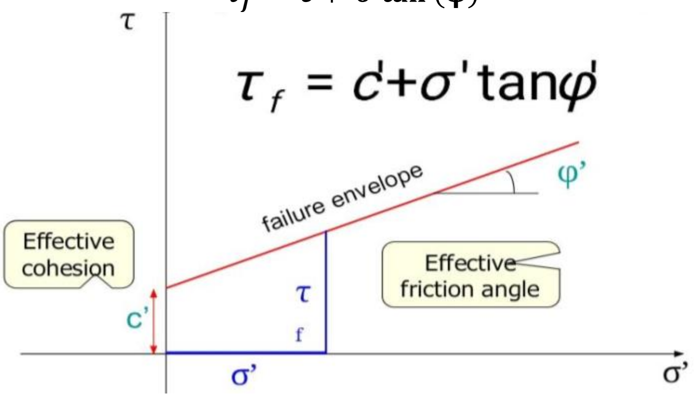




IN TERMS OF TOTAL STRESSES

Tf is a maximum shear stress the soil can take without failure, under ***normal stress (σ)***

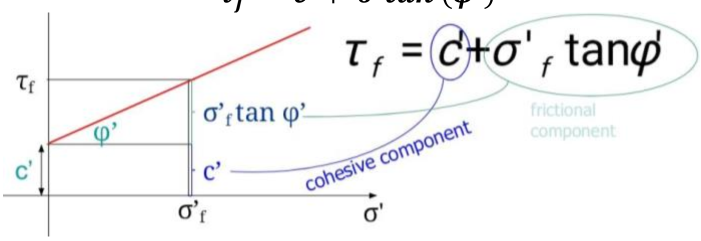
$$\tau_f = c + \sigma \tan(\varphi)$$



IN TERMS OF EFFECTIVE STRESSES (σ')

$$\sigma' = \sigma + pore\ water\ pressure$$

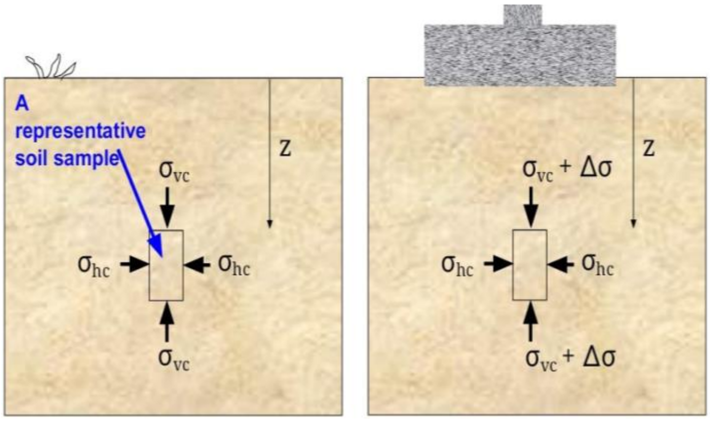
$$\tau_f = c' + \sigma' \tan(\varphi')$$



Shear strength consists of 2 components: cohesive & frictional

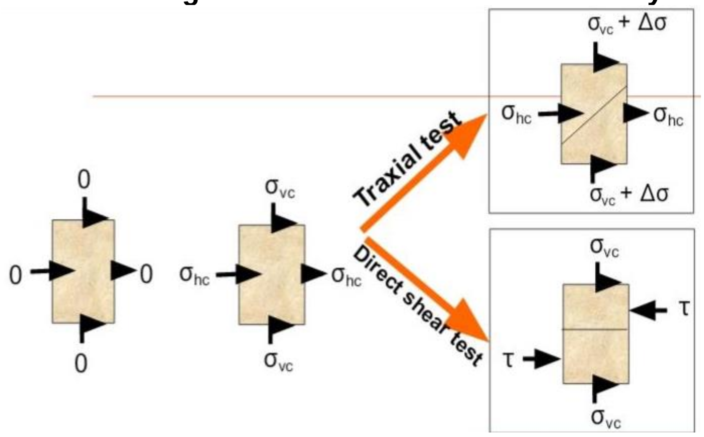
SHEAR STRENGTH TESTS

- Test to determine shear strength parameters
- **Laboratory tests** on specimens taken from representative undisturbed samples, include Vane shear test, Torvane, Pocket penetrometer, Fall cone, Pressuremeter, Static cone penetrometer, & Standard penetration test
- **Field tests:** Direct shear test, Triaxial shear test, direct simple shear test, torsional ring shear test, plane strain triaxial test, laboratory vane shear test, & laboratory fall cone test
- **Field conditions:** constructional affect



Before Construction　　After Construction

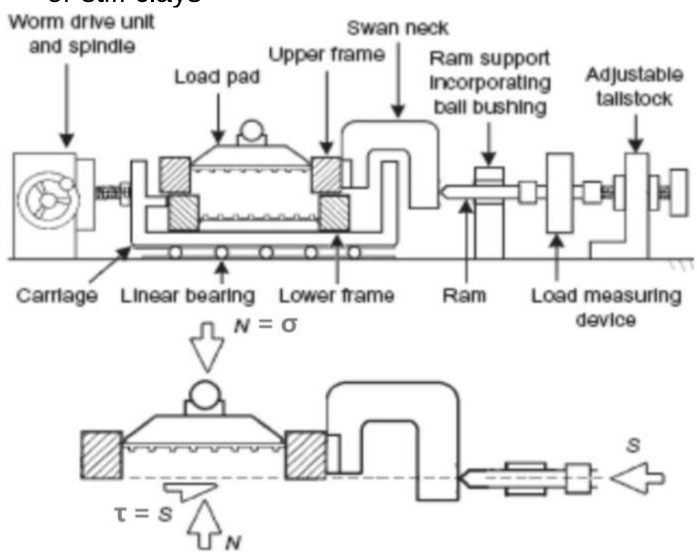
- **Simulating field conditions in the laboratory**

