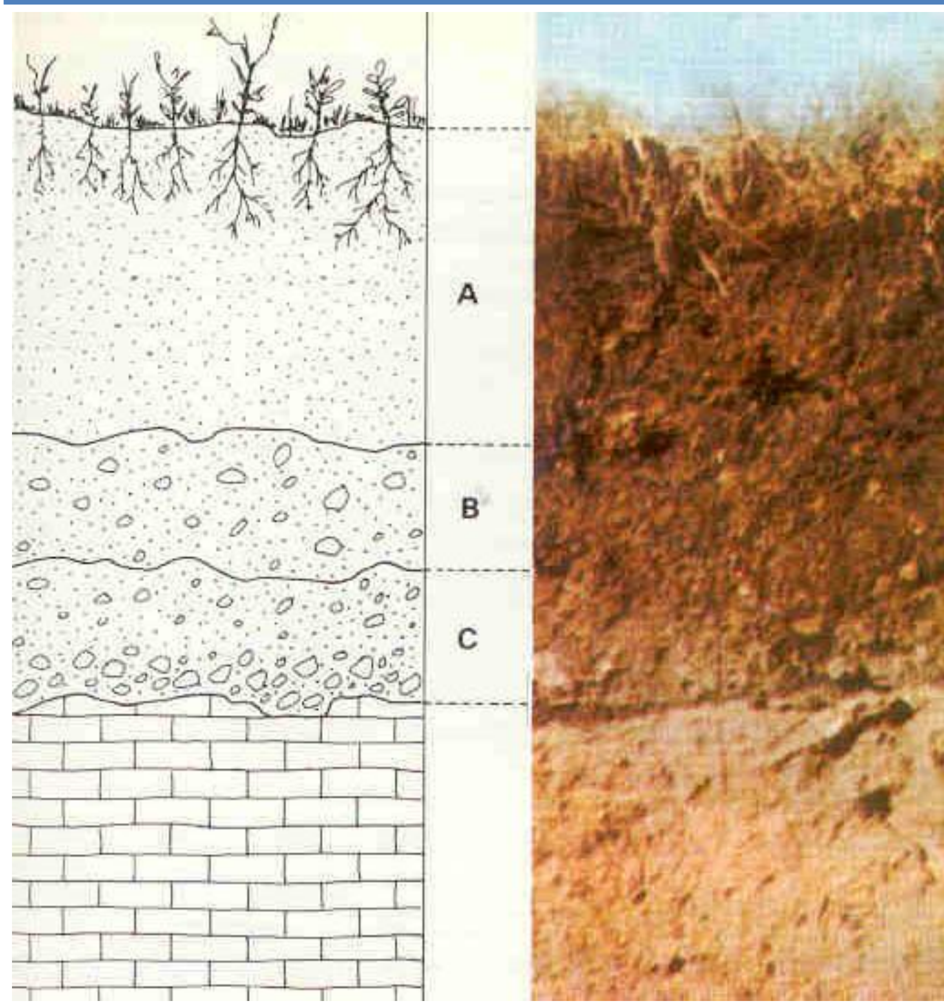
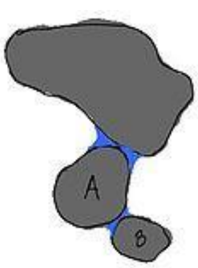
CE 210

Soil Mechanics and Foundation Engineering I





Dr. SaMeH S. Ahmed

College of Engineering - MU

CE 210

Chapter 2 Soil Definition, Classification and Properties

2.1 Introduction

Soils are originated from rocks viz., *igneous rocks, sedimentary rocks and metamorphic rocks.* The soil mechanics engineer is mainly concerned with the loose sedimentary deposits, such as gravels, sands, silts, clays, or mixture of these materials.

The particle size of soils has a great influence on the properties of soils and it is the first step in the identification and determination of the soil characteristics.

2.2 Soil Classification

There are several ways for soil classification; however most of them are based on particle size division. They are usually divided into three groups:

(a) Coarse-grained non-cohesive soils, such as *sands and gravels*
(b) Fine-grained cohesive soils, such as *silt and cla*y
(c) Organic soils, such as *peat*

