TOPIC 7

Soil as a Construction Material

General Introduction

- Material engineers are interested in the basic engineering properties of soils because soils are used extensively in civil engineering projects
- Soil properties are of significant importance in construction of highways, high embankments, high rise buildings, dams, and other civil engineering structures
- Thus, several agencies have developed detailed procedures for investigating soil materials used in construction.
- This topic presents a summary of current knowledge of the characteristics and engineering properties of soils that are important to civil engineers, including;
  - the origin and formation of soils,
  - soil identification, and
  - soil testing methods.

Soil Characteristics

- The basic characteristics of a soil may be described in terms of;
  1. its origin and formation,
  2. shape (surface texture), and
  3. grain size
- Principal engineering properties of any soil are mainly related to the basic characteristics of that soil

1. **Origin and Formation of Soils**

- Soil can be defined from the civil engineering point of view as the loose mass of mineral and organic materials that cover the solid crust of granitic and basaltic rocks of the earth.
- Soil is mainly formed by weathering and other geologic processes that occur on the surface of the solid rock at or near the surface of the earth
- Soils may be described as **residual** or **transported**

Soil Characteristics

2. **Surface texture, shape and size**

- Surface texture of soils can be described in terms of its appearance, which depends mainly on the shapes and sizes of the soil particles and their distribution in the soil mass.
- Soils consisting mainly of silts and clays with very small particle sizes are known as fine-textured soils, whereas soils consisting mainly of sands and gravel with much larger particles are known as coarse-textured soils.
- Engineering properties of a soil are related to its texture.
- For example, the presence of water in fine-textured soils results in significant reduction in their strength, whereas this does not happen with coarse textured soils.

Soil Characteristics

- Soils can therefore be divided into two main categories based on their texture.
- **Coarse-grained soils** are sometimes defined as those with particle sizes greater than 0.05 mm, such as sands and gravel
- **Fine-grained soils** are those with particle sizes less than 0.05 mm, such as silts and clays.
- The dividing line of 0.05 mm (0.075 mm has also been used) is selected because that is normally the smallest grain size that can be seen by the naked eye.
- The distribution of particle size in soils can be determined by conducting a sieve analysis (sometimes known as mechanical analysis)
- Smallest practical opening of these sieves is 0.075 mm (No. 200)
- For soils containing particle sizes smaller than the lower limit, the hydrometer analysis is used

Basic Engineering Properties of Soils

- Civil engineers need to be familiar with basic engineering properties of soils that influence their behavior when subjected to external loads
- Critical engineering properties of soils include:
  1. Phase relations such as porosity, void ratio, degree of saturation, etc
  2. Atterberg Limits

