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Soil Texture (نسيج التربة)

Composition and description of an Individual Soil Particle :

Soil Particle

Inorganic (Minerals and rocks)   Organic (peat: decomposition of plants and animals)

in general: Soil may be divided into three main classes

1- Coarse – grained or non- cohesive soils
2- fine grained or cohesive soils
3- organic soil

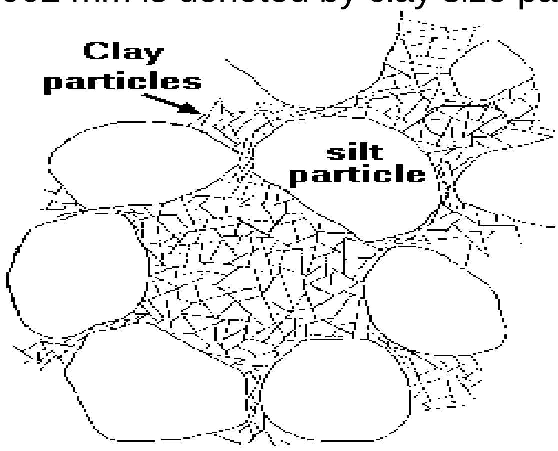
(1 and 2: Inorganic due to weathering process)

Particle Size : Vary from 1x 10^{-6} to rocks of several meters in thickness.

According to MIT:

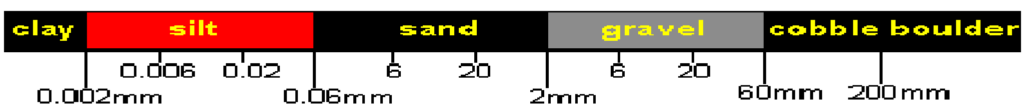
Coarse grained soils:	Boulders	> 300mm
	Cobble	150-300mm
	Gravel	2 - 150mm
	Sand	0.06- 2 mm
Fine –grained soil	Silt	0.002-0.06 mm
	Clay	< 0.002

Note: particles of size < 0.002 mm is denoted by clay size particles



Clay size particles:

- clay minerals (silicate of Mg, Al, Fe)
- Fine particles of quartz or feldspar



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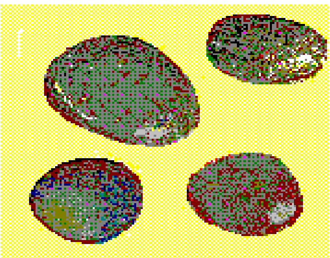
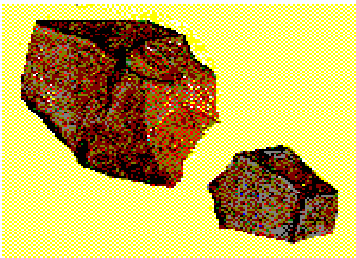
Particle shape

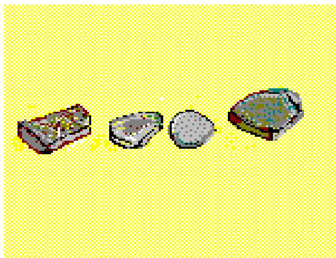
For *sand and silt* : equidimensional , cube or sphere.
For *clay* : platy shape **.**

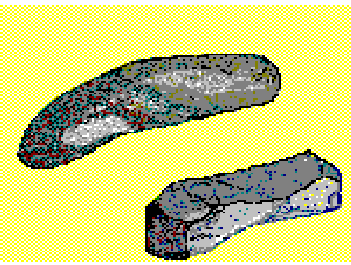
Rounded: Water- or air-worn; transported sediments
Irregular: Irregular shape with round edges; glacial sediments (sometimes sub-divided into 'sub-rounded' and 'sub-angular')
Angular: Flat faces and sharp edges; residual soils, grits
Flaky: Thickness small compared to length/breadth; clays
Elongated: Length larger than breadth/thickness; screen, broken flagstone
Flaky & Elongated: Length>Breadth>Thickness; broken schists and slates
Sieve analysis example


Rounded

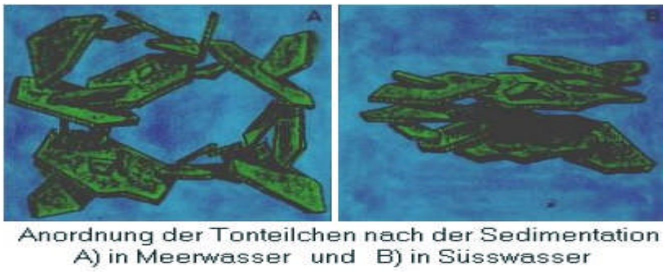

Irregular


Angular


Flaky


Elongated


Flaky & Elongated



Clays Platy Shape

Specific surface: is the surface area per unit mass.