Soil Texture Triangle

This method known also as *Triangular Classification System*

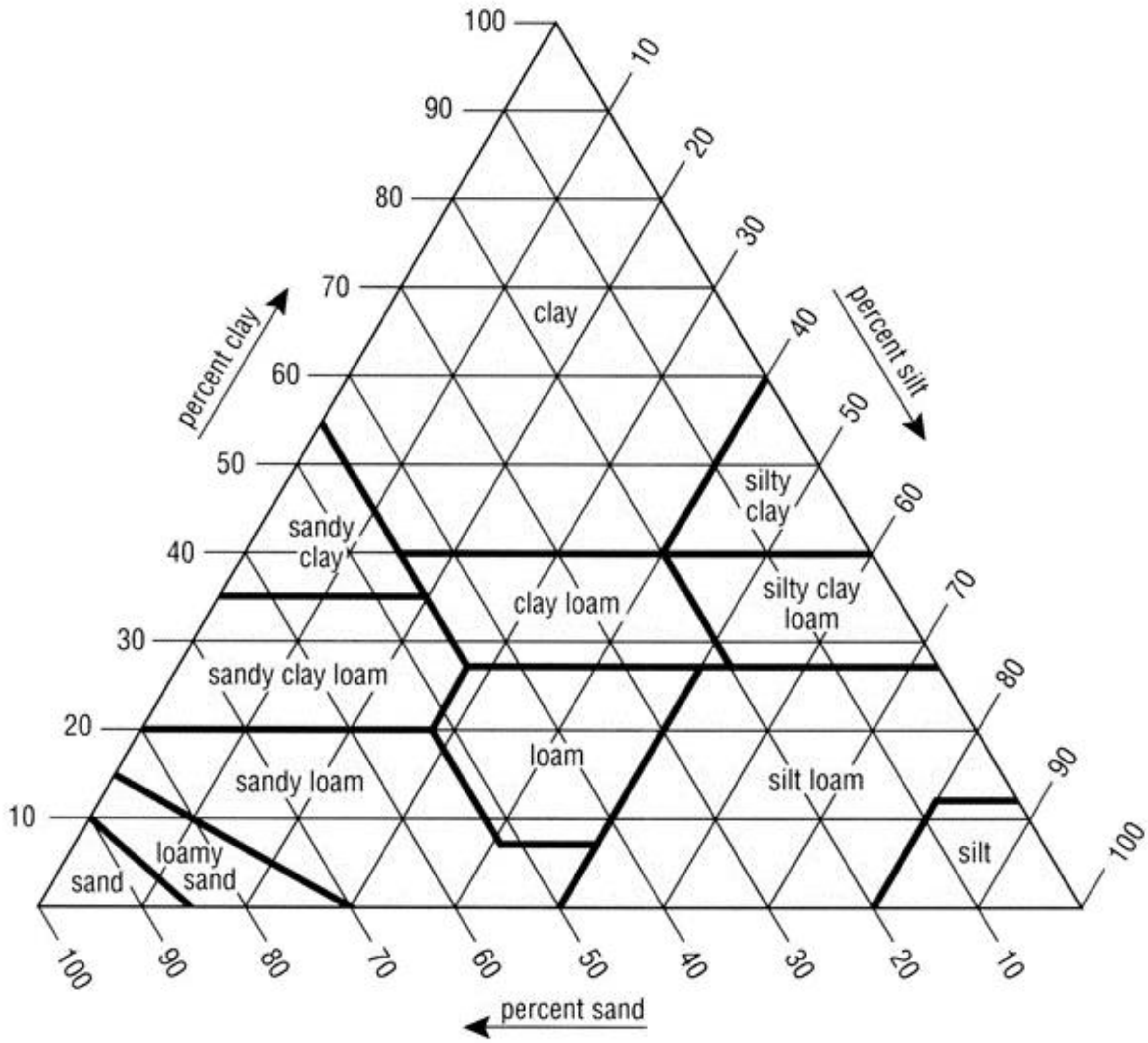


Figure 2.1: The Textural Triangle

How to Use the Soil Texture Triangle

Soil texture depends on its composition and the relative portions of clay, sand, and silt. In sedimentology, clay is defined as particles of earth between 1µm and 3.9µm in diameter. Silt is defined as particles between 3.9µm and 62.5µm in diameter, while sand is particles between 62.5µm and 2mm; in diameter.

To classify a soil sample, you find the intersection of the three lines that corresponds the three proportions. On the chart, all of the percents will add up to 100%.

Example (1): classify a soil sample of 30% sand, 30% clay and 40% silt:

First locate 30% on the clay axis, and draw a line horizontally from left to right. Next, locate 40% on the silt axis, and draw a line going down diagonally to the left. Finally, locate 30% on the sand axis, and draw a line going up diagonally to the left. The intersection is in a region called *Sandy Loam*. See figure below.

