INS 3121
SOIL MECHANICS

Flow of Water in Soils-2

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6.6 Directional variation of permeability

- Most soils are not isotropic with respect to permeability.

- $\alpha = 0°$: k_v (hydraulic conductivity in the vertical)

- $\alpha = 90°$: k_h (hydraulic conductivity in the horizontal)

- The magnitudes of K_v and K_h in a given soil depend on several factors, including the method of depositior in the field

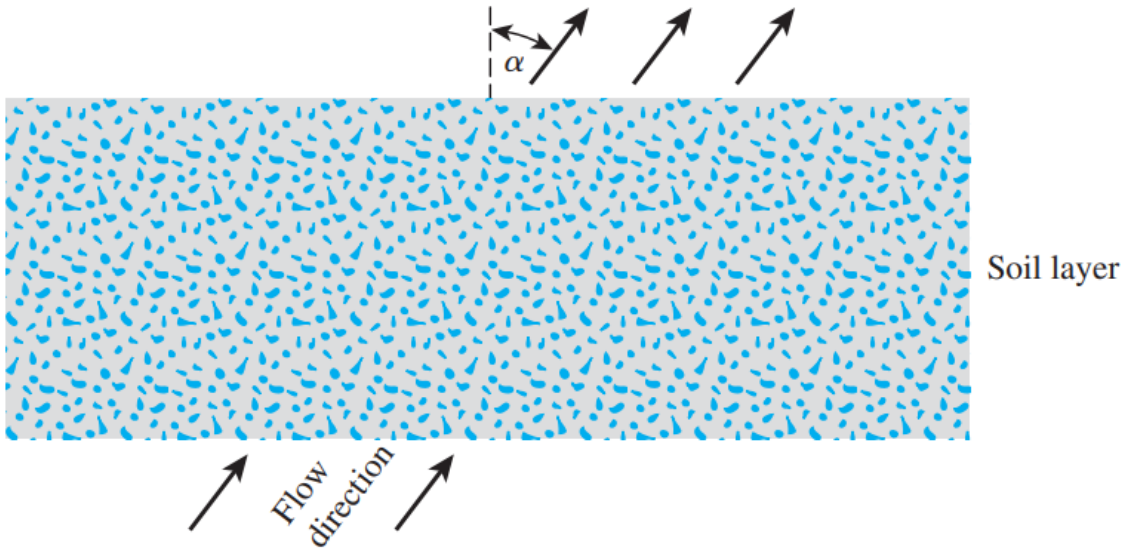

Figure 7.14 Directional variation of permeability

6.6 Directional variation of permeability

- Laboratory test results. The soil specimens were initially compacted at a certain moisture content, and the hydraulic conductivity was determined at 100% saturation.

- Note that, for any given molding moisture content and confining pressure, k_h is larger than k_v.

