Relative density

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

SOIL MECHANICS & FOUNDATION ENGINEERING

The term ***relative density*** is commonly used to indicate the *in situ* denseness or looseness of granular soil. It is defined

as :

$$Dr\ (\%) = \frac{e_{max} - e_o}{e_{max} - e_{min}}$$

$$Dr\,(\%) = \frac{e_{max} - e_o}{e_{max} - e_{min}}$$

Where :

Dr = relative density, usually given as a percentage

e_o = *in situ* void ratio of the soil

e_{max} = void ratio of the soil in the loosest state

e_{min} = void ratio of the soil in the densest state

Or :

$$Dr\,(\%) = \left(\frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}} \right) \left(\frac{\gamma_{d\,max}}{\gamma_d} \right)$$

Where :

Dr = relative density, usually given as a percentage

γ_d = *in situ* dry unit weight (at a void ratio of e_o)

$\gamma_{d\,min}$ = dry unit weight in the loosest condition (at a void ratio of e_{max})

$\gamma_{d\,max}$ = dry unit weight in the densest condition (at a void ratio of e_{min})

General notes

1 - The values of *Dr* may vary from a minimum of 0% for very loose soil to a maximum of 100% for very dense soils.

2 - In-place soils seldom have relative densities less than 20 to 30%.

3 - Compacting a granular soil to a relative density greater than about 85% is difficult.

Soils engineers qualitatively describe the granular soil deposits according to their relative densities, as shown in the following Table :

Relative density (%)	Description of soil deposit
0 - 15	Very loose
15 - 50	Loose
50 -70	Medium
70 -85	Dense
85 - 100	Very dense

Grain shape of coarse soil

(1)   (2)   (3)   (4)   (5)   (6)

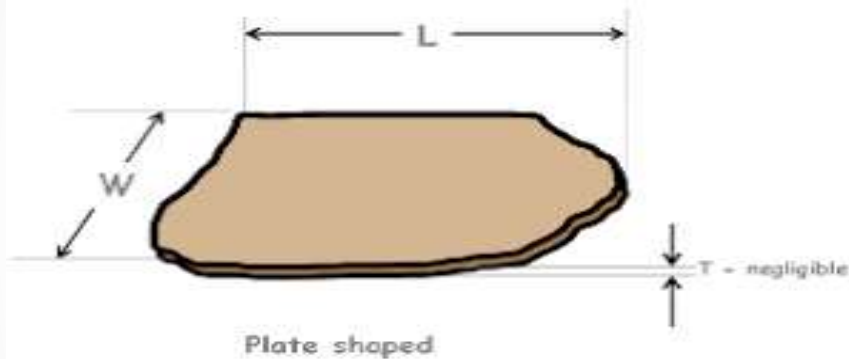(1) = Very angular

(2) = Angular

(3) = Subangular
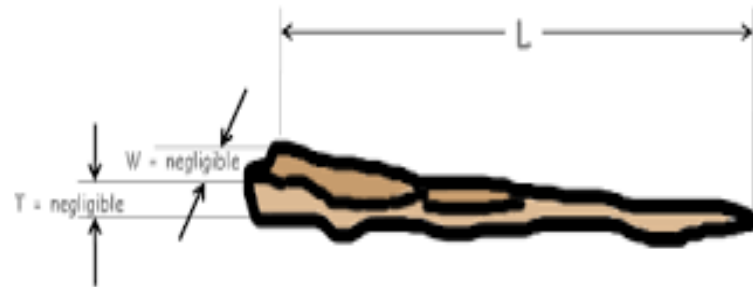
(4) = Subrounded

(5) = Rounded

(6) = Well-rounded

Grain shape of fine soil

Flaky shape

Needle like shape

Grain size distribution Sieve analysis

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

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Mechanihcal analysis

Mechanical analysis is the determination of the size range of particles present in a soil, expressed as a percentage of the total dry weight. Two methods generally are used to find the particle-size distribution of soil:

**(1) *Sieve analysis*—for particle sizes larger than 0.075 mm in diameter,

**(2) *Hydrometer analysis*—for particle sizes smaller than 0.075 mm in diameter.
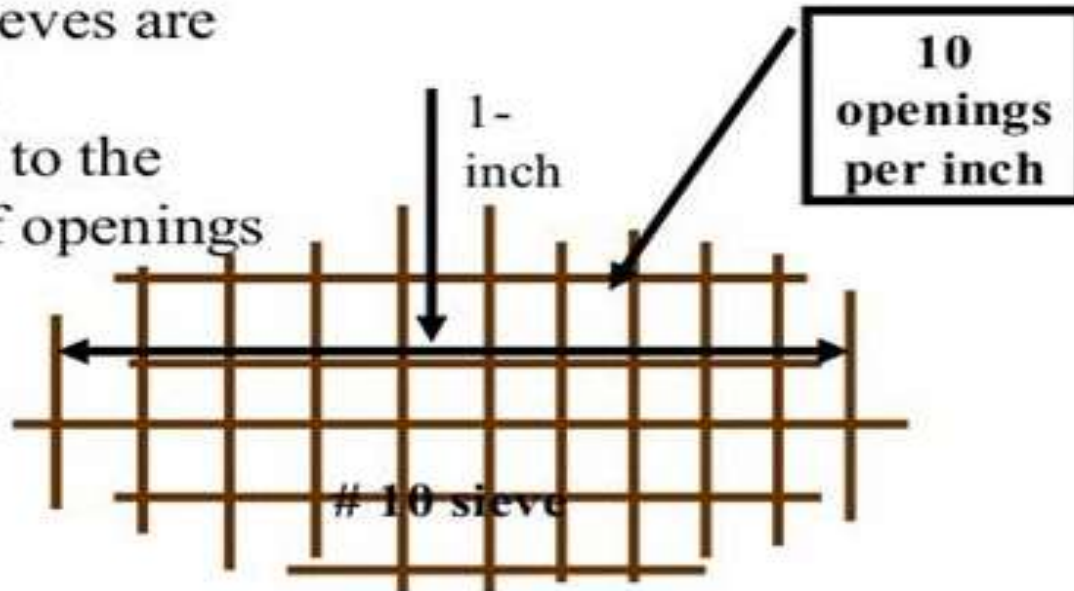
Sieve analysis

Sieve analysis consists of shaking the soil sample through a set of sieves that have progressively smaller openings. U.S. standard sieve numbers and the sizes of openings are given in the following table.

Samples of sieves

Sieve No.	Opening (mm)	Sieve No.	Opening (mm)
3 inch	76.200	20	0.850
2 inch	50.800	25	0.710
1.5 inch	38.100	30	0.600
1 inch	25.400	35	0.500
3/4 inch	19.000	40	0.425
3/8 inch	9.520	50	0.355
4	4.750	60	0.250
5	4.000	70	0.212
6	3.350	80	0.180
7	2.800	100	0.150
8	2.360	120	0.125
10	2.000	140	0.106
12	1.700	170	0.090
14	1.400	200	0.075
16	1.180	270	0.053
18	1.000		

Smaller sieves are numbered according to the number of openings per inch

1-inch

10 openings per inch

10 sieve

To conduct a sieve analysis, one must first oven-dry the soil and then break all lumps into small particles. The soil then is shaken (for 10 min) through a stack of sieves with openings of decreasing size from top to bottom (a pan is placed below the stack).

The following figure shows a set of sieves in a shaker used for conducting the test in the laboratory.

The smallest-sized sieve that should be used for this type of test is the U.S. No. 200 sieve. After the soil is shaken, the mass of soil retained on each sieve is determined.

When cohesive soils are analyzed, breaking the lumps into individual particles may be difficult. In this case, the soil may be mixed with water to make a slurry and then washed through the sieves. Portions retained on each sieve are collected separately and oven-dried before the mass retained on each sieve is measured.

Table of results

The results obtained from this test can be tabulated as follows :

Sieve No.	Sieve opening (mm)	Weight of soil retained (gm)	Cumulative retained	% Retained (% R)	% Finer (% F)

The cumulative weight of soil retained above each sieve (ith sieve) can be calculated as follows :

Cumulative weight = *M*1 + *M*2 + *M*3 + · · · + *Mi*

% Retained on ith sieve (% R) can be calculated as follows :

$$\% \, R = \frac{cumulative \; weight \; at \; (ith \,)sieve}{total \; weight \; of \; the \; sample} \times 100 \, \%$$

% Finer than ith sieve (% F) can be calculated as follows :

$$\% \boldsymbol{F} = \boldsymbol{100} - \% \boldsymbol{R}$$

Once the percent finer for each sieve is calculated the calculations are plotted on semi logarithmic graph paper with percent finer as the ordinate (arithmetic scale) and sieve opening size (grain size) as the abscissa (logarithmic scale). This plot is referred to as the particle-size distribution curve.
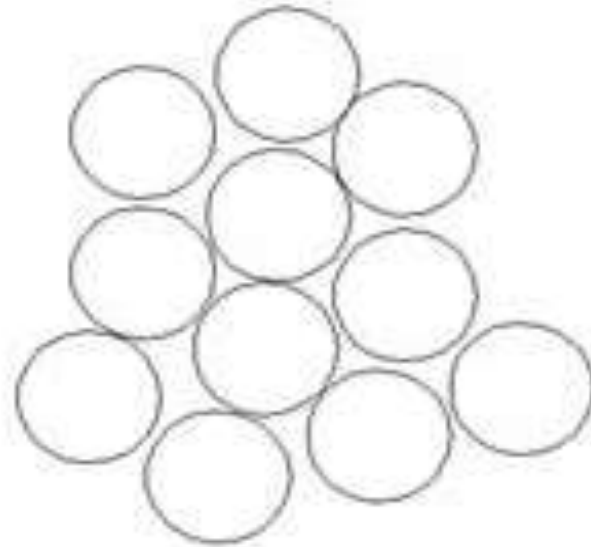
Particle-size distribution curve

