Notes by-

Pravin S Kolhe,

BE(Civil), Gold Medal, MTech (IIT-K)

Assistant Executive Engineer,

Water Resources Department,

www.pravinkolhe.com

Geotechnical Engg.

Basic properties & Inter-relations :-

① Void Ratio = $\frac{\text{Vol. of Voids}}{\text{Vol. of Solids}}$ $\quad e = \frac{V_v}{V_s}$

② Porosity = $\frac{\text{Vol. of voids}}{\text{Total volume}}$ $\quad n = \frac{V_v}{V} \times 100$

③ $n = \frac{e}{1+e}$, $e = \frac{n}{1-n}$

④ Degree of saturation = $\frac{\text{Vol. of water}}{\text{Vol. of voids}}$

$S_r = \frac{V_w}{V_v} \times 100$ (%)

④ Air content = $\frac{\text{Vol. of air}}{\text{Vol. of voids}}$ $\quad a_c = \frac{V_a}{V_v}$

$a_c = 1 - S_r$

⑤ Percentage air void = $\frac{\text{Vol. of air}}{\text{Total vol.}}$ $\quad n_a = \frac{V_a}{V} \times 100$

⑥ Water content = $\frac{\text{Wt. of water}}{\text{Wt. of soil solid}}$ $\quad w = \frac{W_w}{W_s}$

⑦ Unit wt. of water = $\frac{\text{Wt. of water}}{\text{Vol. of water}}$

$\gamma_w = \frac{W_w}{V_w}$

⑧ Density of water = $\frac{\text{Mass of water}}{\text{Vol. of water}}$

$\rho_w = \frac{M_w}{V_w}$ $\quad \boxed{1\,gm/cm^3 = 9.81\,kN/m^3}$

$\left.\begin{array}{l} \rho_w = 1\ gm/cc \\ \gamma_w = 9.81\ kN/m^3 \end{array}\right\}$ at 4°C

⑨ Bulk Unit Wt. = $\frac{\text{Wt. of soil}}{\text{Vol. of soil}}$

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

Bulk Density = $\frac{\text{Mass of soil}}{\text{vol. of soil}}$

$\rho = \frac{M}{V}$

⑩ Dry Unit Wt = $\frac{\text{Wt. of soil solid}}{\text{Vol. of soil}}$

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

Dry Density = $\frac{\text{Mass of soil solid}}{\text{Vol. of soil}}$

$\rho_d = \frac{M_s}{V}$

⑪ Saturated Unit wt. = $\frac{\text{wt. of fully saturated soil}}{\text{Total Vol.}}$

$\gamma_{sat} = \frac{W_{sat}}{V}$

Saturated Density = $\frac{\text{Mass of fully sat. soil}}{\text{Total Vol.}}$

$\rho_{sat} = \frac{M_{sat}}{V}$

⑫ Submerged Unit wt = $\frac{\text{Sub. wt. of soil}}{\text{Total vol.}}$

$\gamma' = \frac{W_{sub}}{V}$

Submerged Density = $\frac{\text{submerged Mass of soil}}{\text{Total vol.}}$

$\rho' = \frac{M_{sub}}{V}$

⑬ $\gamma' = \gamma_{sat} - \gamma_w$ $\qquad \rho' = \rho_{sat} - \rho_w$

⑭ Unit wt. of soil solid = $\frac{\text{Wt. of soil solid}}{\text{Vol. of soil solid}}$

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

Density of soil solid = $\frac{\text{Mass of soil solid}}{\text{Vol. of soil solid}}$

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

⑮ Specific Gravity or Relative Density of (Soil particle) = $\frac{\text{Unit wt/Density of soil solid}}{\text{Unit wt / Density of water}}$

$G = \frac{\gamma_s}{\gamma_w}$ $\qquad G = \frac{\rho_s}{\rho_w}$

⑯ Sp. Gravity of soil Mass = $\frac{\text{Bulk unit wt / Density (soil mass's)}}{\text{That of water}}$