Kaolinite	10 - 20 m^2 /g
Illite	80 -100 m^2 /g
Montmorillonite	800 m^2 /g

Forces on soil particle:

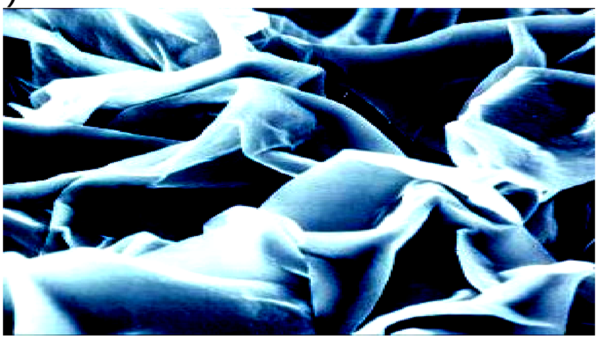
Forces:

- Surface derived forces (*fine – grained*) → Colloid
- Mass derived forces (*Coarse – grained*)

Colloid: this term is used to describe a particle whose behavior is controlled by the surface derived surface.

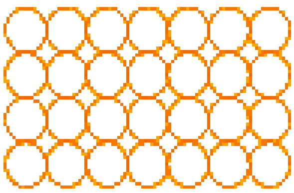
- Colloid range: 1ηm→1μm ,lower limit has a sp. Surface (10^{-9}m) → (10^{-6}m) from 25 m^2/g. (<1ηm lie the diameter of atoms and molecules)
- Clay particle is a colloid because of its small size (< 0.002mm = 2 μm) and irregular

shape (plately Shape).

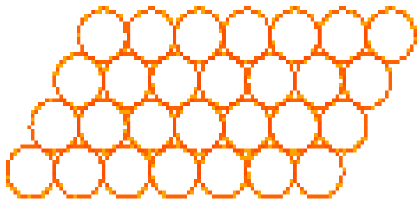


<u>Soil Structure (Fabric):</u> refers to orientation and distribution of particles in a soil mass.

1-for *<u>coarse-grained soils</u>*



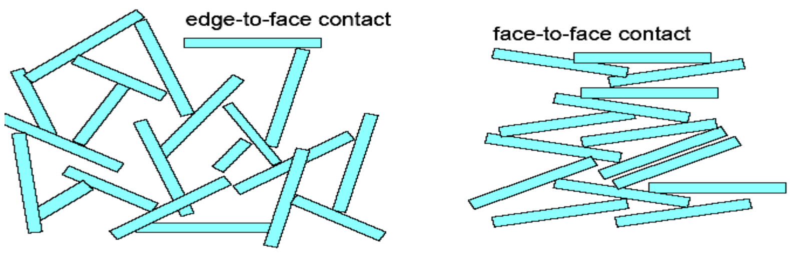
Loose State



dense State

2-for *<u>clay</u>*

Clay Fabric



Flocculated *Dispersed*

<u>Dispersed structure:</u> has parallel particles which tend to repel each other.

<u>Flocculated Structure:</u> in which the soil particles are edge to face and attract each other.

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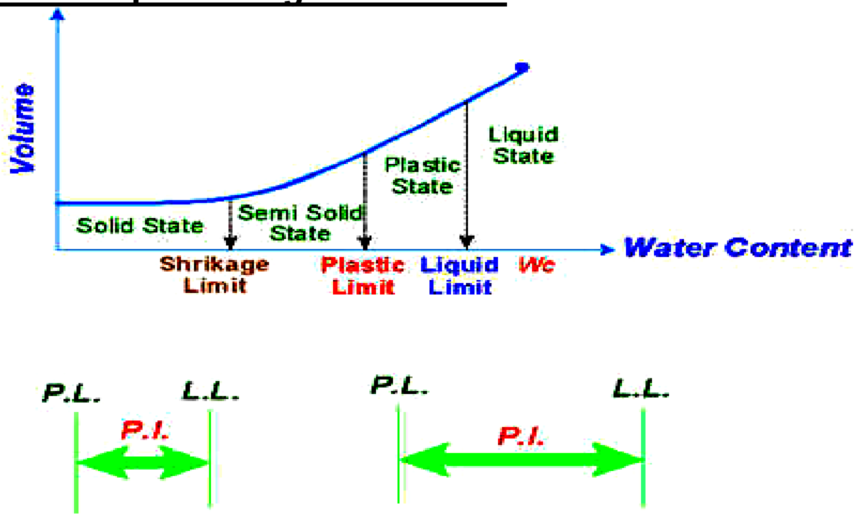
Consistency and Atterberg Limits:

When *clay minerals* are present in fine grained soil, that soil can be remolded in the presence of some *moisture content* without crumbling. This *cohesive nature* is due to the *adsorbed water* surrounding the clay particles.

