# Geotechnical Engineering.

* Soil is defined as the uncemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles.

* Soil mechanics is the branch of science that deals with the study of the physical properties of soil and the behaviour of soil masses subjected to various types of forces.

* Soil Engineering is the application of the principles of soil mechanics to practical problems.

* Geotechnical Engineering is the subdiscipline of Civil Engineering that involves natural materials found close to the surface of the earth. It includes the application of the principles of soil mechanics and rock mechanics to the design of foundations, retaining structures and earth structures.

## Rock cycle and origin of soil :→

* Soils are formed by weathering of rocks and decomposition of organic matter.

* The physical properties of soil are by the minerals that constitute the soil particles and the rock from which it is derived.

*

(Rock cycle)

* Weathering is the process of breaking down rocks by mechanical and chemical processes into smaller pieces.

* Mechanical weathering (Disintegration) (Abrasion)
  eg:→ (i) Due to change in tempr. e.g → Gravel, Sand
  (ii) Due to thermal change.

* Chemical weathering (Decomposition) eg:→ clays
  eg:→ (i) Oxidation, Hydration & Carbonation, Solution.

* Soils are formed by the weathered products at their place of origin are called residual soils.
  eg:→ Black Cotton soils, Laterite soils.

* The transported soils may be classified into several groups, depending on their mode of transportation and depositions. eg:→ ① glacial soils → formed by transportation and deposition of glaciers.
  e.g:→ Drift, till, ~~[illegible]~~

② Alluvial soil → transported by running water and deposited along stream.

③ Lacustrine soils → formed by deposition in quiet lakes.
  eg → varved clay.

④ Marine soils → formed by deposition in the sea.

⑤ Aeolian soils → transported and deposited by wind.
  eg → Sand dunes, Loess
  ↓
  Low density
  High compressibility.
  BC is low.
  V.P is high.

⑥ Colluvial soils → formed by movement of soil from its original place by gravity, such as during landslides.
  eg → Talus.
  ↓
  Irregular coarse particles.

* Gravitational forces are predominant in gravels and sands.

* Surface forces, chemical forces, electrical forces are predominant in clays.

## Commonly used soil Designation :→

1. Varved clay → Contain alternate thin layer of clay and silt; Generally a lacustrine deposit.
2. Moorum :→ Gravel mixed with red clay.
3. Loam :→ Mixture of sand, silt and clay. (Approximately in equal proportion)
4. Caliche :→ conglomerate of gravel, sand and clay cemented by calcium carbonate.
5. Bentonite :→ Decomposed volcanic ash.
   * contain high %age of clay mineral, montmorillonite.
   * Exhibits high degree of shrinkage and swelling.
6. Boulder clay :→ Glacial clay containing all sizes of particles from boulder to clay. Also called as glacial till.
7. Hard pan :→ A layer of extremely hard & cohesive soils. very difficult to penetrate or excavate. eg. → Glacial till.

ty.

## Soil particle size :→

① Soils generally are called, gravel, sand, silt or clay depending on the predominant size of particles.

② Unified soil classification system is now almost universally accepted and has been adopted by American Society for Testing and Materials (ASTM).

③ Gravels are pieces of rocks with occasional particles of quartz, feldspar and other minerals.

④ Sand particles are made of mostly quartz and feldspar.

(All are in mm)

⑤

| | Gravel | Sand | Fines - (Silts & clays) |
| --- | --- | --- | --- |
| USCS | 76.2 to 4.75 | 4.75 to 0.075 | < 0.075 |

⑥ Silts are the microscopic soil fractions that consist of very fine quartz grains and some flake shaped particles that are fragments of micaceous minerals.

⑦ Clays are mostly flake-shaped microscopic submicroscopic particles of mica, clay minerals and other minerals.

⑧ Particles classified as clay on the basic of their size may not necessarily contain clay minerals.

⑨ Clays have been defined as those particles "which develop plasticity when mixed with a limited amount of water".

⑩ Plasticity is the putty like property of clays that contain certain amount of water.

Mechanical Analysis of Soil :→

Mechanical Analysis is the determination of the size range of particles present in a soil, expressed as a percentage of the total dry weight.

It is of two types :→

① Sieve Analysis. $> 0.075$ mm

② Hydrometer Analysis. $\leq 0.075$ mm.

## Sieve Analysis:→

1. Broken lump of oven dried soil sample is separated into two fractions by sieving it through a 4.75 mm. IS Sieve.
2. portion retained on it → coarse Analysis.
(100, 63, 20, 10, 4.75 mm IS Sieve).
3. Soil is shaken through a stack of sieves with opening of decreasing size from top to bottom.
4. portion passing through it → fine. Analysis.
(2 mm, 1 mm, 600, 425, 300, 212, 150, 75 μ sieve).
5. It is advisable to wash the soil fraction, passing through, 4.75 mm sieve, over 75 μ sieve, so that silt and clay particles, sticking to the sand particles may be dislodged.
6.

| Sieve size | %age retained | Cumulative %age retained | %age finer |
| --- | --- | --- | --- |
| ↓ | $p_1$ | $P_1 = p_1$ | $100 - P_1$ |
| | $p_2$ | $P_2 = p_1 + p_2$ | $100 - P_2$ |
| | ⋮ | ⋮ | ⋮ |

## Hydrometer Analysis or Wet Mechanical Analysis or Sedimentation Analysis:→

1. Hydrometer Analysis is based on the principle of sedimentation of soil grains in water.
2. When soil specimen is dispersed in water, the particles settle at different velocities, depending on their shape, size, weight and viscosity of water.
3. It is assumed that, all the soil particles are spheres and velocity of soil particles can be expressed by Stoke's law.

i.e., $$v = \frac{g(\rho_s - \rho_w)}{18\eta} \times D^2$$

where, $v$ = velocity of soil particle cm/sec

$\rho_s, \rho_w$ = density of soil particle and water, in $gm/cm^3$

$\eta$ = viscosity of water in $\frac{gm \cdot sec}{cm^2}$

$D$ = Diameter of soil particles in ~~mm~~ cm

$g = cm/sec^2$

$$\Rightarrow D^2 = \frac{18 \eta \times V}{\rho_s - \rho_w}$$

but, $\rho_s = G_s \rho_w$.

$$= \frac{18 \times \eta}{(G_s - 1)\rho_w} \times \frac{L}{t}$$

If we put $\frac{gm.sec}{cm^2}$ in $\frac{gm.m}{cm^2}$ and D is in mm

$$\Rightarrow \frac{D^2}{100} mm^2 = \frac{18 \times \eta \times L}{60 \times (G_s - 1) \times \rho_w \times t}$$

$$\Rightarrow D \text{ is in mm} = \sqrt{\frac{100 \times 18 \times \eta}{60 \times (G_s - 1) \times \rho_w}} \times \sqrt{\frac{L}{t}}$$

$$= \sqrt{\frac{30\eta}{(G_s - 1)}} \times \sqrt{\frac{L}{t}}$$

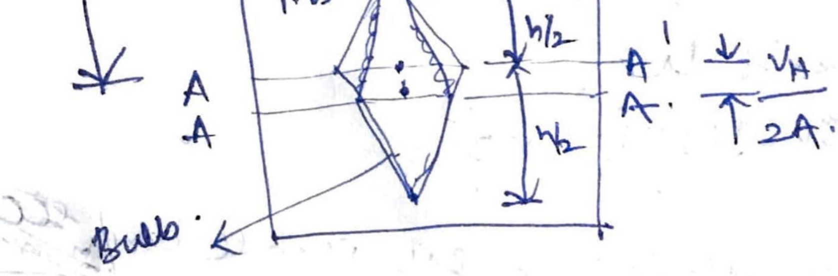
$$\Rightarrow D (mm) = K \sqrt{\frac{L \ (cm)}{t \ (min)}}$$

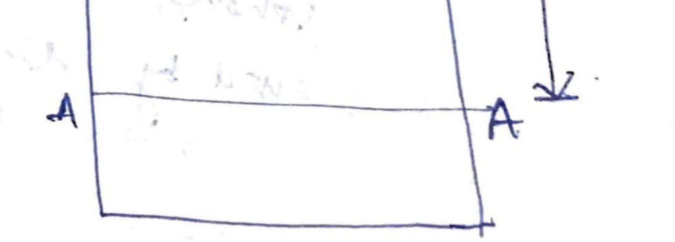
→ He (cm) effective

where,

$$K = \sqrt{\frac{30\eta}{G_s - 1}}$$

## Hydrometer method. :→ -



1. A hydrometer is an instrument used for the determination of the specific gravity of liquids.

2. Hydrometer measures the specific gravity of suspension, at a point by the centre of the immersed volume.

## Calibration of Hydrometer:

1. It is to determine the depth at which specific gravity of soil suspension is measured.

2. The effective depth $H_e$ is given by

$$H_e = \left(H + h/2\right) - \frac{V_H}{A} + \frac{V_H}{2A} = H + \frac{1}{2}\left(h - \frac{V_H}{A}\right)$$

where $H$ = depth from the free surface B'-B' to the lowest mark on the stem.

