Geotechnical Engineering

Course Objectives: The course is designed to students,

1. To create an ability to apply knowledge of geotechnical engineering.
2. To accentuate the understanding of the basic principles of soil mechanics and its application to solve problems related to geotechnical engineering.
3. To improve the basic understanding of the index and engineering properties of soils
4. To improve the concepts to understand the hydraulic behavior of the soils .

Course Outcomes:

CO1 – Identify and tabulate different types of soils and their properties.

CO2 – Calculate and illustrate the permeability characteristics of soils, seepage quantities and pore water pressure below the ground.

CO3 – Analytically compute the vertical stress in a semi-infinite soil mass due to various loading conditions.

CO4 – Understand and interpret the compaction curve with compaction effort, soil type and the basic mechanism of consolidation of soils.

CO5 – Determine the shear strength parameters by analytically and graphically for various geotechnical problems.

Syllabus

Unit – 1 Soil and its Index Properties

Soil formation – soil structure and clay mineralogy – Adsorbed water – Mass- volume relationship – Relative density - Moisture Content, Specific Gravity, In-situ Density, Grain size analysis – Sieve and Hydrometer methods – consistency limits and indices – Tests for field identification and classification of soils - I.S. Classification of soils

Unit – 2 Permeability and Seepage through Soils

Permeability: Soil water – capillary rise – flow of water through soils – Darcy's law - permeability – Factors affecting – laboratory determination of coefficient of permeability – Field determination of permeability - Permeability of layered systems

Seepage through Soils: Total, neutral and effective stresses – quick sand condition – Seepage through soils – Flownets: Characteristics and Uses.

Unit – 3 Stress Distribution in Soils

Boussinesq's equation - Vertical stress due to line load, strip load, and uniformly loaded circular area and Wester Gaard's theories for point loads and areas of different shapes – Pressure bulb concept - Newmark's influence chart – Approximate methods

Unit – 4 Compaction and Consolidation

Compaction: Mechanism of compaction – factors affecting – effects of compaction on soil properties – Field compaction Equipment - compaction quality control

Consolidation: Pressure – void ratio curve – Compression index – Coefficient of Compressibility – Modulus of volume change – Consolidation process – Consolidation settlement - Terzaghi's theory of one dimensional consolidation – coefficient of consolidation – Pre-consolidation pressure – Normally consolidated and over consolidated soils.

Unit – 5 Shear Strength of Soils

Mohr – Coulomb Failure theories – Types of laboratory strength tests – strength tests based on drainage conditions – Shear strength of sands – Critical Void Ratio – Liquefaction- shear strength of clays.

Books

Textbooks:

1. Dr. K R Arora "Soil Mechanics & Foundation Engineering", Standard Publishers Distributers, New Delhi.
2. B C Punmia, Ashok Kumar Jain & Arun Kumar Jain "Soil Mechanics & Foundation Engineering", Lakshmi Publications, New Delhi.

Reference Books:

1. C Venkatramaiah "Geotechnical Engineering", New Age International (P) Limited, Publishers, New Delhi.
2. J A Knappett and R F Craig "Craig's Soil Mechanics", Spons Press, New York.

Web Links (Free Engineering Books)

https://www.engineeringbookspdf.com/

http://technicalbookspdf.com/

www.pdfdrive.com

www.civilenggforall.com

Soil and Its Index Properties

Suresh Praveen Kumar .P
Asst. Professor in CE

Soil and Its Index Properties

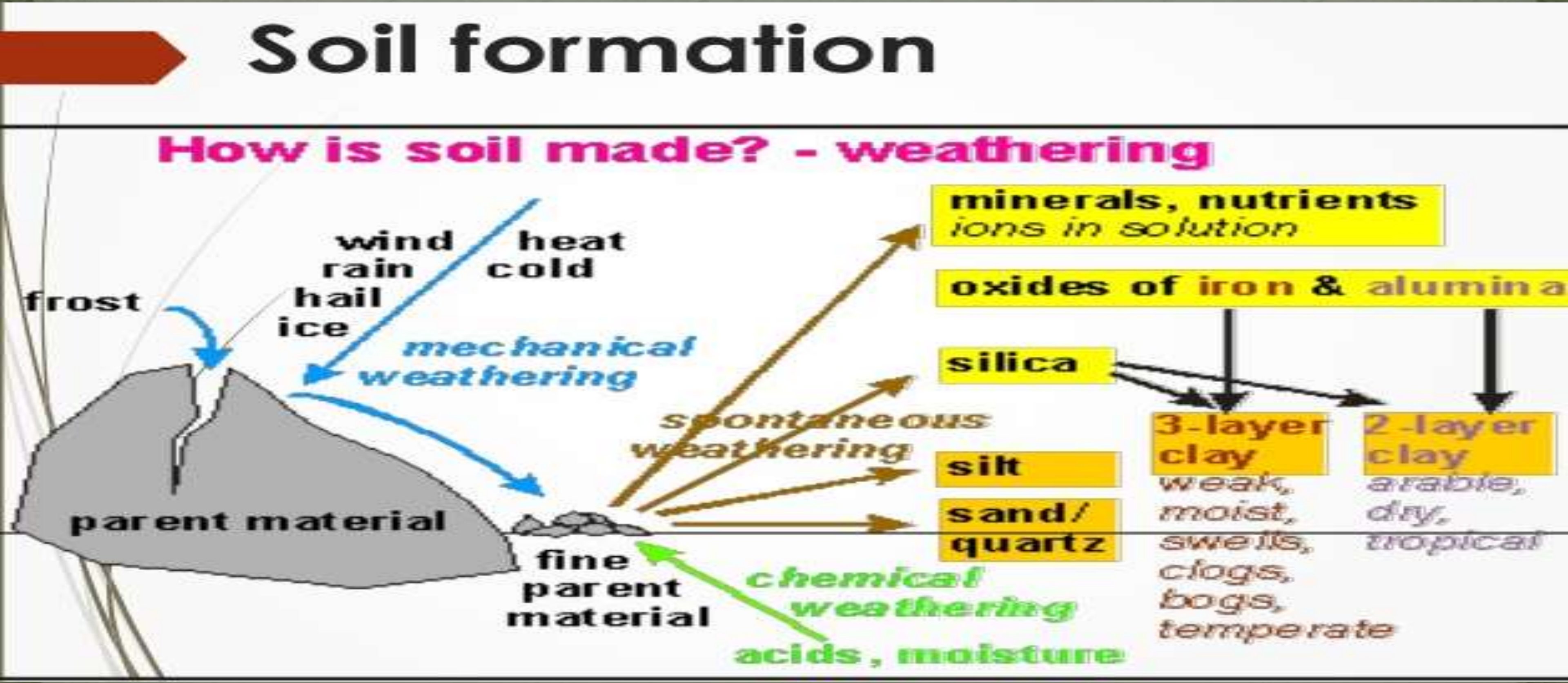
Soil formation – soil structure and clay mineralogy – Adsorbed water – Mass-volume relationship – Relative density - Moisture Content, Specific Gravity, In-situ Density, Grain size analysis – Sieve and Hydrometer methods – consistency limits and indices – Tests for field identification and classification of soils - I.S. Classification of soils

Soil Formation

Soil is defined as a natural aggregate of mineral grains, with or without organic constituents that can be separated by gentle mechanical means such as agitation in water.

Soils are formed by the process of weathering of the parent rock.

The weathering of the rocks might be by mechanical disintegration, and/or chemical decomposition.



Mechanical Weathering

Mechanical weathering of rocks to smaller particles is due to the action of

1. Expansive forces of freezing water in fissures,
2. Sudden changes of temperature or
3. Abrasion of rock by moving water or glaciers.
4. Temperature changes of sufficient amplitude and frequency bring about changes in the volume of the rocks in the superficial layers of the earth's crust in terms of expansion and contraction.
5. Such a volume change sets up tensile and shear stresses in the rock ultimately leading to the fracture of even large rocks.
6. This type of rock weathering takes place in a very significant manner in arid climates where free, extreme atmospheric radiation brings about considerable variation in temperature at sunrise and sunset.
7. Erosion by wind and rain is a very important factor and a continuing event.
8. Cracking forces by growing plants and roots in voids and crevasses of rock can force fragments apart.

Soil Formation – Contd.

Chemical Weathering

1. Chemical weathering (decomposition) can transform hard rock minerals into soft, easily erodible matter.
2. The principal types of decomposition are *hydration, oxidation, carbonation, desilication* and *leaching.*
3. Oxygen and carbon dioxide which are always present in the air readily combine with the elements of rock in the presence of water.

General Types of Soils

The individual size of the constituent parts of even the weathered rock might range from the smallest state (colloidal) to the largest possible (boulders).

This implies that all the weathered constituents of a parent rock cannot be termed soil. According to their grain size, soil particles are classified as cobbles, gravel, sand, silt and clay.

Grains having diameters in the range of 4.75 to 76.2 mm are called gravel.

If the grains are visible to the naked eye, but are less than about 4.75 mm in size the soil is described as sand.

The lower limit of visibility of grains for the naked eyes is about 0.075 mm.

Soil grains ranging from 0.075 to 0.002 mm are termed as silt and those that are finer than 0.002 mm as clay.

This classification is purely based on size which does not indicate the properties of fine grained materials.

Soil Formation – Contd.

On the basis of origin of their constituents, soils can be divided into two large groups: 1. Residual soils and 2.Transported soils.

Residual soils are those that remain at the place of their formation as a result of the weathering of parent rocks. The depth of residual soils depends primarily on climatic conditions and the time of exposure.

An important characteristic of residual soil is - the sizes of grains are indefinite. For example, when a residual sample is sieved, the amount passing any given sieve size depends greatly on the time and energy expended in shaking, because of the partially disintegrated condition.

Transported soils -

1. *Alluvial* soils are those that have been transported by running water. The soils that have been deposited in quiet lakes, are *lacustrine* soils. *Marine soils* are those deposited in sea water.
2. The soils transported and deposited by wind are *aeolian* soils. Those deposited primarily through the action of gravitational force, as in landslides, are *colluvial* soils.
3. *Glacial* soils are those deposited by glaciers.

Organic and Inorganic Soils

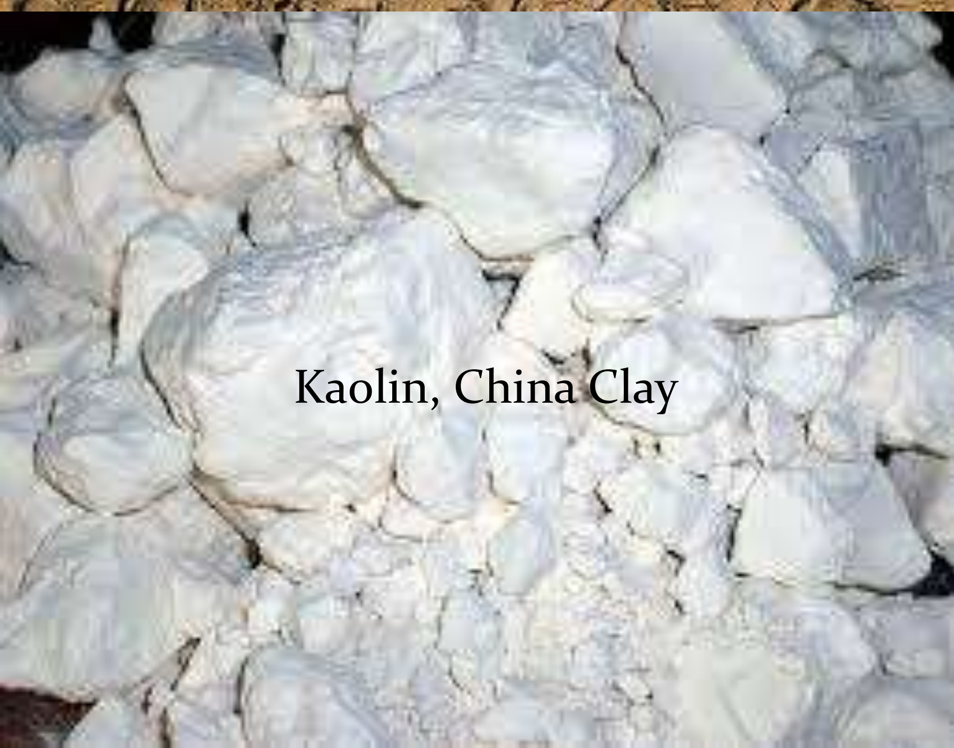
Soils in general are further classified as *organic* or *inorganic*. Soils of organic origin are chiefly formed either by growth and subsequent decay of plants such as peat, or by the accumulation of fragments of the inorganic skeletons or shells of organisms.

Hence a soil of organic origin can be either organic or inorganic. The term organic soil ordinarily refers to a transported soil consisting of the products of rock weathering with a more or less conspicuous admixture of decayed vegetable matter.