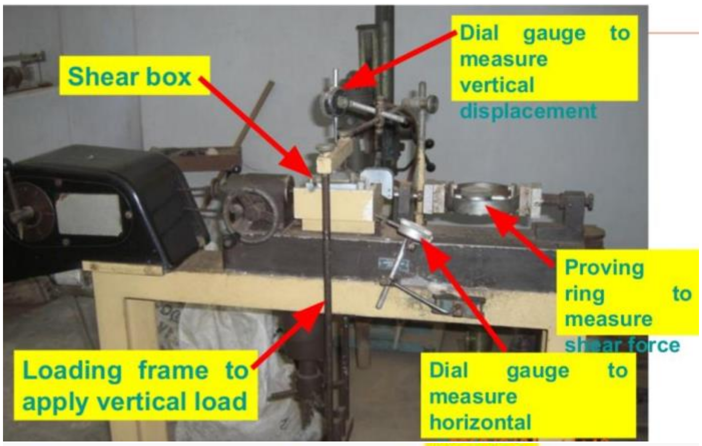


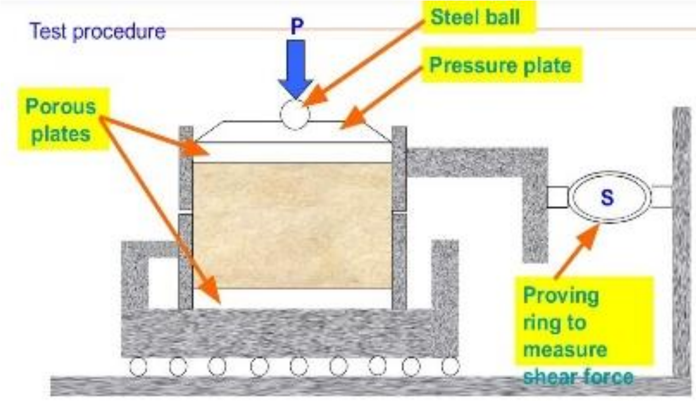
Set the specimen in the apparatus & apply the initial stress condition

Apply the corresponding field stress conditions

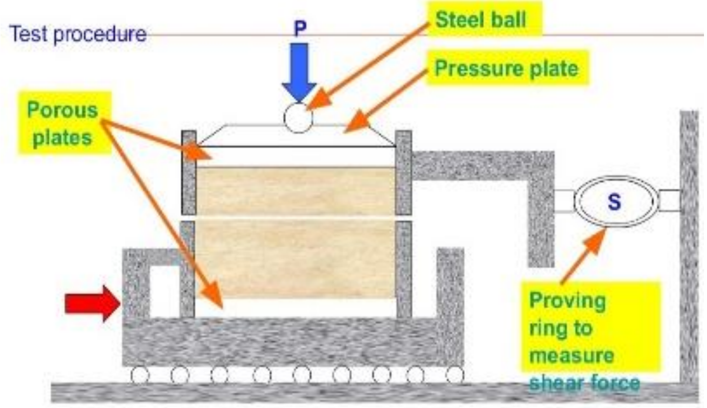
- **Direct shear test:** most suitable for consolidated drained tests specially on granular soils (e.g. sand) or stiff clays







Step 1: Apply a vertical load to the specimen & wait for consolidation



Step 2: Lower box is subjected to a horizontal displacement at a constant rate (strength = stress at failure)

- **Calculation & Analysis**

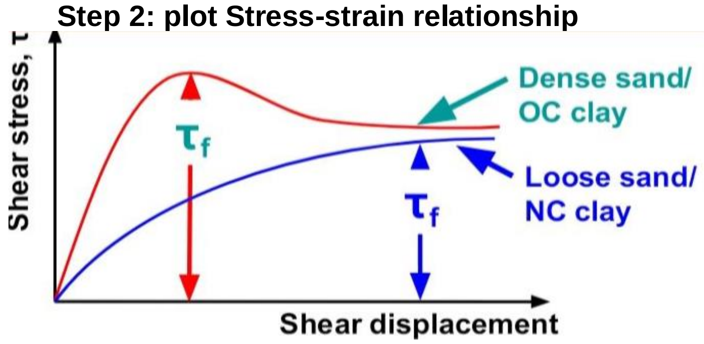
  Step 1: calculate normal & shear stresses