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

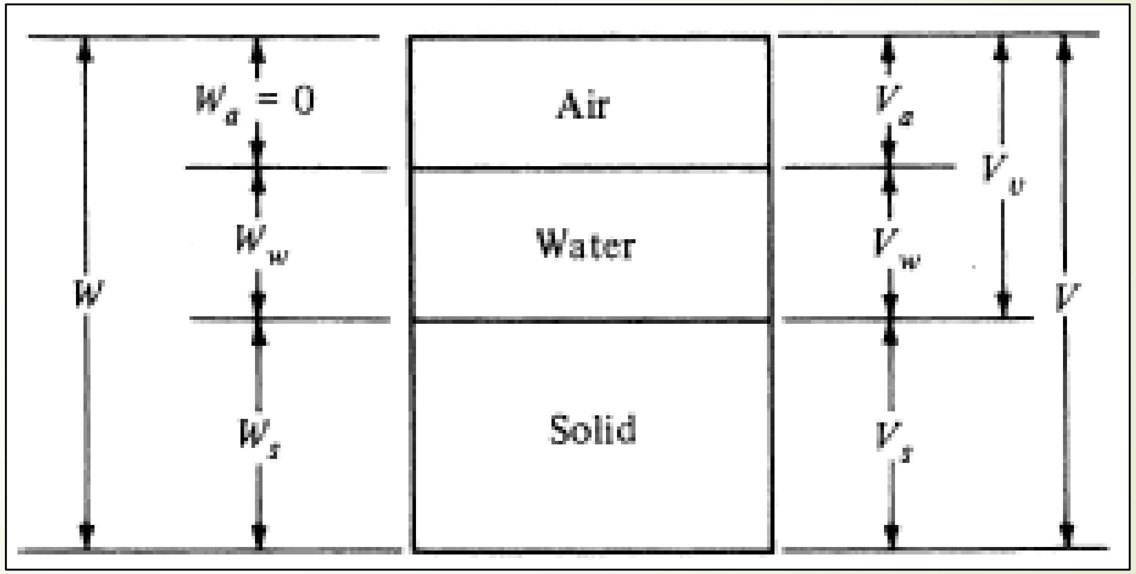
V= Volume of soil

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
- This amount can be measured in terms of the porosity of the soil, which is defined as the ratio of the volume of voids to the total volume of the soil and is designated as *n*

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

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

- The quantity of water in a soil mass is expressed in terms of the moisture content (*w*)
- Moisture content is defined the ratio of the weight of water V_w in the soil mass to the oven dried weight of solids V_s expressed as a percentage.

$$w = \frac{V_w}{V_s} * 100$$

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

Density of Soil

- Three densities are commonly used in soil engineering:

  i. total or bulk density γ,

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a} \quad \text{(weight of air is negligible)}$$

or

$$\gamma = \frac{G_s + Se}{1 + e}\gamma_w$$

G_s = specific gravity of the soil particles

  ii. dry density γ_d,

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

and

  iii. submerged or buoyant density γ'.

$$\gamma' = \gamma_{sat} - \gamma_w$$

where

$$\gamma_{sat} = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w}$$

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 voids $V = 210\ cm^3$ **(given)**

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

Basic Engineering Properties of Soils

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

$$W_w = 340\ g - 230\ g = \mathbf{110\ g}$$

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

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

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

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

Therefore, $V_a = 210 - 110 - 83.64 = 16.\mathbf{36\ cm^3}$

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

Basic Engineering Properties of Soils

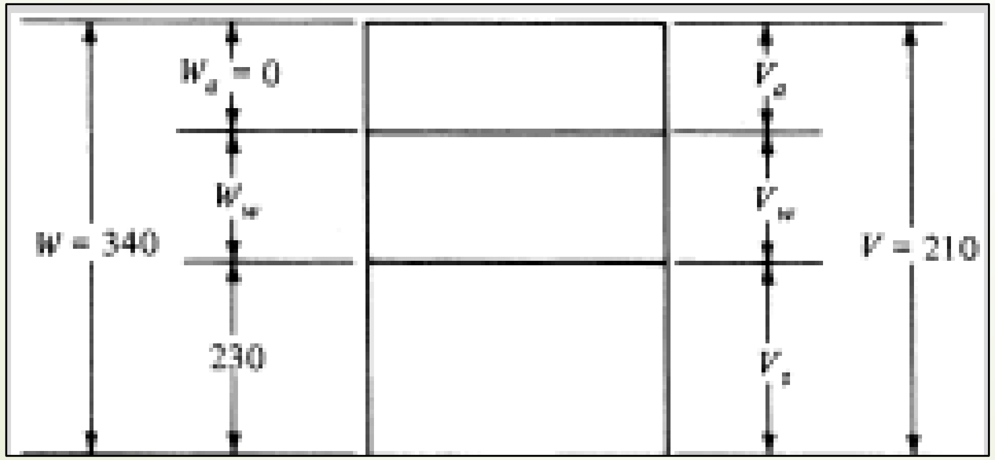
i. Porosity, $n = \frac{V_v}{V} = \frac{126.36}{210} = 0.60$

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, $\gamma_d = \frac{W_s}{V} = \frac{230}{210} = 1.095\ g/\ \boldsymbol{cm^3}$

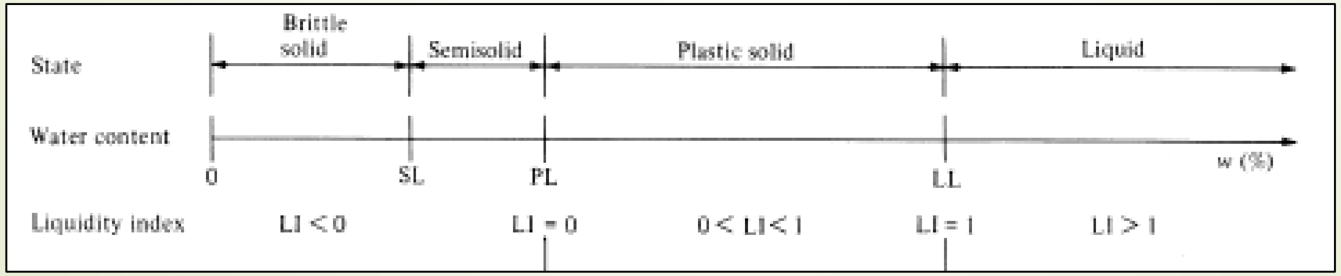
The figure below shows the schematic of the soil mass