Names of Some Soils that are generally used in Practice


Bentonite

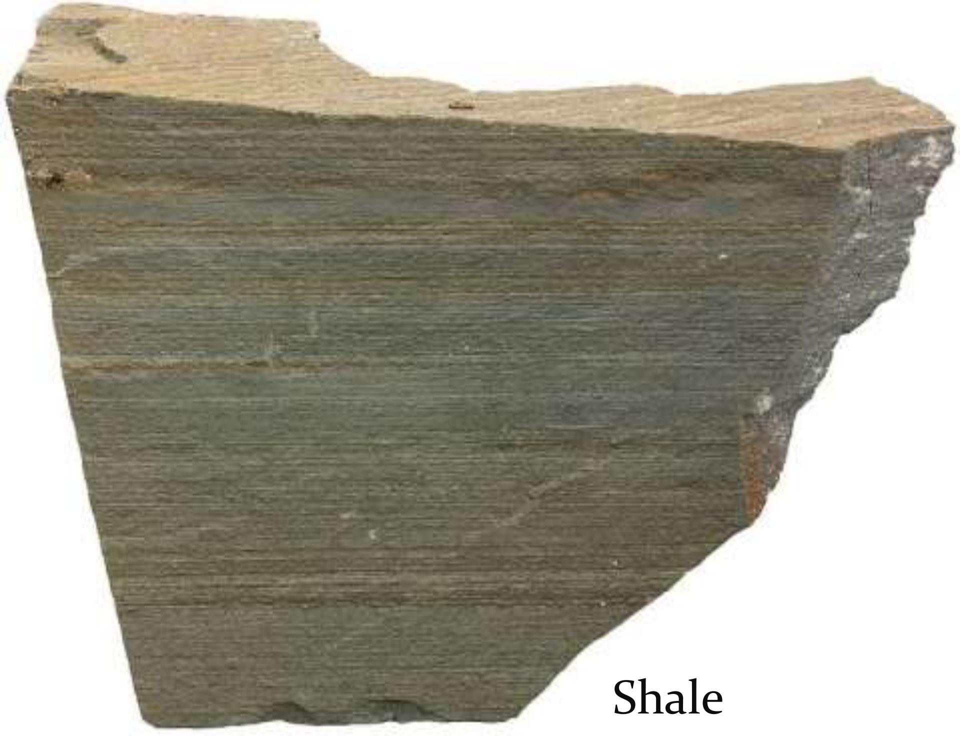

Varved Clays


Kaolin, China Clay


Boulder Clay

Names of Some Soils that are generally used in Practice

Names of Some Soils that are generally used in Practice



Soil Particle Size and Shape

Angular

Sub Angular

Sub Rounded

Rounded

Well Rounded

Structure of Clay Minerals

Clay minerals are essentially crystalline in nature (non-crystalline for example allophane). Two fundamental building blocks are involved in the formation of clay mineral structures. They are:

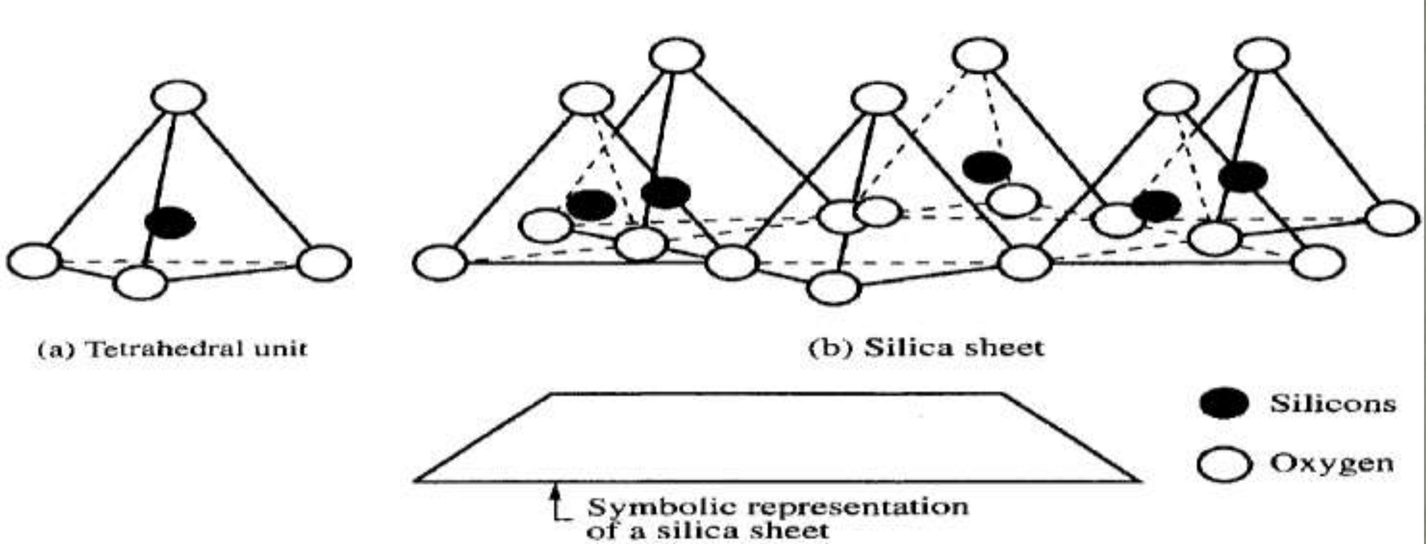
- Tetrahedral unit
- Octahedral unit.

Clay Minerals

S.No.	Name of Mineral	Structural Formulae
01	Kaoline group	
	• Kaolinite	$Al_4Si_4O_{10}(OH)_8$
	• Halloysite	$Al_4Si_4O_6(OH)_{16}$
02	Montmorillonite group	
	• Montmorillonite	$Al_4Si_8O_{20}(OH)_4nH_2O$
03	Illite group	
	• Illite	$K_y(Al_4Fe_2Mg_4Mg_6)Si_{8-y}Al_y(OH)_4O_{20}$

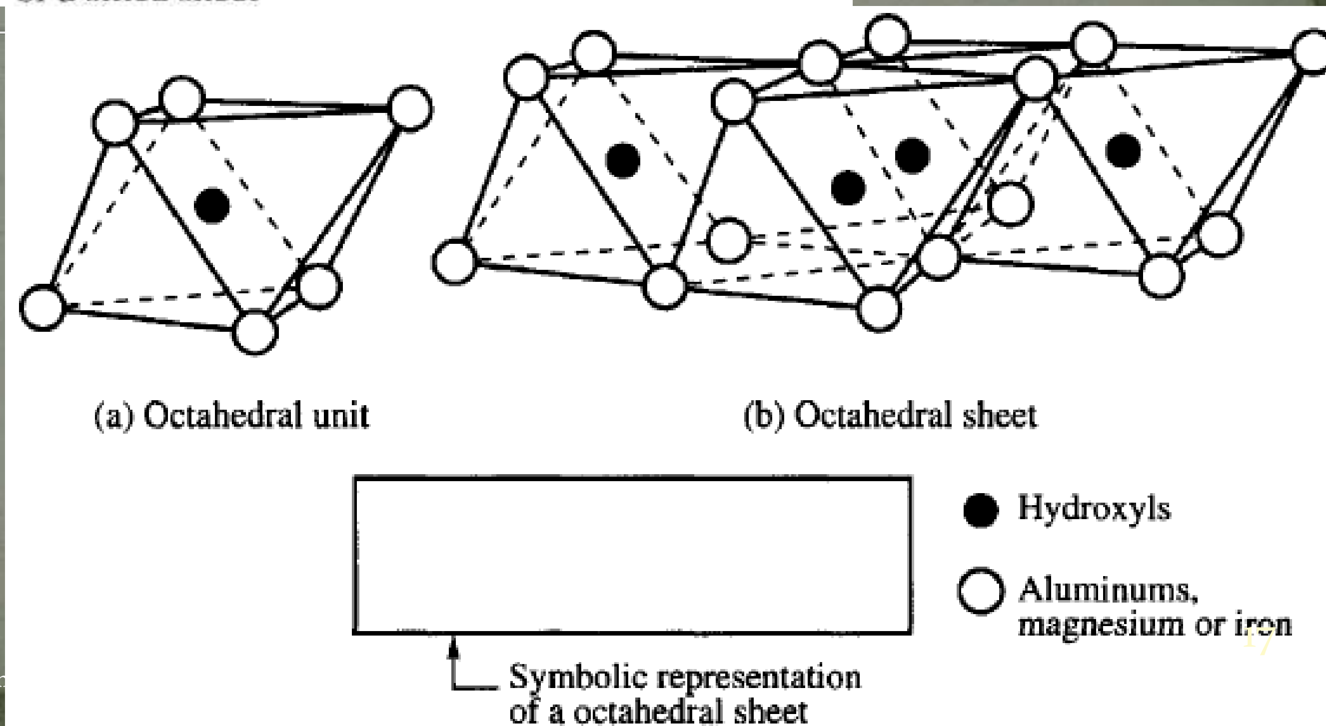
Soil Structure and Clay Mineralogy – Contd.

Formation of Minerals



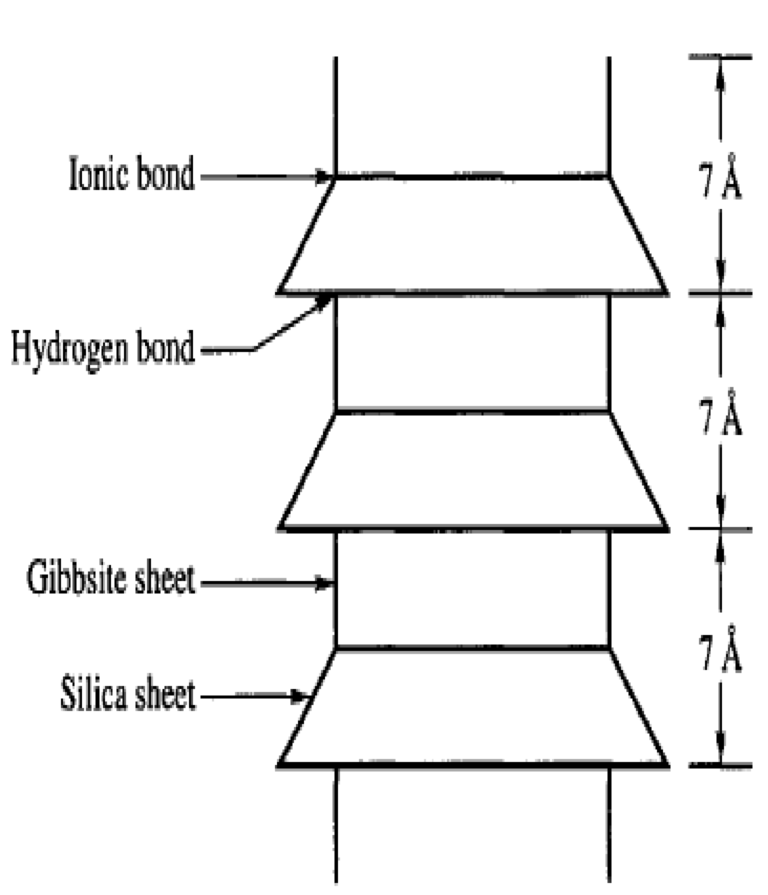
Basic structural units in the silicon sheet (Grim, 1959)

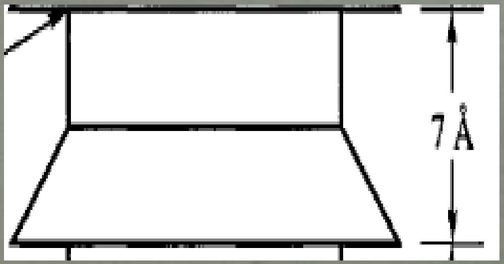
Basic structural units in octahedral sheet (Grim, 1959)



Kaolinite Mineral

- Most common mineral of the Kaolin group.
- Combination of two layers with a silica layer joined to one of gibbsite layer
- It is about 7Å
- Thickness varying from 100Å to 1000Å
- Lateral dimension from 1000Å to 20000Å
- Hydrogen bond
- Water con not enter easily between the layers
- Clay containing kaolinite exhibits less swelling on wetting
- Kaolinite is the main constituent in China clay





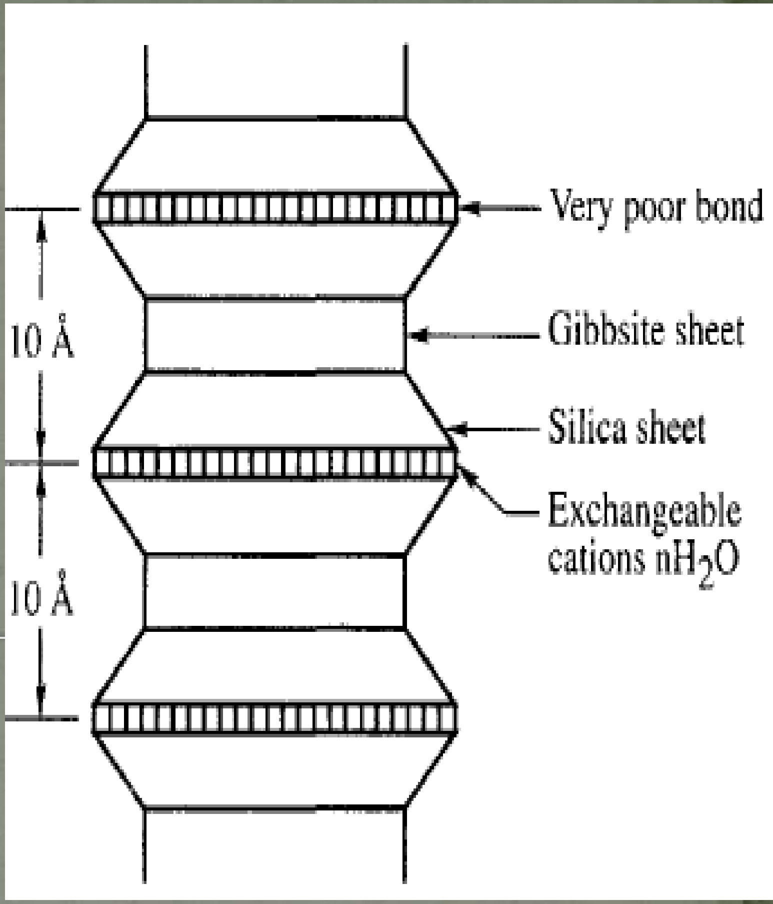
Halloysite Mineral

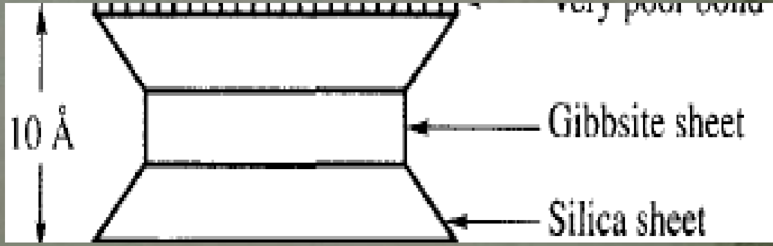
Halloysite minerals are made up of successive layers with the same structural composition as those composing kaolinite.

Successive units are randomly packed and may be separated by a single molecular layer of water. An important structural feature of halloysite is that the particles appear to take tubular forms as opposed to the platy shape of kaolinite.