Consistency: the relative case with which a soil mass can be deformed.

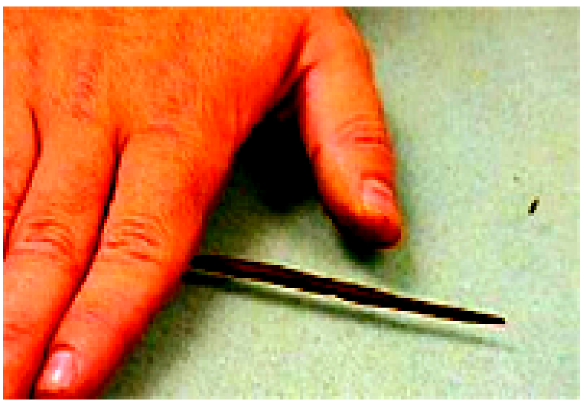
Atterberg Limits: these limits are based on the concept that a fine grained soil can exist in any *four states depending on its water content.*

W_c - Volume relationship of fine grained soils:



Shrinkage Limit S.L : min. water content at which further loose in water does not cause a decrease in soil volume.

Plastic Limit P.L: is the water content of the soil between the plastic and semi-solid states at which threads of 3mm of the soil can be rolled without breaking.

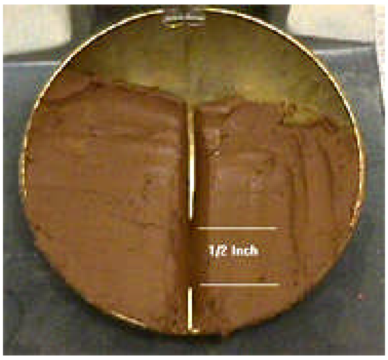


Liquid Limit L.L; Min water content at which soil flow under its own weight.

Plasticity Index P.I: is the numerical difference between the liquid limit and plastic limit.

$$PI = LL - PL$$

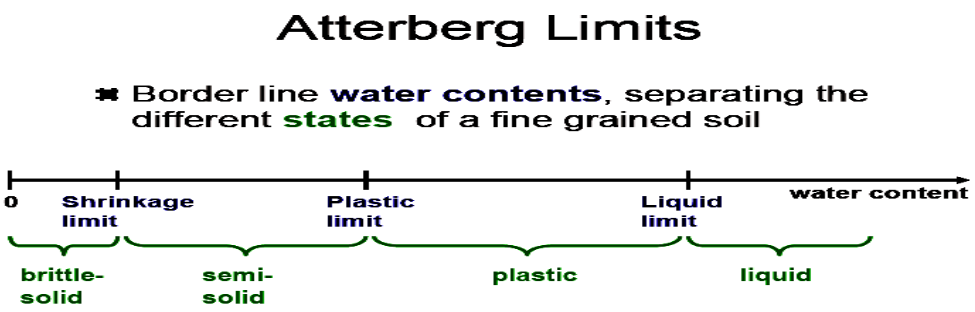




- The classification system uses the term “fines” to describe everything that passes through a # 200 sieve (<0.075mm)
- No attempt to distinguish between silts and clays in terms of particles sizes since the biggest difference between silt and clay is not their particle sizes, but their physical and chemical structures
- The soil consistency is used as a practical and an inexpensive way to distinguish between silts and clays
- Plasticity property is important because it describes the response of a soil to change in moisture content
- Water Content Significantly affects properties of Silty and Clayey soils (unlike sand and gravel)
  - ***Strength decreases as water content increases***
  - ***Soils swell-up when water content increases***
  - ***Fine-grained soils at very high water content possess properties similar to liquids***
  - ***As the water content is reduced, the volume of the soil decreases and the soils become plastic***
  - ***If the water content is further reduced, the soil becomes semi-solid when the volume does not change***

- Atterberg limits are important to describe the consistency of fine-grained soils
- The knowledge of the soil consistency is important in defining or classifying a soil type or predicting soil performance when used a construction material
- A fine-grained soil usually exists with its particles surrounded by water.

