23rd Aug,
SATURDAY

4. INDEX PROPERTIES OF SOILS

Soil Properties

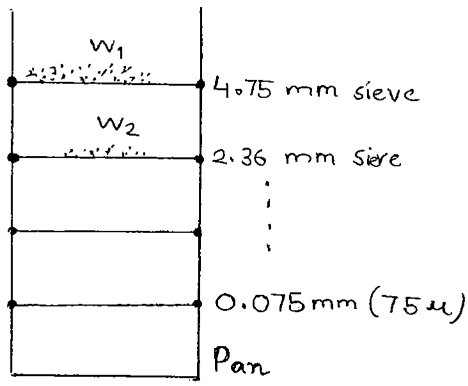
1. Index Properties
   - indicative of behaviour of soil.
   - Eg:- grain size distribution, relative density, atterberg limits.

2. Engineering Properties
   - used for engg. applications
   - Eg:- permeability, shear strengt compressibility.

→ Grain Size Distribution.
- by (i) Sieve analysis → used if size > 75 μ
- (ii) Sedimentation analysis. → used if size < 75 μ

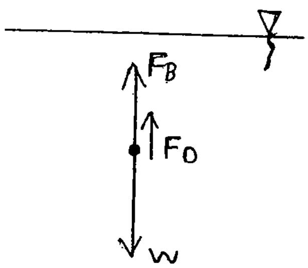
* Sieve Analysis.

size (mm)	% retained.	cumulative %	% finer.
4.75	$P_1 = \frac{W_1}{W} \times 100$	$P_1 = P_1$	$100 - P_1$
2.36	$P_2 = \frac{W_2}{W} \times 100$	$P_2 = P_1 + P_2$	$100 - P_2$
⋮			
0.075			



size vs % finer graph is plotted.

* Sedimentation Analysis
- an indirect method.
- based on "Stoke's Principle"



Settling velocity of particle,

$$V_s = \frac{g}{18}(G-1)\frac{d^2}{\gamma} \longrightarrow \text{Stoke's equation.}$$

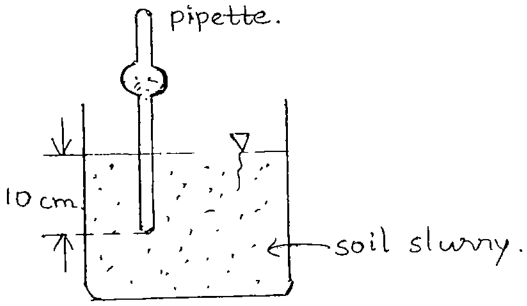
$$\underset{(mm/s)}{V_s} \approx 900 \underset{(mm)}{d^2} \longrightarrow \text{approximate stoke's eqn}$$

Assumptions :

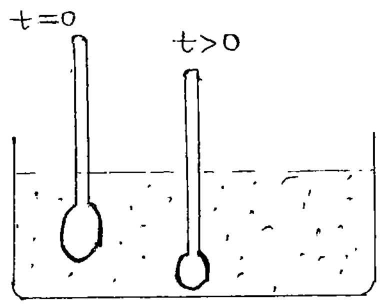
- laminar flow
- particle settle independently without interference.
- Stoke's law is valid only if size is between 0.2μ–0.2mm
  - ⊙ If size > 0.2 mm, it will cause turbulent condition
  - ⊙ If size < 0.2 μ, there will be 'Brownian movement' (zig-zag movement).

* Sedimentation Analysis methods:

1. Pipette Method.



2. Hydrometer method.

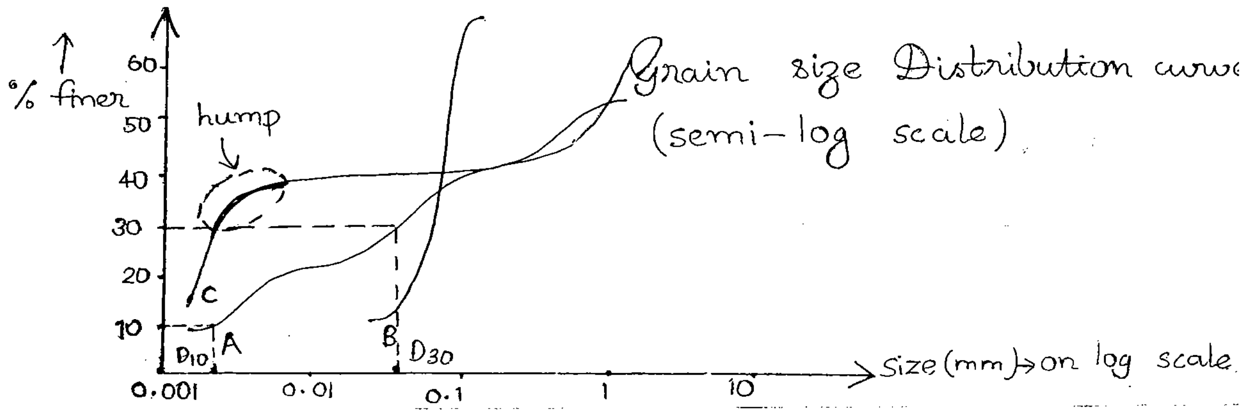


> Corrections for Hydrometer reading.

(i) Temperature correction. (if temp ≠ 27°c)

(ii) Meniscus correction

(iii) Dispersion agent correction (Sodium hexametaphosphate



'Log Scale' is used because:

a) There is large range of data. ($\frac{10}{0.001} = 10000$ times)

b) to get straight line

A → well graded soil – has different sizes

B → uniformly graded soil – same size of particles. (Sand dun

C → gap graded soil – certain sizes are missing.

B&C → poorly graded soil.

→ Important size of Soil. Particle.

a) D_{10} → effective size of soil.

b) D_{30}

c) D_{60}

D : diameter & 10, 30, 60 → % finer

→ Coeffecient of Uniformity (C_u)

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

For well graded gravel, $C_u > 4$

For well graded sand, $C_u > 6$.

If C_u lies b/w 1 & 2, it is called "Uniformly Graded S

→ Coeffecient of Curvature (C_c)

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

> For a well graded soil, $1 < C_c < 3$

> C_c represents shape of curve.

NOTE: Grain size distribution curve is useful only for cohesionless soil (gravel, sand). In the case of clay, grain size distribution curve is not useful, ∵ the clay behaviour is mainly controlled by consistency limits.

→ Relative Density, or Density Index, I_D

$$I_D = \left(\frac{e_{max} - e}{e_{max} - e_{min}}\right) \times 100$$

$e_{min} \leq e \leq e_{max}$

e_{max} → max. void ratio in the loosest state.

e_{min} → min. void ratio in the densest state.

e → natural or insitu void ratio.

If the soil is the loosest state ($e = e_{max}$), $I_D = 0$.

If the soil is in the densest state ($e = e_{min}$), $I_D = 100\%$

$$0 \leq I_D \leq 100\%$$

- $I_D < 15\%$ → very loose state
- $15 \leq I_D < 35\%$ → loose state.
- $35 < I_D < 65\%$ → medium dense state.
- $65 < I_D < 85\%$ → dense state
- $I_D > 85\%$ → very dense state.

The more the I_D value, more will be the density.

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

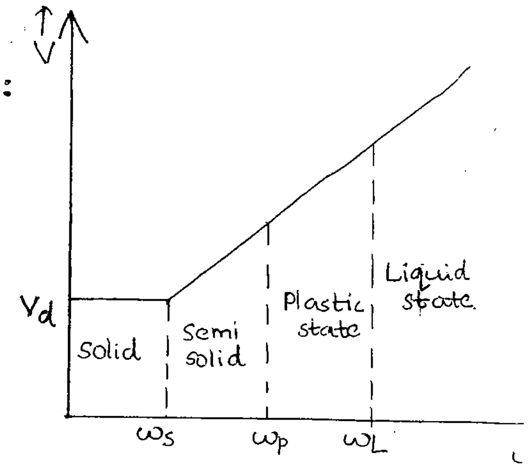
$$\Rightarrow I_D = \left[\frac{\frac{1}{\gamma_{d\,min}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{d\,min}} - \frac{1}{\gamma_{d\,max}}}\right] \times 100$$

→ Consistency Limits or Atterberg Limits

- exist only for cohesive soil.
- depending upon water content of soil;
  1. Liquid state.
  2. Plastic state
  3. Semi-solid state
  4. Solid state.