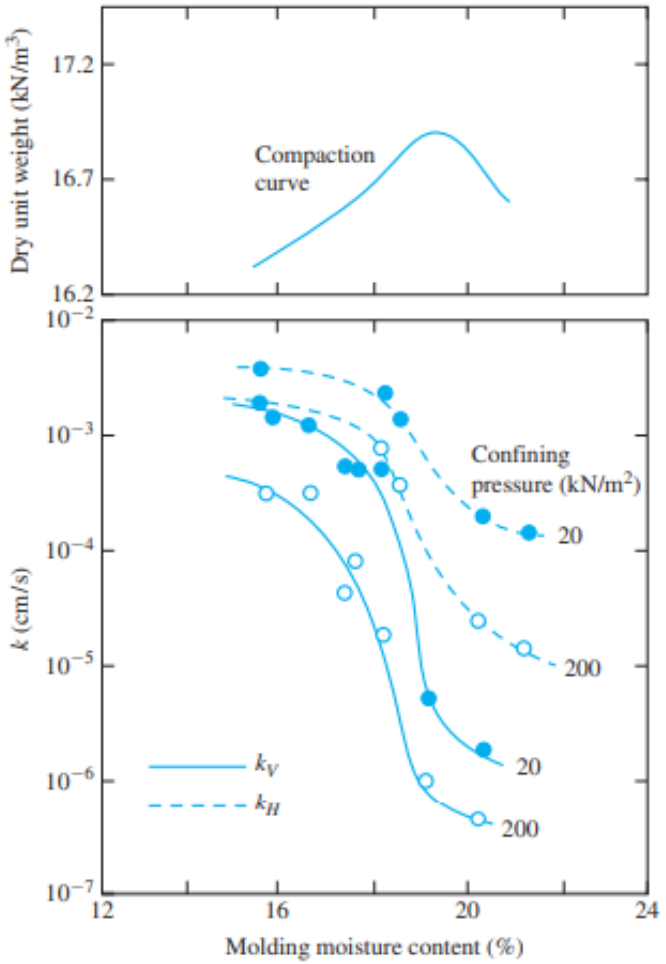

Figure 7.15 Variation of k_V and k_H for Masa-do soil compacted in the laboratory (*Based on the results of Fukushima and Ishii, 1986*)

6.7 Equivalent Hydraulic Conductivity in Stratified Soil

Horizontal Flow

The total flow through the cross-section in unit time can be written as

$$q = v \cdot 1 \cdot H$$

$$= v_1 \cdot 1 \cdot H_1 + v_2 \cdot 1 \cdot H_2 + \cdots + v_n \cdot 1 \cdot H_n$$

$$v = K_{H(eq)} i_{eq}; v_1 = k_{H1} i_1; v_2 = k_{H2} i_2;$$

$$v_3 = k_{H3} i_3; \cdots v_n = k_{Hn} i_n$$

Substituting the preceding relations for the velocities and noting that $i_{eq} = i_1 = i_2 = i_3 = \cdots = i_n$ result in

$$k_{H(eq)} = \frac{1}{H}(k_{H1}H_1 + k_{H1}H_2 + k_{H3}H_3 + \cdots + k_{Hn}H_n)$$

