THE UNIVERISTY OF ZAMBIA

School of Engineering

Department of Civil and Environmental Engineering

CEE 3111 - CIVIL ENGINEERING MATERIALS AND CONSTRUCTION PRACTICES

2023 ACADEMIC YEAR
SEMESTER 1

TOPIC 7

Soil as a Construction Material

General Introduction

- Material engineers are interested in the basic **physical characteristics** of soils since they are frequently utilized in civil engineering projects such as:

  ✓ construction of highways
  ✓ high embankments,
  ✓ high rise buildings,
  ✓ dams, and
  ✓ other civil engineering structures.

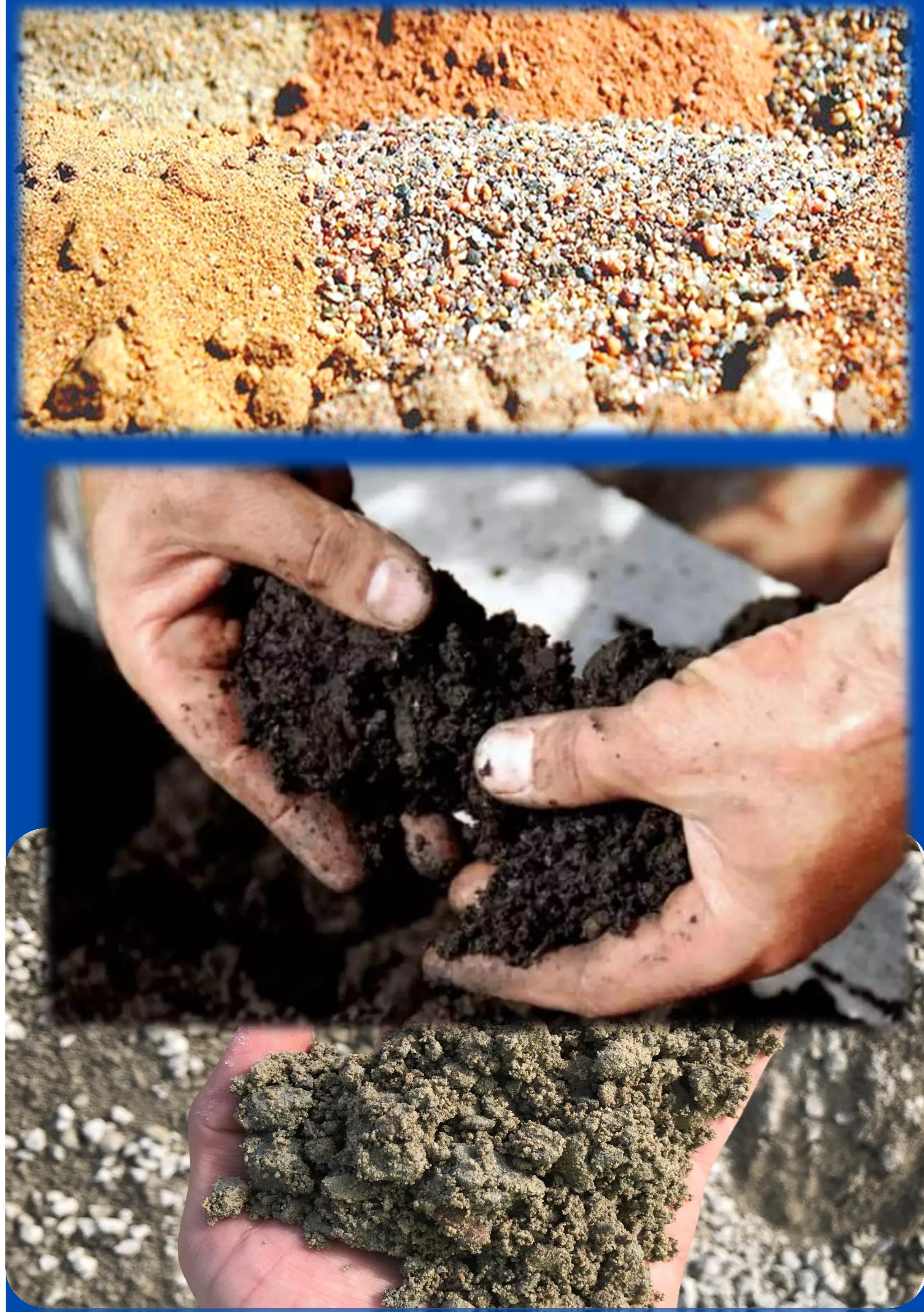
- Several agencies have developed detailed procedures for investigating soil materials used in construction.

Soil Characteristics

- Basic soil features include;
    1. Origin and formation,
    2. Shape (surface texture), and
    3. Grain size
- Soil engineering properties are primarily based on its basic characteristics.

1. Origin and Formation of Soils

- Mainly formed by weathering and other geologic processes.
- Soils may be described as **residual** or **transported.**



Soil Characteristics

2. Surface texture, shape and size

- Soil texture describes particle size and distribution, affecting appearance.
- Fine-textured soils (silts, clays) have small particles, while coarse-textured soils (sands, gravel) have larger ones.
- Texture impacts engineering properties.
- For example, water weakens fine-textured soil more than coarse-textured soil.

Soil Characteristics

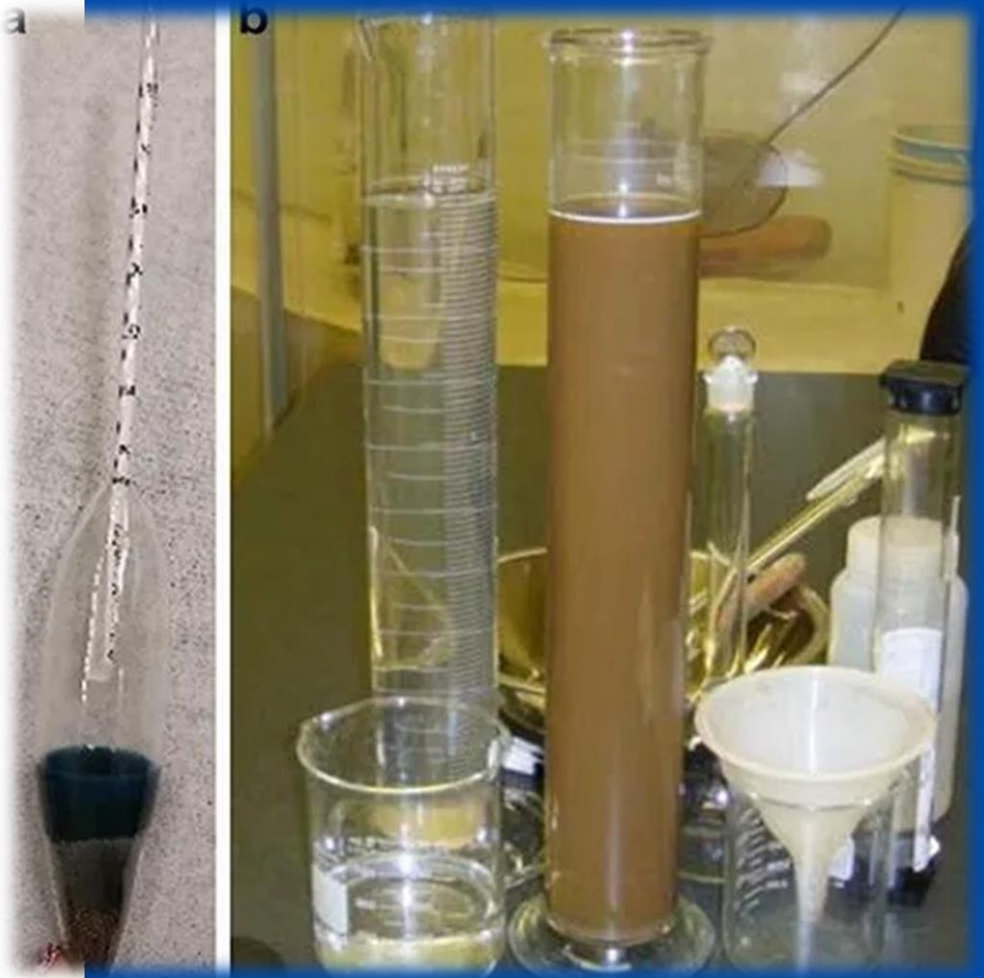
- Soils, excluding stones and gravel, fall into three particle-size categories.

  1. **Sands** (soil particles between 0.05 and 2 mm in diameter),
  2. **Silts** (soil particles between 0.002 and 0.05 mm in diameter), and
  3. **Clays** (soil particles less than 0.002 mm in diameter). The relative proportions of these particle-size fractions in a soil determine its texture.

- Soil texture depends on these particle-size proportions.

- PSD in soils can be determined by conducting a sieve analysis for soils retained on 0.075 mm (No. 200)

- Particles less 0.075 mm, hydrometer analysis is used.