* Atterberg Limits : these are the boundary w/c b/w two different states of soil.

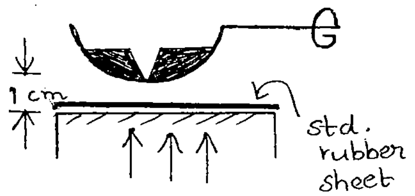
* Types of Atterberg Limits:
  1. Liquid limit, LL or ω_L
  2. Plastic limit, PL or ω_p
  3. Shrinkage limit, SL or ω_s

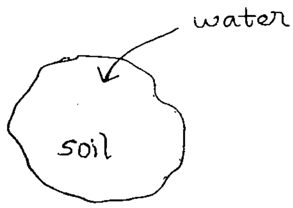


26th Aug, TUESDAY

→ To find ω_L

- Casagrande's Liquid limit test.





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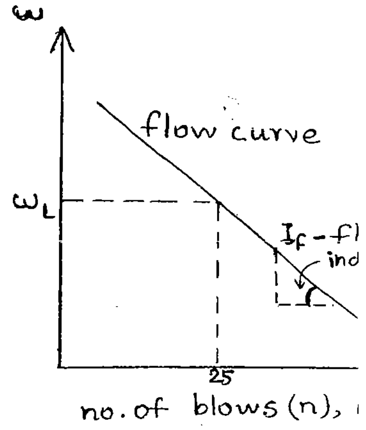
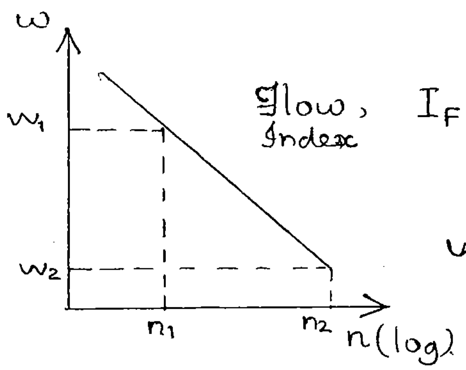
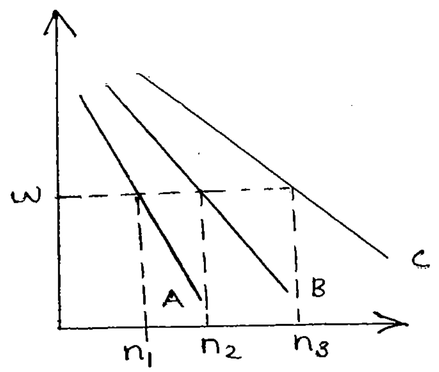




Flow Index, $I_F = \dfrac{w_1 - w_2}{\log_{10}\left(\frac{n_2}{n_1}\right)}$; slope of the flow curve.

w_L – w/c at which 25 no. of blows can close the groove of the apparatus



Flat Flow curve has relatively more shear strength compared to a steep flow curve.

($n_1 < n_2 < n_3$, more no. of blows required to close the groove. ∴ Shear strength of A < B < C)

$$\text{Shear strength} \propto \frac{1}{I_F}$$

* Instead of standard rubber sheet, if hard rubber sheet is used, then ω_L decreases. If soft rubber sheet is used, then ω_L increases.

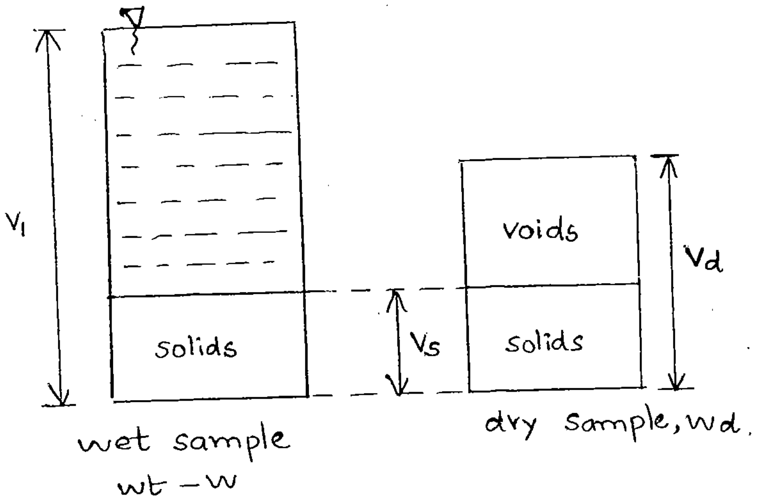
* At liquid limit condition, shear strength of soil is 2.7 kN/m^2 and is same for all soils. (Shear strength is zero for all soils in the liquid state)