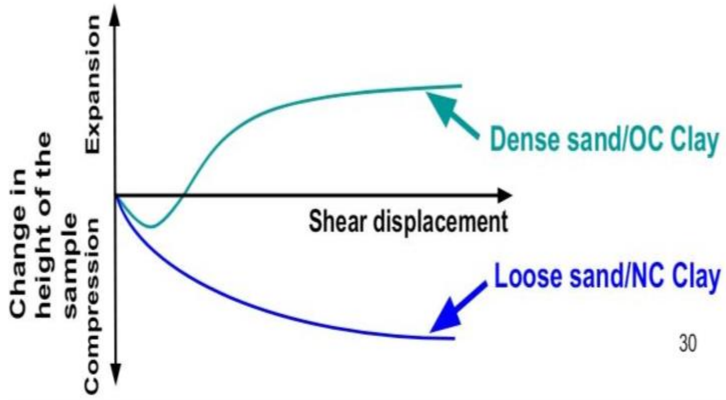
$$\sigma = \ normal \ stress = \frac{normal \ force \ (n)}{area \ of \ cross \ section \ (A)}$$

$$\tau \ (shear \ stress) = \frac{resistance \ sliding \ surface \ (S)}{area \ of \ cross \ section \ (A)}$$

Cross-sectional area changes with horizontal displacement

Step 2: plot Stress-strain relationship



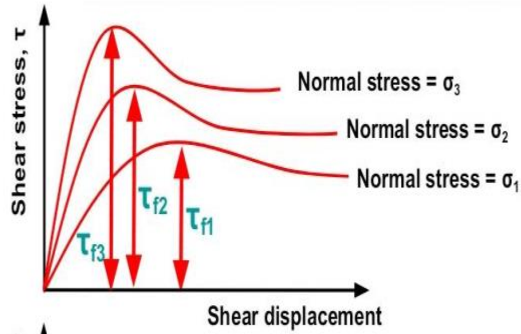


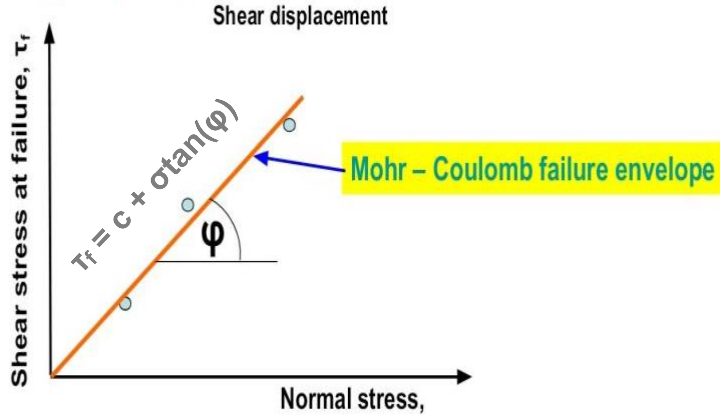
الكسر الاول في المنحنى الاحمر حدث نتيجة ال ***cohesion*** (عند ***τf***) اما

الكسر الثاني حدث نتيجة ال ***friction***

τf = shear stress at failure

Step 3: determine strength parameters (c & φ)

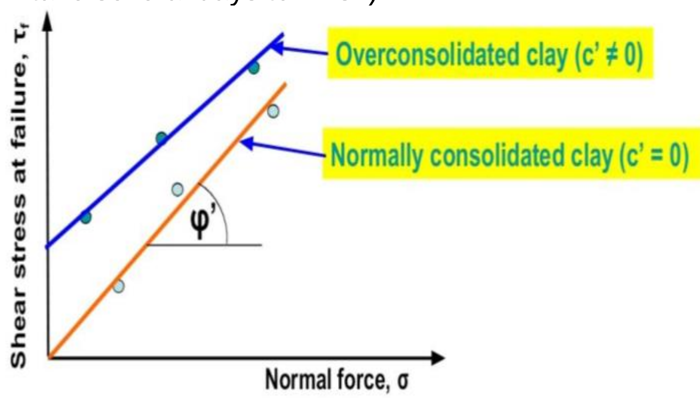




C = Y-intersection (here is 0)

slope = φ = friction

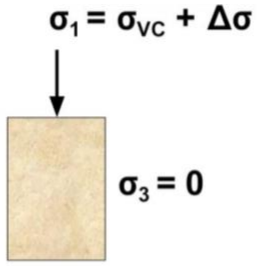
- **Direct shear tests on clays**: horizontal displacement should be applied at a very slow rate to allow dissipation of pore water pressure (so test take several days to finish)

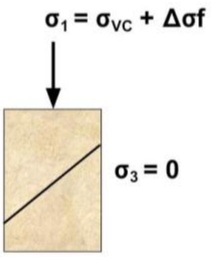


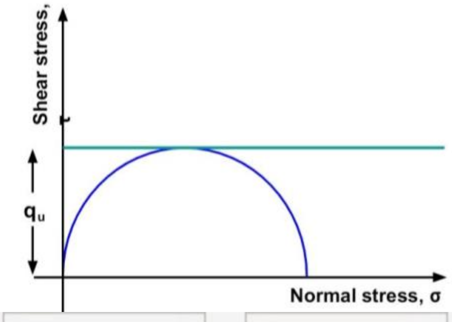
- **Interface tests on direct shear apparatus:** In many foundation design problems & retaining wall problems, it is required to determine φ between soil & the structural material (concrete, steel, or wood)