Soil Characteristics

Sieve No.	Opening (mm)	Sieve No.	Opening (mm)
4	4.75	45	0.355
5	4.00	50	0.300
6	3.35	60	0.250
7	2.80	70	0.212
8	2.36	80	0.180
10	2.00	100	0.150
12	1.70	120	0.125
14	1.40	140	0.106
16	1.18	170	0.090
18	1.00	200	0.075
20	0.85	230	0.063
25	0.71	270	0.053
30	0.60	325	0.045
35	0.500	400	0.038
40	0.425		

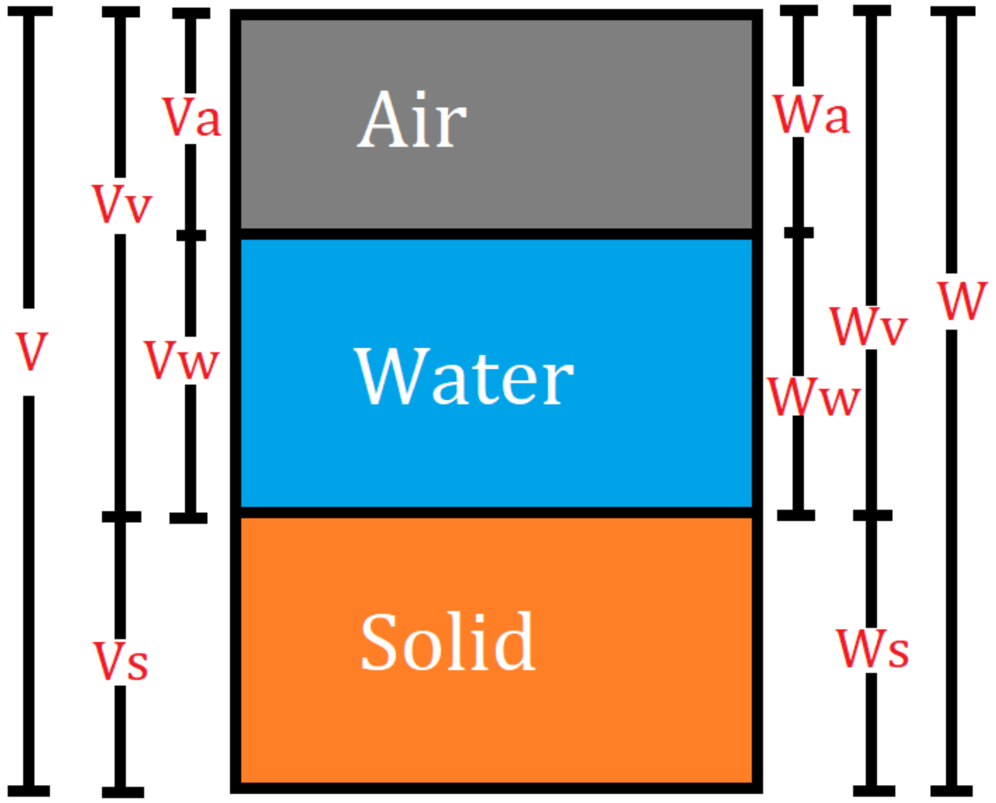
U.S. Sieve sizes

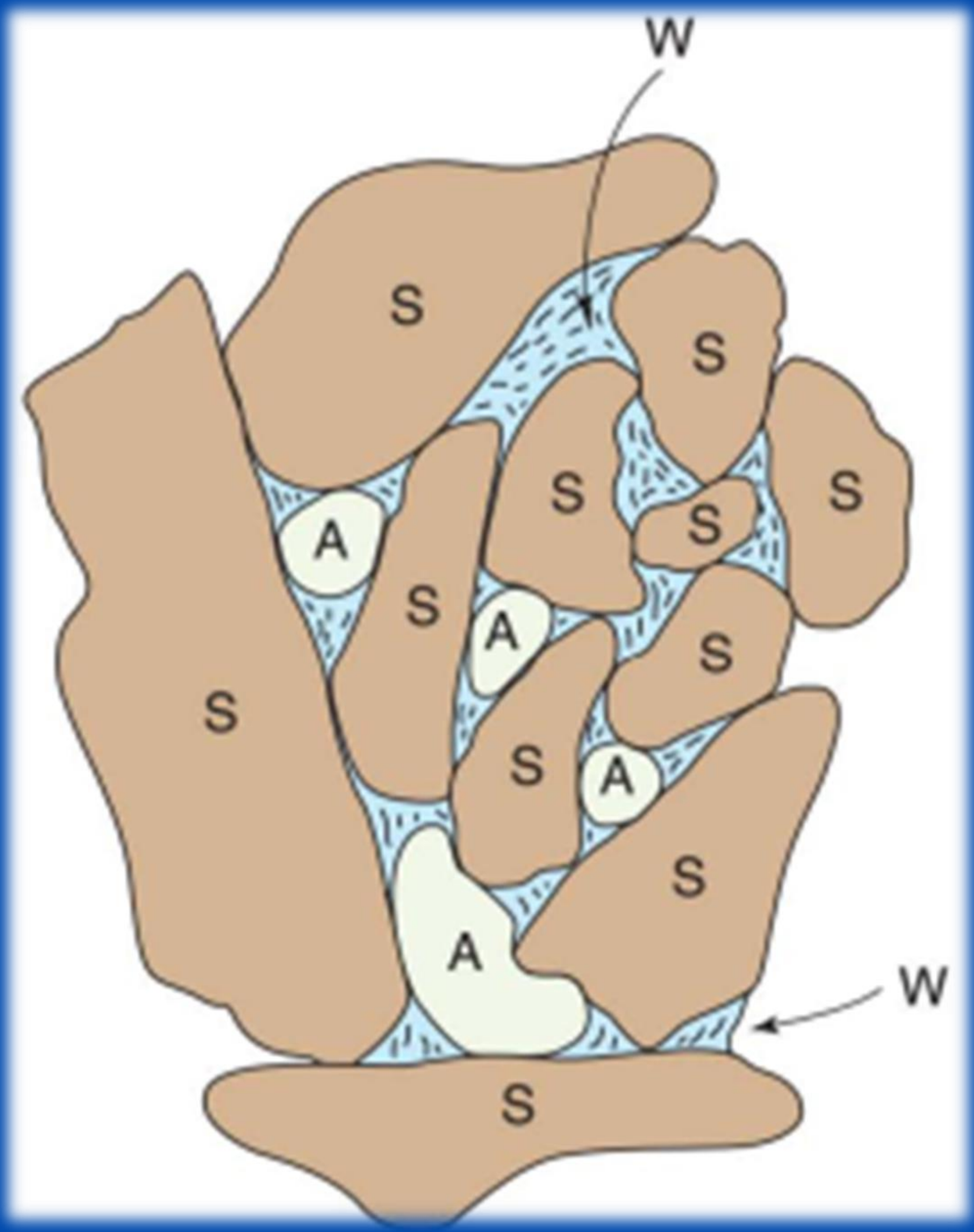
Soil type		Particle Size (mm)
Clay		<0.002
Silt		0.002-0.075
Sand	Fine	0.075-0.42
	Medium	0.42-2.0
	Coarse	2.0-4.75
Gravel		4.75-75

Basic Engineering Properties of Soils

1. Phase relations

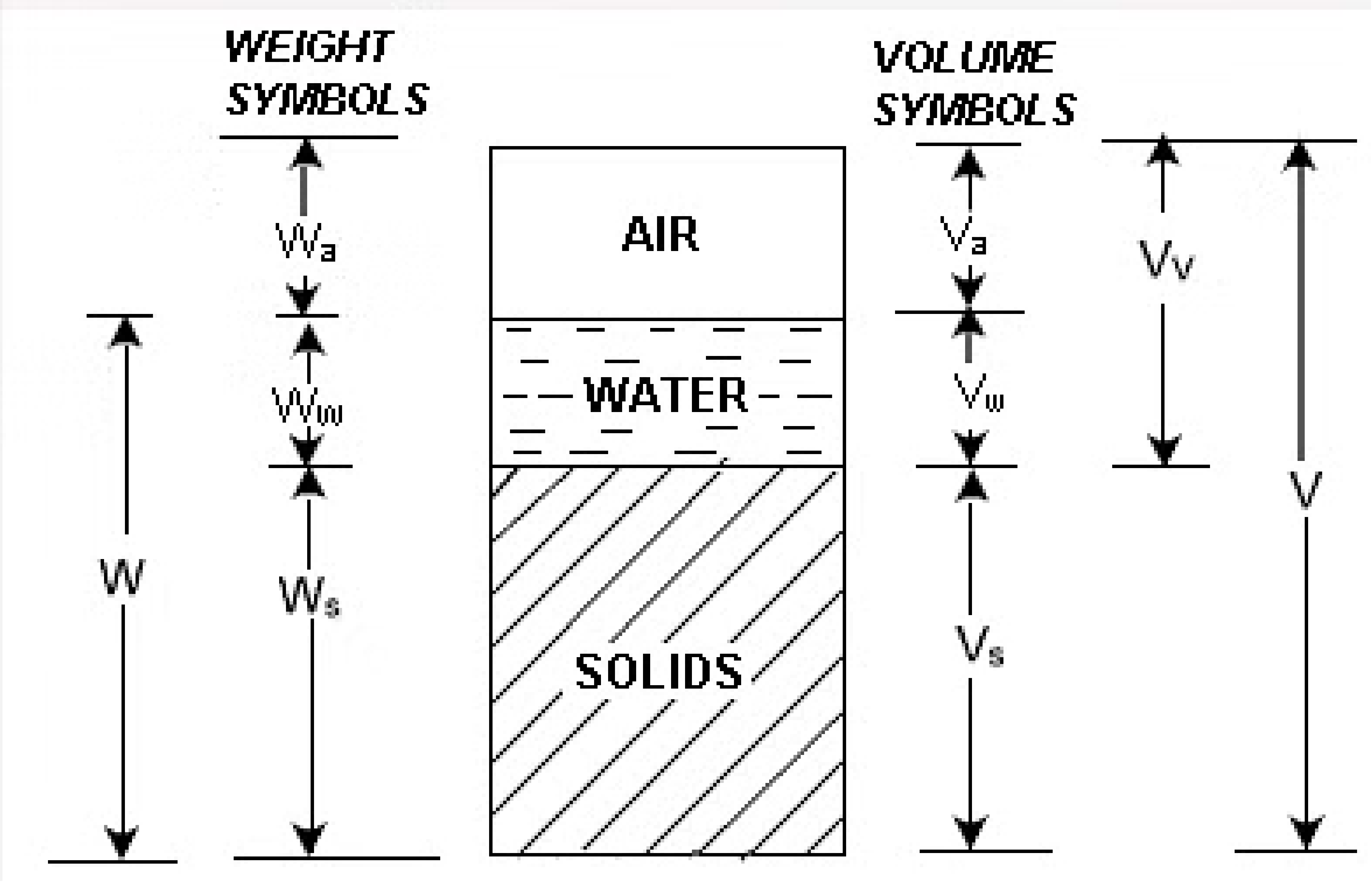
- A soil mass generally consists of solid particles of different minerals with spaces between them.
- The spaces can be filled with air and/or water.
- Soils are therefore considered as three- phase systems that consist of:
  - ✓ air,
  - ✓ water, and
  - ✓ solids.





