

1.5 INDEX PROPERTIES OF SOILS

1. Engineering Properties

- Permeability
- Compressibility
- Shear Strength

2. Index properties –Identification & Classification of soils

3. Specific gravity of soil particles

4. Particle size distribution

5. Consistency limits and indices

6. Density Index

Categories:

i) Properties of individual particles

ii) Properties of the soil mass (or) aggregate properties

1.5.1 PARTICLE SIZE ANALYSIS

1.5.1.1 SIEVE ANALYSIS:

The particle size analysis (or) mechanical analysis is meant the separation of a soil into its different size fraction. The analysis involves two stages.

Sieve analysis -coarse grained soils (above 75μ)

Sedimentation analysis -fine grained soils (below 75μ)

Sieve Analysis:

The sieves are designated by the size of the opening in 'mm'. It can be divided into two parts.

Coarse analysis ($>4.75\text{mm}$)

Fine analysis ($4.75\text{ mm to }75\mu$)

An oven – dried sample of soil is separated into two fraction by sieving it through a 4.75mm IS sieve. The portion retained on it is termed as the gravel fraction and is kept for the coarse analysis, while the portion passing through it is subjected to fine sieve analysis.

Sieve sets: Coarse analysis

Fine analysis

IS: 100, 60, 20, 10 & 4.75mm

IS: 2mm, 1mm, 600, 425, 300, 212, 150 and 75μ

Procedure:-

1. Sieving is performed by arranging the various sieves one over the other.
2. The largest opening size being kept at the top and the smallest size is at the bottom.
3. A receiver is kept at the bottom and a cover is kept at the top.
4. The soil sample (1000g) is put on the top sieve and the whole assembly is filled on a sieve shaking machine.
5. At least 10 minutes of shaking is desirable for soil with small particles.
6. The portion of the soil sample retained on each sieve is weighed.
7. The percentage of soil retained on each sieve is calculated on the basis of the total mass of soil.
8. The percentage passing through each sieve is calculated.

Table 1.1 Sieve Analysis

S.No.	IS Sieve	Particle size 'D' (mm)	Wt. of sample retained (g)	% retained = $\frac{\text{wt. of retained}}{\text{Total Weight}} \times 100\%$	Cumulative % retained (%)	% finer (N) (100 - cumulative %)
1.	4.75	4.75	75	$\frac{75 \times 100}{1000} = 7.5$	7.5%	92.5
2.	2	2				
3.	1.0	1.0				

4.	600 μ	0.6				
5.	425 μ	0.425				
6.	300 μ	0.3				
7.	150 μ	0.15				
8.	75	0.075				
9.	μ Pan	-				

Then the graph is plotted between % fine in y- axis particle size 'D' (mm) in X –axis on log – scale, to get a particle size distribution curve. The curve given an idea about the type of the soil.

Well graded --- It has good representation of particles of all sizes.

Poorly graded --- It has an excess of certain particles and (uniformly graded) deficiency of other.

1.5.1.2 PARTICLE SIZE DISTRIBUTION CURVE

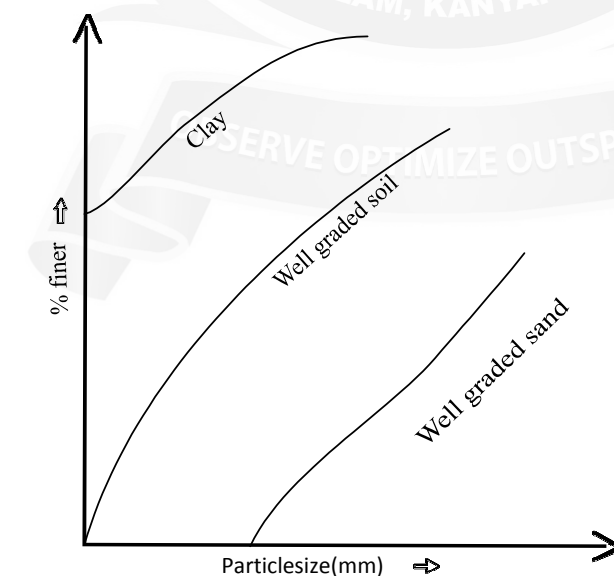


Fig1.5 particle size distribution curve

Two parameters are calculated from these curve, in order to classify the type of soil,

i) Uniformity co-efficient $C_u = \frac{D_{30}}{D_{60}}$

ii) Co-efficient of curvature $C_c = \frac{D_{30}^2}{D_{60}D_{10}}$

D₁₀-Effective size in 'mm'

D₁₀, D₃₀, D₆₀—Particle size corresponding to 10%, 30%, 60% finer than this size in a soil mass.