Basic Engineering Properties of Soils

2. Atterberg Limits

- Clay soils with very low moisture content will be in the form of solids. As the water content increases, however, the solid soil gradually becomes plastic—that is, the soil easily can be molded into different shapes without breaking up.
- Continuous increase of the water content will eventually bring the soil to a state where it can flow as a viscous liquid.
- The stiffness or consistency of the soil at any time therefore depends on the state at which the soil is, which in turn depends on the amount of water present in the soil.
- The water content levels at which the soil changes from one state to the other are the Atterberg limits. They are the shrinkage limit (SL), plastic limit (PL), and liquid limit (LL), as illustrated in figure below:



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 is a method by which soils are systematically categorized according to their probable engineering characteristics.
- It therefore serves as a means of identifying suitable construction materials and predicting the probable behavior of a soil when in use
- 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 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 Classification System

- The classification of a given soil is based on its particle size distribution, LL, and PI. Soils are evaluated within each group by using an empirical formula to determine the group index (GI) of the soils, given as:

$$GI = (F - 35)[0.2 + 0.005(LL - 40)] + 0.01(F - 15)(PI - 10)$$

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

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

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

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

Classification of Soils

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 of a soil deposit for use in highway construction can be summarized as follows;
  1. 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
  2. Materials classified as A-2-6, A-2-7, A-4, A-5, A-6, A-7-5, and A-7-6 will require a layer of subbase material if used as subgrade. If these are to be used as embankment materials, special attention must be given to the design of the embankment.

Classification of Soils

AASHTO Classification System – 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.

Classification of Soils

AASHTO Classification System – Solution to the 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 40%, 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:

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

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

Classification of Soils

Unified Soil Classification System (USCS)

- The system classifies coarse-grained soils on the basis of grain size characteristics and fine-grained soils according to plasticity characteristics.
- USCS uses four definitions for the major groups of materials, consisting of:
  - coarse-grained soils,
  - fine-grained soils,
  - organic soils, and
  - peat
- Material that is retained in the 75 mm (3 in.) sieve is recorded, but only that which passes is used for the classification of the sample
- Soils with more than 50 percent of their particles being retained on the No. 200 sieve are coarse-grained, and those with less than 50 percent of their particles retained are fine-grained soils

Classification of Soils

Unified Soil Classification System (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

Unified Soil Classification System (USCS)

- Gravels can be described as either well-graded gravel (GW), poorly graded gravel (GP), silty gravel (GM), or clayey gravels (GC), and sands can be described as well-graded sand (SW), poorly graded sand (SP), silty sand (SM), or clayey sand (SC).
- A gravel or sandy soil is described as well graded or poorly graded, depending on the values of two shape parameters known as the coefficient of uniformity, Cu, and the coefficient of curvature, Cc, given as:

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

And

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

D_{60} = grain diameter at 60% passing
D_{30} = grain diameter at 30% passing
D_{10} = grain diameter at 10% passing

Classification of Soils

Unified Soil Classification System (USCS)

- Gravels are described as well graded if Cu greater than four and Cc is between one and three.
- Sands are described as well graded if Cu greater than six and Cc is between one and three.
- The fine-grained soils, which are defined as those having more than 50 percent of their particles passing the No. 200 sieve, are subdivided into (depending on the PI and LL of the soil):
  1. clays (C) or
  2. silt (M)

Soil Surveys in Construction

Unified Soil Classification System (USCS)

- Soil surveys entail the investigation of the soil characteristics and the identification of suitable soils for use in construction
- The first step in any soil survey is in the collection of existing information on the soil characteristics of the area in which the structure such as highway is to be located. Such information can be obtained from:
  - geological and agricultural soil maps,
  - existing aerial photographs,
  - examination of excavations and existing cuts.
- The next step is to obtain and investigate enough soil samples to identify the boundaries of the different types of soils so that a soil profile can be drawn.
- Samples of each type of soil are obtained by auger boring or from test pits for laboratory testing.