تربة جيدة التدرج
Well graded soil

تربة رديئة التدرج
Poorly graded soil
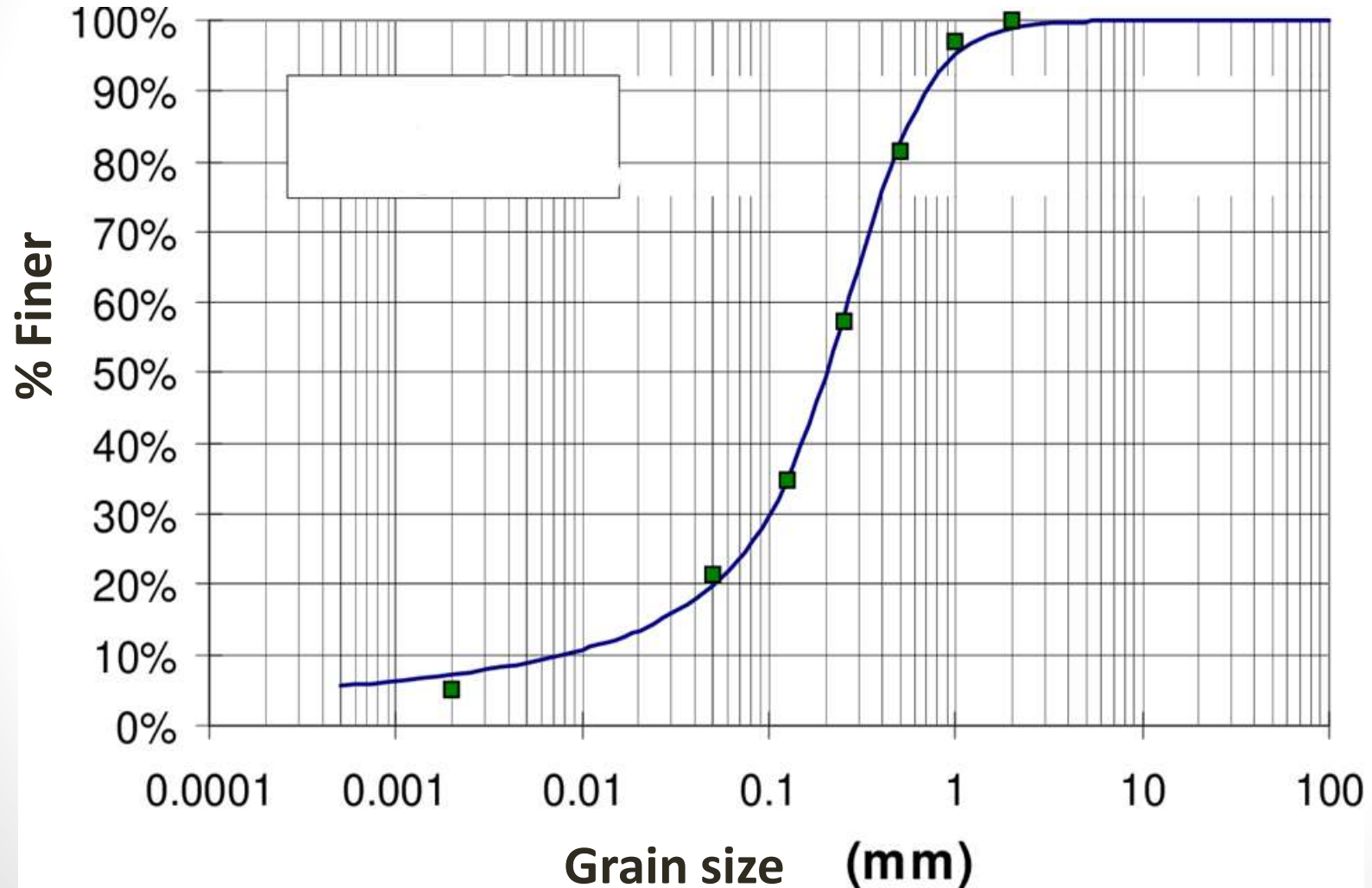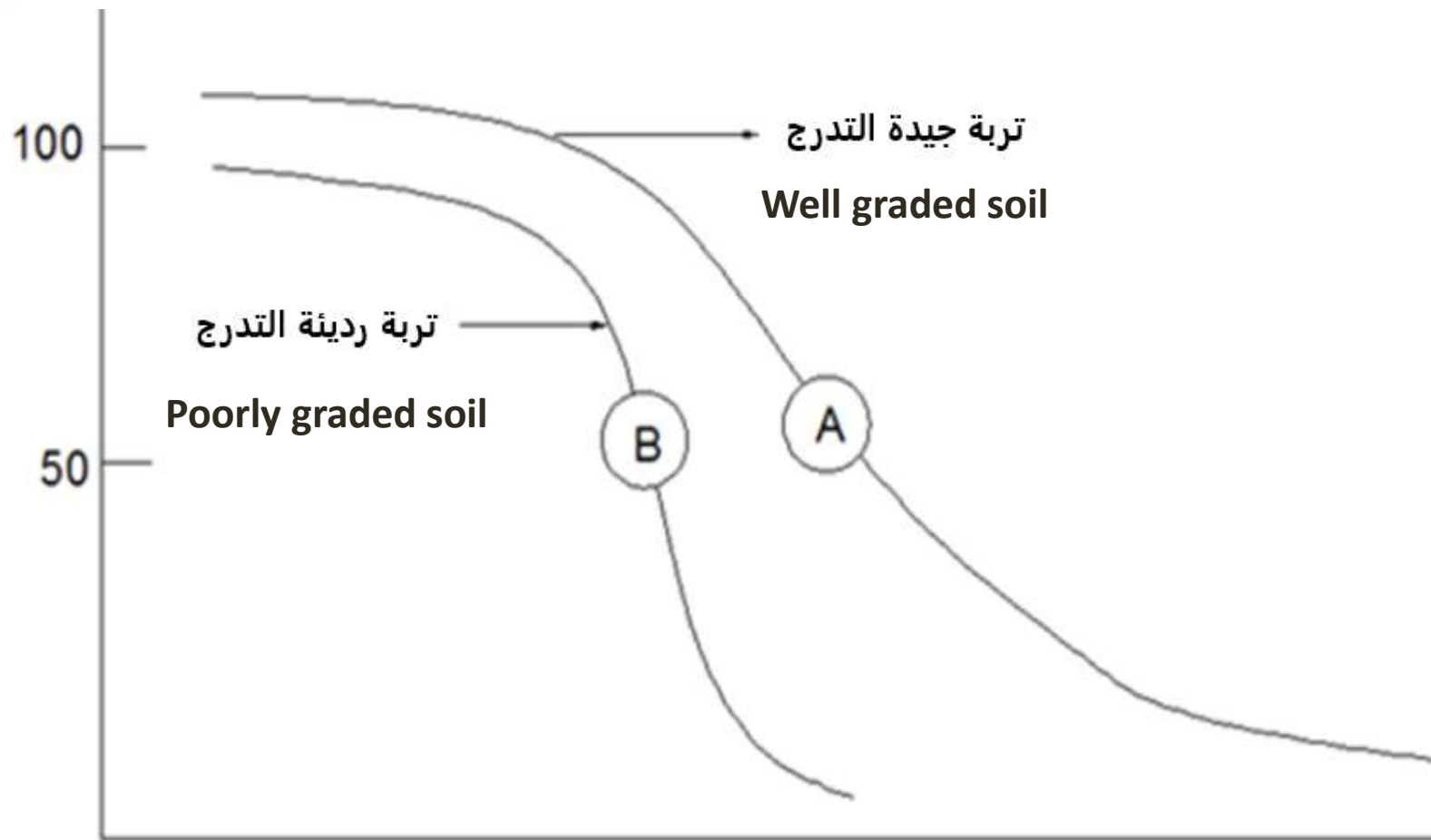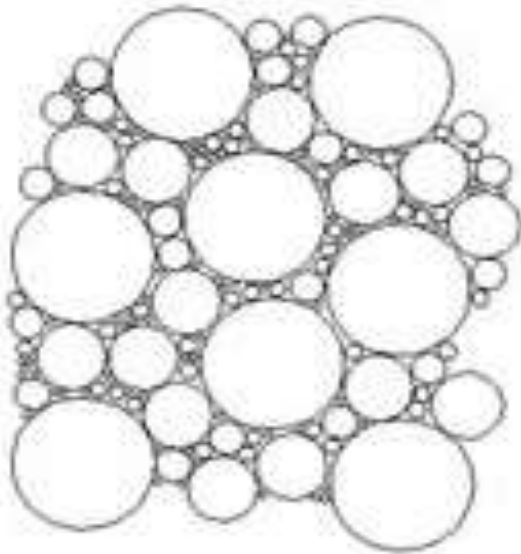
Well graded soil

Poorly graded soil

The particle-size distribution curve can be used to determine the following parameters for a given soil :

1 - (D10): This parameter is the diameter in the particle-size distribution curve corresponding to 10% finer. It is also called as (effective size of a granular soil), which is a good measure to estimate the hydraulic conductivity and drainage through soil.

2 - (D30): This parameter is the diameter in the particle-size distribution curve corresponding to 30% finer.

3 - (D60): This parameter is the diameter in the particle-size distribution curve corresponding to 60% finer.
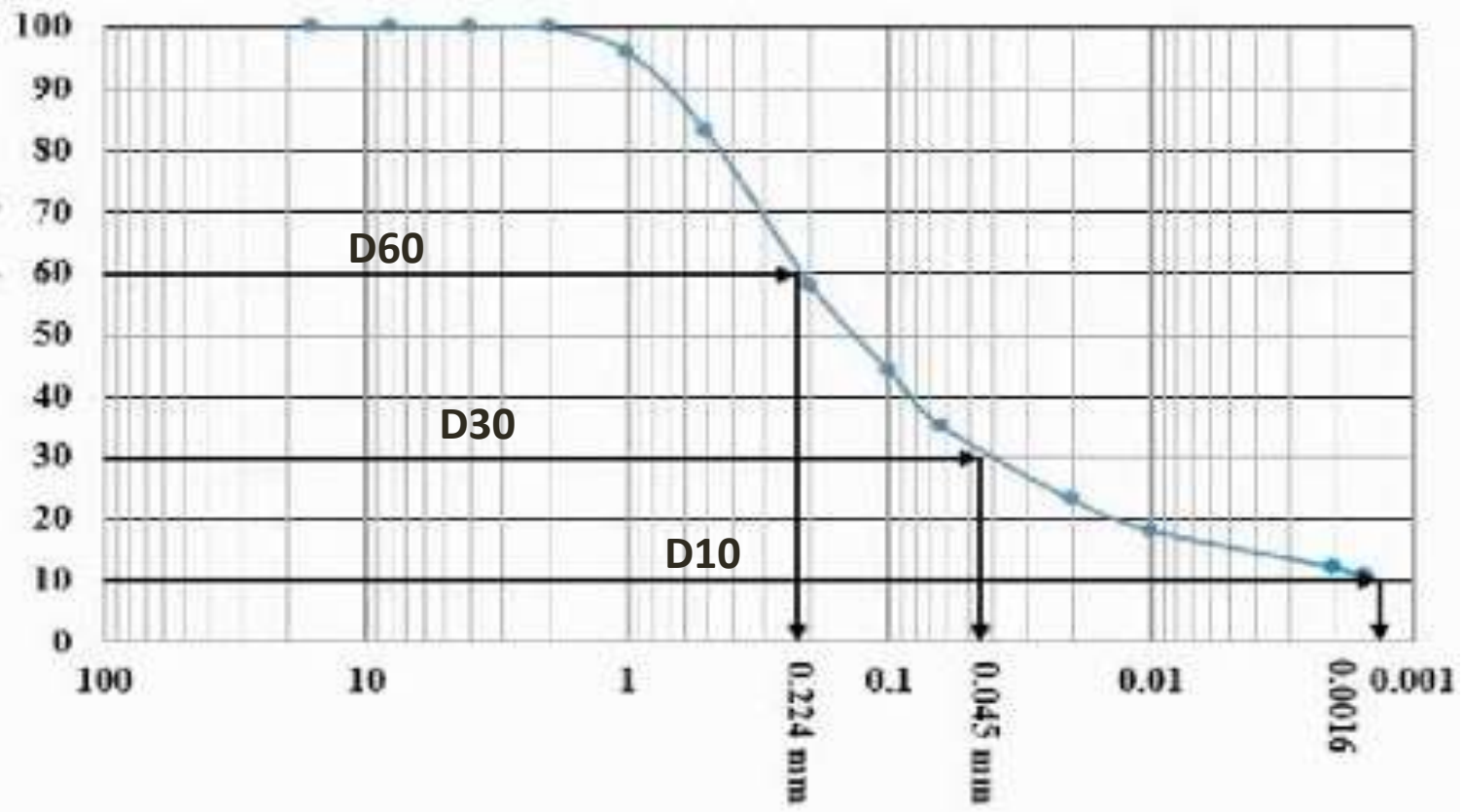
We can use these parameters to determine the following coefficients :