Montmorillonite Mineral

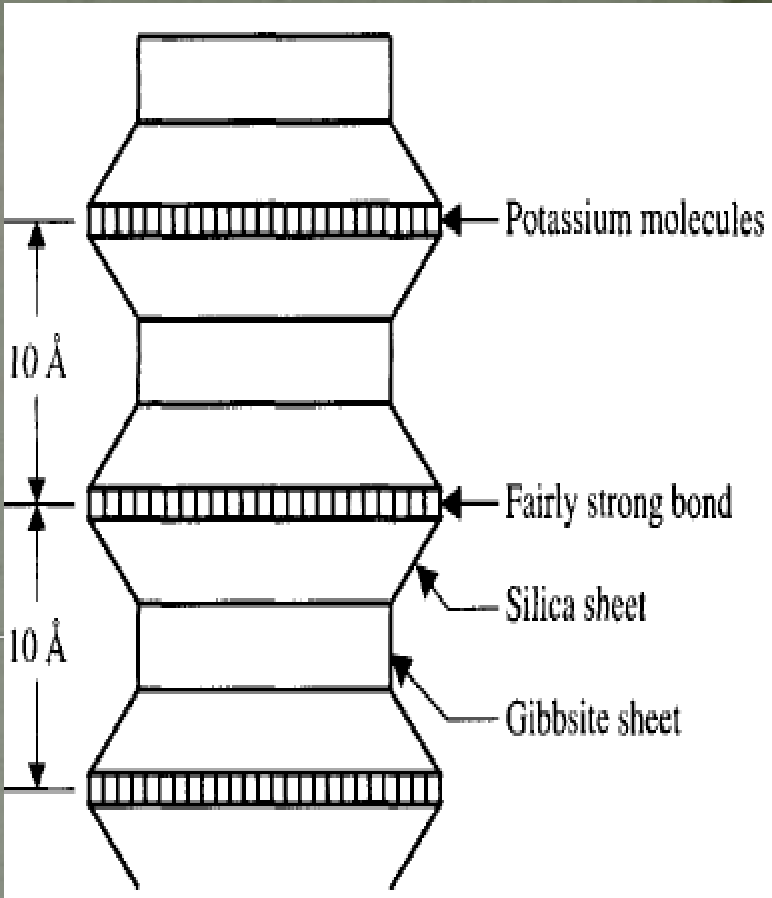
- The montmorillonite mineral is a stacking of basic sheet like structural units, with each unit made up of gibbsite sheet sandwiched between two silica sheets.
- Thickness of each unit is about 10Å.
- Van der Waals forces between silica sheet of adjacent structural units is weak and there is a net negative charge deficiency in octahedral sheet, water and exchangeable cations can enter and separate the layers.
- Exhibits high swelling and shrinkage characteristics
- Thickness of the particle varies from 10Å to 50Å
- Lateral dimension ranging from 1000Å to 5000Å
- Primary constituent of black cotton soil, bentonite clay and other expansive clays.





Illite Mineral

- Basic structural unit of illite is the same as that of montmorillonite
- Bond – non-exchangeable K^+
- Does not swell so much in the presence of water
- Lateral dimension is same as montmorillonite, i.e., 1000Å to 5000Å
- Thickness is more and varies from 50Å to 500Å



Soil Mass Structure

The term soil structure in general, refers to the arrangement or state of aggregation of particles in a soil mass.

But deeper understanding of soil structure demands –

- ✓Consideration of mineralogical composition
- ✓Shape and orientation of soil particles
- ✓Nature and properties of soil water, and
- ✓Forces of interaction between soil and particles and soil water

Types of soil structures –

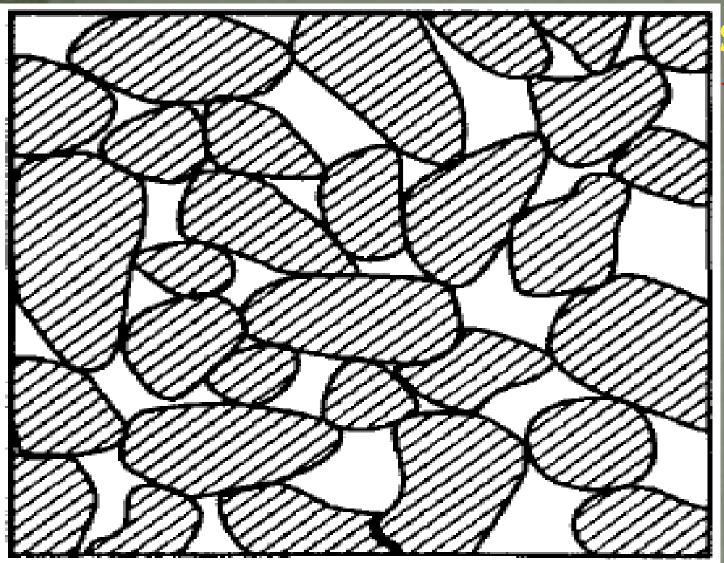
Single grained structure – in the case of coarse grained soil deposits

Honeycomb structure – in the case of silt deposits

Flocculated and dispersed structure – in the case of clay deposits

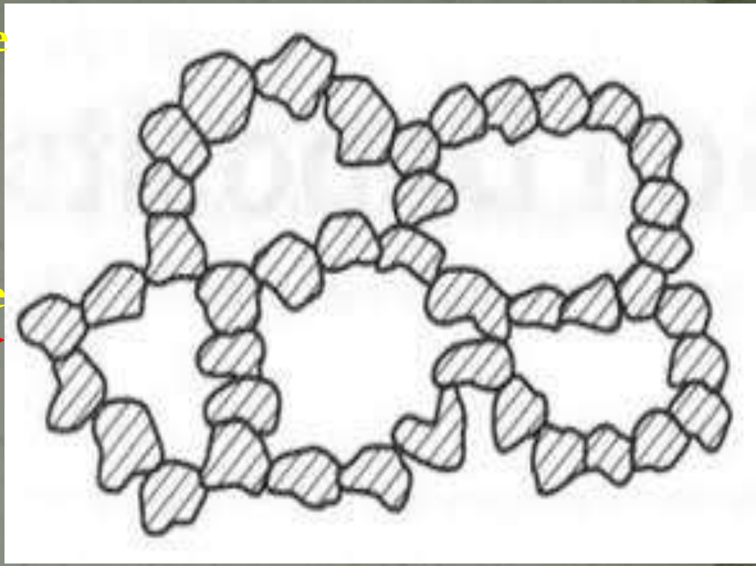
Coarse grained skeleton and cohesive matrix structure – in the case of composite soils

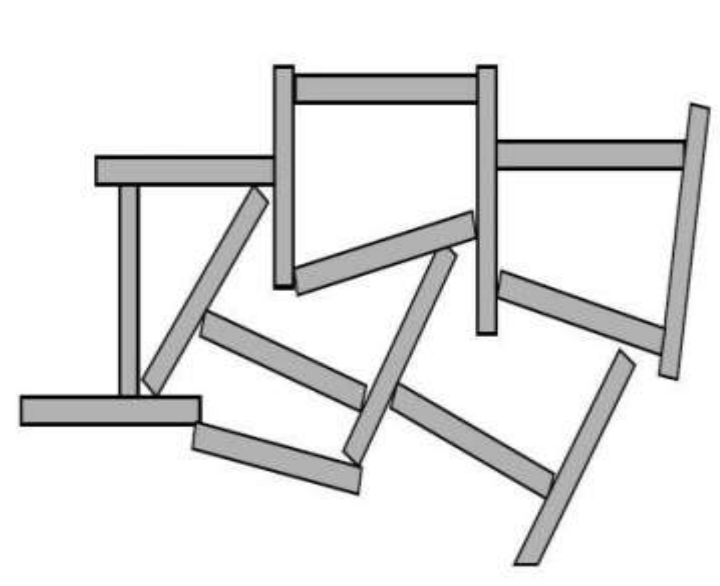
Soil Structure and Clay Mineralogy – Contd.



Single grained structure

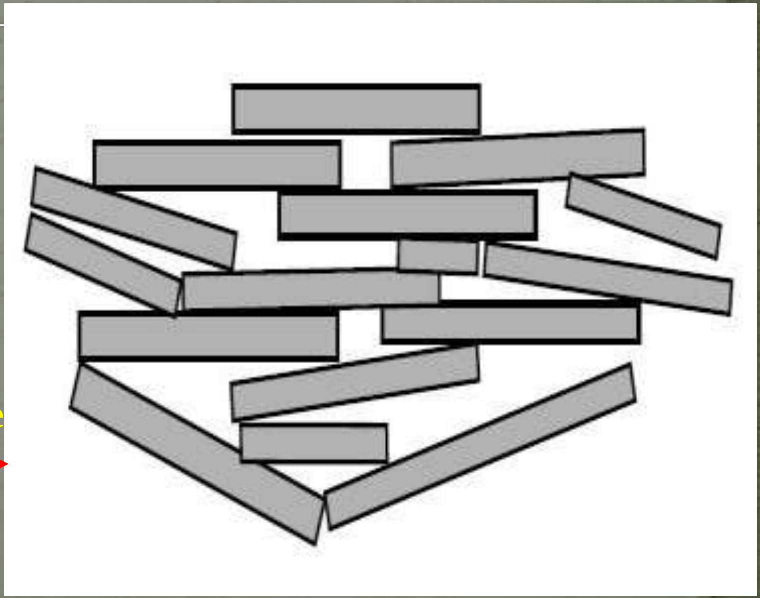
Honeycomb structure



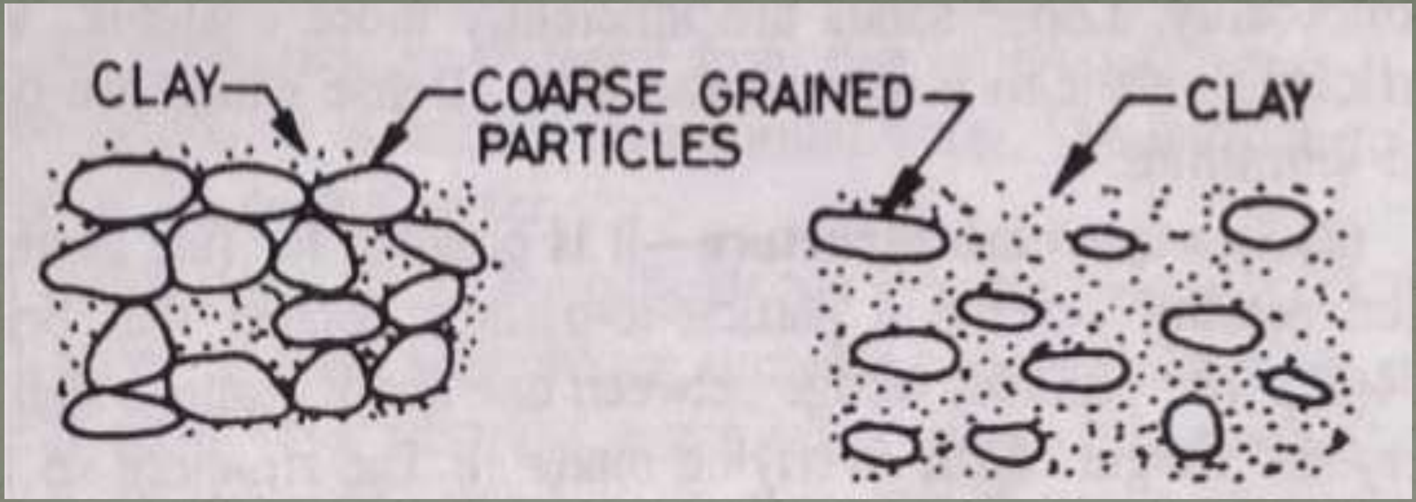


Flocculated structure

Dispersed structure



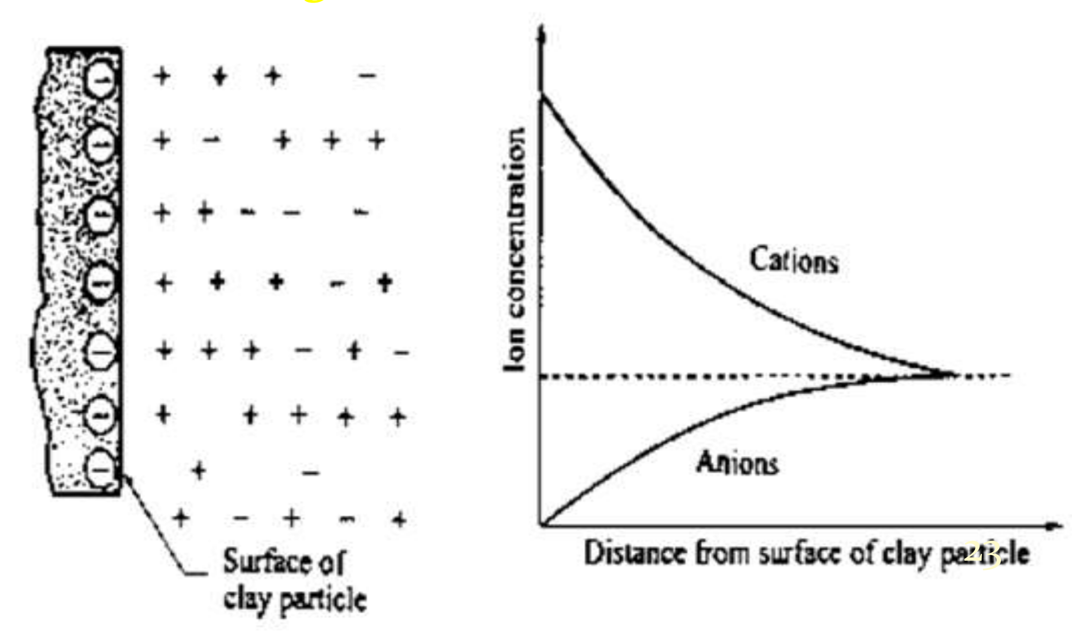
Soil Structure and Clay Mineralogy – Contd.



