Dr. Ahmed Soil Mechanics Notes Chapter Two (Basic Characteristics of Soil)

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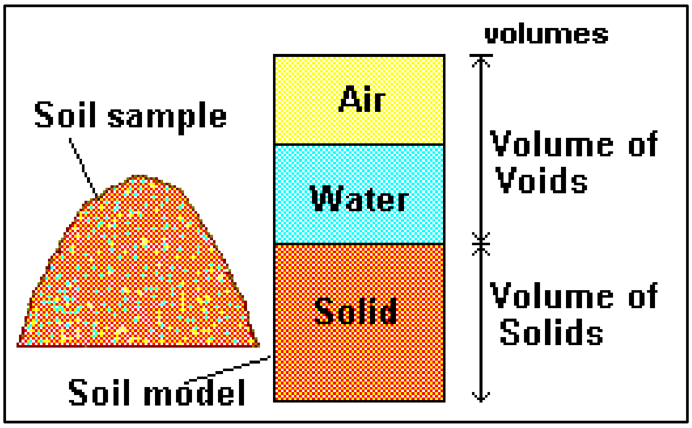

CHAPTER TWO

BASIC CHARACTERISTICS OF SOILS

Lecture Notes

Soil Mechanics

3rd Stage

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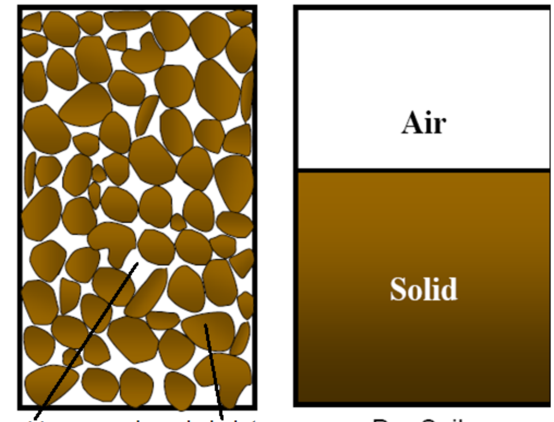
CHAPTER TWO

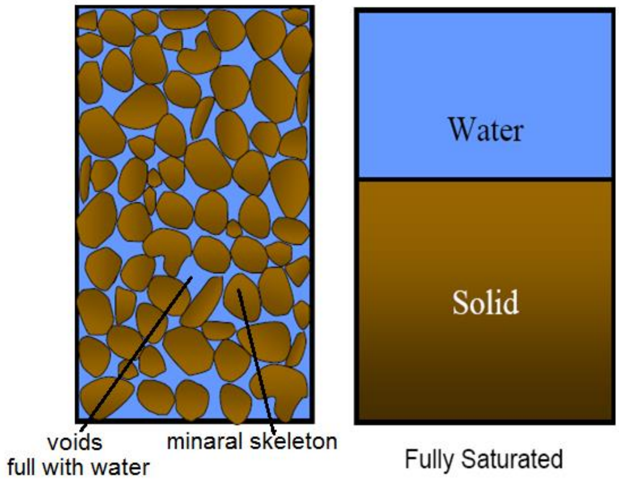
BASIC CHARACTERISTICS OF SOILS

2.1 The Physical State of a Soil Sample

Soils can be of either two-phase or three-phase composition.



Dry Soil

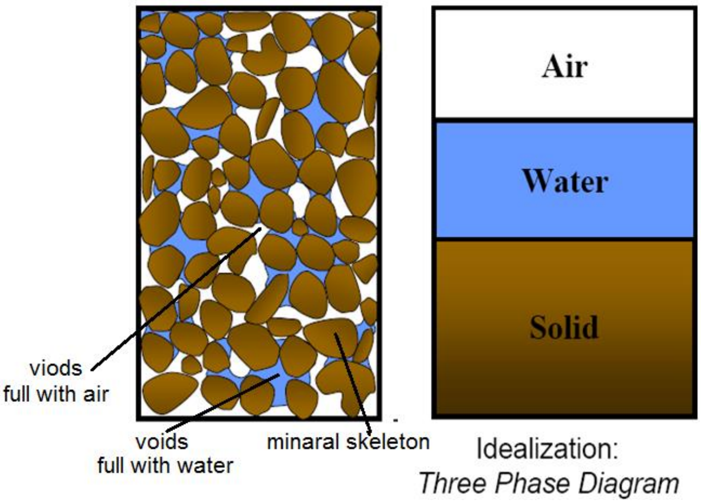


Fully Saturated

A Completely dry soil is two phases, the solid soil particles and pore air

A fully saturated soil is also two-phases, composed of solid soil particles and pore water

A partially saturated soil is three-phase, composed of solid soil particles, pore water and pore air.



Idealization:
Three Phase Diagram

The physical and engineering properties of soil depend on the percentage of each element (solid – water – air)

V_a = volume of air

V_w = volume of water

V_s = volume of solids

V_v = volume of voids = $V_a + V_w$

V = total volume = $V_a + V_w + V_s$

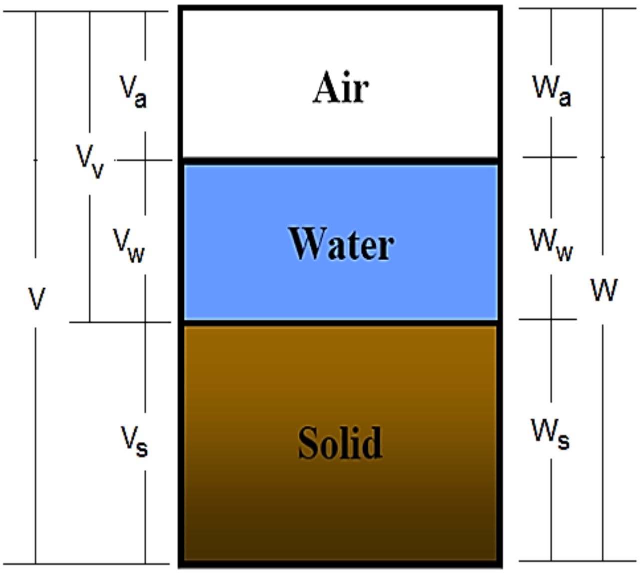
= $V_v + V_s$

W_a = weight of air = 0

W_w = weight of water

W_s = weight of solids

W = total weight = $W_w + W_s$



2.1.1 Volume Relationships

1. Void ratio: It is the ratio of the volume of voids to the volume of solids.

Void ratio = (volume of voids / volume of solids)

$\therefore e = V_v/V_s$.