1 - Coefficient of uniformity (Cu):

This parameter is defined as :

$$Cu = \frac{D_{60}}{D_{10}}$$

2 - Coefficient of curvature (Cc):

This parameter is defined as :

$$Cc = \frac{(D_{30})^2}{(D_{60})(D_{10})}$$

We can use these coefficients to set if the soil is poorly graded soil or well graded soil , as follows :

For (gravel) :

If   **Cu > 4.0**   and   **Cc = (1.0 – 3.0)** , the gravel can be classified as **(well graded gravel)** , otherwise it is **(poorly graded gravel)** .
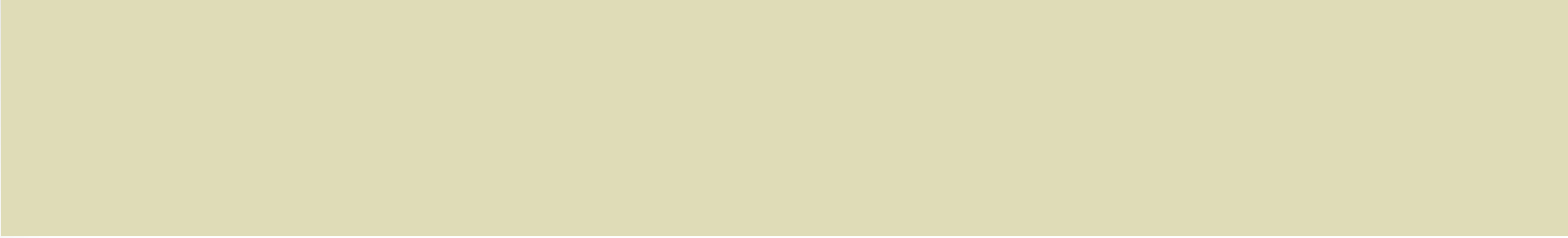
For (sand) :

If   **Cu > 6.0**   and   **Cc = (1.0 – 3.0)** , the sand can be classified as **(well graded sand)** , otherwise it is **(poorly graded sand)** .

Weight-volume relationships

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

SOIL MECHANICS & FOUNDATION ENGINEERING

In natural occurrence, soils are three-phase systems consisting of soil solids, water, and air . To develop the weight–volume relationships, we must separate the three phases :

(that is, solid, water, and air)
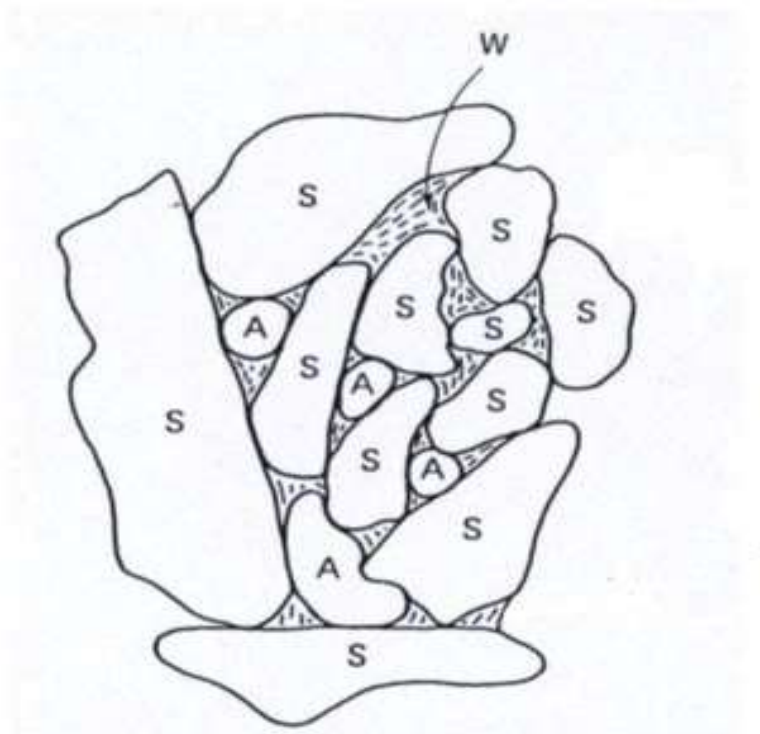
Soil sample

S : Solids

W : Water

A : Air

General elements of soil

General state   **Dry state**   **Saturated state**

The total volume and total weight of a given soil sample can be expressed as follows :
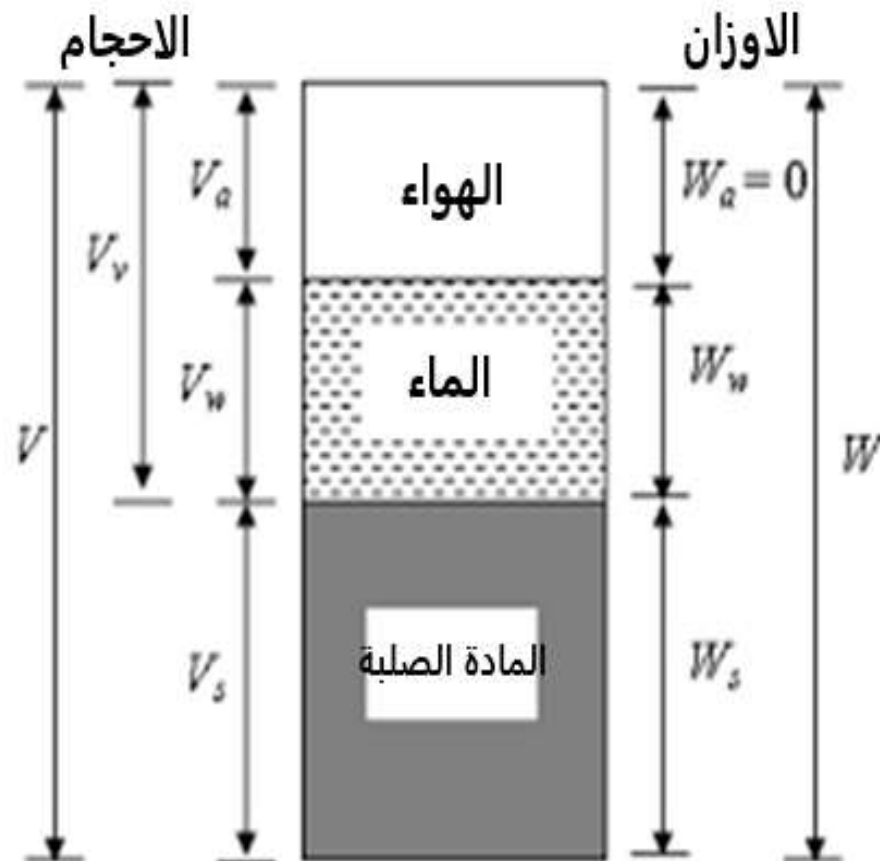
Where :

V : Total volume of soil sample

Vs : Volume of soil solids

Vv : Volume of voids

Vw : Volume of water in the voids

Va : Volume of air in the voids

W : Total weight of soil sample

Ws : Weight of soil solids

Ww : Weight of water in the voids

Wa : Weight of air in the voids = 0
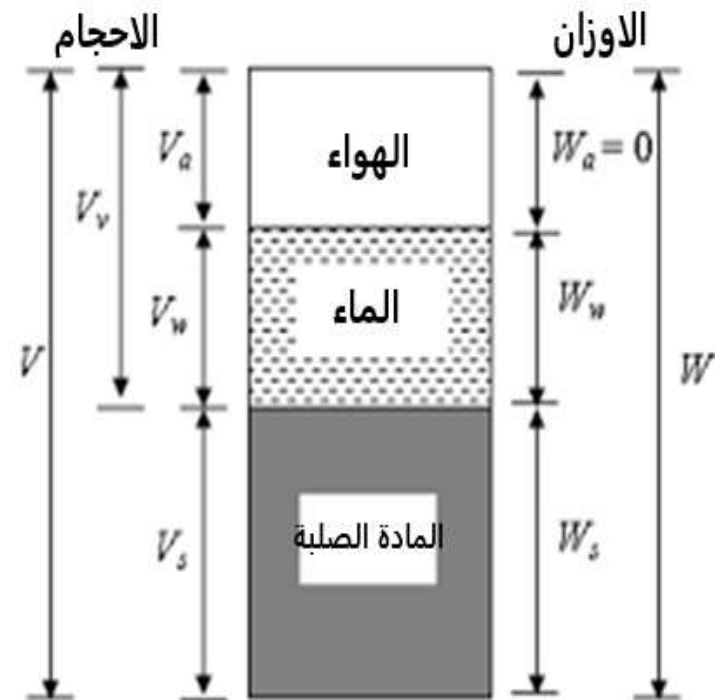
Thus :

$Vv = Vw + Va$

$But \ V = Vs + Vv$

So that $V = Vs + (Vw + Va)$

$W = Ws + Ww + Wa = Ws + Ww + 0$

So that $W = Ws + Ww$

The *volume relationships* commonly used for the three phases in a soil element are :

Void ratio , Porosity , **and** ***Degree of saturation***

Void ratio (e) : It is defined as the ratio of the volume of voids to the volume of solids.
Thus :

$$e = \frac{Vv}{Vs}$$

Porosity (n) : It is defined as the ratio of the volume of voids to the total volume.

Thus :

$$n = \frac{Vv}{V}$$

$$n = \frac{e}{1 + e}$$

Degree of saturation (S) : It is defined as the ratio of the volume of water to the volume of voids .