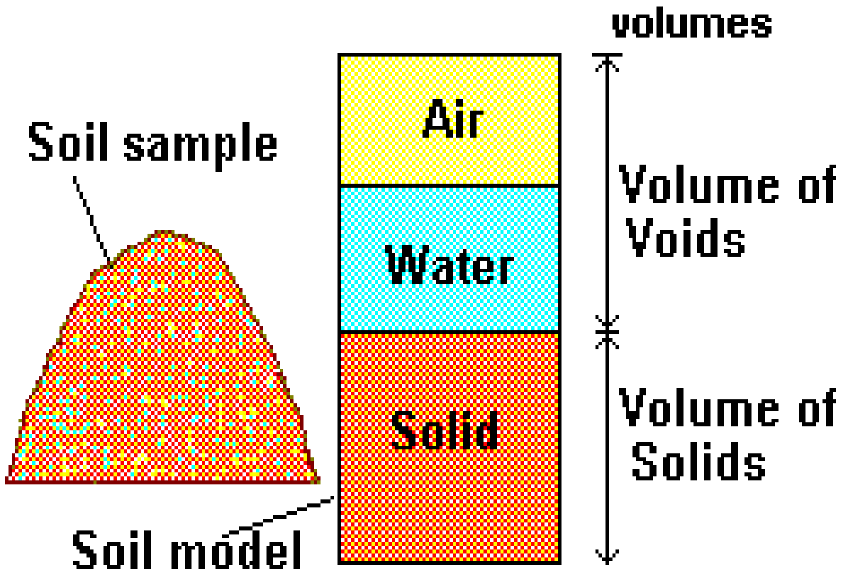
Coarse grained skeleton and cohesive matrix structure

Adsorbed Water

The water held by electro-chemical forces existing on the soil surface is adsorbed water.



Mass Volume Relationships

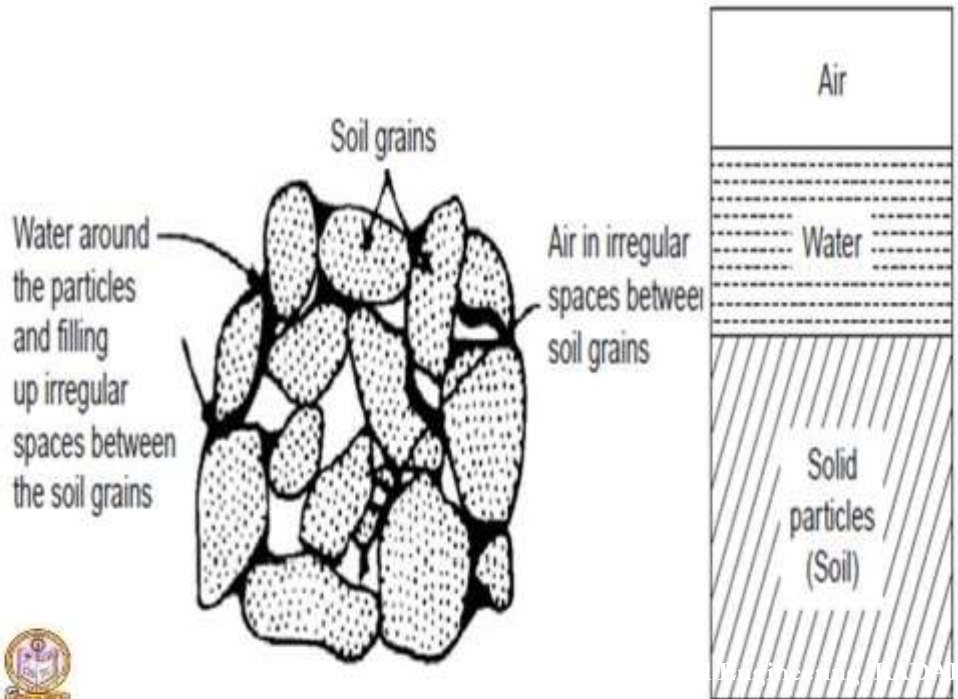


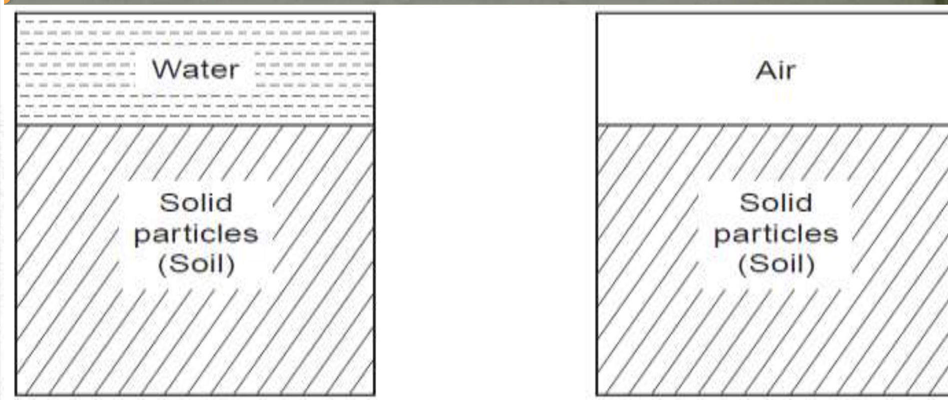
Composition of Soil –

•Soil is a complex physical system.

•'Phase' means any homogeneous part of the system different from other parts of the system and separated from them by abrupt transition.

•Since the volume occupied by a soil mass may generally be expected to include material in all the three states of matter—solid, liquid and gas, soil is, in general, referred to as a "three-phase system".



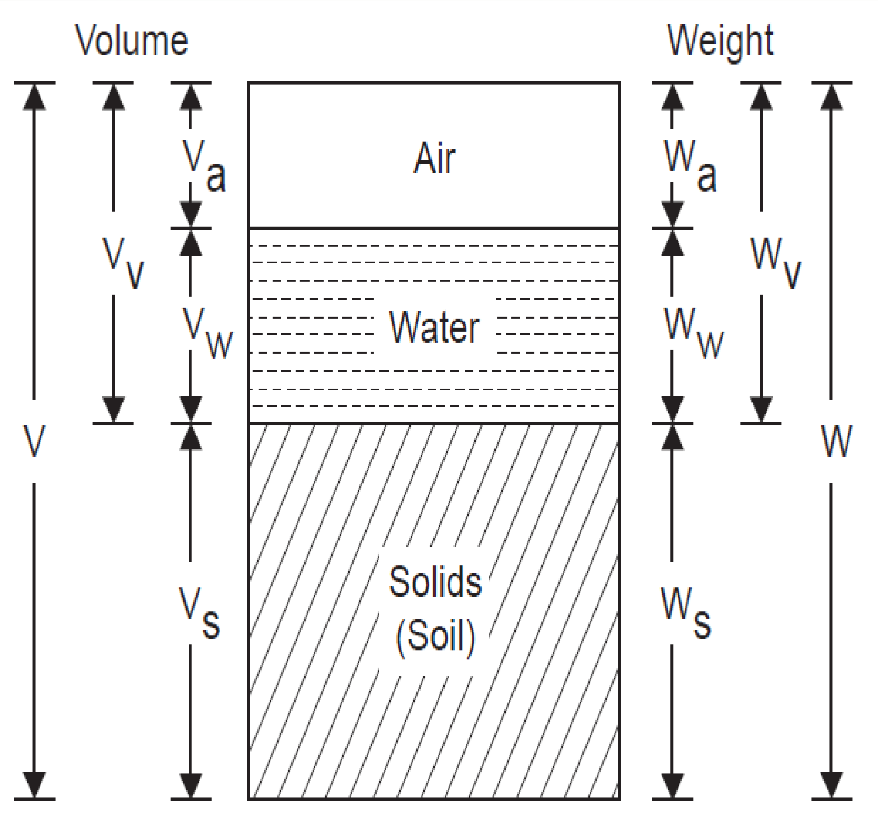


(a) Saturated soil, (b) Dry soil represented as two-phase systems

Representation of soil mass by phase diagram

Mass Volume Relationships – contd.

Basic Terminology



Where:

- W = Total weight of solid mass
- W_v = Weight of material occupying void space
- W_s = Weight of solids
- W_w = Weight of water
- W_a = Weight of air (negligible or zero)
- $W_v = W_w + W_a = W_w + 0 = W_w$
- V = Total volume of soil mass
- V_v = Volume of voids
- V_s = Volume of solids
- V_w = Volume of water
- V_a = Volume of air

Soil-phase diagram (volumes and weights of phases)

Mass Volume Relationships – contd.

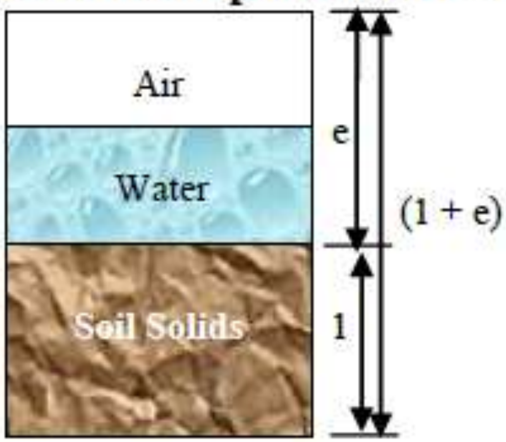
Basic Terminology

1. **Porosity (n)**
2. **Void Ratio (e)**
3. **Degree of Saturation (S or S_r)**
4. **Percent Air Voids (n_a)**
5. **Air Content (a_c)**
6. **Water Content (w)**
7. **Bulk Unit weight or Bulk Density (γ or ρ)**
8. **Unit Weight of Solids (γ_s)**
9. **Unit Weight of Water (γ_w)**
10. **Saturated Unit Weight (γ_{sat})**
11. **Submerged Unit Weight (γ_{sub})**
12. **Dry Unit Weight (γ_d)**
13. **Mass Specific Gravity (G_m)**
14. **Specific Gravity of Solids (G)**

Mass Volume Relationships – contd.

Important Relationships:

Relationship between *e* and *n*:



Vv = e and
V = (1+e)

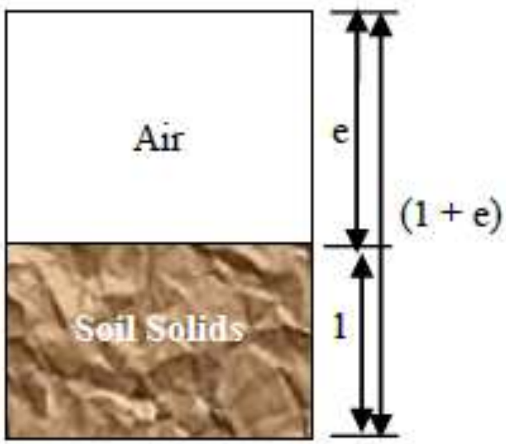
$$n = \frac{V_v}{V} = \frac{e}{1+e}$$

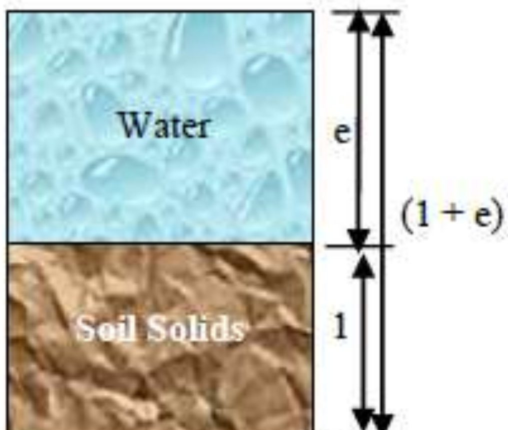
$$n = \frac{V_v}{V} = \frac{e}{1+e}$$

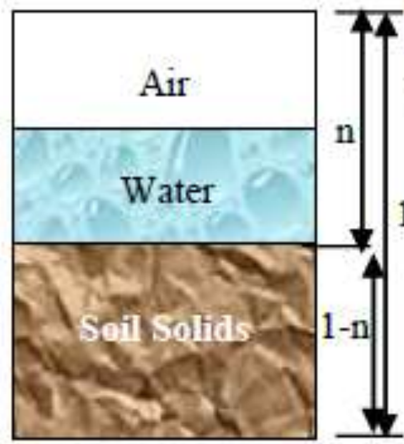
$$\frac{1}{n} = \frac{1+e}{e} = \frac{1}{e} + 1$$

$$\frac{1}{e} = \frac{1}{n} - 1 = \frac{1-n}{n}$$

$$e = \frac{n}{1-n}$$



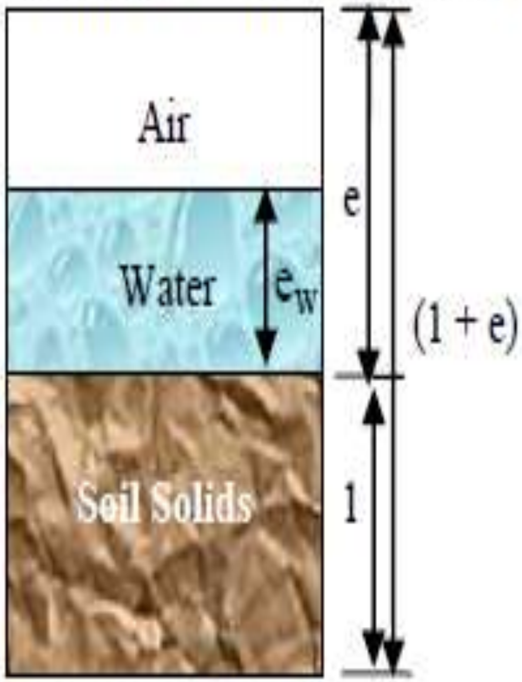




Alternatively,
If we represent
$V = 1$, $V_v = n$ and
$V_s = (1 - n)$
Void ratio $e = \frac{V_v}{V_s}$

$$e = \frac{n}{1-n}$$

Relation between e, S, w and G:



The symbol e_w used for volume of water, referred to as water void ratio.

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

$$e_w = e.S$$

$$w = \frac{W_w}{W_s} = \frac{V_w.\gamma_w}{V_s.\gamma_s} = \frac{e_w.\gamma_w}{1.\gamma_s}$$

Substituting, $e_w = e.S$; and $\gamma_s = G.\gamma_w$

$$w = \frac{e.S.\gamma_w}{G.\gamma_w} = \frac{e.S}{G}$$

$$e.S = w.G$$

Mass Volume Relationships – contd.