$G_m = \frac{\gamma}{\gamma_w}$; $G_m = \frac{\rho}{\rho_w}$

⑰ $e \cdot S_r = Gw$

⑱ $\gamma_d = \frac{\gamma}{1+w}$

⑲ $\gamma = \frac{(G + e \cdot S_r) \cdot \gamma_w}{1+e}$

⑳ $\gamma_d = \frac{G \cdot \gamma_w}{1+e}$ $\Rightarrow \left.\begin{array}{l} S_r = 0 \\ \gamma = \gamma_d \end{array}\right\}$ Dry soil

㉑ $\gamma_{sat} = \frac{(G+e)\gamma_w}{1+e}$ $\Rightarrow \left.\begin{array}{l} S_r = 1 \\ \gamma = \gamma_{sat} \end{array}\right\}$ Fully sat. soil

㉒ $\gamma' = \gamma_{sat} - \gamma_w$
$= \frac{(G-1) \cdot \gamma_w}{1+e}$

㉓ $\gamma_d = \frac{(1-n_a) \cdot G \cdot \gamma_w}{1+wG}$

INDEX PROPERTIES OF SOIL

Properties of soil

Engg. Properties
① Permeability
② Compressibility
③ Shear strength.

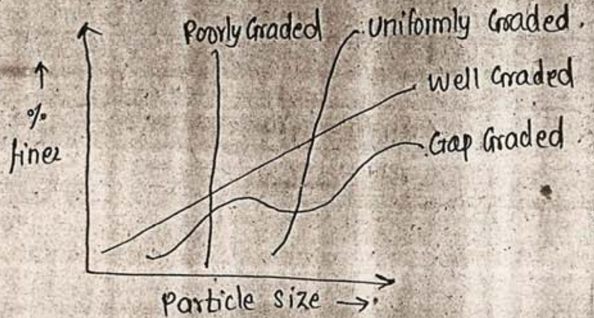
Index Properties
used for identification & classificatⁿ of soil.
① Sp. Gravity
② Particle size Distributⁿ
③ Consistancy limits & indices
④ Density Index

× Particle size Distribution :- (IS classificatⁿ)

clay	silt	Sand			Gravel		cobble	Boulder
		fine	Med.	coarse	F	C		

0.002 mm, 0.075, 0.425, 2.0, 4.75, 20, 80, 300 mm

a] Mechanical / Sieve Analysis: Particle size > 75 μ
b] Wet Mech. / Sedimentatⁿ Analysis: —"— < 75 μ



a] Uniformity coeff: $C_u = \frac{D_{60}}{D_{30}}$
b] Coeff. of curvature $C_c = \frac{(D_{30})^2}{D_{10} \times D_{16}}$

D_{60}, D_{30}, D_{10} = Particle sizes in mm corresponding to 60, 30, 10% fines resp.

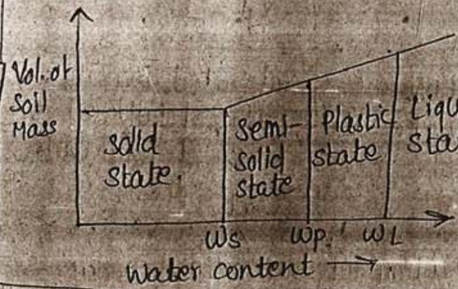
Relative Density:- Degree of compactness of cohesive soil.