Thus :

$$S = \frac{Vw}{Vv} * 100\ \%$$

The common terms used for *weight relationships* are *moisture content* and *unit weight of soil .*

 ***Moisture content* (wc) :** It is also referred to as *water content* and is defined as the ratio of the weight of water to the weight of solids in a given soil sample .

Thus :

$$wc = \frac{w_w}{w_s}$$

Specific gravity (Gs) : It is defined as the ratio of the unit weight of soil solids to the unit weight of water .

The specific gravity of soil solids is often needed for various calculations in soil mechanics . Most of its values full within a range of (2.0 – 2.9) .

The following equation is very useful for solving problems involving three-phase relationships.

$$e * S = Gs * w_c$$

(Wet Density) (γ_m)

The unit weight can also be expressed in terms of the weight of soil solids, the moisture content, and the total volume. Thus :

$$\gamma_m = \frac{W}{V}$$

Or :

$$\gamma_m = \frac{Gs * \gamma_w (1 + w_c)}{(1 + e)}$$

Where :

Gs : Specific gravity of soil solids

w_c : Water content

e : Void ratio

γ_w : Unit weight of water , which is equal to :

(1.0 gm / cm³)

or   (1000 kg / m³)

or   (9.81 kN / m³)

(Dry Density) (γ_d)

Often, to solve earthwork problems, one must know the weight per unit volume of soil, excluding water. This weight is referred to as the *dry unit weight*, (γ_d) . Thus :

$$\gamma_d = \frac{Ws}{V}$$

Or :

$$\gamma_d = \frac{Gs * \gamma_w}{(1 + e)}$$

So that :

$$\gamma_d = \frac{\gamma_m}{(1 + w_c)}$$

Or :

$$\gamma_m = \gamma_d (1 + w_c)$$

(Saturated Density) (γ_s)

If the soil sample is *saturated*—that is, the void spaces are completely filled with water (S = 100 %) , the relationship for saturated unit weight (γ_s) can be derived in a similar manner :

$$\gamma_s = \frac{(Gs + e) * \gamma_w}{(1 + e)}$$

(Submerged Density) (γ_b)

It is the density of the soil when it is submerged under the water . The relationship for submerged unit weight (γ_b) can be derived in a similar manner :

$$\gamma_b = \frac{(Gs - 1) * \gamma_w}{(1 + e)}$$

Or :

$$\gamma_b = \gamma_s - \gamma_w$$

Clay minerals

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

SOIL MECHANICS & FOUNDATION ENGINEERING

Clay minerals

**Clay minerals** are complex aluminum silicates composed of two basic units:

(1) *Silica tetrahedron.*

(2) *Alumina octahedron.*

Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom. The combination of tetrahedral silica units gives a *silica sheet.*

Tetrahedral unit and sheet

Three oxygen atoms at the base of each tetrahedron are shared by neighboring tetrahedra.
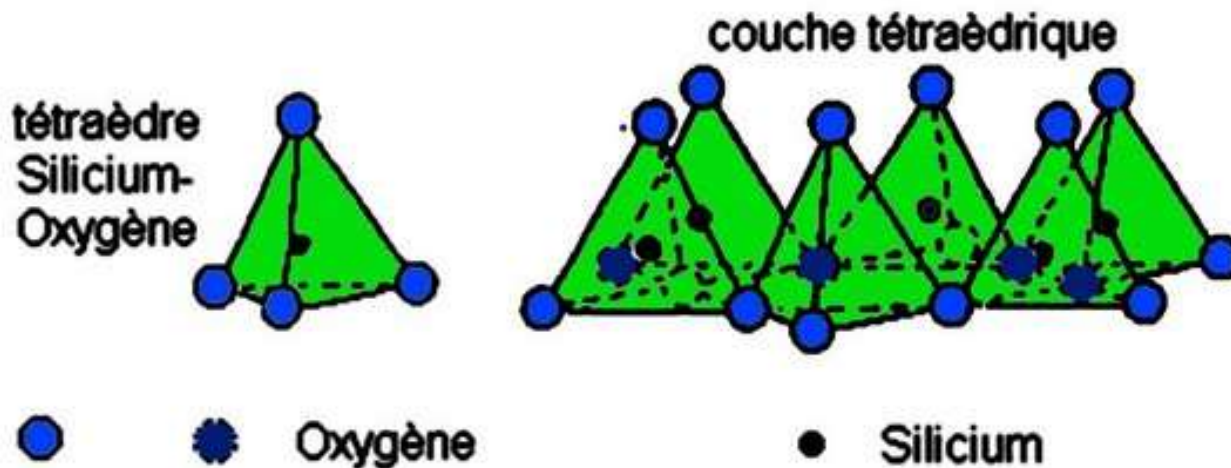
Octahedral unit and sheet

The octahedral units consist of six hydroxyls surrounding an aluminum atom , and the combination of the octahedral aluminum hydroxyl units gives an *octahedral sheet.* (This also is called a *gibbsite sheet*).

Octahedral unit and sheet

octaèdre
Aluminium-
Oxygène/
Hydroxyle

couche octaédrique

⬡   ⬣ Hydroxyle   ◑ Aluminium, Magnésium..
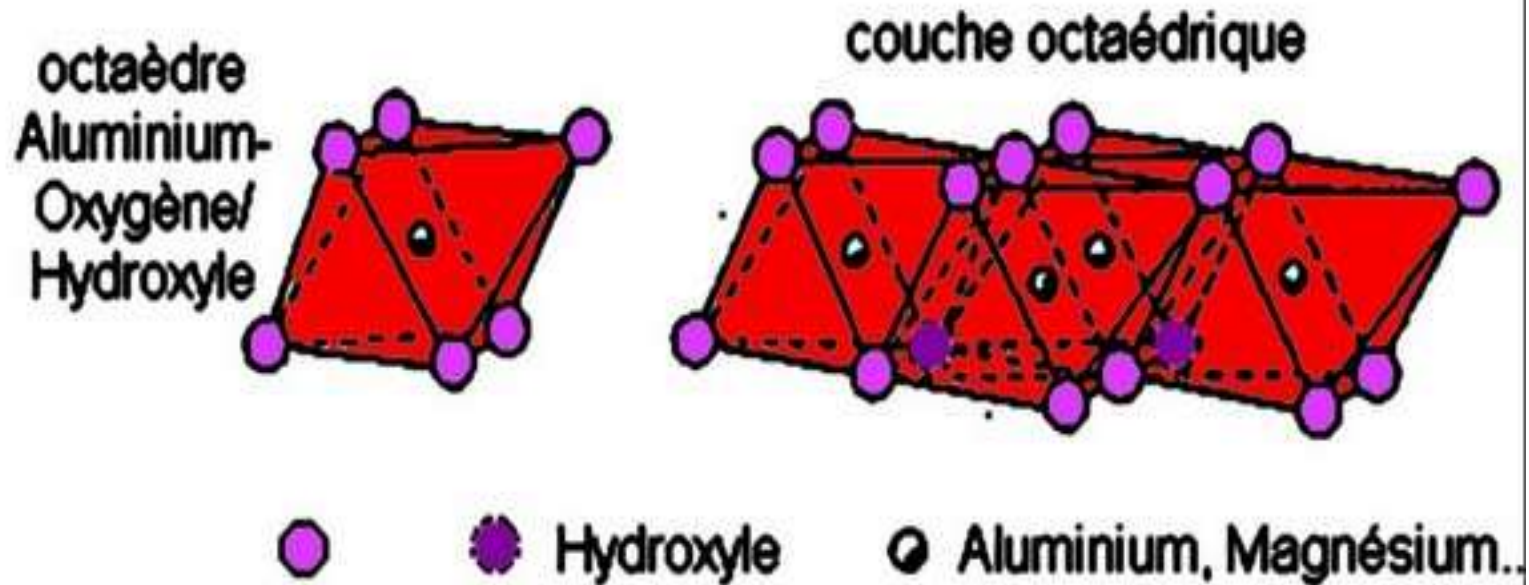
Sometimes magnesium replaces the aluminum atoms in the octahedral units; in this case, the octahedral sheet is called a *brucite sheet.*

KAOLINITE $Al_2O_3 . 2 SiO_2 . 2 H_2O$
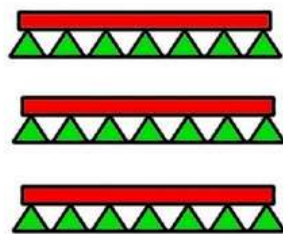
couche octaédrique
couche tétraédrique

distance inter-réticulaire: 7 Å

Argile TO

SMECTITES $2 Al_2O_3 . 8 SiO_2 . 2 H_2O . n H_2O$
(Montmorillonite) $(Mg, Ca) O . Al_2O_3 . 5 SiO_2 . n H_2O$

H_2O H_2O H_2O

substitution de Al par Mg et Fe

H_2O H_2O Ca / Na

H_2O Ca / Na H_2O
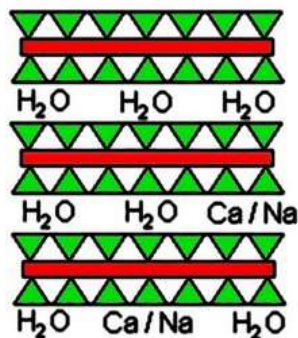
distance 14 Å
gonfle à 17 Å

Argile TOT

ILLITE $K Al_2(OH)_2 . (Al Si_3(O, OH)_{10})$

substitution de Si par Al

K^+ OH^- K^+

K^+ K^+

distance 10 Å

K^+ K^+ Fe / Mg
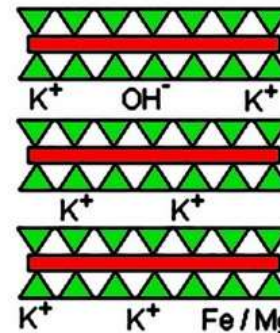
Argile TOT

CHLORITE $Mg_5(Al, Fe) (OH_8) (Al, Si)_4 O_{10}$
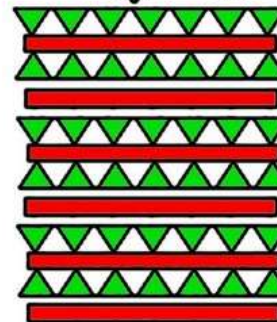
substitution de Al par Fe
couche Mg-OH

distance 14 Å

Argile TOTO

Types of clay minerals

1 – *kaolinite*

2 – Illite

3 - Montmorillonite

Kaolinite

Of the three important clay minerals, **kaolinite** consists of repeating layers of elemental silica-gibbsite sheets in a 1 : 1 lattice. Each layer is about 7.2 Å thick. The layers are held together by hydrogen bonding. Kaolinite occurs as platelets, each with a lateral dimension of 1000 to 20,000 Å and a thickness of 100 to 1000 Å. The surface area of the kaolinite particles per unit mass is about 15 m²/g. The surface area per unit mass is defined as *specific surface.*

Note : *1* Å = 10^{-10} m

Kaolinite

KAOLINITE $Al_2O_3 . 2\, SiO_2 . 2\, H_2O$

couche octaédrique
couche tétraédrique

distance inter-
réticulaire: 7 Å

Argile TC

Illite

Illite consists of a gibbsite sheet bonded to two silica sheets—one at the top and another at the bottom. It is sometimes called *clay mica.* The illite layers are bonded by potassium ions. The negative charge to balance the potassium ions comes from the substitution of aluminum for some silicon in the tetrahedral sheets.