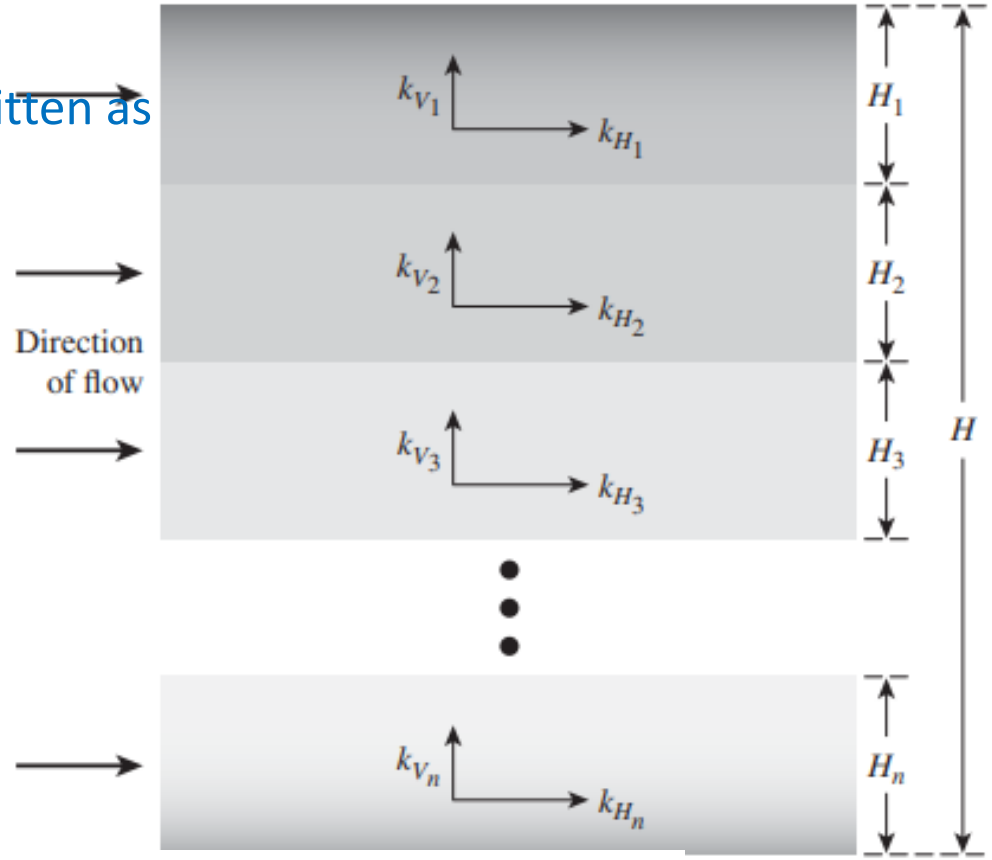

Figure 7.16 Equivalent hydraulic conductivity determination—horizontal flow in stratified soil

6.7 Equivalent Hydraulic Conductivity in Stratified Soil

Verticall Flow

The velocity of flow through all the layers is the same,

$$v = v_1 = v_2 = v_3 = \cdots = v_n$$

The total head loss h is equal to the sum of the head losses in all layers,

$$h = h_1 + h_2 + h_3 + \cdots + h_n$$

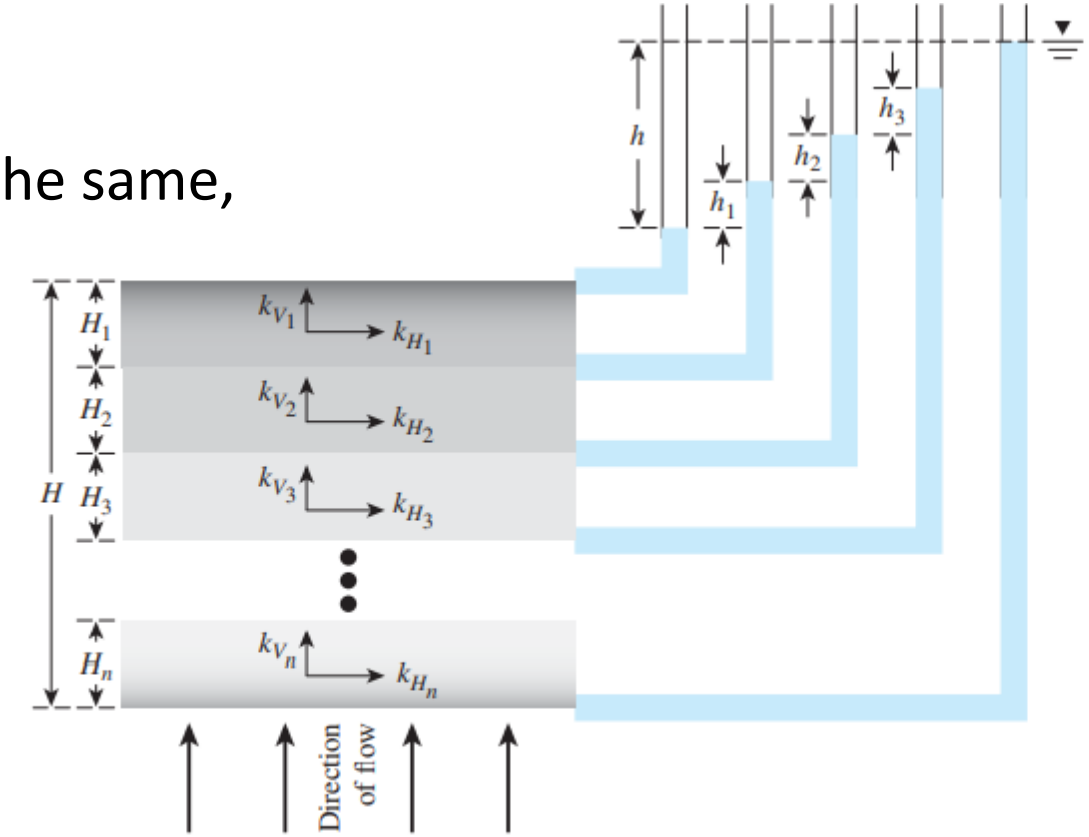

Figure 7.17 Equivalent hydraulic conductivity determination—vertical flow in stratified soil

