24/10/17 Soil-Mechanics Lecture # 01;

Soil → Latin ... layer of earth

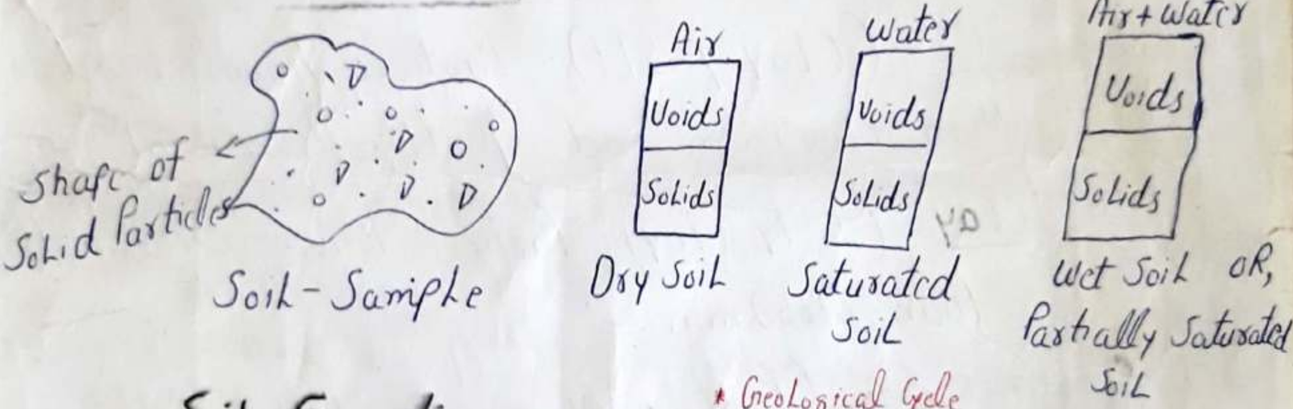
**Soil:** A mixture of organic and inorganic substances obtained from the dis-integration of rocks.

Plowed

**Soil Mechanics:** It is a branch of engineering which deals about the Properties and behaviour of Soil.

**Purpose:** To replace old method of Construction and design.

**Soil and its Constituents:** Three Phase diagram / Block dia-




**Soil Formation:** * Geological Cycle
Erosion → Trasportation → Deposition → Upheaval
wind + water

**Weathering of Rocks:** Change of Rock into new material.

a- **Mechanical Weathering:** Big Pieces of rock are converted into small Particles having same Properties with the Parent element.

1- Impact of water
2- Wind Action
3- Rolling of Glaciers
4- Expansion and Contraction of Rocks.

* If the Soil stays at the place of its formation Just above Parent Rock, (Residual or, Sedentary Soil)

b- **Chemical weathering:** materials having different Properties from Parent material due to oxidation and reduction Process.

## Types of Soil:

* when the soil has been deposited at a place away from the Place of Origin (Transported Soil).

1- **Coarse Grained Soil (Cohesionless Soil):**

a- **Sand:** Particle having size larger than 0.075mm or, 0.06mm and smaller than 2mm.

b- **Gravel:** Particle of soil having size Larger than 2mm.

2- **Fine Grained Soil: (Cohesive Soil)**

a- **Silt:** (Clayey Silt): Particle having size Larger than 0.002mm and smaller than 0.075mm.

b- **Clay:** (Silty Clay): Particle having size smaller than 0.002mm.

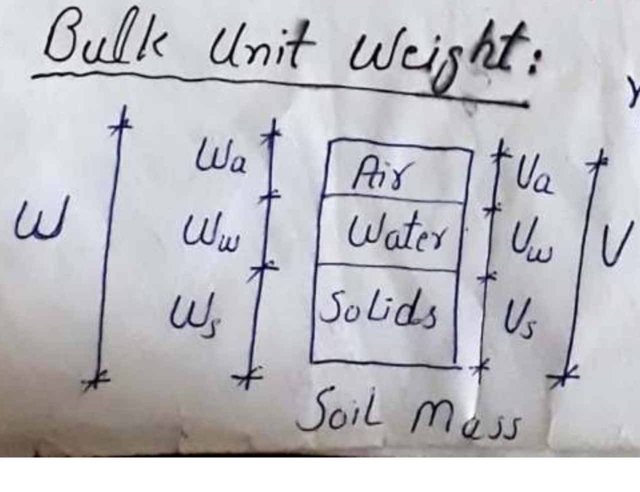
3- **Organic Soil (Peat):** It is a good soil for crops but not for construction Purposes. It is very weak soil and also contain some amount of toxic gases.

## Soil Properties:

* Soil carried & deposited by water (alluvial deposits)
* Soil deposited by wind aeloian deposits.
* Soil deposited by gravity is Colluvial Soil.

1- **Bulk Unit Weight:**

$$\gamma_B = \frac{\text{Total wt. of Soil}}{\text{Total Vol. of Soil}} = \frac{W}{V}$$



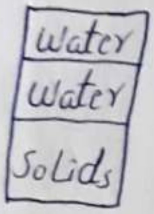
2- Unit wt. of Soil Solid:

$$\gamma_s = \frac{\text{Weight of Soil Solid}}{\text{Vol. of Soil Solid}} = \frac{W_s}{V_s}$$

3- Dry Unit Weight:

$$\gamma_d = \frac{\text{Wt. of Soil Solid}}{\text{Total Vol. of Soil}} = \frac{W_s}{V} \rightarrow W_d$$

4- Saturated Unit Weight:




$$\gamma_{sat} = \frac{\text{Wt. of Saturated Soil}}{\text{Vol. of Saturated Soil}} = \frac{W_{sat}}{V_{sat}}$$

5- Submerged Unit Weight:

$$\gamma_{sub} = \gamma_{sat} - \gamma_w \quad \text{where; } \gamma_w = \frac{\text{Wt. of water}}{\text{Vol. of water}}$$

↳ Unit wt. of water.