Basic Engineering Properties of Soils

- V= Volume of soil
- V_v = total volume of the space occupied by air and water, generally referred to as a void
- V_a = volumes of air
- V_w = volumes of water
- V_s = volumes of solids



Basic Engineering Properties of Soils

Porosity

- The relative amount of voids in any soil is an important quantity that influences some aspects of soil behavior

- **Soil porosity, the** ratio of the volume of voids to total volume, can be used to measure this quantity

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

Void Ratio

- The amount of voids can also be measured in terms of the void ratio, which is defined as the ratio of the volume of voids to the volume of solids and is designated as *e*

$$e = \frac{V_v}{V_s}$$

$$Relation\ between\ porosity\ and\ void\ ratio\ is\ given\ a\ s\ follows\!: e = \frac{n}{1-n}$$

Basic Engineering Properties of Soils

Moisture Content

- Moisture content (w) measures quantity of water in soil.

- Moisture content is the ratio of water weight W_w in soil mass to oven-dried solids weight, W_s given as a percentage.

$$Moisture\ Content = \frac{W_w}{W_s} * 100$$

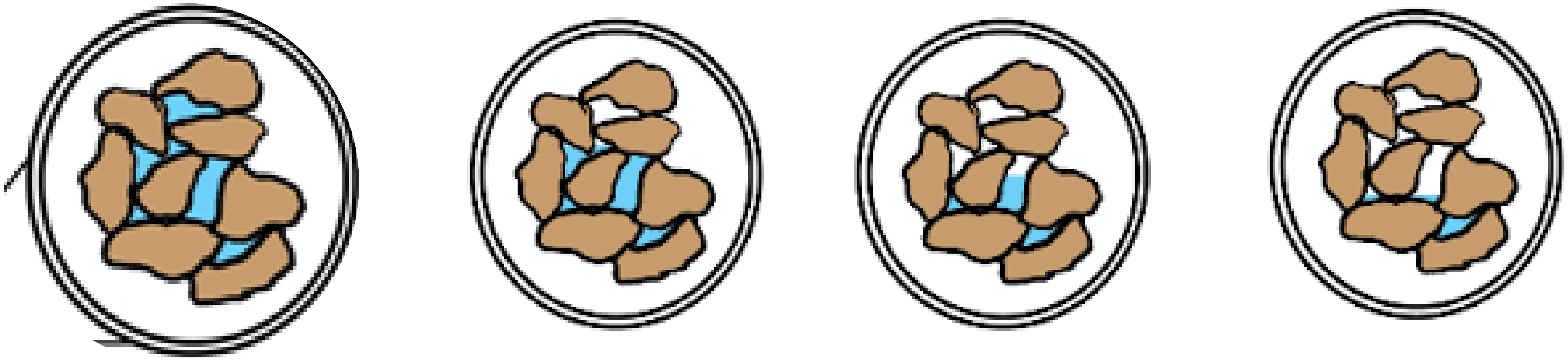
Degree of Saturation

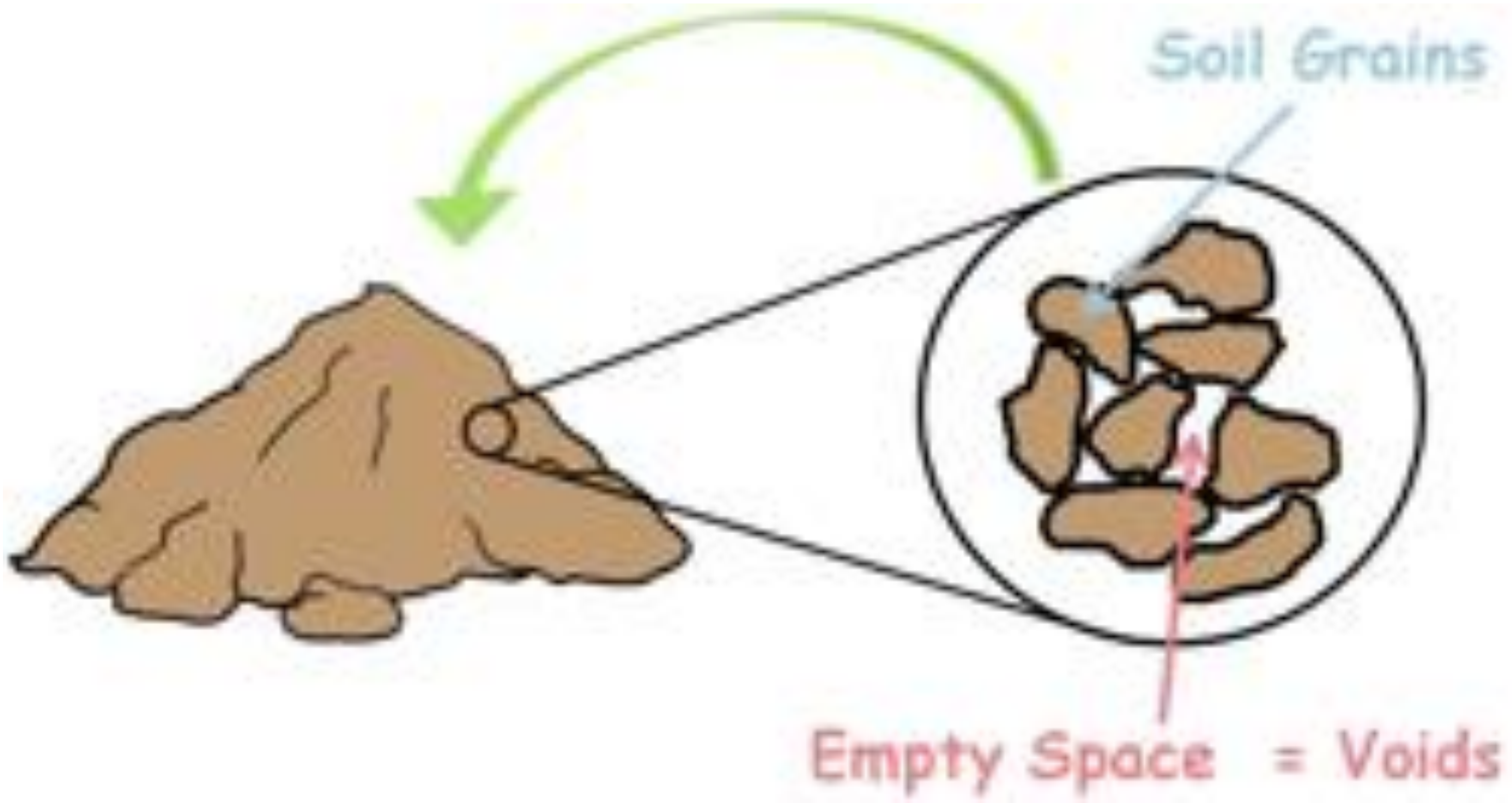
- The degree of saturation is the percentage of void space occupied by water and is given as