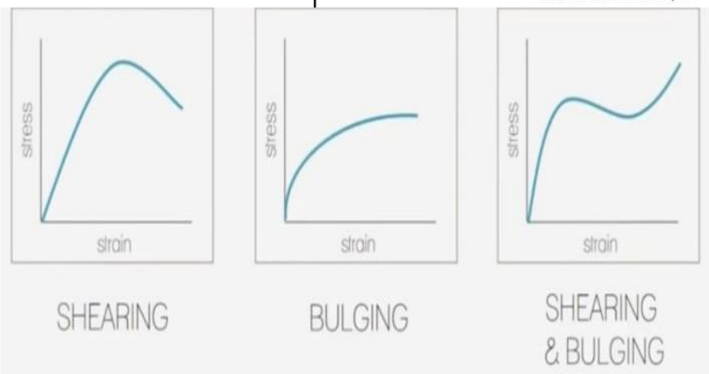
- **Unconfined Compression Test (UC Test):** Confining pressure is zero in the UC test

1. نضع ال *soil* في ال *muld*
2. وبعض ضغطه نزيل البراغي الموجودة في ال ***muld*** وننزع عنه ال ***ring*** من الاعلى ونحاول ان يكون ال ل بنفس حجم ال ***muld***
3. نوزن ال ***soil*** ونأخذ حجمه ايضا لنحسب كثافته (***moisture density***)
4. نضع التربة في جهاز الضغط ونتوقف عند اول كسر يحدث بالعينة وهو يكون (***Unconfined compressive strength***)
5. نحسب ال ***cohesion***

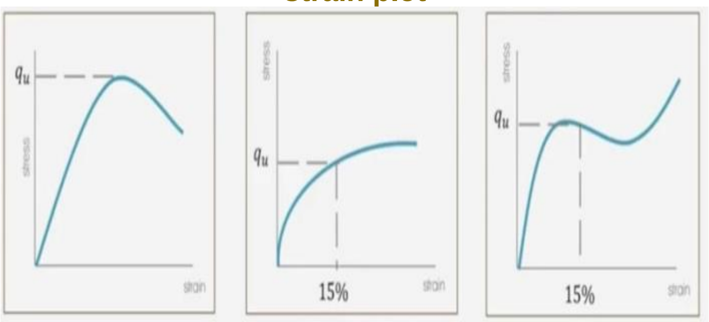








Types of failure & their corresponding stress-strain plot

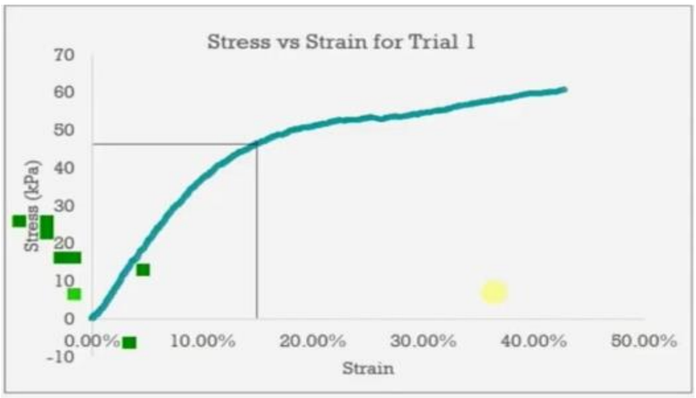


Unconfined compressive strength from stress-strain plot

$$Strain = \frac{deformation\ height}{initial\ height}$$

$$Stress = \frac{Axial\ load}{corrected\ area}$$

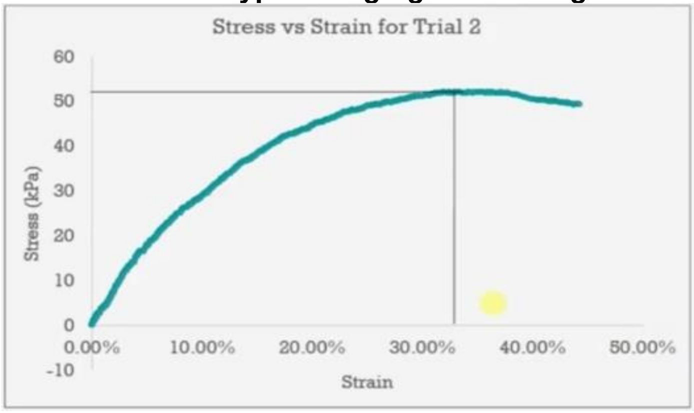
$$Cohesion\ (c) = \frac{aunconfined\ Strenght}{2}$$



Unconfined Compressive strength = 46.3Kpa

$$Cohesion\ (c) = \frac{46.3}{2} = 23.2Kpa$$

Failure type : Bulging & Shearing



Unconfined Compressive strength = 52.0Kpa

$$Cohesion\ (c) = \frac{52.0}{2} = 26Kpa$$

Failure type : Bulging

- **Sand Cone Test:** protector or standard compaction

يستخدم هذا الاختبار للتأكد من **pd & wt%** *في موقع البناء، فاذا كانت* **wt%** *اكبر او اصغر من* **opt.wt%** *فأن ذلك يجعل* **ρmax>ρ** *وهو شيء غير جيد للبناء, ويتوجب علينا حساب ال* **compaction ratio** *للتأكد من صحة ال* **compaction** *الذي قام به المقاول*

