STRUCTURE

1.1 Introduction

1.2 Determination Of Index Properties Of Soil

1.2.1 Water Content

1.2.2 Specific Gravity of Soil Solids

1.2.3 Bulk Unit weight of soil

1.2.4 Particle Size Distribution

1.2.5 Consistency limits

2 Out Come:

3. Assignment Questions

4. Further Reding

1.1 INTRODUCTION

Index properties are the properties of soil that help in identification and classification of soil. Water content, Specific gravity, Particle size distribution, In situ density (Bulk Unit weight of soil), Consistency Limits and relative density are the index properties of soil. These properties are generally determined in the laboratory. In situ density and relative density require undisturbed sample extraction while other quantities can be determined from disturbed soil sampling.

The following are the Index Properties of soil.

1. Water content
2. Specific Gravity
3. In-situ density
4. Particle size distribution
5. Consistency limits
6. Relative Density

Objective:
1. To Study the Properties of Soil
2. To Study The Size Of Soil And Consistency Limits.

1.2 DETERMINATION OF INDEX PROPERTIES OF SOIL

This section explains the important methods approved by Indian Standards for the determination of Index properties of soil both in laboratory and in field.

1.2.1 Water Content

Oven drying method and Calcium carbide method are the two popular methods of determination of water content. Refer to IS 2720 – Part 2- 1973 for more detail.

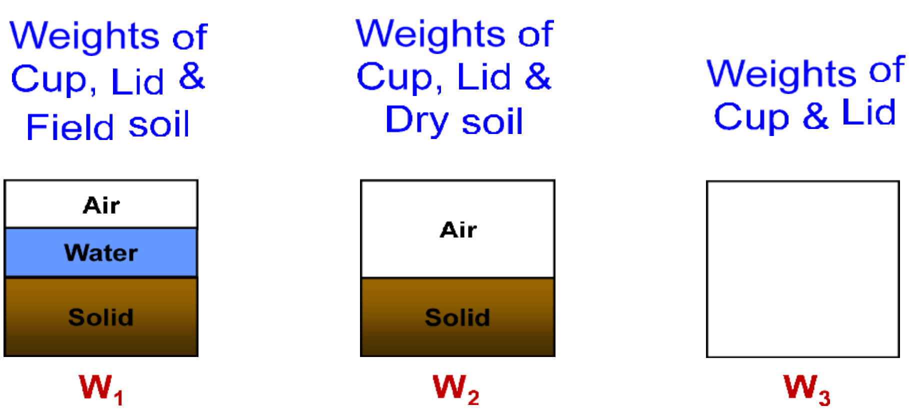
a) <u>OvenDryingMethod</u>

It is an accurate method of determining water content of soil in the laboratory. The procedure is as follows.

1. Collect a representative sample of soil in a steel cup carrying a lid.
2. Find the weight of cup and lid along with soil (W_1)
3. Keep the cup with lid open in a thermostatically controlled oven for 24 hours at around 105^{o}C. Free water in the soil evaporates.
4. After cooling the cup, find the weight of cup and lid along with dry soil (W_2)
5. Find the empty weight of cup and lid (W_3)

<u>Why Steel cup with a lid ?</u>

Lid should be covered after taking the sample to avoid movement of water, dust air etc. Steel (Stainless steel) cup is used to avoid interaction between material of cup, water and minerals & salts (if any) present in soil.



$$\omega = \frac{Weight\ of\ Water}{Weight\ of\ Soil\ Solids} = \frac{W_1 \quad W_2}{W_2 - W_3}$$

Fig. 1 : Determination of water content by Oven Drying method

A sample calculation for the determination of water content in the laboratory by oven drying method is presented in the table below.

Table 1: Determination of water content by Oven drying method

Sl No	Description	Determination No.		
		I	II	III
1	Weight of cup + Wet Soil (W_1) g	44.12	44.11	46.10
2	Weight of cup + Dry Soil (W_2) g	41.18	41.16	43.01
3	Weight of cup (W_3) g	20.12	20.08	20.00
CALCULATIONS				
1	Weight of water $= W_1 - W_3$	2.94	2.95	3.09
2	Weight of solids $= W_2 - W_3$	21.06	21.08	23.01
3	Water content	13.96	13.99	13.43
Average Value		13.79 %		

<u>Problem 1</u>

A sample of soil was tested for water content determination and the following were the results. Find water content.

Weight of empty cup = 55 g

Weight of cup + wet soil = 88 g

Weight of cup + soil after oven drying = 82 g

<u>Solution</u>

Weight of water = 6 g

Weight of solids = 27 g

Water content = 22.2 %

Problem 2

A sample of clayey soil was collected for the determination of water content. The following are the details of measurement. Find water content. If the soil is fully saturated find porosity. Take G = 2.7.

Weight of empty cup = 60 g

Weight of wet soil + cup = 120 g

Weight of dry soil + cup = 100 g (after drying in oven)

Solution

Weight of water = 120 – 100 = 20 g

Weight of dry soil = 100 – 60 = 40 g

Water content = 50%

If the soil is fully saturated, $e = \omega G = 1.35$

Porosity n = 0.574

b) CalciumCarbidemethod orRapidMoistureMeter Method

It is a rapid method of determination of water content of soil. It consists of an air tight container with a diaphragm and a calibrated meter. About 6 g of soil is mixed with fresh Calcium carbide. The mixture is rigorously shaken. Water in the soil reacts with Calcium Carbide to release acetylene gas. The amount of gas produced depends on available water. This gas creates a pressure on sensitive diaphragm and water content is directly recorded on the calibrated meter. The method is not very accurate, but is extremely rapid.

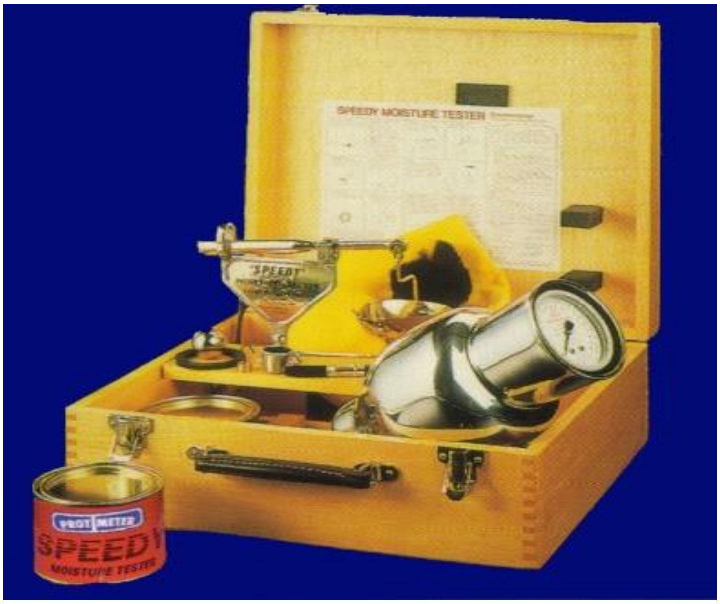


Fig. 2 : Typical picture of Rapid Moisture meter and its assembly

1.2.2 Specific Gravity of Soil Solids

Specific gravity of soil solids is commonly determined by Pycnometer method. Refer to IS 2720 – Part 3- Sections 1 & 2 - 1981 for more detail.

a) Pycnometer method

1. Use pycnometer for the determination of specific gravity of coarse grained fraction and density bottle for that of fine grained fraction.
2. Find the weight of clean, dry and empty pycnometer (W_1).
3. Put dry soil (about one third the height) in the pycnometer and find the weight (W_2).
4. Add water till the top such that the air bubbles are completely removed and find the weight (W_3).
5. Empty the soil and fill water up to the top in the pycnometer and find the weight (W_4).

$$G = \frac{Weight\ of\ Soil}{Weight\ of\ equal\ volume\ of\ water} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} = \frac{W_2 - W_1}{W_4 - W_3 + W_2 - W_1}$$

If the specific gravity is determined using any other liquid (say kerosene), other than water, then, $G = G_{in\,kerosene} * G_K$ where G_K is the specific gravity of the liquid.