Relation between γ, γ_d and w:

We have, $w = \frac{W_w}{W_s}$

Adding 1 to both sides,

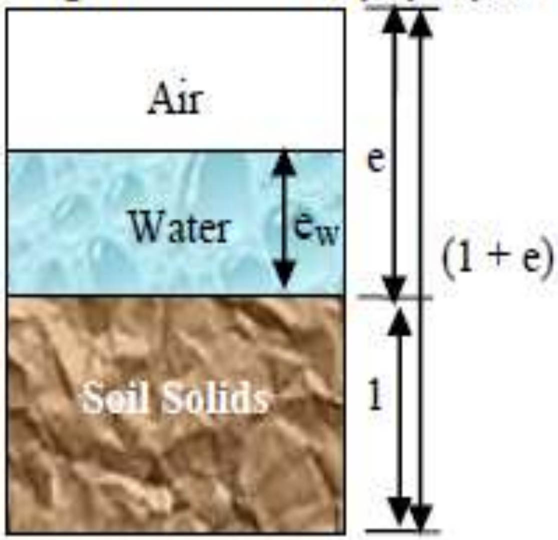
$$1 + w = \frac{W_w}{W_s} + 1 = \frac{W_w + W_s}{W_s} = \frac{W}{W_s}$$

$$W_s = \frac{W}{1 + w}$$

Dividing both sides by V,

$$\frac{W_s}{V} = \frac{W/V}{1 + e} \Rightarrow \gamma_d = \frac{\gamma}{1 + w}$$

Expressions for $\gamma, \gamma_d, \gamma_{sat}$ and γ':



$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V} = \frac{V_s.\gamma_s + V_w.\gamma_w}{V} = \frac{1.\gamma_s + e_w.\gamma_w}{1+e}$$

$$\gamma = \frac{G.\gamma_s + e.S.\gamma_w}{1+e}$$

$$\gamma = \frac{(G + e.S)\gamma_w}{1+e}$$

For dry soil mass $\gamma = \gamma_d$, and S = 0; $\gamma_d = \frac{G\gamma_w}{1+e}$

For fully saturated soil mass $\gamma = \gamma_{sat}$, and S = 1;

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

And further $\gamma' = \gamma_{sat} - \gamma_w = \frac{(G+e)\gamma_w}{1+e} - \gamma_w = \frac{G.\gamma_w - \gamma_w}{1+e}$

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

Mass Volume Relationships – contd.

Expression for *e* in terms of *G*, γ_w and γ_d:

We have,

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

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

$$e = \frac{G\gamma_w}{\gamma_d} - 1$$

Mass Volume Relationships – contd.

Expression for γ_d in terms of n_a, G, γ_w and w:

We have, $V = V_a + V_w + V_s$

Dividing by V,

$$1 = \frac{V_a}{V} + \frac{V_w}{V} + \frac{V_s}{V} = n_a + \frac{W_w}{\gamma_w . V} + \frac{W_s}{\gamma_s . V}$$

$$(1 - n_a) = \frac{w.W_s}{\gamma_w . V} + \frac{W_s}{G.\gamma_w . V} = \frac{w.\gamma_d}{\gamma_w} + \frac{\gamma_d}{G.\gamma_w} = \frac{\gamma_d}{\gamma_w}\left(w + \frac{1}{G}\right) = \frac{\gamma_d}{\gamma_w}\left(\frac{wG + 1}{G}\right)$$

$$\gamma_d = \frac{(1 - n_a).G.\gamma_w}{1 + w.G}$$

Problems

A soil sample in its undisturbed state was found to have a volume of 105 cm^3 and mass of 201 g. After oven drying the mass got reduced to 168 g. Compute (1) water content, (2) void ratio, (3) porosity (4) degree of saturation and (5) air content. Take G = 2.7

$$w = \frac{W_w}{W_s \text{ (or } W_d)} x100 = \frac{W - W_d}{W_d} x100$$

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

$$\gamma_d = \frac{W_s \text{ (or } W_d)}{V}$$

$$e = \frac{G\gamma_w}{\gamma_d} - 1$$

$$e.S = w.G$$

$$a_c = \frac{V_a}{V_v} = \frac{V_v - V_w}{V_v}$$

$$a_c = 1 - \frac{V_w}{V_v} = 1 - S$$

Volume of soil mass (V) = 105 cm^3
Mass of soil mass (M) = 201 g
Mass of dry soil mass (M_d) = 168 g
Specific gravity of soil particles (G) = 2.7

Water content (w) = $(M-M_d)*100/M_d$ = (201-168)*100/168 = 19.6 %

Dry Density (ρ_d) = M_d /V = 168/105 = 1.6 g/cc

Void ratio (e) = {(2.7*1)/1.6} – 1 = 0.69
Porosity (n) = 0.69/(1+0.69) = 0.41
Degree of saturation (S) =wG/e = (0.196*2.7)*100/0.69 = 76.7 %
Air content (a_c) = 1 – S = (1 – 0.767)*100 = 23.3 %

Problems

For a soil sample the specific gravity of soil mass is 1.7 and specific gravity of solid particles is 2.7. Determine the void ratio, (1) assuming the soil sample is dry and (2) the sample has a water content of 12 percent.

Given that,

Mass specific gravity (G_m) = 1.7

Specific gravity of solids (G) = 2.7

$$e = \frac{G\gamma_w}{\gamma_d} - 1$$

For dry soil sample – I ($\gamma = \gamma_d$)

$G_m = \gamma/\gamma_w = \gamma_d / \gamma_w$

$\gamma_d = G_m \cdot \gamma_w$

$e = \{(G. \gamma_w)/ \gamma_d\} - 1 = \{(G. \gamma_w)/ G_m \cdot \gamma_w\} - 1 = (G/ G_m) - 1$

$e = (2.7/ 1.7) - 1 = 0.588 = 58.8\ \%$

When w = 12 % = 0.12

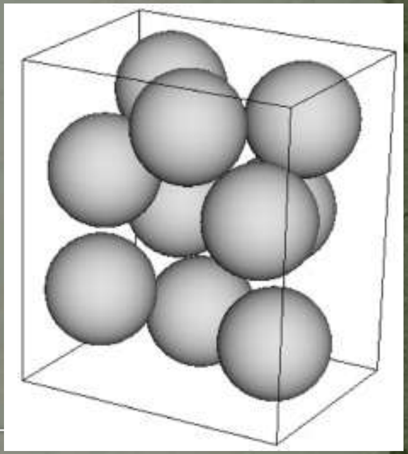
$G_m = \gamma/\gamma_w$ or $\gamma = G_m \cdot \gamma_w = 1.7*9.81 = 16.68\ kN/m^3$

$\gamma_d = \gamma/(1+w) = 16.68/(1+0.12) = 14.89\ kN/m^3$

$e = (2.7*9.81/14.89) - 1 = 0.779 = 77.9\ \%$

Problems

A soil sample assumed to consists of spherical grains all of same diameter will have maximum void ratio when the grains are arranged in a cubical array. Find void ratio and dry unit weight. Take unit weight of grains as 20 kN/m³.



Given that,

Unit weight of grains (γ_s) = 20 kN/m^3

Consider a unit cube packed with the spherical grains of diameter 'd'

No. of spherical grains in the container = (1/d)*(1/d)*(1/d) = $1/d^3$

Volume of each spherical grain = $\pi d^3/6$

Volume of soil solids (V_s) = $(1/d^3)*(\pi d^3/6) = \pi/6$

Total volume of cube (V) = 1 * 1 * 1 = 1 m^3

Volume of voids (V_v) = $V - V_s = 1 - \pi/6 = (6 - \pi)/6$ m^3

Void ratio (e) = $V_v / V_s = (6 - \pi)*6/6\pi = (6 - \pi)/\pi = 0.91$ = 91 %

Dry unit weight (γ_d) = $W_s / V = (V_s . \gamma_s)/ V = (\pi/6)*20/1 = 10.47$ kN/m^3

Problems

1000 m^3 of earthfill is to be constructed. How many cubic meters of soil is to be excavated from borrow pit in which the void ratio is 0.95, if the void ratio of earthfill is to be 0.7?

Given that,

Volume of earthfill (V_1) = 1000 m^3

Void ratio of earthfill (e_1) = 0.7

Void ratio in borrow pit (e_2) = 0.95

Let volume of soil to be excavated from borrow pit = V_2

We have $e = V_v / V_s$

Adding 1 (one) in both sides, $1+e = (V_v / V_s)+1$

$1+e = (V_v + V_s)/ V_s$

$1+e = V/ V_s$

For soil in earthfill, $1+e_1 = V_1/ V_s$ ----- (eqn. 1)

For soil to be excavated from borrow pit, $1+e_2 = V_2/ V_s$ ----- (eqn. 2)

Dividing eqn.(2) by eqn.(1)

V_s is same for earthfill and soil excavated from borrow pit

$V_2 = \{(1+e_2)/(1+e_1)\}* V_1 = \{(1+0.95)/(1+0.7)\}* 1000$

$V_2 = 1147\ m^3$

Problems

A dry soil has a void ratio of 0.65 and its grain specific gravity is = 2.80. What is its unit weight ? Water is added to the sample so that its degree of saturation is 60% without any change in void ratio. Determine the water content and unit weight. The sample is next placed below water. Determine the true unit weight (not considering buoyancy) if the degree of saturation is 95% and 100% respectively.

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

$$e.S = w.G$$

$$\gamma = \frac{(G + e.S)\gamma_w}{1 + e}$$

Given that,

Void ratio (e) = 0.65

Specific gravity (G) = 2.80

Dry Soil –

Unit weight (γ_d) = (2.8*9.81)/(1+0.65) = 16.65 kN/m^3

Partial saturation of the soil – Degree of saturation is 60 %

Water content (w) = (0.65*0.6)/(2.8) = 0.1393 = 13.93 %

Unit weight (γ) = {2.8+(0.65*0.6)}*9.81/(1+0.65) = 18.97 kN/m^3

Soil below water – Degree of saturation is 95 % and 100 %

Unit weight (γ) = {2.8+(0.65*0.95)}*9.81/(1+0.65) = 20.32 kN/m^3

Unit weight (γ) = {2.8+(0.65*1)}*9.81/(1+0.65) = 20.51 kN/m^3

Relative Density

Relative density (density index) – difference between max. void ratio (e_{max}) and natural void ratio (e or e_o) to the difference between max. void ratio (e_{max}) and min. void ratio (e_{min}).

$$I_D = \frac{e_{max} - e_0}{e_{max} - e_{min}}$$

- I_D lies between 0 and 100%
- Measure of the state of packing in the case of cohesionless soils

Density index	Description
< 35	Loose
35 to 65	Medium dense
65 to 85	Dense
> 85	Very dense

Density index	0 to 15	15 to 50	50 to 70	70 to 85	85 to 100
Description	Very loose	Loose	Medium dense	Dense	Very dense

$$e = \frac{G\gamma_w}{\gamma_d} - 1 \qquad e_{max} = \frac{G.\gamma_w}{(\gamma_d)_{min}} - 1 \qquad e_{min} = \frac{G.\gamma_w}{(\gamma_d)_{max}} - 1$$

$$I_D = \frac{\left(\frac{G.\gamma_w}{(\gamma_d)_{min}} - 1\right) - \left(\frac{G\gamma_w}{\gamma_d} - 1\right)}{\left(\frac{G.\gamma_w}{(\gamma_d)_{min}} - 1\right) - \left(\frac{G.\gamma_w}{(\gamma_d)_{max}} - 1\right)}$$

$$I_D = \frac{\gamma_d - (\gamma_d)_{min}}{(\gamma_d)_{max} - (\gamma_d)_{min}} x \frac{(\gamma_d)_{max}}{\gamma_d}$$

Water Content (w) -ratio of weight of water to weight of solids

1. 'Water content' or 'moisture content' of a soil has a direct bearing on its strength and stability. The water content of a soil in its natural state is termed its 'Natural moisture content', which characterizes its performance under the action of load and temperature.
2. The water content may range from a trace quantity to that sufficient to saturate the soil or fill all the voids in it.
3. If the trace moisture has been acquired by the soil by absorption from the atmosphere, then it is said to be 'hygroscopic moisture'.

Methods to determine Water Content (w) –

1. Oven drying method
2. Pycnometer method
3. Rapid methods
   a) Infra red lamp and torsion balance method
   b) Calcium carbide method
   c) Proctor needle method
   d) Nuclear method

Most accurate method

Temperature 105 to 110°C

Organic or calcareous compounds 60 to 80°C

Sandy soils – 4Hrs drying

Clayey soils – 15 Hrs drying






Water Content (w)

1. Oven drying method

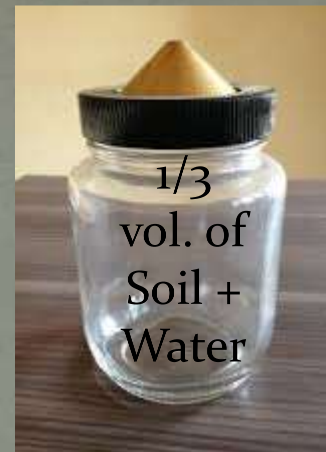
W1 – empty weight of the moisture container
W2 – weight of container plus moist soil
W3 – weight of container plus dry soil

Water content (w) $$w = \frac{W_2 - W_3}{W_3 - W_1} x100$$

Temperature
105 to 110°C

Water Content (w)

2. Pycnometer method



W1 W2 W3 W4

W1 – empty weight of the Pycnometer
W2 – weight of Pycnometer plus 1/3rd volume of the soil
W3 – weight of Pycnometer, 1/3rd volume of the soil plus water
W4 – weight of Pycnometer with full of water

Water content (w)

$$w = \left[\frac{W_2 - W_1}{W_3 - W_4} \cdot \left(\frac{G-1}{G}\right) - 1\right] x100$$

for known specific gravity

Water Content (w)

3. Rapid method

a. Infra red lamp and torsion balance method

about 15 to 30 minutes

25 g of soil

$$w = \frac{m'}{1 - m'}$$

m' = balance scale based on wet mass

b. Calcium carbide method

$$w = \frac{w_r}{1 - w_r} x100\%$$

w_r = moisture content obtained by the rapid moisture tester, expressed as a decimal fraction

Alcohol method
Radiation method
Sand bath method

Specific Gravity (G)