- The amount of water in the soil determines its state or consistency
- Four states are used to describe the soil consistency;
  solid, semi-solid, plastic and liquid



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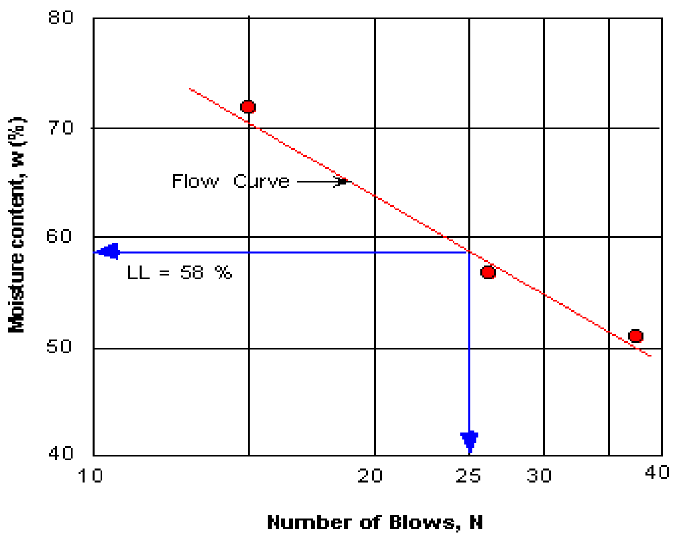

<u>Toughness Index</u> I_t: $I_t = \frac{P.I}{I_f}$

<u>Liquidity Index L.I</u>: is the ratio expressed as a percentage of the natural water content of a given soil sample minus its plastic limit to its plasticity index.

$$L.I = \frac{Wc - P.L}{L.L - P.L} = \frac{Wc - P.L}{P.I}$$

<u>Now if</u> L.I < 0 : Wc < P.L → Soil in semi or solid State
L.I = 0; Wc = P.L → Soil at P.L
0 < L.I < 1: Wc < L.L → Soil at plastic State
L.I =1: Wc = L.L → Soil at L.L
L.I > 1: Wc > L.L → Soil at liquid State.

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Notes on Atterberg Limits:

1-The limits are used in classification and specification (ex: for controlling soil for use in fill).

2-The limits depend on a mount and type of *clay minerals* and the nature of (+ ve) ions in pore water, a soil of greater tendency to attach water to the particle surface will have larger L.L.

3- Soil of higher L.L has higher P.L and higher compressibility.

Activity of clay: is the ratio of plasticity index of a soil sample to percent by weight of the particles finer than 0.002 mm in size.

*So-called 'clay' soils are not 100% clay. The proportion of clay mineral flakes (< 2 μm size) in a fine soil affects its current state, particularly its tendency to swell and shrink with changes in water content. The degree of plasticity related to the clay content is called the **activity** of the soil.*

Activity = I_P / (% clay particles)

Activity depends on:

- specific surface.
- amount of clay particles.
- type of clay minerals.

Atterberg limits for clay minerals.

Mineral	*LL*	*PL*	*SL*	I_P	*Activity, A*
Kaolinite	30 - 110	25 - 40	25 - 29	5 – 70	0.5
Illite	60 - 120	35 - 60	15 - 17	25 – 60	0.5 – 1
Montmorillonite	100 - 900	50 - 100	8.5 - 15	50 - 800	1 – 7

Void Ratio For Granular Soils and Cohesive Soils:

- for cohesive soils, values of (e) mainly depend on pressure.
- for granular soils, (e) depends on :
  - vibration,
  - Range of particle sizes

Relative Density D_r: its use to describe density of natural granular soils.

$$Dr = \frac{e_{max} - e}{e_{max} - e_{min}} x100\%$$

e_{min}, e_{max} =Void ratio of soil in densest and loosest condition
e = natural or in situ void ratio

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Dr%	***Description of soil***
0 - 15	***Very loose***
15 - 35	***loose***
35- 65	***medium***
65 - 85	***dense***
85 - 100	***Very dense***

The expression for relative density can also be written in terms of the dry unit weights associated with the various voids ratios. From the definitions we have

$$e = \frac{G_s \gamma_w}{\gamma_{dry}} - 1$$

and hence

$$I_d = \frac{\dfrac{1}{\gamma_{dry_{\min}}} - \dfrac{1}{\gamma_{dry}}}{\dfrac{1}{\gamma_{dry_{\min}}} - \dfrac{1}{\gamma_{dry_{\max}}}} = \frac{\gamma_{dry_{\max}} (\gamma_{dry} - \gamma_{dry_{\min}})}{\gamma_{dry} (\gamma_{dry_{\max}} - \gamma_{dry_{\min}})}$$