for uniformly graded soil, C_u is nearly unity,

for well graded soil $C_c = 1$ to 3

$C_u > 4$ for gravels

$C_u > 6$ for sands

Uses of particle size Distribution curve:

Used in the clarification of soils

Determination of co-efficient of permeability

Useful in soil stabilization

Indirectly know the strength of soil

1.5.2 SEDIMENTATION ANALYSIS:

In the wet mechanical analysis or sedimentation analysis the soil fraction finer than 75 μ sieve is kept in suspension in a water the analysis is based on Stokes law, according to which the velocity of the settled grains depends upon the size and weight of the grain the settled grains depend upon the size and weight of the grain the normally assumption is

*Soil particles are spherical and have same specific gravity. (G)

*The coarser particles settle more quickly than the finer ones.

$$\text{Velocity } V = \frac{D^2 \gamma_w (G - 1)}{18 \times 10^6}$$

D– Dia of particle

G–Specific gravity

γ_w – unit wt of water

η –Viscosity of water.

It is done either with the help of a hydrometer (or) a pipette. In both the methods, a suitable amount of oven dried soil sample, finer than 75-micron size is mixed with a given volume (V) of water. The mixture is shaken thoroughly and the test is started by keeping the jar, containing soil water mixed vertical. After any time, interval 't' if a sample of soil suspension is taken from a height H_e with the help of formulae, the size of the particle is obtained. Hence sampling at different time intervals, at this sampling depth H_e , give the particles of different sizes. Using the following formulae, percentage finer is obtained.

$$N = \frac{100 G X R}{(G - 1) M_d}$$

Limitation of sedimentation analysis:

1. The analysis is based on the assumption that
2. Soil particles are spherical.
3. Particles settle independent of other particles.
4. The walls of jar in which the suspension is kept, also do not affect the settlement.
5. The upper of particle size for the validity of the law is about lower limit = 0.0002mm.
6. The soil has an average specific gravity, the volume of which is used in compute the diameter 'D'

1.5.2.1 PIPETTE METHOD:

1. In the sedimentation analysis only those particles which are finer than 75μ —size are included.
2. About 12 to 30g of oven dried sample is accurately weighed and mixed with water to make smooth thin paste. To have proper dispersion of soil, a dispersing agent (sodium hexa-meta phosphate and sodium carbonate) is added to the soil. 33g of sodium hexa-meta phosphate and 7g of sodium carbonate in distilled water to make one liter of solution.
3. 25ml of this solution is added to the dish, containing the soil and water.
4. The soil suspension is stirred well for 15 minutes. Then it is transferred to the sedimentation tube. The tube in a constant temperature water bath.
5. The stop watch is started, and soil samples are collected at various time intervals, with the help of pipette.
6. Those soil, which contain organic matter and calcium compounds are pretreated before the dispersing agent is mixed.
7. Since these contents act as cementing agents and cause aggregations of particles. The process of removal of organic matter and calcium compounds is known as pretreatment.
8. Hydrogen peroxide solution is used to remove the organic matter.
9. To remove the calcium compound, the cooled mixture of soil is treated with hydrochloric acid.

1.5.2.1 HYDROMETER METHOD:

1. The volume of suspension is 1000 ml, double the quantity of dry soil and dispersing agent is taken. The sedimentation jar shaken vigorously and kept vertical.
2. The stop watch is simultaneously started. The hydrometer is slowly inserted in the jar and readings are taken at $\frac{1}{2}$, 1, 2 min time intervals.
3. The hydrometer is then taken out. More readings are then taken at the following time intervals: 4, 8, 15, 30 minutes and 1, 2, 4 hours etc.

4. To take the reading The hydrometer is inserted about 30 seconds before the green time interval, so that it is stable at the time when the reading is taken.

$$\text{Effective depth } H_e = h + \frac{H}{2}$$

h = distance from reading R_h on stem to the neck, in cm

H = Height of bulb, in cms.

