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AGRICULTURAL ENGINEERING

Soil and Water Conservation

Soil Mechanics



SOIL MECHANICS

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SOILS, THEIR ORIGIN, FORMATION AND TYPES

Definition of Soil

Soils are the earthy materials (weathered rocks), *inorganic* (such as sand, clay, silt etc.) or *organic* (such as peat), in nature. A soil is thus a natural aggregate of mineral grains, which are separable by gentle mechanical means; and is thus distinguishable from a rock, which is a natural aggregate of minerals connected by strong and permanent cohesive forces.

Origin and Formation of Soils

Soils are formed by the disintegration (technically called *weathering*), of rocks. The disintegrated or weathered material may either be found deposited at its own place of origin, or may get transported by agents like water, wind, ice, etc., before deposition. In the first case, the resultant soil is called a residual soil; and in the second case, it is called a transported soil. Moreover depending upon whether the sediments are transported by *water*, *ice* or *wind*, the soils are called as *alluvial*, *glacial*, or *aeolin*, respectively. The three stages involved above, in the formation of transported soils, can thus be described as follows:

- (i) *Weathering*;
- (ii) *Transportation*; and
- (iii) *Deposition of weathered materials*.

These three stages are briefly discussed below

- (i) **Weathering.** *Mechanical weathering* disintegrates a pre-existing rock into smaller fragments; and *chemical weathering* acting on these small fragments, rearranges the elements into new minerals, and thus *decomposes* them. Mechanical weathering or *erosion* is done mainly by the forces produced by various agencies, like atmospheric gases, temperature changes, running water,
- (ii) **Transportation.** The products of rock weathering are generally transported in large amounts by the running waters (*i.e. rivers*), moving ice (*i.e. glaciers*), and blowing winds. Out of these three transporting agents, running water, *i.e. the rivers* are the most important.

(III) **Deposition of weathered material.** The transportation of the weathered **products** continues as the velocity of the transporting medium remains unchecked. But when these products are brought at rest into big water bodies like oceans and lakes, their deposition will start. Of the Weathered products carried in suspension, the coarser and heavier pieces will settle first, followed by lighter and finer particles. The weathered products carried in solution may precipitate out at a later stage, which may form a separate layer on deposition

Types of Soil

As stated earlier, the soil on the basis of their origin, may be broadly classified into two categories viz:

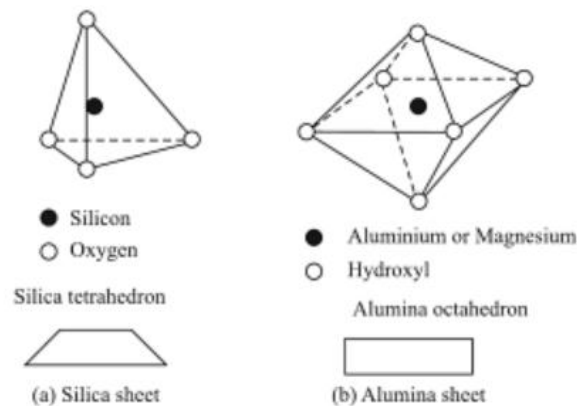
- (a) Residual soils; and
- (b) Transported soils, as defined below:
 - (A) Residual soil: A soil that is formed by weathering of the parent rock and still occupies the position of the rock from which it has been formed, is **called** a residual soil. Residual soils are not as common as transported soils.
 - (B) Transported Soil, any soil that has been transported from its place of origin by wind, water ice or some other agency, and has been re-deposited, is called a transported soil. Transported soils, are classified according to the transporting agency and method of deposition as follows:
 - (a) Alluvial deposits;
 - (b) Lacustrine deposits;
 - (c) Marine deposits;
 - (d) Aeolian deposition and;
 - (e) Glacial deposits;

The above types of soil deposits or soils are defined below:

- (a) Alluvial soils are those soils that have been deposited from suspension in running water
- (b) **Lacustrine soils are those soils that have been deposited from suspension in quiet fresh water lakes.**
- (c) **Marine soils are those soils that have been deposited from suspension in sea water**
- (d) **Aeolian soils are those soils that have been transported by wind usually fine sand deposited in dunes, or silt which forms loess, fall in this category**
- (e) **Glacial soils** are those that have been transported by ice

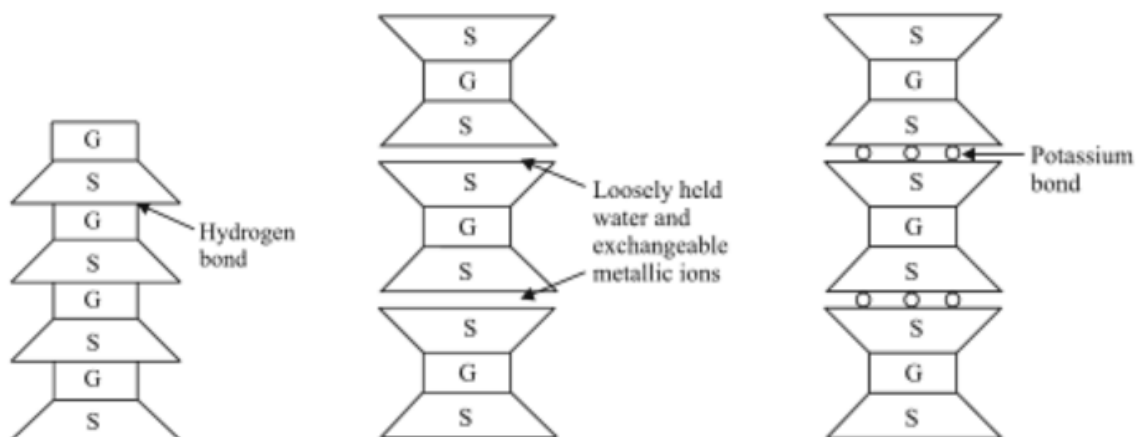
Structures in Clay Minerals

The clayey soils are formed by the disintegration (chemical weathering) of the clay minerals, like *kaolinite*, *illite* or *montmorillonite*. The **basic structural units** of most of the clay minerals consist of a **silica tetrahedron** and an *alumina octahedron*, respectively containing one negative charge and one positive charge, as shown in the figure below.