Further, the temperature influences specific gravity. At higher temperature viscosity of water will be less and vice versa. Viscosity of the medium affects G. The effect of temperature should be considered as follows.

$$G_{27} = G_t \frac{Specific\ Gravity\ of\ Water\ at\ t^oC}{Specific\ Gravity\ of\ Water\ at\ 27^o\ C}$$

From Indian Standard point of view 27^oC is standardized.

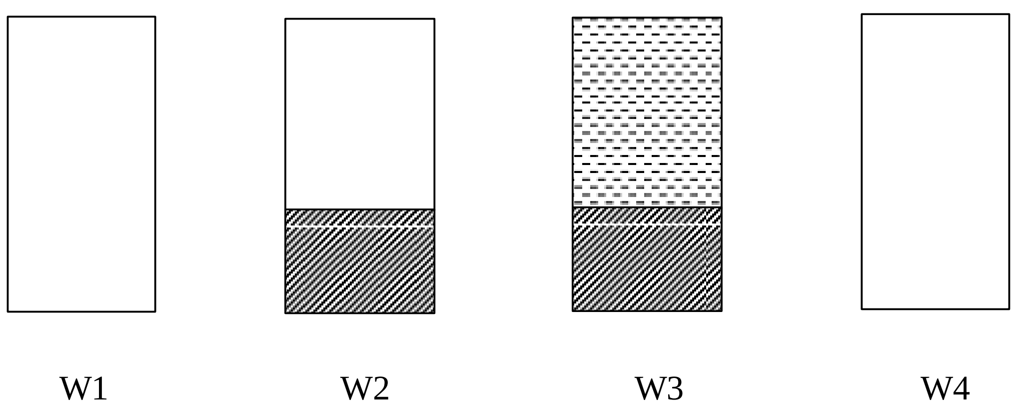


Fig. 3 : Stages in determination of Specific Gravity of soil using Pycnometer or Density Bottle

b) Whypycnometer forcoarsegrainedsoilanddensitybottleforfinegrained soil?

Coarse grained soil requires larger size container owing to the bigger particle size. Large quantity of fine grained soil is difficult to handle especially expelling out air. Hence smaller density bottle of 50 ml capacity is used.

c) Whypycnometer hasaconicaltopwithaopening?

The purpose of conical top is to reduce the cross section gradually to a minimum such that any difference in level of water in different stages should not cause serious error. Further, the opening will allow any air present in the voids of soil to be expelled out.

Table 2 : Tabular entry for Specific Gravity Test on Soil

SPECIFIC GRAVITY OF SOIL

S. No.	Description	Determination No. I	II	III
1	Temperature in °C	31	31	31
2	Weight of bottle (W_1) in g	18.57	18.50	18.62
3	Weight of bottle + Dry soil (W_2) in g	28.57	28.50	28.62
4	Weight of bottle + Soil + Water (W_3) in g	90.88	90.20	91.02
5	Weight of bottle + Water (W_4) in g	84.74	84.00	84.83
	CALCULATION:			
1	Specific gravity $G = \frac{W_2 - W_1}{(W_4-W_1)-(W_3-W_2)}$	2.59	2.63	2.62
2	Average G (at 31°C)		2.61	
3	Corrected G (at 27°C), $G' = G \times \frac{\text{Relative density of water at room temperature}}{\text{Relative density of water at } 27^\circ C}$ $= 2.61 \times \frac{0.995369}{0.996542} = 2.6069$, say 2.61			

***Note:** The figures given in the above table are for illustration purpose only.*

Problem 3

A Specific Gravity test is performed on river sand and the following are the results.

Weight of pycnometer = 900 g

Weight of pycnometer + dry soil = 1300 g

Weight of pycnometer + soil + water = 3050 g

Weight of pycnometer + water = 2800 g

The test was performed at 5^{o}C during winter. Find G

Specific Gravity of water at $5^oC = 1.000$

Specific Gravity of water at $27^oC = 0.997$

Solution

Data

$W_1 = 900$ g

$W_2 = 1300$ g

$W_3 = 3050$ g

$W_4 = 2800$ g

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

$$G = 2.667$$

$$G_{27} = G_T * \frac{Specific\ Gravity\ of\ water\ at\ T^O C}{Specific\ Gravity\ of\ water\ at\ 27^O C}$$

$$G_{27} = 2.675$$

Problem 4

The following are the results of specific gravity test on locally available sand.

Weight of pycnometer = 800 g

Weight of pycnometer + soil + water = 2800 g

Weight of pycnometer + water = 2600 g

G = 2.7

Find the weight of dry soil taken in the pycnometer in the beginning.

Data

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

$W_1 = 800$ g

$W_2 = ?$

$W_3 = 2800$ g

$W_4 = 2600$ g

G = 2.7

$$W_2 = 1118\ g$$

Problem 5

A density bottle was used to find specific gravity of clay and kerosene was the liquid medium instead of water. Find G given the following details.

Weight of density bottle = 80 g

Weight of density bottle + dry soil = 110 g

Weight of density bottle + soil + kerosene = 141 g

Weight of density bottle + kerosene = 120 g

Specific Gravity of kerosene = 0.8

Data

$W_1 = 80$ g
$W_2 = 110$ g
$W_3 = 141$ g
$W_4 = 120$ g
$GL = 0.8$

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

$G_{in\ liquid} = 3.333$

$$G = G_{in\ liquid} * G_L$$

$G = 2.667$

1.2.3 Bulk Unit weight of soil

The density of soil (especially in coarse grained portion) is the direct indication of strength and stiffness. The following are the popular methods of finding bulk density in field.

1. Core Cutter Method
2. Sand Replacement method

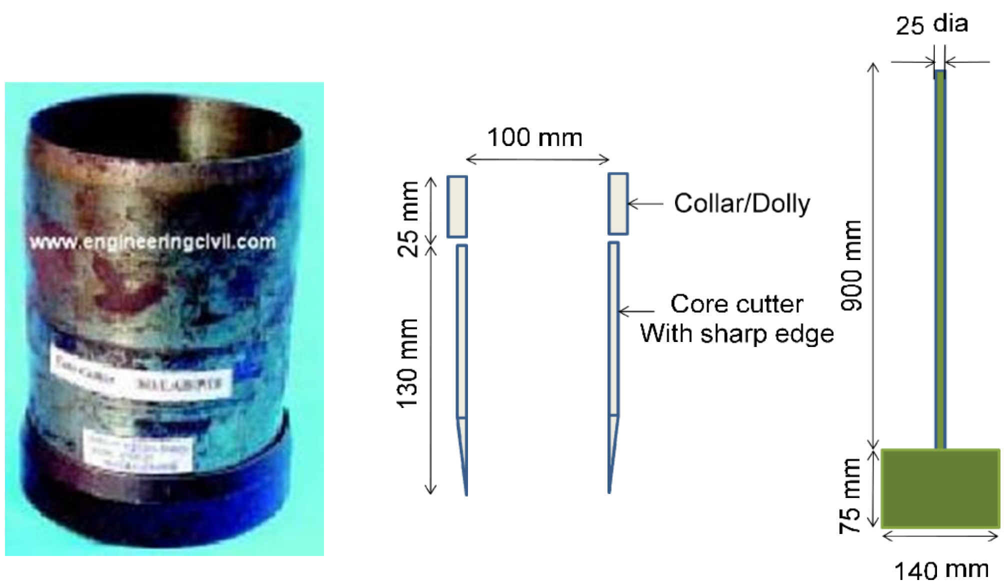


Fig. 4 : Apparatus for field density determination of soil using Core Cutter

a) Determination of In-situ unit weight of soil by Core Cutter Method

The following are the steps involved in determination of bulk density and hence dry density of soil at a site.

1. Refer IS 2720 – Part 29 – 1975
2. Main apparatus include Core cutter with a sharp edge, dolly or Collar and a rammer.
3. This method is appl cable for soil that sticks to the surface of cutter (Clayey soil) and that is not very stiff (where cutter can be penetrated in to ground by ramming).
4. Sampling is done vertically by ramming downwards.
5. The inner surfaces of core cutter and dolly are greased.
6. The ground surface is leveled after removing the top soil.
7. Core cutter with collar on top and sharp edge at bottom is placed on the ground.
8. It is then driven in to the ground using the rammer till the soil collects up to the collar.
9. It is carefully taken out by loosening from outside such that the soil inside remains in tact.
10. Dolly is carefully removed. The soil surface in the core cutter is trimmed from both the ends.