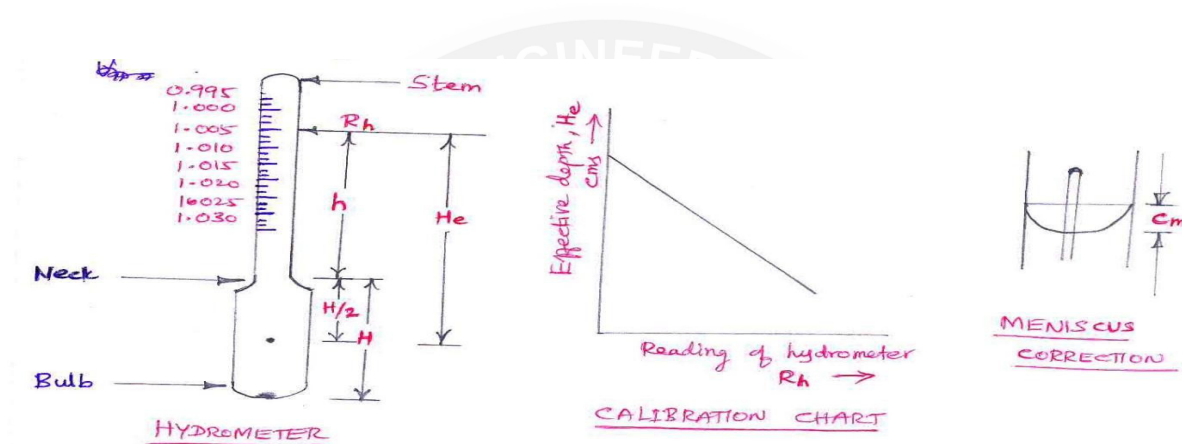


Fig 1.6 Hydrometer

Corrections to the hydrometer readings: Temperature Correction: (C_t)

The hydrometer is generally designed at 27°C . If the temperature of soil suspension is not 27°C , a temperature correction C_t should be applied to the observed hydrometer reading. If the test temperature is more than 27°C , temperature correction is positive. If the test temperature is less than 27°C , temperature correction is negative. So $C_t + \text{Observed reading}$.

Meniscus Correction: (C_m)

Since the soil suspension is opaque, the hydrometer reading is taken at the top of the meniscus. Actual reading to be taken at water level, will be more since the readings increase in the downward. Hence meniscus correction C_m is positive. Its magnitude can be found by immersing hydrometer in a jar containing clear water and finding the difference between the top and bottom of the meniscus.

Dispersing agent correction: (C_d)

The addition of dispersing agent in water increase its density, and hence the diversity agent correction C_d is always negative.

Correction hydro meter reading, $R = R_h + C_m \pm C_t - C_d$

$= C_m \pm C_t - C_d$ may be negative(or)positive.

R_h =observed hydrometer reading.

C_t =Temperature correction.

C_m =meniscus correction.

C_d =Dispersing agent correction.

1.5.3 CONSISTENCY LIMITS (OR) ATTERBERG LIMITS:

It is the water contents at which the soil mass passes from one state to the next. They ore mostuseful for engineering purposes are

- * Liquid limit
- * Plastic limit
- * Shrinkage limit

Expressed as percentage of water content.

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

STATES OF CONSISTENCY

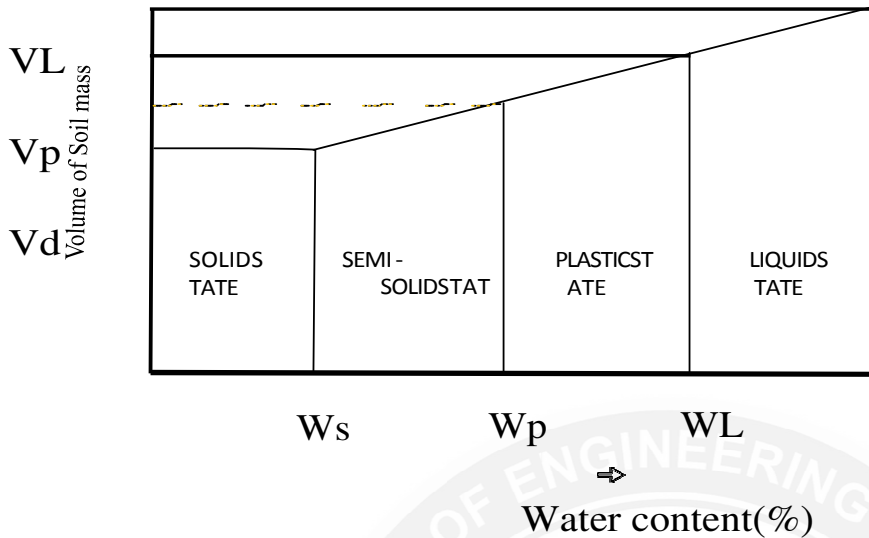


Fig1.7 States of Consistency

1.5.3.1 LIQUID LIMIT (WL)

It is the water content corresponding to the limit between liquid and plastic state of the soil. It is defined as the minimum water content at which the soil is still in the liquid state.

ABOUT APPARATUS :

TEST:

The Liquid limit (WL) is determined in the Lab with the help of Casagrande's apparatus. The apparatus consist of rubber base ball over which a brass cup can be raised and lowered to fall on the rubber base with the help of rotating the handle. The height of fall of the cup can be adjusted with the help of screws.

PROCEDURE

- About 120g of a soil passing through 425 μ sieve is thoroughly mixed with water in the dish to form a uniform paste.
- A portion of paste placed in the cup, spread in position and groove the soil specimen.
- The handle is rotated and the number of blows are counted until the two parts of

the soil sample come into contact.