Basic Units and Symbolic representation of Clay mineral

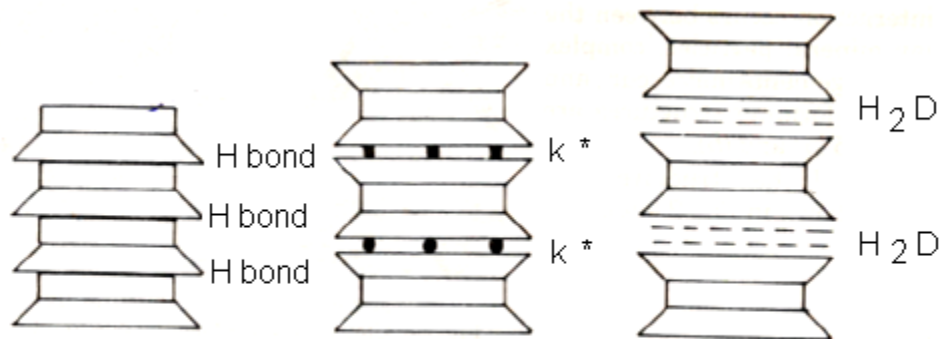
These two basic units combine to form *sheet structures*, which are represented symbolically in figure above. The various clay minerals are formed by the stacking of combinations of the basic sheet structures with different forms of loading between the combined sheets, as shown in figures below.



Symbolic Structures of kaolinite, montmorillonite and illite.

Before the above joining of the basic units (*i.e.* silica tetrahedron and alumina octahedron) occurs to form a clay mineral, silicon and aluminium may sometimes be partially replaced by other elements, such as magnesium, potassium, iron, etc., in these units ; and this reaction is known as **isomorphous substitution**. In kaolinite clay mineral, there occurs a very limited isomorphous substitution; and the combined silica-alumina sheets are held

together fairly tightly by *hydrogen (H) bonding*, as a kaolinite particle may consist of over 100 stacks of the silica and alumina sheets.



Clay Minerals Bonding sheets, called gibbsite sheets

In an illite clay mineral, one alumina sheet is combined with two silica sheets, as shown in (b). In the alumina octahedral sheet, aluminium is partially substituted by magnesium and iron; while in the silica tetrahedral sheet; there occurs a partial substitution of silicon by aluminium. The combined sheets are linked together by fairly weak bonding due to non-exchangeable potassium ions held between them.

In the **montmorillonite** clay mineral, the basic structure is the same as in illite clay mineral; and in the alumina octahedral sheet there also occurs a partial substitution of aluminium by magnesium. But, the space between the combined sheets is occupied by water molecules and exchangeable cations other than potassium, as there exists very weak bond between the combined sheets due to these ions. Considerable swelling of montmorillonite can occur due to additional water being absorbed between the combined sheets.

CLASSIFICATION AND IDENTIFICATION OF SOILS

Numerous classification systems have been suggested, and particles are classified as of clay-size, silt-size, sand-size, gravel-size, and cobble-size, depending upon the increase in diameter. Different classifications consider different limiting values under the above categories. The important classifications are:

- (i) U.S. Bureau of Soil and Public Road Administration (PRA) classification (a)];
- ii) International soil classification, proposed at International Soil Conference at Washington,D.C. in 1927 (b)];
- (iii) the M.I.T. classification proposed by Prof. Gilboy of U.S.A(c)];
- (iv) the Unified classification system and
- (v) the I.S.I classification which has been derived from unified soil classification system

	0.005 mm	0.05	0.10	0.25	0.50	1.0	2.0 mm	
Clay (Size)	Silt (Size)	V. F.	Fine	Medium	Coarse	Fine Gravel	Gravel	
		Sand						

(a) U. S. Bureau of soils and PRA classification

	0.0002	0.0006	0.002	0.006	0.02	0.05	0.1	0.2	0.5	1.0	2.0 mm	
Ultra Clay	F	C	F	C	F	C	F	M	C	V.C.	Gravel	
(Colloids)	Clay		Silt		MO (Majla)		Sand					

(b) International Classification

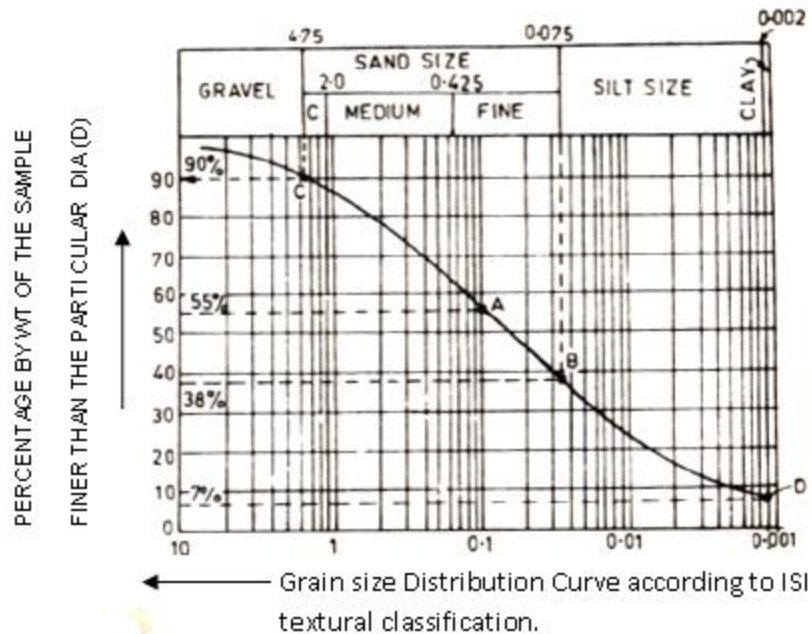
	0.0002		0.006		0.02		0.06		0.2		0.6		2.0 mm
Clay (Size)		Fine		Med.		Coarse		Fine		Med.		Coarse	Gravel
(Colloids)		Silt (Size)					Sand						

(c) M.I.T. Classification

	0.002 mm	0.075	0.425	2	4.75	20	80	300
Clay (Size)	Silt (Size)	Fine	Med.	Coarse	Fine	Coarse	Cobble	Boulder
		Sand			Gravel			