2. Porosity: It is the ratio of the volume of voids to the total volume.

Porosity = (volume of voids/ total volume)

$\therefore n = (V_v/V)$ %

3. Air content: It is the ratio of the volume of air to the volume of voids.

Air content = (volume of air/ volume of voids)

$\therefore a_c = (V_a/V_v)$

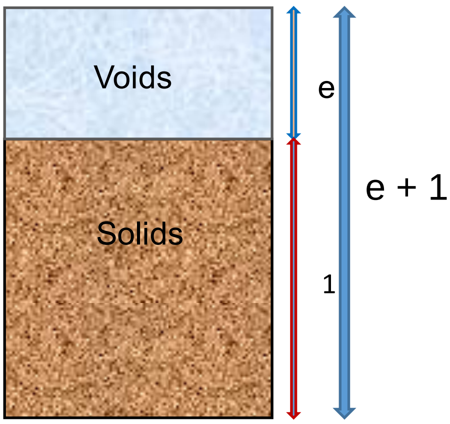
4. Percentage Air Voids: It is the ratio of the volume of air to total volume.

Percentage air voids = (volume of air/ total volume)

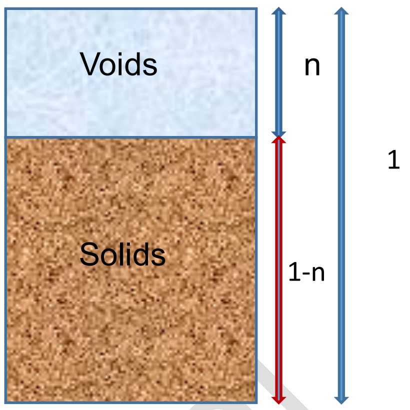
$\therefore n_a = (V_a/V)$%

If the volume of the void is taken as "e," the volume of solids by definition of porosity will be "1" and total volume is "1+e".

$$\therefore n = \frac{V_v}{V} = \frac{e}{1+e}$$



If the volume of voids is taken as “n,” the volume of solids, by definition of void ratio will be “1-n” and total volume equal to “1”.



$$\therefore e = \frac{V_v}{V_s} = \frac{n}{1-n}$$

5. Degree of Saturation: It is the ratio of the volume of water to the volume of voids.

Degree of saturation = (volume of water/ volume of voids)

$\therefore$s = (V_w/V_v) %

When s = 0% $\Longrightarrow$ dry soil

s = 100% $\Longrightarrow$ saturated soil

0 < s < 100% $\Longrightarrow$ partially saturated soil

2.1.2 Weight Relationships

6. Water Content or Moisture Content: it is the ratio of the weight of water to the weight of soils.

Water content = (weight of water / weight of dry soil)*100%

$$w = \frac{W_w}{W_s} * 100\%$$

2.1.3 Soil Unit Weight

7. Total unit weight (Bulk unit weight) (γ_t): It is the total weight of soil per total volume

Total unit weight = (total weight of soil mass / total volume of soil mass)

$$\gamma_t = \frac{W}{V} \quad \cdots \text{N/m}^3 \quad \text{or} \quad \text{kN/m}^3$$

8. Dry Unit Weight (γ_d): It is the weight of soil solids per total volume of the soil mass.

Dry unit weight = (total weight of soil solids / total volume of soil mass)

$$\gamma_d = \frac{Ws}{V} \quad \cdots \text{kN/m}^3$$

9. Water Unit Weight (γ_w): It is the weight of water per total volume of the water mass.

Water unit weight = 9.81 kN/m^3

10. Saturated Unit Weight (γ_{sat}): It is the weight of saturated soil per unit of total volume of the soil mass.

Saturated unit weight = (total weight of saturated soil mass / total volume of soil mass)

$$\gamma_{sat} = \frac{W_{sat}}{V} \quad \cdots \text{kN/m}^3$$

11. Submerged Unit Weight (Buyout Unit Weight) (γ_b) = (γ_{sat}) - (γ_w)

2.1.4 Soil Density

Total density (Bulk density), $\rho_t = \frac{M}{V}$ ……Kg/m^3

Dry density, $\rho_d = \frac{M_d}{V}$ ....kg/m^3

Saturated density, $\rho_{sat} = \frac{M_{sat}}{V}$ ....kg/m^3

Submerge density, $\rho_b = \rho_{sat} - \rho_w$ kg/m^3, ρ_w = 1000 kg/m^3

1000 kg = 9.81 kN

12. Unit Weight of Solids (γ_s): It is the ratio of weight of solids to the volume of solids.

$$\gamma_s = \frac{W_s}{V_s}$$

13. Specific Gravity (G_s): It is the ratio of the weight of a given volume of soil solids to the weight of an equal volume of distilled water.

Specific gravity = (weight of a given volume of soil solid / weight of an equal volume of distilled water)

$$G = \frac{W_s}{W_w} = \frac{\gamma_s}{\gamma_w} \quad \text{no unit}$$

SPECIFIC GRAVITY	
gravel	2.65 - 2.68
sand	2.65 - 2.68
silty sand	2.66 - 2.70
silts	2.66 - 2.70
inorganic clays	2.70 – 2.80
organic soils	variable may fall below 2.0
soils high in mica, iron	2.75 - 2.85