1. تأخذ عينة من التربة من موقع البناء وتوزنها بعد تجفيفها باستخدام مايكروويف فتحصل على الكتلة الجافة ***Ms***
2. تضع في الحفرة التي قمت باخذ العينة منها كمية من التربة المعروف كثافتها، وتحسب حجم العينة:

$$V_{soil} = \frac{M}{\rho} \rightarrow V_T = V_{soil} - V_{cone}$$

3. تحسب ال ***dry density*** من الحجم والكتلة من الخطوتين السابقتين

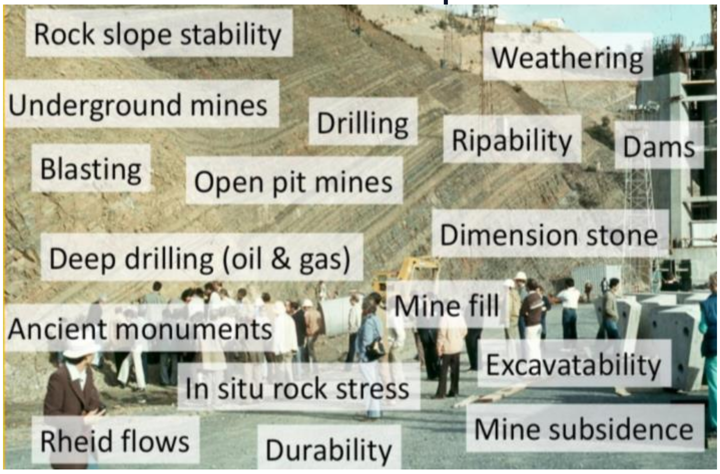
$$\rho_d = \frac{M_s}{V_T}$$

4. تحسب ال ***Compaction Ratio*** وبناء عليه تحدد هل كان عمل المقاول جيد او لا) اذا كانت النسبة > 95٪ يكون جيد، اقل غير جيد)

$$CR = \frac{\rho_d}{\rho_{max}} x100\%$$

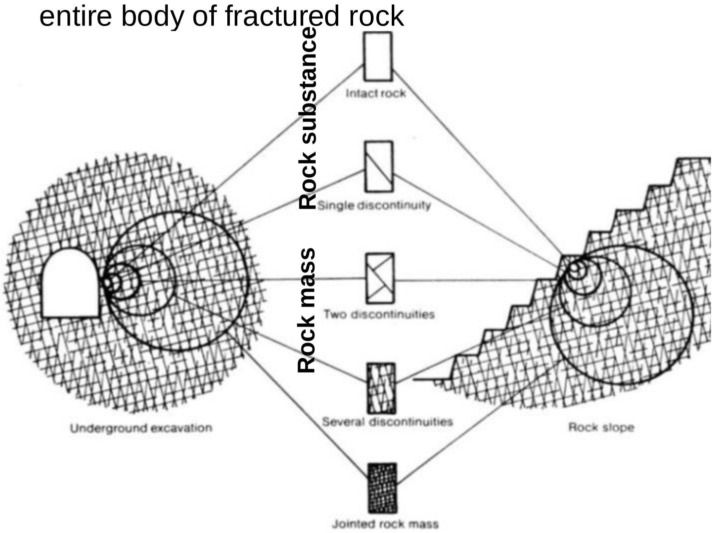
ROCK MECHANICS

- **Rock Mechanics deals with**: Rock slope stability, Weathering, Underground mine, Drilling, Ripability, Dams, Blasting, Open pit mines, Dimension stone, Deep drilling (oil, gas), Mine fill, Ancient monument, Excavatability, In situ rock stress, Mine subsidence, Rheid flows, & Durability
- **Rock mechanics is scale-dependent**



If the angle of slope is high (angle of internal friction), the slope is unstable

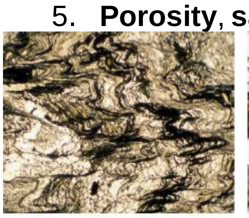
- **The rock substance:** is the rock material itself
- **The rock mass:** the whole outcrops, or is the entire body of fractured rock

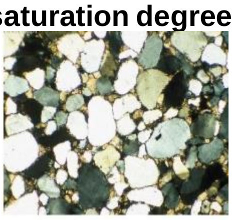


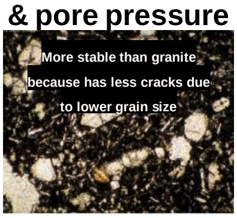
Road cuts: هي مساطب يصنعوها على المنحدرات لتقليل خطر الصخور

ROCK SUBSTANCE

- **Mechanical behavior of substance depends on**
  1. **Lithology**: such as crystalline, foliated, particular, cemented…
  2. **Strength of the minerals** in a rock (Qz vs mica)
  3. **Degree of weathering & alteration** of mineral: affect the strength & durability of rock substance
  4. **Micro-fabric:** cleavage plane, micro fracture…
  5. **Porosity**, **saturation degree, & pore pressure**


Thin section of schist

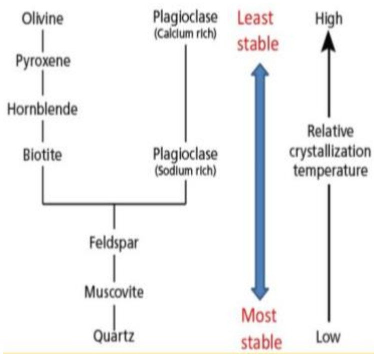

Thin section of sandstone

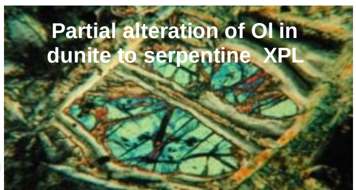


Thin section of basalt

the strength & durability related to weathering degree	
Fresh (F)	• no visible signs of weathering • perhaps slight discolouration on joints
Slightly Weathered (SW)	• Some discolouration of rock & discontinuity surfaces • May be weaker than fresh rock
Moderately Weathered (MW)	• Rock may be discoloured but the loss of strength & hardness is not great
Highly Weathered (HW)	• Entirely discoloured, Fe-oxide staining • Porosity increased or decreased (change), loss of strength & hardness
Completely Weathered (CW)	• all rock material is disintegrated • Original fabric is still intact but the rock disintegrate by gentle agitation in water