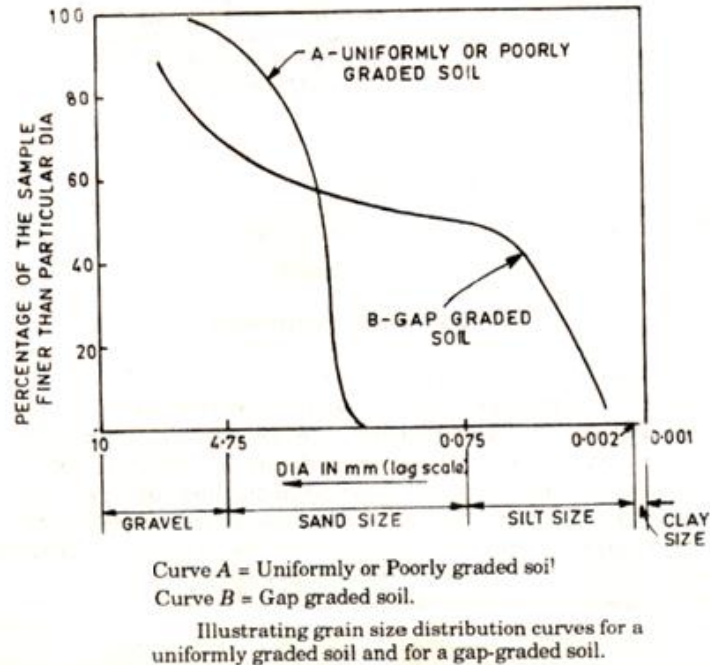
(d) I.S. Classification (IS : 1498-1970)

Grain Size Distribution Curve. As we know, a sample of naturally occurring soil would rarely have particles of just one size. The usual situation is that it contains a variety of sizes in different proportions. As stated earlier, the soil sample can be subjected to *sieve analysis* and/or a *hydrometer test* in a laboratory to determine the distribution of grain sizes present in it. Considering following figure, it is being observed that $55 - 38 = 17\%$ material is in the size range of 0.075 mm and 0.1 mm. In this very manner, it can be easily calculated that sizes of 90% of particles are smaller than 4.75 mm (point C). Hence, $90 - 38 = 52\%$ material is in the size range of 0.075 mm and 4.75 mm, which is the *sand-size* range.



Proceeding in this manner, it can be easily calculated that (between points *B* and *D*), $38 - 7 = 31\%$ of particles range between 0.075 mm and 0.002 mm, which is *silt-size*. Hence, the sample of soil plotted above can be stated to have 7% particles of clay-size, 31% particles of silt size, and 52% particles of sand-size, and the rest 10% being of gravel size, and that all sizes of sand, silt and gravel are present in the sample. Such a distribution is known as **well-graded**.

The following figure shows two curves, first for a **uniformly graded** soil (curve A), in which more than 80% of particles are in the *sand-size* zone, and second for a **gap-graded** soil (curve B) which has particles of silt and gravel size but not of sand size.



Coefficient of Uniformity and Coefficient of Curvature. In order to describe the **shape** of the grain size distribution curve with a single number, two coefficients are generally **used**, *i.e.* the *coefficient of uniformity* (C_u), and (ii) the *coefficient of curvature* (C_{cr}). These **are defined as follows**:

$$C_u = \text{Coefficient of uniformity} = \frac{D_{60}}{D_{10}}$$

$$C_{cr} = \text{Coefficient of curvature} = \frac{D_{30}^2}{D_{60} \cdot D_{10}}$$

A uniformly graded soil will have its coefficient of uniformity (C_u) of less than 2.0 (nearly 1.0) ; and a well graded soil will have its coefficient of curvature (C_{cr}) more than 1.0 but less than 3.0. Moreover, C_u is greater than 4 for gravels and 6 for sands (USBR 1960). In actual practice, the utility of these coefficients is limited.

Experimental Determination of Grain Size Distribution in a Soil sample

As stated earlier, *sieve analysis*, and a *hydrometer* are used to determine the grain size distribution of a soil sample. For large sized particles, sieve analysis is used, and for smaller particles, hydrometer testing is used, as described below:

Sieve analysis. In the B.S. and ASTM standards, the sieve sizes are given in terms of number of openings per inch. The number of openings per square inch is equal to the square of the sieve. In the Indian Standard (IS) specifications (IS: 460—1962), the sieves

are designated by the size of the aperture in mm. The complete procedure for particles size determination can be divided into three stages viz:

- (a) *sieve analysis of soil fraction retained on 4.75 mm aperture sieve ;*
- (b) *sieve analysis of soil passing 4.75 mm aperture sieve and retained on 75 micron aperture sieve ; and*
- (c) *sedimentation analysis of soil passing 75 micron aperture sieve.* These procedures are discussed below: An oven dried sample of soil is first of all separated into two fractions, by sieving it through a 4.75 mm IS sieve. The soil which is retained on 4.75 mm sieve will be of gravel size, and that passing through it will be of sand, silt or clay-sizes. The portion retained on this sieve is called *gravel fraction*, and is analysed for coarse *analysis*. The portion passing through it, is analysed for *fine analysis*.

In the coarse analysis, a set of 100 mm, 63 mm, 20 mm, 10 mm and 4.75 mm sieve are used. This analysis is done by dry sieving. In **fine analysis**, a set of 2 mm, 1 mm, 600 μ , 425 μ , 300 μ , 250 μ , 212 μ , 150 μ , 75 μ , aperture sieves are used. This analysis will separate the coarse, medium and fine **sand sizes**. This analysis is done by dry sieving or wet sieving. But dry sieving cannot be used if soil sample contains appreciable amount of clay, as in that case silt and clay sized particles will stick to sand sized particles.