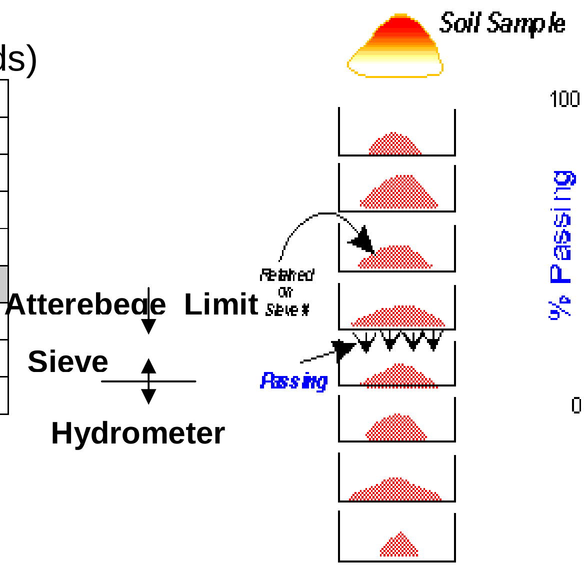
<u>Particle size Distribution:</u>

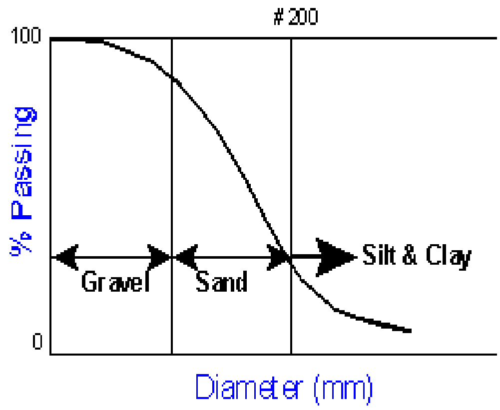
steps:

- sieve analysis (dry mechanical analysis).
- hydrometer analysis (wet analysis).
- combined analysis.

<u>Sieves</u> (U.S standards)

No.	***Penning size***
4	***4.76***
10	***2.00***
20	***0.84***
30	***0.59***
40	***0.42***
60	***0.25***
100	***0.147***
200	***0.075***



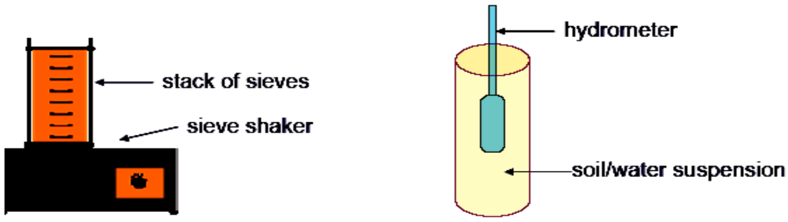


3/8", ¼" sieves is the size of the opening

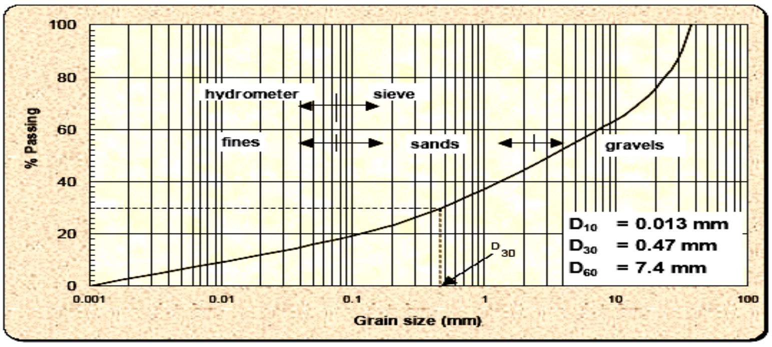
- *No.10 sieve …. has 10 apertures per linear inch*
- *Use sieves __No.3/8"__, __No.4__, __No.10__, __No.40__, __No.140__ & __No.200__*

Determination of GSD:

- In coarse grain soils ...... By sieve analysis
- In fine grain soils ...... By hydrometer analysis



Sieve Analysis   Hydrometer Analysis



Grain Size Distribution Curve

- can find % of gravels, sands, fines
- define D_{10}, D_{30}, D_{60}.. as above.

