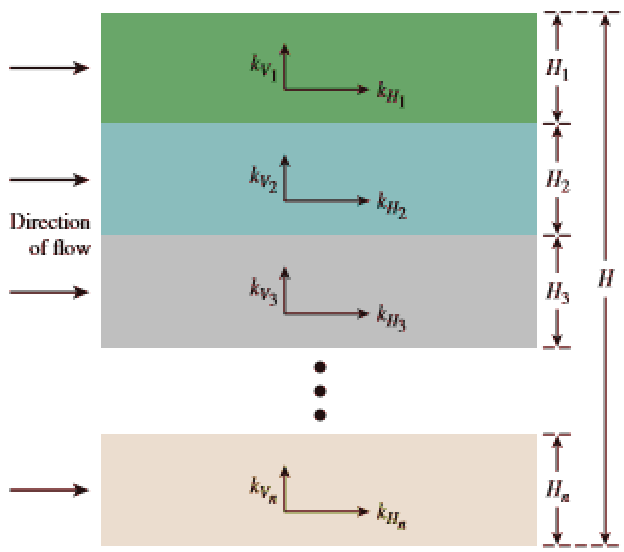
Equivalent Hydraulic Conductivity in Stratified Soil

The stratified soil deposit where the hydraulic conductivity for flow in a given direction changes from layer to layer, an equivalent hydraulic conductivity can be computed to simplify calculations.

The following derivations relate to the equivalent hydraulic conductivities for flow in vertical and horizontal directions through multilayered soils with horizontal stratification.

EQUIVALENT HORIZONTAL HYDRAULIC CONDUCTIVITY

The figure shows that N layers of soil with flow in the horizontal direction. Let us consider a cross section of unit length passing through the n layer and perpendicular to the direction of flow.



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

$$q = v \cdot 1 \cdot H$$
$$= v_1 \cdot 1 \cdot H_1 + v_2 \cdot 1 \cdot H_2 + v_3 \cdot 1 \cdot H_3 + \ldots + v_n \cdot 1 \cdot H_n$$

Where:

v = average discharge velocity (mm/sec, cm/sec, or m/sec)

v_1, v2, v3,…,v_n =discharge velocities of flow in layers denoted by the subscripts.

Consider a cross section of unit passing through the layers of soil and perpendicular to the direction of flow.

If kH_1, kH_2, kH_3,…, kHn are hydraulic conductivities of the individual layers in the horizontal direction and kHeq is the equivalent hydraulic conductivity in the horizontal direction, then, from Darcy's law.

$$v = k_{H(eq)} i_{eq}$$

$$v_1 = K_{H1} i_1$$

$$v_2 = K_{H2} i_2$$

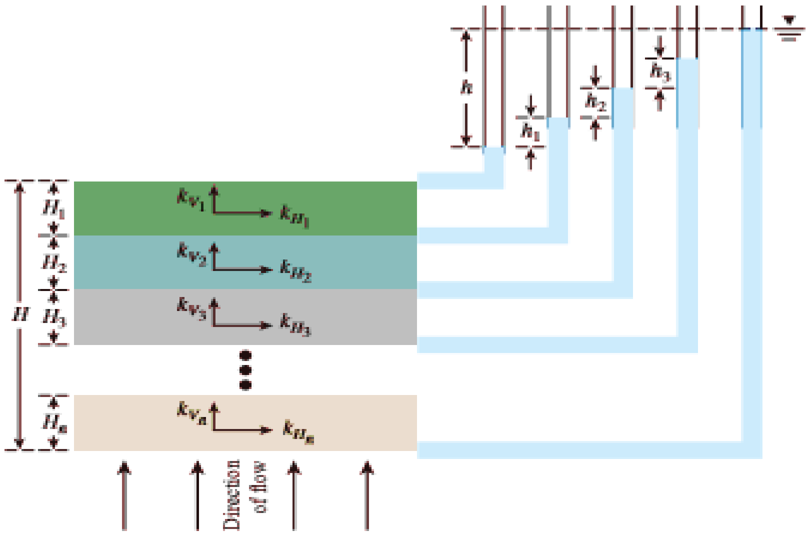
$$v_3 = K_{H3} i_3$$

Next, substitute the preceeding relations for velocities and noting that:

