

Hydraulic Behavior of Granular Substrate

Design Lab 1.101 9-28 and 9-29

In lecture we developed the following ideas and equations to describe the storage and flux of water in a porous (granular) media.

Porosity - The porosity, n , is the fraction of volume occupied by pore spaces. Only the pore spaces are available to hold or pass water. For total volume, V , and pore volume, V_P ,

$$(1) \quad n = V_P / V.$$

One can estimate the porosity by filling a known volume, V , with dry granular material. Then, slowly pour water into the material, keeping track of how much water is added. Add water until the water surface is just visible at the surface of the granular material. The added water volume, $V_W = V_P$, such that $n = V_W/V$.

Darcy's Law - Flow in a porous media is driven by gradients in hydraulic head,

$$(2) \quad h = z + p/\rho g.$$

Here z indicates elevation above a specified datum, p is the pressure, ρ is the density of the fluid and g is the gravitational constant. The volumetric flow rate, $Q[\text{m}^3\text{s}^{-1}]$ is then given by Darcy's law,

$$(3) \quad Q = -K A \partial h/\partial x,$$

where A is the cross-sectional area of the flow domain and K is the hydraulic conductivity. The hydraulic conductivity will vary with grain size, d , and porosity, as well as with the fluid viscosity, μ . The Kozeny-Carmen Equation captures these dependencies,

$$(4) \quad K = \frac{\rho g}{\mu} \left(\frac{n^3}{(1-n)^2} \right) \frac{d^2}{180}.$$

Laboratory Tasks

- 1) Determine the porosity of each grain type using the method described above.
- 2) Determine the hydraulic conductivity for each grain type.

You will have a re-usable test column made from a short piece of tubing, of length L and cross-section A . Fill the column with one of the grain types and connect it into the water source at your station and the outlet you constructed via threaded couplings (don't forget the Teflon tape!). By adjusting the valves you can adjust the pressure at the inflow (p_1) and outflow (p_2) of the test column. Let the pressure drop be $\Delta p = p_2 - p_1$. If the test column is horizontal, then the head gradient across the column is $\partial h/\partial x = \Delta p/\rho g L$. For four different Δp determine the flow rate, Q , by capturing a volume of effluent, $Vol.$ over a fixed time interval, T , i.e. $Q = Vol./T$. Plot Q versus $\Delta p A/\rho g L$ and use the fitted linear slope to estimate the hydraulic conductivity, K . Repeat this procedure for each substrate. Note that with both valves closed, Δp should be zero. Use this to evaluate whether an offset exists in the pressure gauges. Be sure to correct for this offset.