Relative Density = Density Index = $R_D = I_D$

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

e_{max} = Void Ratio of Soil at loosest state
e_{min} = e at dense
e = Natural void ratio

* **Consistancy limit & Indices : Atterbergs limit** :→



1] Liquid limit (w_L): Min. water content at which soil mass flows like liquid.
⇒ Boundary betⁿ plastic limit & liquid limit
2] plastic limit (w_p):- Water content at which soil mass can still be deformed without cracking.
3] Shrinkage limit (w_s):- Max. water content at which there is no reduction in vol. of soil mass accompanying reduction in water content

Atterbergs ~~Limits~~:-		Index :-
a	Plasticity Index	$I_p = (W_L - W_P)$
b	Flow Index	$I_f = (W_1 - W_2) / \log_{10}(N_2/N_1)$
c	Toughness Index	$I_T = I_P / I_F$
d	Consistancy Index	$I_c = (W_L - w) / I_P$
e	Liquidity Index	$I_L = (w - W_P) / I_P$
f	Activity Number	A = I_P / percentage finer than 2 μ

Where N_1 = No. of blows at w_1
N_2 = No. of blows at w_2

If $w = w_L$ ---- soil at liquid limit
$I_c = 0$, $I_L = 1$
If $w = w_p$ ---- soil at plastic limit
$I_c = 1$, $I_L = 0$

Soil water :- Water present in soil.
a] Free water / Gravitational water
b] Held water :-
1] Structural water
2] Adsorbed water
3] Capillary water.

$$h_c = \frac{4 T_s \cdot \cos\alpha}{d \cdot \gamma_w}$$

T_s = surface Tension
h_c = capillary rise
α = contact angle
d = Dia. of Tube.

PERMEABILITY

Darcy's Law :- Velocity ∝ Hydraulic Gradient
[Laminar flow] $V \propto i$
$V = K \cdot i$

K = Darcy's coeff. of permeability

$q = AV = K \cdot i \cdot A$ $i = \frac{H}{L}$ = Loss of head per unit length

Determination of coeff. of Permeability :-
1] ~~Laboratary~~ Methods :-
a] Constant Head permeability Test :-

$$K_{at\ 27°C} = \left[\frac{\gamma_w \text{ at } 27°C}{\gamma_w \text{ at } T°C}\right]\left[\frac{\eta \text{ at } T°C}{\eta \text{ at } 27°C}\right] \cdot K_{T°C}$$

b] Falling head or variable Head Test :-

$$K = \frac{aL}{At} \log_e\left(\frac{h_1}{h_2}\right)$$

c] Capillarity Permeability Test :-

II] Field Methods :-

a] Pumping out test in unconfined aquifer :-

$$k = \frac{q}{\pi(H^2-h^2)}\log_e\left(\frac{R}{r}\right)$$

b] Pumping out test in confined aquifer :-

$$k = \frac{q}{2\pi b(h_2-h_1)}\log_e\left(\frac{r_2}{r_1}\right)$$

c] Pumping-in Test :-

i] constant water level / open end pipe

$$k = \frac{q}{5.5\, r\, H}$$

ii] Packer Method :-

$$k = \frac{q}{2\pi LH}\sinh^{-1}\left(\frac{L}{2r}\right) \qquad L < 10r$$

$$k = \frac{q}{2\pi LH}\log_e\left(\frac{L}{r}\right) \qquad L \geq 10r$$

III] Indirect Methods :-

a] Computation based on grain size :-

$$k = D_s^2 \cdot \frac{\gamma_L}{\eta_L} \cdot \frac{e^3}{1+e} \cdot C_s$$

D_s = eff. particle size
γ_L = Unit wt. of liquid
η_L = Viscosity of liquid
e = Void Ratio
C_s = Composite shape factor.

b] Allen Hazen's Eqn :- $k = C D_{10}^2$
C = const. = 100

c] Computation based on specific surface :-

$$k = \frac{1}{K_0 \cdot S^2} \cdot \frac{\gamma_L}{\eta_L} \cdot \frac{e^3}{1+e}$$

K_0 = factor influenced by particle shape
S = specific surface of particle.