- After recording the number of blows approximately 10 g of soil from near the closed groove is taken for water content determination.
- Since it is difficult to adjust the water content precisely equal to the liquid limit when the groove should close in 25 blows, the liquid limit is determined by plotting a graph between number of blows in x - axis on a log scale and the corresponding water content in y - axis.
- Such a graph known as the flow curve. Slope of the flow curve is called flow index.

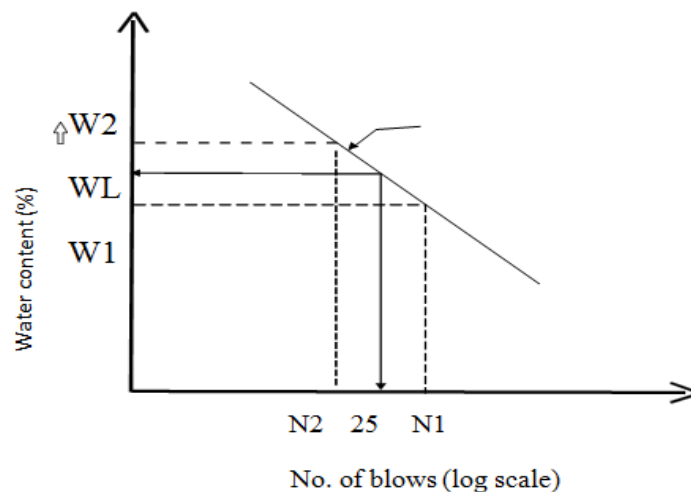


Fig 1.8 Flow Curve

1.5.3.2 PLASTIC LIMIT:

It is water content corresponding to a limit between the plastic and the semi – solid state.

It is defined as the minimum water content at which a soil will just begin to crumble when rolled into a thread approximately 3mm in diameter.

PROCEDURE:

- To determine the plastic limit, the soil specimen, passing 425 micron sieve, is mixed thoroughly with distilled water until the soil mass becomes plastic enough to be easily moulded with fingers.

- A ball is formed with about 10g of this plastic soil mass and rolled between the fingers and a glass plate with just sufficient pressure to roll the mass into a uniform diameter throughout its length
- When a diameter of 3mm is reached, the soil become to crumbled threads are kept for water content determination.
- The test is repeated twice with fresh samples the plastic limit (WP) is then taken as the average of three water contents.

1.5.3.3 SHRINKAGE LIMIT :

It is defined as the maximum water content at which a reduction in water content will not cause decrease in the volume of a soil mass. It is lower water content at which a soil can still be completely saturated.

Procedure :

- The volume V_1 of the shrinkage dish is first determined by filling to overflow with mercury, removing the excess by pressing a flat glass plate over its top and then taking the mass of the dish filled with mercury. The mass of the mercury contained in the dish divided by its density (13.6 g/cc) gives the volume of the dish.
- About 50 g of soil passing 425 μ IS sieve is mixed with distilled water and make the soil paste.
- Soil paste is places in the shrinkage dish by three layer inorder to fill the voids, tapping of shrinkage dish is taking place.
- Before going to fill the soil paste, the dish is coated with oil. Excess soil paste on the top of the shrinkage dish has to be removed and leveled.
- The dish filled with soil is then immediately weighted. The mass " M_1 " of the wet soil pat is obtained be subtracting the mass of the soil with dish and the weight (or) mass of dish. The dish with soil placed in the oven.
- The mass " M_d " of the day soil pat is found by similar manner.
- To find the volume ' V_2 ' of the dry soil pat, the mercury is filled in dish, the dry soil pat is placed on the surface of the mercury in the dish and is carefully forced

down by means of three prong glass plate.

- The mass of the mercury displaced from the dish divided by its density gives the volume 'V₂' of the dry soil pat.
- The shrinkage limit is calculated by the following relation,

$$W_s = \frac{(M_1 - M_d) - (V_1 - V_2)\gamma_w}{M_d}$$

FOLLOWING ARE THE DIFFERENT PARAMETERS OBTAINED FROM ATTERBERG LIMITS(ATTERBERG INDICES)

1. Plasticity Index(I_P):

It is defined as liquid limit minus plastic limit (difference) I_P = W_L - W_P

2. Flow Index(I_F):

It is the slope of flow curve obtained by plotting water content as ordinate on natural scale against number of blows as abscissa on log scale.

$$I_f = \frac{W_1 - W_2}{\log_{10} \left(\frac{N_1}{N_2} \right)}$$

W₁ – W/C corresponding to no. of blows N₁

W₂ – W/C corresponding to no. of blows N₂

3. Toughness Index(I_T)

It is defined as the ratio of plasticity index to flow index.

$$I_T = \frac{I_p}{I_f}$$

4. Consistency Index(I_C):

a) PLASTIC LIMIT:

It is water content corresponding to a limit between the plastic and the semi – solid state.