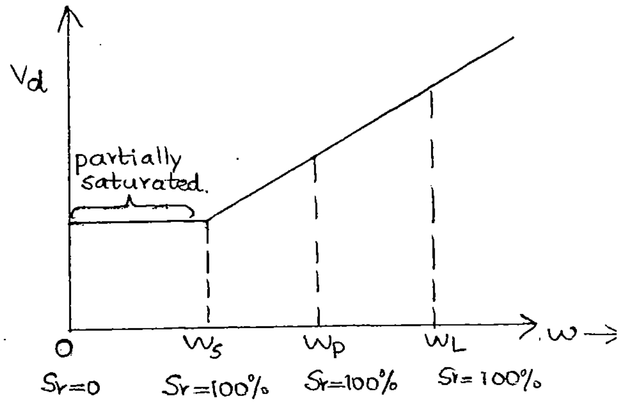
→ Plastic Limit Test. (or Thread Test)

Plastic limit is the minimum w/c at which soil can be rolled into a thread of 3mm diameter without crumbling.

→ Shrinkage Limit.

Shrinkage limit is the minimum w/c that can make the soil fully saturated ($S_r = 100\%$). or it is the min. w/c of soil with 100% desaturation that can be filled in the voids





1. $$w_s = \frac{(V_d - V_s)\gamma_w}{W_d} \times 100$$

$$w_s = \left(\frac{1}{\gamma_d} - \frac{1}{\gamma_s}\right)\gamma_w \times 100$$

$$= \left(\frac{1}{G_m} - \frac{1}{G}\right) \times 100$$

2. $$w_s = \left(\frac{1}{G_m} - \frac{1}{G}\right) \times 100$$

$$e = \frac{wG}{S_r}$$

$$e = \frac{w_s G}{1}$$

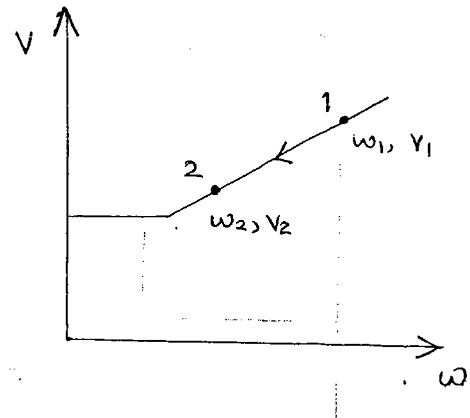
3. $$w_s = \frac{e}{G} \times 100$$; $e \rightarrow$ void ratio at saturation level or dry condition.

4. $$w_s = \left(w_1 - \frac{(V_1 - V_d)\gamma_w}{W_d} \right) \times 100$$

$w_1 \rightarrow$ initial water content $= \dfrac{w - W_d}{W_d}$

→ Shrinkage Ratio (SR).

$$SR = \frac{\frac{V_1 - V_2}{V_d} \times 100}{w_1 - w_2}$$



If $V_2 = V_d$, $w_2 = w_s$,

$$SR = \frac{(V_1 - V_d)/V_d \times 100}{w_1 - w_s}$$

→ Volumetric Shrinkage (VS)

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

$$SR = \frac{\frac{(V_1 - V_d)}{V_d}}{\frac{(V_1 - V_d)\gamma_w}{W_d}} = \frac{\gamma_d}{\gamma_w}$$

$$\therefore \boxed{SR = \frac{VS}{w_1 - w_s}}$$

Also $$SR = \frac{\gamma_d}{\gamma_w}$$; $$\gamma_d = \frac{W_d}{V_d}$$

SR is the mass specific gravity in dry condition.