d] Loudon's eqn :- $\log_{10}(k \cdot S^2) = a + b \cdot n$

$a = 1.365$
$b = 5.15$ } at 10°C
n = porosity

e] Computation from consolidation test data :-

$$k = m_v \cdot c_v \cdot \gamma_w$$

a] Avg. permeability parallel to bedding plane

$$k_x = \frac{k_1 Z_1 + k_2 Z_2 + \cdots + k_n Z_n}{Z_1 + Z_2 + \cdots + Z_n}$$

b] Avg. permeability ⊥ar to bedding plane :-

$$\frac{V \cdot Z}{k_z} = \frac{V \cdot Z_1}{k_1} + \frac{V Z_2}{k_2} + \cdots + \frac{V \cdot Z_n}{k_n}$$

SEEPAGE ANALYSIS

Total head or (Effective head) = Pressure head + Datum/Position Head.

$$h = h_w + Z$$

Seepage Pressure = $P_s = h \cdot \gamma_w$

Seepage Force = $J = P_s \cdot A = i \cdot Z \cdot A \cdot \gamma_w$

Where $i = \frac{h}{Z}$

Seepage force per unit vol = $j = i \cdot \gamma_w$

Effective stress = $\sigma' = \gamma' Z \pm P_s$
$= \gamma' Z \pm i \cdot Z \cdot \gamma_w$

+ve sign ⇒ Flow in downward direction
−ve sign ⇒ Flow in upward direction

2D Flow : Laplace Eqn :-

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = 0$$

Effect of wind - ① Dune ② pollution

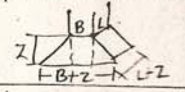
Elastic limit of Rock exceeded

fracture plane

GE | STRESSES IN SOIL

Stress calculation at a depth 'z' & 'r'-radially

① Dispersion model,



	Rect.	Circular	
	$\Delta\sigma z = \dfrac{Q}{(L+z)(B+z)}$	$\dfrac{Q}{\frac{\pi}{4}(D+z)^2}$	$Q = q \times B \times L$ pt. load udl

② Equivalent Point load mtd.

a) Boussinesq

$$\Delta\sigma z = \frac{3Q}{2\pi z^2}\left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{5/2} = \frac{Q}{\frac{\pi}{4}D^2}\left[1-\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{3/2}$$

b) Westergaard

$$\Delta\sigma z = \frac{Q}{\pi z^2}\left[\frac{1}{1+2\left(\frac{r}{z}\right)^2}\right]^{3/2} = \frac{Q}{\frac{\pi}{4}D^2}\left[1-\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{1/2}$$

③ Newmarks chart

Assumptⁿ - Bossinesq's Eqⁿ :- (Homogeneous soil)

① Semi ... elastic medium, ② E = const. ③ Homogeneous

④ Isotropic ⑤ seminfinite.

Westergaard Eqⁿ - (Layered soil)

Compaction - Removal of air, Dynamic, quick,

Standard (I.S.)
- Mould : 127.3 mm High, 100 mm Dia. [sample - 3 layer x 25 blow]
- Rammer : 2600 gm wt, 310 mm Free fall — compacting energy = 6 kgcm/ml

$\gamma d = \dfrac{\gamma}{1+w}$ | $\gamma d = \dfrac{(1-n_a)G\gamma w}{1+e}$ | $eS_r = WG$, $e = WG$ → 0 air void

S_r WG/S_r ⇒ ~~fresh~~ sat.

Modified (AASHO) Test
- 127.3 mm High, 100 mm dia [sample 5 layer x 25 blows]
- Rammer : 4.5 ~~kg~~ kg wt, 457 mm free fall — compacting energy = 27.5 kgcm/ml

* zero air void ⇒ 100% saturation.

Field compactⁿ mtds :- ① Ramming → sheep foot
② Rolling → Smooth wheel
③ Vibrating → Pnumatic

①Smooth wheel rollers :- coarse grain / ~~cohesive~~ Non-cohesive

②Sheep foot — cohesive

③ Pnumatic tyre : Both - cohesive & non cohesive.