$$S = \frac{V_w}{V_v} * 100$$

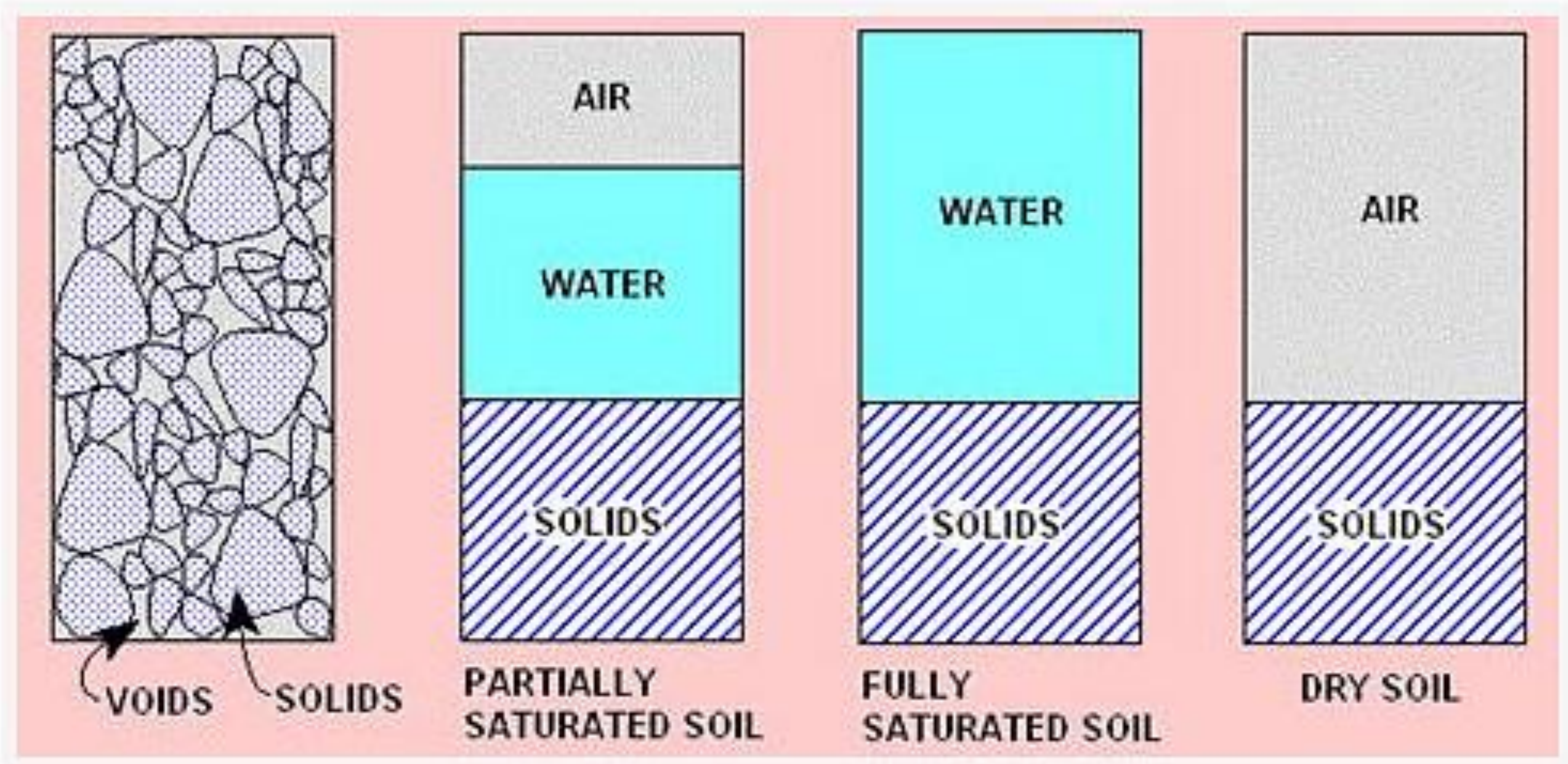
- The soil is saturated when the void is fully occupied with water, that is, when S = 100% and partially saturated when the voids are only partially occupied with water

Basic Engineering Properties of Soils





Basic Engineering Properties of Soils



Basic Engineering Properties of Soils

Density of Soil

Three densities are commonly used in soil engineering:

I. total or bulk density γ,

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a} \quad \text{(weight of air is negligible)} \qquad \text{or} \qquad \gamma = \frac{G_s + Se}{1 + e}\gamma_w$$

ii. dry density γ_d,

G_s = specific gravity of the soil particles

$$\gamma_d = \frac{W_s}{V} = \frac{W_s}{V_s + V_w + V_a} = \frac{\gamma}{1 + w}$$

and

iii. submerged or buoyant density γ'.

$$\gamma' = \gamma_{sat} - \gamma_w \qquad \text{where} \qquad \gamma_{sat} = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w}$$

Basic Engineering Properties of Soils

Example

The wet weight of a specimen of soil is 340 g and the dried weight is 230 g. The volume of the soil before drying is 210 cc. If the specific gravity of the soil particles is 2.75, determine the following:

i. porosity,
ii. void ratio,
iii. degree of saturation, and
iv. dry density

Solution

$$Porosity, n = \frac{V_v}{V}$$

Find volume of specimen, $, V = 210cm^3(\boldsymbol{given})$

Find volume of voids, $V_v = V_a + V_w$

Basic Engineering Properties of Soils

First find volume of water, $V_w = \frac{W_w}{\gamma_w}$

$$W_w = 340g - 230g = 110g$$

$$V_w = \frac{110}{1} = 110cm^3$$

Now find volume of air by first finding volume of solids, $V_s = \frac{M_s}{\gamma_s}$

$$V_s = \frac{230}{2.75} = 83.64cm^3$$

We know that total volume of sample, $V = 210cm^3 = V_w + V_s + V_a$

Therefore, $V_a = 210 - 110 - 83.64 = 16.36cm^3$

And finally $V_v = V_a + V_w = 16.36 + 110 = 126.36\ \boldsymbol{cm^3}$

Basic Engineering Properties of Soils

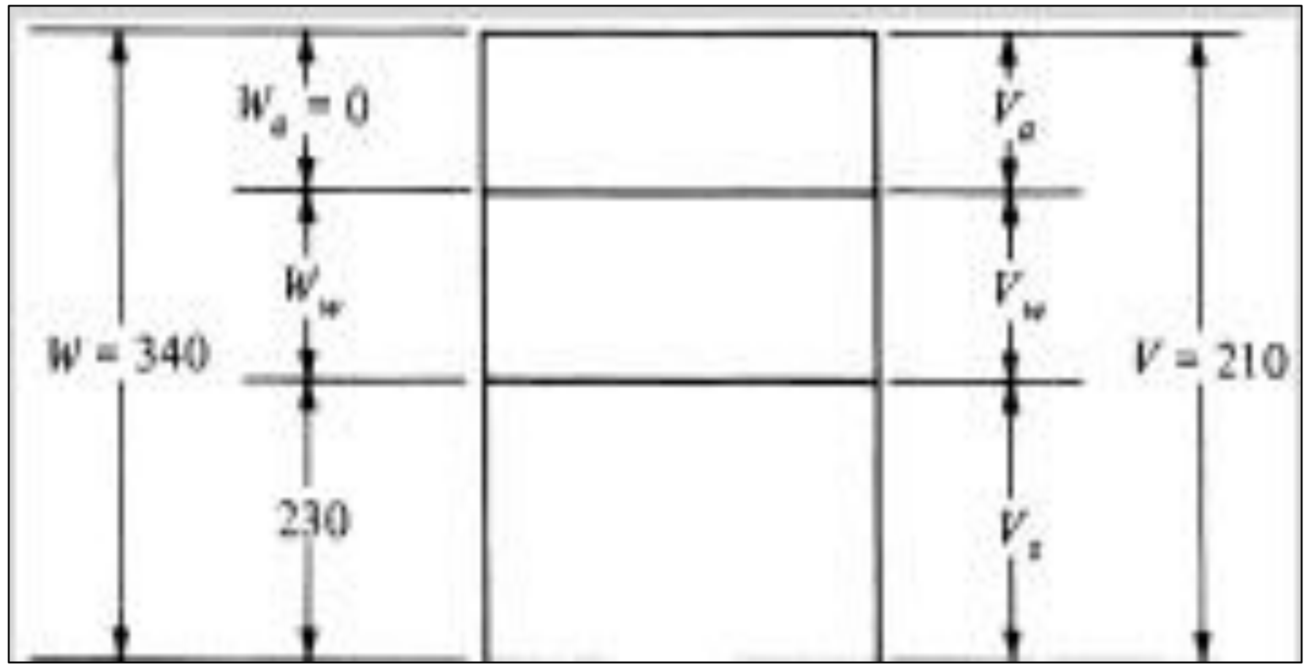
i. Porosity, $n = \frac{V_v}{V} = \frac{126.36}{210} = 0.60$

ii. Void ratio, $e = \frac{n}{1-n} = \frac{0.60}{1-0.60} = 1.5$

iii. Degree of Saturation, $S = \frac{V_w}{V_v} * 100 = \frac{110}{126.26} * 100 = 87.05\%$

iv. Dry density, $\gamma_d = \frac{W_s}{V} = \frac{230}{210} = 1.095\ g/cm^3$

The figure below shows the schematic of the soil mass



Basic Engineering Properties of Soils

2. Atterberg Limits

- Low-moisture clay soils are solids. More water makes solid soil plastic, so it can be molded into numerous forms without breaking up.

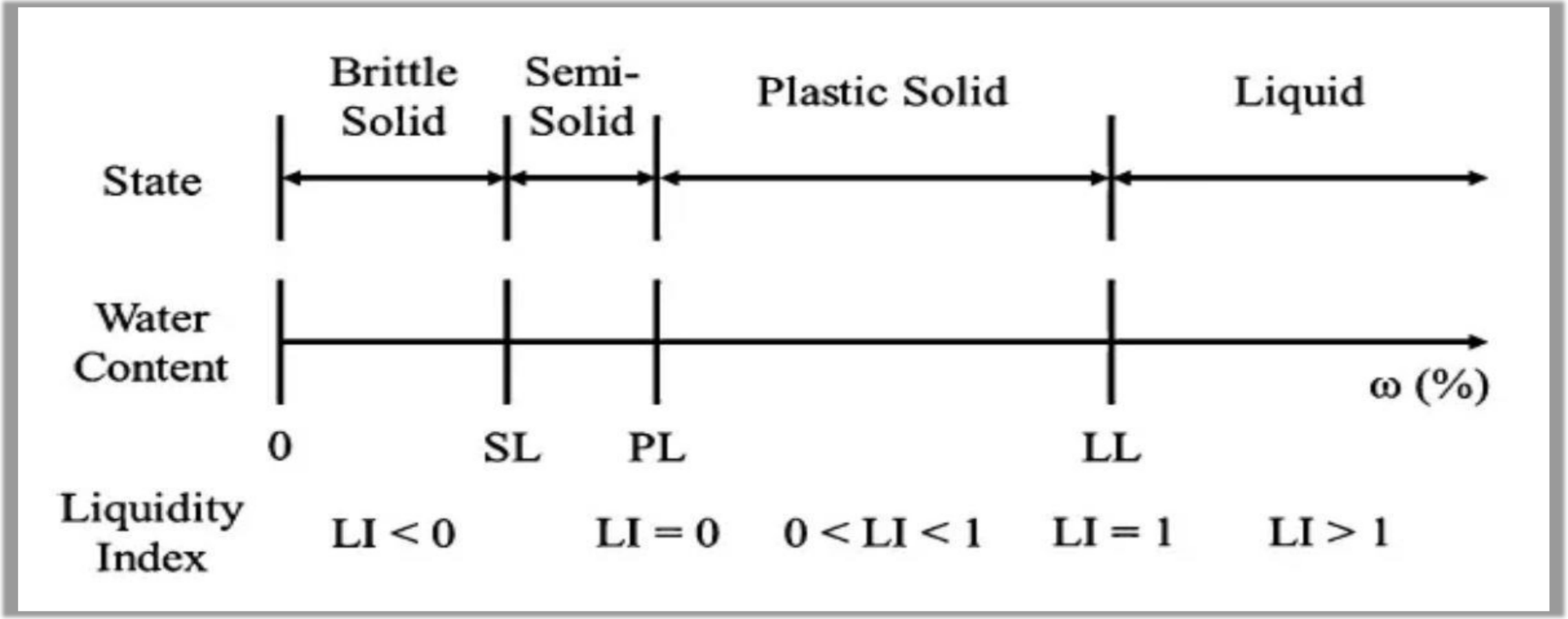
- As water content rises, soil will become viscous liquid.