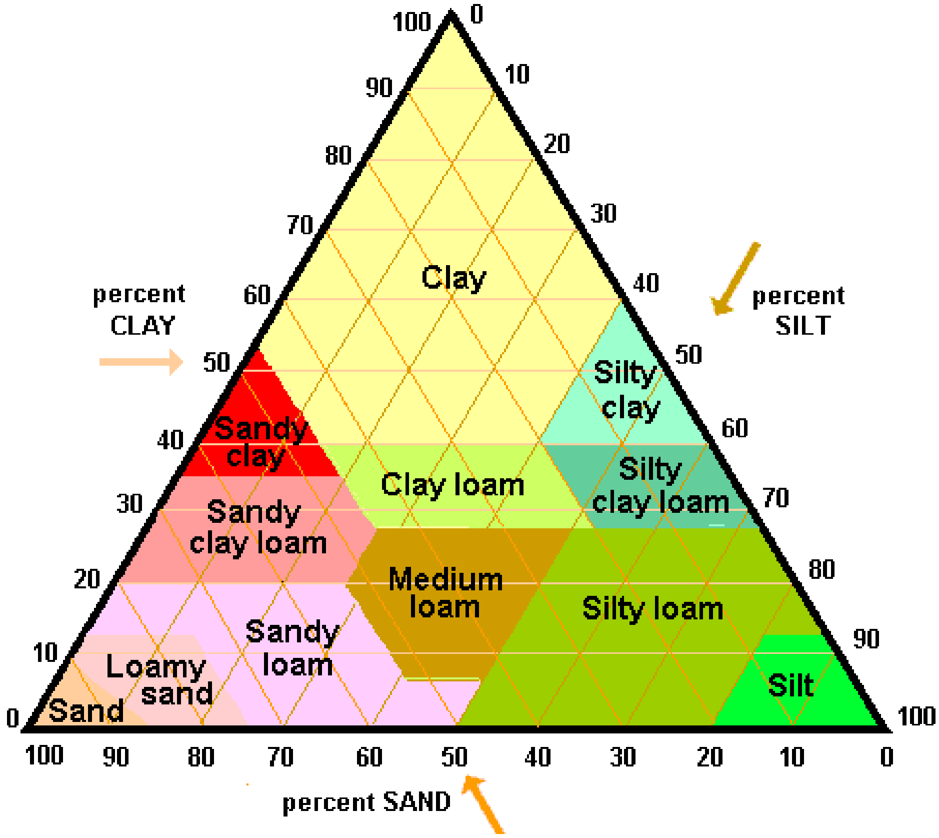
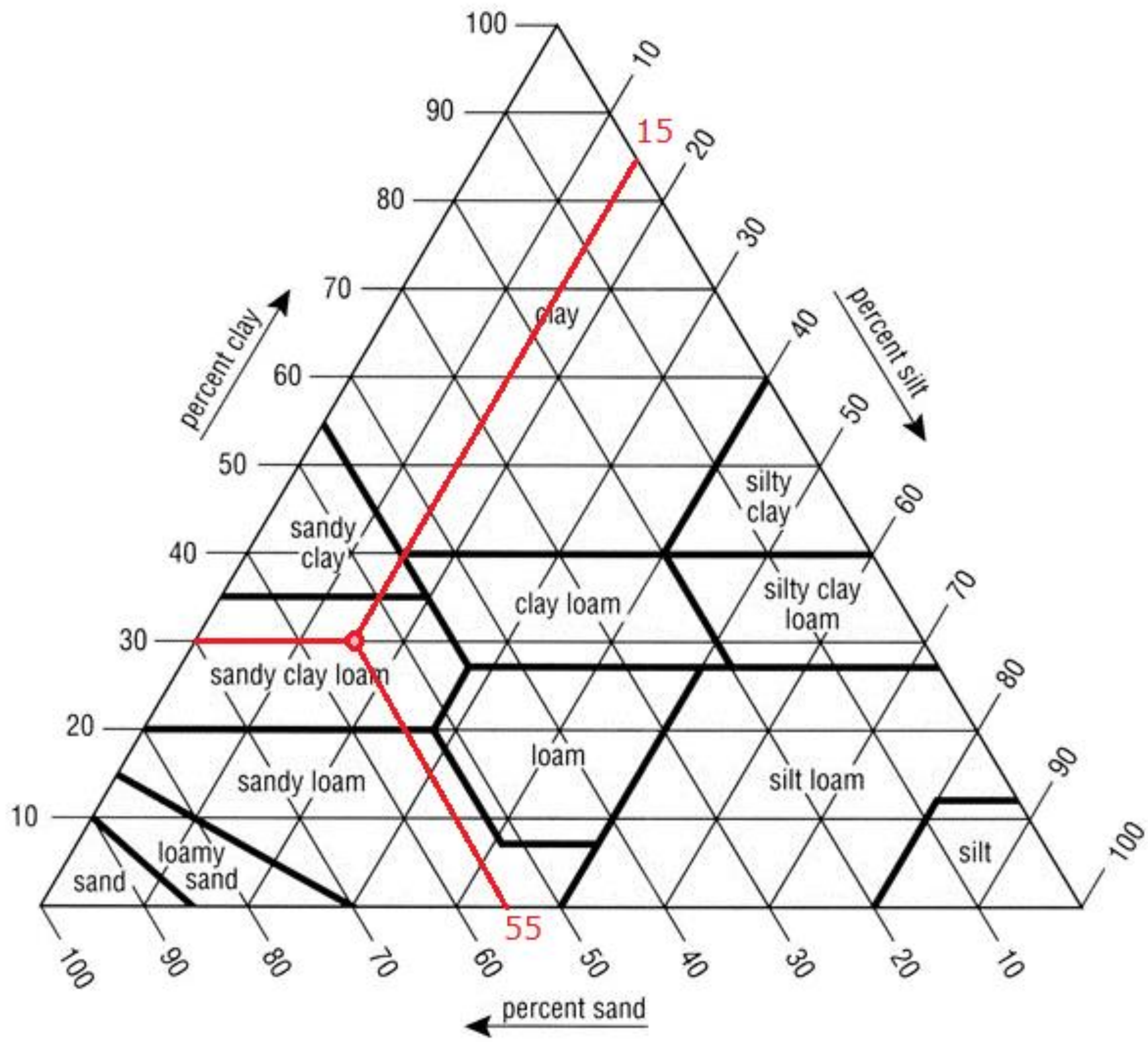