Soil Surveys in Construction

Unified Soil Classification System (USCS)

- In cases where rock locations are required, depths may be increased.
- The engineering properties of the samples are then determined and used to classify the soils.
- It is important that the characteristics of the soils in each hole be systematically recorded, including:
  - the depth,
  - location,
  - thickness,
  - texture, and so forth.
- It is also important that the location of the water level be noted
- Soil profiles can also be obtained from one of two geophysical methods of soil exploration known as the resistivity and seismic methods

Soil Compaction

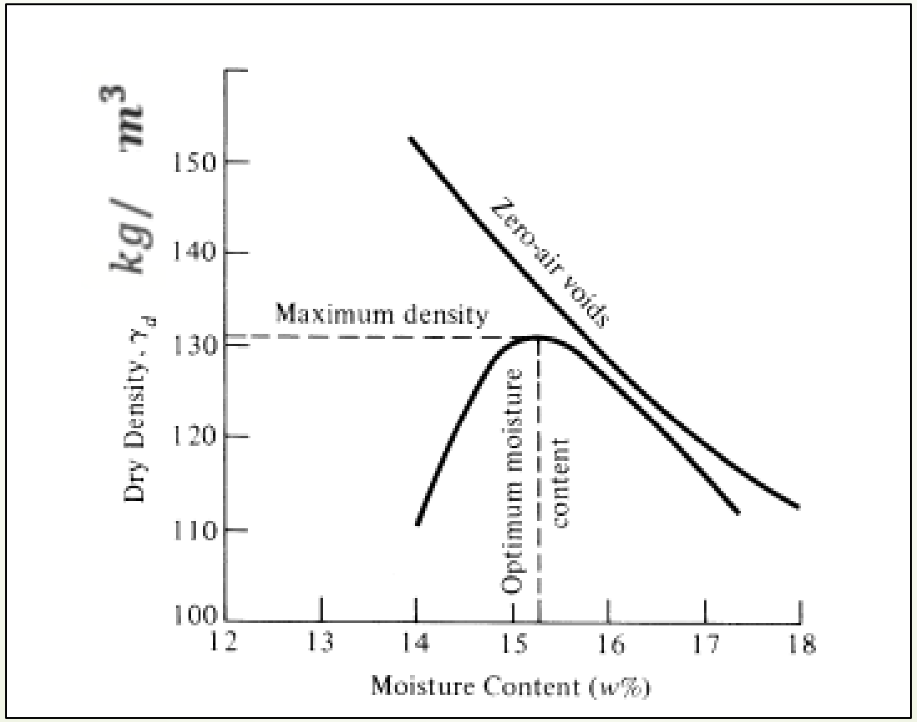
- When soil is to be used as embankment or subbase material in highway construction, it is essential that the material be placed in uniform layers and compacted to a high density
- Proper compaction of the soil will reduce subsequent settlement and volume change to a minimum, thereby enhancing the strength of 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


CA


CATERPILLAR
PS-300C
CAT

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

- The dry density increases with increase in moisture content to a maximum value when an optimum moisture content is reached.
- Further increase in moisture content results in a decrease in the dry density attained
- This phenomenon is due to the effect of moisture on the soil particles.
- At low moisture content, the soil particles are not lubricated, and friction between adjacent particles prevents the densification of the particles.
- As the moisture content is increased, larger films of water develop on the particles, making the soil more plastic and easier for the particles to be moved and densified.

Soil Compaction

- When the optimum moisture content is reached, however, the maximum practical degree of saturation ($S<100\%$) is attained.
- The degree of compaction at the optimum moisture content cannot be increased by further compaction because of the presence of entrapped air in the void spaces and around the particles.
- Further addition of moisture therefore results in the voids being overfilled with water, with no accompanying reduction in the air.
- The soil particles are separated, resulting in a reduction in the dry density

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 0.0009439 m^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.