1. Pycnometer (or) Density bottle method

W1

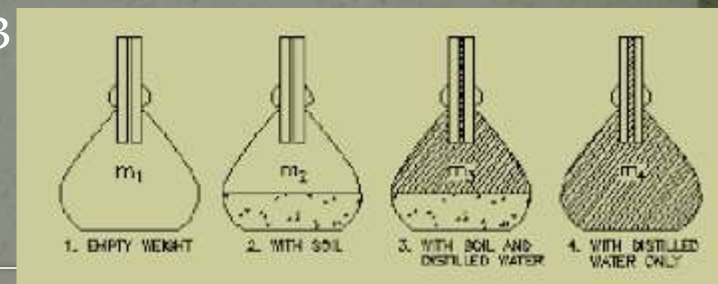
W2

W3

W4

Pycnometer method

Density bottle method

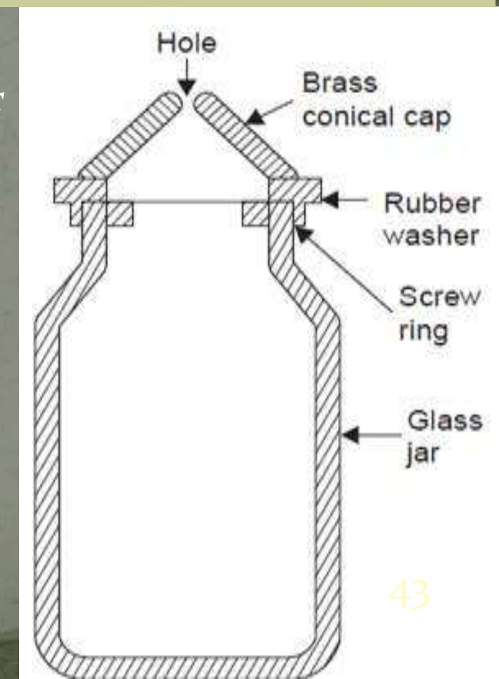


W_1 – empty weight of the Pycnometer (or Density bottle)

W_2 – weight of Pycnometer (or Density bottle) plus 1/3rd volume of the soil

W_3 – weight of Pycnometer (or Density bottle), 1/3rd volume of the soil plus water

W_4 – weight of Pycnometer (or Density bottle) with full of water



Specific gravity (G)

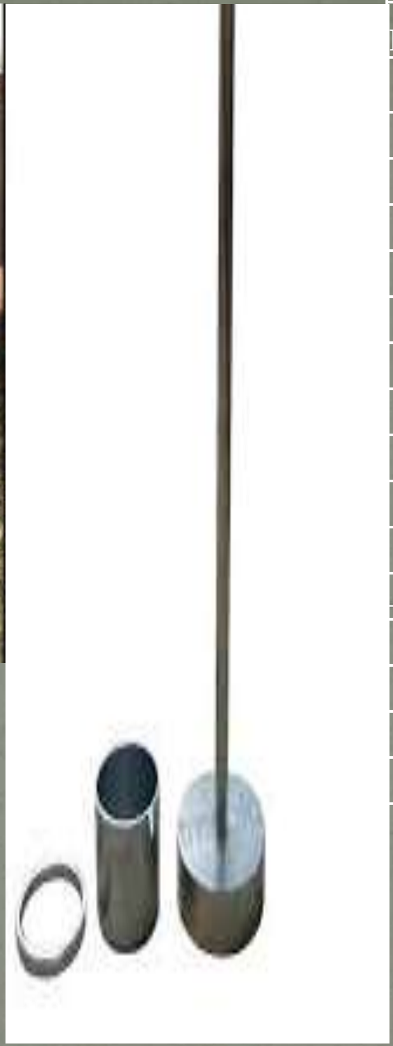
$$G = \frac{\text{Weight of soil solids}}{\text{Weight of water of volume equal to that of solids}}$$

$$G = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)}$$

Specific gravity of water varies only in a small range (1.0000 at 4°C and 0.9922 at 40°C)

In-Situ Density

1. Core cutter method



S.No.	Description	1
Field Compaction		
1	Location	
2	Internal Dia. of core cutter in cm	10
3	Height of the core cutter in cm	12.7
4	Volume of the core cutter in cm^3	997.46
5	Weight of core cutter W1 in gms	827
6	Weight of cutter + wet soil W2 in gms	2992
7	Weight of wet soil (5 - 4) in gms	2165.00
8	Wet / Bulk density γ = 6 / V in g/cc	2.17
9	Moisture content container No.	P 10
10	Weight of container in gms	31
11	Weight of container + wet soil in gms	110
12	Weight of container + dry soil in gms	104.5
13	Weight of water (10 - 11) in gms	5.50
14	Weight of dry soil (11 - 9) in gms	73.50
15	Moisture content w = 12 *100 / 13 in %	7.48
16	Dry density γ_d = 7 / (1 + (14)) in g/cc	2.02

In-Situ Density

2. Sand replacement method

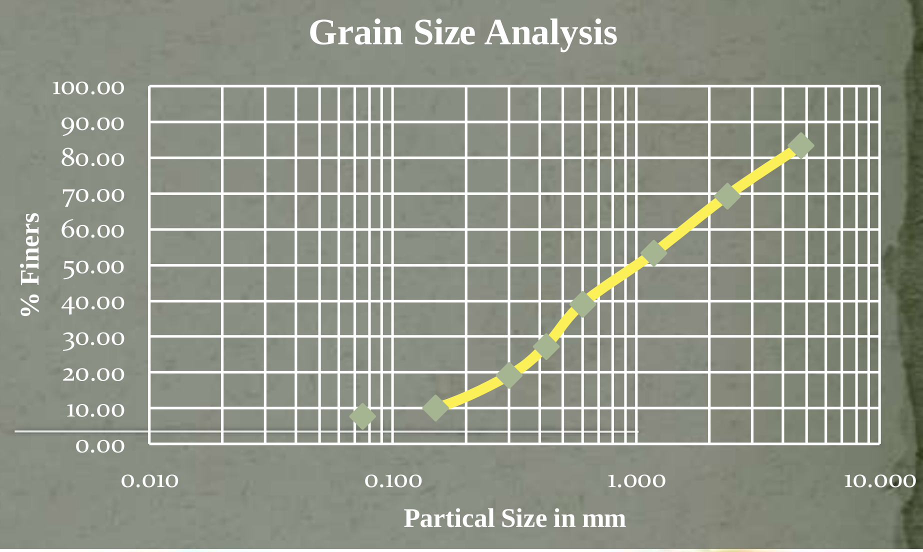
S.No.	Description	1
1	Weight of sand pouring cylinder with dry sand (W1) in gms	7048.50
2	Weight of sand pouring cylinder with dry sand after releasing into conical spreader (W2) in gms	6670.00
3	Weight of sand in conical spreader = 1 - 2 in gms	378.50
4	Weight of sand pouring cylinder after releasing into calibrating can (W3) in gms	4653.00
5	Weight of sand in calibrating can plus conical spreader = 2 - 4 in gms	2017.00
6	Diameter of the calibrating can (D) in cms	10.00
7	Height of calibrating can (H) in cms	15.00
8	Volume of the calibrating can (V) in cc	1178.10
9	Weight of sand in calibrating can = 5 - 3 in gms	1638.50
10	Bulk density of sand γ_{sand} = 9 / 8 in g/cc	1.39
11	Weight the refilled sand pouring cylinder (W4) in gms	7350.00
12	Weight of sand pouring cylinder after releasing into pit (W5) in gms	3800.00
13	Weight of sand in pit including conical spreader = 11 - 12 in gms	3550.00
14	Weight of sand in pit = 13 - 3 in gms	3171.50
15	Volume of pit (Vp) = 14 / 10 in cc	2280.34
16	Weight of soil excavated from pit (W6) in gms	5200.00
17	Bulk density of soil γ = 16 / 15 in g/cc	2.28
18	Moisture content container No.	S14
19	Weight of container in gms	21.42
20	Weight of container + wet soil in gms	120.87
21	Weight of container + dry soil in gms	115.62
22	Weight of water (20 - 21) in gms	5.25
23	Weight of dry soil (21 - 19) in gms	94.20
24	Moisture content w = 22 *100 / 23 in %	5.57
25	Dry density γ_d = 17 / (1 + (24)) in g/cc	2.16

Grain size analysis

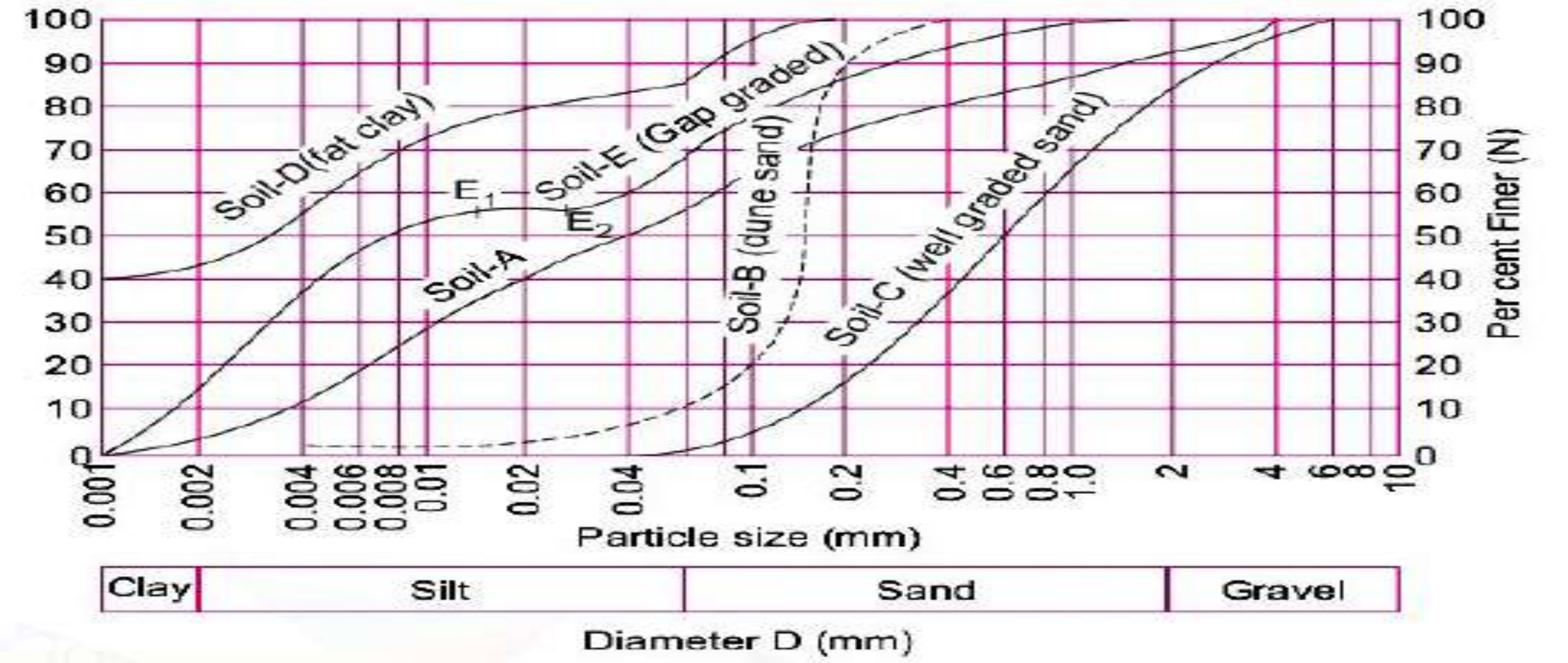
Sieve and Hydrometer methods

Clay	Silt	Sand			Gravel	
		Fine	Medium	Coarse	Fine	Coarse

S.No.	IS Sieve No.	Aperture Size in mm	Wt. of soil retained in gms	% wt. retained	Cumulative % wt. retained	% passing through
1	4.75 mm	4.750	167	16.70	16.70	83.30
2	2.36 mm	2.360	140	14.00	30.70	69.30
3	1.18 mm	1.180	160	16.00	46.70	53.30
4	600 μ	0.600	142	14.20	60.90	39.10
5	425 μ	0.425	118	11.80	72.70	27.30
6	300 μ	0.300	82	8.20	80.90	19.10
7	150 μ	0.150	91	9.10	90.00	10.00
8	75 μ	0.075	23	2.30	92.30	7.70
9	Pan	0.000	77	7.70	100.00	0.00



Grain size analysis



Grain size analysis

Sieve and Hydrometer methods

•Take 50 gms of pretreated dry soil passing from 75 micron sieve.
•Place the soil in an evaporating dish and cover it up with 100 cc of dispersing solution and warm gently for about 10 minutes.
•Transfer the sample to the cup of mechanical stirrer using distilled water until the cup is three fourth full and operate the mixer for about four minutes.
•Meanwhile keep the clean hydrometer in a 1000 cc jar filled with distilled water and 100 cc dispersing agent solutions.
•After stirring, wash the specimen into a 1000 cc jar and enough water to bring the level to 1000 cc.
•Mix thoroughly the suspension in the jar by placing the palm of the hand in the open end and turning the jar upside down and back.
•Place the jar on the table and insert the hydrometer,. Start the stop watch simultaneously.

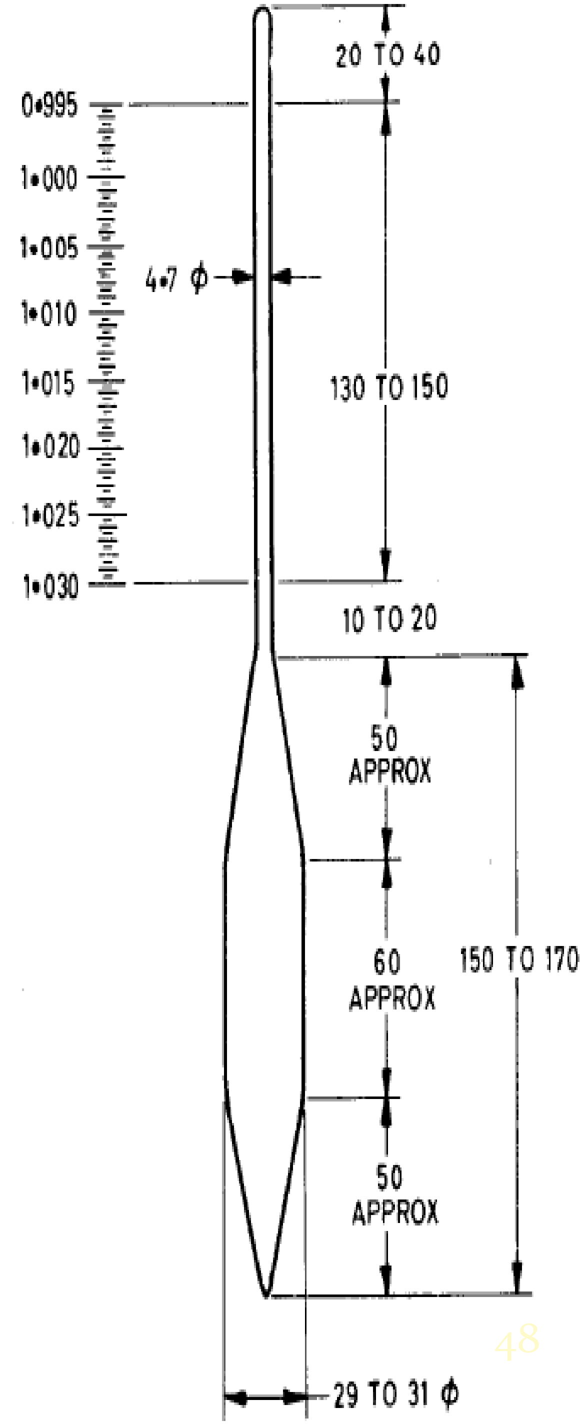
Read the top of the meniscus at 0.5, 1, 2 and 4 minutes.