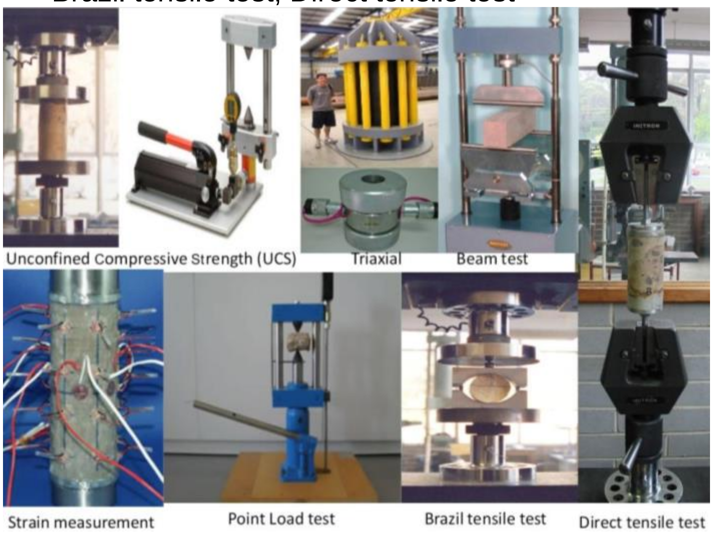
- **Alteration of the minerals** changes the strength & mechanical properties of the rock substance, especially where clay minerals are the end result of the chemical alteration





Rock Classification System (Williamson & Kuhn,1988)	
Degree Of Weathering	
A	Micro Fresh State (MFS)
B	Visual Fresh State (VFS)
C	Stained State (STS)
D	Partly Decomposed State (PDS)
E	Completely Decomposed State (CDS)
Strength Estimate Element	
A	Rebound reaction to hammer blow (RQ)
B	Pits with hammer blow (PQ)
C	Dents with hammer blow (DQ)
D	Craters with hammer blow (CQ)
E	Can be remoulded with finger pressure(MBL)
Planar & Linear Element	
A	Solid with random breakage (SRB)
B	Solid with preferred breakage (SPB)
C	Latent planes of separation (LPS)
D	Planes of separation in 2 dimensions (2-D)
E	Planes of separation in 3 dimensions (3-D)
Grain Size	
A	Greater than 2.55 t/m³
B	2.40 – 2.55 t/m³
C	2.25 – 2.40 t/m³
D	2.10 – 2.25 t/m³
E	Less than 2.10 t/m³
Rating	
AAAA	Least design consideration (very good)
EEEE	Most design consideration (we don't use it)

- **Strength testing of the rock substance**: Unconfined Compressive Strength (UCS), Strain measurement, Point Load test, Triaxial, Beam test, Brazil tensile test, Direct tensile test



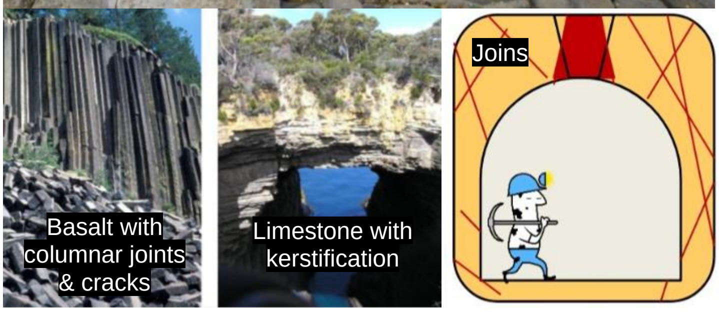
- **Durability testing of the rock substance**: used to determine rock properties for construction, building cladding, dam walls, roads, concrete aggregate, mining machinery tip wear, etc.
  - ➢ Slake Durability Index, Wetting/drying, Freeze / thaw tests, Wearability, Los Angeles Abrasion, Polished Stone, Skid resistance, Aggregate Crushing, Na-Sulfate & Mg-Sulfate Soundness

- **Excavability testing**: depending on rock strength, include Drillability, Rippability, & Ripper-tip wear

Seismic waves velocity is a function of rock densities (directly proportional to the density)

ROCK MASS

- Rock mass are the discontinuities in the rock, & They are more important than the rock substance

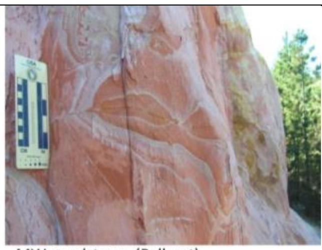


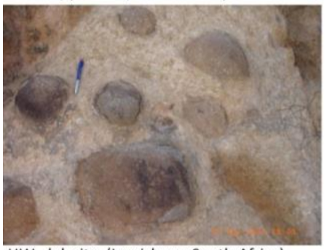
- The description of rock mass is laid out in the Australian Standards & the International Society of Rock Mechanics recommended methods. It is quite specific & follows a rigid set of descriptions