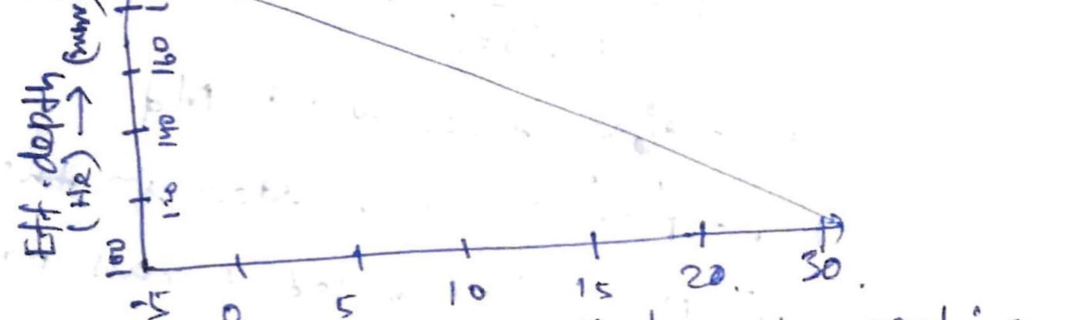
$h$ = height of bulb.

$V_H$ = volume of hydrometer.

$A$ = cross sectional area of Jar.

3. The marking on the hydrometer stem give the S.G of the suspension, at the centre of the bulb.

4. It has been assumed that, rise in suspension level from A-A to A'-A' at the centre of the bulb is equal to half the total rise due to the volume of the hydrometer.

5. 


(Calibration chart)

6. Hydrometer reading,

$R_h = (1.015 - 1) \times 1000 = 15$ ✓ $\Rightarrow R_h = R_h' + C_m$

7. As the sedimentation progress, the G of suspension decreases and the hydrometer goes deeper and deeper, and effective depth increases.

## Correction of hydrometer reading :→

(i) Meniscus correction. → Always (+ve)

i.e., $R_h = R_h' + C_m$.

(ii) Temp$^r$ correction. →

If more than 27°C, (+ve). S.G. decreases of soil suspension

If less than 27°C. (−ve)

(iii) Dispersion Agent correction, →

Always (−ve) ∵ S.G. of soil suspension increases.

So, $R_h = R_h' + C_m \pm C_t - C_d$.

## Composite correction :→

$R_h = R_h' + C_m \pm C_t - C_d$

$= R_h' \pm C$.

* The negative of the hydrometer reading, in the comparison cylinder is equal to the composite correction.

+2 (i.e., 1.002), correction is −2.

−3 (i.e., 0.997), correction is +3.

## Relation between %age finer and hydrometer reading :→

i.e., $N' = \frac{100\,G_s}{M_d\,(G_s - 1)} \times R$

where, $N'$ = %age finer w.r.t $M_d$.

$M_d$ = Mass of soil, added in the solution.

∴ $N = N' \times \frac{M'}{M}$ ; $M'$ = Cumulative mass passing 75 μ IS sieve.

M = Total dry mass of soil sample.

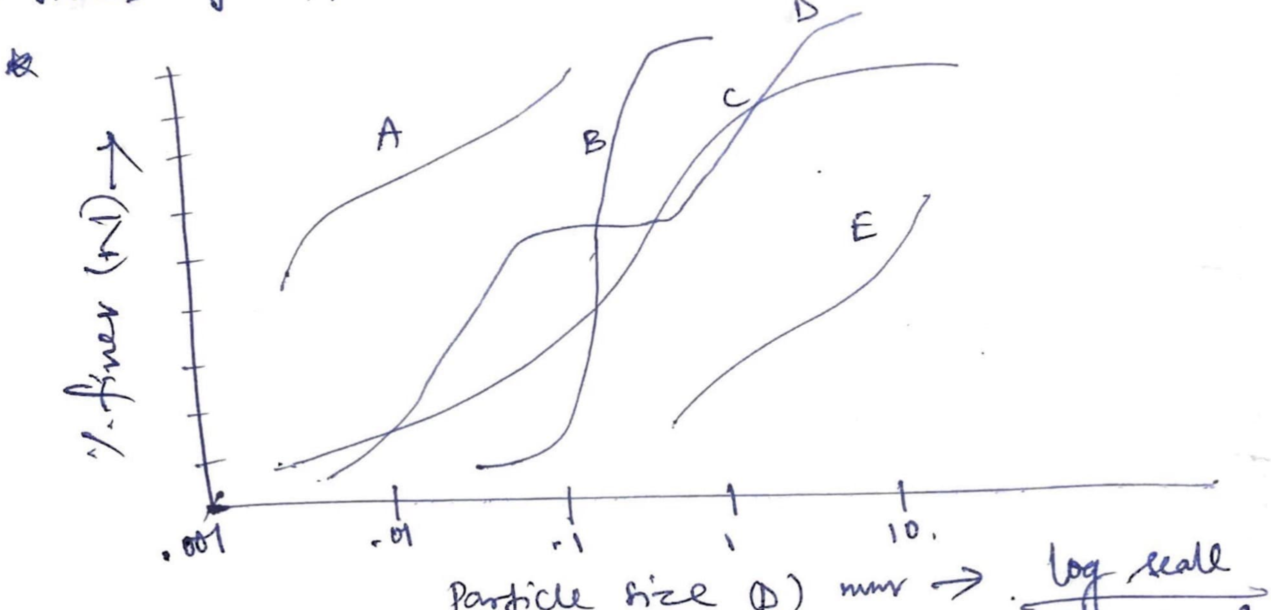
N = %age finer w.r.t total dry mass of the soil sample.

| Date | Time | Elapsed time in min (t) | Hydrometer reading ($R_h'$) | Temp °C | $R_h = R_h' + C_m$ | Effective depth ($H_e$) | $K'$ constant | particle size (D) in (mm) | $R = R_h' \pm C$ | % finer based on $M_d$ | % finer based on total dry mass $N = N' \times \frac{M'}{M}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1/2 | | | | | | | | | |
| | | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | | 4 | | | | | | | | | |
| | | 8 | | | | | | | | | |
| | | 15 | | | | | | | | | |
| | | 30 | | | | | | | | | |
| | | 1 | | | | | | | | | |
| | | 2 | | | | | | | | | |
| | | 4 | | | | | | | | | |
| | | 8 | | | | | | | | | |
| | | 24 | | | | | | | | | |

## Grain size distribution. Curve. :→

* The particle size distribution. curve, also known as a gradation. curve represents the distribution of particles of different sizes in the soil mass.

*




* A curve situated higher up and to the left (curve A) indicates a relatively fine-grained soil, where as a curve situated to the right (curve E) indicates a coarse grained soil.

* A curve with a hump, such as Curve "D" represents the soil, in which some of the intermediate size particles are missing. such a soil is called, gap-graded or skip-graded.

* A flat S-curve, such as curve 'C' represents a soil, which contains the particles of different sizes in good proportions, such a soil is called, well-graded or uniformly graded soil.

* A steep curve like 'B', indicates a soil containing the particles of almost same size, such soils are known as uniform soils.

Two parameters are :→

* Co-efficient of uniformity i.e., $C_u = \frac{D_{60}}{D_{10}}$ and co-efficiency of curvation. i.e., $C_c = \frac{D_{30}^2}{D_{60} \times D_{10}}$

Where, $D_{10}$, $D_{30}$, $D_{60}$ are diameter of particle size, finer than, 10%, 30% & 60% respectively.

* Larger, Numeric value of $C_u$ more is the range of particles.

* Soils, $C_u < 2$, are uniform soils.

* Sands, $C_u \geq 6$ → well graded, Gravels, $C_u \geq 4$ → well graded.

* Well graded soil, $1 < C_c < 3$.
* For gap graded soil, both $C_u$ and $C_c$ are required.

Particle shape :→

* Engineering properties of coarse grained soils depends on shape of particles.
* Cohesionless soils have bulky particles.
* Bulky particles are formed by physical disintegration of rocks.
* Soil containing bulky grains behave like heap of loose bricks or broken stone pieces. Such soils can support heavy loads in static conditions. When vibration takes place, large settlement can occur.
* The bulky particle are of type, angular, sub-angular, subrounded and rounded, which has max$^n$ or min$^m$ void ratio, shear strength parameters, compressibility etc.

* The angularity, 'A' is defined as,

$$A = \frac{\text{Average radius of corners and edges}}{\text{Radius of the max}^m \text{ inscribed shape}}.$$

* The sphericity of bulky particles is defined as, $S = \frac{D_e}{L_p}$, where, $D_e$ = Equivalent diameter of particle, assumed to be sphere.

$L_p$ = Length of particle.

* Flatness (F) and Elongation, (E) are defined as,

$$F = B/T \quad \text{and} \quad E = L/B$$

where, L, B and T are respectively, length, width and thickness.

* More is the sphericity (S), less is the tendency to fracture and higher the value of flatness or elongation, more is the tendency to fracture.

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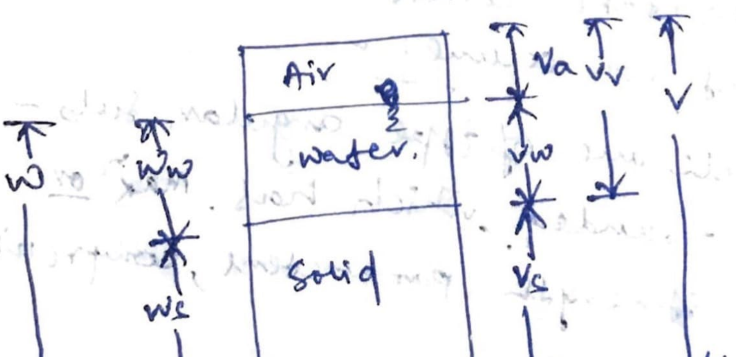
* Cohesive, clayey soils have particles which are thin and flaky, like a sheet of paper. Soils composed of flaky particles are highly compressible. These soils deform easily under static loads, like loose papers in a basket subjected to a pressure. Such soils are relatively more stable when subjected to vibration.