Illite

ILLITE $K\,Al_2(OH)_2 . (Al\,Si_3(O, OH)_{10})$

substitution de Si par Al

K^+ OH^- K^+

K^+ K^+

K^+ K^+ Fe / Mg
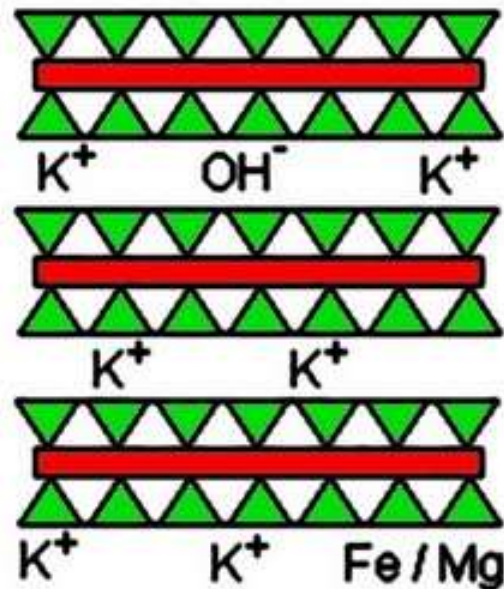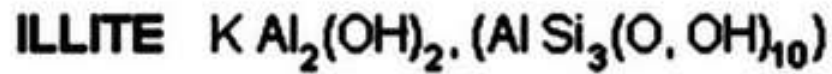
distance 10 Å

Argile TOT

Illite

Illite particles generally have lateral dimensions ranging from 1000 to 5000 Å and thicknesses from 50 to 500 Å. The specific surface of the particles is about 80 m²/g.

Montmorillonite

Montmorillonite has a structure similar to that of illite—that is, one gibbsite sheet sandwiched between two silica sheets.

In montmorillonite there is isomorphous substitution of magnesium and iron for aluminum in the octahedral sheets.

Montmorillonite

SMECTITES $\quad 2\,Al_2O_3\,,8\,SiO_2\,,2\,H_2O\,,n\,H_2O$

(Montmorillonite) $\quad (Mg,\,Ca)\,O\,,Al_2O_3\,,5\,SiO_2\,,n\,H_2O$

substitution de Al
par Mg et Fe

$H_2O \quad H_2O \quad H_2O$

$H_2O \quad H_2O \quad Ca\,/\,Na$

distance 14 Å
gonfle à 17 Å

$H_2O \quad Ca\,/\,Na \quad H_2O$
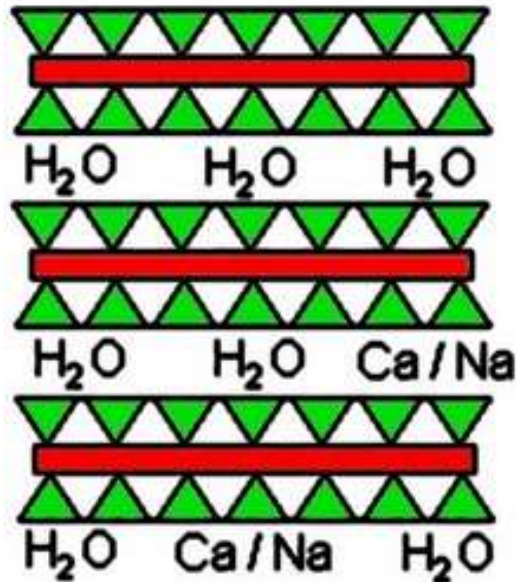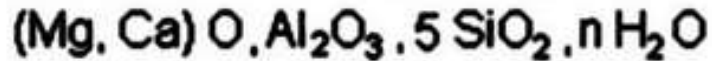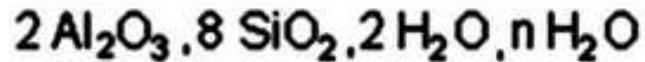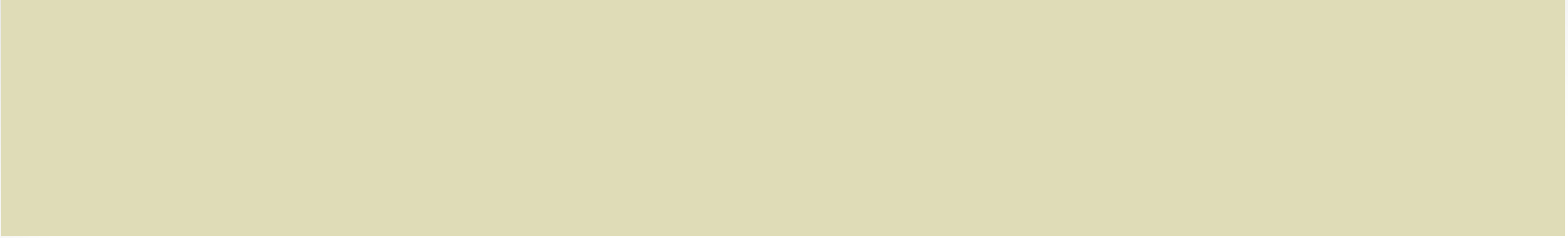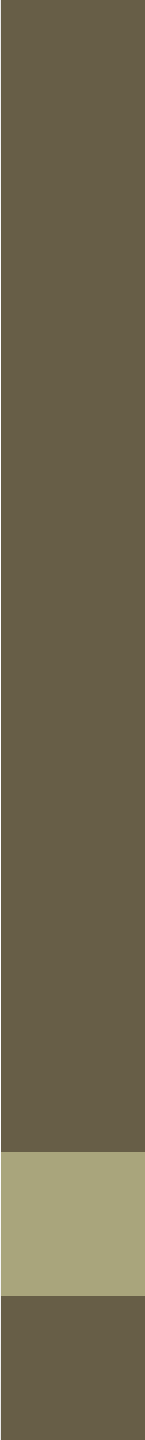
Argile TOT

Montmorillonite

Particles of montmorillonite have lateral dimensions of 1000 to 5000 Å and thicknesses of 10 to 50 Å. The specific surface is about 800 m²/g.

The clay particles carry a net negative charge on their surfaces. This is the result both of isomorphous substitution and of a break in continuity of the structure at its edges. Larger negative charges are derived from larger specific surfaces. Some positively charged sites also occur at the edges of the particles.
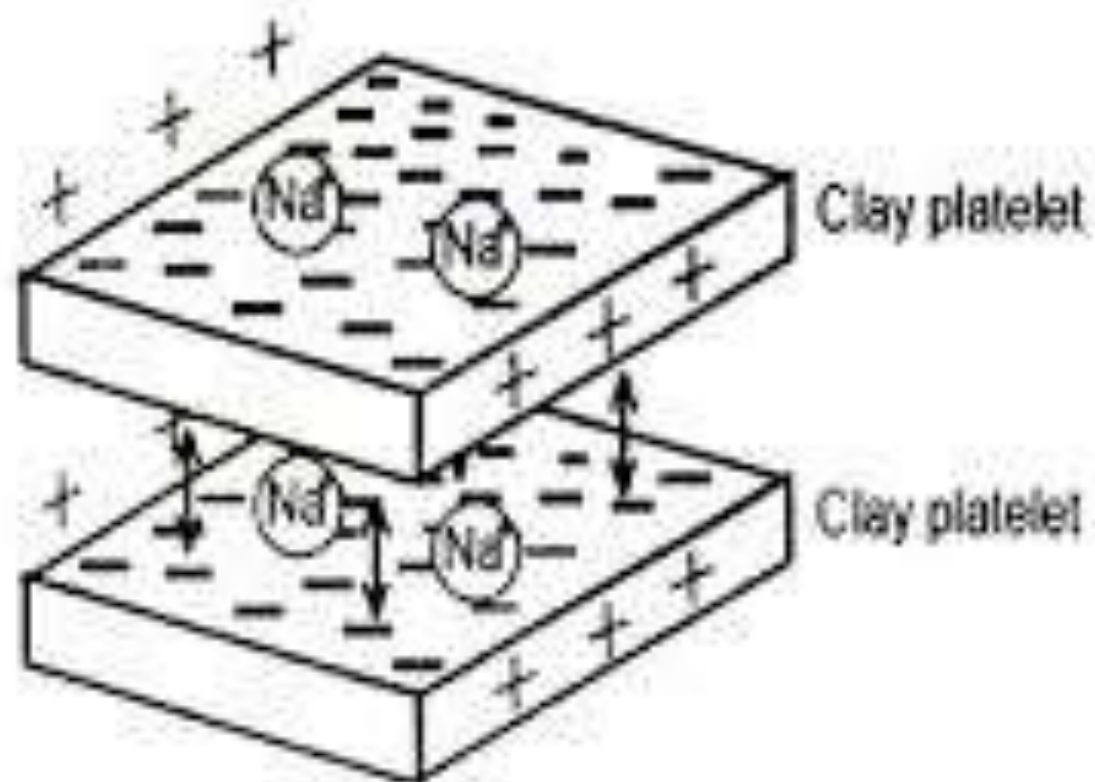
A list of the reciprocal of the average surface densities of the negative charges on the surfaces of some clay minerals follows:

Clay mineral	Reciprocal of average surface density of charge ($Å^2$/electronic charge)
Kaolinite	25
Clay mica and chlorite	50
Vermiculite	75
Montmorillonite	100

Structure of clay particles

Face to face structure

Edge to face structure

Structure of clay particles
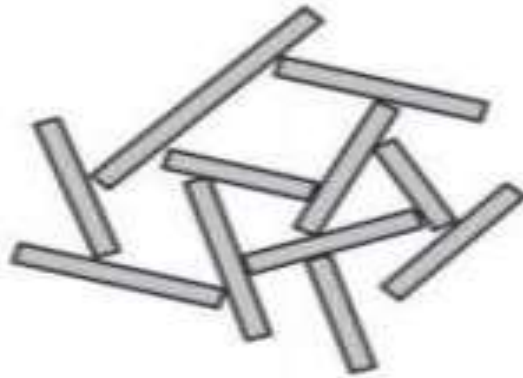
Flocculant Structure

Dispersed Structure

Grain size distribution Hydrometer analysis

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

SOIL MECHANICS & FOUNDATION ENGINEERING

Hydrometer analysis

Hydrometer analysis is used only for soils passing **sieve No. 2oo** (grains less than 0.075 mm). It is based on the principle of sedimentation of soil grains in water. When a soil specimen is dispersed in water, the particles settle at different velocities, depending on their shape, size, weight, and the viscosity of the water.