Figure 2.2: Example of finding a soil classification using Textural Triangle

Example (2): Classify a soil sample that is 30% clay, 15% silt, and 55% sand.

First locate 30% on the clay axis, and draw a line horizontally from left to right. Next, locate 15% on the silt axis, and draw a line going down diagonally to the left. Finally, locate 55% on the sand axis, and draw a line going up diagonally to the left. The intersection is in a region called *Sandy Clay Loam*. See figure below.



2.3 Particle Size Distribution

Table 2.1 shows the particle size classification that divides soils into fractions on equivalent particle size diameters measuring in mm.

Table 2.1: Particle Size Classification

	IS	BS
Gravel	80-4,75 mm	60-2.0 mm
Sand	4.75-0.075 mm	2.0-0.06 mm
Silt	0.075-0,002 mm	0.06-0.002 mm
Clay	Less than 0.002 mm	Less than 0.002 mm

2.4 The Particle Size Distribution Test

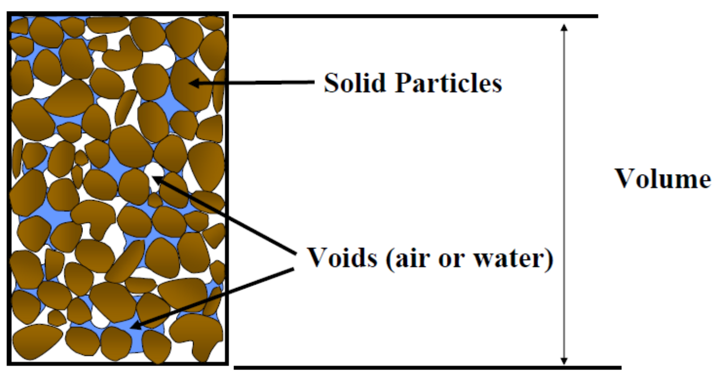
This part will be covered during the lab exercise

2.5 Soil Phases

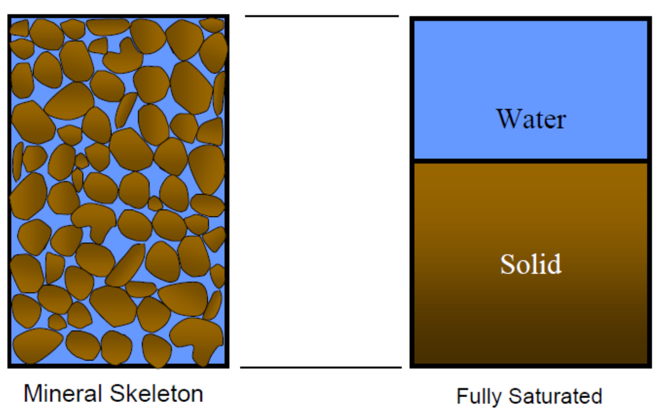
Three Phases of Soils:

Naturally occurred soils always consist of solid particles, water, and air, so that soil has three phases: *solid, liquid and gas*.