Hydrometer or Pipette testing is used for **silt and clay analysis** (for soil passing 75 μ sieve). As pointed out earlier, the gravel and sand particles in a soil sample, are measured by sieve analysis, while the silt and clay sized particles are measured by a hydrometer or by a pipette apparatus, as discussed below:

Pipette method. This sedimentation analysis can be used only in the laboratory, and the apparatus used is costly and delicate. On the other hand, the *hydrometer testing*, when carefully carried out, gives results which are practically equally accurate, and it can be used both in the laboratory as well as in the field. Both these methods although of course, use the same principle, which is based on *Stokes law*. According to this law, the velocity with which a grain settles down in suspension, all other factors being equal, is dependent upon the shape, weight, and size of the grains. However, in the usual analysis, it is assumed that the soil particles are spherical and have the same specific gravity (*i.e.* the average specific gravity of all grains). *With this assumption, the coarser particles, will settle more quickly than the finer ones. The settling or terminal velocity, then can be worked out as follows:*

Stoke's law

$$\text{or } v = \frac{D^2}{18\mu} \cdot [\gamma_s - \gamma_w]$$

$$\text{or } D^2 = \left[\frac{18 \cdot \mu \cdot v}{\gamma_s - \gamma_w} \right]$$

$$\text{or } D = \sqrt{\frac{18 \mu \cdot v}{\gamma_s - \gamma_w}}$$

Now $\gamma_s = \rho_s \cdot g$, where, ρ_s is the density of soil grain

And $\gamma_w = \rho_w \cdot g$, where, ρ_w is the density of water

$$\gamma_s - \gamma_w = \rho_s \cdot g - \rho_w \cdot g = g(\rho_s - \rho_w)$$

$$= \rho_w \cdot g \left(\frac{\rho_s}{\rho_w} - 1 \right) = \rho_w \cdot g \cdot (G - 1)$$

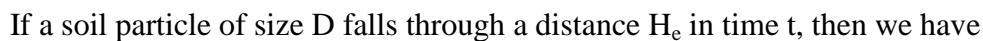
Where G is the sp. Gravity of soil = $\frac{\rho_s}{\rho_w}$

$$D = \sqrt{\frac{18 \mu \cdot v}{\rho_w \cdot g \cdot (G - 1)}}$$

$$\text{or } D = \sqrt{\frac{18 \cdot \mu \cdot v}{\gamma_w \cdot (G - 1)}}$$

Hydrometer testing. The use of a hydrometer for testing the density or specific gravity of milk is well known to all of us. This principle can be extended to measure the varying specific gravity of a soil suspension, as the grain settle, thereby determining the grain-size distribution curve. The readings on a hydrometer stem are so marked that they indicate the density of a fluid at the centre of the bulb at any time. These readings are generally graduated on the stem by subtracting 1 and multiplying the digit by 1000, from the specific gravity. Say for example, a specific gravity of 1.03 will be graduated on the stem by $(1.03 - 1) 1000 = 30$. Hence, the hydrometer stem is graduated on left side for corresponding specific gravities shown on right side. These readings increase in the downward direction. Let these readings or graduations on the hydrometer be represented as R_h . Then, the density as measured by a hydrometer, will be given by

$$\rho = \left[1 + \frac{R_h}{1000} \right]$$

$$D = \sqrt{\frac{18 \mu \cdot v}{\gamma_{\omega} (G-1)}}$$


$$D = \sqrt{\frac{18\mu}{\gamma_{\omega}(G-1)}} \sqrt{\frac{H_e}{t}}$$

or $D = K \sqrt{\frac{H_e}{t}}$

or $D=0.00106\sqrt{\frac{H_e}{t}}$ in SI or MKS units

Three corrections are generally applied to the above observed hydrometer readings. These three corrections are

(i) *Temperature correction;*

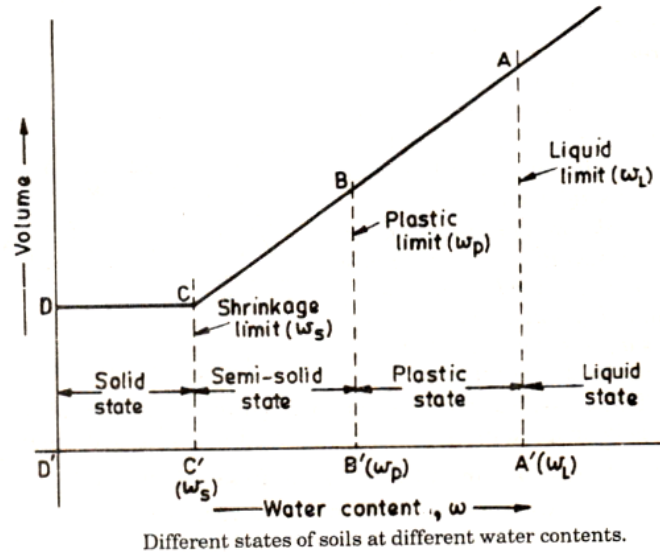
- (ii) **Meniscus correction;**
- (iii) **dispersing agent**

- (a) **Temperature Correction (C_t).** The hydrometers are generally calibrated either at 20°C or at 27°C, temperature. So, if the test experiment is performed at a *temperature more than this calibration temperature, a positive correction is applied, and vice versa,*
- (b) **Meniscus correction (C_m).** Since the soil suspension is opaque, the hydro-meter reading is observed at the top of the meniscus. Actual reading to be taken at the water level will be more since the readings increase in the downward direction. Hence, the *meniscus correction is always positive.* Its magnitude can be found by immersing the hydrometer in jar containing clear water, and finding the difference between the readings corresponding to the top and bottom of the meniscus.
- (c) **Dispersion agent correction (C_d).** Since the addition of a dispersion agent in water, increases its density, a *negative dispersion correction* should always be applied to the observed hydrometer readings.

Classification of Soils on the Basis of Plasticity

However, it can be seen *that clay with a large quantity of water in it is a viscous paste: with less water it can be moulded; and when dried (i.e. water removed), it looks and feels like a solid.* On the basis of experimentations and observations, it has been established that the behaviour of clay is largely controlled by the amount of water present in it, as discussed below : With enough water in clay, it behaves like a liquid ; and with water removed, it becomes a solid, as pointed out earlier. Now the problem before Atterberg (in 1911) was to determine, as to what is the quantum of water that needs to be there in the clay to make it behaved like a liquid, or like a material which lends itself to be moulded, or one that seems like a solid. *Water content (w)* is the measure of the wetness of the soil, which defines four states of the soil and the corresponding *three boundaries* between them. These four states, are

- (i) liquid state,
- (ii) plastic state,
- (iii) semi-solid state, and
- (iv) solid state.