For simplicity, it is assumed that all the soil particles are spheres and that the velocity of soil particles can be expressed by **Stokes' law**, according to which :

$$V = \frac{\gamma_s - \gamma_w}{18\,\mu} * D^2$$

Where :

V = Velocity of drop of soil particles

γ_s = Unit weight of soil particles

γ_w = Unit weight of water

μ = Viscosity of water

D = Diameter of soil particle

Thus we can use **Stokes' law** for determining the diameter of the grain settled in the water as follows :

$$D = \sqrt{\frac{18\,\mu}{\gamma_s - \gamma_w} * \frac{h}{t}}$$

Where :

h = Distance of settling = Effective depth (L)

t = time elapsed

If we take γ_w = 1.0 gm / cm³ , we can simplify the last law as :

$$D\,(\,mm\,) = k * \sqrt{\dfrac{L\,(\,cm\,)}{t\,(\,min\,)}}$$

Where the values of (k) can be taken from Table (6 – 4), while the values of (L , t) can be taken from the hydrometer test results .

Values of (k)

Table 6-4   Values of K^* for use in Eq. (6-9a) for several unit weights of soil solids and temperature combinations

Temp., °C	ϵ_s of Soil Solids							
	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.0151	0.0148	0.0146	0.0144	0.0141	0.0139	0.0137	0.0136
17	0.0149	0.0146	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134
18	0.0148	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134	0.0132
19	0.0145	0.0143	0.0140	0.0138	0.0136	0.0134	0.0132	0.0131
20	0.0143	0.0141	0.0139	0.0137	0.0134	0.0133	0.0131	0.0129
21	0.0141	0.0139	0.0137	0.0135	0.0133	0.0131	0.0129	0.0127
22	0.0140	0.0137	0.0135	0.0133	0.0131	0.0129	0.0128	0.0126
23	0.0138	0.0136	0.0134	0.0132	0.0130	0.0128	0.0126	0.0124
24	0.0137	0.0134	0.0132	0.0130	0.0128	0.0126	0.0125	0.0123
25	0.0135	0.0133	0.0131	0.0129	0.0127	0.0125	0.0123	0.0122
26	0.0133	0.0131	0.0129	0.0127	0.0125	0.0124	0.0122	0.0120
27	0.0132	0.0130	0.0128	0.0126	0.0124	0.0122	0.0120	0.0119
28	0.0130	0.0128	0.0126	0.0124	0.0123	0.0121	0.0119	0.0117
29	0.0129	0.0127	0.0125	0.0123	0.0121	0.0120	0.0118	0.0116
30	0.0128	0.0126	0.0124	0.0122	0.0120	0.0118	0.0117	0.0115

* Units for K: $mm\left(\dfrac{min}{cm}\right)^{1/2}$

Type of hydrometer

The type of hydrometer
used in the laboratory is
(ASTM 152H)

which has gradations of :

0 , 10 , 20 , 30 , 40 , 50 , 60

In the laboratory, the hydrometer test is conducted in a sedimentation cylinder usually with 50 g of oven-dried sample. The sedimentation cylinder is 457 mm high and 63.5 mm in diameter. It is marked for a volume of 1000 ml.

Sedimentation cylinders

Dispersing agent

Sodium hexametaphosphate generally is used as the *dispersing agent.* The volume of the dispersed soil suspension is increased to 1000 ml by adding distilled water.

Concentration and quantity of dispersing agent

The quantity of dispersing agent added to the soil sample is **(125 cc)** and its concentration is **(4 %)** . Electrical mixer is usually used for (1 min) .

Readings of hydrometer
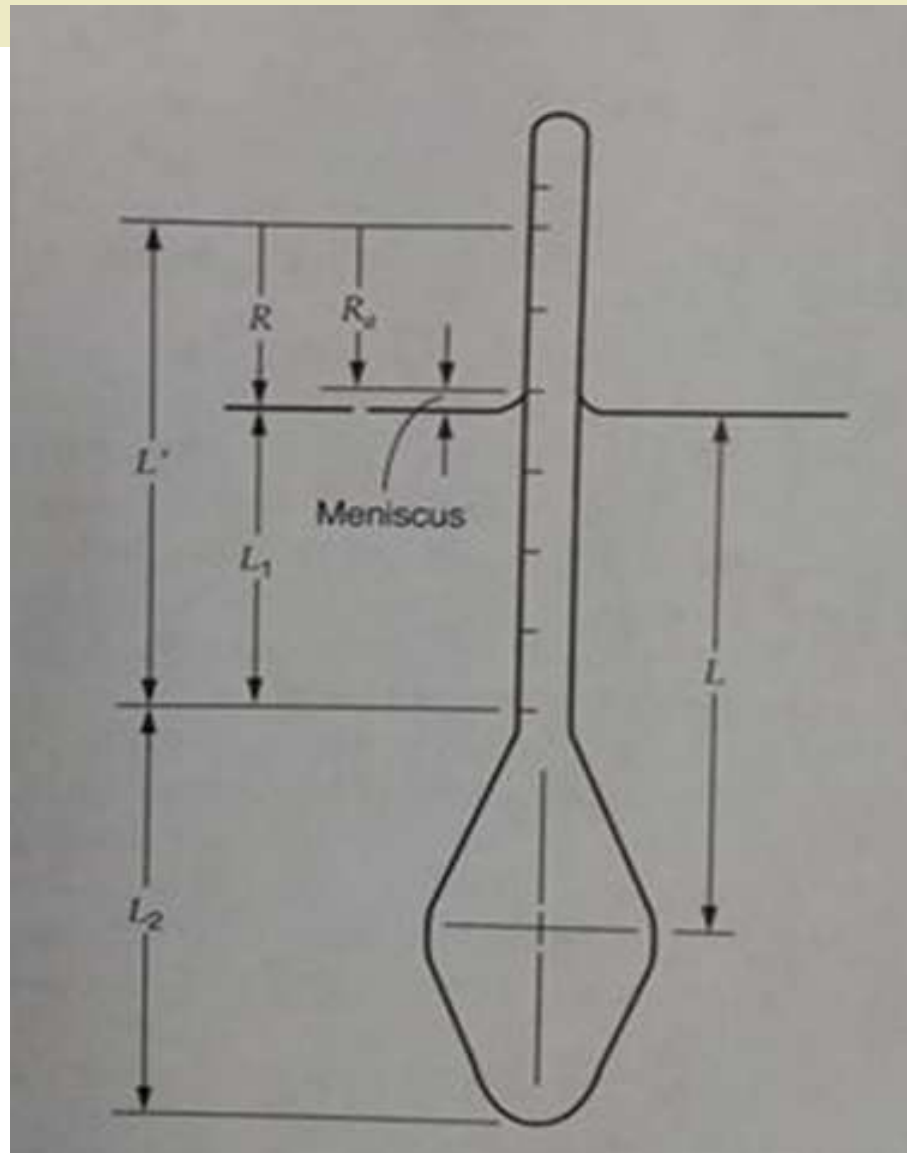
When a hydrometer is placed in the soil suspension at any time **(t)** , measured from the start of sedimentation it measures the specific gravity in the vicinity of its bulb at an effective depth **(L)** . The values of **(L)** can be taken from Table (6 – 5) depending on actual hydrometer reading (Ra) corrected for meniscus (Ra + 1.0) .

Table 6-5 Values of L (effective depth) for use in Stokes' formula for diameters of particles for ASTM soil hydrometer 152H

Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth L, cm
0	16.3	21	12.9	42	9.4
1	16.1	22	12.7	43	9.2
2	16.0	23	12.5	44	9.1
3	15.8	24	12.4	45	8.9
4	15.6	25	12.2	46	8.8
5	15.5	26	12.0	47	8.6
6	15.3	27	11.9	48	8.4
7	15.2	28	11.7	49	8.3
8	15.0	29	11.5	50	8.1
9	14.8	30	11.4	51	7.9
10	14.7	31	11.2	52	7.8
11	14.5	32	11.1	53	7.6
12	14.3	33	10.9	54	7.4
13	14.2	34	10.7	55	7.3
14	14.0	35	10.5	56	7.1
15	13.8	36	10.4	57	7.0
16	13.7	37	10.2	58	6.8
17	13.5	38	10.1	59	6.6
18	13.3	39	9.9	60	6.5
19	13.2	40	9.7		
20	13.0	41	9.6		

The specific gravity is a function of the amount of soil particles present per unit volume of suspension at that depth. Also, at a time **(t)** , the soil particles in suspension at a depth **(L)** will have a diameter smaller than **(D)** as calculated . The larger particles would have settled beyond the zone of measurement.

Hydrometers are designed to give the amount of soil, in grams, that is still in suspension. They are calibrated for soils that have a specific gravity of **(*Gs* = 2.65)** . So that the readings for soils of other specific gravities must be corrected . See Table (6 -2) .

Table 6-2 Correction factors a for unit weight of solids

ϵ_s of soil solids	Correction factor a
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

By knowing the amount of soil in suspension , *L* , and *t* , we can calculate the percentage of soil by weight finer than a given diameter. Note that *L* is the depth measured from the surface of the water to the center of gravity of the hydrometer bulb at which the density of the suspension is measured. The value of *L* will change with time *t*.

$$\% F = \frac{Rc * a}{Ws} * 100$$

$$\% \, F = \frac{Rc * a}{Ws} * 100$$

Where :

$\% \, F$ = Percentage of soil by weight finer than a given diameter

a = Correction for specific gravity taken from table (6 – 2)

Ws = The amount of soil used , in grams

Rc = Corrected reading

The actual reading of hydrometer (Ra) must be corrected for temperature and dispersing agent before it used in the above law , (Ra $\longrightarrow$ Rc) .

Corrections for actual readings of hydrometer

As mentioned above the main corrections of hydrometer readings are :

1 – Dispersing agent correction :

It has a value of **(3.0)** which is usually subtract from the actual reading so as to remove the effect of the dispersing agent .

2 - Temperature correction (C T) :

It depends on the temperature of the suspension , and its values can be taken from Table (6-3) .

Table 6-3 Temperature correction factors C_T

Temp., °C	C_T
15	1.10
16	−0.90
17	−0.70
18	−0.50
19	−0.30
20	0.00
21	+0.20
22	+0.40
23	+0.70
24	+1.00
25	+1.30
26	+1.65
27	+2.00
28	+2.50
29	+3.05
30	+3.80

Thus :

We can say that :

Rc = Ra − 3.0 + CT

Where :

Rc = Corrected reading of hydrometer used for

finding (% F) . $[\% \boldsymbol{F} = \dfrac{\boldsymbol{Rc} * \boldsymbol{a}}{\boldsymbol{Ws}} * \boldsymbol{100}]$

Ra = Actual reading of hydrometer .