Rock Mass Description: Degree of weathering	
Fresh (F)	no visible signs of weathering • May be slight discolouration on joints
Slightly Weathered (SW)	Some discolouration of rock & discontinuity surfaces • Joints may be open <5mm
Moderately Weathered (MW)	Less than 50% of the rock mass is disintegrated or discoloured. • Joints may be filled with clays
Highly Weathered (HW)	More than 50% of the rock mass is decomposed or discoloured • Joints are open & filled with clay

Completely Weathered (CW)	all rock mass is disintegrated. The original structure of the rock mass can still be seen, but the rock behaves as a soil


F tillite, (Durban, South Africa)

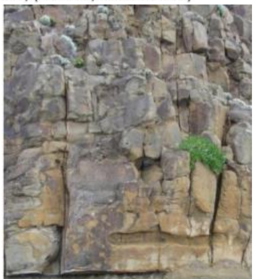

MW mudstone, (Ballarat)

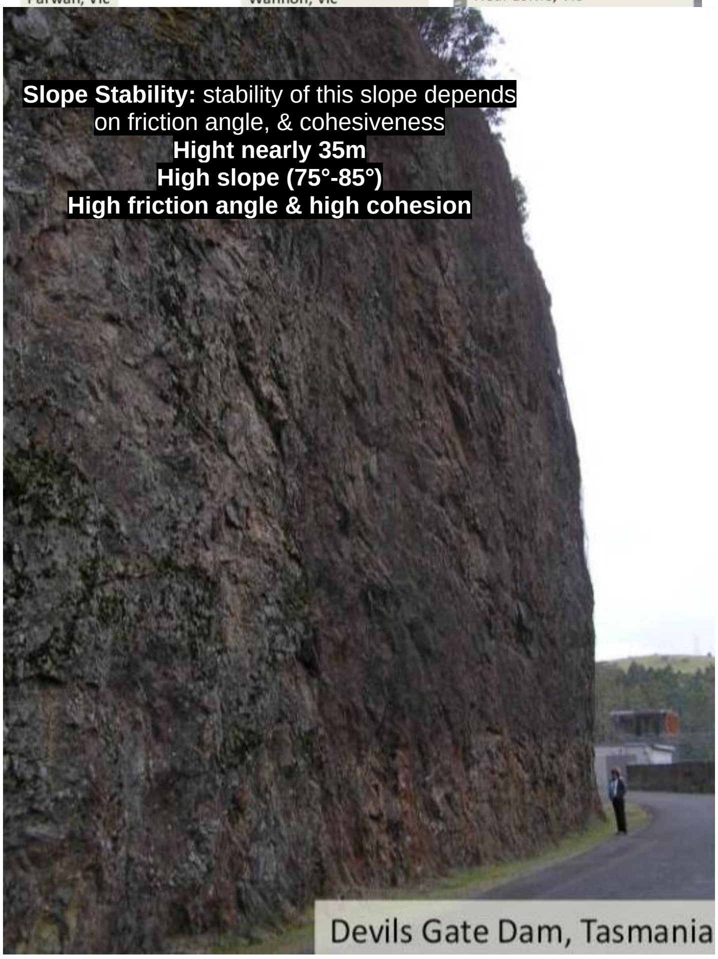

HW dolerite, (Lewisburg, South Africa)


CW granite, (Durban, South Africa)