→ Plasticity Index, I_P

$$\boxed{I_P = w_L - w_P}$$

If $I_P = 0$; non plastic soil.
$I_P < 7$; low plastic soil.
7 − 17 ; medium plastic soil.
> 17 ; high plastic soil.

→ Shrinkage Index, I_S

$$\boxed{I_S = w_P - w_S}$$

→ Toughness Index, I_T

$$\boxed{I_T = \frac{I_P}{I_f}}$$

Shear strength ∝ I_T

→ Consistency Index, I_C

$$\boxed{I_C = \frac{w_L - w}{I_P} \times 100}$$

→ Liquidity Index, I_L

$$\boxed{I_L = \frac{w - w_P}{I_P} \times 100}$$; $w \rightarrow$ natural w/c of soil.

$$\boxed{I_C + I_L = 1 \text{ or } 100\%}$$

- If $I_L > 1$, the soil is in liquid state.
  ($w > w_L \rightarrow$ liquid state)
- If I_L is −ve, the soil is either in semi-solid or solid sta
  ($w < w_P$).

→ Activity Number, A

$$A = \frac{I_p}{C} \quad ; \quad C = \% \text{ of clay particles.}$$

⊙ For a given soil, A is constant.

'A' indicates swelling and shrinkage characteristics.

If $A < 0.75$; inactive soil.

$0.75 - 1.25$; normal active soil.

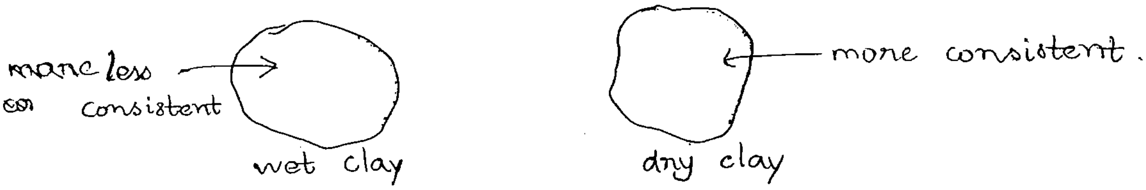
> 1.25 ; active soil. (Bentonite & BC soil)

→ Effect of Size of Particle.

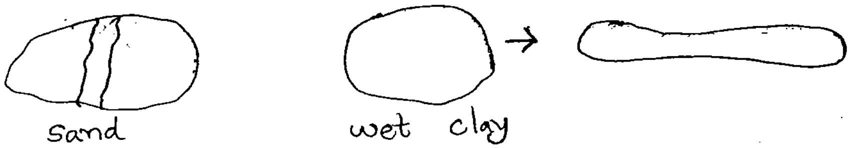
⊙ If size of particle decreases, w_L increases
w_p increases ⇒ I_p increa

⊙ If silt or fly ash (non-plastic) is added to clay, w_L decreases
w_p decreases ⇒ I_p decre

⊙ consistency : resistance against deformation, depends o water content. More the w/c, less the consiste



⊙ plasticity : property due to which soil deforms plastically without rupture is called plasticity.



⊙ If lime is added to clay, w_L decreases, w_p increases and I_p decreases.

P-17

2. Fat Clay → highly compressible clay : $W_L > 50\%$

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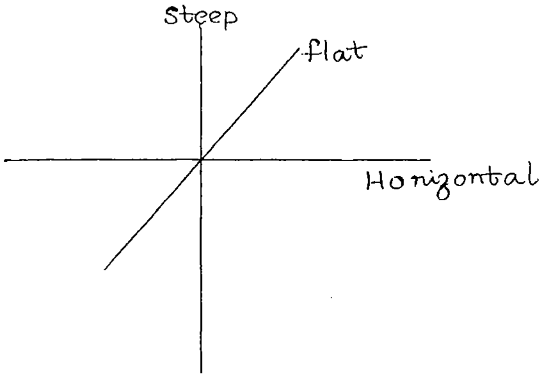


29th Aug,
FRIDAY
P-19.