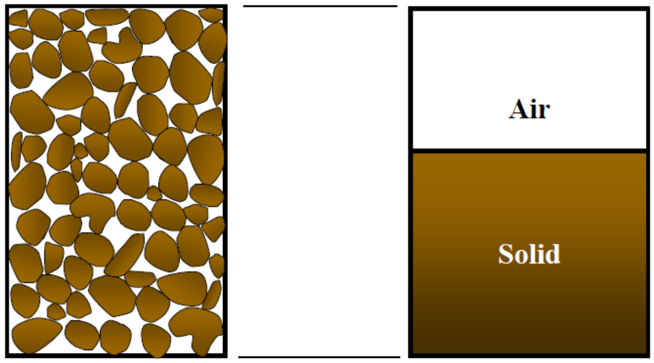
Soil model



Fully Saturated Soils (Two phase)



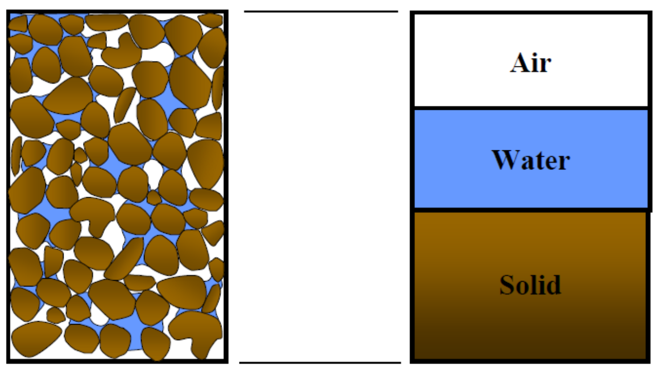
Dry Soils (Two phase) [Oven Dried]



Mineral Skeleton

Dry Soil

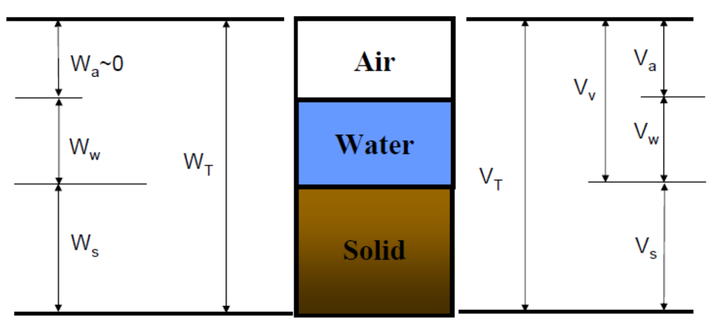
Three Phase Diagram



Mineral Skeleton

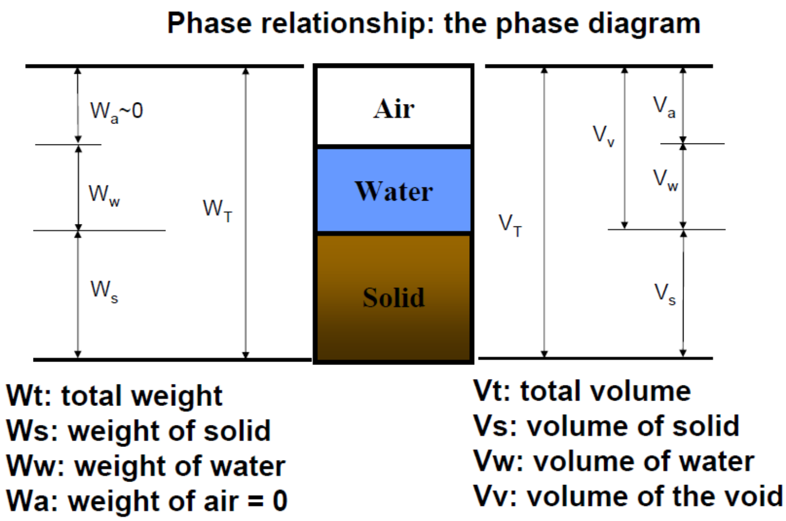
Idealization:
Three Phase Diagram

Three Phase Diagram



Weight

Volume



There are a variety of parameters used to describe the relative proportions of air, water and solid in a soil. This section defines these parameters and some of their interrelationships. The basic notation is as follows:

V_a, V_w, and V_s represent the volumes of air, water and solids in a soil mixture;

W_a, W_w, and W_s represent the weights of air, water and solids in a soil mixture;

M_a, M_w, and M_s represent the masses of air, water and solids in a soil mixture;