## Weight volume relationships :→

* The moist soil or wet soil is a three phase system, consists of solid + water + air.

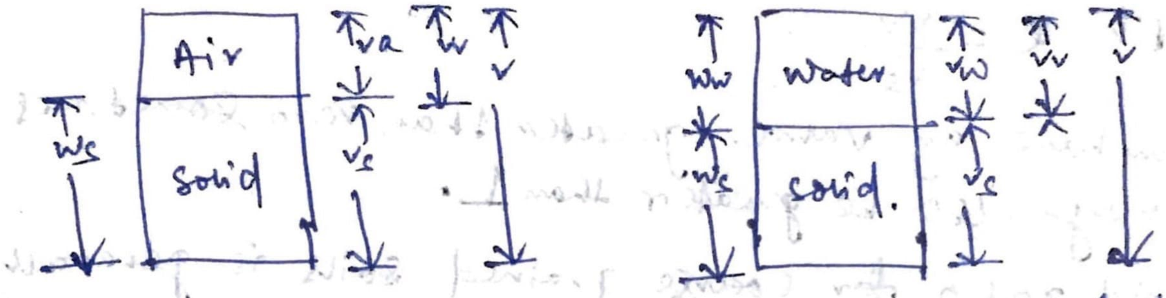



(Three phase of soil element)

where,
$W_w$ = weight of water.
$W_s$ = weight of solid.
$W$ = weight of moist soil.
$V_a$ = volume of air
$V_w$ = volume of water.
$V_s$ = volume of solid.
$V_v$ = volume of void
$V$ = volume of moist soil.

* The dry soil and saturated soil is a two phase system, consist of, solid + air and solid + water, respectively.

*




( Two phase of soil element in dry state & saturated state).

① water content, $w = \frac{W_w}{W_s} \times 100$.

For, dry soil, $w = 0$, For, saturated soil, $w > 0$.

② Bulk unit wt of soil, $\gamma = \frac{W}{V}$ → Total wt. in partially saturated conditions.

③ saturated unit wt, $\gamma_{sat} = \frac{W}{V}$ → Total wt in, saturated condition.

④ Dry unit wt of soil, $\gamma_d = \frac{W_s}{V}$.

⑤ Unit wt of solids, $\gamma_s = \frac{W_s}{V_s}$ → constant for a given soil.

⑥ submerged unit wt, $\gamma' = \gamma_{sat} - \gamma_w$

$\gamma_s > \gamma_{sat} > \gamma > \gamma_d > \gamma'$ , $\gamma_w$ = Unit wt of water, = 1 gm/cc or 9.81 kN/m³.

## specific gravity, unit weight, void ratio, moisture content and relationships :→

specific gravity of soil.
" " of solids
True " " of soil

$\} = G$ or $G_s = \frac{\gamma_s}{\gamma_w}$

Apparent specific gravity of soil.
Mass specific gravity of soil.
Bulk " of soil

$\} = G_m = \frac{\gamma}{\gamma_w}$

* for a given soil, 'G' is constant, but '$G_m$' is not constant.
* 'G' of soil varies from 2.6 – 2.85
* $G_m < G$

① * void ratio; $e = \frac{V_v}{V_s}$

* Can have any value greater than zero, sometimes 'e' may also be greater than 1.
* void ratio for coarse grained soils is generally less than that for fine grained soils.
* generally $0.35 \leq e \leq 0.91$..

② porosity; $\eta = \frac{V_v}{V} \times 100$, it is also called, %age voids.

$0 < n < 100\%$ ; $n = \frac{e}{1+e}$

③ Degree of saturation; $S_r = \frac{V_w}{V_v} \times 100$

$0 \leq S_r \leq 100\%$

for dry soil, $S_r = 0$,

for saturated soil, $S_r = 1$ or $100$.

④ Air content; $a_c = \frac{V_a}{V_v}$.

$0 \leq a_c \leq 100$.

for saturated soil, $a_c = 0$.

for dry soil, $a_c = 1$.

i.e., $S_r + a_c = 1$ or $100\%$.

⑤ percentage of air voids $(n_a) = \frac{V_a}{V} \times 100$.

$0 \leq n_a \leq n$

for saturated soil, $n_a = 0$.

for dry soil $n_a = n$.

i.e., $n_a = n \cdot a_c$.

## Interrelationships →

① $S \times e$

$= \frac{V_w}{V_v} \times \frac{V_v}{V_s} = \frac{V_w}{V_s}$

$wG = \frac{W_w}{W_s} \times \frac{\gamma_s}{\gamma_w}$

$= \frac{W_w}{W_s} \times \frac{W_s \times V_s}{W_w \times V_w}$

$= \frac{V_w}{V_s}$

$\therefore Se = wG$ → ①

② $\gamma = \frac{W}{V} = \frac{W_s + W_w}{1+e}$

$V = V_s + V_v$

$\frac{V}{V_s} = 1 + \frac{V_v}{V_s}$

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

$= \frac{\gamma_s \times V_s + \gamma_w \times V_w}{1+e}$

$Se = \frac{V_w}{V_s}$

$= \frac{\gamma_s + \gamma_w \times Se}{1+e} = \frac{G\gamma_w + \gamma_w \times Se}{1+e}$

$= \frac{\gamma_w(G + Se)}{1+e}$ ✓

③ $\gamma_{sat} = \frac{\gamma_w(G+e)}{1+e}$, when $S=1$.

④ $\gamma_d = \frac{W_s}{V} = \frac{\gamma_s \times V_s}{V} = \frac{G\gamma_w \times V_s}{V} = \frac{G\gamma_w}{1+e}$

$\Rightarrow \gamma_{sat} = \frac{G\gamma_w}{1+wG}$

⑤ $\gamma' = \gamma_{sat} - \gamma_w$

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

$= \frac{G-1}{1+e} \times \gamma_w$

⑥ $\gamma = \frac{\gamma_w(G + Se)}{1+e}$

$= \frac{\gamma_w(G + wG)}{1+e} = \frac{G\gamma_w}{1+e}(1+w)$

$= \gamma_d(1+w)$

(7) $V = V_s + V_w + V_a$

$\Rightarrow V = \frac{V_s}{V} + \frac{V_w}{V} + \frac{V_a}{V}.$

$\Rightarrow 1 = \frac{V_s}{V} + \frac{V_w}{V} + n_a$

$\Rightarrow 1 - n_a = \frac{V_s}{V} + \frac{V_w}{V}$

$\Rightarrow \frac{1}{1+e} + \frac{se}{1+e} = 1 - n_a$

$\Rightarrow \frac{1+se}{1+e} = 1 - n_a.$

$\Rightarrow 1 - n_a = (1+se) \times \frac{1}{1+e}$

$= (1+se) \times \frac{\gamma_d}{G\gamma_w}$

$\Rightarrow \gamma_d = \frac{G\gamma_w(1-n_a)}{1+se}$

or, $\frac{G\gamma_w(1-n_a)}{1+wG}.$

Relative Density :→

The term relative density is commonly used to indicate the in-situ denseness or looseness of granular soil. It is defined as, density index,

(Cohesionless soil deposit)

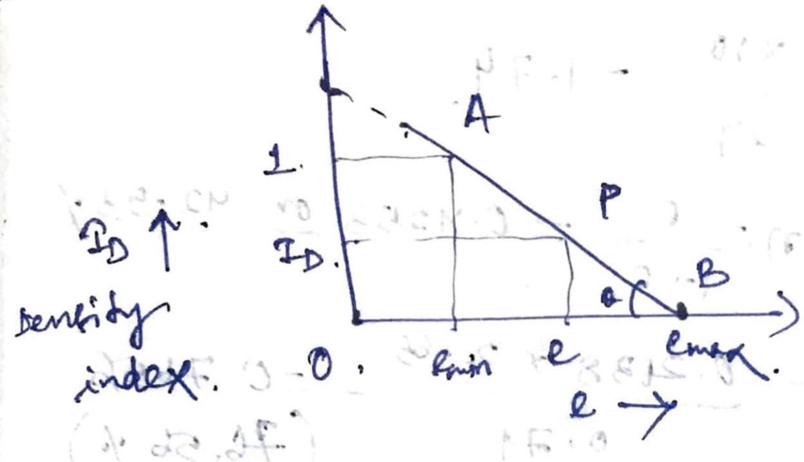
$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$

where, $e_{max}$ = void ratio in the loosest state.

$e_{min}$ = void ratio in the densest state.

$e$ = natural void ratio of the deposit.