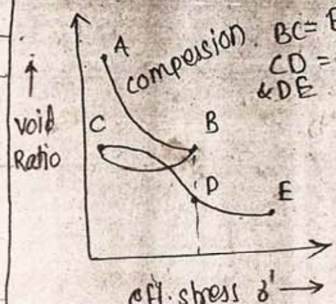
Consolidation - explusion of water, static load, Time dependent.
: Both water & soil is impcompressible.

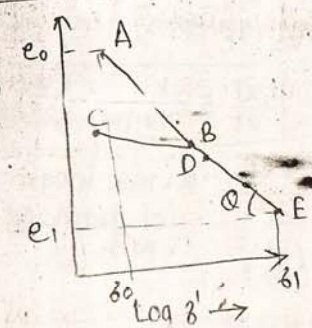
Primary consolidatⁿ :- Excess pore pre.

Secondary consolidatⁿ :- Viscosity of water.

Spring analogy :-
- Skeleton of soil particle ⇒ Springs.
- Voids in soil ⇒ water in container.
- stress in soil ⇒ Load on piston placed on spring.
- Coeff. of permeability ⇒ outlet drainage.

Consolidation of laterally confined soil specimen (1D)





① compression Index = $C_c = \tan\theta = \dfrac{e_0 - e_1}{\log(\sigma_1) - \log(\sigma_0)} = \dfrac{\Delta e}{\log\left(\frac{\sigma_1}{\sigma_0}\right)}$

② Swelling / Expansion Index $C_s = 0.007\,(w_L - 10)$ – Remoulded
$= 0.009\,(w_L - 10)$ – undisturbed

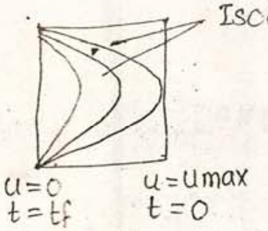
③ coeff. of compressibility – a_v = Decrease in void ratio per unit increase in pre.
$= \dfrac{-\Delta e}{\Delta\sigma} = -\left(\dfrac{e_0 - e}{\sigma_1 - \sigma_0}\right)$

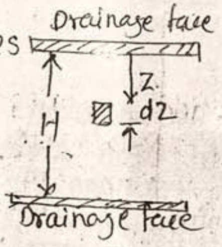
④ Coeff. of vol. change = Coeff. of vol. compressibility = m_v = $-\dfrac{\Delta V}{V_0} \times \dfrac{1}{\Delta\sigma}$

For 1D consolidat^n. (Laterally confined)

~~$\Delta H =$~~ Δ $m_v = \frac{\Delta H}{H} \times \frac{1}{\Delta \sigma'}$

Terzaghi's assumption - ① soil is homogeneous ② Full saturated ③ Incompressible ④ k = const. Secondary consolidat^n neglected





[Graph: [Time Vs Pre] Vs [Depth]]

Basic DE of consolid^n: $\boxed{\frac{\partial \bar{u}}{\partial t} = \frac{K}{m_v \cdot \gamma_w} \cdot \frac{\partial^2 \bar{u}}{\partial z^2}}$

Time ... or $= T_v = \frac{C_v \times t}{h^2}$ h = max. length of drainage path.

$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$

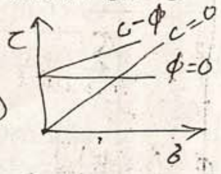
consolidometer ⇒ oedometer -

$\Delta H = H_0 \frac{C_s}{1+e} \log_{10}(\ldots)$

Mohr-colomb Theory $\tau_f = c + \sigma \tan\phi$.

Types of soil according to shear strength

① cohesive ($c-\phi$)
② cohsionless ($c=0$)
③ Purely cohesive ($\phi=0$)



$\boxed{\gamma = \frac{(G + e \cdot S_r) \cdot \gamma_w}{1+e}}$