Let, V = Volume of the core cutter

W_1 = Empty weight of core cutter

W_2 = Weight of core cutter with soil

Then, Bulk unit weight of soil at the site

$$\gamma_b = \frac{W_2 - W_1}{V}$$

A representative sample of soil from the middle of core cutter is placed for the determination of water content.

$$\boldsymbol{\gamma_d = \frac{\gamma_b}{(1+\omega)}}$$

Table 3 : Tabular entry for Insitu density of Soil by Core Cutter method

IN-SITU DRY DENSITY OF SOIL BY CORE CUTTER METHOD

S. No.	Description	Determination No.		
		I	II	III
1	Internal dia. of core cutter in mm	100	100	100
2	Internal height of core cutter in mm	129.75	129.75	129.75
3	Volume of cutter (V) in cc	1019.05	1019.05	1019.05
4	Weight of core cutter (W_1) in g	1130	1130	1130
5	Weight of core cutter + Soil (W_2) in g	3120	3122	3119
6	Weight of soil ($W_2 - W_1$) in g	1990	1992	1989
7	Bulk density of soil $\gamma = \frac{W_2 - W_1}{V}$ g/cc	1.95	1.95	1.95
8	Moisture content (w) in %	17.75	17.76	17.73
9	Dry density of soil $\gamma_d = \frac{100\gamma}{100 + w}$ g/cc	1.66	1.66	1.66
	Average value	1.66g/cc		

Note: *The figures given in the above table are for illustration purpose only.*

<u>Problem 6</u>

A core cutter of 100 mm internal diameter and 128 mm height was used to determine the unit weight of soil at a site. The total weight of core cutter and soil was 3015 g and empty weight of core cutter was 1374 g. A representative sample of soil was kept in a steel cup of weight 60 g for the determination of water content. Weights of cup and soil before and after placing in oven were respectively 106.4 g and 92 g. Find dry unit weight of soil and degree of saturation if G = 2.7.

Weight of core cutter + soil = 3015 g

Weight of core cutter = 1374 g

Weight of soil = 1641 g

Volume of core cutter = $0.785D^2H = 1.048 \text{ X } 10^{-3}$ m^3

Bulk Unit weight of soil = 15.66 kN/m^3

Weight of water = 14.4 g

Weight of solids = 32 g

Water content = 45%

Dry unit weight = 10.8 kN/m^3

Void ratio e = 1.45

Degree of Saturation S = 83.8%

Determination of In-situ unit weight of soil by Sand Replacement Method

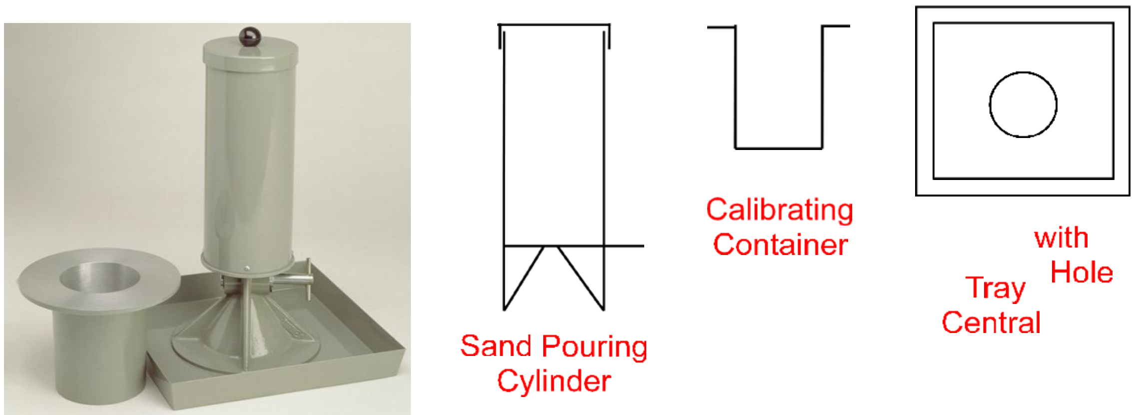


Fig. 5 : Apparatus for field density determination of soil from Sand Replacement approach

1. This method is particularly suitable for granular soil that does not stick to the surface of sampler.

2. Refer IS 2720 – Part 28 – 1974.

3. The equipment consists of sand pouring cylinder with cone, calibrating container and a tray with a central hole.

4. The work involves two stages, namely, calibration of container and determination of volume of hole.
5. For the purpose of c libration of container, clean, dry, uniformly graded medium sized sand (called standard sand) is filled in to Sand Pouring Cylinder (SPC) up to the top, shutter is closed and weight of SPC is noted (W_1).

6. The SPC is placed on a smooth glass plate and the sand is allowed to run out of cone. Weight of SPC after running sand in to cone is noted (W_2).

7. SPC is refilled and placed on calibrating container and sand is allowed to run out. The weight of SPC is noted after running sand in to calibrating container (W_3).

8. Weight of sand in cone $W_{cone} = W_1 - W_2$

9. Weight of sand in calibrating container $W_{cc} = W_1 - W_3 + W_{cone}$

10. Volume of calibrating container is determined (V_{cc}).

$$\text{Unit weight of standard sand } \gamma_{sand} = \frac{W_{cc}}{V_{cc}}$$

11. SPC with sand up to W_1 is taken to the field where bulk unit weight is required. The surface is cleaned and leveled.

12. The tray with central hole is placed in position. A hole of approximately same size as calibrating container is dug.

13. The removed soil is collected on the sides of tray and its weight is noted (W_{soil}).

14. The SPC is placed on the hole and sand is allowed to run in to hole. Weight of SPC is noted (W_4).

15. Weight of sand in the hole $W_5 = W_1 - W_4 + W_{cone}$

$$\text{Volume of the hole } V_{soil} = \frac{W_5}{\gamma_{sand}}$$

$$\text{In-situ unit weight of soil } \gamma_b = \frac{W_{soil}}{V_{soil}}$$

Problem 7

The following are the results of test for in situ bulk unit weight at a site by sand replacement method. Find γ_b and ρ_b.

Initial weight of sand and SPC W_1 = 10550 g

Weight of sand in SPC after pouring in to cone W_2 = 10105 g

Weight of sand in SPC after pouring in to calibrating container W_3 = 9545 g

Weight of sand in SPC after pouring in to hole W_4 = 9402 g

Diameter of Calibrating container = 100 mm

Height of Calibrating container = 127.3 mm

Weight of soil W_{soil} = 1820 g

$W_{cone} = W_1 - W_2 = 445$ g
$W_{cc} = W_1 - W_3 + W_{cone} = 1450$ g
$W_5 = W_1 - W_4 + W_{cone} = 1593$ g
$V_{cc} = 0.785D^2H = 1.273 \times 10^{-3}$ m^3

1 $\gamma_{sand} = \frac{W_{cc}}{V_{cc}} = 14.24\ kN/m^3$

2 $V_{soil} = \frac{W_5}{\gamma_{sand}} = 1.09 \times 10^{-3} m^3$

3 $\gamma_b = \frac{W_{soil}}{V_{soil}} = 16.27\ kN/m^3$

4 $\rho_b = \frac{\gamma_b}{g} = 1660\ kg/m^3$

1.2.4 Particle Size Distribution

1. Soil in nature exists in different sizes, shapes and appearance. Depending on these attributes, the soil at a site can be packed either densely or loosely. Hence, it is important to determine the percentage of various sized soil particles in a soil mass. This process is called particle size distribution analysis. For this purpose, a particle size distribution curve is plotted. Packing of soil, amount of voids present influence the strength and stability of soil mass.

The distribution of grain size influences packing. Good distribution of all sizes reduces voids if compacted well.