$i_{eq} = i_1 = i_2 = i_{3\ldots} = i_n$ in the general formula :

$$\mathbf{K_{H(eq)} = \frac{1}{H} (K_{H1}H_1 + K_{H2}H_2 + K_{H3}H_3 + \ldots + K_{HN}H_N)}$$

EQUIVALENT VERTICAL HYDRAULIC CONDUCTIVITY



The above figure shows n layers of soil with flow in the vertical direction. In this case, the velocity of flow through all the layers is the same. However, the total head loss, h, is equal to the sum of the head losses in all layers. Thus,

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

and

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

By using Darcy's Law, we can rewrite $v = v_1 = v_2 = v_3 \ldots = v_n$ as

$$\mathbf{K_{V(eq)}\left(\frac{h}{H}\right) = K_{V1}i_1 = K_{V2}i_2 = K_{V3}i_3 = K_{VN}i_N}$$

Where:

K_{V1}, K_{V2}, K_{V3} … K_{Vn} = the hydraulic conductivities of the individual layers in the vertical direction. *(mm/sec, cm/sec, m/sec)*

$K_{V(eq)}$ = equivalent hydraulic conductivity *(mm/sec, cm/sec, m/sec)*

Another formula from the equation $h = h_1 + h_2 + h_3 + \ldots + h_n$ which gives:

$$h = H_1 i_1 + H_2 i_2 + H_3 i_3 + \ldots + H_n i_n$$

Combining solving the two equations:

Equation 1: $K_{V(eq)} \left(\frac{h}{H}\right) = K_{V1} i_1 = K_{V2} i_2 = K_{V3} i_3 = K_{VN} i_N$ and

Equation 2: $h = H_1 i_1 + H_2 i_2 + H_3 i_3 + \ldots + H_n i_n$

which gives:

$$K_{V(eq)} = \frac{H}{\frac{H1}{Kv1} + \frac{H2}{Kv2} + \frac{H3}{Kv3} + \ldots + \frac{Hn}{Kvn}}$$

Where:

K_{V1}, K_{V2}, K_{V3} ... K_{Vn} = the hydraulic conductivities of the individual layers in the vertical direction. *(mm/sec, cm/sec, or m/sec)*

$K_{V(eq)}$ = equivalent hydraulic conductivity

(mm/sec, cm/sec or, m/sec)

H = total head loss in all layers *(cm or m)*

H = h1 + h2 + h3 *(cm or m)*

Porosity is the volume of void space in geologic material.

Specific yield determines how much water is available within a rock or sediment when saturated because these empty spaces are usually occupied by groundwater.

Porosity is therefore defined as the specific yield minus the specific retention. Void space within the ground can also be called voids, interstices, pores, or pore space. These pores are of main importance in groundwater studies because they serve as water conduits when they are connected by diagenesis.

The origin of these empty spaces comes from the very geologic processes that governed the deposition of sediments, but modified after the rock becomes lithified by diagenesis or structured processes that result in development of fractures, joints, and openings. Porosity is simply defined as the ratio of the volume of the interstices to the total volume:

$$\mathbf{n} = \frac{\boldsymbol{Vv}}{\boldsymbol{V}}$$

where:

n = porosity

Vv = volume of interstices or voids *(mm/sec, cm/sec or, m/sec)*

V = total volume or bulk volume *(mm/sec, cm/sec or, m/sec)*

Method for Porosity Measurement:

An imbibition method can be used to estimate porosity in sediments. Such methods involve the displacement of one fluid by another.

1. In this case, the displaced fluid is air and the displacing fluid would be distilled water to avoid chemical interaction with the sediments. The volume of the displacing fluid is previously measured so that the volume of voids can be calculated.
2. After the fluid has displaced all the air, the total volume (sediment and water) is then measured.
3. Estimate of total porosity of each sample, a 250 mL (cc), a 500 mL (cc), or 1,000 mL (1000 cc) graduated cylinder was first filled partially with a known volume of water. Sediment was carefully added to the cylinder and allowed to settle and compact.
4. Additional water and sediment were added to the column. Care was taken to not allow air entrapment within the saturated column.
5. The column was compacted slightly by tapping the side of the cylinder with a rubber mallet to approximate natural system packing conditions near surface. The volume of sediment was determined along with the volume of water added.
6. When the water level in the cylinder rose above the surface of the sediment, a correction was made to the water volume added (subtraction).
7. Then, the estimated porosity was determined by dividing the volume of water by the volume of sediment.