HW Basalt, Parwan, Vic


MW Rocklands Rhyolite, Wannon, Vic

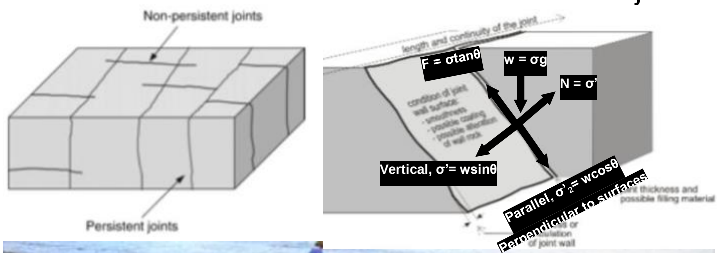

MW Otway Group sandstone, Near Lorne, Vic

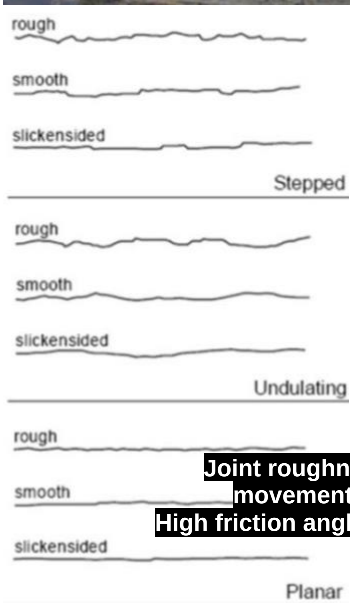


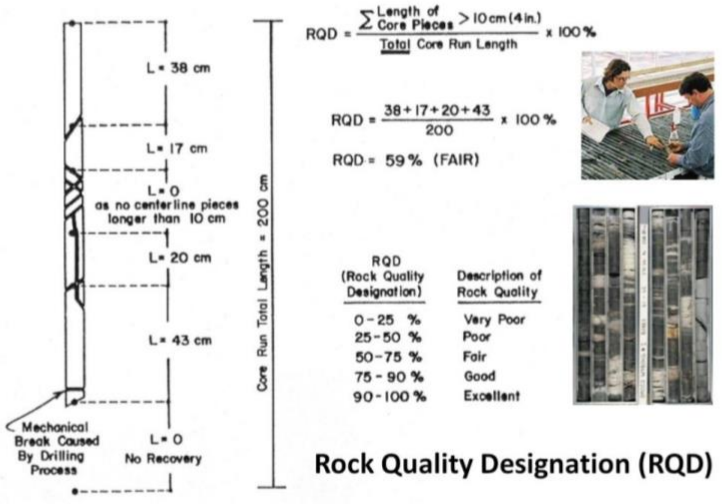
Devils Gate Dam, Tasmania

- **Type of discontinuities:** Joints (in sets usually every set in 3D), Fractures (random joints), Faults (displacement on fracture), Bedding planes, & Non-conformity surfaces

- **Geometry of discontinuities**:
  1. **Number of joint sets, & Block size**
  2. **Joint orientations**: dip or dip direction of joints
  3. **Joint persistence**: continuity of joints
  4. **Joint spacing**: distance between 2 joints
  5. **Frequency or intensity**: number of joints in a certain area (joint/area), inversely related to block size & joint spacing
  6. **Aperture or width:** is the distance between 2 joint's surface (الفتحة)
  7. **Filling:** materials that fill the joint's aperture
  8. **Roughness:** locking of movement along joint
  9. **Rock Quality Designation (RQD)**
- Joint Types:
  1. **Persistence Joints**: long-distance joints without interruption, has higher affect
  2. **Non-Persistence Joints**: short-distance joint







- **Common Rock Mass Classification Systems**:
  1. **Rock Mass Rating (RMR)**:UCS, RQD, Spacing & Condition of discontinuities, Groundwater condition, Orientation of discontinuities
  2. **Rock Structure Rating (RSR)**: Rock type, Geologic structure, Rock jointing, Orientation (w.r.t. drive), Joint condition, & Groundwater
  3. **Q-System**: RQD, Joint set no. (Jn), Joint roughness no. (Jr), Joint alteration no. (Ja), Joint water reduction factor (Jw), Stress reduction factor (SRF)

$$Q = \frac{RQD \ x \ Jr \ x \ Jw}{SRF \ x \ Jn \ x \ Ja}$$

A. CLASSIFICATION –PARAMETERS AND THEIR RATINGS

	Parameter			Range of values				
1	Strength of intact rock material	Point-load strength index		>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred
		Uniaxial comp. strength		>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa / 1 - 5 MPa / < 1 MPa
	Rating			15	12	7	4	2 / 1 / 0
2	Drill core Quality *RQD*			90% - -100%	75% - -90%	50% - 75%	25% - 50%	< 25%
	Rating			20	17	13	8	3
3	Spacing of discontinuities			> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm
	Rating			20	15	10	8	5
4	Condition of –discontinuities (See E)			Very rough –surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation –> 5 mm Continuous
	Rating			30	25	20	10	0
–5	Ground water	Inflow per 10 m tunnel length (l/m)		None	< 10	10 - 25	25 - 125	> 125
		(Joint water press)/ (Major principal σ)		0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5
		General conditions		Completely dry	Damp	Wet	Dripping	Flowing
	Rating			15	10	7	4	0

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike –and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

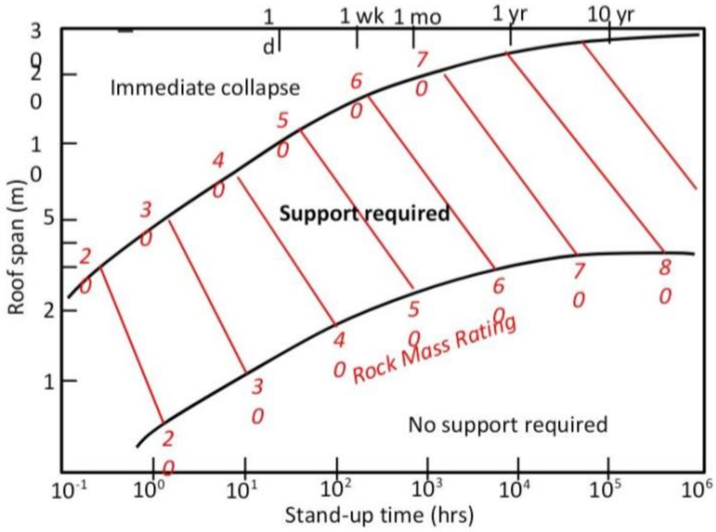
E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence)	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
Rating	6	4	2	1	0
Separation (aperture)	None	< 0.1 mm	0.1 - 1.0 mm	1 - 5 mm	> 5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Ratings	6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very favourable	Fair
Drive against –dip - Dip 45-90°	Drive against –dip - –Dip 20-45°	–Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

- **Rock mass classification schemes using:**
  1. determine ground support in underground mining & engineered rock slope
  2. as a "ready reckoner" to determine the ground support, rock anchors, rock bolts, mesh, shotcrete, steel sets…



Ground support depends on mass quality, roof span & time