Table 4 : Types of soils and their average grain sizes and shapes

Soil Type	Description	Average grain size
Gravel	Rounded and/or angular bulky hard rock	Coarse: 80 mm to 20 mm Fine: 20 mm to 4.75 mm
Sand	Rounded and/or angular bulky hard rock	Coarse: 4.75 mm to 2 mm Medium: 2 mm to 0.425 mm Fine: 0.425 mm to 0.075 mm
Silt	Particles smaller than 0.075 mm, exhibit little or no strength when dried	0.075 mm to 0.002 mm
Clay	Particles smaller than 0.002 mm, exhibit significant strength when dried; water reduces strength	<0.002 mm

Importance of Particle Size Distribution

1. Used for the soil classification.
2. Used to design drainage filter.
3. Used to select fill materials of embankments, earth dams, road sub-base materials.
4. Used to estimate performance of grouting, chemical injection and dynamic compaction.
5. Effective Size, D_{10}, can be correlated with the hydraulic conductivity.
6. More important to coarse-grained soils

a) Particlesizedistributioncurve

It is a graph with percentage finer (N) plotted along the vertical axis (ordinate) in normal scale and particle diameter (D) along the horizontal axis (abscissa) in logarithmic scale. It gives an idea about the size and gradation of soil. A soil sample is well graded if it has a good distribution of all sized particles, otherwise, it is called poorly graded. Uniformly graded sample is a special category of poorly graded samples in which all soil particles have the same size. Gap graded samples possess different proportions of same sized particles in increasing sizes. Intermediate size particles are missing. For achieving good density, well graded soils are most suitable.

D_{10}, D_{30}, D_{60} are the important particle sizes. D_{10} represents a size in mm such that 10 % of particles are finer than this size. It is some times called effective diameter. D_{30} and D_{60} represent sizes in mm such that 30 % and 60 % of particles respectively are finer than this size obtained on the particle size distribution curve. The following terminologies are defined.

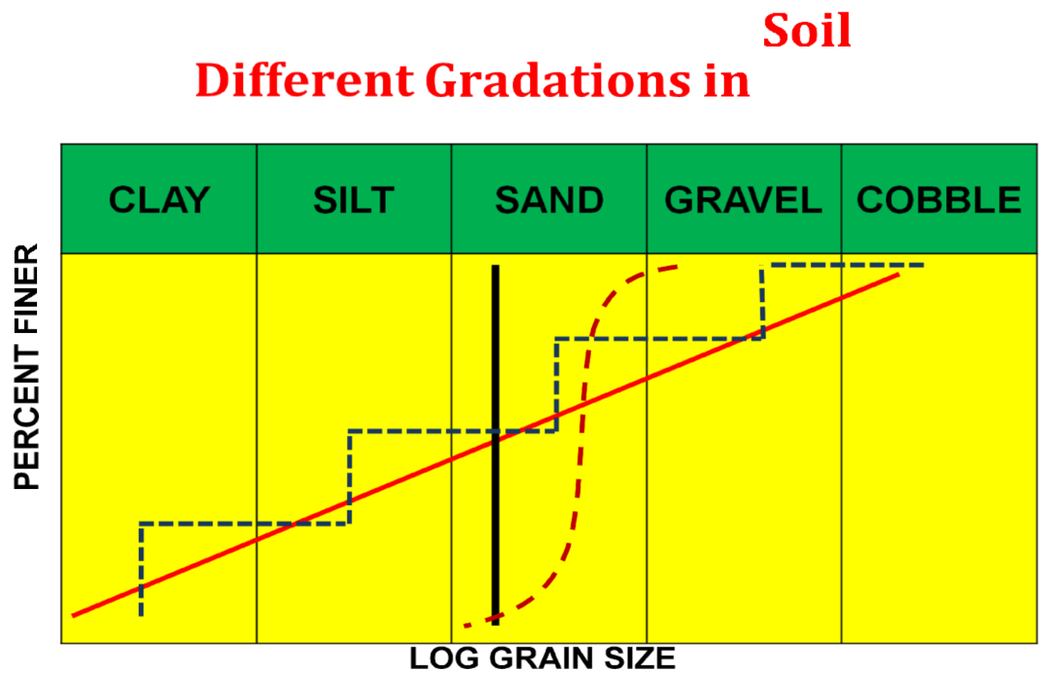


Fig. 6 : Particle size distribution curve

Uniformity coefficient is a measure of range of particle sizes is given by,

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

Coefficient of Curvature represents the shape of particle size distribution curve and is given by,

$$C_c = \frac{D_{30}^2}{D_{10} X D_{60}}$$

For well graded soil, C_c should be between 1 and 3 and C_u should be greater than 4 (if gravel) or 6 (if sand). Even if either of the two conditions is not satisfied, the sample is poorly graded.

Particle size distribution is obtained by sieve analysis for coarse grained fractions and sedimentation analysis for fine grained fractions. Hydrometer analysis is a popular sedimentation analysis.

b) <u>SieveAnalysis</u>

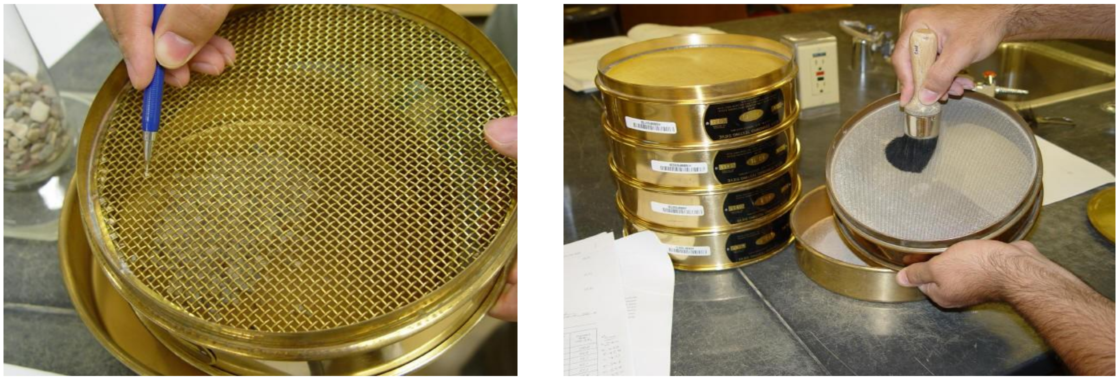


Fig. 7 : Sieve analysis for particle gradation

Refer IS 2720 – Part 4 – 1975 for more details.

A set of IS sieves are arranged in order with one having largest aperture at the top and that with smallest aperture at the bottom. A lid at the top and a receiver at the bottom complete the assembly.

A known weight of representative sample of soil (say 1000 g) is placed in the top sieve.

The assembly is vibrated on a sieve shaker for at least 10 minutes.

Depending on the particle size, soil is collected in different sieves. Weight of soil in each sieve is measured.

Table 2 gives the details of calculation. Particle size distribution curve is plotted. The soil sample is classified as well graded or poorly graded.

Table 5 : Particle size distribution Analysis

IS sieve number	Sieve size (mm)	Weight of Soil on each sieve (g)	Cumulative weight retained	% Cumulative weight retained	% Finer
4.75	4.75				
2.36	2.36				
1.18	1.18				
600	0.600				
425	0.425				
300	0.300				
212	0.212				
150	0.150				
75	0.075				
Receiver					
Total					

Problem 8

A sample of 1000 g of soil from a site was performed sieve analysis. The weights of soil collected on each sieve are presented in the tabular entry. Find effective diameter, D_{30}, D_{60} and coefficients of uniformity and curvature.