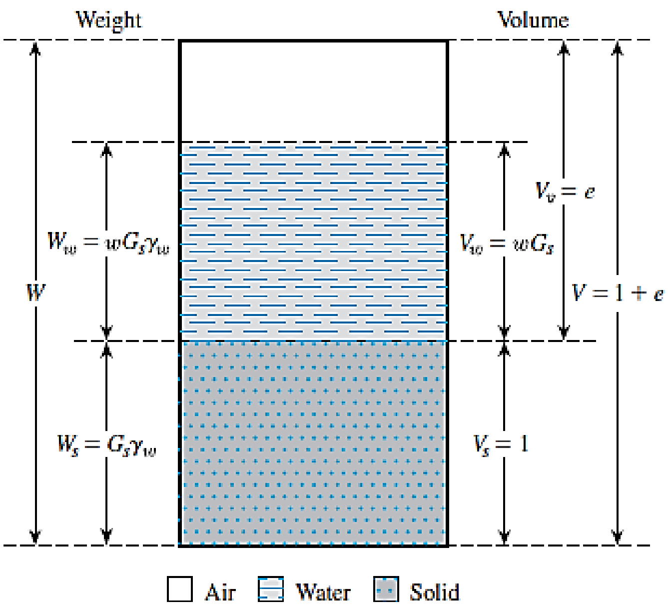
Important Relationships

$S\,e = \omega\, G_s$

$$\gamma_t = \frac{G + s.e}{1+e}\gamma_w = \frac{1+\omega}{1+e}G\gamma_w$$

$$\gamma_d = \frac{G}{1+e}\gamma_w = \frac{\gamma_t}{1+\omega}$$

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



Prove:

$S.e = \omega.\ G_s$

$$S = \frac{V_w}{V_v}$$

$$V_w = \frac{W_w}{\gamma_w} = \frac{wG_s\gamma_w}{\gamma_w} = wG_s$$

$$S = \frac{wG_s}{e}$$

$S.e = \omega.\ G_s$, if soil is saturated then $e = \omega.\ G_s$

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V} = \frac{G_s\gamma_w + wG_s\gamma_w}{1+e} = \frac{(1+w)G_s\gamma_w}{1+e}$$

Various Forms of Relationships for γ, γ_d, and γ_{sat}

Moist unit weight (γ)		Dry unit weight (γ_d)		Saturated unit weight (γ_{sat})	
Given	**Relationship**	**Given**	**Relationship**	**Given**	**Relationship**
w, G_s, e	$\frac{(1+w)G_s\gamma_w}{1+e}$	γ, w	$\frac{\gamma}{1+w}$	G_s, e	$\frac{(G_s+e)\gamma_w}{1+e}$
S, G_s, e	$\frac{(G_s+Se)\gamma_w}{1+e}$	G_s, e	$\frac{G_s\gamma_w}{1+e}$	G_s, n	$[(1-n)G_s+n]\gamma_w$
w, G_s, S	$\frac{(1+w)G_s\gamma_w}{1+\frac{wG_s}{S}}$	G_s, n	$G_s\gamma_w(1-n)$	G_s, w_{sat}	$\left(\frac{1+w_{sat}}{1+w_{sat}G_s}\right)G_s\gamma_w$
w, G_s, n	$G_s\gamma_w(1-n)(1+w)$	G_s, w, S	$\frac{G_s\gamma_w}{1+\left(\frac{wG_s}{S}\right)}$	e, w_{sat}	$\left(\frac{e}{w_{sat}}\right)\left(\frac{1+w_{sat}}{1+e}\right)\gamma_w$
S, G_s, n	$G_s\gamma_w(1-n)+nS\gamma_w$	e, w, S	$\frac{eS\gamma_w}{(1+e)w}$	n, w_{sat}	$n\left(\frac{1+w_{sat}}{w_{sat}}\right)\gamma_w$
		γ_{sat}, e	$\gamma_{sat}-\frac{e\gamma_w}{1+e}$	γ_d, e	$\gamma_d+\left(\frac{e}{1+e}\right)\gamma_w$
		γ_{sat}, n	$\gamma_{sat}-n\gamma_w$	γ_d, n	$\gamma_d+n\gamma_w$
		γ_{sat}, G_s	$\frac{(\gamma_{sat}-\gamma_w)G_s}{(G_s-1)}$	γ_d, S	$\left(1-\frac{1}{G_s}\right)\gamma_d+\gamma_w$
				γ_d, w_{sat}	$\gamma_d(1+w_{sat})$

Void Ratio, Moisture Content, and Dry Unit Weight for Some Typical Soils in a Natural State

Type of soil	Void ratio, e	Natural moisture content in a saturated state (%)	Dry unit weight, γ_d (kN/m³)
Loose uniform sand	0.8	30	14.5
Dense uniform sand	0.45	16	18
Loose angular-grained silty sand	0.65	25	16
Dense angular-grained silty sand	0.4	15	19
Stiff clay	0.6	21	17
Soft clay	0.9–1.4	30–50	11.5–14.5
Loess	0.9	25	13.5
Soft organic clay	2.5–3.2	90–120	6–8
Glacial till	0.3	10	21

Example (2.1)

For a saturated soil, show that $\gamma_{sat} = \left(\frac{e}{w}\right)\left(\frac{1+w}{1+e}\right)\gamma_w$

Solution

$$\gamma_{sat} = \frac{w_{sat}}{V} = \frac{w_{sat}}{V} * \frac{w_s}{v_s} * \frac{v_s}{w_s} = \left(\frac{\frac{w_{sat}}{w_s}}{\frac{V}{v_s}}\right) * \frac{w_s}{v_s}$$

$$= \left(\frac{\frac{\boldsymbol{w_s + w_w}}{\boldsymbol{w_s}}}{\frac{\boldsymbol{v_s + v_v}}{\boldsymbol{v_s}}}\right) * \frac{w_s}{v_s} * \frac{\boldsymbol{\gamma_w}}{\frac{\boldsymbol{w_w}}{\boldsymbol{v_w}}} = \frac{\boldsymbol{e}}{\boldsymbol{\omega}}\left(\frac{\boldsymbol{1+\omega}}{\boldsymbol{1+e}}\right)\boldsymbol{\gamma_w}$$

prove

Example (2.2)

For a moist soil sample, the following are given:

Total volume: V = 1.2 m^3, Total mass: M = 2350 kg, Moisture content: ω = 8.6%, and specific gravity of soil solids: G_S= 2.71

Determine the following: **(a).** Moist density, **(b).** Dry density, **(c).** Void ratio **(d).** Porosity, **(e).** The degree of saturation, and **(f).** The volume of water in the soil sample.