$I_D = f(e)$.




$$\tan\theta = \frac{I_D - 0}{e_{max} - e} \rightarrow (1)$$

$$\tan\theta = \frac{1 - 0}{e_{max} - e_{min}} \rightarrow (2)$$

from (1) & (2)

$$\Rightarrow I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

& It indicates, relative compaction of soils & most imp for coarse-grained soils.

| $I_D$ | Denseness of soil. |
|---|---|
| < 15 | Very loose |
| 15 - 35 | Loose |
| 35 - 65 | Medium loose |
| 65 - 85 | Dense |
| > 85 | Very Dense |

**Q.1** A moist soil, sample weighs 3.52 N. After drying in an oven, its weight is reduced to 2.9 N. The specific gravity of solids and the mass specific gravity are, respectively, 2.65 and 1.85. Determine the water content, void ratio, porosity and the degree of saturation. Take, $\gamma_w = 10$ kN/m³.

**Sol^n** →

$W_w = 3.52 - 2.90 = 0.62$ N.

$$w = \frac{W_w}{W_s} = \frac{0.62}{2.90} = 0.2138 \text{ or } 21.38\%$$

$\gamma = G_m \gamma_w = 1.85 \times 10 = 18.5$ kN/m³.

$$\gamma_d = \frac{\gamma}{1+w} = \frac{18.5}{1.2138} = 15.24 \text{ kN/m}^3.$$

$$1+e = \frac{G\gamma_w}{\gamma_d} = \frac{2.65 \times 10}{15.24} = 1.74$$

$$\Rightarrow e = 0.74; \quad n = \frac{e}{1+e} = 0.4253 \text{ or } 42.53\%$$

$$\Rightarrow S = \frac{wG}{e} = \frac{0.2138 \times 2.65}{0.74} = 0.7656 \ (76.56\%)$$

**Q.2** A soil has a porosity of 40%, the specific gravity of solids of 2.65 and a water content of 12%. Determine the mass of water required to be added to 100 $m^3$ of this soil for full saturation.

Sol$^n$: → Let, $V_s = 1\ m^3$

$\rho_s$ [illegible] $= G_s \times \rho_w = 2.65 \times 1000\ kg/m^3$

Mass of solids / kg $= 2650\ kg/m^3$

Mass of water $(\rho_w)/m^3 = 0.12 \times 2650\ kg/m^3$

$= 318\ kg/m^3$

$V_w = .318\ m^3$

$$e = \frac{n}{1-n} = \frac{0.40}{1.0-0.40} = 0.667$$

$V_v = e \times V_s = 0.667 \times 1.0 = 0.667\ m^3$

$V_a = 0.667 - 0.318 = 0.349\ m^3$

Volume of additional water for full saturation

$= 0.349\ m^3$

$V_{soil} = V_s + V_v = 1.0 + 0.667$

$= 1.667\ m^3$

Volume of water required for 100 $m^3$ of soil $= \frac{0.349}{1.667} \times 100 = 20.94\ m^3$

Mass of water required, $= 20.94\ m^3 \times 1000\ kg/m^3$

$= 20\,940\ kg$ (Ans)

Q.3 In a compaction test on a soil, the mass of wet soil when compacted in the mould was 1.855 kg. The water content of the soil was 16%. If the volume of the mould was 0.945 litres, determine the dry density, void ratio, degree of saturation, and percentage of air voids. Take $G = 2.68$.

Solⁿ:→ $\rho = \dfrac{M}{V} = \dfrac{1.855\ kg}{(0.945 \times 10^{3})\ m^3} = 1962.96\ kg/m^3$

$\rho_d = \dfrac{\rho}{1+w} = \dfrac{1962.96}{1+0.16} = 1692.21\ kg/m^3$

$1+e = \dfrac{G\rho_w}{\rho_d} = \dfrac{2.68 \times 1000}{1692.21} = 1.584$

$\Rightarrow e = 0.584$

$S = \dfrac{wG}{e} = \dfrac{0.16 \times 2.68}{0.584} = 0.7342 = 72.42\%$

$\rho_d = \dfrac{(1-n_a)G\rho_w}{1+wG}$

$\Rightarrow 1-n_a = \dfrac{1692.21 \times (1+0.16 \times 2.68)}{2.68 \times 1000} = 0.9022$

$\Rightarrow n_a = 0.0978 = 9.78\%$

Q.4. A compacted cylindrical specimen, 50 mm dia and 100 mm length, is to be prepared, from oven dry soil. If the specimen is required to have a water content of 15 %, and percentage air voids of 20 %. Calculate the mass of the soil and water required for the preparation of the sample. Take $G = 2.69$

Sol$^n$ :→ $M_W = (0.15 \times M_S)$ kg

$V_W = (0.15 \times M_S \times 10^{-3})\ m^3$

$V_S = \frac{M_S}{\rho_S} = \frac{M_S}{G \times \rho_w} = \left(\frac{M_S}{2.69 \times 1000}\right) m^3$

$V_a = (.2 \times V)\ m^3$

$V = \frac{\pi}{4} \times (50)^2_{mm^2} \times 100$ mm.

$= \frac{\pi}{4} (.050)^2 \times .1$

$= 196.35 \times 10^{-6}\ m^3$

$\Rightarrow \underbrace{(0.15 \times M_S \times 10^{-3})\ m^3}_{V_W} + \underbrace{\left(\frac{M_S}{2.69 \times 1000}\right) m^3}_{V_S} + \underbrace{(0.2 \times 196.35 \times 10^{-6})\ m^3}_{V_a}$

$= 196.35 \times 10^{-6}\ m^3$.

$\Rightarrow M_S = 0.301$ kg (Ans)

$\Rightarrow M_W = 0.301 \times 0.15 = 0.045$ kg (Ans)

Q.5 A borrow area soil has a natural water content of 10%, and a bulk density of 1.8 Mg/m³. The soil is used for an embankment to be compacted at 18% moisture content to a dry density of 1.85 Mg/m³. Determine the amount of water to be added to 1.0 m³ of borrow soil. How many cubic metre of excavation is required for 1 m³ of compacted embankment?

Ans :-

for Borrow area soil

$$\rho_d = \frac{1.8}{1.1} = 1.636 \text{ gm/cc}$$

Borrow soil ← $\therefore \gamma_d = \rho_d \times 9.81$

$= 1.636 \text{ gm/cc} \times 9.81$

$= 16.05 \text{ kN/m}^3$

For 1 m³ of borrow soil.

$M_w = 0.1 \times 16.05 \text{ kN} = 1.605 \text{ kN}$

In 1 m³ of embankment

$M_{w1} = 0.18 \times 16.05 = 2.889 \text{ kN}$

Water to be added $= 2.889 - 1.605$

$= 1.284 \text{ kN}$

Embankment $\gamma_d = 1.85 \times 9.81$

$= 18.15 \text{ kN/m}^3$

$\therefore$ Volume of soil required

$$= \frac{18.15}{16.05} = 1.131 \text{ m}^3 \text{ of soil required.}$$

(Ans)

## Consistency of soil :→

* Consistency is meant the relative ease, with which soil can be deformed. Consistency denotes degree of firmness of the soil, which may termed as, soft, firm, stiff or hard.

* The water content at which, the soil changes, from one state to the other are known as, consistency limits or Atterberg's Limit.

* If water evaporate the soil, suspension passes through various states of consistency. i.e,
  (i) liquid state.
  (ii) plastic state.
  (iii) semi-solid state.
  (iv) solid state.

* The Atterberg limits, which divide the four states of consistency are i.e. (i) liquid limit ($w_L$)
  (ii) plastic limit ($w_p$)
  (iii) shrinkage limit ($w_s$)

* These limits are expressed as %age of water content.

### Liquid limit ($w_L$) :→

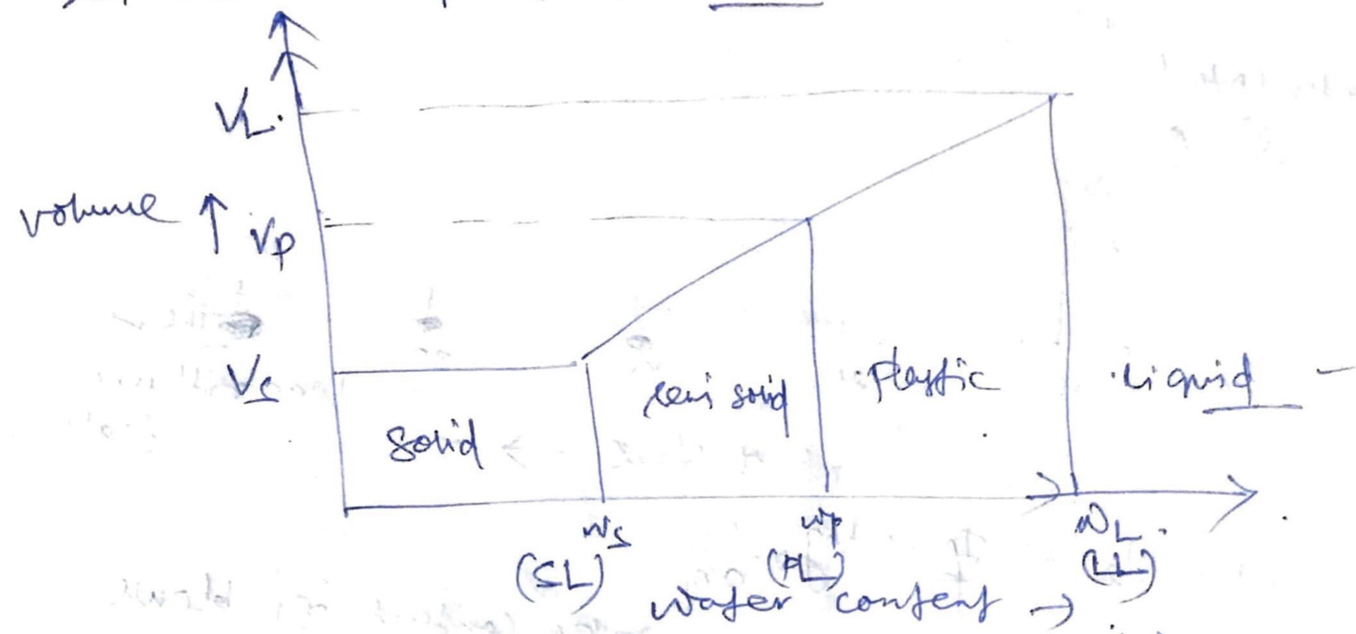
It is defined as the minm water content, at which the soil is, still in the liquid state, but has small shearing strength against its flow, i.e, 2.7 kN/m².