IS sieve number	Sieve size (mm)	Weight of Soil on each ieve (g)	Cumulative weight retained	% Cumulative weight retained	% Finer
4.75	4.750	60	60	6	94
2.36	2.360	110	170	17	83
1.18	1.180	150	320	32	68
600	0.600	170	490	49	51
425	0.425	110	600	60	40
300	0.300	120	720	72	28
212	0.212	90	810	81	19
150	0.150	60	870	87	13
75	0.075	80	950	95	5
Receiver		50	1000	100	0
Total		1000			

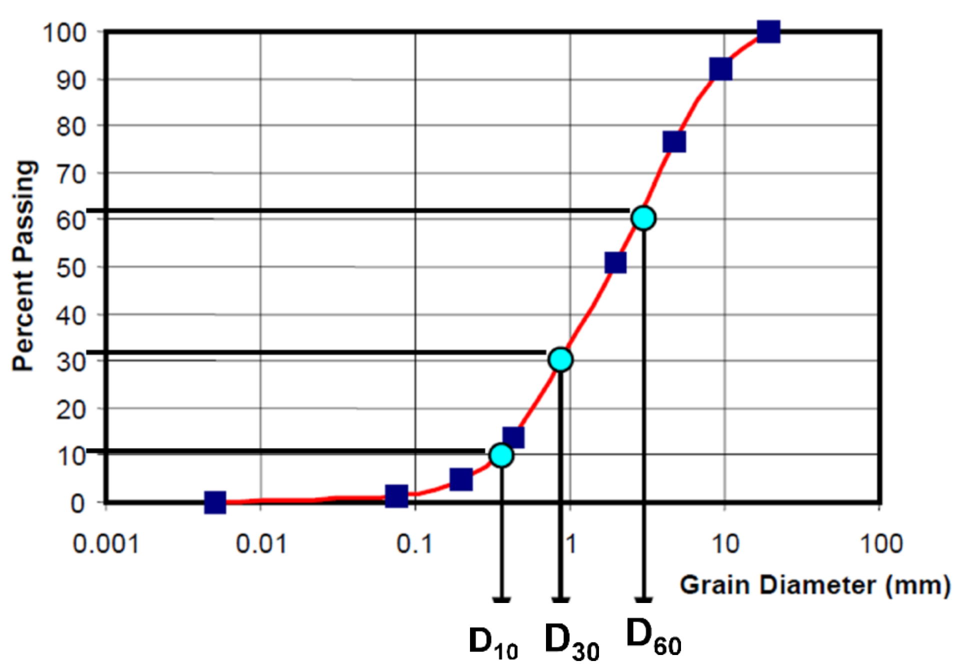


Fig. 8 : Particle size distribution curve

c) Sedimentation Analysis

It is also called wet analysis and is applicable for fine grained soils

The analysis is based on Stoke's law which states that the velocity at which soil particles settle in a suspension depend on shape, size and weight of particles. Assuming spherical particles and same density, $v \propto D^2$

$$v = \frac{1}{18} D^2 \frac{\gamma_s - \gamma_\omega}{\eta} = \frac{1}{18} D^2 \frac{(G-1)\gamma_\omega}{\eta}$$

Here, v = Terminal velocity of sinking soil particle
D = Diameter of soil particle
γ_s = Unit weight of soil solids
γ_w = Unit weight of water
G = Specific Gravity of Soil Solids
η = Viscosity of water

The particles are assumed to settle independent of each other and without the interference of wall of container.

Based on the velocity of settlement, the diameter of soil particles may be computed. For the purpose of evaluating velocity of settlement of soil particles, hydrometer analysis is performed.

d) Hydrometer analysis

A hydrometer is a device made of glass, consisting of a bulb with calibrated weight and stem with calibrated readings such that when placed in pure water it floats at a level giving reading 1.000. If it floats in a denser fluid, the readings are greater than 1 (up to 1.030).

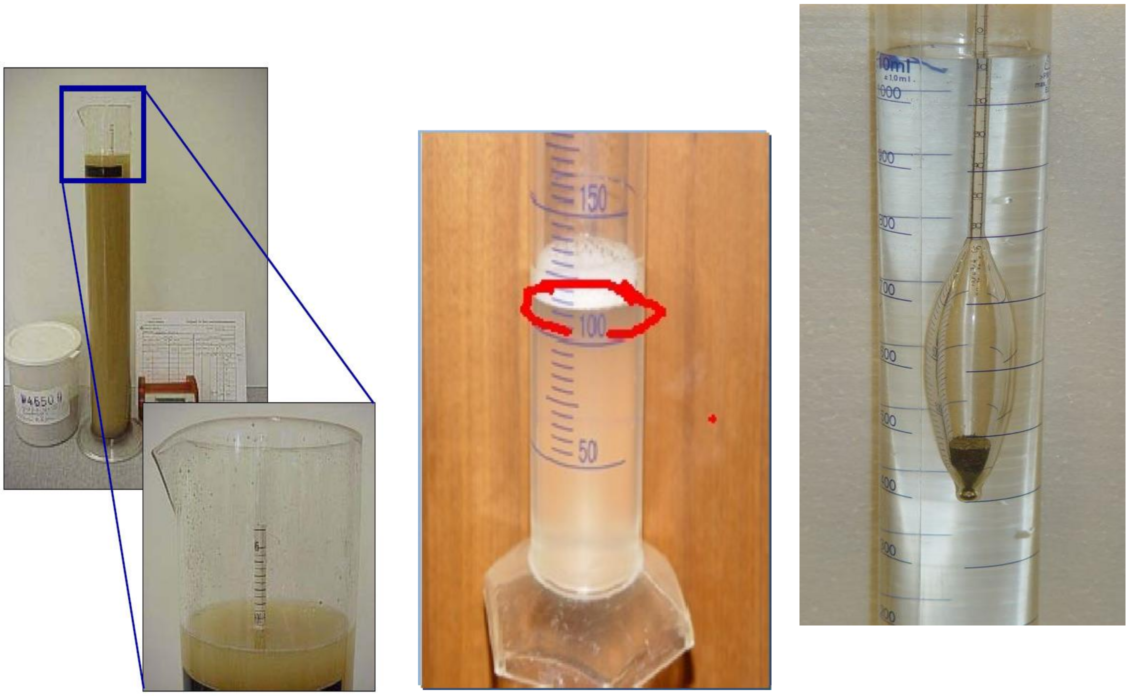


Fig. 9 : Determination of grain size distribution from Hydrometer test

Effective depth He of hydrometer depends on volume of hydrometer (V_h), height of bulb (h), cross sectional area of jar (A) and hydrometer reading (R_h). Height above the ease of the stem (H) is a function of R_h. H_e is given by, $H_e = H + \frac{1}{2}(h - \frac{V_h}{A})$. Hence, calibration curve for hydrometer is prepared prior to the test as shown.

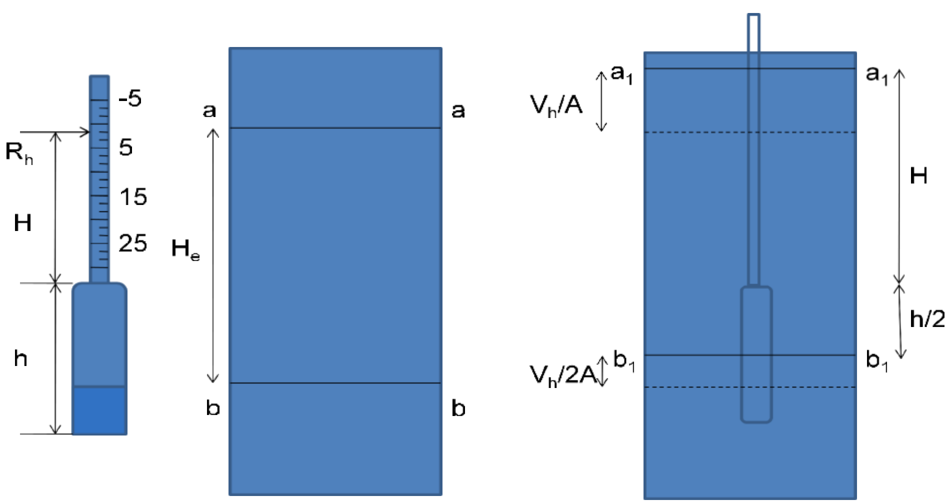


Fig. 10 : Determination of grain size distribution from Hydrometer test

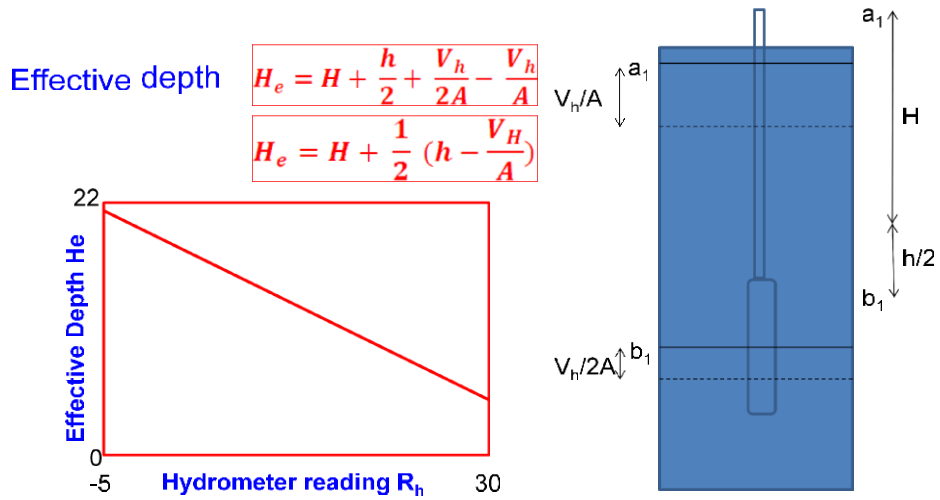


Fig. 11 : Determination of grain size distribution from Hydrometer test

e) Correction for Hydrometer reading

The recorded hydrometer reading may require the following corrections depending in the situation.