After 4 minutes reading, remove the hydrometer, clean the outside and float it in the second jar containing distilled water and dispersing agent.

Record the temperature of the suspension.

Take further readings at 8, 15, 30 minutes and 1, 2, 4, 8 and 24 hour after the start of the test. For each of these readings, insert the hydrometer just before the reading.

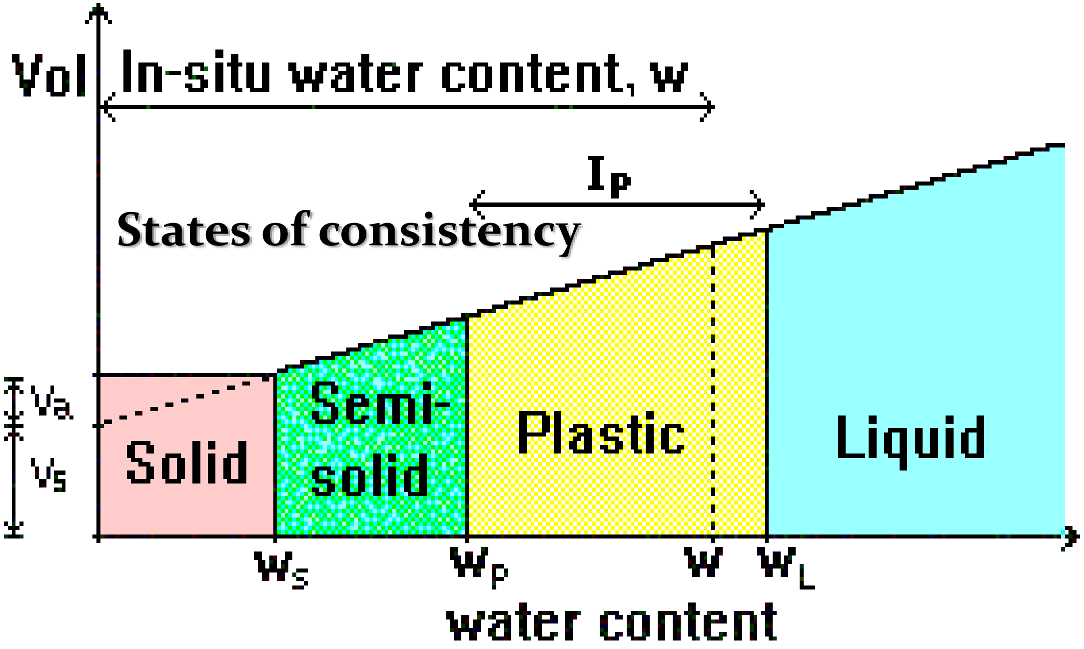
For determining the corrections, read the top and bottom of the meniscus formed on the stem of the hydrometer when it is floating in the second jar containing the distilled water and dispersing agent only.



Consistency limits

The term consistency refers to the relative ease with which a soil mass can be deformed and is used to describe the degree of firmness of fine grained soils for which consistency relates to a large extent to water content.

The water contents, which arbitrarily defined the boundary between the four states of consistency are referred to as consistency limits or Atterberg limits.



Liquid limit – it is the water content at which a groove, cut with a standard grooving tool, in soil pat taken in the cup of a standard liquid limit device closes for a distance of 13 mm when the cup is imparted 25 blows.

Liquid limit – denoted by w_L and is the boundary between plastic and liquid states of consistency. It is the minimum water content at which the soil mass still flows like a liquid.

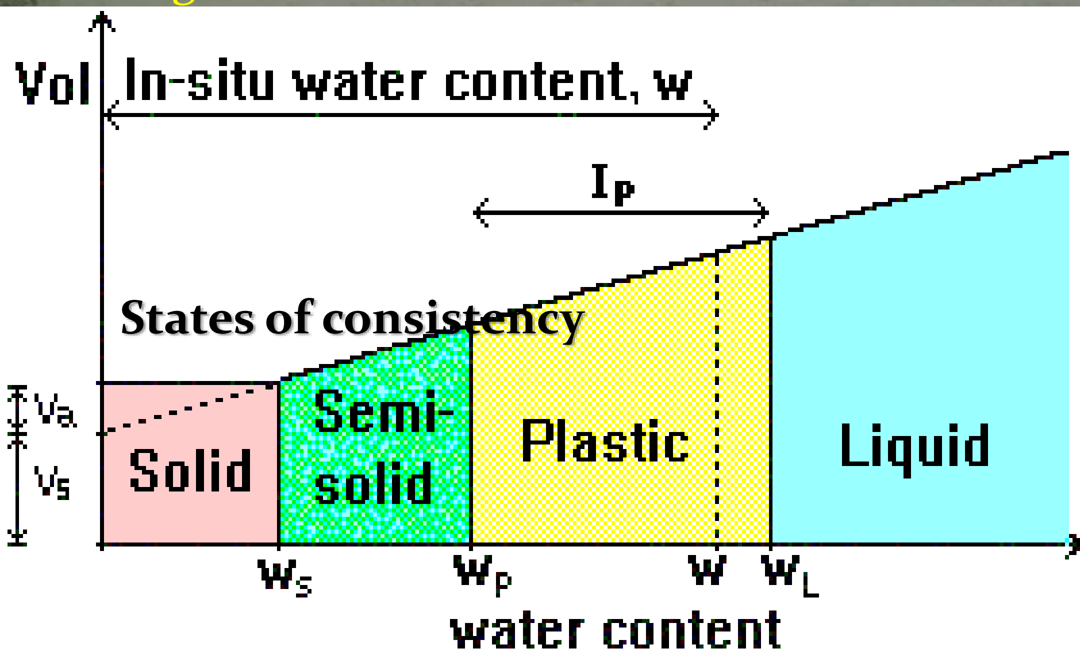
Consistency limits

S.No.	Description	1	2	3	4
1	Number of blows	34	23	18	12
2	Container No.	130	123	128	132
3	Weight of container in gms	26.08	25.3	26.95	26.06
4	Weight of container + wet soil in gms	38.86	46.63	60.36	43.43
5	Weight of container + dry soil in gms	34.91	39.59	49.02	37.22
6	Weight of water in gms (4 – 5)	3.95	7.04	11.34	6.21
7	Weight of dry soil in gms (5 – 3)	8.83	14.29	22.07	11.16
8	Water content *w* in % = 6 * 100 / 7	44.73	49.27	51.38	55.65

Liquid limit

Consistency limits

Plastic limit – it is the water content at which the soil mass can be rolled into a thread of 3 mm diameter and the thread first shows signs of cracking.



Shrinkage limit – denoted by w_S and is the boundary between solid and semi solid states of consistency. It is defined as the maximum water content at which there is no reduction in volume of soil mass accompanying reduction in water content.

Plastic limit – denoted by w_P and is the boundary between semi solid and plastic states of consistency. It is the minimum water content at which the soil mass can still be deformed without cracking.

Consistency limits

Plastic Limit

Plastic limit

S.No.	Description	1	2	3
1	Container No.	33	19	22
2	Weight of container in gms	32	31.5	23.42
3	Weight of container + wet soil in gms	156	124	30.87
4	Weight of container + dry soil in gms	144.5	115	29.27
5	Weight of water in gms (3 – 4)	11.5	9	1.6
6	Weight of dry soil in gms (2 – 4)	112.5	83.5	5.85
7	Water content *w* in % = 5 * 100 / 6	10.22	10.78	27.35

Shrinkage limit

S.No.	Description	1
	Water content of wet soil pat	
1	Shrinkage dish No.	1
2	Weight of shrinkage dish in gms	23
3	Wt. of shrinkage dish + Wt. of wet soil pat in gms	63.5
4	Wt. of shrinkage dish + dry soil pat in gms	52.6
5	Weight of dry soil pat in gms	29.6
6	Weight of water in gms	10.9
7	Water content of soil pat (*w*)in %	36.8
	Volume of wet soil pat	
8	Evaporating dish No.	1
9	Wt. of mercury filling shrinkage dish + Wt. of evaporating dish in gms	350.3
10	Wt. of evaporating dish in gms	76.2
11	Wt. of mercury filling shrinkage dish in gms	274.1
12	Volume of wet soil pat V = (11) / 13.6 in cm^3	20.2

	Volume of dry soil pat	
13	Evaporating dish No.	1
14	Wt. of mercury displaced by dry soil pat + evaporating dish in gms	304.3
15	Wt. of evaporating dish in gms	76.2
16	Wt. of mercury displaced by dry soil pat in gms	228.1
17	Volume of dry soil pat Vd = (16) / 13.6 in cm^3	16.8
18	Shrinkage limit Ws = (7 - ((12 - 17) / 5)*100) in %	**25.4**
19	Shrinkage ratio SR = 5 * γ_w/ 17	**1.76**
20	Volumetric shrinkage VS = (7 - 18) * SR	**20.2**

Atterberg Indices

1. Plasticity index
2. Flow index
3. Toughness index
4. Consistency index
5. Liquidity index

Activity Number

Sensitivity

Problems

The natural dry density of a soil deposit was found to be 17.5 kN/m^3. A sample of the soil was brought to the laboratory and the minimum and maximum dry densities were found as 16 kN/m^3 and 19 kN/m^3 respectively. Calculate the density index for the soil deposit.

Problems

A field test gave the following results – mass of core cutter + soil is 3200 gm, mass of core cutter is 1500 gm, internal volume of core cutter is 1000 cc, water content is 12% and specific gravity is 2.67. Calculate in-place bulk density, dry density, degree of saturation and saturated density.

Problems

To determine the in-situ density of a compacted embankment, a small hole is dug into the embankment and the excavated soil is weighed. Uniformly graded dry sand is then poured into the hole from a weighed sand pouring cylinder fitted with pouring cone at its bottom. The cylinder after filling the hole is weighed. The mass of sand filling the pouring cone is determined afterwards. The density of sand used in the cylinder is determined by filling it in a 1000 cm^3 calibrating can whose empty mass is 944 g. If the water content of the embankment soil is 8% and other test data are as given below. Determine the in-situ dry density.

Mass of excavated soil = 925 g
Mass of cylinder + sand before test = 5332 g
Mass of cylinder + sand after filling the hole = 4152 g
Mass of sand filling the pouring cone = 432 g
Mass of calibrating can + sand = 2483 g

To determine the in-situ density of a compacted embankment, a small hole is dug into the embankment and the excavated soil is weighed. Uniformly graded dry sand is then poured into the hole from a weighed sand pouring cylinder fitted with pouring cone at its bottom. The cylinder after filling the hole is weighed. The mass of sand filling the pouring cone is determined afterwards. The density of sand used in the cylinder is determined by filling it in a 1000 cm^3 calibrating can whose empty mass is 944 g. If the water content of the embankment soil is 8% and other test data are as given below. Determine the in-situ dry density.

Mass of excavated soil = 925 g

Mass of cylinder + sand before test = 5332 g

Mass of cylinder + sand after filling the hole = 4152 g

Mass of sand filling the pouring cone = 432 g

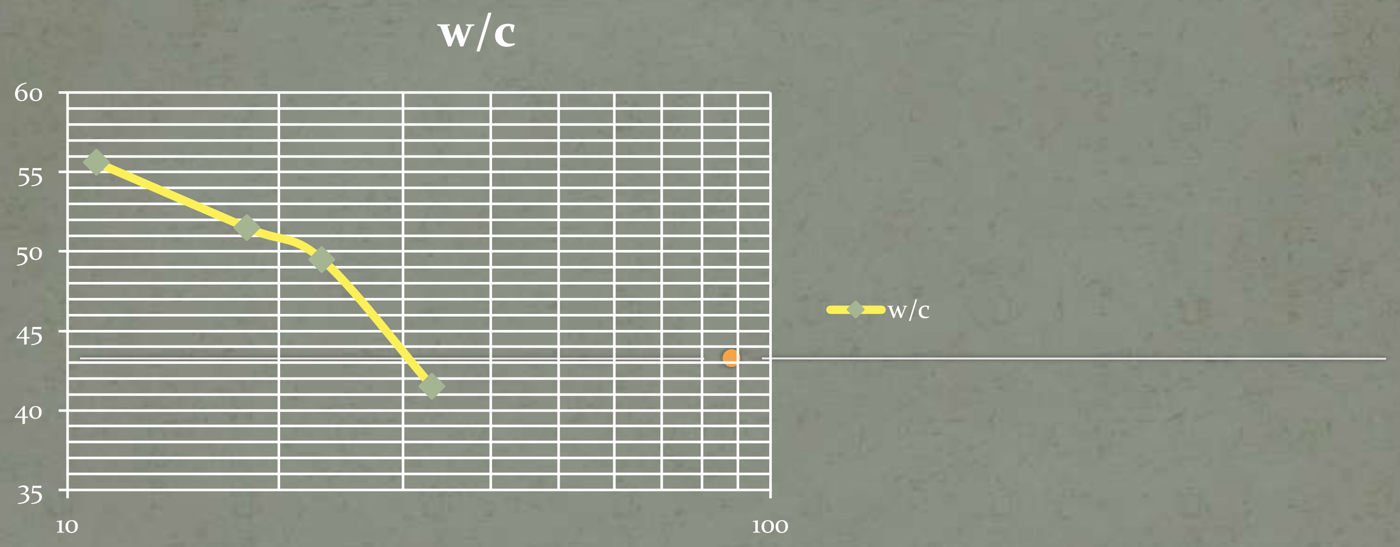
Mass of calibrating can + sand = 2483 g

Problems

The following test results refer to a liquid limit test

Number of blows	**33**	**23**	**18**	**11**
Water content (%)	**41.5**	**49.5**	**51.5**	**55.6**

The plastic limit is 23.5%. Determine the plasticity index and toughness index for the soil.