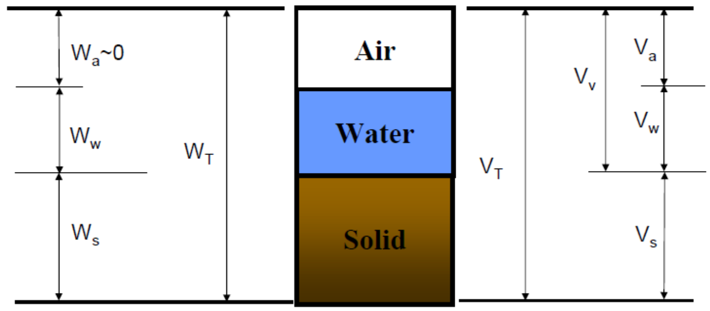
ρ_a, ρ_w, and ρ_s represent the densities of the constituents (air, water and solids) in a soil mixture;

Note that the weights, W, can be obtained by multiplying the mass, M, by the acceleration due to gravity, g; e.g., $W_s = M_s g$

Specific Gravity is the ratio of the density of one material compared to the density of pure water ($\rho_w = 1g/cm^3$).

Specific gravity of solids, $$G_s = \frac{\rho_s}{\rho_w}$$

Note that unit weights, conventionally denoted by the symbol γ may be obtained by multiplying the density instead of ρ by the acceleration due to gravity, g.



Vt = Vs + Vv = Vs + Vw + Va;

It is convenient to assume the volume of the solid phase is unity (1) without lose generality.

Mt = Ms + Mw; and

Wt = Ws + Ww, since W=Mg

2.6 Water Content, Volume and Density Relationship of Soils

Water Content, w is the ratio of mass of water to mass of solid. It is easily measured by weighing a sample of the soil, drying it out in an oven and re-weighing. Standard procedures are described by ASTM.

$$w = \frac{M_w}{M_s} = \frac{W_w}{W_s}$$

2.6.1 Void Ratio

Void ratio, e, is the ratio of the volume of voids to the volume of solids:

$$e = \frac{V_V}{V_S} = \frac{V_V}{V_T - V_V} = \frac{n}{1-n}$$

Void ratio: e = Vv/Vs;

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

2.6.2 Porosity

Porosity, n, is the ratio of volume of voids to the total volume, and is related to the void ratio:

$$n = \frac{V_v}{V_t} = \frac{V_v}{V_s + V_v} = \frac{e}{1+e}$$

Porosity n = Vv/Vt

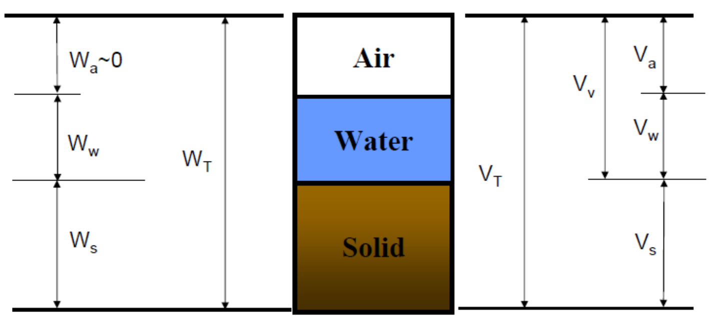
$$n = \frac{V_v}{V_t} = \frac{V_v}{V_s + V_v} = \frac{V_v / V_s}{1 + V_v / V_s} = \frac{e}{1+e}$$

Apparently, for the same material we always have e > n. For example, when the porosity is 0.5 (50%), the void ratio is 1.0 already.

2.6.3 Degree of Saturation

Degree of saturation, S, is the ratio of the volume of water to the volume of voids:

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



Degree of saturation: S =Vw/Vv x 100%
Saturation is measured by the ratio of volume.

Moisture content (Water content): *w* = Ww/Ws,
Ww – weight of water, Ws – weight of solid
Water content is measured by the ratio of weight.
So that *w* can be greater than 100%.

2.6.4 Percentage Air Voids

The ratio of the volume of air to total volume of the soil is known as **percentage air voids.**

$$Percentage\ air = \frac{V_A}{V}\ x\ 100$$

Definition of 3 types of unit weight

Total unit weight (moisture unit weight, wet unit weight) γ :

$$\gamma = \frac{W_t}{V_t} = \frac{W_s + W_w}{V_t}$$

Dry unit weight γ_d :

$$\gamma_d = \frac{W_s}{V_t}, \quad \because V_t > V_s \quad \therefore \gamma_d < \gamma_s$$

Saturated unit weight (when saturation S=1) γ_{sat} :

$$\gamma_{sat} = \frac{W_t}{V_t}$$

Moisture unit weight γ:

$$\gamma = \frac{W_t}{V_t} = \frac{W_s + W_w}{V_t}$$

Solid unit weight γ_s

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

dry unit weight γ_d

$$\gamma_d = \frac{W_s}{V_t}, \quad \because V_t > V_s \quad \therefore \gamma_d < \gamma_s$$