6- Specific Gravity: G:

$$G = \frac{\text{Unit wt. of Substance}}{\text{Unit wt. of water}}$$

$\gamma_w = 998\ kg/m^3$
$62.4\ lb/ft^3$
$9.8\ kN/m^3$

a- Mass Specific Gravity / Bulk Sp-Gravity / Apparent Sp-Gravity:

$$G_m = \frac{\text{Bulk Unit wt. of Soil}}{\text{Unit wt. of water}} = \frac{\gamma_B}{\gamma_w}$$

b- Sp-Gravity of Soil Solid / True Sp-Gravity / Absolute Sp-Gravity:

$$G_s = \frac{\text{Unit wt of Soil Solid}}{\text{Unit wt of water}} = \frac{\gamma_s}{\gamma_w}$$

## 7- Volume Ratios:

**A- Porosity:** $n = \dfrac{\text{Vol. of Voids}}{\text{Total Vol. of Soil Mass}} = \dfrac{V_v}{V}$

**B- Void Ratio:** $e = \dfrac{V_v}{V_s} = \dfrac{\text{Volume of Voids}}{\text{Volume of Soil Solid}}$

**C- Degree of Saturation:** $S = \dfrac{\text{Volume of Water}}{\text{Volume of Voids}} = \dfrac{V_w}{V_v}$

**D- Air Content:**

$$a_c = \frac{\text{Volume of Air}}{\text{Volume of voids}} = \frac{V_a}{V_v}$$

## 8- Weight Ratio:

**E- Water Content or, Moisture Content (W or, M):**

$$W = \frac{\text{wt. of water}}{\text{wt. of Soil Solid}} = \frac{W_w}{W_s \rightarrow W_d} \times 100$$

**Relationship b/w Porosity and voids Ratio of Soil:**

$$n = \frac{V_v}{V} \quad (\text{where; } V = V_s + V_v)$$

$$n = \frac{V_v}{V_s + V_v} = \frac{V_v/V_s}{\frac{V_s + V_v}{V_s}} = \frac{V_v/V_s}{V_v/V_s + V_s/V_s}$$

$$n = \frac{e}{(e+1)} \text{ or, } \frac{e}{1+e} \quad \left(\text{Because } e = \frac{V_v}{V_s}\right)$$

OR,

$$n + ne = e \Rightarrow n = e - ne \Rightarrow n = e(1-n)$$

or, $e = n/(1-n)$

# Lecture # 02;

## Relation among Water Content ($\omega$), Void Ratio ($e$), Degree of Saturation ($S$) and Sp. Gravity of Soil Solid ($G_s$).

$$\omega = \frac{W_w}{W_s}$$

As; $\gamma_w = W_w / V_w$ and, $\gamma_s = W_s / V_s$

$W_w = \gamma_w \times V_w$ $\quad$ $W_s = \gamma_s \times V_s$

$$\omega = \frac{\gamma_w \times V_w}{\gamma_s \times V_s}$$

Also; $S = \dfrac{V_w}{V_v}$ So, $V_w = S \times V_v$

$$\omega = \frac{\gamma_w \times S \times V_v}{\gamma_w \times G_s \times V_s}$$

and; $G_s = \dfrac{\gamma_s}{\gamma_w}$ So; $\gamma_s = \gamma_w \times G_s$

$$\boxed{\omega = \frac{S \times e}{G_s}}$$

Also; $e = V_v / V_s$.

## Relation among Bulk Unit wt. ($\gamma_B$), Unit wt. of Water ($\gamma_w$), Sp-Gravity of Solids ($G_s$), Water Content ($\omega$), and Void Ratio of Soil ($e$):

$$\gamma = \gamma_B = \frac{W}{V}$$

where; $W = W_w + W_s$

and $V = V_v + V_s$ $\quad$ If $W_a \approx 0$

$$\gamma_B = \frac{W_w + W_s}{V_v + V_s} = \frac{\frac{W_s}{W_s}(W_w + W_s)}{\frac{V_s}{V_s}(V_s + V_v)} = \frac{W_s\left(\frac{W_w + W_s}{W_s}\right)}{V_s\left(\frac{V_s + V_v}{V_s}\right)}.$$

$$\gamma_B = \frac{W_s\left(\frac{W_w}{W_s} + 1\right)}{V_s\left(1 + \frac{V_v}{V_s}\right)}$$

where; $\omega = \dfrac{W_w}{W_s}$, $\gamma_s = \dfrac{W_s}{V_s}$ and $e = \dfrac{V_v}{V_s}$.

$$\gamma_B = \frac{\gamma_s \times (1 + \omega)}{(1 + e)}$$

$$\gamma_B = \frac{G_s \times \gamma_w \times (1+\omega)}{(1+e)}$$

As, $G_s = \frac{\gamma_s}{\gamma_w}$ or, $\gamma_s = G_s \times \gamma_w$.

**Relation Ship among Bulk Unit Weight, Unit Weight of water, Sp- Gravity of Soil, degree of Saturation and void Ratio:**

$$\gamma_B = \frac{G_s \times \gamma_w \times (1+\omega)}{(1+e)}$$

As; $\omega = \frac{e \cdot S}{G_s}$.

$$\gamma_B = \frac{G_s \times \gamma_w \times \left(1 + \frac{e \cdot S}{G_s}\right)}{(1+e)} = \frac{G_s \times \gamma_w \times \left(\frac{G_s + e \cdot S}{G_s}\right)}{(1+e)}$$

$$\gamma_B = \frac{\gamma_w (G_s + e \cdot S)}{(1+e)}$$

**Relation Ship among Dry Unit Wt. ($\gamma_d$), Unit Wt. of Water ($\gamma_w$), Sp- Gravity of Soil Solid ($G_s$) and Void Ratio ($e$):**

Dry Unit Wt $= \gamma_d = \frac{W_s}{V}$

where; $\gamma_s = \frac{W_s}{V_s} \Rightarrow W_s = \gamma_s \times V_s$

and $V = V_v + V_s$

Also; $G_s = \frac{\gamma_s}{\gamma_w} \Rightarrow \gamma_s = G_s \times \gamma_w$.