With reference to standard liquid limit device, it is defined as the, minm water content at which a part of soil cut by a groove of standard dimensions i.e., 2mm will flow together, for a distance of 12mm, under an impact of 25 blows in the device.

### plastic limit ($w_p$) :→

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

Shrinkage Limit ($w_s$) :→ It is defined as the max^m water content at which further reduction in water content will not cause a decrease in the volume of a soil mass.



(Different states of soil)

plasticity index ($I_p$) :→

$I_p = w_L - w_p$

Always – $I_p \geq 0$

When, $I_p = 0$, It is – non-plastic.

consistency Index ($I_c$)

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

$1 \geq I_c \geq 0$
(PL ... LL)

If $I_c > 1$, semi solid state & It will be stiff.

If $I_c < 0$ the soil mass, behaves, just like a liquid & it will be soft.

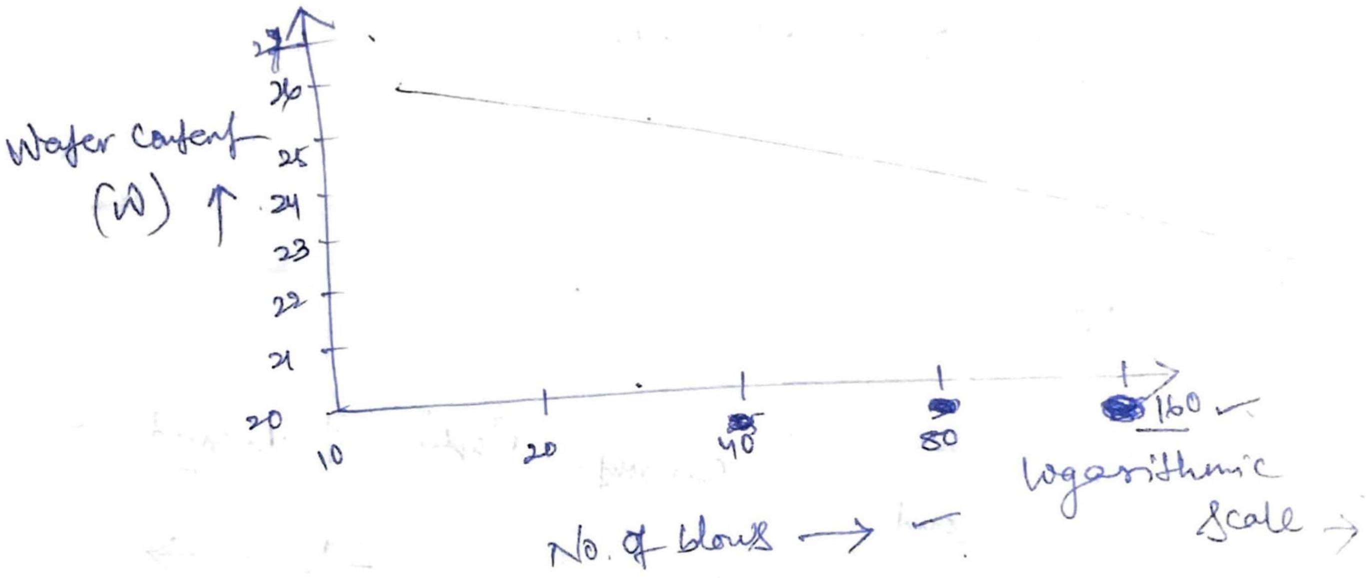
Liquidity index ($I_L$)

$$I_L = \frac{w - w_p}{I_p}$$

$0 \leq I_L \leq 1$
(PL ... LL)

$I_c + I_L = 1$ or $100\%$

## Liquid limit determination :→




$$w_1 - w_2 = I_f \times \log_{10} \frac{n_2}{n_1}$$

where, $w_1$ = water content in $n_1$ blows.
$w_2$ = water content $n_2$ blows.

$I_f$ = slope of the curves i.e., flow index.

$$\Rightarrow I_f = \frac{w_1 - w_2}{\log\left(\frac{n_2}{n_1}\right)}$$

∴ Flow index ($I_f$) is the slope of the flow curve obtained between the no. of blows and the water content in Casagrande's method of determination of the liquid limit.

* About 120 gm of the specimen, passing 425 μ, is mixed throughly, with distilled water. The soil paste squeezed down and spread into position and groove is cut in the soil pat.

* The handle is rotated, at 2 rev/sec and the no. of blows are counted, until the two parts of the soil sample come into contact.

* The water content corresponding to 25 no. of blows is the liquid limit. Height of fall = 10 mm.

* As particle size decreases, LL, PL or PI increases.

* If silt is added to clay, LL, PL or PI decreases.

## Plastic limit determination :-

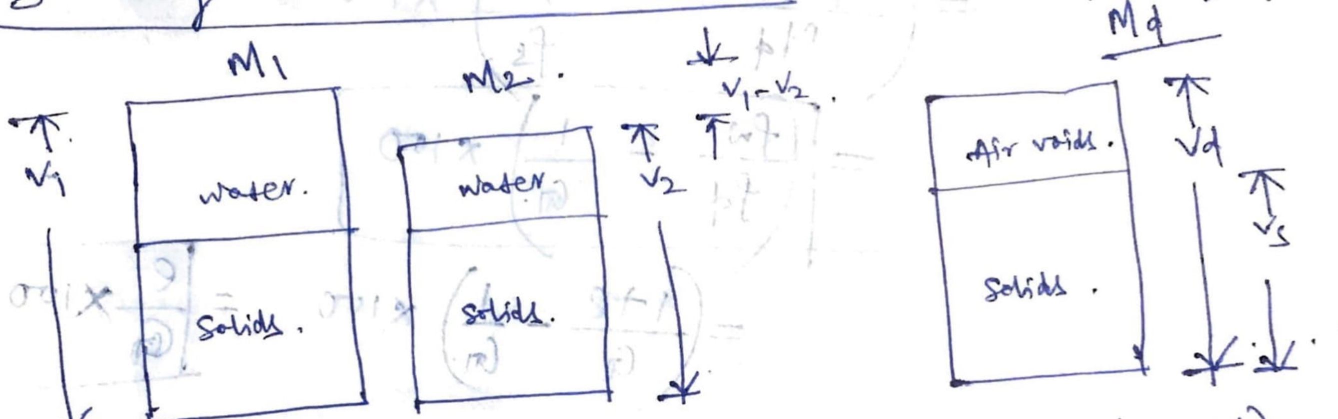
* Take soil specimen passing through 425 µ sieve, mixed thoroughly with distilled water.

* A ball is formed with about 8 gm of this plastic soil & rolled into a thread of dia 3mm, if the thread just start to crumble, the water content corresponding to this condition is known as plastic limit.

Toughness index $(I_T) = I_T = \frac{I_p}{I_f}$

* It is a measure of the shearing strength of the soil, at the plastic limit.

## Shrinkage limit determination :-




(original soil pat) (soil pat at shrinkage) (Dry soil pat)

$$W_s = \frac{(M_1 - M_d) - (V_1 - V_2)\rho_w}{M_d} \times 100$$

$$= \left[\frac{M_1 - M_d}{M_d} - \frac{(V_1 - V_2)\rho_w}{M_d}\right] \times 100$$

$$= \left[w_1 - \frac{(V_1 - V_d)\rho_w}{M_d}\right] \times 100$$

Determination of specific gravity of solids from Shrinkage limit :→

$$w_s = \frac{(V_d - V_s)\rho_w}{M_d} \times 100$$

$$= (V_d - V_s) \times \frac{\rho_w}{M_d} \times 100$$

$$= \left(V_d - \frac{M_d}{\rho_s}\right) \times \frac{\rho_w}{M_d} \times 100$$

$$= \left(\frac{V_d \times \rho_w}{M_d} - \frac{\rho_w}{\rho_s}\right) \times 100$$

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

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

Shrinkage parameters :→

(i) Shrinkage index, $I_s = w_l - w_s$.

(ii) Shrinkage ratio and shrinkage volume :→

Shrinkage ratio (SR) is defined as the ratio of given volume change expressed as a percentage of dry volume, to the corresponding change in water content.

$$SR = \frac{\left(V_1 - V_2 / V_d\right) \times 100}{w_1 - w_2}$$

$$= \frac{\frac{V_1 - V_d}{V_d} \times 100}{w_1 - w_s}$$

$$\Rightarrow SR = \frac{SV}{w_1 - w_s}$$

(iii) Linear shrinkage :→

Linear shrinkage (LS) is defined as the change in length divided by the initial length when the water content is reduced to the shrinkage limit.