It is defined as the ratio of liquid limit minus natural water content to the plasticity index.

$$I_C = \frac{W_L - W}{I_p} \quad \text{If } W = W_L, I_C = 0$$

If $W = W_p, I_C = 0$

∴ I_C varies from '0' to '1' (100%)

Plasticity range

$I_C = \text{negative} \rightarrow \text{liquid state} (< 0)$

$I_C = \text{positive} \rightarrow \text{but greater than 1 (100\%)} \rightarrow \text{semi-solid (or) solid state}$

b) Liquidity Index (I_L):

It is defined as the ratio of natural water content minus plastic limit of plasticity index.

$$I_L = \frac{W - W_p}{I_p}$$

When the soil mass is at liquid limit $W = W_L$ and $I_L = 1$

When the soil mass is at plastic limit $W = W_p$ and $I_L = 0$

Plasticity $\rightarrow 0$ to 1 (100%) $I_L > 1 \rightarrow \text{liquid state}$

$I_L > 0 \rightarrow \text{semi solid (or) solid state}$ Activity number,

$$A = \frac{I_p}{\text{percent filter more than } 2\mu}$$

Table 1.2 Activity of clay

A	Soil type
< 0.75	Inactive

0.75 –1.40	Normal
>1.40	Active

Table 1.3 Plasticity value

Plasticity index(%)	Plasticity
0	Non-plastic
<7	Low-plastic
7-17	Medium
>17	high

c)Shrinkage Ratio (SR):-

When a wet soil mass with its water content above shrinkage limit is dried to a water content greater than or equal to shrinkage limit, then whatever reduction in volume of soil mass takes place will be equal to the volume of water evaporated.

It is defined as the ratio of reduction in volume of soil mass expressed as % of its dry volume to the corresponding reduction in water content.

$$SR = \frac{\frac{W_1 - W_2}{W_D} \times 100}{W_1 - W_2}$$

V_1 = vol. of soil mass @ water content W_1 V_2 = vol. of soil mass @ water content

$W_2 V_d$ = volume of dry soil mass

W_1, W_2 = water contents in %

d)Volumetric Shrinkage(VS):

It is defined as the reduction in volume of soil mass expressed as a percentage of its dry volume when the soil mass is dried from a water content above shrinkage limit to shrinkage limit.

$$VS = \frac{V_1 - V_d}{V_d} \times 100 \%$$

V_1 – volume of soil mass at any water content $W_1 > W_s$ V_d – volume of dry soil mass

$$SR = \frac{\frac{W_1 - W_2}{W_d} \times 100}{W_1 - W_d} - \frac{V_s}{W_1 - W_d}$$

$$V_s = SR(W_1 - W_d)$$

PROBLEM

1) The mass and volume of a saturated clay specimen were 29.8g and 17.7cm³ respectively. On oven drying the mass got reduced to 19g and the volume to 8.9 cm³. Calculate shrinkage limit, shrinkage ratio and volumetric shrinkage. Also compute 'G' of soil.

Given:

Mass of wet soil specimen $M = 29.8 \text{ g}$

Volume of wet soil specimen $V = 17.7 \text{ cm}^3$

Mass of dry soil specimen $M_d = 19.0 \text{ g}$

Volume of dry soil specimen $V_d = 8.9 \text{ cm}^3$

Solution:

i) Shrinkage limit

$$\begin{aligned} W_s &= \frac{(M - M_d) - (V - V_d)\rho_w}{M_d} \\ &= \frac{(29.8 - 19.0) - (17.7 - 8.9) \times 1}{19.0} \\ &= 0.1053 \Rightarrow 10.53 \% \end{aligned}$$

ii) Shrinkage ratio (SR):

$$SR = \frac{M_d}{V_d \cdot \gamma_d}$$

$$= \frac{19}{8.9 \times 1} = 2.13$$

$$\text{iii) Volumetric Shrinkage}(V_s) = \frac{V - V_d}{V_d}$$

$$= \frac{17.7 - 8.9}{8.9} = 98.8\%$$

$$W_s = \frac{V_d \gamma_w}{M_d} - \frac{1}{G}$$

$$\frac{1}{G} = \frac{V_d \gamma_w}{M_d} - W_s$$

$$\frac{1}{G} = \frac{8.9}{19} - 0.01053$$

$$\frac{1}{G} = 0.3631$$

$$G = 2.75$$

2) The following data on consistency limits are available for two soils A and B.

	Soil A	Soil B
Plastic limit	16 %	19 %
Liquid limit	30 %	52 %
Flow index	11	6
Natural water content	32 %	40 %

Find which soil is a) more plastic b) better foundation material on remoulding c) better shear strength as a function of water content d) better shear strength at plastic limit. Classify the soil as per ISCS. Do these soils have organic matter?