C_m : Correction for meniscus

The solution containing soil will be opaque. Hence, it is difficult to obtain reading corresponding to lower meniscus. Rh is taken to upper meniscus and correction is applied. The correction is always positive.

C_t : Correction for temperature

Hydrometer is calibrated at 27oC. If the laboratory temperature is higher, the liquid will be less viscous and hydrometer sinks more. Rh will be less than actual needing positive correction. Similarly, low laboratory temperature requires negative correction.

C_d : Correction for dispersing agent

A dispersing agent is added to water to disperse the soil particles and allow them to settle individually. Dispersing agent increases the density of water and hydrometer floats higher. Therefore the correction is always negative.

Hence, corrected hydrometer reading $R = R_h + C_m \pm C_t - C_d$

Here, R_h is the observed hydrometer reading. The three corrections are known as composite correction (C).

$$\therefore R = R_h \pm C = R_h + C_m \pm C_t - C_d$$

Here, $C = C_m \pm C_t - C_d$

From the hydrometer reading R, diameter D of soil particle and corresponding percentage finer are computed.

Limitations of Hydrometer Analysis

Assumption	Reality
Sphere particle	Platy particle (clay particle) as D ≤ *0.005mm*
Single particle	(No interference between particles & wall)
Many particles in the suspension	Known specific gravity of particles
Terminal velocity	Average results of all the minerals in the particles, including the adsorbed water films.

Problem 9

A soil sample of particle size ranging from 0.075 mm to 0.003 mm is put on top of the water surface in a tank. Depth of water in the tank is 3 m. Estimate the time required for the first particle and also the entire sample to reach the bottom of tank. Assume μ = 0.01 poise and G = 2.7

Note: μ = Absolute viscosity (Poise)

1 Poise = 1 N-s/m^2/g = 1 N/m-s

Viscosity η = μ/g 1 N/m-s/9.8 m/s^2 = 0.102 N-s/m^2

Data

μ = 0.01 Poise

η = 0.00102 N-s/m^2 = 1.02X10-6 kN-s/m^2

G = 2.7

γ_ω = 9.8 kN/m^3

Firstparticletosettlehasdiameter0.075mm

Velocity v = 5.104 X 10^{-3} m/s

In a tank of water depth 3 m, time taken for settling = 587.77 s

Lastparticletosettlehasdiameter0.003mm

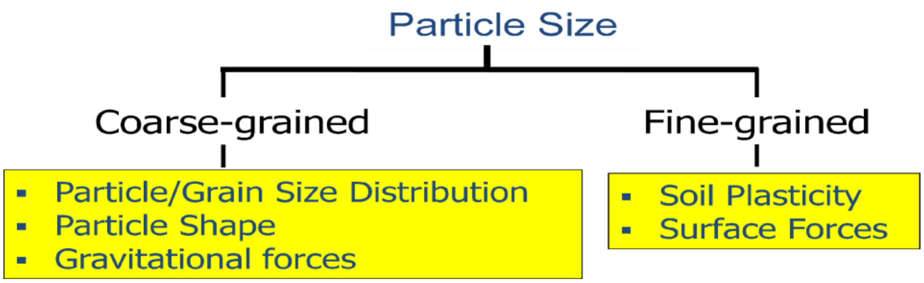
Velocity v = 8.17 X 10^{-6} m/s

In a tank of water depth 3 m, time taken for settling = 367197 s

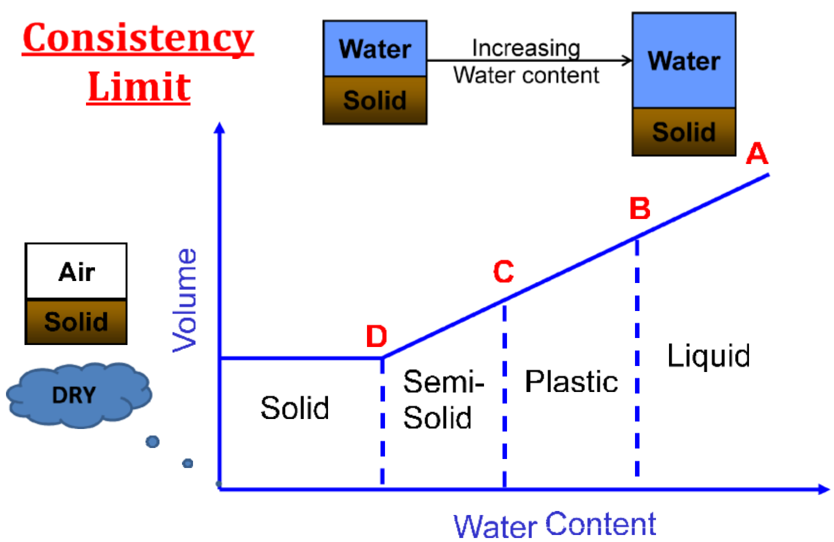
$$v = \frac{1}{18} D^2 \frac{(G-1)\gamma_w}{\eta}$$

1.2.5 Consistency Limits

Engineering Characterization of Soils



Consistency is the relative ease with which soil can be deformed. It is applicable to fine grained soils whose consistency depends on water content. Relative consistency can be expressed as very stiff, stiff, medium stiff, soft, very soft with increasing water content. Atterberg, a Swedish agriculturist in 1911 observed four states of consistency, namely, Liquid state, Plastic state, Semi solid state and Solid state in clayey soil with changing water content. He set arbitrary limits for these states called consistency or atterberg limits.



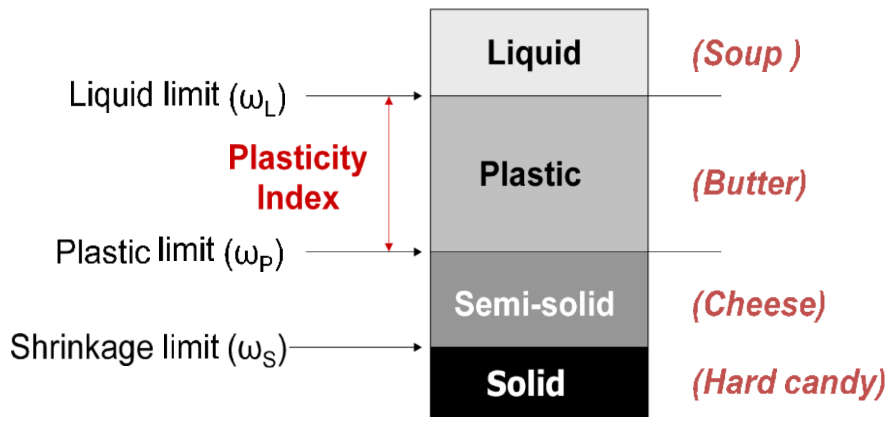


Fig. 12 : Consistency Limits in soil

Liquid Limit (w_L), Plastic Limit (w_P) and Shrinkage Limit (w_S) are the atterberg limits. These limits are most useful for engineering purpose in order ro classify the soils.