CT = Temperature correction , taken from Table
 (6 − 3).

Readings of hydrometer must be taken at time intervals :

1 min , 2min , 4min , 8min , 15 min , ½ hr , 1hr , 2hr , 24hr

At each hydrometer reading , temperature of the suspension must be taken using a thermometer .

Origin of Soil and Formation

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

SOIL MECHANICS & FOUNDATION ENGINEERING

Historical Background

For engineering purposes, **SOIL** is defined as :

The uncemented aggregate of mineral grains and decayed organic matter (Solid Particles) with liquid and gas in the empty spaces between the solid particles.

SOIL is used as a construction material in various civil engineering projects, and it supports structural foundations.

Thus, civil engineer must study the properties of soil, such as its origin, grain size distribution, ability to drain water, compressibility, shear strength, and load bearing capacity.

SOIL MECHANICS is the branch of science that deals with the study of the physical properties of soil and the behavior of soil masses subjected to various types of forces.

SOIL ENGINEERING is the application of the principles of soil mechanics to practical problems.

GEOTECHNICAL ENGINEERING is the sub discipline of civil engineering that involves natural materials found close to the surface of the earth. It includes the application of the principles of soil mechanics and rock mechanics to the design of foundations, retaining structures, and earth structures.

ORIGIN OF SOIL AND GRAIN SIZE

In general, soils are formed by weathering of rocks.

The physical properties of soil are primarily dictated by the minerals that constitute the soil particles and, hence, the rock from which it is derived.

This lecture provides an outline of the rock cycle and the origin of soil and the grain-size distribution of particles in a soil mass.

TYPES OF ROCKS

1- Igneous rocks

2- Sedimentary rocks

3- Metamorphic rocks

WEATHERING

Weathering is the process of breaking down rocks by *mechanical* and *chemical processes* into smaller pieces.

TYPES OF WEATHERING

1- Mechanical Weathering.
2- Chemical Weathering.

1- Mechanical Weathering

Mechanical weathering may be caused by the expansion and contraction of rocks from the continuous gain and loss of heat, which results in ultimate disintegration.

Frequently, water seeps into the pores and existing cracks in rocks. As the temperature drops, the water freezes and expands. The pressure exerted by ice because of volume expansion is strong enough to break down even large rocks. Other physical agents that help disintegrate rocks are glacier ice, wind, the running water of streams and rivers, and ocean waves. It is important to realize that in mechanical weathering, large rocks are broken down into smaller pieces without any change in the chemical composition.

2- Chemical Weathering

In chemical weathering, the original rock minerals are transformed into new minerals by chemical reaction. Water and carbon dioxide from the atmosphere form carbonic acid, which reacts with the existing rock minerals to form new minerals and soluble salts. Soluble salts present in the groundwater and organic acids formed from decayed organic matter also cause chemical weathering.
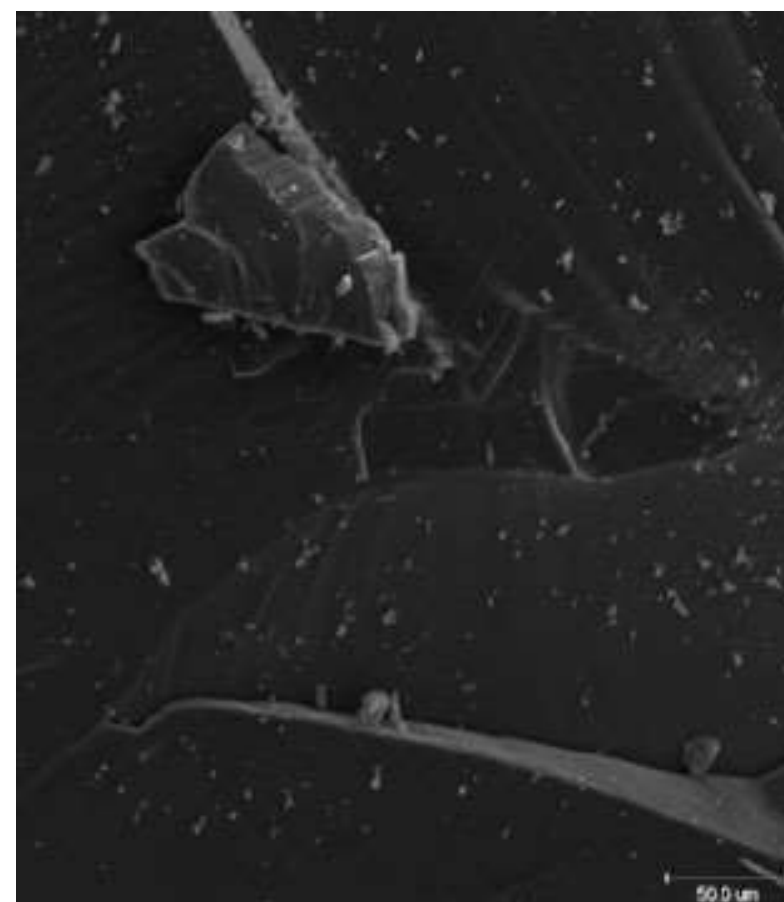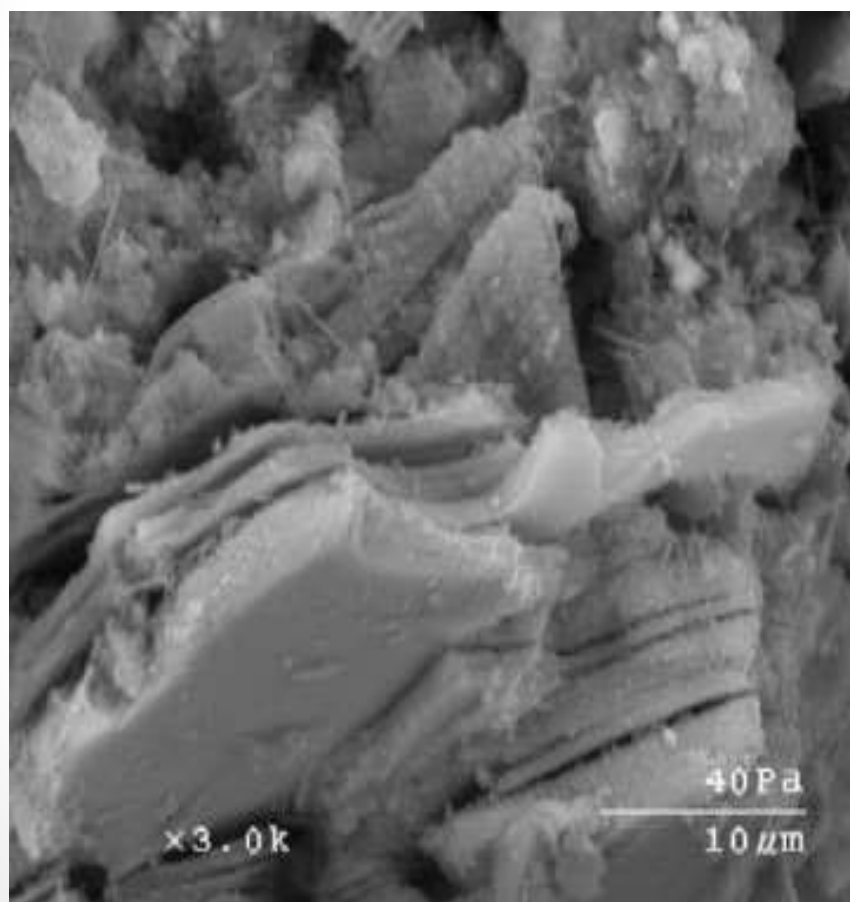
WEATHERING PRODUCTS

Type of soil	Grain size (mm)
Gravel	More than (4.75) mm
Sand	(4.75 – 0.075) mm
Silt	(0.075 – 0.002) mm
Clay	Less than (0.002) mm

Transportation of Weathering Products

The products of weathering may stay in the same place or may be moved to other places by **ice, water, wind, and gravity.**

The soils formed by the weathered products at their place of origin are called *Residual Soils.*

An important characteristic of residual soil is the gradation of particle size. Fine grained soil is found at the surface, and the grain size increases with depth. At greater depths, angular rock fragments may also be found.

Transported Soils

The transported soils may be classified into several groups, depending on their mode of transportation and deposition:

1. *Glacial soils*—formed by transportation and deposition of glaciers.

2. *Alluvial soils*—transported by running water and deposited along streams.

Transported Soils

3. *Lacustrine soils*—formed by deposition in quiet lakes.

4. *Marine soils*—formed by deposition in the seas.

5. *Aeolian soils*—transported and deposited by wind.

6. *Colluvial soils*—formed by movement of soil from its original place by gravity, such as during landslides.

Atterberg limits

SALIM MHEIDY SALIH

MSc. CIVIL ENGINEERIG

SOIL MECHANICS & FOUNDATION ENGINEERING

Introduction

When clay minerals are present in fine-grained soil, the soil can be remolded in the presence of some moisture without crumbling. This cohesive nature is caused by the adsorbed water surrounding the clay particles. A Swedish scientist named **Atterberg** developed a method to describe the consistency of fine-grained soils with varying moisture contents.

At a very low moisture content, soil behaves more like a solid. When the moisture content is very high, the soil and water may flow like a liquid. Hence, on an arbitrary basis, depending on the moisture content, the behavior of soil can be divided into four basic states—*solid, semisolid, plastic,* and *liquid*—

Definitions

Liquid limit (L.L.) :

It is the moisture content, in percent, at the point of transition from plastic state to liquid state .

Plastic limit (P.L.) :

It is the moisture content, in percent, at the point of transition from semisolid state to plastic state .

Shrinkage limit (S.L.) :

It is the moisture content, in percent, at the point of transition from solid state to semisolid state .

These parameters are also known as **_Atterberg limits_**.

See the following Table .

States or Limits	Degree of Saturation	Volume	Color
Liquid State	The soil is fully saturated (S = 100 %)	The volume is decreased	Dark
Liquid Limit (L.L.)			
Plastic State			
Plastic Limit (P.L.)			
Semi-Solid State			
Shrinkage Limit (S.L.)			
Solid State	Partially saturated (S < 100 %)	The volume is constant	Light

Liquid limit (L.L.)

A liquid limit device or (Cassagrande device) is shown in the adjacent picture . This device consists of a brass cup and a hard rubber base. The brass cup can be dropped onto the base by a cam operated by a crank.

To perform the liquid limit test, the soil must air dried and passed through sieve No. 40, then water added to the soil to make a paste which placed in the cup of the device. A groove is then cut at the center of the soil pat with the standard grooving tool (as shown in the picture) .