- The stiffness or consistency of the soil at any time is dependent on its state, which depends on its water content.

- The water content levels at which the soil changes from one state to the other are the Atterberg limits.

- These are the
  - **shrinkage limit (SL),**
  - **plastic limit (PL), and**
  - **liquid limit (LL)**

Basic Engineering Properties of Soils



Basic Engineering Properties of Soils

Shrinkage Limit (SL)

- The water content where further loss of moisture will not result in any more volume reduction

Plastic Limit (PL)

- The water content at which soil sample change from plastic state to semi-solid state. (i.e. soil loses its plasticity & behave like a brittle material)

Liquid Limit (LL)

- The boundary water content between the liquid state and the plastic state when the sample changes from possessing no shear strength to having an very low shear strength

Plasticity Index (PI)

- The range of moisture content over which the soil is in the plastic state

$$PI = LL - PL$$

Basic Engineering Properties of Soils

Permeability of Soils

- This is a property that describes how water flows in a soil

Shear Strength of Soils

$$S = C + \sigma tan\emptyset$$

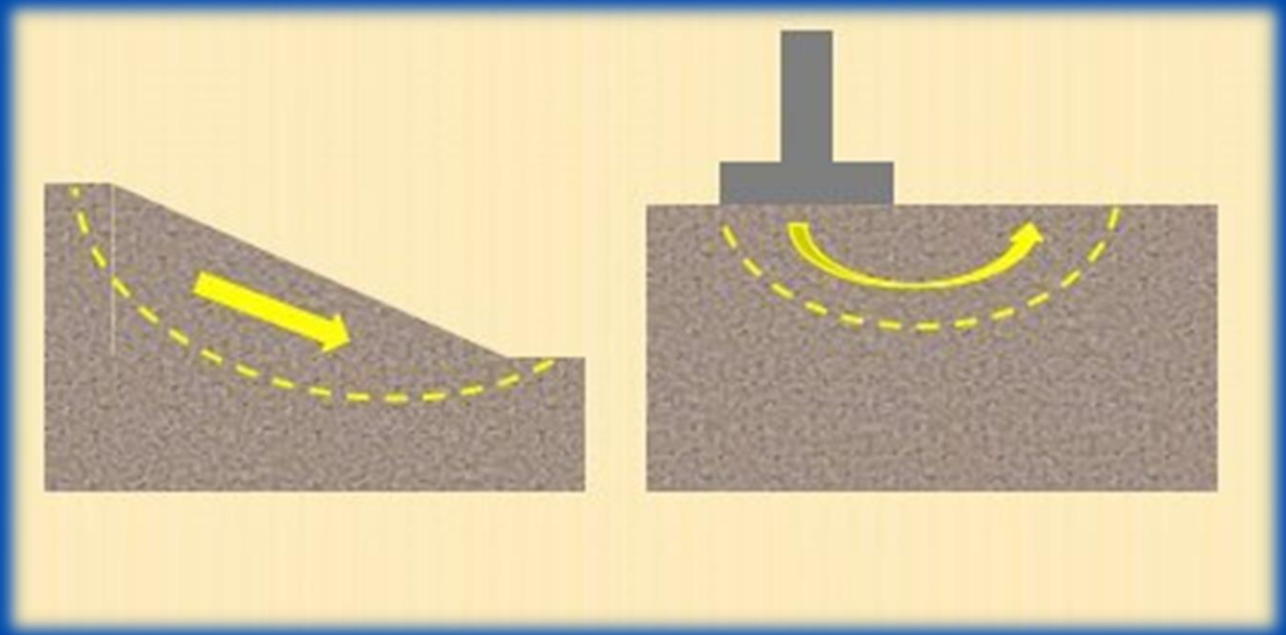
Where:

$S = Shear\ Strength\ in\ kg/cm^2$

$C = Cohesion\ in\ kg/cm^2$

$\sigma = Normal\ Stress\ in\ kg/cm^2$

$\emptyset = Angle\ of\ friction\ in\ degrees$



Classification of Soils

- Soil classification organizes soils by engineering properties.
- It helps identify suitable construction materials and predict soil behavior when used.
- Classifying the soil should be considered as a means of obtaining a general idea of how the soil
- Commonly used classification system for highway purposes include:
  1. The American Association of State Highway and Transportation Officials (AASHTO) Classification System (Most commonly used)
  2. The Unified Soil Classification System (USCS) (used to a lesser extent)
  3. Slightly modified version of the USCS is used fairly extensively in the United Kingdom.

Classification of Soils - AASHTO

AASHTO Classification System

- In the current publication, soils are classified into seven groups, A-1 through to A-7, with several subgroups as shown in the table below

AASHTO Classification of Soils and Soil Aggregate Mixtures

General Classification	*Granular Materials (35% or Less Passing No. 200)*							*Silt-Clay Materials (More than 35% Passing No. 200)*			
	A-1			*A-2*							*A-7*
Group Classification	*A-1-a*	*A-1-b*	*A-3*	*A-2-4*	*A-2-5*	*A-2-6*	*A-2-7*	*A-4*	*A-5*	*A-6*	*A-7-5, A-7-6*
Sieve analysis											
Percent passing											
No. 10	–50 max.	—	—	—	—	—	—	—	—	—	
No. 40	30 max.	50 max.	51 min.	—	—	—	—	—	—	—	—
No. 200	15 max.	25 max.	10 max.	35 max.	35 max.	35 max.	35 max.	36 min.	36 min.	36 min.	36 min.
Characteristics of fraction passing No. 40:											
Liquid limit	—		—	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.	40 max.	41 min.
Plasticity index	6 max.		N.P.	10 max.	10 max.	11 min.	11 min.	10 max.	10 max.	11 min.	11 min.*
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

Classification of Soils - AASHTO

- LL, PI, and particle size distribution classify soil. Within each group, soils are appraised using an empirical formula to establish their group index (GI), presented as:

$$GI = \quad F - 35 \quad 0.2 + 0.005\,LL - 40 + 0.01(F - 15)(PI - 10)$$

Where:

GI = $Group\ Index\ to\ the\ nearest\ whole\ number.$

$(A\ value\ of\ zero\ should\ be\ recorded\ when\ a\ negative\ value\ is\ obtained\ for\ the\ GI)$

F = $Percent\ of\ soil\ particles\ passing$ 0.075$mm\ sieve\ in\ whole\ number$

$(based\ on\ material\ passing$ 75 $mm)$

LL = $Liquid\ Limit\ expressed\ as\ a\ whole\ number$

PL = $Plastic\ Index\ expressed\ as\ a\ whole\ number$

Classification of Soils - AASHTO

AASHTO Classification System

- When soils are properly drained and compacted, their value as subgrade material decreases as the GI increases.
- For example, a soil with a GI of zero (an indication of a good subgrade material) will be better as a subgrade material than one with a GI of 20

- Under the AASHTO system granular soils fall into classes A-1 to A-3.
  - ✓ A-1 soils consist of well-graded granular materials
  - ✓ A-2 soils contain significant amounts of silts and clays, and
  - ✓ A-3 soils are clean but poorly graded sands.
- Suitability for highway construction;
  - ✓ Soils classified as A-1-a, A-1-b, A-2-4, A-2-5, and A-3 can be used satisfactorily as subgrade or subbase material if properly drained and compacted
  - ✓ Soils classified as A-2-6, A-2-7, A-4, A-5, A-6, A-7-5, and A-7-6 require a subbase layer if used as subgrade. These should be used as embankment materials with careful design.

AASHTO Classification – Example

The following data were obtained for a soil sample.

Mechanical Analysis		
Sieve No.	*Percent Finer*	*Plasticity Tests:*
4	97	LL = 48%
10	93	PL = 26%
40	88	
100	78	
200	70	

Using the AASHTO method for classifying soils, determine the classification of the soil and state whether this material is suitable in its natural state for use as a subbase material.