1. $\gamma = 1746\ kg/m^3$; $w = 8.6\%$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{1746}{1.086} = 1607\ kg/m^3$$; $\gamma_s = 2.6\ g/cc$

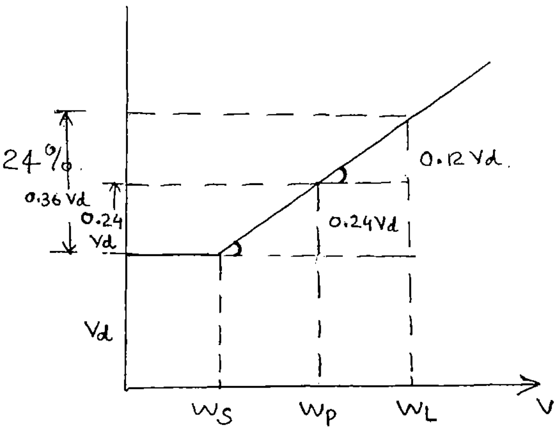
$\therefore G = 2.6$.

$$\gamma_d = \frac{G\gamma_w}{1+e} \Rightarrow e = 0.617.$$

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} = \frac{0.642 - 0.617}{0.642 - 0.462} = \underline{\underline{13.9\ \%}}$$

2. $w_L = 45\%$; $w_p = 33\%$

$$\frac{V_L - V_d}{V_d} \times 100 = 36\% \quad ; \quad \frac{V_P - V_d}{V_d} \times 100 = 24\%.$$



$$\frac{0.36\ V_d - 0.24\ V_d}{W_L - W_p} = \frac{0.24\ V_d}{W_p - W_S}.$$

$$\frac{0.12}{45-33} = \frac{0.24}{33 - W_S}$$

$$\therefore W_S = \underline{\underline{9\ \%}}$$

3. $$SR = \frac{\dfrac{V_L - V_d}{V_d} \times 100}{W_L - W_S} = \frac{36}{45-9} = \underline{\underline{1}}$$

4. $G_m = \frac{\gamma_{sat}}{\gamma_w} = 1.88$

$G_m = \frac{\gamma_d}{\gamma_w} = 1.74$

$e = \frac{wG}{S_r} = 0.46$

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

$1.88 = \frac{G+0.46}{1+0.46}$

$G = 2.9$

5. $w_s = \left(\frac{1}{G_m} - \frac{1}{G}\right) 100 = \left(\frac{1}{1.74} - \frac{1}{2.9}\right) 100 = 23\%$

6. $SR = \frac{\gamma_d}{\gamma_w} = 1.74$

7 $W = 95.6$ gm ; $V_1 = 68.5$ cc

$W_d = 43.5$g ; $V_d = 24.1$ cc.

Initial water content of soil, $w_1 = \left(\frac{W - W_d}{W_d}\right) \times 100$

$= 119.77\%$

Shrinkage limit, $w_s = \left(w_1 - \frac{(V_1 - V_d)\gamma_w}{W_d}\right) 100$

$= \left(1.197 - \frac{(68.5 - 24.1)1}{43.5}\right) 100$

$= 17.7\%$

8. $w_s = \left(\frac{1}{G_m} - \frac{1}{G}\right) 100$

$G_m = \frac{\gamma_d}{\gamma_w}$; $\gamma_d = \frac{W_d}{V_d} = 1.804.$

$G_m = 1.804$

$17.7\% = \left(\frac{1}{1.804} - \frac{1}{G}\right) 100$

$G = 2.65$

9. To find initial void ratio, e_1 :

$$e_1 = \frac{w_1 G}{S_r} = \frac{1.197 \times 2.65}{1} = \underline{\underline{3.15}}$$

OR

$$\gamma_{d_1} = \frac{W_S}{V_1} = \frac{43.5}{68.5} = 0.635 \text{ g/cc}$$

$$\gamma_{d_1} = \frac{\gamma_w G}{1+e_1} \Rightarrow e_1 = \underline{\underline{3.15}}$$