$$\gamma_d = \frac{\gamma_s \times V_s}{V_v + V_s}$$

$$\gamma_d = \frac{G_s \times \gamma_w \times V_s}{V_v + V_s}$$

$$\gamma_d = \frac{\frac{G_s \times \gamma_w \times V_s}{V_s}}{\frac{V_v + V_s}{V_s}} = \frac{\gamma_w \times G_s}{1 + \frac{V_v}{V_s}}$$

where: $e = \frac{V_v}{V_s}$.

$$\gamma_d = \frac{\gamma_w \times G_s}{1+e}$$

## Relation b/w Dry Unit Weight ($\gamma_d$), Bulk Unit Wt. ($\gamma_B$), and Water Content of Soil ($\omega$):

$$\omega = \frac{W_\omega}{W_s} \Rightarrow 1+\omega = 1 + \frac{W_\omega}{W_s}$$

$$1+\omega = \frac{W_s + W_\omega}{W_s} \Rightarrow 1+\omega = \frac{W}{W_s} \Rightarrow \frac{1+\omega}{V} = \frac{W}{W_s \times V}$$

$$\frac{W_s}{V} = \frac{W}{(1+\omega)\times V}$$

where; $\gamma_d = \frac{W_s}{V}$

and; $\gamma_B = W/V$

$$\boxed{\gamma_d = \frac{\gamma_B}{1+\omega}}$$

## Relation b/w Mass Sp-Gravity ($G_m$), Sp-Gravity of Soil ($G_s$), water Content ($\omega$) and void Ratio ($e$):

$$\gamma_B = \frac{\gamma_\omega \cdot G_s \cdot (1+\omega)}{(1+e)}$$

As; $G_m = \frac{\gamma_B}{\gamma_\omega}$

$\gamma_B = \gamma_\omega \times G_m$

$$\gamma_\omega \times G_m = \frac{\gamma_\omega \cdot G_s \cdot (1+\omega)}{(1+e)}$$

$$\boxed{G_m = \frac{G_s \times (1+\omega)}{1+e}}$$

Int the [illegible]

Pb-1: A moist Soil Sample weighing 45 lbs has volume of 0.43 $ft^3$. After drying the soil it weighs 40 lbs. Calculate Bulk Unit Weight, water Content, Degree of Saturation, void ratio and Porosity of Soil Sample? If Sp-Gravity of Soil Solid is 2.67.

Sol: Given Data: Total Weight = $W = 45$ lbs,

Weight of dry Soil = $W_d = 40$ lbs, Total Volume = $V = 0.43\ ft^3$,

Sp-Gravity = $G_s = 2.67$.

Required: $\gamma_B = ?$ , $\omega = ?$ , $S = ?$ , $e = ?$ , $n = ?$

Solution: $\gamma_B = \frac{W}{V} = \frac{45}{0.43} = 104.65\ lb/ft^3$.

$$\omega = \frac{W_w}{W_s} \times 100 = \frac{5}{40} \times 100 = 12.5\ \%$$

$\gamma_w = \frac{W_w}{V_w}$ or, $V_w = \frac{W_w}{\gamma_w} = \frac{5}{62.4}$ where; $\gamma_w = 62.4\ lb/ft^3$

$$V_w = 0.08\ ft^3.$$

$$\gamma_s = \frac{W_s}{V_s} \text{ or, } V_s = \frac{W_s}{\gamma_s} = \frac{40}{\gamma_w \times G_s} = \frac{40}{62.4 \times 2.67}$$

$$V_s = 0.24\ ft^3.$$

$$V = V_v + V_s \Rightarrow V_v = V - V_s \Rightarrow V_v = 0.43 - 0.24$$

$$V_v = 0.19\ ft^3.$$

$$S = \frac{V_w}{V_v} = \frac{0.08}{0.19} = 0.42 = 42.1\ \%$$

$$e = V_v/V_s = 0.19/0.24 = 0.79$$

$$n = V_v/V = 0.19/0.43 = 0.44 = 44\ \%$$

ii- To find Volume of saturated Soil:

Empty weight = $W'$.

Wt + mercury = $W''$.

wt. of mercury filling the dish = $W'' - W'$.

∴ Vol. of Mercury filling the dish = $\frac{W'' - W'}{\gamma_m}$ → 13.6

↳ Range of water Content over which the soil remains in the plastic state.

**Plasticity Index: P.I:** It is the numerical difference between L.L and P.L.

$$P.I = L.L - P.L \quad (\%age).$$

**Liquidity Index: L.I or, Index of relative Plasticity:**

↳ Also known as Water Plasticity Ratio.

$$L.I = \frac{\omega - P.L}{P.I}$$

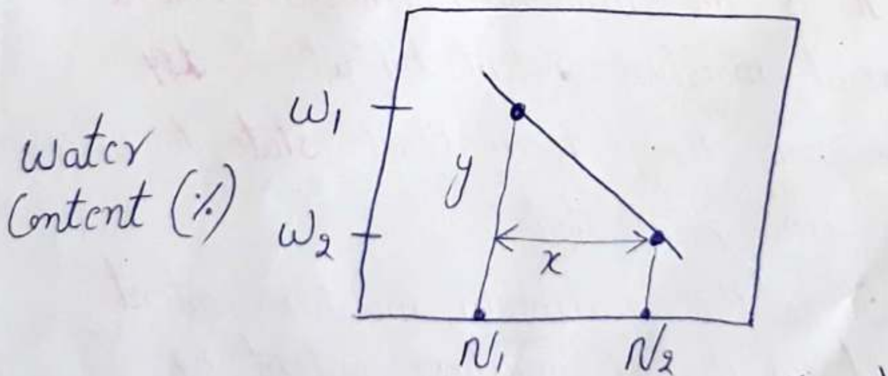
where; $\omega$ = water Content

P.L = Plastic Limit.

P.I = Plasticity Index.

**Flow ~~Curve~~ Index: F.I:** It is slope of Flow Curve.

$$F.I = \frac{y}{x} = \frac{\omega_1 - \omega_2}{\log N_2 - \log N_1}$$




CC = $cm^3$
↳ ml

**Toughness Index:**

$$T.I = \frac{P.I}{F.I}.$$

**Pb-2:** A Saturated Soil has a water Content of 39.3% and Mass Sp-Gravity of 1.84. Find Sp-Gravity of Soil Solid and void Ratio of Soil Sample?