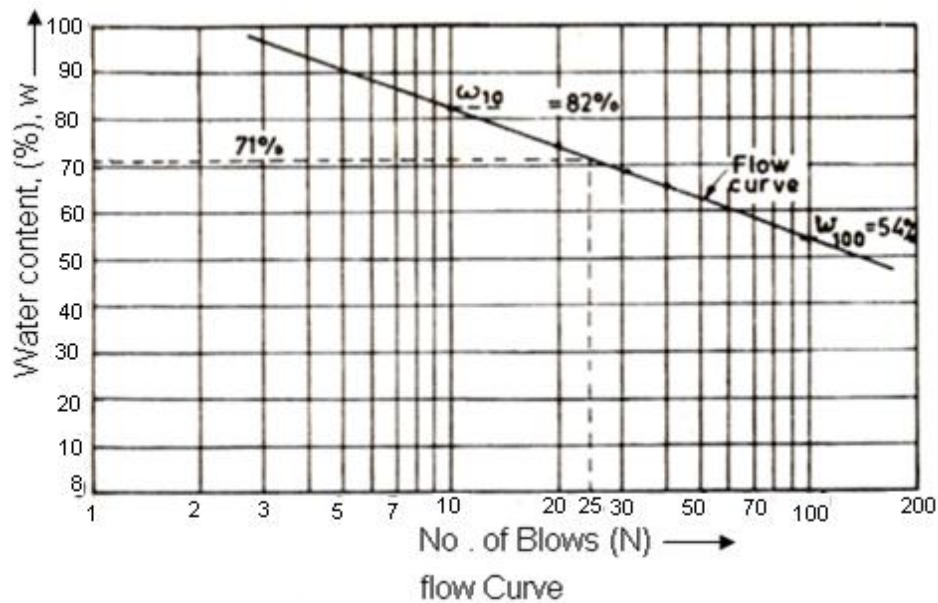
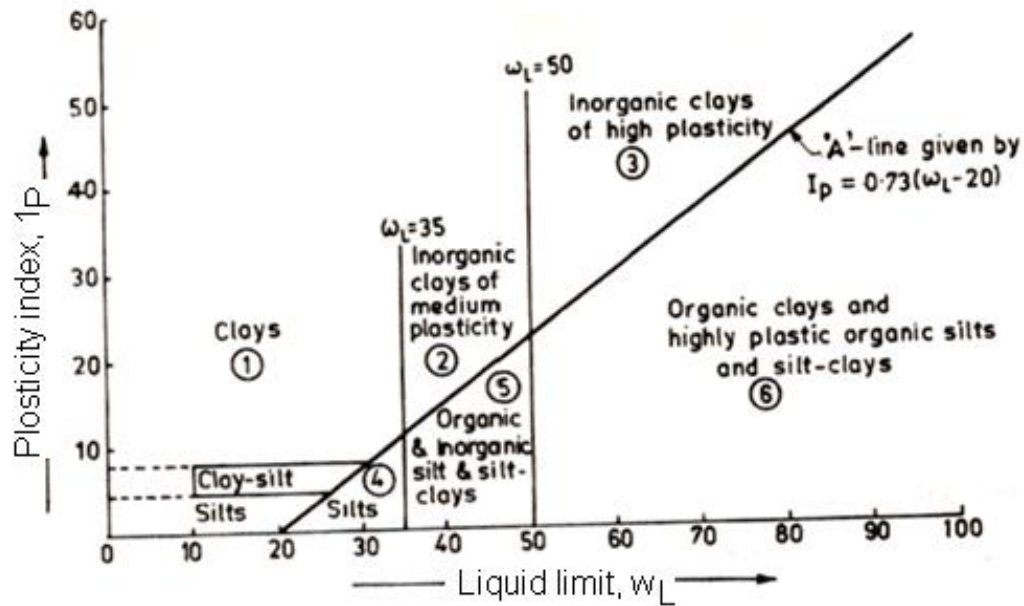
These states and boundaries are shown in the above figure and discussed below :

Soil, in the **liquid state**, behaves like a liquid, *i.e.* it exhibits negligible or nil shear strength. As its water content is reduced to the boundary limit A - A' (called *liquid limit*), the soil *just* begins to exhibit *some* shear strength. **Liquid limit (L.L.)** is the water content (w_L) at which the soil possesses an arbitrarily fixed small amount of shear strength and it represents the boundary between liquid state and plastic state of soil. Soil possesses an arbitrarily fixed small amount of shear strength and it represents the boundary between liquid state and plastic state of soil. Soil in the plastic state has water content, which enables, the soil to behave like plastic material *i.e.* the soil can be moulded, or shaped, or distorted without it being ruptured. As the water content reduces, and reaches the boundary limit B-B' (called *plastic limit*), the soil sample just begins to rupture or crumble when we try to mould it into an arbitrarily fixed shape. Thus, the **plastic limit (P.L.)** is the water content (w_p) at which the soil sample first loses its full plasticity, and begins to crumble when moulded because they behave like plastic material for a large range of water contents. Clean sand is a non-plastic material. Typical values of liquid and plastic limits for a number of soils are given in table. These limits, are generally called the **Atterberg's limits**.

Atterberg's Limits for Some Common Soils

S. No	Soil type	Clay size Particles	Silt size particles %	Sand Size Particles %	L .L . (w _L)	P . L. (w _p)	P.I. or I _p (W _L – W _p)
1.	Montmorillonite – Na	100	0	0	710	54	656
2.	ILLITE – Na	100	0	0	120	53	67
3.	Kaolinite – Na	100	0	0	53	32	21
4.	Delhi Silt	15	70	15	32	22	10
5.	Ghaggar clay	38	58	4	51	25	26
6.	Dhauauri clay	35	64	1	51	30	21
7.	Beas shale	30	68	2	35	19	16
8.	Bombay marine clay	66	32	2	90	40	50
9.	London clay	50	-	-	74	25	49

From table it can be easily seen that clay mineral *Montmorillonite* is a highly plastic material (*P.I.* or *I_p* being as high as 656); *Illite* is not as plastic (*PI* = 67); and *Kaolinite* is the least plastic (*PI* = 21) of the three common clay minerals. A method to classify soils, on the basis of plasticity (*i.e.* L.L. and P.I.), was suggested in 1948 by Casagrande in the form of a plasticity chart, (given below) which constitute an important basis for soil classification, even today. It may also be pointed out here that grain size classification is generally useful for coarse-grained soils, and *plasticity classification for fine-grained soils*. Thus, various classifications have been developed based on both these methods, and will be discussed later, after we describe below the methods used for determining the two Atterberg's limits, *i.e.* LL. and P.L.