OR

$$\gamma_{sat} = \gamma_w \left(\frac{G+e_1}{1+e_1}\right)$$

$$\frac{W}{V_1} = \left(\frac{2.65+e_1}{1+e_1}\right) = \frac{95.6}{68.5}$$

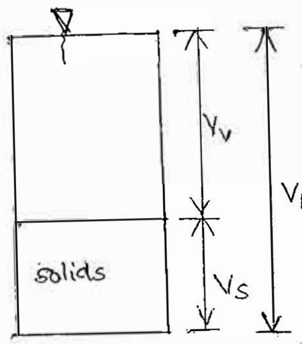
$$e_1 = \underline{\underline{3.15}}$$

OR

$$V_s = \frac{W_S}{\gamma_s} = \frac{43.5}{G\gamma_w} = 16.42 \text{ cm}^3.$$

$$V_v = V_1 - V_s = 52.08 \text{ cm}^3.$$

$$e_1 = \frac{V_v}{V_s} = \frac{52.08}{16.42} = \underline{\underline{3.17}}$$



To find final void ratio, e_2 :

$$e_2 = w_s G$$

$$= \frac{17.7}{100} \times 2.65 = \underline{\underline{0.47}}$$

OR

$$\gamma_{d2} = \frac{W_S}{V_2} = 1.804 \text{ g/cc}$$

$$\gamma_{d2} = \frac{\gamma_w G}{1+e_2}$$

$$e_2 = \underline{\underline{0.47}}$$

(OR)

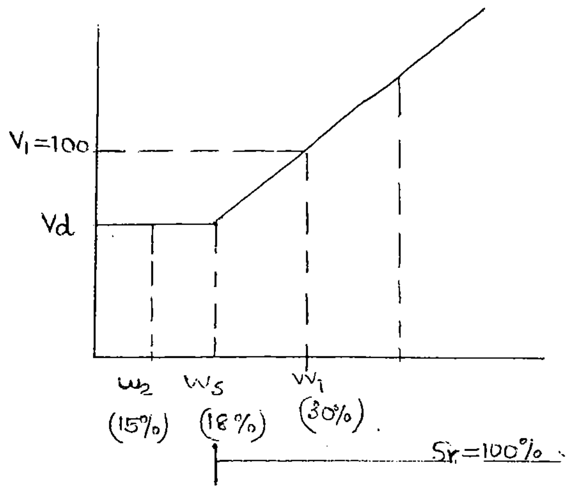
$$\frac{V_2}{V_1} = \frac{1+e_2}{1+e_2}$$

$$\frac{24.1}{68.5} = \frac{1+e_2}{1+3.15}$$

$$e_2 = \underline{\underline{0.47}}$$

10. Let e_1 be void ratio of w_1 of 30%.

$$e_1 = \frac{w_1 G}{S_r} = \frac{0.3 \times 2.72}{1} = 0.816$$



$V_1 = 100$ cc.

Let e_2 be void ratio at w_s.

$$e_2 = w_s G = 0.489.$$

$$\frac{V_1}{V_d} = \frac{1+e_1}{1+e_2}$$

$$\frac{100}{V_2} = \frac{1+0.816}{1+0.489} \Rightarrow V_2 = \underline{\underline{82 \text{ cc}}} = V_d$$

For all $w < w_s$, $\underline{\underline{V_2 = V_d}}$

(OR)

$$w_s = w_1 - \frac{(V_1 - V_d)\gamma_w}{W_d} \quad \text{(lengthy)}$$

11. $\gamma_d = \frac{W_d}{V} = \frac{390}{225} = 1.733$ g/cc.

$\gamma_d = \frac{\gamma_w G}{1+e_1} \Rightarrow e_1 = 0.56.$

Let e_2 be void ratio at increased volume.

$$\frac{V_2}{V_1} = \frac{1+e_2}{1+e_2} \Rightarrow \frac{1.08 V_1}{V_1} = \frac{1+e_2}{1+0.56} \quad \therefore e_2 = \underline{\underline{0.684}}$$

$$e_2 = \frac{w_2 G}{S_r} \Rightarrow 0.47 = w_2 \times 2.7$$

$$w_2 = 25.4\%$$

12. $$C_u = \frac{D_{60}}{D_{10}} = 4$$

$$D_{60} = 4 D_{10}.$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = 1$$

$$\frac{D_{30}^2}{4 D_{10}^2} = 1 \Rightarrow \frac{D_{30}}{D_{10}} = 2$$

13. $$I_p = w_L - w_p$$

$$15 = 56 - w_p$$

$$\therefore w_p = 41\%$$

$\because$ given natural water content ($w = 45\%$) lies b/w liquid limit & plastic limit, the soil is in plastic state.