**Given Data:** $\omega = 39.3\%$ , $S = 1 = 100\%$ , $G_m = 1.84$,

**Required:** $G_s = ?$ , $e = ?$

**Solution:**

$$\omega = \frac{e \cdot S}{G_s} \quad \text{or,} \quad e = \frac{G_s \times \omega}{S}$$

$$e = \frac{G_s \times 39.3}{100} \Rightarrow e = 0.393\,G_s \rightarrow (1)$$

$$G_m = \frac{G_s \times (1+\omega)}{(1+e)} \Rightarrow 1.84 = \frac{G_s \times (1+39.3)}{(1+0.393\,G_s)}$$

$39.3/100 = 0.393$

$1.84 + 0.72\,G_s = G_s + .393\,G_s$

$1.84 = 0.67\,G_s$

$\Rightarrow G_s = 2.75$

$$\boxed{G_s = 2.75}$$

$$(1) \Longrightarrow e = 0.393 \times 2.75 = 1.08$$

**Pb-3:** The bulk Unit Wt. of Soil Sample is 125 $lb/ft^3$ and Sp-Gravity of Soil is 2.66. Determine dry Unit Weight, Voids Ratio, Porosity and degree of saturation If water Content is 10%.

**Given Data:** $\gamma_B = 125\ lb/ft^3$ , $G_s = 2.66$ , $\omega = 10\%$

**Required:** $\gamma_d = ?$ , $e = ?$ , $S = ?$

**Solution:**

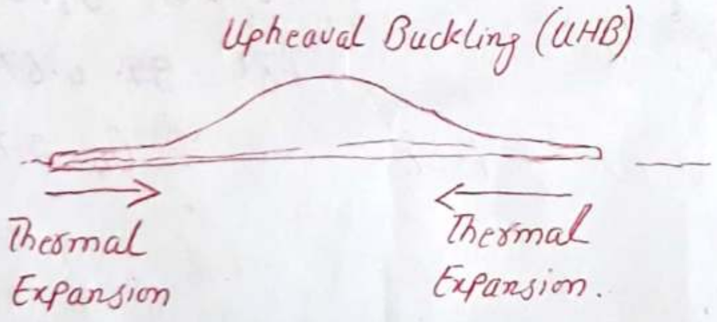
$$\gamma_d = \frac{\gamma_B}{1+\omega} = \frac{125}{1+0.10} = 113.63\ lb/ft^3$$

$$\gamma_d = \frac{\gamma_w \times G_s}{1+e} \quad \text{OR,} \quad e = \left(\frac{\gamma_w \times G_s}{\gamma_d} - 1\right)$$

$$e = \left(\frac{62.4 \times 2.66}{113.64} - 1\right) = 0.461$$

$$n = \left(\frac{e}{1+e}\right) \times 100 = \left(\frac{0.461}{1+0.461}\right) \times 100 = 31.55\%$$

$$w = \frac{e \cdot S}{G_s} \Rightarrow S = \frac{w \times G_s}{e} = \frac{10 \times 2.66}{0.461} = 57.7$$



# Lecture # 03;

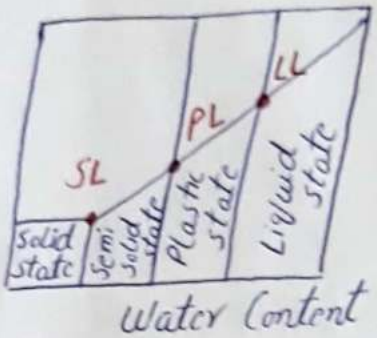
## Atterberg's Limits OR, Consistency Limits:

↳ It is state of Soil from which we Know about the cohesion & adhesion b/w Particles of soil.

### 1- Liquid Limit of Soil:

It is the minimum water content at which 25 blows will close a groove of standard dimension for a distance of $\frac{1}{2}$".

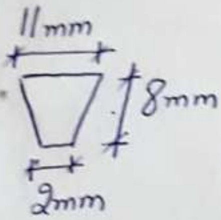
→ "The water content at which the soil changes from one state to the other."




"The minimum moisture content Percentage by dry weight at which the soil starts flowing under its own weight."

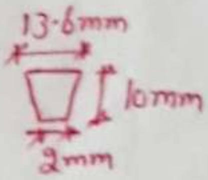
Grooving Tool:

Cup is lifted upto 1cm.

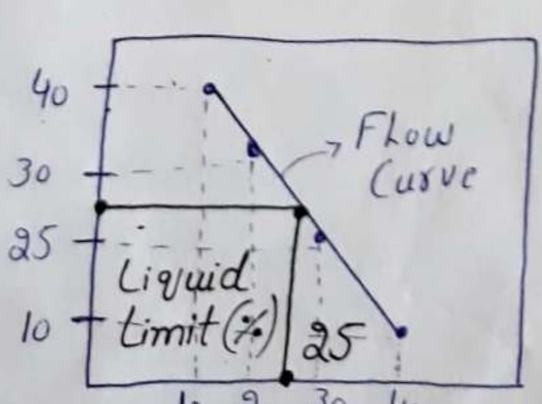



2 rev/sec

Exact 25 blows




| Observation Number: | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| No. of Blows (N) | $N_1=40$ | $N_2=30$ | $N_3=20$ | $N_4=10$ |
| Water Content (%) | $\omega_1=10$ | $\omega_2=25$ | $\omega_3=30$ | $\omega_4=40$ |




Liquidity Index of a soil indicates the nearness of its water content to its liquid limit.

- When the soil is at its L.L, its L.I is 100% & it behave as Liquid.
- When the soil is at the Plastic Limit, its L.I is zero.
- Negative value of L.I indicates a water content which is less than the Plastic Limit. Soil is then in hard state.

Consistency:

It is a resistance which is found b/w Particles of soil in the Presence of water against those forces which tries to change the shape of soil or disintegrate Soil.

2- **Plastic Limit:** It is the maximum water content at which the soil mass just crumbles (break) when rolled into a thread of $\frac{1}{8}''$ diameter. Convert it into ball with help of glass
→ Then convert it into threads so that crack will produce.