Solution

Part (a) $$\rho = \frac{M}{V} = \frac{2350}{1.2} = \mathbf{1958.3\ kg/m^3}$$

Part (b) $$\rho_d = \frac{M_s}{V} = \frac{M}{(1+w)V} = \frac{2350}{\left(1+\frac{8.6}{100}\right)(1.2)} = \mathbf{1803.3\ kg/m^3}$$

Part (c) $$\rho_d = \frac{G_s\rho_w}{1+e}$$

$$e = \frac{G_s\rho_w}{\rho_d} - 1 = \frac{(2.71)(1000)}{1803.3} - 1 = \mathbf{0.503}$$

Part (d)

$$n = \frac{e}{1+e} = \frac{0.503}{1+0.503} = \mathbf{0.335}$$

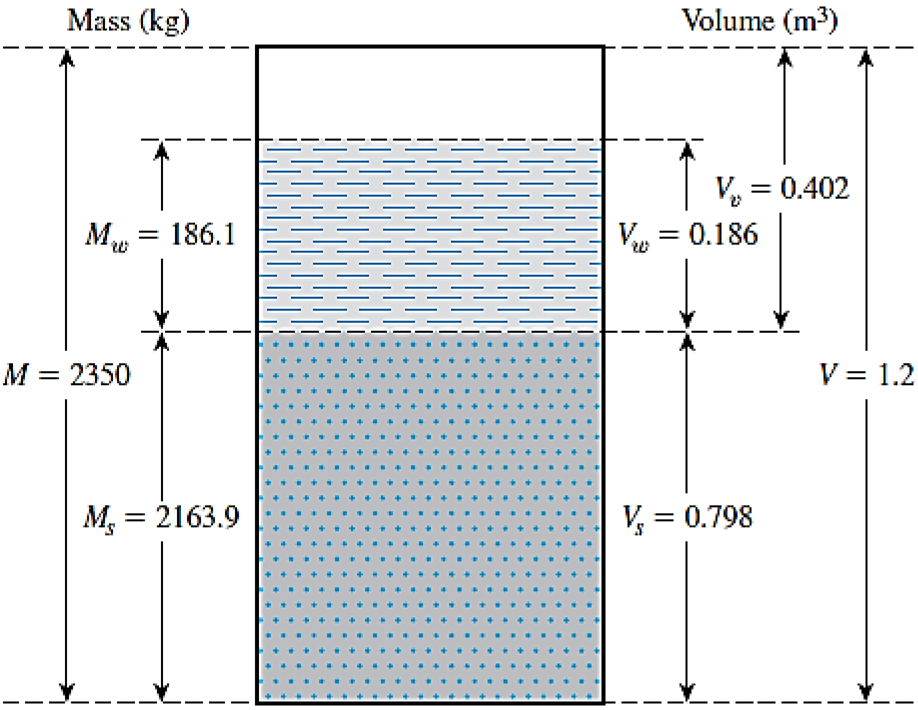
Part (e)

$$S = \frac{wG_s}{e} = \frac{\left(\frac{8.6}{100}\right)(2.71)}{0.503} = 0.463 = \mathbf{46.3\%}$$

Part (f)

$$\frac{M_w}{\rho_w} = \frac{M - M_s}{\rho_w} = \frac{M - \frac{M}{1+w}}{\rho_w} = \frac{2350 - \left(\frac{2350}{1+\frac{8.6}{100}}\right)}{1000} = \mathbf{0.186\ m^3}$$

Use the following figure and solve the problem using alternative solution



Example (2.3)

The following data are given for a soil: Porosity; n = 40%, Specific gravity of the soil solids; G_s = 2.68, Moisture content: ω =12%

Determine the mass of water to be added to 10 m^3 of soil for full saturation.

Solution

$$\gamma = \frac{W_s + W_w}{V} = G_s\gamma_w(1-n)(1+w) \Longrightarrow \rho = G_s\rho_w\,(1-n)(1+w)$$

$$\gamma_{sat} = \frac{W_s + W_w}{V} = \frac{(1-n)G_s\gamma_w + n\gamma_w}{1} = [(1-n)G_s + n]\gamma_w$$

$$\rho_{sat} = [(1-n)G_s + n]\rho_w$$

$$\rho = (2.68)(1000)(1-0.4)(1+0.12) = 1800.96 \text{ kg/m}^3$$

$$\rho_{sat} = [(1-0.4)(2.68)+0.4]\,(1000) = 2008 \text{ kg/m}^3$$

Mass water needed for 1 m^3 = $\rho_{sat} - \rho = 2008 - 1800.96 = 207.04$ kg

Total mass of water must be added = $207.04 \times 10 = \mathbf{2070.4\ kg}$

Example (2.4)

In its natural condition, a soil sample has a mass of 2290 g and a volume of 1.15 × 10^{-3} m^3. After being completely dried in an oven, the mass of the sample is 2035 g. The value of G_s for the soil is 2.68. Determine the bulk density, unit weight, water content, void ratio, porosity, the degree of saturation and air content.

Solution

$$\text{Bulk density, } \rho = \frac{M}{V} = \frac{2.290}{1.15\times10^{-3}} = 1990 \text{ kg/m}^3$$

$$\text{Unit weight, } \gamma = \frac{Mg}{V} = 1990\times9.8 = 19\,500 \text{ N/m}^3$$

$$= 19.5 \text{ kN/m}^3$$

$$\text{Water content, } w = \frac{M_w}{M_s} = \frac{2290-2035}{2035} = 0.125 \text{ or } 12.5\%$$

$$\text{Void ratio, } e = G_s(1+w)\frac{\rho_w}{\rho} - 1$$

$$= \left(2.68 \times 1.125 \times \frac{1000}{1990}\right) - 1$$

$$= 1.52 - 1$$

$$= 0.52$$

$$\text{Porosity, } n = \frac{e}{1+e} = \frac{0.52}{1.52} = 0.34 \text{ or } 34\%$$

$$\text{Degree of saturation, } S_r = \frac{wG_s}{e} = \frac{0.125 \times 2.68}{0.52} = 0.645 \text{ or } 64.5\%$$

$$\text{Air content, } A = n(1 - S_r) = 0.34 \times 0.355$$

$$= 0.121 \text{ or } 12.1\%$$

Example (2.5)

A soil sample with γ_t/γ_W = 1.91, G_s = 2.69 and ω = 29%. Find n, e, and S.