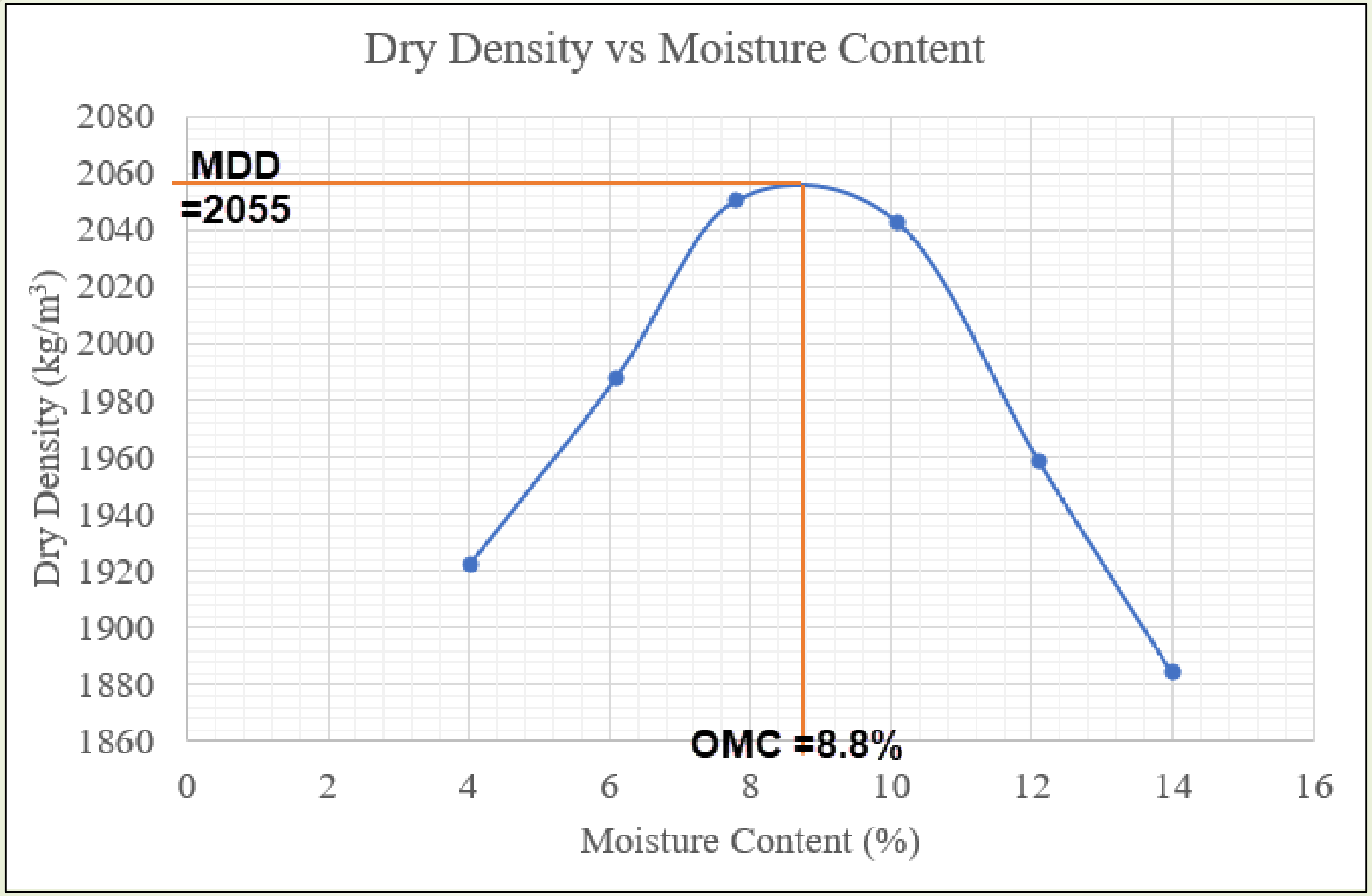
Soil Compaction

Solution

Sample	Weight (kg)	Bulk Density, $\gamma = W/V$ (kg/cm^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



Special Soil Tests

- Apart from the tests discussed so far, there are a few special soil tests that are sometimes undertaken to determine the strength or supporting value of a given soil
- The two most commonly used tests under this category are:
  1. California Bearing Ratio (CBR) Test and
  2. Hveem Stabilometer Test.

CBR Test

- CBR test is a penetration test meant for the evaluation of subgrade strength of roads and pavements.
- The results obtained by these tests are used with the empirical curves to determine the thickness of pavement and its component layers.

Hveem Stabilometer Test.

- Test used to obtain material characteristics such as resiliency modulus of soils

Thank You!!!