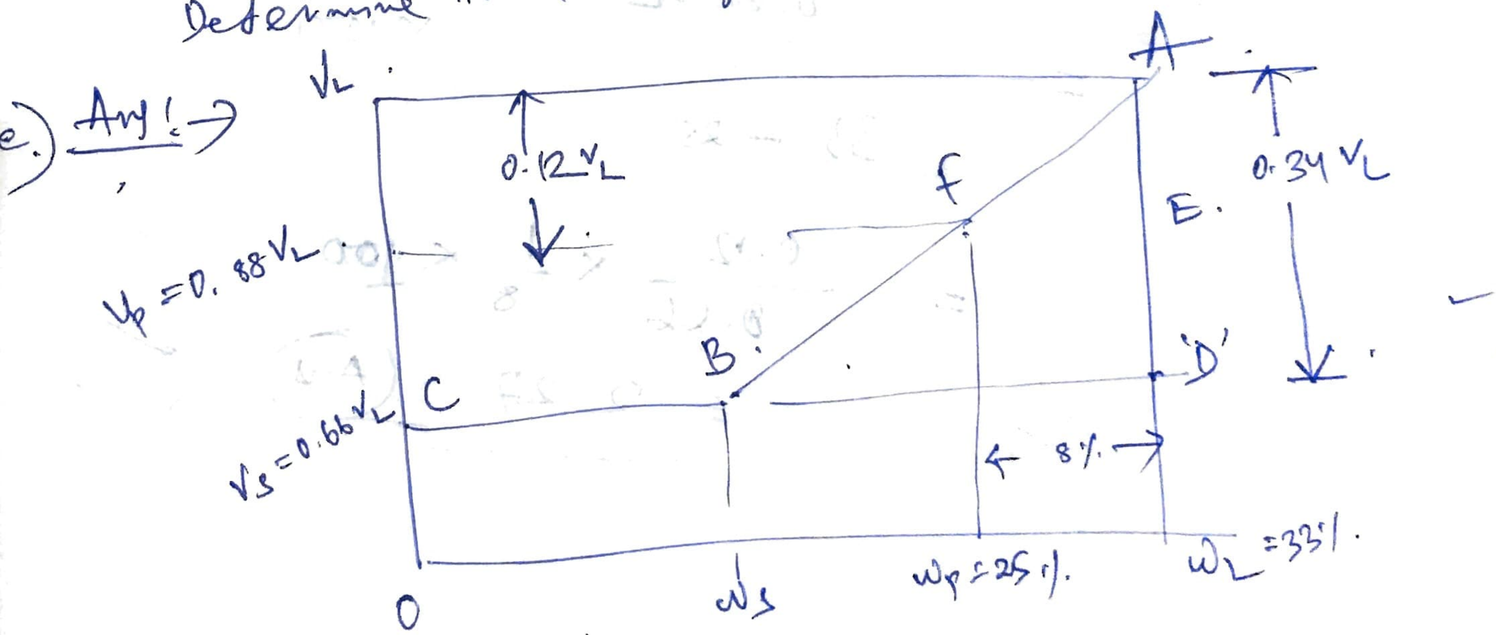
$$LS = \left[\frac{\text{Initial length} - \text{Final length}}{\text{Initial length}}\right] \times 100.$$

or, $SV(\%) = SR\left[(w)\% - SL\right].$

or, $$LS = \left[1 - \left(\frac{100}{VS + 100}\right)^{1/3}\right] \times 100.$$

Q.6. The plastic limit of a soil is 25%, and its plasticity index is 8%. When the soil is dried from its state at plastic limit, the volume change is 25% of its volume at plastic limit. Similarly, the corresponding volume change from the liquid limit to the dry state is 34% of its volume at liquid limit. Determine the shrinkage limit and shrinkage ratio.

Ans! →




$w_p = 25\%$, $I_p = 8\%$

$\therefore w_L = 25 + 8 = 33\%$

$V_s = V_L - 0.34\,V_L = 0.66\,V_L$.

$V_s = V_p - 0.25\,V_p = 0.75\,V_p$.

$\Rightarrow 0.75\,V_p = 0.66\,V_L$

$\Rightarrow V_p = 0.88\,V_L$.

$\Delta$ ABD & $\Delta$ AFE are similar.

$$\therefore \frac{AD}{BD} = \frac{AE}{FE} \Rightarrow BD = \frac{AD \times FE}{AE}$$

$$= \frac{0.34\,V_L \times 8}{0.12\,V_L}$$

$= 22.6\,\%$

$w_s = 33 - 22.6 = 10.4\,\%$

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

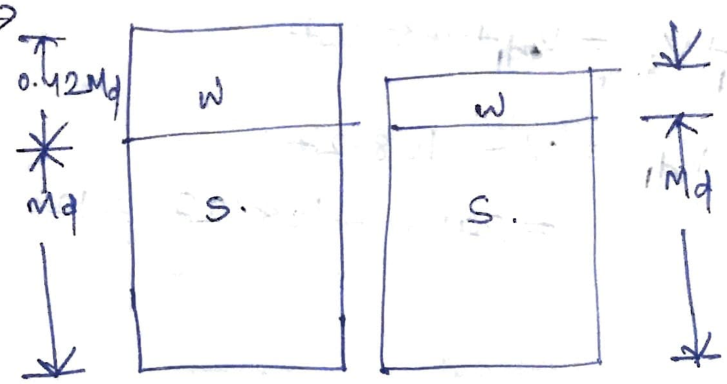
$$= \frac{\frac{V_L - 0.88\,V_L}{0.66\,V_L} \times 100}{33 - 25}$$

$$= \frac{0.12}{0.66} \times \frac{1}{8} \times 100$$

$= 2.27$ Ans

Q.7 A saturated soil sample has a volume of 25 cm³, at the liquid limit. If the soil has liquid limit and shrinkage limit of 42% and 20% respectively, determine the minᵐ volume, which can be attained by the soil specimen. Take G = 2.72

Solⁿ :→




By volume. $0.42\,M_d\ cm^3 + \frac{M_d}{G\rho_w}\ cm^3 = 25\ cm^3$

$\Rightarrow M_d = 31.74$ gm.

$0.2\,M_d\ cm^3 + 0.368\ M_d\ cm^3$

$\Rightarrow 18.03\ cm^3$ (Ans)

Q.8 An oven dried sample of soil has a volume of 265 cm³ and a mass of 456 gm. Taking G = 2.71, determine the void 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?

Solⁿ :→ $\rho_d = \frac{M_d}{V} = \frac{456}{265} = 1.721\ gm/cm^3$

$\rho_d = \frac{G\rho_w}{1+e}$, G = 2.71.

$\Rightarrow e = 0.575$.

Shrinkage limit, $w_s' = \frac{e}{G} = \frac{0.575}{2.71} = 0.212 = 21.2\%$ (Ans)

$V_d = 265\ cm^3$ (given).

$V_s = \frac{M_d}{\rho_s} = \frac{M_d}{G\rho_w} = \frac{456}{2.71} = 168.27\ cm^3$ ✓

$V = 1.1 V_d = 1.1 \times 265 = 291.5\ cm^3$ ✓

~~$V = V_{d1} + V_s = V_{d1} + 168.27$~~

~~$\Rightarrow V_{d1} = V - 168.27$~~

~~$= 291.5 - 168.27 = 123.23\ cm^3$~~

$\Rightarrow$

$V = V_w + V_s = V_w + 168.27$.

$\Rightarrow V_w = V - 168.27$

$= 291.5 - 168.27 = 123.23\ cm^3$

$\Rightarrow M_w = 123.23\ gm$. ✓

Final water content, $\frac{M_w}{M_d} = \frac{123.23}{456} = 0.27$

$= 27\ \%$ ✓

Q.9. Following are the results of a Shrinkage limit test: Initial volume of soil in a saturated state $= 24.6\ cm^3$. ✓

Final volume of soil, in a dry state, $= 15.9\ cm^3$. ✓

Initial mass in a saturated state $= 44.0\ gm$

Final mass in a dry state $= 30.1\ gm$. ✓

~~Determine the Shrinkage limit of the soil.~~

volumetric shrinkage (VS) and linear shrinkage (LS).

of the soil is of MC of 28 %.

$SR = \frac{\frac{\Delta V}{V_f}}{\frac{\Delta M}{M_2}} = \frac{M_2}{V_f \rho_w} = \frac{30.1}{15.9} = 1.89$ ✓

$SR = 1.89$

Sol$^n$ :-> Shrinkage limit ($w_s$)

$= \left[ \frac{44.0 - 30.1}{30.1} - \frac{(24.6 - 15.9)\ 1}{30.1} \right] \times 100$.

LS (%) ... consistency ... deformation ... plasticity

$= 46.18 - 28.9 = 17.28\%$

$VS(\%) = SR\,[w(\%) - SL]$.