Since

$$\gamma_d = \frac{W_s}{V_t} = \frac{W_t - W_w}{V_t} = \frac{W_t}{V_t} - \frac{W_w}{V_t} = \gamma - \frac{W_w}{W_s}\frac{W_s}{V_t} = \gamma - w\gamma_d$$

$$so \quad that \quad \gamma_d + w\gamma_d = \gamma \quad and \quad \gamma_d = \frac{\gamma}{1+w}$$

From the original form of the dry unit weight

$$\gamma_d = \frac{\gamma}{1+w}$$

By taking the Taylor expansion and truncated at the first order term:

$$\gamma_d = \frac{\gamma}{1+w} = \gamma(1 - w + w^2 - w^3 + w^4 - w^5 + \ldots) \approx \gamma(1-w)$$

Because the moisture content *w* is a number always smaller than one, i.e., *w*<1.

Thus, the dry unit weight γ_d can be approximated as:

$$\gamma_d = (1-w)\gamma$$

Relationships among S, e, w, and Gs

$$S = \frac{V_w}{V_v}, then \quad V_w = SV_v = Se, \quad given \quad V_s = 1$$

A simple way to get Das,

$$w = \frac{W_w}{W_s} = \frac{\gamma_w V_w}{\gamma_s V_s} = \frac{\gamma_w eS}{G_s \gamma_w} = \frac{eS}{G_s}, \quad \because V_s = 1, \quad \therefore V_v = 1$$

$$thus \quad Se = wG_s$$

When the soil is 100% saturated (S=1) we have,

$$e = wG_s$$

Relationships among γ, n, w, and Gs

$$W_s = \gamma_s V_s = G_s \gamma_w (1-n), \quad given \quad V_s = 1-n$$
$$W_w = wW_s = wG_s\gamma_w(1-n)$$

So that the dry unit weight γ_d is

$$\gamma_d = \frac{W_s}{V_t} = \frac{G_s\gamma_w(1-n)}{1-n+n} = G_s\gamma_w(1-n)$$

And the moist unit weight γ is

$$\gamma = \frac{W_t}{V_t} = \frac{W_s + W_w}{V_t} = \frac{G_s\gamma_w(1-n) + wG_s\gamma_w(1-n)}{1}$$
$$= (1+w)G_s\gamma_w(1-n) = G_s\gamma_w(1-n)(1+w)$$

When S=1 (fully saturated soil)

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

the moisture content *w* when S=1 can be expressed as

$$w = \frac{W_w}{W_s} = \frac{n\gamma_w}{G_s\gamma_w(1-n)} = \frac{n}{G_s(1-n)} = \frac{e}{G_s}$$
$$recall \quad Se = wG_s, thus \quad e = wG_s \quad \because S = 1$$

Weight-Volume Relationships

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}	$\gamma_d(1+w_{sat})$

The 3rd column is a special case of the 1st column when S = 1.

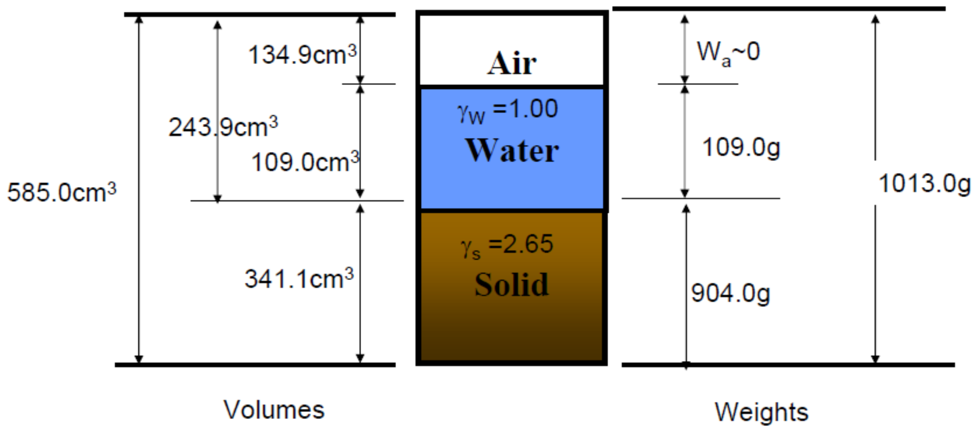
Example:

Determine moisture content, void ratio, porosity and degree of saturation of a soil core sample. Also determine the dry unit weight, γ_d

Data:

- Weight of soil sample = 1013g
- Vol. of soil sample = 585.0 cm^3
- Specific Gravity, Gs= 2.65
- Dry weight of soil = 904.0g