Solution

$$G_s = \frac{\gamma_s}{\gamma_w} \rightarrow \gamma_s = 9.81 * 2.69 = 26.389\ kN/m^3$$

Since all values given in the example are unit less assume the V_s is 1 m^3

$$\gamma_s = \frac{W_s}{V_s} \rightarrow W_s = 26.389 * 1 = 26.389\ kN$$

$$\frac{\gamma_t}{\gamma_w} = 1.91 \rightarrow \gamma_t = 1.91 * 9.81 = 18.737 kN/m^3$$

$$\omega = \frac{W_w}{W_s} \rightarrow W_w = 0.29 * 26.389 = 7.65\ kN$$

Total weight = W_s + W_w = 26.389+7.65 = 34.04 kN,

$$\gamma_t = \frac{W}{V} \rightarrow V = \frac{34.04}{18.737} = 1.817\ m^3$$

$$e = \frac{V_v}{V_s} = \frac{1.817 - 1}{1} = 0.817, n = \frac{e}{1+e} * 100\% = \frac{0.817}{1 + 0.817} * 100\% = 45\%$$

$$S = \frac{V_w}{V_v} * 100\% = \frac{\frac{7.65}{9.81}}{0.817} * 100\% = 95.5\%$$

Example (2.6)

For a saturated soil; given γ_d = 17.70 kN/m^3; and ω = 18%; determine (a) γ_{sat}, (b) void ratio, e (c) G_s, and (d) moist unit weight when the degree of saturation is 50%.

Solution

S.e =ω. G_s, when soil saturated S = 100%

1*e = 0.18 * G_s, $\Longrightarrow G_s = \dfrac{e}{0.18}$

$$\gamma_d = \frac{Gs}{1+e}\gamma_w \Rightarrow \gamma_d = \frac{\frac{e}{0.18}}{1+e}(9.81) \Rightarrow 17.70 = \frac{\frac{e}{0.18}}{1+e}(9.81)$$

$$\therefore e = 0.481$$

$$G_s = \frac{e}{0.18} = \frac{0.481}{0.18} = 2.672$$

$$\gamma_{sat} = \frac{e+Gs}{1+e}(\gamma_w)$$

$$\gamma_{sat} = \frac{0.481 + 2.672}{1+0.481}(9.81) = 20.885 \quad \text{kN/m}^3$$

For S = 50%

S.e =ω. G_s $\Longrightarrow$ 0.5 * 0.481 = ω * 2.672 $\Longrightarrow$ ω = 0.09, ω% = 9.0%

$$\gamma_t = \frac{\omega+1}{1+e}G_s\gamma_t = \frac{0.09+2.672}{1+0.18} * 9.81 = 19.29\ kN/m^3$$

2.2 Soil Texture

Soil texture is an important soil characteristic that drives crop production and field management. The textural class of soil is determined by the sizes of particles that make up soil vary over a wide range. Soils are called *gravel*, *sand*, *silt*, or *clay*, depending on the predominant size of particles within the soil.

Gravels are pieces of rocks with occasional particles of quartz, feldspar, and other minerals.

Sand particles are made of mostly quartz and feldspar

Silts are the microscopic soil fractions that consist of very fine quartz grains and some flake-shaped particles that are fragments of micaceous minerals.

Clays are mostly flake-shaped microscopic and submicroscopic particles of mica

In general: Soil may be divided into two main classes

1- Coarse-grained or non- cohesive or cohesionless soils (Gravel and Sand)

- Excellent foundation material for supporting structures and roads.
- The best embankment material.
- The best backfill material for retaining walls.
- Might settle under vibratory loads or blasts.
- Dewatering can be difficult due to high permeability.
- If free draining does not frost susceptible

2- Fine-grained or cohesive soils (silt and clay)

- Very often, possess low shear strength.
- Plastic and compressible.
- Loses part of shear strength upon wetting.
- Loses part of shear strength upon disturbance.
- Shrinks upon drying and expands upon wetting.
- Very poor material for backfill.
- Poor material for embankments.
- Practically impervious.
- Clay slopes are prone to landslides.

