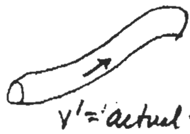
IV-3 COEFFICIENT OF PERMEABILITY
(Hydraulic Conductivity)

COEF. OF PERMEABILITY (Hydraulic Conductivity)

1. THEORETICAL RELATIONSHIPS

1.1 Kozeny-Carman Equation

1) Poiseuille eqn. for laminar flow through a capillary tube



$v' = \left(\frac{\gamma}{\mu}\right) C_s R_H^2 i'$ ← Permeant

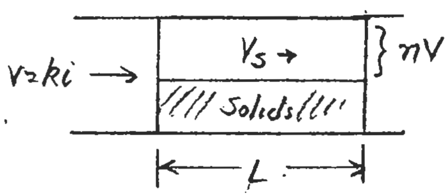
v' = actual velocity

i' = actual gradient

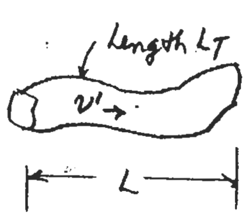
- γ = unit weight of fluid (g/cc)
- μ = viscosity of fluid $\approx 10^{-5}$ g-sec/cm² for H_2O at 20°C
- C_s = shape factor of tubes ($\approx 1/3 - 1/2$)

$$R_H = \text{hydraulic radius} = \frac{\text{area of flow}}{\text{wetted perimeter}} = \frac{\text{pore volume}}{\text{surface area}}$$

2) Convert from capillary tube to soil à la Part IV-2 for flow per unit area, $Q/A = v = ki$; k = coefficient of permeability = hydraulic conductivity



$\cdot\ v = n V_s = \frac{e}{1+e} V_s$



$T_0 = \frac{L_T}{L}$

$\cdot\ V_s = \frac{v'}{T_0}$; $i' = \frac{i}{T_0}$

$$\cdot\ R_H = \frac{e V_s}{\text{Surface Area}} = \frac{e}{\text{Surface Area} = SSA \cdot W_s} = \frac{e}{SSA \cdot G_s}$$

$V_s = W_s / G_s$ (for $\gamma_w = 1$)

3) Resultant equation

$$v = ki = \frac{e}{1+e}\left[V_s = \frac{v'}{T_0} = \left(\frac{\gamma}{\mu}\right)\frac{C_s}{T_0}\left(\frac{e}{SSA \cdot G_s}\right)^2 \frac{i}{T_0}\right]$$

$$\therefore\ k\ (\text{cm/sec}) = \left(\frac{\gamma}{\mu}\right)\left[\frac{C_s}{T_0^2}\left(\frac{e}{1+e}\right)\left(\frac{e}{SSA \cdot G_s}\right)^2\right]$$

Permeant $\left(\frac{1}{\text{cm} \cdot \text{sec}}\right)$; Physical Permeability, K (cm²)

1.2 Effect of Permeant

1) If no change in fabric, then k affected only by γ/μ

2) For flow of water at 20°C, $k(\text{cm/sec}) \approx 10^5 (K, \text{cm}^2)$

3) Effect of temperature

$$k_T = k_{20°C} \frac{\mu_{20°}}{\mu_T}$$

		Reference (Lab) ↓	
T(°C) =	10	20	30
μ (milli poise) =	13	10	8
	×0.77		×1.25

- ≈ 25% change / 10°C
- In situ T = 10°C NE

∴ 1 poise = $\frac{\text{dyne-sec}}{\text{cm}^2}$; poise × 10^{-1} = Pa·sec

2. HYDRAULIC CONDUCTIVITY OF SOILS (flow of Water)

2.1 General Magnitudes [Also see Fig. 19.5 of L&W ('69)]

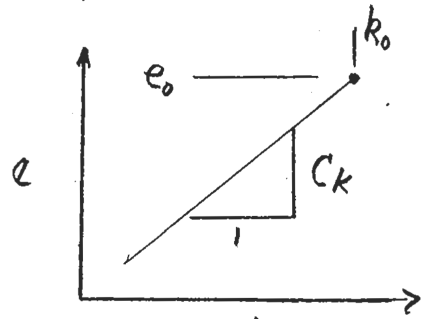
Soil Type	k (cm/sec)	
Fine sand	10^{-2}	$k \approx (D_{10mm})^2$
Non-plastic silt	10^{-5}	
CL-CH clay	$10^{-8 \pm 1}$	

2.2 Effect of Void Ratio

1) granular soils

$$k \propto \frac{e^3}{(1+e)} \cdot S^3$$ with approx. relationship for S < 100%

2) Saturated, natural cohesive soils

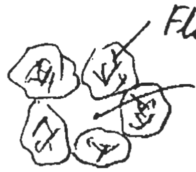


$C_k = de/d\log k \approx (\frac{1}{3} - \frac{1}{2}) e_0$
(see Sheet A, Fig. 17)

$$\therefore k = k_0 (10)^{\left(\frac{e - e_0}{C_k}\right)}$$

(See Sheet A, Fig. 11 for example)