→ Soil → Too dry → $d > \frac{1}{8}''$ → Add more 2cc water
→ Soil → wet → $d < \frac{1}{8}''$ → Add dry soil.

Repeat the process again so that cracks are produce at $d = \frac{1}{8}''$ and this limit is known as P.L.

3- **Shrinkage Limit:** It is the water content at which further loss of water will not cause any decrease in the volume of soil.

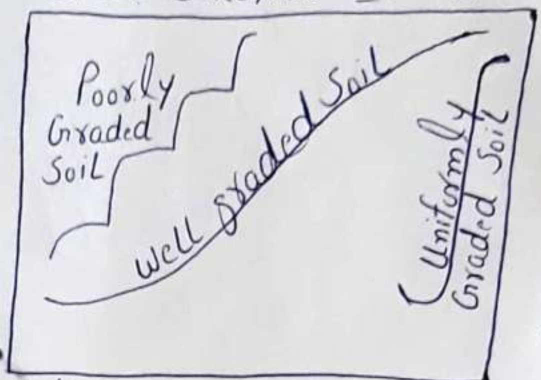
$$W_s = \left[ \frac{\omega - (V - V_d) \times \gamma_w}{W_d} \right] \times 100$$

where, $W_s$ = Shrinkage limit
$\omega$ = water content
$V$ = Initial Volume (Volume of saturated soil)
$V_d$ = Vol. of dry soil
$W_d$ = Wt. of dry soil

i- water content and weight of dry soil:
Weight of empty shrinkage dish = $W$
Wt. of shrinkage dish + Saturated soil = $W_1$
Wt. of shrinkage dish + dry soil = $W_2$
Wt. of dry soil = $W_2 - W$
Wt. of water = $W_1 - W_2$.

$$\text{Water Content} = \omega = \frac{W_w}{W_d} \times 100 = \frac{W_1 - W_2}{W_2 - W} \times 100.$$

**Types of Soil:** 1- Well graded Soil
2- Poorly graded Soil → Gap-Graded
3- Uniformly graded Soil




Gradation Curve OR, Grain Size distribution Curve.

## Hazen's Co-efficient:

### 1- Co-efficient of Uniformity ($C_u$) OR, Uniformity Co-efficient:

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

$D_{60}$ → Particle Size such that 60% of the soil is finer than this size.

Also known as effective Size ← $D_{10}$ → Particle Size such that 10% of the Soil is finer than this Size.

Uniform Soil: $C_u < 5$, Medium Soil: $C_u = 5-15$,
Non Uniform Soil: $C_u > 15$.

### 2- Co-efficient of Curvature: $C_c$:

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

$D_{60} = 2mm$
$D_{30} = 0.3mm$
$D_{10} = 0.06mm$

For Well Graded Soil: $C_c = 1-3$
For Gravel: $C_c > 4$.
For Sand: $C_c > 6$.

**Stoke's Law:** If a sphere is allowed to fall through a liquid of indefinite extent, its velocity will increase rapidly at first under the acceleration of gravity, however a constant terminal velocity is reached with in few seconds and is maintained indefinitely as long as the conditions are not changed.

This velocity is given by the following equations;

$F_D = 6 \pi \eta r U_T$ (r → radius; η → Viscosity (Kg/m/sec))

$$U = \frac{(\gamma_s - \gamma_w)}{18 \times \mu} \times D^2$$

where;

$U$ = velocity of fall of Particle.

$\gamma_s$ = Unit wt. of sphere.

$\gamma_w$ = Unit wt. of water.

$\mu$ = Viscosity of liquid

$D$ = Diameter or, Size of sphere or, Particle.

**Validity of Law:** 0.2mm — 0.002mm Size

**Limitations / Assumptions:**

1- Soil Particles are sphere.

2- Particles fall independently of other Particles, and there is no effect on velocity of fall of Particle by the neighboring Particles.

3- Wall of the container has no effect on the velocity of fall of Particles.

# Classification of Soil:

## 1- Grain Size Classification / Particle Size Classification:

### i- US-Bureau of Soil Classification:

| Clay | Silt | Sand | | | | Gravel | |
|---|---|---|---|---|---|---|---|
| | | Very Fine Sand | Fine Sand | Medium Sand | Coarse Sand | Fine Gravel | Coarse Gravel |
| Particle < Size 0.002 mm | 0.05 mm | 0.1 mm | 0.25 mm | 0.5 mm | 1.00 mm | 2.00 mm | |

### ii- ASTM Soil Classification System:

American Society for Testing and materials

| Clay | Colloids OR, Colloidal Clay | Silt | Sand | | Gravel |
|---|---|---|---|---|---|
| | | | Fine Sand | Coarse Sand | |
| 0.001 mm | 0.005 mm | 0.074 mm | 0.25 mm | 2.00 mm | |

### iii- M.I.T Soil Classification System:

Massachusetts

| Clay | | | Silt | | | Sand | | | Gravel |
|---|---|---|---|---|---|---|---|---|---|
| Fine Clay | Medium Clay | Coarse Clay | Fine Silt | Medium Silt | Coarse Silt | Fine Sand | Medium Sand | Coarse Sand | |
| 0.0002 mm | 0.0006 mm | 0.002 mm | 0.006 mm | 0.02 mm | 0.06 mm | 0.2 mm | 0.6 mm | 2.00mm | |

## 2- Soil Classification By Triangular Chart: OR, Textural Classification:

- A-4, A-5 → Silty Soil
- A-6, A-7 → Clayey Soil
  - ↳ Fair to Poor

Excellent to Good:
- A-1 → Stone Fragments (Gravel & Sand)
- A-3 → Fine Sand
- A-2 → Silty or Clayey Gravel Sand

Texture means visual appearance of the surface of a material

Sand = 20% , Silt = 20% , Clay = 60%
This is Clay Soil.