Given:

1) Plasticity index

For Soil A

$$\text{Plasticity index } I_P = W_L - W_P$$

$$= 30 - 16 \Rightarrow 14\%$$

For Soil B

$$\text{Plasticity index } I_P = W_L - W_P$$

$$= 52 - 19 \Rightarrow 33\%$$

Since plasticity index of soil B is greater, then soil B is more plastic.

2) Consistency index

For Soil A

$$I_c = \frac{W_L - w}{I_p}$$

$$= \frac{30 - 32}{14} = -0.143\%$$

For Soil B

$$I_c = \frac{W_L - w}{I_p}$$

$$= \frac{52 - 40}{33} = 0.36\%$$

I_c for soil A is negative, hence it will turn into slurry when remoulded. It is not suitable for foundations. However soil B will be suitable. Because $I_c = 0.25$ to 0.50 (soft)

3) Flow index

For Soil A

$$I_F=11$$

For Soil B

$$I_F=6$$

Since, the flow index of soil B is lesser than of soil A. Thus soil B has better shear strength as a function of water content.

4) Toughness index

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

Since, the toughness index for soil B is greater than that of soil A. Thus soil B has better shear strength at plastic limit.

5) Classification of the soil as per ISCS

When I_P and w_L are named on the plasticity chart

For Soil A

plasticity index $I_P=14\%$

$$W_L=30\%$$

For Soil B

Plasticity index $I_P=33\%$

$$W_L=52\%$$

Hence, soil A and soil B fall in the zones of 'CL' and 'CH' respectively.

Thus, soil A is inorganic clay for low plasticity. While soil B is inorganic clay for high plasticity.

Hence, these soils do not have organic matter.

3) An undisturbed saturated specimen of clay has a volume of 18.9 cm³ and a mass of 30.2 g. On oven drying, the mass reduces to 18.0 g. The volume of dry specimen as determined by displacement of mercury is 9.9 cm³. Determine shrinkage limit, specific gravity, shrinkage ratio and volumetric shrinkage.

Given:

$$M_1 = 30.2 \text{ g}$$

$$M_d = 18.0 \text{ g}$$

$$\rho_w = 1 \text{ g/cm}^3$$

$$V_1 = 18.9 \text{ cm}^3$$

$$V_2 = 9.9 \text{ cm}^3$$

Solution:

$$W_s = \frac{(M_1 - M_d) - (V_1 - V_2)\rho_w}{M_d}$$

$$W_s = \frac{(30.2 - 18) - (18.9 - 9.9)1}{18.0} \times 100$$

$$= 17.8\%$$

ii)

$$G = \frac{M_d}{V_1 - (M_1 - M_d)}$$

$$G = \frac{18.0}{18.9 - (30.2 - 18)} = 2.69$$

iii) Shrinkage ratio; $SR = \frac{\gamma_d}{\gamma_w} = \frac{\rho_d}{\rho_w}$

$$= \frac{1.818}{1} = 1.82$$

iv) Volumetric shrinkage, $VS = \frac{(V_1 - V_d)100}{V_d}$

$$VS = \frac{(18.9 - 9.9)100}{9.9} = 91\%$$

4) The mass specific gravity of a fully saturated specimen of clay having a water content of 36% is 1.86. On oven drying, the mass specific gravity drops to 1.72. Calculate the specific gravity of clay and its shrinkage limit.

Solution:

$$e = w_{\text{sat}} G = 0.36G$$

$$\text{mass specific gravity, } G_m = \left[\frac{(G+e)\gamma_w}{1+e} \right] \frac{1}{\gamma_w}$$

$$1.86 = \left[\frac{G + 0.36G}{1 + 0.36G} \right]$$

$$1.86 = \left[\frac{1.36G}{1 + 0.36G} \right]$$

$$G = 2.69$$

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

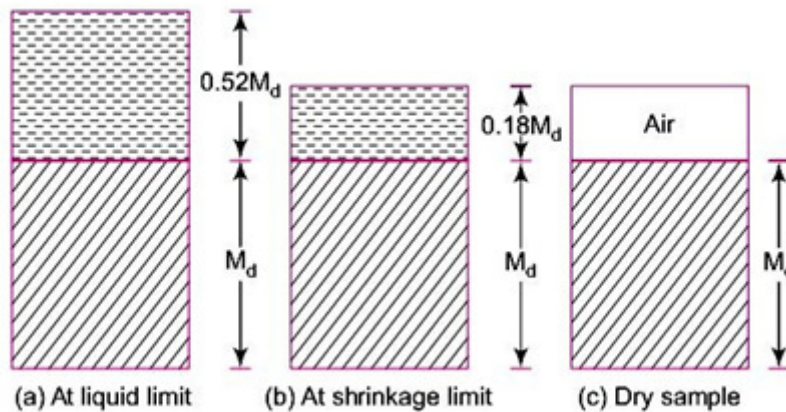
$$\frac{\gamma_w}{\gamma_d} = \frac{1}{1.72}$$