The slope of this flow curve (refer example) is called **flow index**. It is represented by

$$I_f = \frac{w_2 - w_1}{\log_{10} N_1 - \log_{10} N_2}$$

The group index of a soil depends upon

- the amount of material passing the 75 μ IS sieve,
- the liquid limit; and
- the plastic limit.

It is given by the equation:

Group index = GI = $0.2 a + 0.005 ac + 0.01 bd$

Where,

a = that portion of the percentage of the soil passing 75 μ sieve, greater than 35 and not exceeding 75 ; expressed as a positive whole number (0 to 40)

b = that portion of percentage of soil passing 75 p sieve, greater than 15 and not exceeding 55, expressed as a whole number (0 to 40),

c = that portion of the liquid limit, greater than 40 and not exceeding 60, expressed as a positive whole number (0 to 20),

d = that portion of the plasticity index greater than 10 and not exceeding 30, expressed as a positive whole number (0 to 20)

Highly Organic Soils and Other Miscellaneous Soil Materials. These soils contain large percentage of fibrous organic matter, such as peat, and the particles of decomposed vegetation. In addition, certain soils containing shells, concretions, cinders and other non-soil materials in sufficient quantities are also grouped in this division.

Boundary classifications. There are no rigid boundaries between soil groups, and the boundary cases can be conveniently designated by dual symbols, such as GW-SW or CL-ML. *The common boundary classifications for coarse-grained soils are: GW-GP; GM-GC; GW-GM; GW-GC; SW-SP; SM-SC; SW-SM; SW-SC; GW-SW; GP-SP; GM-SM; and GC-SC. The common boundary classifications for the fine grained soils are ML-MI; CL-CI; OL-OI; MI-MH; CI-CH; OI-OH; CL-ML ; ML-OL ; CL-OL ; CI-MI; MI-OI; CI-OI; MH-CH ; MH-OH ; and CH-OH.* The boundary classifications between coarse-grained and fine-grained soils are: SM-ML; and SC-CL. It is possible in coarse grained soils with fines between 5 to 10 per cent and *P.I.* between 4 & 7 to have a soil which can be represented by both GM and GC or SM and SC. In such cases, the non-plastic classification is favoured.

SOLVED EXAMPLES

(i) A soil of 23 KN wet weight has a total volume of 1.5m^3 . The dry weight of the soil is 20 KN. The specific gravity of soil solids is 2.7. Determine water content, void ratio, Porosity and Degree of saturation. Represent your answer through a phase diagram.

Data Given: - $W = 23 \text{ KN}$; $V = 1\text{m}^3$

$$W_s = 20 \text{ KN} ; G = 2.7$$

Assume: $v_w = 9.81 \text{ KN/m}^3$

$$\omega = ? ; e = ? ; n = ? ; s = ?$$

(a) Weight of water = $W_w = W - W_s = 23 - 20 = 3 \text{ KN}$.

$$\therefore \text{Water content} = \omega = \frac{W_w}{W_s} = \frac{3}{20} = 0.15$$

$$\text{OR} = 15\%$$

(b) By definition,

$$G = \frac{v_s}{v_w} \Rightarrow v_s = G v_w$$

$$\frac{W_s}{V_s} = G v_w$$

$$\Rightarrow v_s = \frac{W_s}{G v_w}$$

$$V_s = \frac{20}{2.7 \times 9.810} \quad v_w = 9.81$$

$$\boxed{V_s = 0.7551 \text{ m}^3}$$

(c) By definition,

$$v_w = \frac{W_w}{V_w}$$

$$\Rightarrow V_{\omega} = \frac{W_{\omega}}{v_{\omega}}$$

$$V_{\omega} = 0.3058 \text{ m}^3$$

(d) We know, $\boxed{V = V_s + V_v}$

$$V_v = 1.5 - V_s$$

$$= 1.5 - 0.7551$$

$$\underline{V_v = 0.7449 \text{ m}^3}$$

(e) By definition,

$$e = \frac{V_v}{V_s} = \frac{0.7449}{0.7551}$$

$$\underline{e = 0.9864}$$

By definition,

$$\text{Porosity} \quad n = \frac{V_v}{V} = \frac{0.7449}{1.5}$$

$$n = 0.4966$$

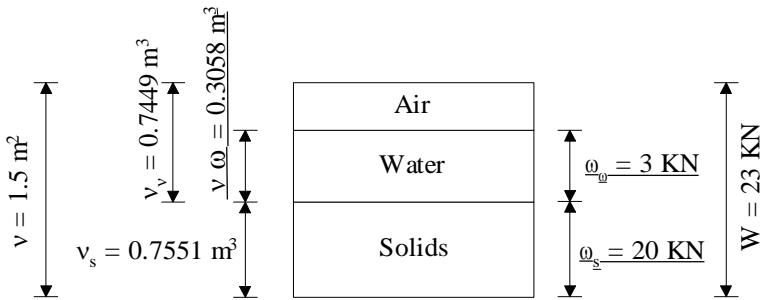
$$\therefore \underline{n = 49.66\%}$$

By definition

$$\text{degree of saturation} \} s = \frac{V_{\omega}}{V_v} = \frac{0.3058}{0.7449}$$

$$\underline{s = 0.410}$$

$$\boxed{s = 41.08\%}$$



(ii) A field soil sample weighing 17 KN/m^3 has a water content of 25%. Specific gravity of soil solids is 2.65. Determine dry weight, void ratio, porosity and degree of saturation of soil sample.