AASHTO Classification – Example

- Since more than 35% of the material passes the No. 200 sieve, the soil is either A-4, A-5, A-6, or A-7
- LL 48%, and therefore the soil cannot be in group A-4 or A-6. Thus, it is either A-5 or A-7.
- The PI = 48 – 26 = 22%, which is greater than 10%, thus eliminating group A-5. The soil is A-7-5 or A-7-6.
- (LL -30) =18 < PI (22%). Therefore the soil is A-7-6, since the plasticity index of A-7-5 soil subgroup is less than (LL - 30). The GI is given as:

$$GI = (70 - 35)[0.2 + 0.005(48 - 40)] + 0.01(70 - 1.5)(22 - 10) = 15$$

The soil is A-7-6 (15) and is therefore unsuitable as a subbase material in its natural state.

Classification of Soils - USCS

- The approach classifies coarse-grained soils by grain size and fine-grained soils by plasticity.

- USCS defines four major material groups:

  1. coarse-grained soils,
  2. fine-grained soils,
  3. organic soils, and
  4. Peat

- Material retained in the 75 mm (3 in.) sieve is recorded, but only that which passes is classified.

- Coarse-grained soils retain more than 50% of their particles on the No. 200 sieve, while fine-grained soils retain less.

Classification of Soils - USCS

USCS Definition of Particle Sizes

Soil Fraction or Component	Symbol	Size Range
1. Coarse-grained soils		
Gravel	G	75 mm to No. 4 sieve (4.75 mm)
Coarse		75 mm to 19 mm
Fine		19 mm to No. 4 sieve (4.75 mm)
Sand	S	No. 4 (4.75 mm) to No. 200 (0.075 mm)
Coarse		No. 4 (4.75 mm) to No. 10 (2.0 mm)
Medium		No. 10 (2.0 mm) to No. 40 (0.425 mm)
Fine		No. 40 (0.425 mm) to No. 200 (0.075 mm)
2. Fine-grained soils		
Fine		Less than No. 200 sieve (0.075 mm)
Silt	M	(No specific grain size—use Atterberg limits)
Clay	C	(No specific grain size—use Atterberg limits)
3. Organic soils	O	(No specific grain size)
4. Peat	Pt	(No specific grain size)

Gradation Symbols	*Liquid Limit Symbols*
Well graded, W	High LL, H
Poorly graded, P	Low LL, L

Classification of Soils - USCS

Letter	Definition
G	gravel
S	sand
M	silt
C	clay
O	organic

Letter	Definition
P	poorly graded (many particle of about the same size
W	well-graded (many different particle sizes
H	high liquid limit
L	low liquid limit

[USCS Summary]

[USCS Detailed Classification]

[Soil Classification Example]

Soil Surveys in Construction

- Soil surveys examine soil properties and identify construction-suitable soils.

- Any soil survey begins with the collecting of existing soil data in the area where the building, such as a roadway, will be built. Such information can be obtained from:

  - ✓ geological and agricultural soil maps,
  - ✓ existing aerial photographs,
  - ✓ examination of excavations and existing cuts.

- Next, collect and study enough soil samples to determine the soil type boundaries for a soil profile.

- Samples of each soil type are collected through auger drilling or test pits for laboratory analysis.

Soil Surveys in Construction

Soil Compaction

Soil compaction – is the process of increasing the density of soil by packing the particles closer together with a reduction in volume of air whereas;

- There is no significant change in the volume of water in the soil
- The higher the degree of compaction, the higher the shear strength & the lower the soil compressibility

Compaction improves characteristics of soils in the following ways!!!

- Increases Strength
- Decreases permeability
- Reduces settlement of foundation
- Increases slope stability of embankments

Soil Compaction

- Highway embankment and subbase soil must be layered and compacted to a high density.

- Proper soil compaction reduces settlement and volume change, strengthening the embankment or subbase.

- Compaction is achieved in the field by using;
  - hand-operated tampers,
  - sheepsfoot rollers,
  - rubber-tired rollers, or
  - other types of rollers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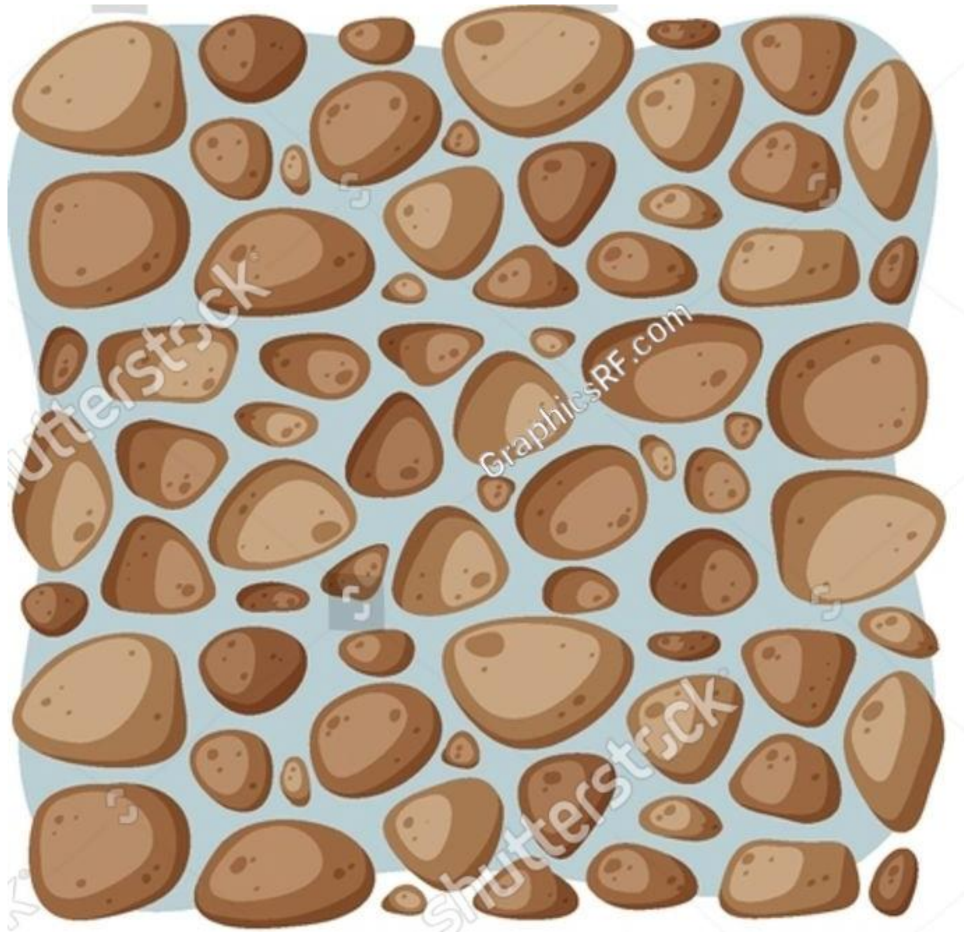
Soil Compaction

- Dry density increases with moisture content until an optimal level is reached.
- Further increased in moisture content lowers dry density.
- Low moisture content makes soil particles unlubricated and limits densification through friction.
- As moisture increases, larger water films form on particles, making soil more flexible and easier to move and densify.



Soil Compaction

- Reaching the optimal moisture content results in the highest practical saturation (S<100%).

- Due to entrapped air in void spaces and surrounding particles, further compaction cannot increase compaction at the ideal moisture content.

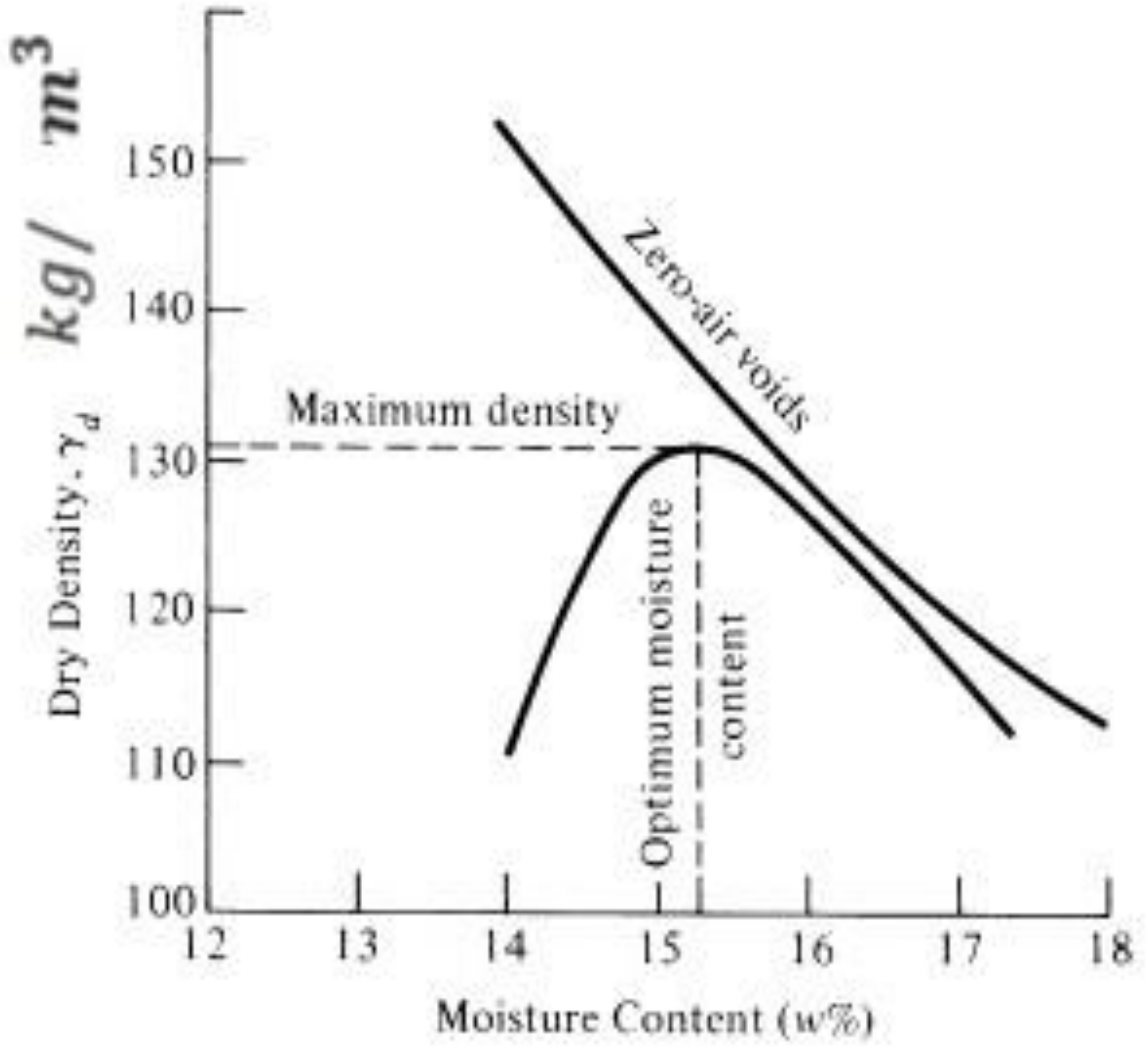
- Water overfills the spaces without reducing air.