2.3 Description of Individual Soil Particles

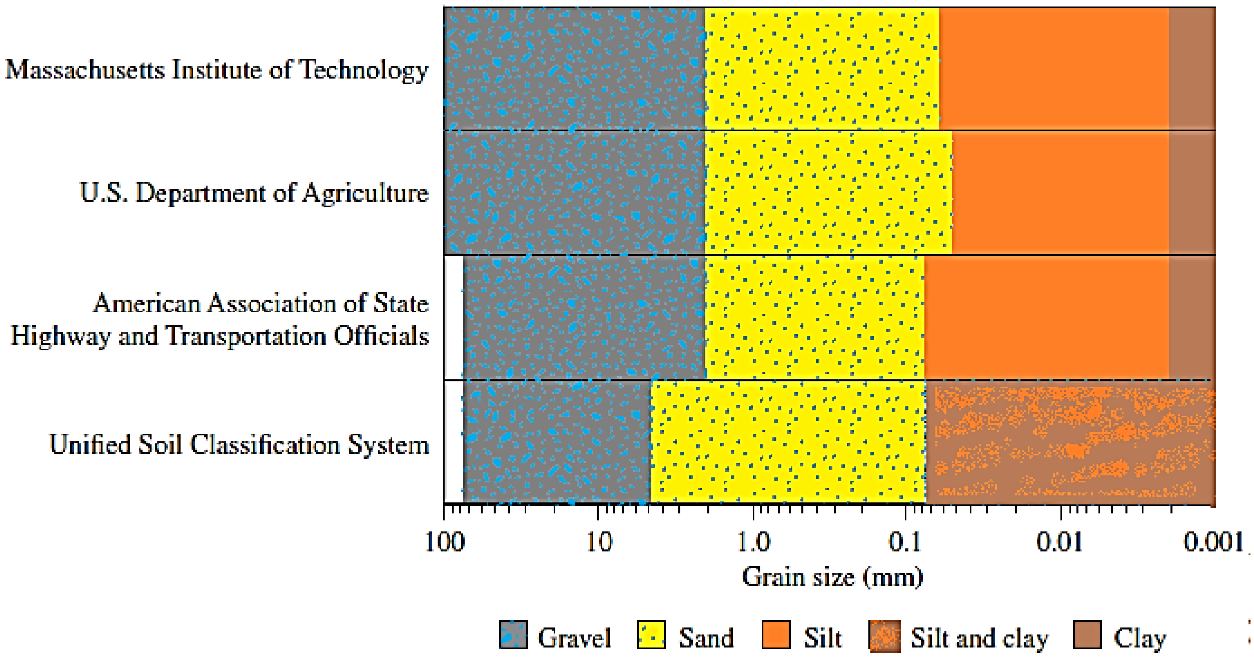
2.3.1 Particle size characteristic

To describe soils by their particle size, several organizations have developed particle-size classifications. The table below shows the particle size classifications developed by the Massachusetts Institute of Technology (MIT), the U.S. Department of Agriculture, the American Association of State Highway and Transportation Officials (AASHTO), and the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation.

In table below, the **MIT** system is presented for illustration purposes only. This system is important in the history of the development of the size limits of particles present in soils; however, the Unified Soil Classification System (USCS) is now almost universally accepted and has been adopted by the American Society for Testing and Materials (**ASTM**). The figure below shows the size limits in a graphic form.

Particle-Size Classifications				
	Grain size (mm)			
Name of organization	**Gravel**	**Sand**	**Silt**	**Clay**
1. Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
2. U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
3. American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
4. Unified Soil Classification System 5. U.S. Army Corps of Engineers, 6. U.S. Bureau of Reclamation, 7. American Society for Testing and Materials)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays) <0.075	

Note: Sieve openings of 4.75 mm are found on a U.S. No. 4 sieve; 2-mm openings on a U.S. No. 10 sieve; 0.075-mm openings on a U.S. No. 200 sieve.



Soil-separate-size limits by various systems

According to MIT:

Coarse-grained soils: Boulders > 300mm

Cobble 150-300mm

Gravel 2-150mm

Sand 0.06- 2 mm

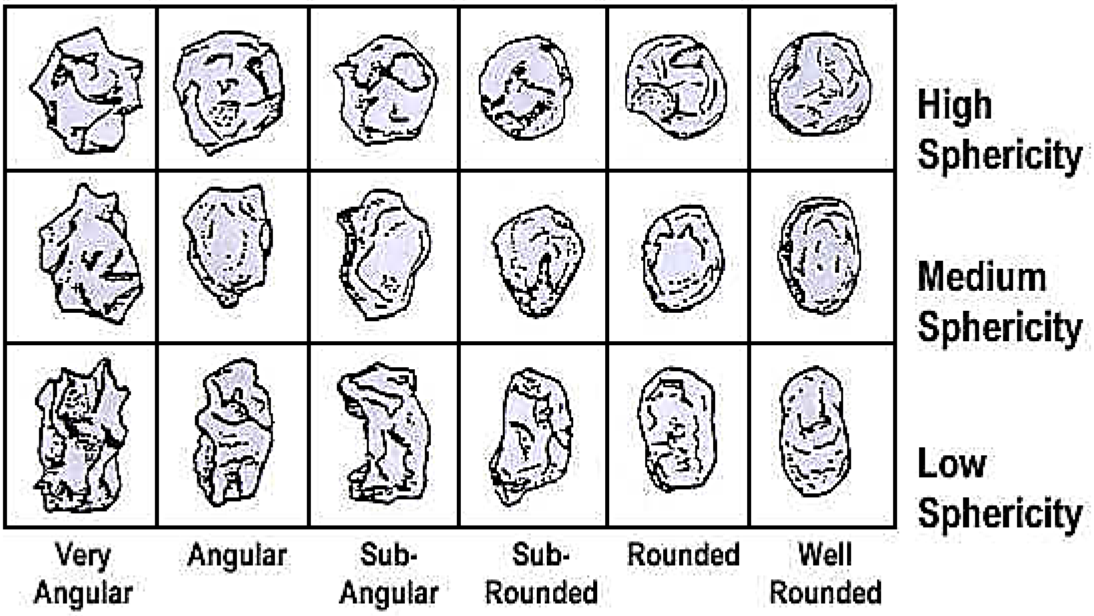
Fine –grained soil: silt 0.002-0.06 mm

Clay < 0.002

2.3.2 Particle shape

Equal-dimension, sphere, blade, rod, disk, flaky, and needle

2.3.3 Degree of roundness



2.3.4 Surface texture

Dull or polished and smooth or rough

2.3.5 Soil Color

- gray
- yellow
- brown
- red
- blue etc

Soil color is influenced by the amount of proteins present in the soil. Yellow or red soil indicates the presence of iron oxides. Dark brown or black color in soil indicates that the soil has a high organic matter content. Wet soil will appear darker than dry soil.

2.3.6 Composition of a soil particle

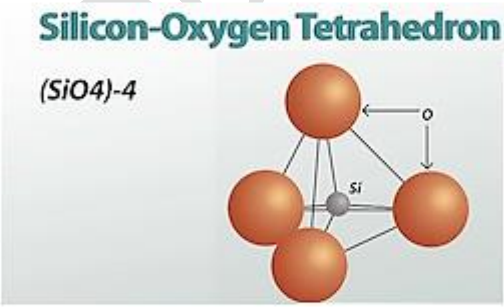
The nature and arrangement of the atoms in a soil particle (composition) have a significant influence on engineering properties of soil (permeability, strength, compaction, and stress transmission of soil)

In general, the soil atoms classified as silicates, carbonates, phosphates, and oxides. The most important are the silicate minerals which accounts for 90% of the total soil in the world.