$$w_s = \frac{1}{1.72} - \frac{1}{2.69} = 0.21 = 21\%$$

5) The Atterberg limits of a clay soil are: liquid limit 52%, plastic limit 30% and shrinkage limit 180%. If the specimen of this soil shrinks from a volume of 39.5 cm³ at the liquid limit to a volume of 24.2 cm³ at the shrinkage limit, calculate the true specific gravity.

Solution:

Figure (a, b, c) shows that the states of the specimen at liquid limit, shrinkage limit and dry condition, respectively.



Difference of volume of water in (a) and (b) = $39.5 - 24.2 = 15.3 \text{ cm}^3$

Difference of mass of water in (a) and (b) = 15.3 g .

But from Fig.(a),(b), this difference is equal to $(0.52 - 0.18)M_d$

$$(0.52 - 0.18) M_d = 15.3 \text{ or } M_d = \frac{15.3}{0.34} = 45 \text{ g}$$

Mass of water in (b) = $0.18 M_d$

$$= 0.18 \times 45 = 8.1 \text{ g}$$

Volume of water in (b) = 8.1 cm^3

Volume of solids V_s in (b) = $24.2 - 8.1 = 16.1 \text{ cm}^3$

$$\rho_s = \frac{M_d}{V_s}$$

$$= \frac{45}{16.1} 2.8 \text{ g/cm}^3$$

$$G_s = \frac{\gamma_s}{\gamma_w} = \frac{\rho_s}{\rho_w} = \frac{2.8}{1} = 2.8$$

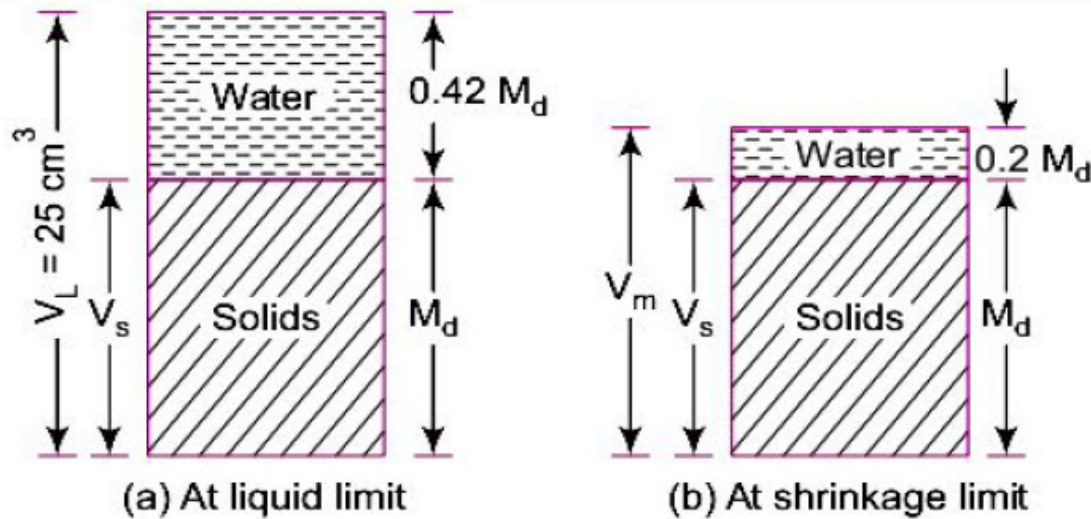
6) A saturated soil sample has a volume of 25 cm^3 at the liquid limit. If the soil has liquid limit and shrinkage limit of 42% and 20%, respectively, determine the minimum volume which can be attained by the soil specimen. Take $G = 2.72$.

Solution:

The soil specimen will attain minimum volume at shrinkage limit. Figure(a) and (b) show the states of the specimen at liquid limit and shrinkage limit respectively.