Sand = 70% , Silt = 20% , Clay = 10% (Sandy loam)

Sand Size = 0.05mm - 2.0mm , Silt Size = 0.005mm - 0.05mm
Clay Size < 0.005mm

→ Coarse Grained Soil
→ Fine Grained Soil

## 3- Unified Soil Classification System: USCS:

## 4- AASHTO Soil Classification System:

A-1: A-1-a, A-1-b
A-2: A-2-4, A-2-5, A-2-6, A-2-7
A-3
A-4
A-5
A-6
A-7: A-7-5, A-7-6

## Permeability of Soil:

Ability of Soil to allow water to Pass through its Pores.

1- Permeable/Pervious Soil
2- Impermeable/Impervious Soil
→ when the Permeability is extremely Low

## Hydraulic Gradient:

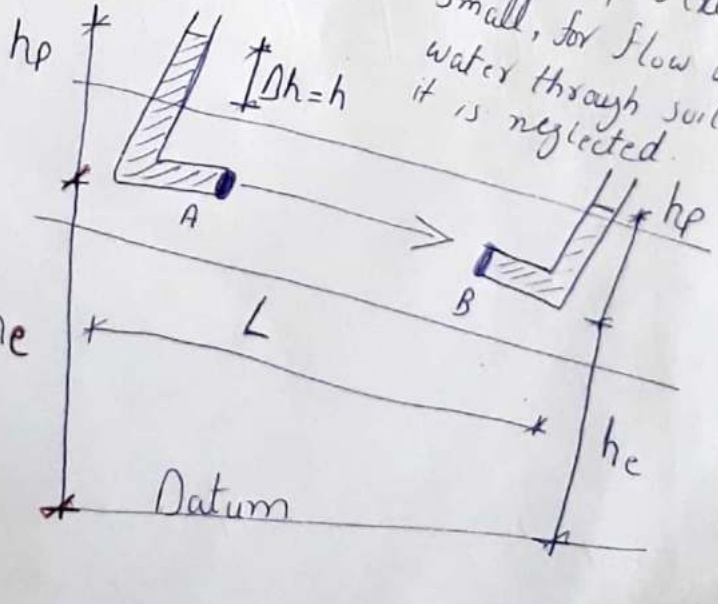
$$\text{Total Head at any Point} = h_e + h_p + h_v$$

$h_p$ → Piezometric Head.

$h_v$ → $\frac{V^2}{2g}$ → velocity is extremely small, for flow of water through soil, it is neglected.

* If more than 50% of the Soil is retained on No. 200 Sieve it is designated as Coarse Grained Soil. 8 Groups of CGS.
* If more than 50% of the Soil ~~is retained~~ Passes No. 200 Sieve, it is Fine Grained Soil. 6 groups of FGS.

Vertical distance of the Point above the datum = $h_e$



Head Loss divided by distance in which head loss take place. $i = h/L$ → h: head Loss, L: Length, i: Hydraulic Gradient

**Darcy's Law:** For a laminar flow in a homogenous soil, velocity ∝ hyd-Gradient.

$v \propto i \Rightarrow v = ki \Rightarrow v \cdot A = A \cdot ki$

$Q = kiA$ → Darcy's Eqtn.

where; $Q$ = Discharge, $k$ = coefficient of Permeability,
$v$ = velocity of flow or, discharge velocity or, Superficial velocity.

**K:** Rate of flow per unit of Area of soil mass per unit hyd-Gradient. $K = \frac{Q}{i \times A}$

$K$ = Clean Gravel = $10 - 100$ = Very Good
$K$ = Clay = $10^{-8} - 10^{-5}$ = Very Poor
→ Drainage Properties

**Validity of Darcy's Law:**

1- When flow is laminar.
2- Reynold Number $= \frac{V \times d \times \gamma_w}{\eta \times g} \leq 1$
3- Particle size should not more than 3mm.

**Discharge Velocity:** $V_d$ or, $V \Rightarrow V = V_d = Q/A$.
Rate of discharge per unit total area of soil mass.

**Seepage Velocity:** $V_s \Rightarrow V_s = Q/A_v$.

**Relation b/w V and $V_s$:** $Q = A \cdot V = A_v \cdot V_s$.

$\frac{A \cdot V}{A} = \frac{A_v \cdot V_s}{A} \Rightarrow V = \frac{A_v}{A} \times V_s$

As; $n = \frac{V_v}{V} = \frac{A_v}{A}$.

$$\therefore \quad V = n \cdot V_s = \left(\frac{e}{1+e}\right) \times V_s$$

According to USBR (United State Bureau of Reclamation).

* Soil having coefficient of Permeability greater than $10^{-3}$ mm/sec are classified as Pervious.
* Soil with the coefficient of Permeability b/w $10^{-5} - 10^{-3}$ mm/sec are designated as impervious (Semi-Pervious).

## Determination of Coefficient of Permeability:

A- Laboratory method
i- Constant Head Permeability Test.
ii- Variable Head Permeability Test
↳ For Less Permeable Soil.

B- Field Methods
i- Pumping Out Test
ii- Pumping in Test.

* Instrument;
→ Constt Head Permeameter.
→ Porous disc should be atleast ten times more Permeable than soil Sample.

or you can tamped it also to obtain required density

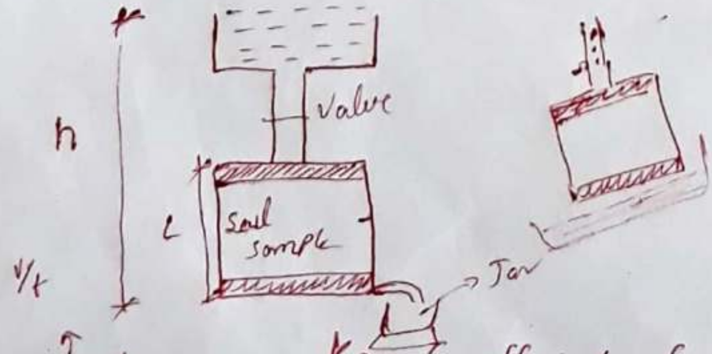
$$\frac{V}{n} = V_s.$$

As; $V = k \times i$

$$V_s = \frac{k \times i}{n}$$

$$V_s = k_p \times i$$

or, $k_p = k/n$




$$k = \frac{Q \times L}{A \times h}$$

$k_p$ = Co-efficient of Percolation.
↳ Slow movement of water through the Pores in soil or Permeable rock.