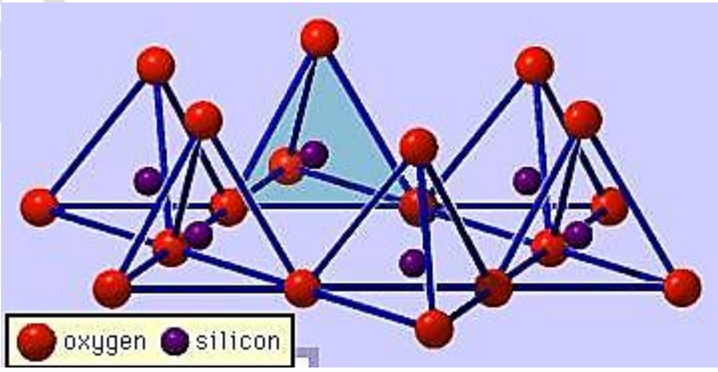
2.4 Clay Minerals

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

1. Silica Tetrahedron:

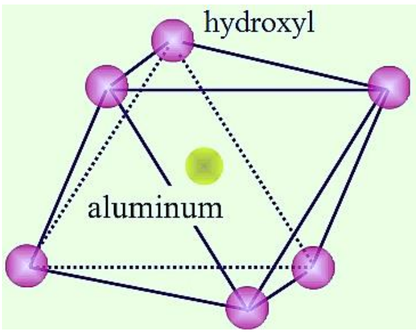


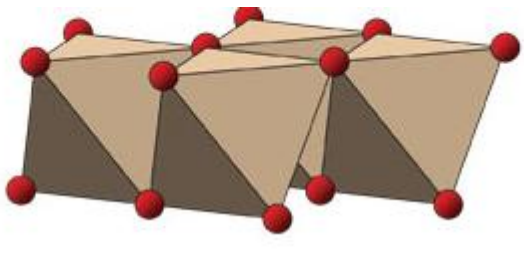
Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom. The combination of tetrahedral silica units gives a silica sheet. Three oxygen atoms at the base of each tetrahedron are shared by neighboring tetrahedral.



2. Alumina octahedron

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)





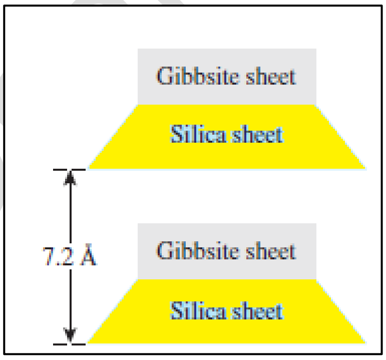
Alumina octahedra

Sometimes magnesium replaces the aluminum atoms in the octahedral units; in this case, the octahedral sheet is called a brucite sheet.

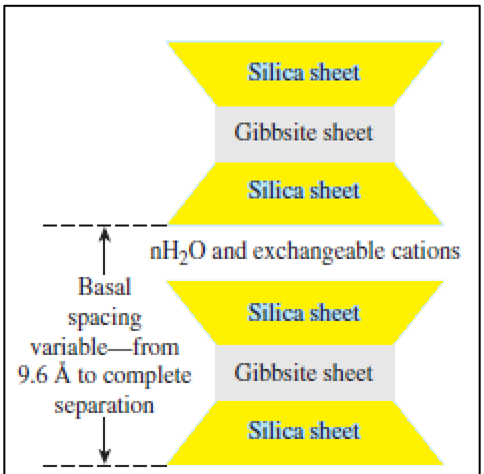
In a silica sheet, each silicon atom with a positive charge of four is linked to four oxygen atoms with a total negative charge of eight. However, each oxygen atom at the base of the tetrahedron is linked to two silicon atoms. This means that the top oxygen atom of each tetrahedral unit has a negative charge of one to be counterbalanced. When the silica sheet is stacked over the octahedral sheet, these oxygen atoms replace the hydroxyls to balance their charges.

Three important clay minerals,

Kaolinite consists of repeating layers of elemental silica-gibbsite sheets, as shown in the figure and is about 7.2 Å thick. In this clay, the bonding is through electrical bonds and resists entering water between the layers thus the clay has medium viscosity and high strength and low swelling

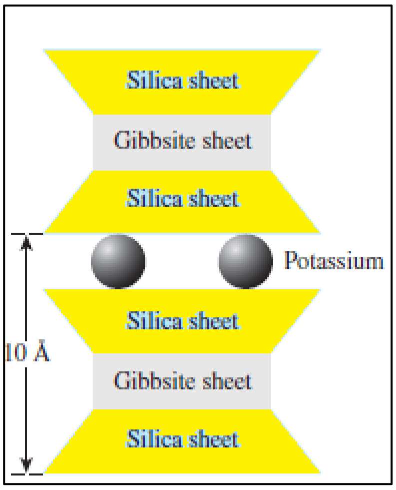


Montmorillonite has a structure similar to that of illite, that is, one gibbsite sheet sandwiched between two silica sheets. In montmorillonite, there is the isomorphous substitution of magnesium and iron for aluminum in the octahedral sheets. Potassium ions are not present as in illite, and a large amount of water is attracted to the space between the layers. This clay has low resists for water entering thus the clay has medium viscosity and low strength and high swelling



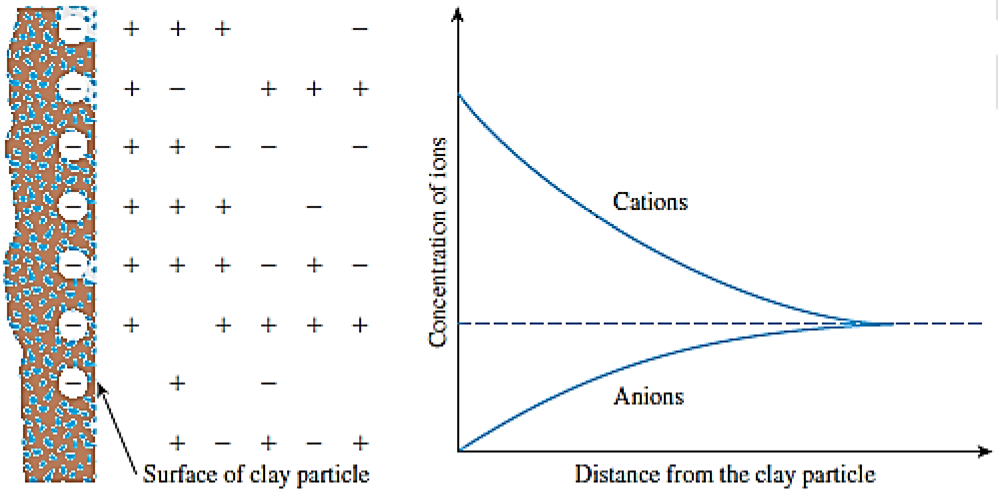
(c)

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.