2.3 Effect of Fabric with Sedimentary Clays



Flow mainly controlled by voids between flocs

- Floc size = function particle size & shape + environment — Part II-2
- $\left(\frac{e}{SSA \cdot G_s}\right)^2$ term should be for flocs, not individual particles

- Clays do not require an "initial" gradient for flow
- For marine illitic clays, $r_k = k_h/k_v \approx 1.0 - 1.5$ à la Fig 12, Sheet A

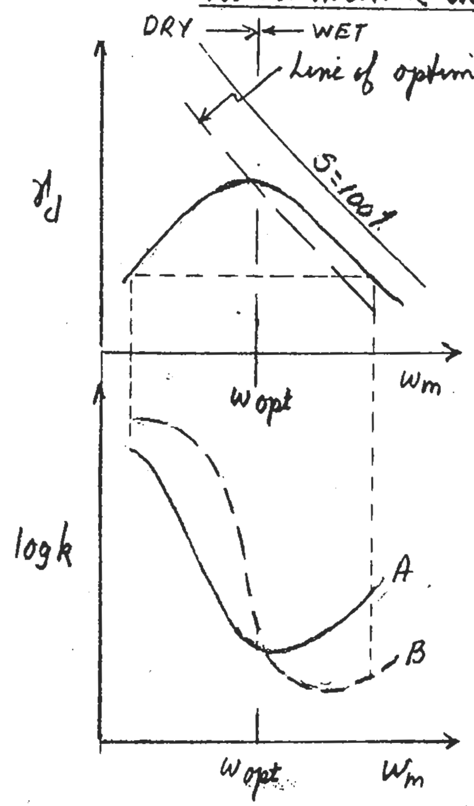
  Also $k_v \approx 10 \pm 5 \times 10^{-8}$ cm/sec

2.4 Compacted Cohesive Soils

2.4.1 Overview of Compaction

See Sheet B

2.4.2 Variation in k with w_m & γ_d (Dynamic or kneading compaction)



a) Importance of fabric

- Dry of optimum → dense aggregates with large voids → high k FLOCCULATED FABRIC
- Wet of optimum → more uniform distribution of particles w/ small voids → low k DISPERSED FABRIC

∴ at same γ_d, $k_{wet} << k_{dry}$

b) Minimum k for given Comp. Effort

- Curve A → k_{min} at $w_m \approx w_{opt}$, i.e. at max. γ_d (min. e)
- Curve B → k_{min} at $w_m > w_{opt}$, i.e., Δfabric more important than decr. γ_d — Usual Case

* ∴ In field, always use $w_m \geq w_{opt}$ to get low k for clay liner *

c) See Sheet C for actual data

3. LABORATORY MEASUREMENT TECHNIQUES

3.1 Natural Cohesive Soils

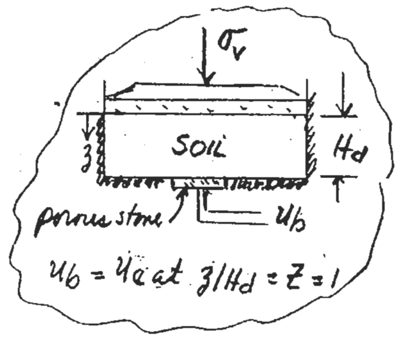
Note:
- Tests on specimens trimmed from undisturbed tube samples
- Measure k as $f(\sigma'_c, \sigma'_{vc}) \rightarrow e$ vs $\log k$ data

1) Triaxial cell
   - Requires top & bottom porous stones w/ drainage lines
   - Usually run constant head test (with u backpressure) with burettes to measure both inflow & outflow (check for leaks)

2) Modified oedometer with falling head test

   See Tavenas et. al. (1983) CGJ, 20(4), Fig. 8 - Oedometer cell adapted for falling head permeability tests.

3) CRS consolidation



$\dot{\varepsilon} = d\varepsilon/dt$

$\varepsilon = \varepsilon_v = \Delta H/H_o$

- Apply constant $\dot{\varepsilon}$ with measurements of σ_v, u_b and ε_v (want $u_b/\sigma_v \approx 20 \pm 10\%$)
- For constant $m_v = d\varepsilon_v/d\sigma'_v$

  (a) Ave. $\sigma'_{vc} = \sigma_v - \frac{2}{3} u_b$

  (b) $k_v = \dfrac{\dot{\varepsilon} H_d^2 \gamma_w}{2 u_b}$

  (c) Coef. of consolidation, $c_v = \dfrac{k_v}{m_v \gamma_w} = \dfrac{H_d^2}{2 u_b}\left(\dfrac{d\sigma_v}{dt}\right)$

  $t = \dot{\varepsilon} dt / d\sigma_v$

NOTE: Equations also available for constant $CR = d\varepsilon_v/d\log\sigma'_{vc}$

Part V-2 Notes

3.2 Compacted Cohesive Soils

Comments

a) Compaction mold used only for design (since compact soil in mold)

b) Triaxial cell most common for testing tube samples of compacted soil