Data: - $v_b = 17 \text{ KN/m}^3$; $\omega = 25\% = 0.25$; $G = 2.65$

Assume: $v_w = 9.81 \text{ KN/m}^3$

$v_d = ?$; $e = ?$; $n = ?$

We know, (a) $v_d = \frac{v_b}{(1 + \omega)} = \frac{17}{(1 + 0.25)}$

$$v_d = 13.6 \text{ KN/m}^3$$

(b) $v_d = \frac{G v_w}{1 + e} \Rightarrow 1 + e = \frac{G v_w}{v_d}$

$$e = \frac{G v_w}{v_d} - 1 = \frac{2.65 \times 9.81}{13.6} - 1$$

$$e = 0.9115$$

(c) $GW = es$

$$s = \frac{GW}{e} = \frac{2.65 \times 0.25}{0.9115} = 0.7268$$

$$s = 72.68\%$$

(d) $n = \frac{e}{1 + e}$

$$n = \frac{0.9115}{1 + 0.9115}$$

$$n = 0.4768 = \underline{47.68\%}$$

Answers: - Dry weight $v_d = \underline{13.6 \text{ KN/m}^3}$

$$\text{Void ratio } e = \underline{0.9115}$$

$$\text{Porosity } n = 0.4768 = \underline{47.68\%}$$

$$\text{Degree of saturation } s = \underline{72.68\%}$$

(iii) A partly saturated soil sample obtained from an earth field has natural water content or 20% and a unit weight of 19.62 KN/m^3 . Assuming specific gravity of soil 2.7. Calculate void ratio and degree of saturation in the field of the soil gets saturated subsequently determine unit weight and also buoyant unit weight [submerged unit weight].

Data: - (A) $\omega = 20\% = 0.2$

$$v_b = 19.62 \text{ KN/m}^3$$

$$G = 2.7$$

$$\text{Assume: } v_w = 9.81 \text{ KN/m}^3$$

$$e = ? ; s = ?$$

$$\text{Sol: - (a) } v_d = \frac{v_b}{1 + \omega} = \frac{19.62}{1 + 0.2}$$

$$\boxed{v_d = 16.35 \text{ KN/m}^3}$$

$$(b) \quad v_d = \frac{G v_\omega}{1 + e}$$

$$1 + e = \frac{G v_\omega}{v_d}$$

$$e = \frac{G v_\omega}{v_d} - 1 = \frac{2.7 \times 9.81}{16.35} - 1$$

$$e = 0.62$$

(c) $G\omega = es$

$$s = \frac{G\omega}{e} = \frac{2.7 \times 0.2}{0.62} = 0.8709$$

$$s = 87.09\%$$

(B) When $s = 1$; $v_{\text{sat}} = ?$; $v_{\text{sub}} = ?$

$$v_{\text{sub}} = v_{\omega} \left[\frac{G-1}{1+e} \right]; v_{\text{sat}} = \frac{(G+e)}{(1+e)} v_{\omega}$$

Note: - If the soil gets fully saturated and if there is no increase in the volume of the soil rather than the void ratio of that soil mass remains unchanged.

$$v_{\text{sat}} = \frac{(G+e)}{(1+e)} v_{\omega} = \frac{(2.7+0.62)}{(1+0.62)} \times 9.81$$

$$v_{\text{sat}} = 20.10 \text{ KN/m}^3$$

$$v_{\text{sub}} = \frac{(G-1)}{(1+e)} \times v_{\omega} = \frac{2.7-1}{(1+0.62)} \times 9.81$$

OR $v_{\text{sub}} = 10.29 \text{ KN/m}^3$

Answers: - $v_{\text{sat}} = 20.10 \text{ KN/m}^3$ and $v_{\text{sub}} = 10.29 \text{ KN/m}^3$

(v) A field soil capacity has a bulk density of 18 KN/m^3 and a water content of 5%. Calculate the amount of water to be added to 1 m^3 of soil to raise the water content to 16%. Assume the void ratio to remain constant. Specific gravity of soil may be taken as 2.7.

Data: - $v_{b1} = 18 \text{ KN/m}^3$

$$\omega_1 = 5\% = 0.05 \quad ; \quad \omega_2 = 16\% = 0.16$$

$$d v_{\omega} = ?$$

$$V = 1 \text{ m}^3$$

$$G = 2.7$$

$e = \text{constant}$

Assume: $v_w = 9.81 \text{ KN/m}^3$

Case 1: -

Let W_{ω_1} be the weight of water present in the soil mass

Let V_{ω_1} be the corresponding volume of water.

$$(i) v_d = \frac{v_{b_1}}{1 + \omega_1} = \frac{18}{1 + 0.05} = \underline{17.142 \text{ KN/m}^3}$$

$$(ii) \text{ But, } v_d = \frac{W_s}{V}$$

$$W_s = v_d \times V$$

$$\therefore \boxed{W_s = 17.142 \text{ KN}}$$

$$(iii) \omega_1 = \frac{W_{\omega_1}}{W_s} \Rightarrow W_{\omega_1} = \omega_1 \cdot W_s = 0.05 \times 17.142 = \underline{0.8571 \text{ KN}}$$

$$\therefore \boxed{W_{\omega_1} = 0.8571}$$

$$(iv) \text{ But, } v_w = \frac{W_{\omega_1}}{V_{\omega_1}} \Rightarrow V_{\omega_1} = \frac{W_{\omega_1}}{v_w} = \frac{0.8571}{9.81}$$

$$\therefore \boxed{V_{\omega_1} = 0.0873 \text{ m}^3}$$

Case 2: -

$$\omega_2 = 16\% = 0.16, \quad W_{\omega_2} = ?, \quad v_{\omega_2} = ?$$

$$\underline{W_s = 17.142 \text{ KN}} \quad \dots \text{ (from Case 1)}$$

$$(i) \omega_2 = \frac{W_{\omega_2}}{W_s} \Rightarrow W_{\omega_2} = \omega_2 \times W_s = 0.16 \times 17.142$$

$$W_{\omega_2} = 2.742 \text{ KN}$$

$$(ii) v_w = \frac{W_{\omega_2}}{V_{\omega_2}}$$

$$\Rightarrow V_{\omega_2} = \frac{W_{\omega_2}}{v_w} = \frac{2.742}{9.81}$$

$$V_{\omega_2} = 0.2795 \text{ m}^3$$

$$\text{So, } dv_w = v_{w2} - v_{w1}$$

$$= 0.2795 - 0.0873$$

$$= 0.1922$$

$$\boxed{dv_w = 195.2 \text{ liters}}$$

(vi) An over dried soil sample of volume 260 cm^3 weighs 430gms. If the specific gravity of soils is 2.7, what is water content when the soil becomes fully saturated without any change in its volume? What will be the water content which is needed to fully saturate the sample and also to cause 10% increase in its dry volume