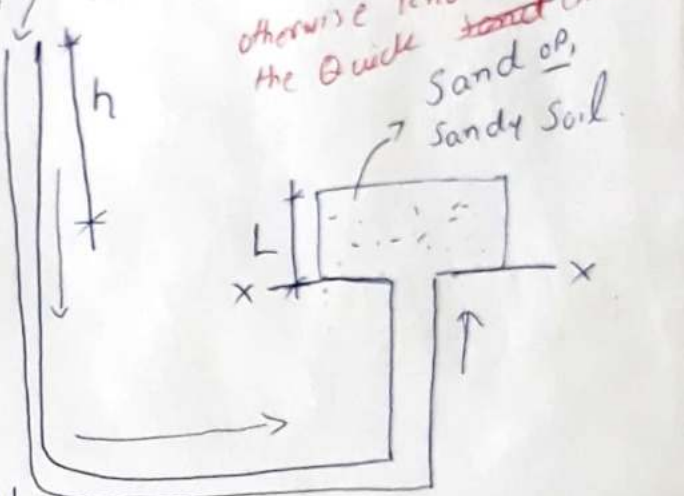
$k_p > k$

**Quick Sand:** When the Seepage Pressure due to upward flow of water in Sand/Sandy Soil balances the downward force of gravity (weight of material), a condition of instability arises in Sand. Sand in this state is called Quick Sand.

* **Seepage:** Flow of water under gravitational forces in a Permeable medium.

when water Pressure with in the Soil gets high enough to eliminate it shear strength all together its called Liquefaction otherwise known as the Quick Sand Condition

**Critical hydraulic Gradient:**




At the bottom Surface i-e; at x-x

$$\text{Upward force} = (h+L)\gamma_w \cdot A \rightarrow (1)$$

$$\text{DownWard force} = \frac{\gamma_w \times (G_s+e)}{(1+e)} \times V$$

Since; $\gamma_B = \frac{W}{V} \Rightarrow W = \frac{\gamma_w \times (G_s+e)}{(1+e)} \times V$ where; $V = A \times L$

$$W = \frac{\gamma_w \times (G_s+e)}{(1+e)} \times A \times L \rightarrow (2)$$

The Soil is literally behaving as a Liquid rather than a solid. It's Quick Sand

At balance; Upward Force = DownWard force

$$(h+L)\gamma_w \times A = \frac{\gamma_w \times (G_s+e)}{1+e} \times A \times L$$

$$\frac{h+L}{L} = \frac{G_s+e}{1+e} \times \frac{L}{L}$$

$$\frac{h}{L} + 1 = \frac{G_s + e}{1+e}$$

$$\therefore \frac{h}{L} = \frac{G_s + e}{1+e} - 1$$

$$i_c = \frac{G_s + e - 1 - e}{1+e}$$

$$\boxed{i_c = \frac{G_s - 1}{1+e}}$$

**Flow Net:** A Graph which consists of two types of lines i-e; Flow lines and Equipotential line.

**Flow Line:** line along which each Particle of water flow from U/S to D/S level.

**Equipotential line:** Line which connects all the Points having the same head.
Contour lines

**Flow Channel OR, Flow Path:** It is a Space b/w two adjacent flow lines.

Qtn-2: (a)- A Sample of saturated Soil has a water content of 25 Percent and a bulk unit weight of $20 kN/m^3$. Determine the dry unit weight, void ratio and Sp. Gravity of solids.

(b)- What would be the bulk unit wt. of the soil in (a) if it is compacted to same void Ratio but has a degree of saturation of 90%?

Given Data; (a) $S = 1 = 100\%$, $\omega = 0.25 = 25\%$, $\gamma_B = 20\ kN/m^3$

(b) $S = 0.90 = 90\%$

Required: (a) $\gamma_d = ?$, $e = ?$, $G_s = ?$

(b) $\gamma_B = ?$

Solution: (a)- $$\gamma_d = \frac{\gamma_B}{1+\omega} = \frac{20}{1+0.25} = 16\ kN/m^3$$

$$\omega = \frac{S \times e}{G_s} \Rightarrow e = \frac{\omega \times G_s}{S} = \frac{0.25 \times G_s}{1} = 0.25 \times G_s$$

$$e = 0.25 \times G_s \longrightarrow (1)$$

$$\gamma_d = \frac{\gamma_w \times G_s}{1+e} \Rightarrow e = \frac{\gamma_w \times G_s}{\gamma_d} - 1$$

$$e = \frac{9.8 \times G_s}{16} - 1 \Rightarrow e = \frac{9.8 \times G_s - 16}{16} \rightarrow (2)$$

Comparing eqtn (1) and (2);

$$0.25 \times G_s = \frac{9.8 \times G_s - 16}{16} \Rightarrow G_s = 2.75$$

Put in (1) $\Rightarrow e = 0.25 \times 2.75 = 0.67$

(b)- $$\gamma_B = \frac{\gamma_w \times (G_s + e \cdot S)}{1+e} = \frac{9.81 \times (2.75 + 0.67 \times 0.90)}{1 + 0.67}$$

$$\gamma_B = 19.67\ kN/m^3$$

## Assignment # 01;

**Qtn: 1:** A sample of wet soil has a volume of $0.0192\,m^3$ and a mass of 32 kg. After drying the sample in an oven, its mass reduces to 28.5 kg. Determine i)- Bulk density ii)- Water Content iii)- Dry density iv)- Saturated density. v)- Void Ratio vi)- Porosity vii)- Degree of saturation. Take Sp- Gravity of soil Solid as 2.65.