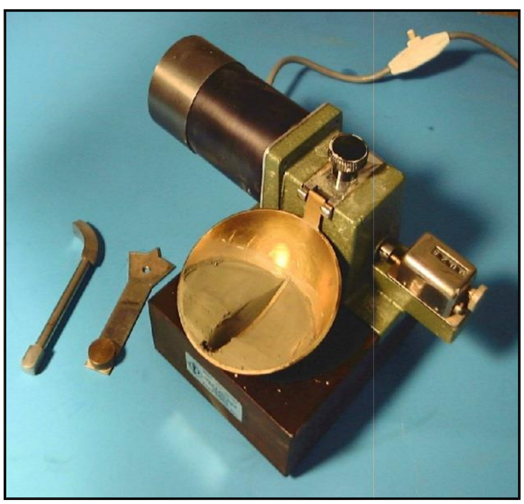
a) <u>LiquidLimit(w_L) </u>: It is the water content corresponding to an arbitrary limit between liquid and plastic states of consistency of a soil. It is a minimum water content at which soil is still in liquid state, but possessing a small shear strength and exhibiting some resistance to flow.

b) <u>PlasticLimit(w_P) </u>: It is the water content corresponding to an arbitrary limit between plastic and semi-solid states of consistency of a soil. It is a minimum water content at which soil will just begin to crumble when rolled in to a thread of approximately 3 mm diameter.

c) <u>ShrinkageLimit(w_S) </u>: It is the water content corresponding to an arbitrary limit between semi-solid and solid states of consistency of a soil. It is the lowest water content at which soil is fully saturated. It is also the maximum water content at which any reduction in water content will not reduce the volume of the soil mass.

Figure explains the three limits. Water content is plotted along the horizontal axis and volume of soil mass is plotted on the vertical axis. It can be seen that the soil mass in dry state possesses some volume. Any addition of water will not immediately increase the volume as water occupies the void space till wS is reached. Further increase in water content will continuously increase the volume of soil mass.

Determination of Liquid Limit from Casagrande approach



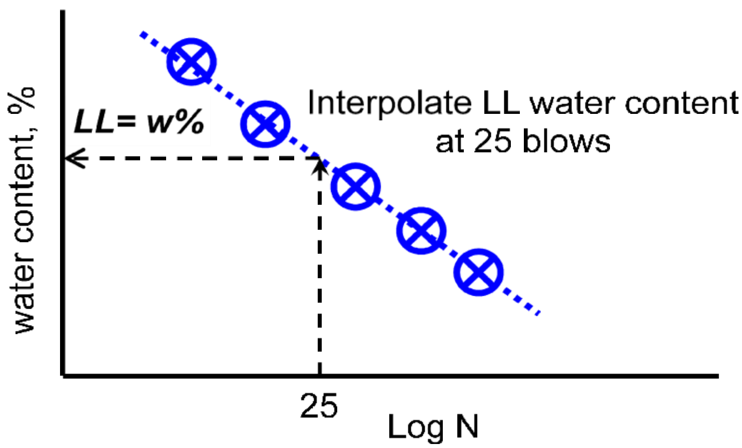


Fig. 13 : Determination of Liquid Limit

The water content at which a groove cut in a soil paste will close upon 25 repeated drops of a brass cup with a rubber base.

A required amount of soil passing through a 425µm sieve is mixed with water until a uniform consistency is achieved.

The liquid limit device is calibrated such that the height fall is 10 mm. The soil is then taken into the cup such that the surface is parallel to the horizontal. Then using a grooving tool, the soil is taken out such that the grooving tool is always perpendicular to the cup at the time of contact.

Blows are given such that handle revolves at 2 revolutions per second. The number of blows required for the soil to fail is noted and a sample along the failure plane is taken for moisture content determination. Best results are obtained for blows ranging between 15 to 35.

Determination of Liquid Limit by FALL CONE Method

The fall cone test is more popular in Europe. This method attempts to eliminate the shortcomings of Casagrande test

Fall cone test for liquid limit determination consists of a Standard cone that is brought into contact with soil and clamped. At time zero cone is released and penetration at end of 5 seconds is recorded. Water content of soil is determined, cup emptied, and test repeated as necessary at other water contents to produce a semi-log curve of w versus penetration.

Test Procedure for Fall Cone Test

1. Obtain the soil passing through 425 micron sieve, just as for the liquid limit test. The difference is that it is a larger quantity and is placed in the cup.
2. The cone tip is brought into contact with the soil surface and time-initialized.
3. The cone is released for a free-fall into the soil and the penetration at the end of 5 seconds is recorded.
4. Since the water content for a penetration depth of 20 mm would be a chance occurrence, several trials at different water contents on both sides of 20-mm penetration are used to construct a semi-log plot of penetration versus water content.
5. In one point test, the liquid limit is obtained as follows

$$\omega_L = \frac{\omega}{0.77 \log_{10} x}$$

where x = Penetration in mm

ω = Water content corresponding to penetration x

Table 6: Distinctions between Casagrande and Fall Cone methods

Casagrande Method	Fall Cone Method
Professor Casagrande standardized the test and developed the liquid limit device.	Developed by the Transport and Road Research Laboratory, UK.
Multipoint test.	Both Multipoint & One-point test.
Resistance to flow.	Resistance to penetration.
At low ω_L slightly lower values	At low ω_L slightly higher values

Determination of Plastic Limit

The moisture content at which a thread of soil just begins to crack and crumble when rolled to a diameter of 3 mm. The plastic limit (ω_P) is the water content (w%) where soil starts to exhibit plastic behavior. It is the water content at which a soil changes from a plastic consistency to a semi-solid consistency. It was developed by Atterberg in 1911. The water content at which a 3 mm thread of soil can be rolled out but it begins to crack and cannot then be re-rolled was arbitrarily defined as Plastic limit.

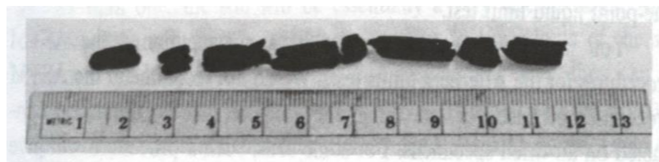


Fig. 14 : Determination of Plastic Limit

Determination of Shrinkage Limit

It is the water content where further loss of moisture will not result in any more volume reduction. It is much less commonly used than the liquid limit and the plastic limit. It is the water content at which the soil volume ceases to change.

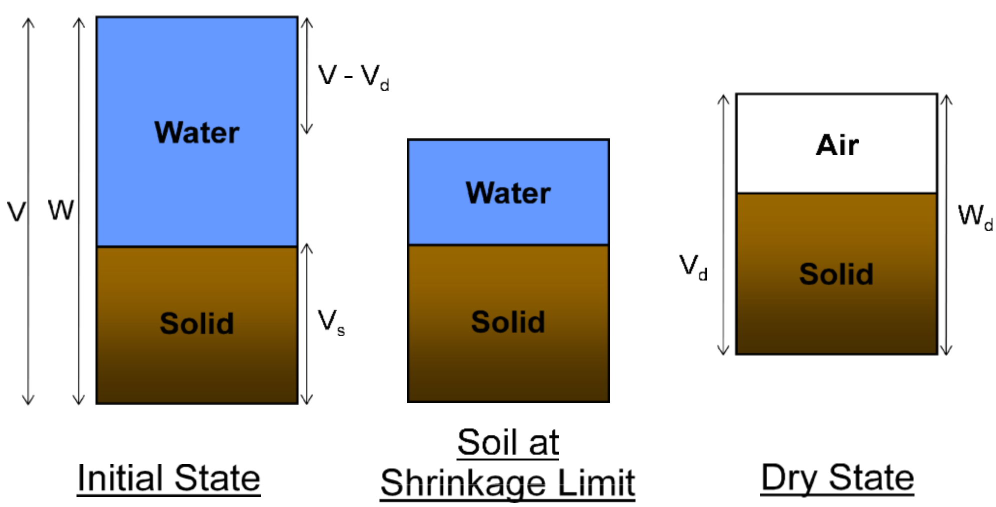
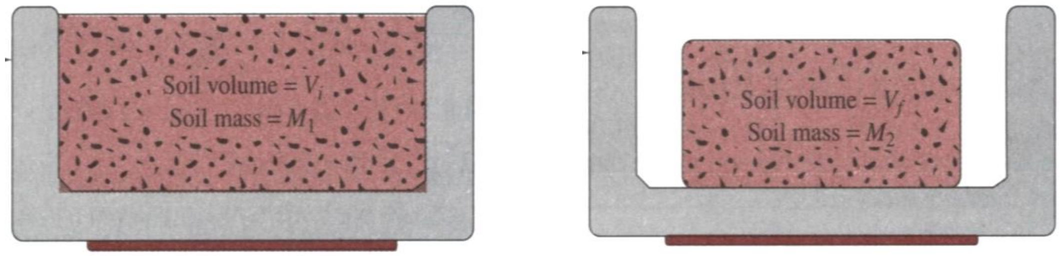


Fig. 15 : Determination of Shrinkage Limit



Soil volume: V, Soil weight: W Soil volume: $V_{d,}$ Soil weight: W_d

Before drying After drying

Fig. 16 : Determination of Shrinkage Limit

$$\omega_S = \frac{(W - W_d) - (V - V_d)\gamma_\omega}{W_d}$$

Here. W = Initial weight of soil

W_d = Dry weight of soil

V = Initial volume of soil

V_d = Dry volume of soil

γ_ω = Unit weight of water

Problem 10

In a shrinkage limit test the following data was obtained.
Initial weight of soil = 1.928 N
Initial volume of soil = 106000 mm^3
Weight of soil after drying = 1.46 N
Volume of soil after drying = 77400 mm^3.
Find shrinkage limit and initial and final void ratios. Take G = 2.7.

