Lecture 4: Groundwater
Porosity and Specific Yield

- **Porosity**: The volume fraction of void to solid in dried sample.
- **Saturation**: When these voids are fully filled with water.

**Specific Yield** $S_y$: the ration of the column of water that drains from a rock owing to gravity, to the total rock volume.

- $h_1, h_2$ resp., are the heights of the saturated layer.
- $Q$ is the volume of the water discharged to reach $h_2$ from $h_1$.
- \[ S_y = \frac{Q}{(h_1-h_2)A} \]

Caution: rock above $h_i$ is wet, but unsaturated.

**Lab. setup**: Takes a lot of time for water to drip.
Specific Yield

- **Importance:** This is actually the fraction which is accessible.
- **Note 1:** In accessible voids are NOT counted in porosity.
- **Note 2:** To access full \(n\)-fraction, oven heating was required.
- Clearly \(S_y \leq n\), the porosity and

\[ S_r = n - S_y \]

\(S_r\) is called the **Specific Retentivity**.
- \(S_r\) is largely due to the adhesion of water molecules to the rock layer.
- **Specific Yield of a well:** to be done later.

<table>
<thead>
<tr>
<th></th>
<th>Some Specific Yields</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>2</td>
</tr>
<tr>
<td>Silt</td>
<td>18</td>
</tr>
<tr>
<td>Medium Sand</td>
<td>26</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>7</td>
</tr>
<tr>
<td>Fine Sand</td>
<td>21</td>
</tr>
<tr>
<td>Fine Gravel</td>
<td>25</td>
</tr>
</tbody>
</table>
Hydraulic Conductivity

- $h_1$ and $h_2$ are the heights of the water column.
- $Q$ is in cu.m./sec, is the rate of flow.

Darcy’s law

There is a constant $K$ (depending just on the material) so that

$$Q = KA(h_1 - h_2)/L$$

- $Q$ is in cu.m/s
- $L$ is the length of the pipe and $A$ its cross-section area.
Darcy’ law

- The first law to relate the motion of ground-water
- **Conductivity** $K$: is an attribute of the substance.
- **Dimension of $K$:** is meter/second.

<table>
<thead>
<tr>
<th>Material</th>
<th>$K$ in cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>$10^{-9} – 10^{-6}$</td>
</tr>
<tr>
<td>Silt</td>
<td>$10^{-6} – 10^{-4}$</td>
</tr>
<tr>
<td>Fine Sands</td>
<td>$10^{-5} – 10^{-3}$</td>
</tr>
<tr>
<td>Gravels</td>
<td>$10^{-2} – 1$</td>
</tr>
</tbody>
</table>

source: Fetter

- Note that Darcy’s law *almost* gives us *water particle velocities*.
- **WARNING:** Only saturated and slow moving flows.
- Typical velocities: few cm a day to few meters a day.
- $K$ actually depends on both the rock/soil and the fluid (e.g., water, oil) which is moving.
- This leads to a fluid independent constant called *intrinsic permeability* measured in *darcys*, which we skip.
The head difference is maintained at $h_1 - h_2$.
The sample is held by two permeable stoppers.
The sample thickness is $L$ and cross-section $A$.
The system is at steady state and the outflow $Q$ is measured.

$$K = \frac{QL}{A \cdot (h_1 - h_2)}$$
Measuring K: varying heads

- Start with height $h(0) = h_1$ and stop after time $T$ and at height $h(T)$.
- Let cross-section of both tubes be $A$.
- Let $Q$ be the total water discharged.

We have $Q = KA(h(t) - h_2)/L$, whence we have:

$$\frac{dh}{dt} = -K(h(t) - h_2)/L \quad h(0) = h_1$$

- $h(t) = (h_1 - h_2)e^{-Kt/L} + h_2$ whence we have:

- $K = L \log[(h_1 - h_2)/(h(T) - h_2)]/T$
The General Darcy

Darcy's observation is that the flow *does not change* even if we vary the angle of inclination provided:

- The length of the rock-sample is not changed.
- The difference in the heads at the ends remains the same.