If M_d is the mass of solid, volume of water at liquid limit is

$$V_L = 0.42 M_d \text{ cm}^3$$



Volume of solids,

$$V_s = \frac{M_d}{G \rho_w} = \frac{M_d}{2.71 \times 1} = \frac{M_d}{2.71} \text{ cm}^3$$

$$= 0.368 M_d \text{ cm}^3$$

$$\text{Total volume} = 0.42 M_d + 0.368 M_d = 25$$

$$M_d = 31.74 \text{ g}$$

At the shrinkage limit, soil attains its minimum volume V_m

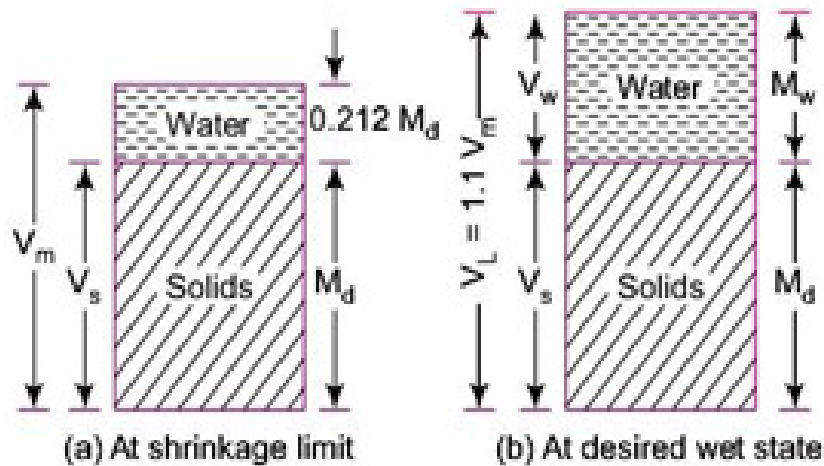
$$V_m = V_s + 0.2 M_d$$

$$= 0.368 M_d + 0.2 M_d$$

$$= 0.568 \times 31.74$$

$$= 18.03 \text{ cm}^3$$

7) An oven dried sample of soil has a volume of 265 cm³ and a mass of 456 g. Taking $G = 2.71$, determine the voids ratio and shrinkage limit. what will be the, water content which will fully saturate the soil sample and also cause an increase in volume equal to 10% of the original dry volume?



$$\text{Dry Density, } \rho_d = \frac{M_d}{V}$$

$$= \frac{456}{265}$$

$$= 1.721 \text{ g/cm}^3$$

$$\rho_d = \frac{G \rho_w}{1 + e}$$

$$1.721 = \frac{2.7 \times 1}{1 + e}$$

$$e = 0.575$$

$$\text{shrinkage limit} = \frac{e}{G}$$

$$= \frac{0.575}{2.71}$$

$$= 0.212 = 21.2\%$$

Figures (a) and (b) show the states of the specimen at shrinkage limit and desired final state, respectively.

Now $V_m = 265 \text{ cm}^3$,

$$V_s = \frac{M_d}{G}$$

$$= \frac{456}{2.71} = 168.27 \text{ cm}^3$$

At the final desired state $V = 1.1V_m = 1.1 \times 265 = 291.5 \text{ cm}^3$ ----- (1)

But from fig (a), $V = V_w + V_s = V_w + 168.27$ ----- (2)

From 1 and 2 we get $V_w = 291.5 - 168.27 = 123.23 \text{ cm}^3$

Mass of water in final state, $M_w = 123.23 \text{ g}$

Hence water content in final state $= \frac{M_w}{M_d} = \frac{123.23}{456} = 0.27 = 27\%$

Note:

Table 1.4 classification based on activity

<i>Activity</i>	<i>Classification</i>
< 0.75	Inactive
0.75 – 1.40	Normal
> 1.40	Active

Table 1.5 sensitivity classification

<i>Sensitivity</i>	<i>Classification</i>	<i>Structure</i>
1	Insensitive	–
2 to 4	Normal or less sensitive	Honeycomb structure
4 to 8	Sensitive	Honeycomb or Flocculent structure
8 to 16	Extra sensitive	Flocculent structure
> 16	Quick	Unstable

8) A clay sample has liquid limit and plastic limit of 96% and 24% respectively. Sedimentation analysis reveals that the clay soil has 50% of the particles smaller than 0.002mm. Indicate the activity classification of the clay soil and the probable type of clay mineral.

Solution:

We have $w_L=96\%$ and $w_P=24\%$

Hence plasticity index, $I_P=w_L - w_P$

$$=96-24=72\%$$

$$\text{Activity } A_c = \frac{I_p}{C_w}$$

$$= \frac{72}{50} = 1.44$$

Since the activity No. is greater than 1.4, clay may be classified as being active. Also, the probable clay mineral is montmorillonite.

9) A clay specimen has unconfined compressive strength of 240 kN/m^2 in undisturbed state. Later, on remoulding, the unconfined compressive strength is found to be 54 kN/m^2 . Classify the clay soil on the basis of sensitivity and indicate the probable structure of clay soil.

Solution:

$$\text{Sensitivity, } S_t = \frac{q_u(\text{undisturbed})}{q_u(\text{disturbed})}$$

$$= \frac{240}{54} = 4.44$$

Since S_t is between 4 and 8, the given clay is classified as sensitive. The possible structure of clay soil may be honey-comb or flocculent.