<u>Data</u>

W = 1.928 N

V = 106000 mm^3

$W_d = 1.46$ N

$V_d = 77400\ mm^3$

$G = 2.7$

$\gamma_\omega = 9.8\ kN/m^3 = 9.8X10^{-6}\ N/mm^3$

$\omega_S = 12.86\ \%$

$\omega = 32.05\%$

$$\omega_S = \frac{(W - W_d) - (V - V_d)\gamma_\omega}{W_d}$$

Since soil is saturated beyond shrinkage limit, S = 1

$\omega_S G = Se_{final}$ $e_{final} = 0.35$

$\omega G = Se_{initial}$ $e_{initial} = 0.87$

The following are a few important definitions.

d) Plasticity : It is the property of soil that allows it to deform rapidly without rupture, elastic rebound and volume change. The thin film of water adhering to clay particles is responsible for its plastic behavior.

e) PlasticityIndex(I_P) : It is the difference between liquid and plastic limits. A soil with $I_P = 0$ is called non-plastic (NP). Higher the I_P, more plastic will be the soil.

$$\therefore I_P = \omega_L - \omega_P$$

f) ConsistencyIndex(I_C) : It is the ratio of liquid limit minus natural water content to plasticity index of soil.

$$I_C = \frac{\omega_L - \omega}{I_P}$$

Here, w is the natural water content. When, $I_C < 0$, soil is in liquid state. When $I_C = 0$, soil is at its plastic limit and when $I_C > 1$, soil is in semi-solid state and beyond and it is stiff. Hence, more the I_C, the stiffer will be the soil.

g) <u>LiquidityIndex(I_L) :</u> It is the ratio of natural water content minus plastic limit to plasticity index of soil.

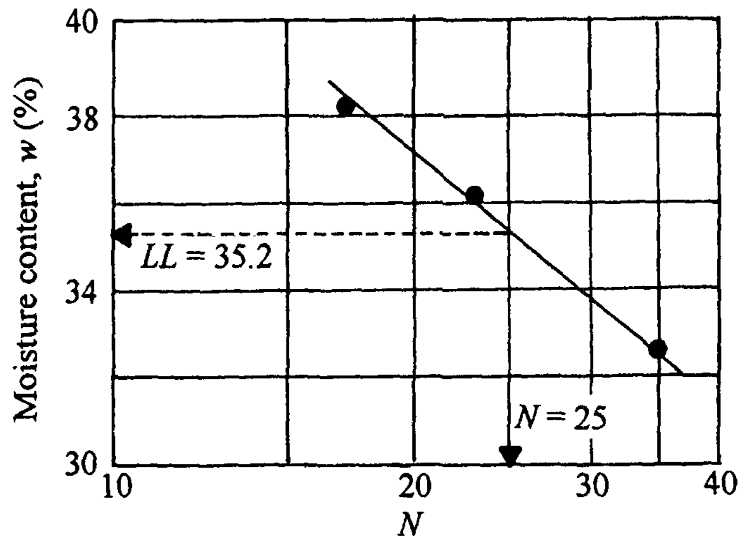
$$I_L = \frac{\omega - \omega_P}{I_P}$$

Here, w is the natural water content. When, $I_L = 1$, soil is at its liquid limit. When $I_L = 0$, soil is at its plastic limit and when $I_L < 0$, soil is in semi-solid state and beyond. Hence, more the I_L, the softer will be the soil.

<u>FlowIndex(I_F)</u>

It is the slope of flow curve.

$$I_F = \frac{\omega_1 - \omega_2}{\log_{10}\frac{n_2}{n_1}}$$



<u>ToughnessIndex(I_T)</u>

1. It is the ratio of plasticity index to flow index.
2. It indicates the stiffness of soil.
3. More the toughness in ex, greater will be the stiffness and resistance to deformation of soil

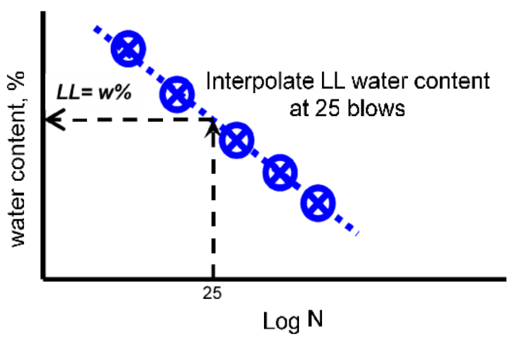
$$I_T = \frac{I_P}{I_F}$$

Problem 11

A clayey soil was tested for liquid and plastic limits and the following were the results. Find plasticity index, flow index, toughness index, consistency index and liquidity index. Plastic Limit was found to be 28% and natural water content was 35%.

Number of Blows	34	23	18	12
Water Content	44.6	49.4	51.4	55.6

$\omega = 35\%$	$\omega_1 = 55.6\%$	$I_F = 24.3\%$
$\omega_P = 28\%$	$\omega_2 = 44.6\%$	$I_T = 0.84$
$\omega_L = 48.5\%$	$n_1 = 12$	$I_L = 0.34$
$I_P = 20.5\%$	$n_2 = 34$	$I_C = 0.66$



$$I_F = \frac{\omega_1 - \omega_2}{\log_{10}\frac{n_2}{n_1}}$$

$$I_P = \omega_L - \omega_P$$

$$I_T = \frac{I_P}{I_F}$$

$$I_L = \frac{\omega - \omega_P}{I_P}$$

$$I_C = \frac{\omega_L - \omega}{I_P}$$

Activity of Clay

It is the ratio of Plasticity Index to percentage clay fraction.

$$A = \frac{PI}{\%\,clay\ fraction\,(weight)}$$

$clay\ fraction: < 0.002\,mm$

Type of Clay	Activity
Inactive Clay	< 0.75
Normal Clay	0.75 – 1.25
Active Clay	> 1.25

1. It was proposed by Skempton (1953).
2. Plasticity Index is influenced by both the amount and type of clay. Activity separates this effect.
3. Higher the activity of clay, greater will be the volume increase when wetted, and greater will be shrinkage when dried.

Determination of Density Index

Please refer to IS 2720 – Part 14 – 1983.

To find e_{max}

1. Fill 1000 ml graduated glass cylinder up to 500 ml with distilled water.
2. Place a large funnel on top such that its bottom tip is in water.
3. Slowly place dry soil in to cylinder through the funnel such that particles settle uniformly & independently.
4. Measure the weight and volume of soil to find dry density and hence e_{max}

To find e_{min}

1. Place the soil in compaction mould with collar in wet state.
2. Using needle vibrator compact it and add more soil to fill beyond collar.
3. Remove the collar and level the soil. Find the volume and dry weight and hence dry density. e_{min} can be determined later.

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$$ or $$D_r = \left[\frac{\gamma_{d\,max}}{\gamma_d}\right]\frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}}$$

2 OUT COME :

1 ABLE TO FIND PROPERTIES OF SOIL BY CONDUCTING LABORATORY TEST .

3 ASSIGNMENT QUESTIONS

1. WHAT IS INDEX PROPERTIES OF SOIL ?

4 FURTHER READING

1http://nptel.ac.in/courses/105106142/