This is remarkable in its similarity to ordinary fluid flow.

- It will also lead us to the gradient form of the ground-water differential equation.
The Piezometer: is a water column with a porous end, and is used to measure the piezometric head at any point in the soil.

Let $h$=ht. of water table and $h'$ be the point at which the piezometer is inserted. Let $h_i$ be the readings.

(i) If $h' < h$ then $h' < h_1$.
(ii) If $h' = h$ then $h' = h_2$.
(iii) If $h' > h$ then $h' > h_3$. 
The total head $h(p)$ is the sum of the hydrological head $w(p)$ and the elevation $e(p)$.

$$h(p) = e(p) + w(p)$$

- $w(p) > 0$ iff the point $p$ is saturated.
- $w(p) = 0$ iff $p$ is on the water table.
- $w(p) < 0$ iff $p$ is unsaturated.

**Darcy’s Law**

Water moves from higher total head to lower total head.
Well Recharge

- Let $p_1$ and $p_2$ be points on the water table.
- Clearly $h(p_i) = e(p_i)$ since $w(p_i) = 0$.
- Thus $h(p_1) > h(p_2)$ and groundwater flows from $p_1$ to $p_2$.
- A well from which water is drawn causes a *dip* in the water table, called the *draw-down cone*.
- This cone causes the well to recharge. The strength of the recharge is given by the angle of attack.
- If the water-table falls below the well-bottom then recharge stops.

![Diagram of well recharge](image-url)
Groundwater and Rains

- A typical terrain with a depression. Water Table following the topography.
- Rains cause infiltration. Since in the depression, the thickness is small, WT rises faster here. A significant Groundwater flows away from the depression.
- Still more rains causes the water-table to touch the surface and this creates a pond.
- Eventually scenario (i) returns.
In general, we would like to
- analyse groundwater and surface water
- prescribe corrective measures
- understand sustainable use

A real-life scenario
- Various surface features such as farmslands, forests, built-up areas, which affect infiltration.
- Similar soils appearing as layers, and their geological properties, such as porosity, conductivity etc.
- climactic data such as rainfall, evaporation, etc.
- Water requirements and usage, such as for irrigation, domestic use, and so on.
Bore-logs

SFE

DATE: 11/05/2009

SOHAMS FOUNDATION ENGINEERING PVT. LTD.

PROJECT: Soil Investigation at Gudvanwadi Check Dam

LEGEND

- Soil & Boulder (Overburden)
- Jointed Basalt Rock (MW)
- Basalt Rock (SW)
- Amygdoloidal Basalt Rock (SW)
- HTAB
- Very Highly weathered Rock (Murrum)

<table>
<thead>
<tr>
<th>BH. NO</th>
<th>BH-1</th>
<th>BH-2</th>
<th>BH-3</th>
<th>BH-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>10.10 m</td>
<td>10.05 m</td>
<td>10.20 m</td>
<td>10.00 m</td>
</tr>
<tr>
<td>RL. M.</td>
<td>95.085 m</td>
<td>96.31 m</td>
<td>97.65 m</td>
<td>99.20 m</td>
</tr>
<tr>
<td>Chainage</td>
<td>15.00 m</td>
<td>35.00 m</td>
<td>55.00 m</td>
<td>75.00 m</td>
</tr>
</tbody>
</table>
Papagni Again
Discussion

1. Draw a possible graph relating moisture content with head.
2. Would porosity measurement change due to handling of the sample? And conductivity?
3. What care would you take in the lab set-ups discussed in the class?
4. Why should Darcy's law break down for high velocity flows?
5. When would you use fixed head vs. varying head set-ups?
6. Study the Papagni data carefully and comment on it.
7. Compare and contrast the definition of electrical conductance.