- The soil particles are separated, resulting in a reduction in the dry density

Soil Compaction

- The strength of the compacted soil is directly related to the maximum dry density achieved through compaction.

- The relationship between dry density and moisture content for practically all soils takes the form shown below:



Soil Compaction

Example

The table shows results obtained from a standard AASHTO compaction test on six samples, 4 in. diameter, of a soil to be used as fill for a highway. The net volume of each sample is 0.0009439m^3

Sample	Weight (kg)	Moisture Content (%)
1	1.89	4.00
2	1.99	6.10
3	2.09	7.80
4	2.12	10.10
5	2.07	12.10
6	2.03	14.00

Determine the maximum dry density and the optimum moisture content of the soil.

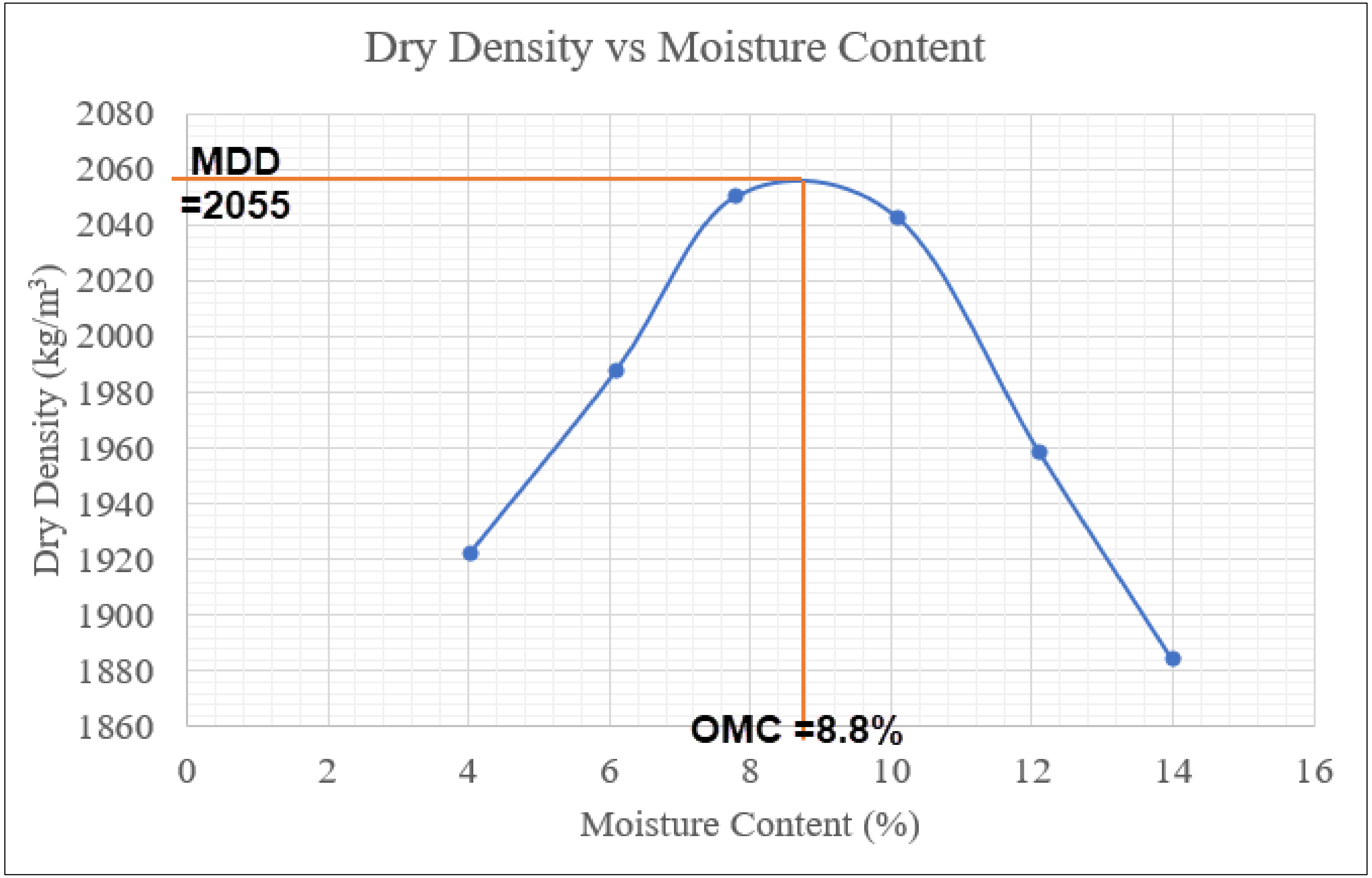
Soil Compaction

Solution

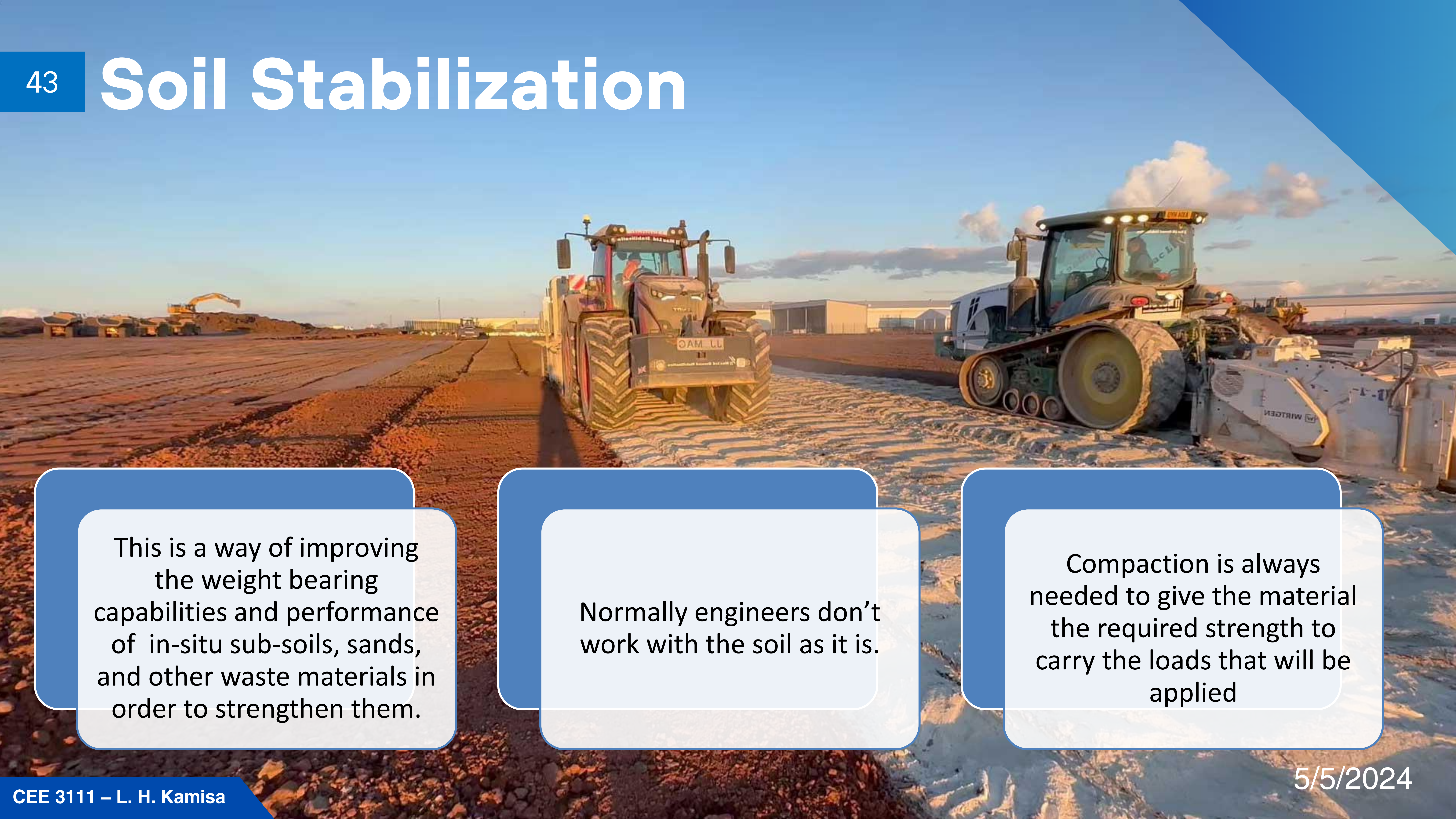
Sample	Weight (kg)	Bulk Density, $\gamma = W/V$ (kg/m^3)	Moisture Content (%)	Dry Density, $\gamma_d = \gamma/(1+w)$
1	1.89	1999.10	4.00	1922.21
2	1.99	2109.63	6.10	1988.34
3	2.09	2210.55	7.80	2050.60
4	2.12	2248.99	10.10	2042.68
5	2.07	2196.13	12.10	1959.08
6	2.03	2148.07	14.00	1884.28