Uniformity Coefficient (Cu)

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

D_{60},D_{10}=soil diameter at which 60% and 10% of the soil weight is finer.

- smaller Cu means smaller range of particle size.
- A soil of Cu < 4 is considered uniform for gravel
- Cu < 6 is considered uniform for sand

Coefficient of Graduation (Cc) or Curvature:

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

If 1 < __Cc__ < 3 the soil is well graded.

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Sorting Coefficient

$$S_c = \sqrt{\frac{D_{75}}{D_{25}}}$$

Well or Poorly Graded Soils

Well Graded Soils

Wide range of grain sizes present

Gravels: C_c = 1-3 & C_u >4

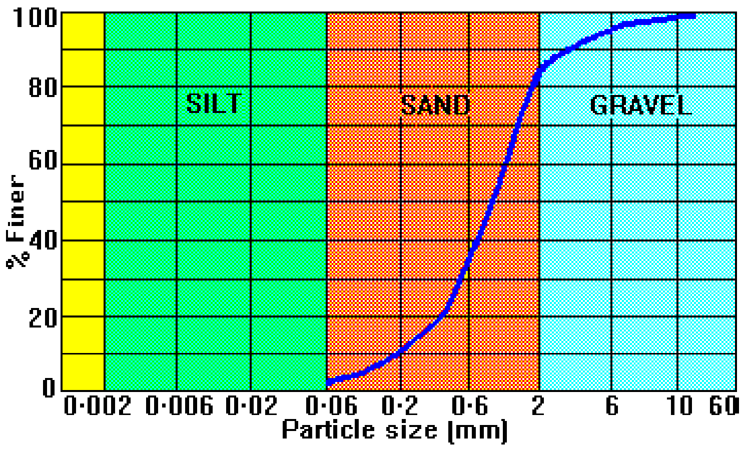
Sands: C_c = 1-3 & C_u >6

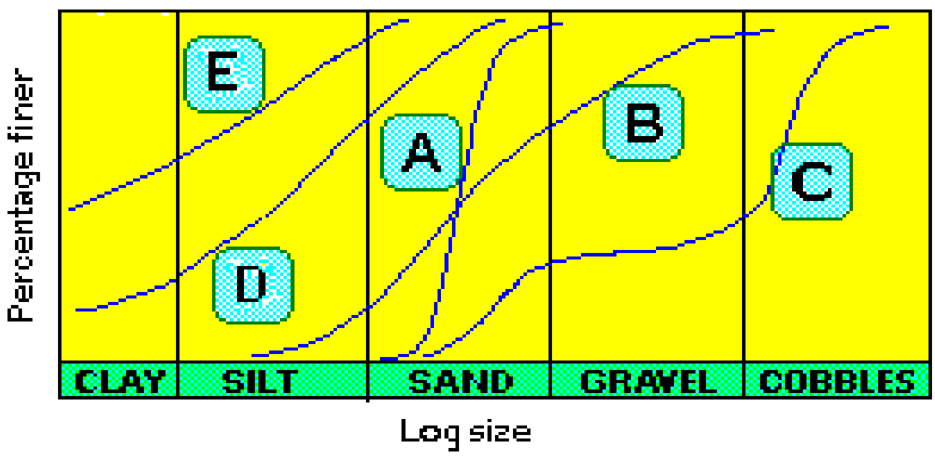
Poorly Graded Soils

Others, including two special cases:

(a) **Uniform** soils – grains of same size

(b) **Gap** graded soils – no grains in a specific size range





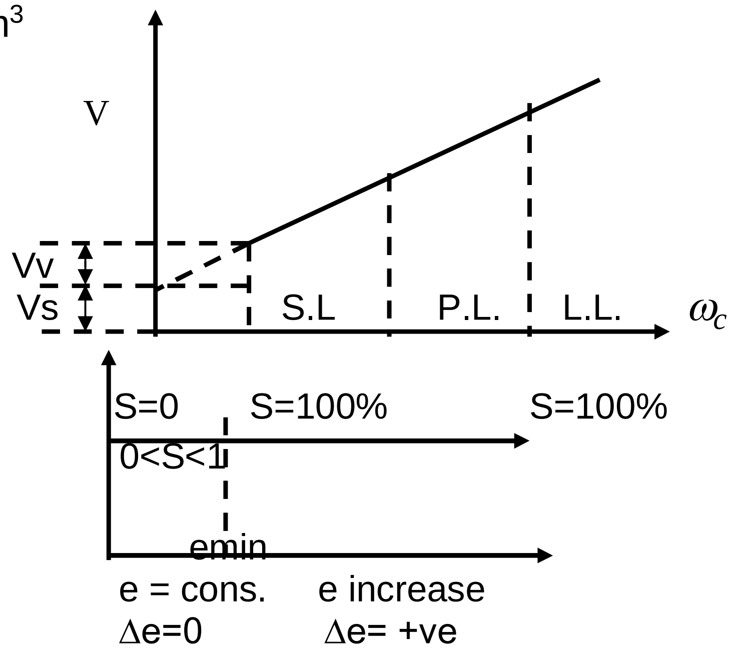
Tutorial

Problem 4: A dry sample of soil having the following properties: L.L=52.1, PL=30% , Gs=2.7 and e = o.53 .Find shrinkage limit , dry density , dry unit weight and air content of dry state .

$$\gamma_d = \frac{Gs}{1+e}\gamma_w = \frac{(2.7)(9.81)}{1+0.53} = 17.311 kN/m^3$$

$$\rho_d = \frac{17.311}{9.81} = 1.764 Ton/m^3$$

$$n = \frac{e}{1+e} = \frac{0.53}{1+0.53} = 0.3464$$



For the dry state S = 0%

$$A = n(1-S) = 0.3464(1-0) = 0.3464$$

At S = 100% ω_c find S.L.

$$\because Se = \omega_c Gs$$

1 x 0.53 = S.L. x 2.7

$\therefore$ S.L = 0.1962 = 19.62 %

Problem 5

A saturated soil sample has a volume of 20 cm^3 at L.L. Given L.L=42% ,P.L=30 % , S.L=17% and Gs=2.74. Find minimum volume which the soil can attain.

Solution

At L.L $\because Se = \omega_c Gs$ $\therefore$ S = 1

1 x e = 0.42 x 2.74 $\therefore e_{at\ L.L} = 1.1508$

$$n = \frac{e}{1+e} = \frac{1.1508}{1+1.1508} = 0.535$$

$$n_{atL.L} = \frac{Vv}{V} \Rightarrow 0.535 = \frac{Vv}{20} \Rightarrow Vv = 10.701 cm^3$$

$$Vs = V - Vv = 20 - 10.701 = 9.3 cm^3$$

$e_{atS.L.} = \omega_c G_s$ because S = 1

$\therefore$ e = 0.17 x 2.74 = 0.4658

$$n_{atS.L} = \frac{e}{e+1} = \frac{0.4658}{1+0.4658} = 0.3177$$

$$e_{S.L} = \frac{Vv}{Vs} \Rightarrow 0.4658 = \frac{Vv}{9.3} \Rightarrow Vv = 4.3319 cm^3$$

$$\therefore V = Vs + Vv = 9.3 + 4.3319 = 13.63 cm^3$$

Problem 6-A sample of saturated clay had a volume of $97cm^3$ and a mass of 0.202 kg. When completely dried out the volume of the sample was 87 cm^3 and its mass 0.167 kg. Find initial water content, shrinkage limit and specific gravity of the solid particles.

Solution

Ww = 0.202 – 0.167 = 0.035 kg = 35g

$$\omega_c = \frac{W_w}{W_s} = \frac{35}{167} = 0.21 = 21\%$$

$\because$ $W_{water} = V_{water} = 35cm^3$

$\therefore$ $V_{solid} = 97 – 35 = 62 \ cm^3$

For shrinkage limit $Vv = V_{dry} – V_{solid} = 87 - 62 = 25 \ cm^3$

$\because$ at S.L. → S = 100%

$\therefore$ Vv = Vw = 25 cm^3

$\because$ Vw = Ww = 25g

$$\therefore \quad S.L = \frac{W_w}{W_s} = \frac{25}{167} = 0.15 = 15\%$$

$$e = \frac{V_v}{V_s} = \frac{25}{62} = 0.4032$$

$$Se = \omega_c Gs$$

1 x 0.4032 = 0.15 x Gs

$\therefore$ Gs = 2.688

Problem 7- The Atterberg Limits of a clays soil are : LL= 52%, P.L =30% and SL= 18%. If a Specimen of this soil Shrinks from a volume of $39.5cm^3$ at the L.L to a volume of 24.2 cm^3 at the S.L . Calculate the specific gravity.