6.7 Equivalent Hydraulic Conductivity in Stratified Soil

Verticall Flow

Using Darcy's law, one can rewrite as,

1. $$k_{V(\mathrm{eq})}\left(\frac{h}{H}\right) = k_{V_1}i_1 = k_{V_2}i_2 = k_{V_3}i_3 = \cdots = k_{V_n}i_n$$

2. $$h = H_1 i_1 + H_2 i_2 + H_3 i_3 + \cdots + H_n i_n$$

$$k_{V(eq)} = \frac{H}{\left(\frac{H_1}{k_{V1}}\right) + \left(\frac{H_2}{k_{V2}}\right) + \left(\frac{H_3}{k_{V3}}\right) + \cdots + \left(\frac{H_n}{k_{Vn}}\right)}$$

6.7 Permeability test in the field by pumping from wells

Case 1 (unconfined layer)

- The steady state is established when the water level in the test well and observation wells becomes constant

$$q = k\left(\frac{dh}{dr}\right)2\pi rh$$ or

$$\int_{r_2}^{r_1} \frac{dr}{r} = \left(\frac{2\pi k}{q}\right)\int_{h_2}^{h_1} h\,dh$$

$$k = \frac{2.303\,q\,\log_{10}\left(\frac{r_1}{r_2}\right)}{\pi(h_1^2 - h_2^2)}$$

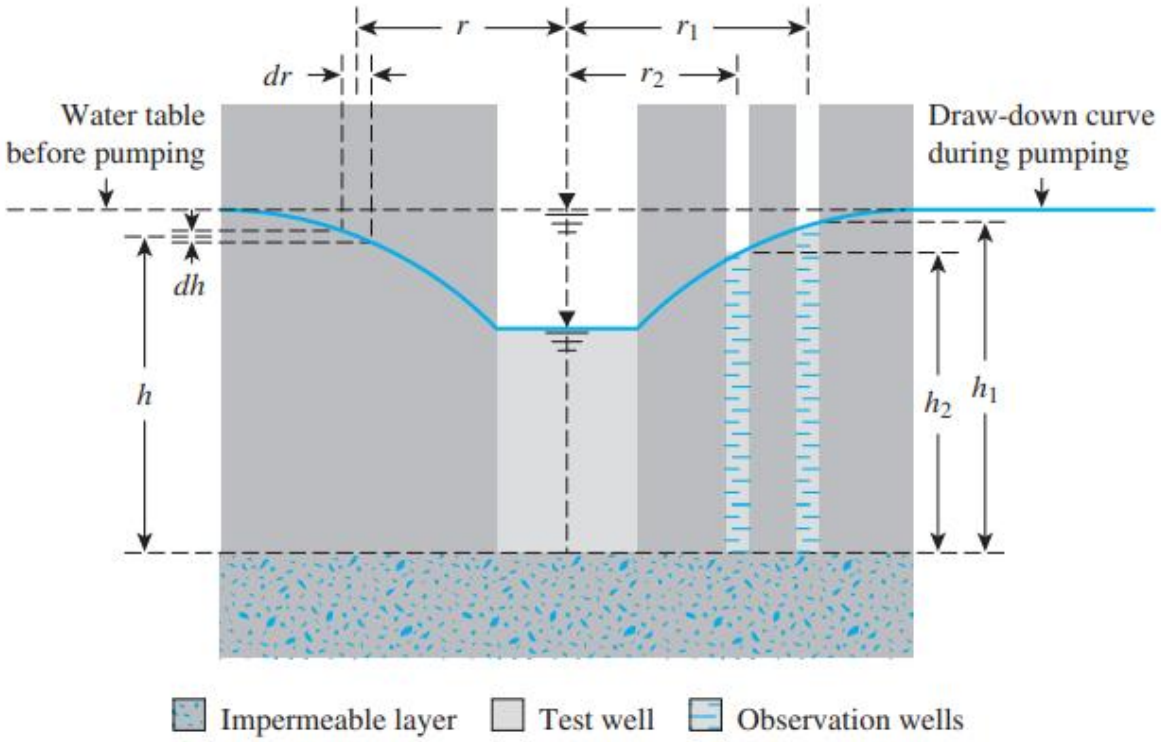

Figure 7.21 Pumping test from a well in an unconfined permeable layer underlain by a impermeable stratum.