Soil Compaction

Solution



Soil Stabilization

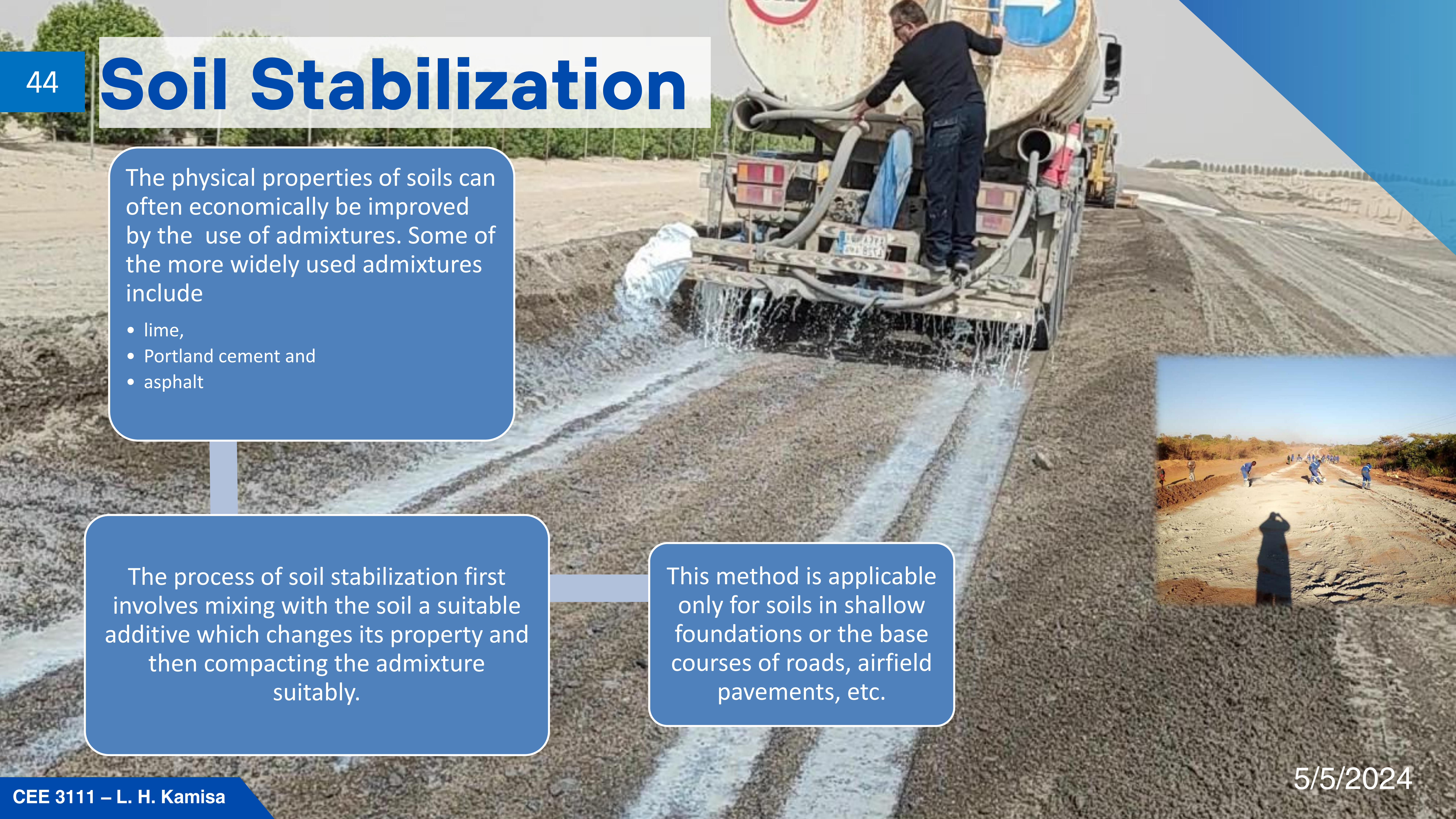


This is a way of improving the weight bearing capabilities and performance of in-situ sub-soils, sands, and other waste materials in order to strengthen them.

Normally engineers don't work with the soil as it is.

Compaction is always needed to give the material the required strength to carry the loads that will be applied

Soil Stabilization



The physical properties of soils can often economically be improved by the use of admixtures. Some of the more widely used admixtures include

- lime,
- Portland cement and
- asphalt

The process of soil stabilization first involves mixing with the soil a suitable additive which changes its property and then compacting the admixture suitably.

This method is applicable only for soils in shallow foundations or the base courses of roads, airfield pavements, etc.

Special Soil Tests

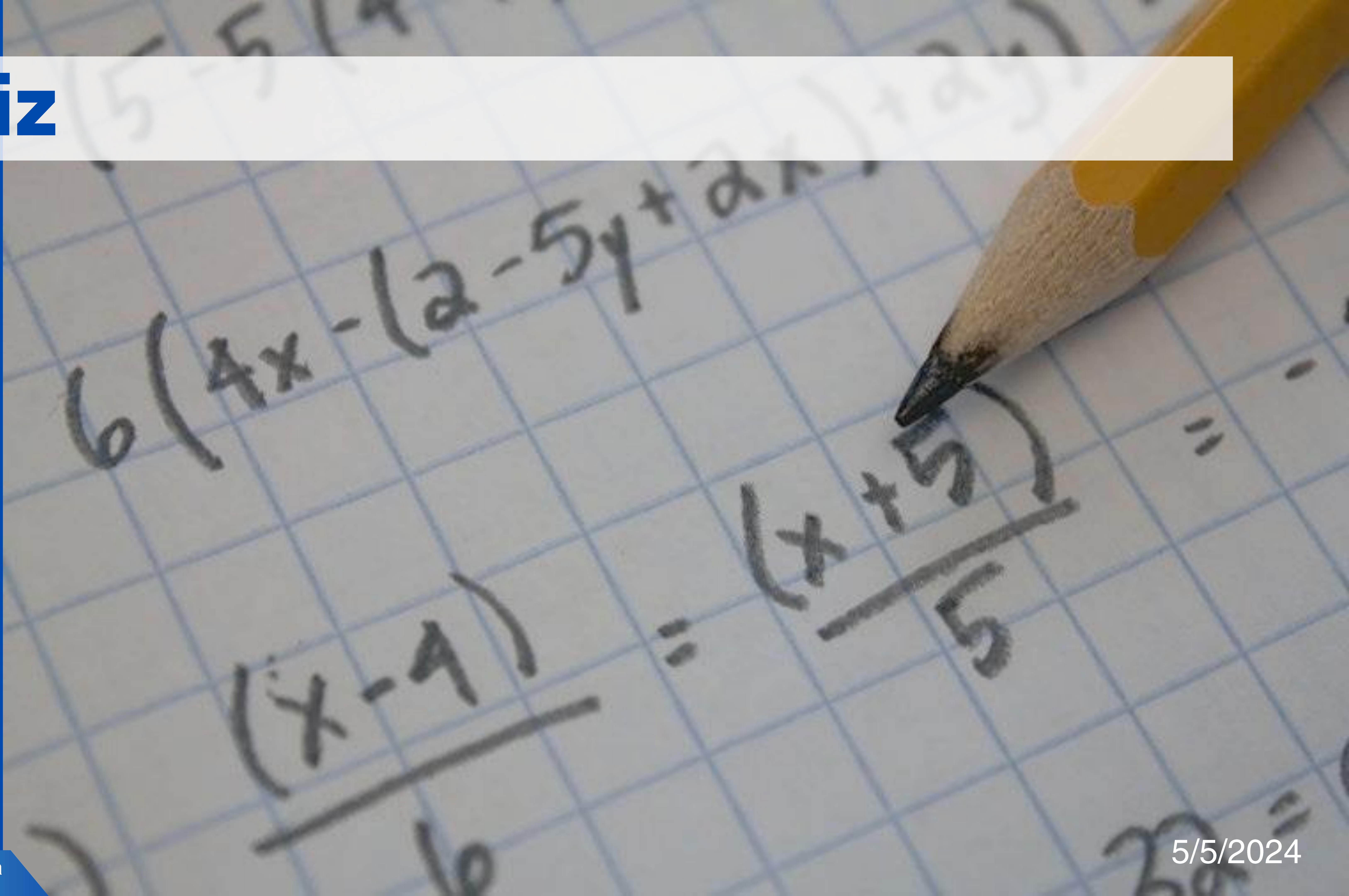
- Some additional soil tests conducted to assess the strength or supporting capacity of a soil include:

  1. California Bearing Ratio (CBR) Test and
  2. Hveem Stabilometer Test.

CBR Test
- CBR penetration tests evaluate road and pavement subgrade strength.
- Test findings are utilized with empirical curves to determine pavement and layer thickness.

Hveem Stabilometer Test.
- Test for soil resilience modulus.

Quiz



Thank You!!!