Data: - Case 1: - $V = 260 \text{ cm}^3 = (260 \times 10^{-6}) \text{ m}^3$

$$W_s = 430 \text{ gms} = \frac{430}{1000} \text{ kg} = \frac{430}{1000} \times \frac{9.81}{1000}$$

$$W_s = 4.218 \times 10^{-3} \text{ KN}$$

$$\text{Assume: } v_w = 9.81 \text{ KN/m}^3$$

$$(i) \quad G = 2.7, \quad V_v = V_w$$

$$G = \frac{v_s}{v_w}$$

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

$$v_s = G v_w$$

$$\frac{W_s}{V_s} = G v_w$$

$$V_s = \frac{W_s}{G v_w} = \frac{4.218 \times 10^{-3}}{2.7 \times 9.81}$$

$$V_s = 0.1592 \times 10^{-3} \text{ m}^3$$

(ii) Here, $s = 1$, $V_w = V_v$

$$V = V_s + V_v$$

$$\begin{aligned} V_v = V - V_s &= 260 \times 10^{-6} - 0.1592 \times 10^{-3} \\ &= 0.260 \times 10^{-3} - 0.1592 \times 10^{-3} \end{aligned}$$

$$V_v = 0.1008 \times 10^{-3} = V_w$$

(iii) $v_w = \frac{W_w}{V_w}$

$$W_w = v_w \times V_w = 9.81 \times 0.1008 \times 10^{-3}$$

$$W_w = 0.988 \times 10^{-3} \text{ KN}$$

(iv) Water Content $\omega = \frac{W_w}{W_s}$

$$\omega = \frac{0.988 \times 10^{-3}}{4.218 \times 10^{-3}}$$

$$\omega = 0.2342 = 23.42\%$$

Water content $\omega = 23.42\%$

Case 2: -

(i) $V = 260 \times 10^{-6} \times 1.1 \quad \dots (10\% \text{ increase } \therefore 1 + 0.1 = 1.1)$

$$V = 286 \times 10^{-6} \text{ m}^3$$

$$V_s = 0.1592 \times 10^{-3} \text{ m}^3 \quad \dots \text{ (from Case 1)}$$

$$(ii) \quad V = V_s + V_v$$

$$V_v = V - V_s = 0.286 \times 10^{-6} - 0.1592 \times 10^{-3}$$

$$V_v = 0.1268 \times 10^{-3} \text{ m}^3$$

$$(iii) \quad v_w = \frac{W_w}{V_w}$$

$$W_w = V_w \times v_w$$

$$W_w = 1.243 \times 10^{-3} \text{ KN}$$

$$\omega = \frac{W_w}{W_s} = \frac{1.243 \times 10^{-3}}{4.218 \times 10^{-3}} = 0.2946$$

$$\boxed{\omega = 29.46\%}$$

(vii) An undisturbed soil from a borrow pit has a water content of 15%, void ratio of 0.6 and specific gravity of soil of 2.7. This soil is required to construct an embankment of total volume $4 \times 10^4 \text{ m}^3$. The soil in the embankment is expected to have a water content of 18% and a dry unit weight of 17.3 KN/m^3 . Calculate the quantity of soil and the weight required to excavated from the borrow pit for constructing an embankment. Also calculate the weight of embankment soil.

Data: - Case (a)

Embankment

$$(v_d)_E = 17.3 \text{ KN/m}^3$$

$$(\omega)_E = 18\% = 0.18$$

$$V_E = 4 \times 10^4 \text{ m}^3$$

$$W_s = ?$$

$$G = 2.7$$

$$(i) \quad (v_d)_E = \frac{W_s}{V_E}$$

$$(v_d)_E \times V_E = W_s$$

$$W_s = 17.3 \times 4 \times 10^4$$

$$(W_s)_E = \underline{69.2 \times 10^4 \text{ KN}}$$

The weight of solids so obtain will be the same even in borrow pit.

$$\approx (W_s)_b = (W_s)_E = \underline{69.2 \times 10^4 \text{ KN}}$$

Case (b) Borrow pit

$$(\omega)_b = 15\% = 0.15$$

$$(e)_b = 0.6 \quad \text{Assume:} \quad v_w = 9.81 \text{ KN/m}^3$$

$$G = 2.7$$

$$(i) \quad v_d = \frac{G v_w}{1 + e} = \frac{2.7 \times 9.81}{1 + 0.6} = \underline{16.554 \text{ KN/m}^3}$$

$$\text{But,} \quad (v_d)_b = \frac{(W_s)_b}{V_b}$$

$$V_b = V_b = \frac{(W_s)_b}{(v_d)_b}$$

$$= \frac{69.2 \times 10^4}{16.554}$$

$$V_b = \underline{4.1802 \times 10^4 \text{ m}^3}$$

$$V_b = \underline{41,802.58 \text{ m}^3}$$

This is the quantity of soil to be excavated from the borrow pit.

Case (c)

- (i) Weight of borrow pit soil to be excavated:

$$\begin{aligned}W_b &= (W_s)_b (1 + \omega_b) \\&= 69.2 \times 10^4 [1 + 0.15]\end{aligned}$$

$$W_b = \underline{79.58 \times 10^4 \text{ KN}}$$

- (ii) $W_E = \underline{81.666 \times 10^9 \text{ KN}}$ $v_b = v_d (1 + \omega_E)$

$$= 17.3 [1 + 0.18]$$

$$v_b =$$

$$(v_b)_E = \frac{W_E}{V_E}$$

$$W_E = (v_b)_E \cdot V_E$$