Solution

$\because$ $V_{solid \ at \ S.L} = V_{solid \ at \ L.L.}$

$(V – Vw)_{at \ S.L} = (V – Vw)_{at \ L.L}$

$\therefore$ 24.2 – ($Vw_{at \ S.L}$) = 39.5 – ($Vw_{at \ L.L}$)

$$\omega_c = \frac{W_w}{W_s} \qquad \therefore W_w = \omega_c W_s$$

$$Ww_{atS.L} = 0.18(Ws)$$

$\because$ Ww = Vw (because γ_w =1)

$\therefore$ 24.2 - 0.18 Ws =39.5 – 0.52Ws → Ws = 45g.

$\therefore Ww_{\text{at S.L}} = 0.18 \times 45 = 8.1g = Vw_{\text{at S.L.}}$

$$\therefore e_{\text{at S.L.}} = \frac{V_v}{V_s} = \frac{8.1}{16.1} = 0.53$$

$\because Se = \omega_c Gs$

$$1x0.503 = 0.18Gs \Rightarrow Gs = 2.79$$

Another Solution

$$\rho_{soild} = \frac{Ws}{Vs} = \frac{45}{16.1} = 2.79g/cm3$$

$$Gs = \frac{\rho_s}{\rho_w} = \frac{2.79}{1} = 2.79$$

Problem 8- A saturated Sample of clay with an SL of 22% has a natural water content of 35%. What would its dry volume be as a percentage of its original (natural) volume if Gs = 2.70

Solution:

At S.L S = 100%

$\therefore Se = \omega_c Gs$

1 x e = 0.22 x 2.7

$\therefore$ e = 0.594

At natural water content S = 100%

$$Se = \omega_c Gs$$

1 x e = 0.35 x 2.7

$\therefore$ e = 0.945

$$\frac{V_{dry}}{V_{sat.}} = \frac{1+e_{dry}}{1+e_{sat}} = \frac{1+0.594}{1+0.945} = 0.82 = 82\%$$

Problem 9-The Shrinkage limit of a 0.1m^3 sample of a clay is 15% and its natural water content is 34%. Assume Gs is 2.68 , estimate the volume of the sample when the water content.

Solution

At S.L. S = 100%

$$Se = \omega_c Gs$$

$\therefore$ 1 x e = 0.15 x 2.68

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$\therefore e_{S.L} = 0.402$

At natural water content ω_n

$Se = \omega_c Gs \rightarrow 1 \times e = 0.34 \times 2.68$

$\therefore e_{n} = 0.9112$

$$n = \frac{e}{1+e} = \frac{0.9112}{1+0.9112} = 0.4767$$

$$\therefore n = \frac{V_v}{V}$$

1t ω_n

$$0.4767 = \frac{V_v}{0.1}$$

$\therefore Vv = 0.04767\ m^3$

$\therefore Vs = V - Vv = 0.1 - 0.04767 = 0.05233 m^3$

$$e_{atS.L.} = \frac{Vv}{Vs} \Rightarrow 0.402 = \frac{Vv}{0.05233}$$

$\therefore Vv = 0.021\ m^3{}_{at\ S.L.}$

$\therefore V_{at\ S.L} = Vs + Vv = 0.05233 + 0.021 = 0.0733 m^3$

Problem 10- The L.L of a medium sensitive clay is 56% and P.I 28%.At it natural water content , the void ratio is 1.03 while after shrinkage the minimum void ratio is 0.72. Assuming Gs = 2.72 , calculate the shrinkage limit of the clay.

Solution :

At shrinkage limit S = 100%

$Se = \omega_c Gs$

$1 \times 0.72 = \omega_c \times 2.72$

$\therefore \omega_c = S.L = 0.2647 = 26.47\%$

2-24 For a given sandy soil $e_{max} = 0.86$ and $e_{min} = 0.43$ what is the void ratio at $D_r = 56\%$

Solution

$$Dr = \frac{e_{max} - e}{e_{max} - e_{min}}(100) \Rightarrow 0.56 = \frac{0.86 - e}{0.86 - 0.43}$$

$\therefore e = 0.6192$

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2-26 For a given sandy soil; e_{max} = 0.72 ; e_{min}= 0.46 ; Gs = 2.68 what will be the moist. unit weight of compaction(kN/m3)in the field if D_r =78% and ω_c =9%?

Solution

$$Dr = \frac{e_{max} - e}{e_{max} - e_{min}}(100) \Rightarrow 0.78 = \frac{0.72 - e}{0.72 - 0.46}$$

$\therefore$ e = 0.5172

$$\gamma_t = \frac{1+\omega_c}{1+e} Gs\gamma_w = \frac{1+0.09}{1+0.5172}(2.68)(9.81) = 18.88\ kN/m^3$$