$\Rightarrow VS = 1.89\,(28 - 17.28) = 20.26\%$

$$LS(\%) = \left[1 - \left(\frac{100}{(VS)\% + 100}\right)^{1/3}\right] \times 100$$

$$= \left[1 - \left(\frac{100}{20.26 + 100}\right)^{1/3}\right] \times 100 = 5.96\%$$

**Consistency :->** It is the resistance offered by a soil against deformation, varies with water content.

| Consistency | Consistency Index |
|---|---|
| Very soft | 0 - 25 |
| Soft | 25 - 50 |
| medium (firm) | 50 - 75 |
| Stiff | 75 - 100 |
| very stiff | > 100 |

**plasticity :->** property which allows it to be deformed, without rupture.

**Activity :->** It is the ratio of the plasticity index to the %age of clay fraction. It is a measure of the water holding capacity of clayey soil.

$$A_c = \frac{I_P}{C_w}$$

$1]$ $\times 100$.

where, $I_p$ = plasticity index.
$C_w$ = %age of clay fraction by weight.

* The swelling and shrinkage characteristics are represented by a number called, 'Activity number'.

* If, $A_c < 0.75$ → Inactive.
$0.75 < A_c < 1.40$ → Normal.
$A_c > 1.40$ → Active.

* For "montmorillonite" clay mineral, $A_c > 4$.
* For a soil of specific origin, $A_c$ is constant.

## Sensitivity of clay :-

The degree of disturbance of undisturbed clay sample due to remoulding is expressed by sensitivity ($S_t$) which is defined as the ratio of its unconfined compression strength in the natural or undisturbed state to that in the remoulded state, without change in the water-content.

$$S_t = \frac{q_u \text{ (undisturbed)}}{q_u \text{ (remoulded)}}$$

| Sensitivity | Classification | Structure |
|---|---|---|
| 1 | Insensitive | Highly over consolidated clay |
| 2-4 | Normal | Honey comb structure |
| 4-8 | Sensitive | Honey comb or flocculent structure |
| 8-16 | Extra sensitive | Flocculent structures |
| >16 | Quick | Unstable |

Q. 10. A clay sample has, LL & PL, 96% and 24% respectively. sedimentation analysis, reveals that, clay soil has 50% of the particles, smaller than 0.002 mm. Indicate the activity smaller than 0.002 mm - Indicate the activity classification of the clay soil and probable type of clay mineral.

Ans :→ $I_p = \omega_L - \omega_p = 96 - 24 = 72\%$

$A_c = \frac{I_p}{C_0} = \frac{74}{50} = 1.48$, Since, $A_c > 1.48$.

clay may be classified as being active.

probable clay mineral is, montmorillonite.

Q. 11 A clay specimen has, unconfined compression strength of 240 kN/m², in undisturbed state. Later on remoulding the UCS is found to be, 54 kN/m². classify the clay soil on the basic of its sensitivity and indicate the probable structure of clay soil.

Ans :→ sensitivity, $S_t = \frac{q_u \text{ (undisturbed)}}{q_u \text{ (remoulded.)}}$

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

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

**Soil structure :→**

The geometrical arrangement of soil particles w.r.t one another is known as, soil structure. The soils in nature have different structures depending upon the particle size and the mode of formation. The first two types are for coarse grained soils and Type '3' & '4' for fine grained soils. clays.

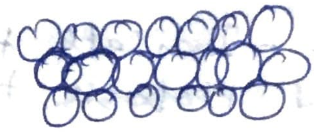
(1) Single grained structure :→ (1) It is formed due to gravel and sand, in which gravitational forces are predominant than surface forces.

(2) Since the particles are not, exactly sphere,

void ratio between the loosest and densest conditions varies between 0.90 and 0.35.

(3)

(loosest packing)
e = 0.90.



(Densest packing)
e = 0.35.

(4) smaller the void ratio, higher the shear strength and lower the compressibility and permeability

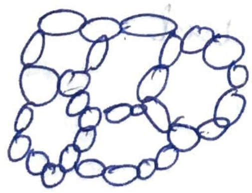
(5) when loose sands are subjected to shocks and vibrations particles move to more dense state

(6) Dense sands are quite stable, they are not affected by shock and vibrations.

(2) Honey-comb structure :-

(1) It is possible for fine sands or silts to get to develop a particle to particle contact that bridges over large voids in the soil mass.

(2)



(Honey-comb structure)

(3) Honey comb structure develops when particle size between 0.002 mm and 0.02 mm. This is due to cohesion, bcz of their fineness. but do not possess plasticity characteristics associated with clay soils.

(4) Particle wedge between one another into a stable condition, and form a skeleton like an arch which carry the weight of the overlying materials.

(5). Honey comb structure are loose. They can support load, under static conditions. under vibration and shocks, structure collapses and large deformation take place.

(6).

(3) Flocculated structure :→

(1) This is due to presence of clay particle of face to edge orientation. clay particle have negative charge on surface and positive charge on the edges.

(2) soil in flocculent structure have high void ratio and water content. soils are insensitive to vibrations. soils in flocculated structure have low compressibility, high permeability and high shear strength.

(3) It is more predominant in salt water than those in fresh water.

(clay particle)

(flocculated structure)

(4) Dispersed structure :→

(1) Dispersed structure develop in remoulded clay. Remoulded converts the edge to face orientation to face to face orientation.

(2) This is formed, when there is net repulsive force between particles.

(3) It has low shear strength, high compressibility and low permeability.

(Dispersed structure)

* When soil contains, different type of particles, a Composite structure is formed.

* Remoulding causes a loss of strength, in cohesive soils.

* The phenomenon of regain of lost strength, with the passage of time, with no change in water content is known as "thixotropy".

## Clay Minerals :-

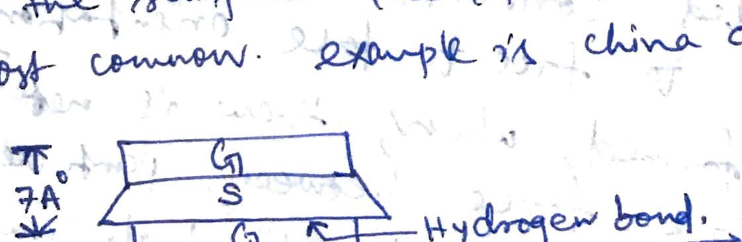
Clay mineralogy is the science dealing with the structure of clay minerals on microscopic, molecular and atomic scale.

### Kaolinite mineral :-

(1) The basic structural unit consist of alumina sheet (gibbsite) 'G' combined with silica sheet (S). Total thickness of structural unit is about 7 A°.

(2) Water can not easily enter between structural unit, & cause expansion. This mineral is stable.

(3) Flat surface of mineral attract +ve ions (cations) and water. A thick layer of adsorbed water is formed on the surface. The specific surface is about 15 $m^2/gm$. Most common example is china clay.



## Montmorillonite Mineral :→

(1) The basic structural unit consists of an alumina sheet sandwiched between two silica sheets. Thickness of each structural unit is about 10 A°.

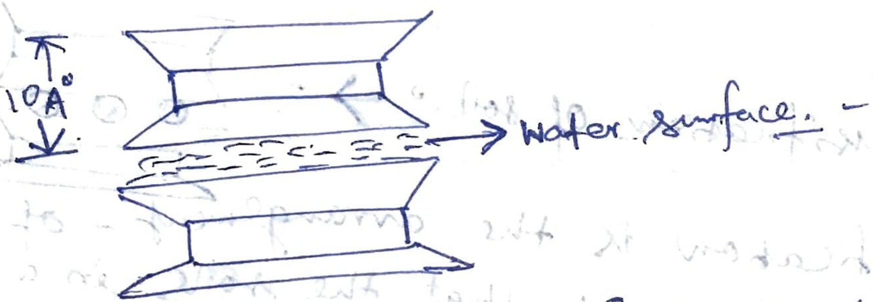
(2) Two structural unit joined together, due to natural attraction for cations in the intervening space and due to vander waal forces.

(3) The negatively charged surface of silica sheet, attract water, in the space between two structural units, which result in the expansion of the mineral.

(4) The soil contain large amount of mineral montmorillonite exhibits high shrinkage and swelling characteristics.

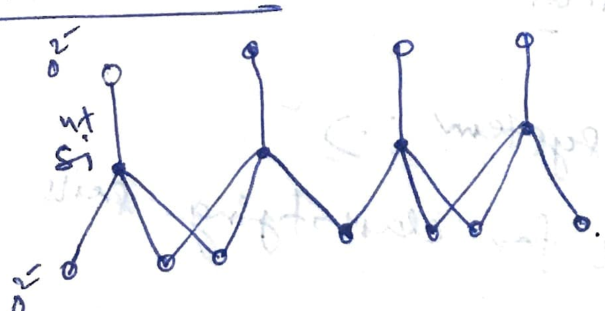
(5) The water in the intervening space can be removed by heating 200°C to 300°C.

(6) The specific surface is about 800 $m^2/gm$.




## Illite Mineral :→

(Basic structural unit of clay mineral)




$4 \times (-2) = -8$

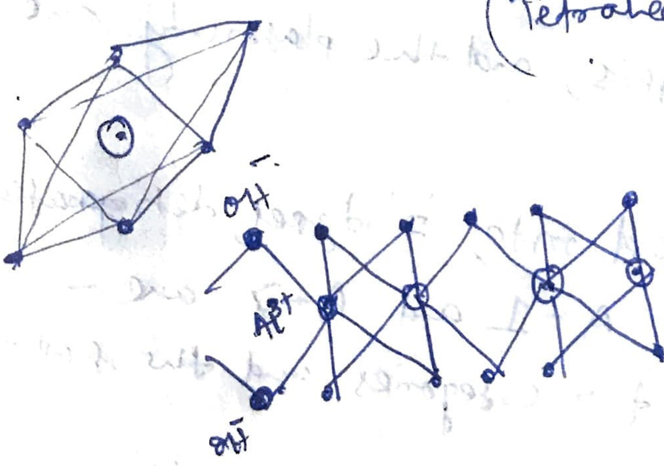
$4 \times (+4) = +16$

$6 \times (-2) = -12$

Net = −4.