Problems

The mass and volume of a saturated clay specimen were 29.8 gms and 17.7 cm^3 respectively. On oven drying the mass got reduced to 19 gms and the volume to 8.9 cm^3. Calculate shrinkage limit, shrinkage ratio and volumetric shrinkage. Also compute the specific gravity of soil.

Field identification of soils

The sample is first spread on a flat surface.
If more than 50% of the particles are visible to the naked eye (unaided eye), the soil is coarse grained, otherwise, it is fine grained.

Coarse grained soils - if the soil is coarse grained, it is further identified by estimating the percentage of gravel size, sand size, silt size and clay size particles. If the percentage of gravel size is greater than that of sand, the soil is gravel, otherwise it is sand.
Gravels and sands further classified as – clean, if they contain fines less than 5% and dirty, if they contain fines more than 12%. Gravels and sands containing 5 to 12% fines are given boundary classification.
To differentiate fine sand from silt, dispersion test is adopted. When a spoonful of soil is poured in a jar full of water, fine sand settles in a minute or so, whereas silt takes 15 minutes or more.
Fine grained soils –

1. Dilatancy (reaction to shaking) test
2. Toughness test
3. Dry strength test

IS Classification of soils

Purpose - to arrange various types of soils into specific groups based on physical properties and engineering behavior of soils with the objective of finding the suitability of soils for different engineering applications, such as in the construction of earth dams, highways and foundations of buildings etc.,

Soil classification systems –

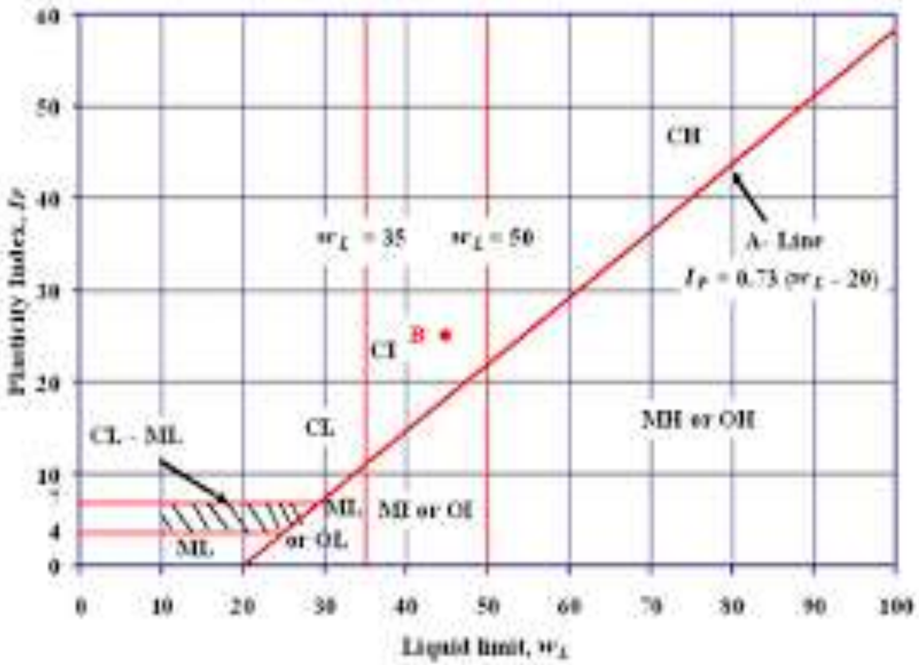
1. Highway Research Board classification system
2. Unified Soil Classification system
3. Indian Standard soil classification system

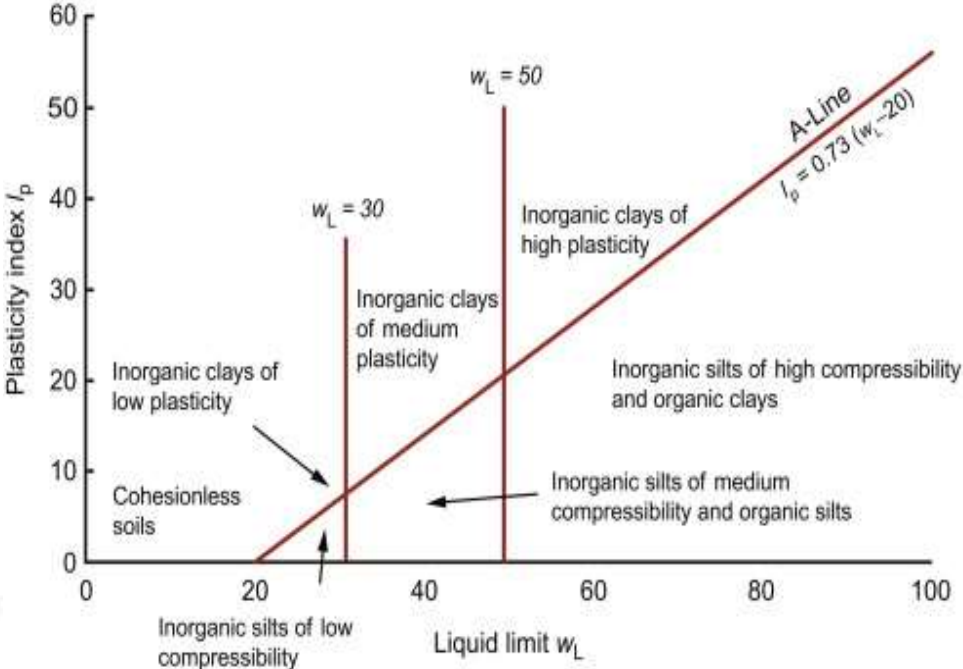
Particle size classification systems –

1. US Bureau of soil and Public Roads Administration (PRA) classification system
2. MIT classification system (proposed by Prof. Gilboy)
3. Indian Standard particle size classification system (based on MIT system)

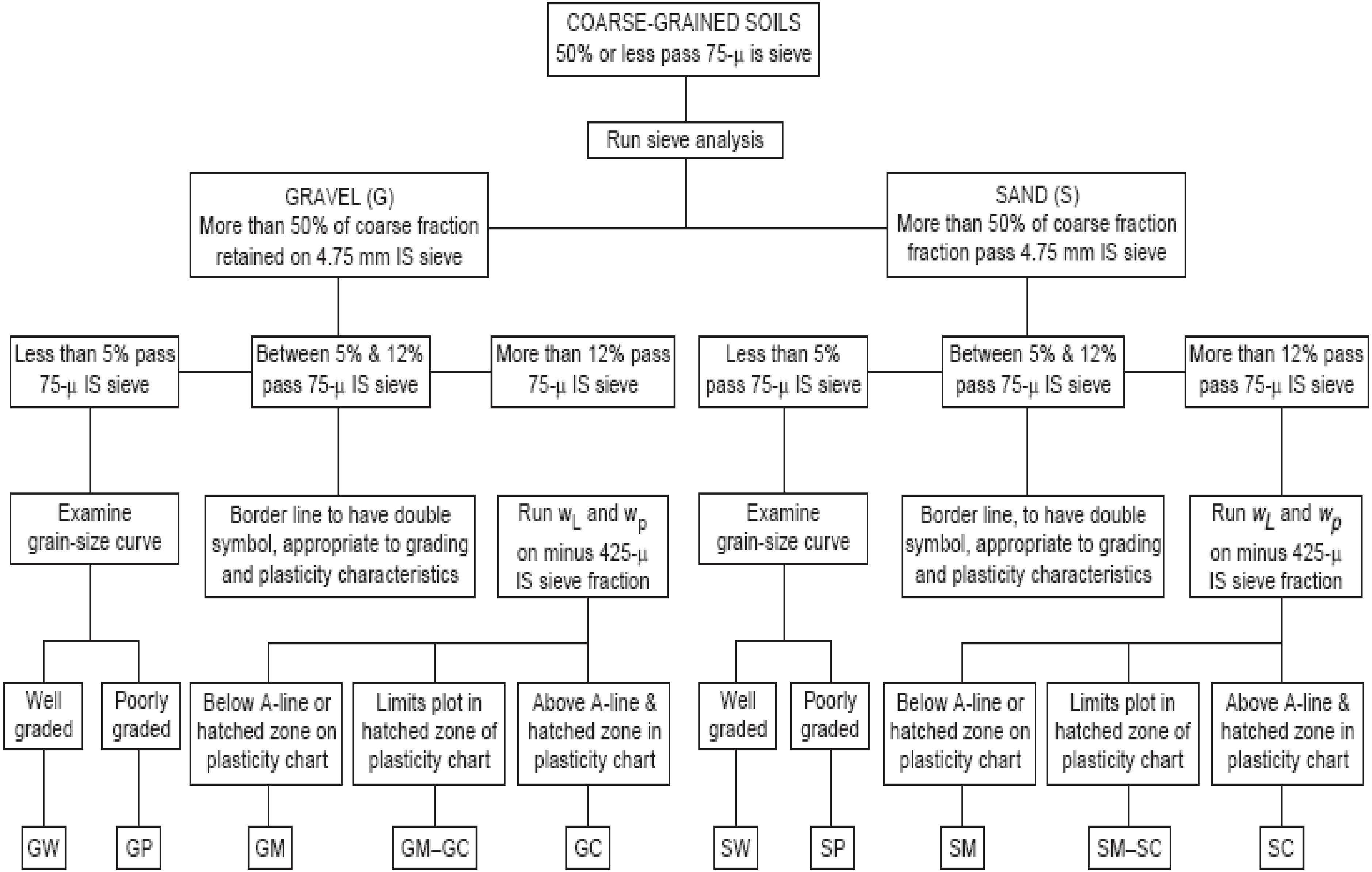
IS Classification of soils

IS Classification of soils

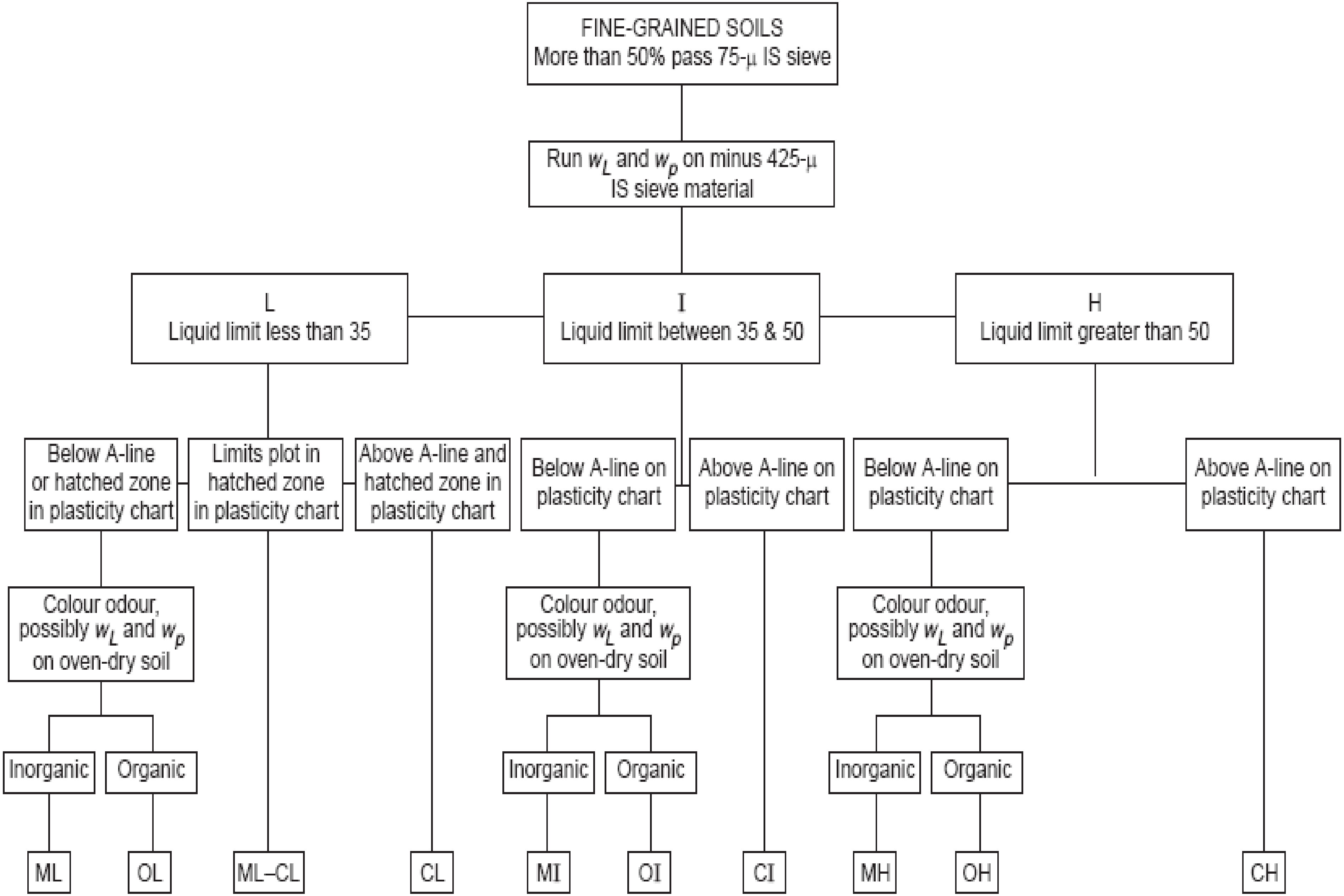




IS Classification of soils



IS Classification of soils



Problems

Classify the soil with the composition – percent finer than 0.075 mm is 55%, liquid limit is 50% and plastic limit is 40%.

Problems

A soil sample is found to have the following properties. Classify the soil according to IS classification system.

Passing 75 μ sieve	= 10%
Passing 4.75 mm sieve	= 70%
Uniformity coefficient	= 8
Coefficient of curvature	= 2.8
Plasticity index	= 4