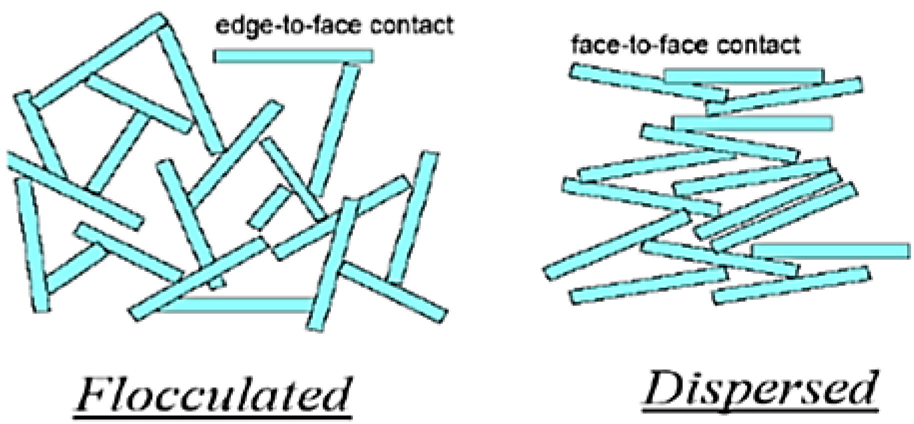
In dry clay, the negative charge is balanced by exchangeable cations like Ca^{+2}, Mg^{+2}, Na^{+}, and K^{+} surrounding the particles being held by electrostatic attraction. When water is added to clay, these cations and a few anions float around the clay particles. This configuration is referred to as a diffuse double layer.



2.5 Structure of Compacted Clay Soil

If the clay is compacted with a low moisture content, the diffuse double layers of ions surrounding the clay particles cannot be fully developed; hence, the inter-particle repulsion is reduced. This reduced repulsion results in a more random particle orientation and a lower dry unit weight.

When the moisture content of compaction is increased, the diffuse double layers around the particles expand, which increases the repulsion between the clay particles and gives a flocculation structure



Homework Chapter (2)

1 For a given soil, show that

$$\gamma_{sat} = n\left(\frac{1 + w_{sat}}{w_{sat}}\right)\gamma_w$$

2 For a given soil, show that

$$e = \frac{\gamma_{sat} - \gamma_d}{\gamma_d - \gamma_{sat} + \gamma_w}$$

3 For a given soil, show that

$$w_{sat} = \frac{n\gamma_w}{\gamma_{sat} - n\gamma_w}$$

4 The moist weight of 2.83×10^{-3} m^3 of soil is 55.5×10^{-3} kN . If the moisture content is 14% and the specific gravity of soil solids is 2.71, determine the following:

- **a.** Moist unit weight
- **b.** Dry unit weight
- **c.** Void ratio
- **d.** Porosity
- **e.** Degree of saturation
- **f.** Volume occupied by water

5 The moist unit weight of a soil is 19.2 kN/m^3. Given that $G_s = 2.69$ and $w = 9.8\%$, determine:

- **a.** Void ratio
- **b.** Dry unit weight
- **c.** Degree of saturation

6 Refer to Problem 3 . Determine the weight of water, in kN, to be added per cubic meter (m^3) of soil for

- **a.** 90% degree of saturation
- **b.** 100% degree of saturation

7 Undisturbed soil sample was collected from the field in steel Shelby tubes for laboratory evaluation. The tube sample has a diameter of 71 mm, length of 558 mm, and a moist weight of 42.5×10^{-3} kN. If the oven-dried weight was 37.85×10^{-3} kN, and $G_s = 2.69$, calculate the following:

- **a.** Moist unit weight
- **b.** Field moisture content
- **c.** Dry unit weight
- **d.** Void ratio
- **e.** Degree of saturation

8 When the moisture content of a soil is 26%, the degree of saturation is 72%, and the moist unit weight is 16.98 kN/m^3. Determine:

- **a.** Specific gravity of soil solids
- **b.** Void ratio
- **c.** Saturated unit weight

9 For a given soil, the following are known: $G_s = 2.74$, moist unit weight, $\gamma = 20.6$ kN/m^3, and moisture content, $w = 16.6\%$. Determine:

a. Dry unit weight
b. Void ratio
c. Porosity
d. Degree of saturation

10 Refer to Problem 9. Determine the weight of water, in kN, to be added per cubic meter (m^3) of soil for

a. 90% degree of saturation
b. 100% degree of saturation

11 The moist density of a soil is 1750 kg/m^3. Given $w = 23\%$ and $G_s = 2.73$, determine:

a. Dry density
b. Porosity
c. Degree of saturation
d. Mass of water, in kg/m^3, to be added to reach full saturation.

12 For a moist soil, given the following: $V = 7.08 \times 10^{-3}$ m^3; $W = 136.8 \times 10^{-3}$ kN; $w = 9.8\%$; $G_s = 2.66$. Determine:

a. Dry unit weight
b. Void ratio
c. Volume occupied by water

13 For a given soil, $\rho_d = 1800$ kg/m^3 and $n = 0.3$. Determine:

a. Void ratio
b. Specific gravity of soil solids

14 The moisture content of a soil sample is 17% and the dry unit weight is 16.51 kN/m^3. If $G_s = 2.69$, what is the degree of saturation?

15 For a given soil, $w = 18.2\%$, $G_s = 2.67$, and $S = 80\%$. Determine:

a. Moist unit weight in kN/m^3
b. Volume occupied by water

16 The degree of saturation of a soil is 55% and the moist unit weight is 16.66 kN/m^3. When the moist unit weight increased to 17.92 kN/m^3, the degree of saturation increased to 82.2%. Determine:

a. G_s
b. Void ratio