(Silica)

(Tetrahedral unit)




$6 \times (-1) = -6$

$4 \times (+3) = +12$

$6 \times (-1) = -6$

Net = zero.


(Gibbsite)

(Octahedral unit)

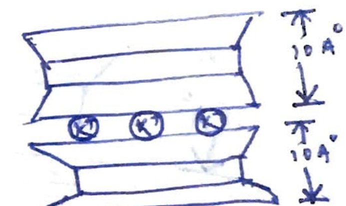
(1) Due to isomorphic substitution of silicon by aluminium, in silica sheet, illite has larger negative charge than that in, montmorillonite.

(2) The link between different structural unit is through non exchangeable potassium ($K^+$). , hence lattice of illite is stronger than that of montmorillonite.

(3) Illite swell less than montmorillonite, bcz the ($K^+$) ion just fit in between the silica sheet surfaces.

(4) The specific surface is about 80 $m^2$/gm.

NB:→ Kaolinite > illite > Montmorillonite → stronger.
Montmorillonite > illite > Kaolinite → swelling.




## Engineering classification of soil:→

Soil classification is the arrangement of soils into different groups such that the soils in a particular group have similar behaviour.

## AASHTO classification system:→

* This system is useful for classifying soils for highways.

* The particle size Analysis, and the plasticity are required to classify.

* soil system are divided into 7 types designated as A-1 to A-7. The soils A-1 and A-7 are further subdivided into two categories and the soil A-2 into four categories.

* Soil with lowest no. A-1 is the most suitable, as a highway material or subgrade.

* Fine grained soils are further rated, for their suitability for highways by the group index (GI).

$$GI = 0.2\,(F-35) + 0.005\,(F-35)(w_L-40) + 0.01\,(F-15)(I_p-10)$$

where, $F-35 = a$, $w_L-40 = c$

$F-15 = b$, $I_p-10 = d$.

$F-35$, & $F-15 \leq 40$, and $w_L-40$ & $I_p-10 \leq 20$.

where, $F$ = % by mass passing 75 µ sieve size (No. 200) expressed as whole no.

$w_L$ = liquid limit (%), expressed as whole no.

$I_p$ = plasticity index (%), expressed as whole no.

* If GI is -ve', group index is reported as zero. Smaller the value of group index, the better is the soil in that category. Group index of zero indicates a good subgrade whereas a group index of 20 or above shows very poor sub-grade.

A-7-5 (PL ≥ 30%),
A-7-6 (PL < 30%)

## Unified soil classification system :→

This system is most popular system for use in all types of engineering problems, involving soils. Various soils are classified into four major groups :→

(i) coarse grained.
(ii) Fine grained.
(iii) organic soils.
(iv) peat.

There are in all 15 groups of soil.

→ 8 - groups of coarse-grained soils.
→ 6 groups of fine grained soils.
→ 1 group for peat.

| Soil type | prefix: | Sub-group. | Suffix. |
|---|---|---|---|
| Gravel. | G. | well-graded. | W |
| Sand. | S | poorly-graded. | P. |
| Silt | M | Silty. | M |
| clay. | C | clayey | C. |
| organic. | O | $w_L < 50\%$. | L |
| peat. | Pt. | $w_L > 50\%$. | H. |

(1) Coarse grained soils :→

If more than 50%. of the soil is retained on No. 200 (0.075 mm) sieve, it is designated as coarse-grained soils.

(2) fine grained soils :→

If more than 50% of the soil passes No. 200 sieve (0.075 mm) it is called fine grained soil.

1. Coarse grained soils :→

Coarse grained soils are designated as gravel (G) if 50%. or more of coarse fraction retained on 4.75 mm sieve, otherwise it is termed as Sand (S).

Coarse grained soils contain less than 5%. fines are well graded (W), they are given symbol GW and SW and if poorly graded (P) the symbols GP and SP.

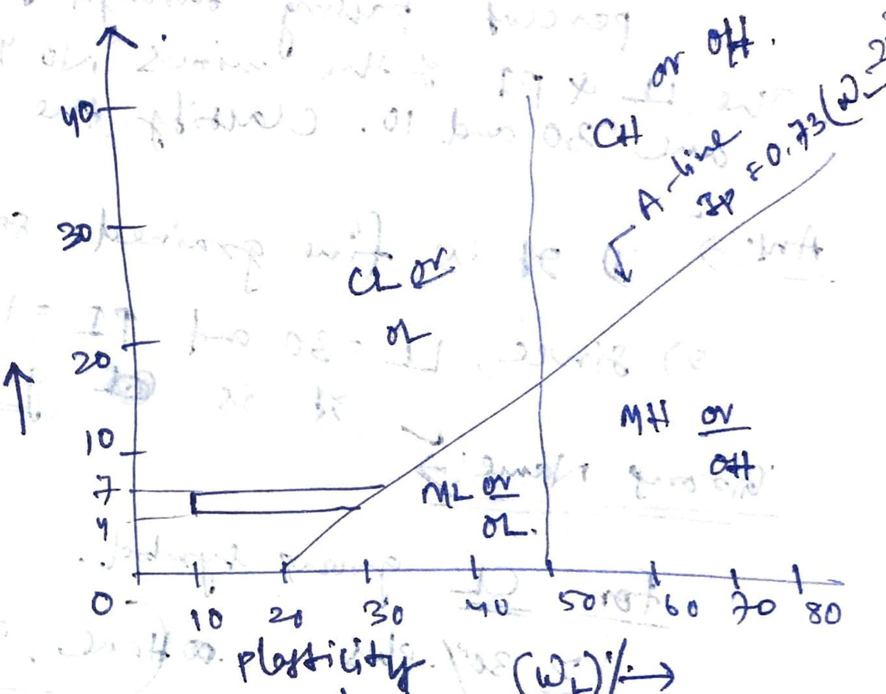
If the coarse grained soils, contains more than 12% fines, they are designated as GM, GC, SM or SC. If the %age fines is between 5 to 12%, dual symbol such as GW-GM, GW-GC, GP-GM, GP-GC, SW-SM, SW-SC, SP-SM, SP-SC.

## 2. Fine grained soils :-)

Fine grained soils are further divided into two types :-

(1) Soils of low compressibility (L) ($w_L < 50\%$) ML, OL and CL.

(2) Soils of high compressibility ($w_L > 50\%$) MH, ~~CH and OH~~




plasticity chart (USC)

* A-line separate clays from silt.

* If oven drying decreases the L.L by 25% or more, the soil is classified as organic (OL or OH)

High organic soil :- These soils are termed as peat, (Pt) which is identified by visual inspection.

* If $4 \le PI \le 7$, plots in the hatched area, use dual symbol CL-ML.

1. If $4 \le PI \le 7$, and plots in the hatched area, use dual symbol, GC-GM or SC-SM.

Q.12

The result of the particle size analysis of a soil are as follows :→

percent passing through the No. 200 sieve = 58.

percent passing through the No. 40 sieve = 80

percent passing through the No. 10 sieve = 100

The LL & PI of the minus No. 40 fraction of the soil are 30 and 10. Classify the soil by UCS.

Ans. → 1) It is fine grained soil, (Since > 50% (i.e. 58%) passing No. 200)

2) Since, LL = 30 and PI = 10,

It is group symbol = CL.

Group Name :→

For CL group symbol.

≥ 30% plus No. 200 → Here, 58%

↓

% sand ≥ % gravel

% sand = 100 − 58 = 42%

% gravel = 0 %

↓

< 15% gravel

gravel % = 0

↓

Sandy lean clay.

200
40
10
04

Q.13 From the grain size distribution of two soils,

Soil A minus No. 200 is 8, %age retained on No. 4 is 0, $D_{10}$ = 0.085 mm

$D_{30}$ = 0.12 mm

& $D_{60}$ = 0.135 mm.

LL & PL of soil minus No. 40 sieve is 30 & 20.

Determine the group symbol & group Name according USCS.

Ans! →

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.135}{0.085} = 1.59 < 6$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{(0.12)^2}{(0.135)(0.085)} = 1.25 > 1.$$

LL = 30, PI = 30 − 22 = 8 > 7

∴ group symbol = SP − SC. (bcz, gravel % = 0).

SP − SC

↓

< 15 % gravel (gravel % = 0)

↓

**poorly graded sand with clay**

Soil B → %age passing No. 200 is 61

LL = 26 PL = 20

PI = LL − PL = 26 − 20 = 06

Ans! → Since, passing No. 200 is 61 > 50%.

Hence, it is fine grained soil.

PI index plots in the hatched area

group symbol = CL − ML.

CL − ML

↓

≥ 30 % plus No. 200. (passing no. 200 is 61 %)

↓

% sand ≥ % gravel.

% sand = 100 − 61 = 39.

% gravel = 0.

gravel % = 0.

↓

< 15 1/. gravel.

↓

**sandy silty clay**