By the use of the crank-operated cam, the cup is lifted and dropped from a height of 10 mm at a rate of (2 blows /sec) . The moisture content, in percent, required to close a distance of 12.7 mm along the bottom of the groove after 25 blows is defined as the *liquid limit* .
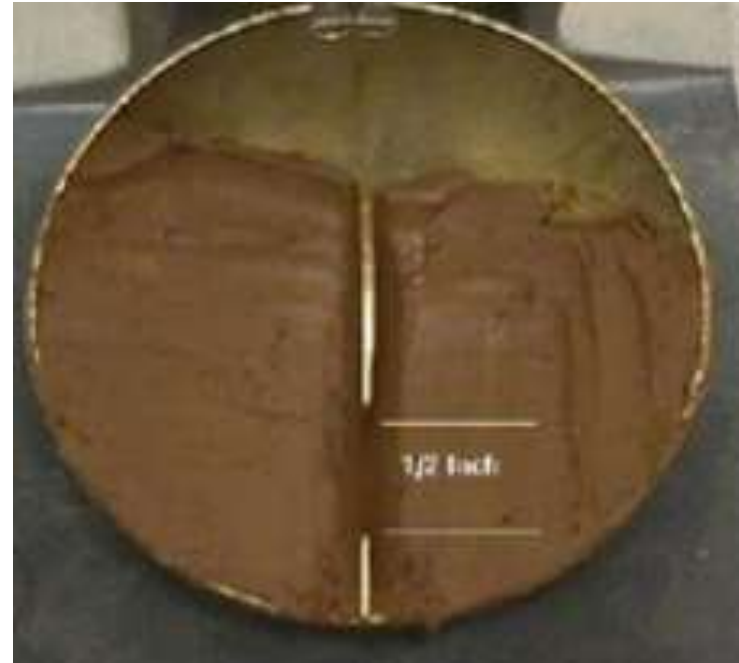
It is difficult to adjust the moisture content in the soil to meet the required 12.7 mm closure of the groove in the soil pat at 25 blows. Hence, at least three tests for the same soil are conducted at varying moisture contents, with the number of blows **(N)** required to achieve closure of the groove . The moisture content of the soil, in percent, and the corresponding number of blows are plotted on semi logarithmic graph paper . The relationship between moisture content and log N is approximated as a straight line. This line is referred to as the **flow curve.** The moisture content corresponding to **(N = 25)** , determined from the flow curve, gives the liquid limit of the soil.
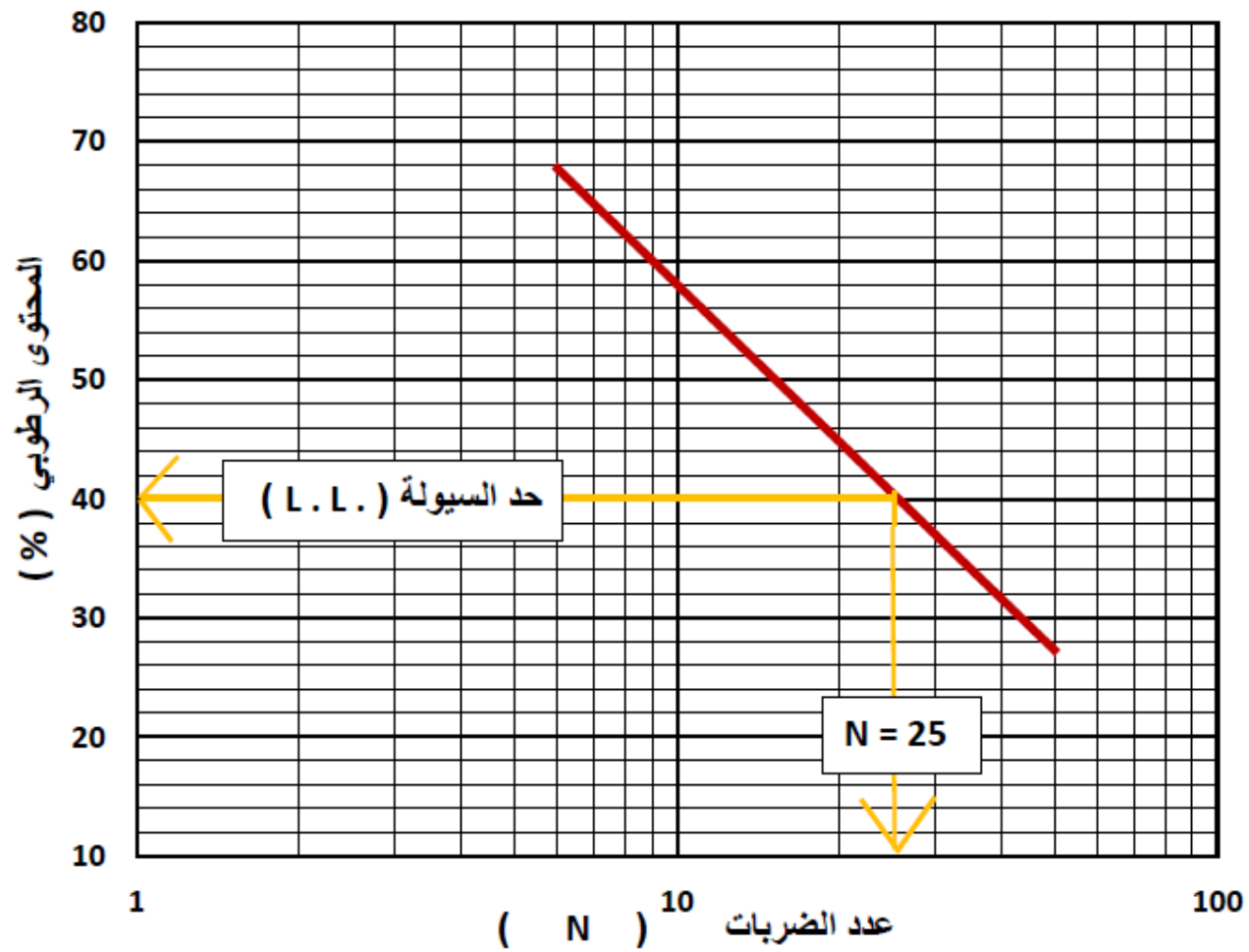
From the analysis of hundreds of liquid limit tests, the U.S. Army Corps of Engineers (1949) in Mississippi, proposed an empirical equation of the form :

$$L.L. = w.c \times \left(\frac{N}{25}\right)^{0.121}$$

Where :

N = Number of blows in the liquid limit device for a (12.7 mm) groove closure .

wc = Corresponding moisture content .

Plastic limit (P.L.)

The ***plastic limit*** is defined as the moisture content in percent, at which the soil crumbles, when rolled into threads of 3.0 mm in diameter. The plastic limit is the lower limit of the plastic stage of soil. The plastic limit test is simple and is performed by repeated rollings of an ellipsoidal-sized soil mass by hand on a ground glass plate (see the adjacent Figure).

Plasticity Index (P.I.)

The ***plasticity index* (*PI*)** is the difference between the liquid limit and the plastic limit of a soil, or :
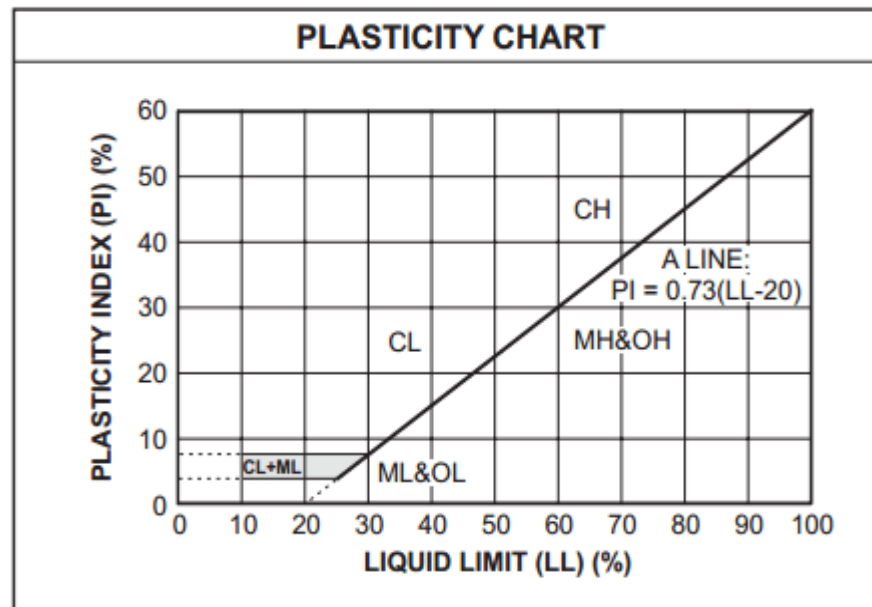
$$\textbf{P.I. = L.L. – P.L.}$$

Where :

P.I. = Plasticity Index

L.L. = Liquid Limit

P.L. = Plastic Limit

The plasticity index is important in classifying fine-grained soils. It is fundamental to the Cassagrande plasticity chart , which is currently the basis for the **Unified Soil Classification System**.

PLASTICITY CHART

A LINE:
PI = 0.73(LL-20)

The Plasticity Index can be classified in a qualitative manner as follows:

P.I.	Description
0	Nonplastic
1 - 5	Slightly plastic
5 - 10	Low plasticity
10 - 20	Medium plasticity
20 - 40	High plasticity
> 40	Very high plasticity

Liquidity Index (L . I .)

The relative consistency of a cohesive soil in the natural state can be defined by a ratio called the *liquidity index* , which is given by :

$$LI = \frac{w - P.L.}{P.I.}$$

Where :

W = In situ water content of soil

P.L. = Plastic Limit

P.I. = Plasticity Index

Consistency Index (C . I .)

Another index that is commonly used for engineering purposes is the **Consistency Index** , which may be defined as :

$$CI = \frac{L.L. - w}{P.I.}$$

Where :

W = In situ water content of soil

L.L. = Liquid Limit

P.I. = Plasticity Index

Correlation between (CI) and Unconfined Compression Strength of Clay

C.I.	Unconfined Compression Strength (kN / m²)
< 0.5	< 25
0.5 – 0.75	25 - 80
0.75 – 1.0	80 - 150
1.0 – 1.5	150 - 400
> 1.5	> 400

Activity

Because the plasticity of soil is caused by the adsorbed water that surrounds the clay particles, we can expect that the type of clay minerals and their proportional amounts in a soil will affect the liquid and plastic limits. Skempton (1953) observed that the plasticity index of a soil increases linearly with the percentage of clay-size fraction (% finer than 2 μm by weight) present .

Skempton defined a quantity called **_activity_**, which may be expressed as :

$$A = \frac{P.I.}{(\% \ of \ clay \ size \ fraction)}$$

Where :

A = Activity

P.I. = Plasticity Index

Activity is used as an index for identifying the swelling potential of clay soils . Typical values of activities for various clay minerals are given in the following Table :

Clay mineral	Activity
Kaolinite	0.3 – 0.5
Illite	0.5 – 1.2
Montmorillonite	1.5 – 7.0