Solution



- From the three phase diagram we can find:
  - Moisture content, w $\quad w = \frac{W_w}{W_s} = \frac{109\,(g)}{904\,(g)} \times 100 = 12.1\%$
  - Void ratio, e $\quad e = \frac{V_v}{V_s} = \frac{243.9cm^3}{341.1cm^3} = 0.715$
  - Porosity, n $\quad n = \frac{V_v}{V_T} = \frac{243.9\,(cm^3)}{585.0\,(cm^3)} \times 100 = 41.7\%$
  - Degree of saturation, S $\quad S = \frac{V_w}{V_v} = \frac{109}{243.9} \times 100 = 44.7\%$
  - Dry unit weight, γ_d $\quad \gamma_d = \frac{W_s}{V_T} = \frac{904}{585} = 1.55\,\frac{g}{cm^3}$

2.7 Measurement of Moisture Content, Specific Gravity and, Density

The methods of determination of specific gravity of soil particles, the moisture content and bulk density of soil samples are:

2.7.1 Moisture Content of Soil

The degree of saturation should not be confused with moisture content which is the ratio of weight of water in the sample to the weight of solids.

$$Moisture\ Content\ \ m = \frac{W_w}{W_s}$$

Or

$$Percentage\ of\ moisture\ content = m\ x\ 100$$

2.7.2 Specific Gravity of Soil Particles

Specific Gravity is the ratio of the density of one material compared to the density of pure water ($\rho_w = 1g/cm^3$).

Specific gravity of solids, $$G_s = \frac{\rho_s}{\rho_w}$$

Note that unit weights, conventionally denoted by the symbol γ may be obtained by multiplying the density instead of ρ by the acceleration due to gravity, g.

$$Specific\ gravity\ of\ soil\ particles\ \ G_s = \frac{Weight\ of\ soil\ particles}{Weght\ of\ an\ equal\ volume\ of\ water}$$

But weight of an equal volume of water = weight of water displacement by the solids = weight of solids in air – submerged weight of solids.

Hence

$$Specific\ gravity\ G_s = \frac{W_s}{W_s - (W_1 - W_2)}$$

2.7.3 Bulk Density of Soil

The density of complete soil sample (i.e., solids and voids) is usually expressed as bulk density.

$$Bulk\ desity\ \gamma = \frac{Weight\ of\ soil, W_s}{Volume\ of\ soil, V_s}$$

Another definition: Weight of a unit volume of a loose material (such as a powder or soil) to the same volume of water.

2.7.4 Dry Density

The dry density is usually calculated from the measured values of bulk density and moisture content. The relationship between γ and γ_d and m is therefore of value.

$$Moisture\ Content\ \ m = \frac{W_w}{W_s}$$

$$W = W_s + W_w = W_s + mW_w = W_s(1 + m)$$

$$\gamma = \frac{W}{V} = \frac{W_s(1+m)}{V} = \gamma_d\,(1+m)$$

$$\gamma_d = \frac{\gamma}{1+m}$$

2.7.5 Saturated Density

The volume of soil sample will not change the voids are filled with water, the weight of this water = $V_v\,\gamma_w$

$$\text{Saturated density } \gamma_{sat} = \frac{W_s + V_v\,\gamma_w}{V}$$

2.7.6 Submerged Density

When the soil is below water table it will be saturated. As previously noted, but it will also be submerged.

Now, Submerged density of soil = Saturated density – Density of water

$$\text{Submerged density of soil } \gamma^{-} = \gamma_{sat} - \gamma_w$$

2.8 Conclusion:

Note that unit weights, conventionally denoted by the symbol γ may be obtained by multiplying the density instead of ρ by the acceleration due to gravity, g.

Density, Bulk Density, or Wet Density, ρ, are different names for the density of the mixture, i.e., the total mass of air, water, solids divided by the total volume of air water and solids (the mass of air is assumed to be zero for practical purposes):

$$\rho = \frac{M_s + M_w}{V_s + V_w + V_a} = \frac{M_t}{V_t}$$

Dry Density, ρ_d, is the mass of solids divided by the total volume of air water and solids:

$$\rho_d = \frac{M_s}{V_s + V_w + V_a} = \frac{M_s}{V_t}$$

Buoyant Density, ρ', defined as the density of the mixture minus the density of water is useful if the soil is submerged under water:

$$\rho' = \rho - \rho_w$$

where ρ_w is the density of water

From the above definitions, some useful relationships can be derived by use of basic algebra.

$$\rho = \frac{(G_s + Se)\rho_w}{1 + e}$$

$$\rho = \frac{(1 + w)G_s\rho_w}{1 + e}$$

$$w = \frac{Se}{G_s}$$