**Given data;** $W = 32\,kg$, $V = 0.0192\,m^3$, $W_s = 28.5\,kg$

$G_s = 2.65$

**Required;** $\gamma_B = ?$, $\omega = ?$, $\gamma_d = ?$, $\gamma_{sat} = ?$,

$e = ?$, $n = ?$, $S = ?$

**Solution:** $W_w = W - W_s = 32 - 28.5 = 3.5\,kg$

$$\omega = \frac{W_w}{W_s} \times 100 = \frac{3.5}{28.5} \times 100 = 12.3\%$$

$$\gamma_B = \frac{W}{V} = \frac{32}{0.0192} = 1666.67\,kg/m^3$$

$$\gamma_d = \frac{W_s}{V} = \frac{28.5}{0.0192} = 1484.37\,kg/m^3$$

$$\gamma_d = \frac{G_s \times \gamma_w}{1+e} \Rightarrow e = \frac{G_s \times \gamma_w}{\gamma_d} - 1 = \frac{2.65 \times 1000}{1484.37} - 1$$

$$e = 0.785$$

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e} = \frac{(2.65 + 0.785)}{1 + 0.785} \times 1000 = 1924.37\,kg/m^3$$

$$n = \frac{e}{1+e} = \frac{0.785}{1+0.785} = 0.44 \text{ or, } 44\%$$

$$\omega = \frac{S \times e}{G_s} \Rightarrow S = \frac{\omega \times G_s}{e} = \frac{0.123 \times 2.65}{0.785} = 0.415 \text{ or, } 41.5\%$$

## Quiz;

**Pb:** A sample of soil has a volume of 65ml and weighs 0.96N. After complete drying, its weight reduces to 0.785N. If the Sp-Gravity of solid Particles is 2.65, determine the degree of saturation.

**Given Data:** $V = 65ml = 0.000065 m^3$ As, $1ml = 10^{-6} m^3$

$W = 0.96N$, $W_d = 0.785N$,

$G_s = 2.65$.

**Required:** $S = ?$

**Solution:**

$$\gamma_B = \frac{\gamma_w \times (G_s + e \times S)}{(1+e)} \longrightarrow (1)$$

$$\gamma_B = \frac{W}{V} = \frac{0.96}{0.000065} = 14769 \, N/m^3.$$

$\gamma_w = 9800 \, N/m^3$

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

$V_s = 0.000030 m^3$

As, $\gamma_s = \frac{W_s}{V_s}$.

$$V_s = \frac{W_s}{\gamma_s} = \frac{0.785}{25970}$$

But $G_s = \frac{\gamma_s}{\gamma_w}$

$\gamma_s = G_s \times \gamma_w$

$\gamma_s = 2.65 \times 9800$

$\gamma_s = 25970 \, N/m^3$

Also;

$V = V_v + V_s$

$V_v = V - V_s$

$V_v = 0.000065 - 0.000030$

$V_v = 0.000035 m^3$.

$$e = \frac{0.000035}{0.000030}$$

$e = 1.167$

Putting all the values in (1). & Solve it for 'S'.

$S = 0.527$ or, $52.7\%$

3rd lecture:-

⇒ Westgaurd Theory:-

Assumption:

- The Soil is elastic medium.
- The Soil is homogenous.
- Lateral Strain was assumed to be zero.
- ~~lateral~~ vertical Strain was Considered.
- The Soil medium is lateraly reinforced with various closely spaced Sheet of ~~neglit~~ negligible Thickness.

According to Wesgaurd The verticle Stress at depth "Z" is given by

$$\sigma_z = \frac{Q}{Z^2} \times K_w$$

$\sigma_z$ = Vertical Stress at depth "Z"
Q = Load
Z = depth
$K_w$ = Westgaurds Coefficient

$$K_w = \frac{1/\pi}{\left[1 + 2(r/z)^2\right]^{3/2}}$$

Comparision b/w Bossenev and Westgaurd

For $\frac{R}{Z} < 1.5$

In this Case the value $K_B$ is larger than $K_w$.

But for the $\frac{R}{Z} > 1.5$

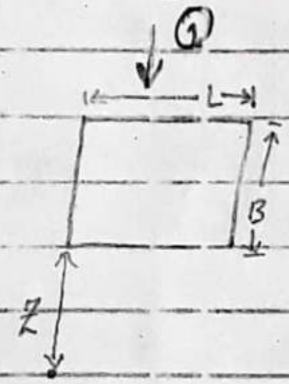
In this Case the value of $K_w$ and $K_B$ will be identical.

=> 2 : 1 Method (Approximate Method).

Foundation Engineer often used this method for the Calculation of Vertical Stresses at a depth Z.

According to this method the vertical stress at depth "Z" is given by

$$\sigma_z = \frac{Q}{(B+Z)\times(L+Z)}$$




=> ISOBAR (pressure Bulb):

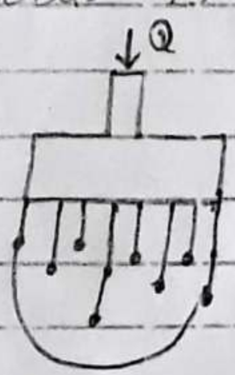
Line or Curve which Connect all The points below the ground Surface having Same vertical Stresses.

In other words, Isobar is a Contour of equal Stress.

Isobar is useful for determining the effect of load on the vertical Stresses at various points.

The area bounded by isobar is known as pressure Bulb.

This zone of with in which the Stresses have Significant effect on the Settlement of Structure.



Shape of Isobar is Similar to electrical bulb or onion.

⇒ Shear Strength:-

The maximum resistance to Shear Stresses before the failure is Known as Shear Strength.

The Shear Stresses develop when the Soil Sample is Subjected to direct Comparision.

In Soil the failure take place due to movement of the particle not due to breaking of particle.

The Shear Strength is one of the principle property of soil due to a Soil is Stable Subjected to load. Bearing Capacity of Soil also because of Shearing Strength. All the problems of Soil is directly or indirectly related with Shear Strength.

⇒ Main Constituents of Shear Strength.

1- Friction resistance offered by particle due to their Shape and Surface.
2- Cohesion and ~~adhesion~~ adhesion.
3- Structural resistance offered by interlocking of particles.

## Mohr Coloumb's law:-

In 1776 Mohr Coloumb explain the Shear Strength of Soil which given by the Equation.

$$\tau = c + \delta_n \tan\phi \quad \longrightarrow \text{for clayey soil}$$

$\tau$ = Shear Stress
$c$ = Cohesion
$\delta_n$ = Normall Stresses
$\phi$ = Angle of Internal friction.

for Sandy Soil; , $c = 0$

$$\tau = \delta_n \tan\phi$$