6.7 Permeability test in the field by pumping from wells

Case 2 (confined aquifer)

- A confined aquifer

$$q = k\left(\frac{dh}{dr}\right)2\pi rH \quad \text{or}$$

$$\int_{r_2}^{r_1}\frac{dr}{r} = \int_{h_2}^{h_1}\frac{2\pi kH}{q}\,dh$$

$$\boxed{k = \frac{q\ \log_{10}\left(\frac{r_1}{r_2}\right)}{2.727H(h_1-h_2)}}$$

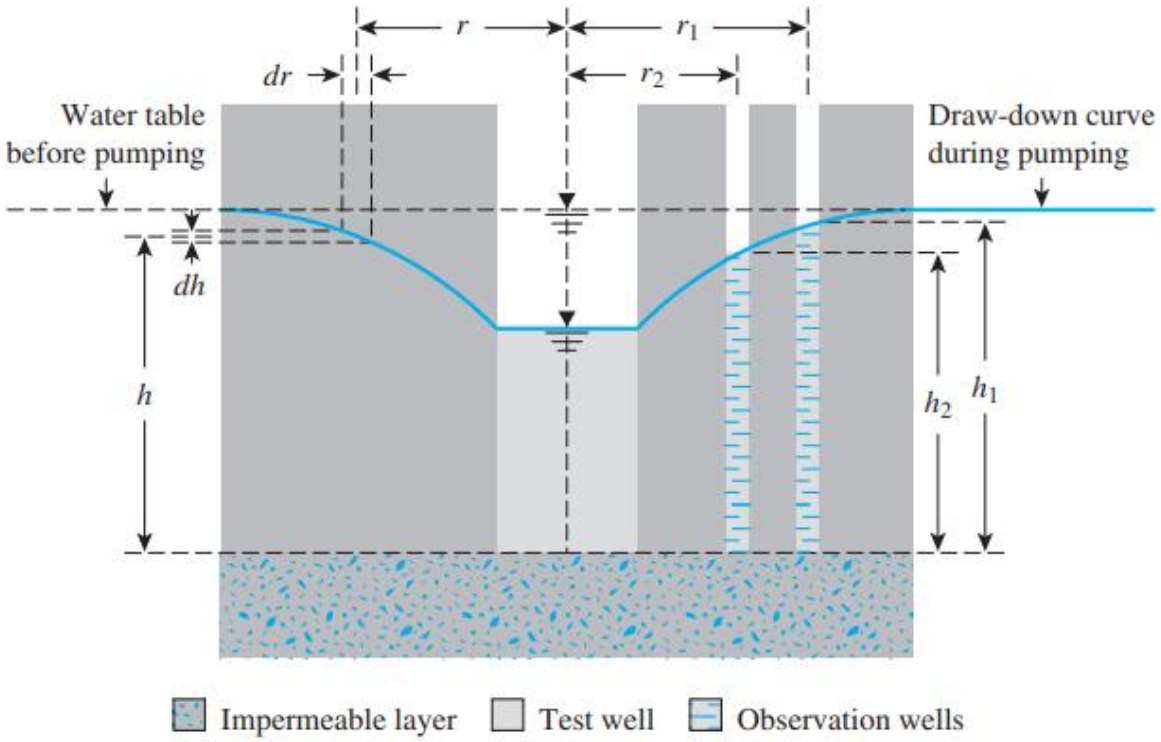

Figure 7.21 Pumping test from a well in an unconfined permeable layer underlain by a impermeable stratum.

- The hydraulic conductivity of saturated cohesive soils also can be determined by laboratory consolidation tests.
- The actual value of the hydraulic conductivity in the field also may be somewhat different than that obtained in the laboratory because of the non-homogeneity of the soil.