Period #7: Fluid Flow in Soils (I)

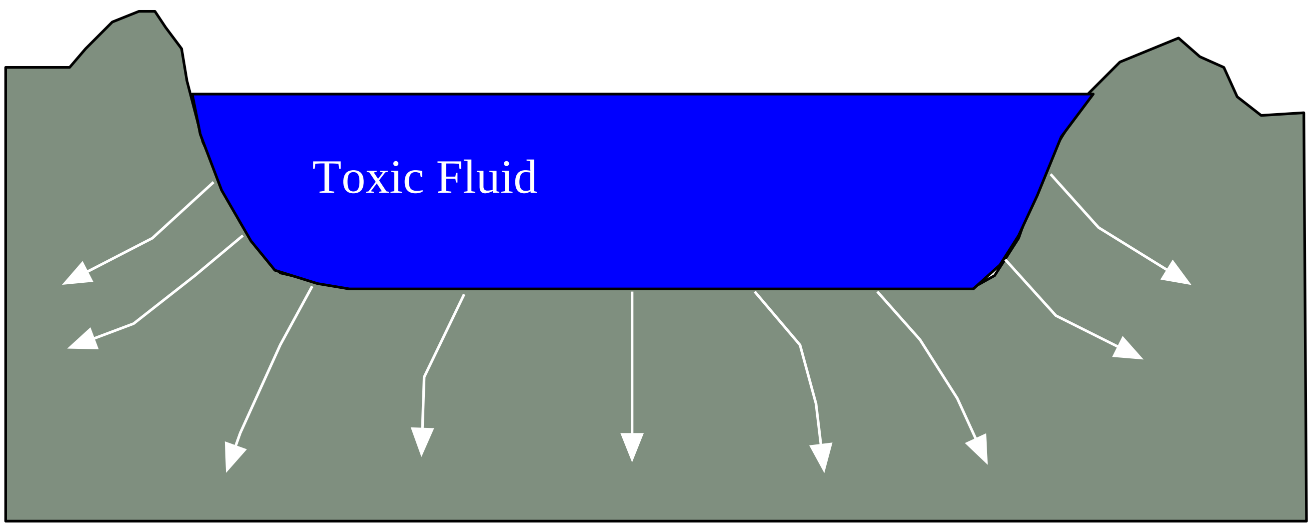
A. Motivation:

The ability of engineers to understand and predict the flow of fluids (usually water) in soils is essential for many application in civil engineering. Some typical examples are as follows:

(i) environmental engineering:

When toxic liquids are retained in holding lagoons, important questions that need to be answered are:

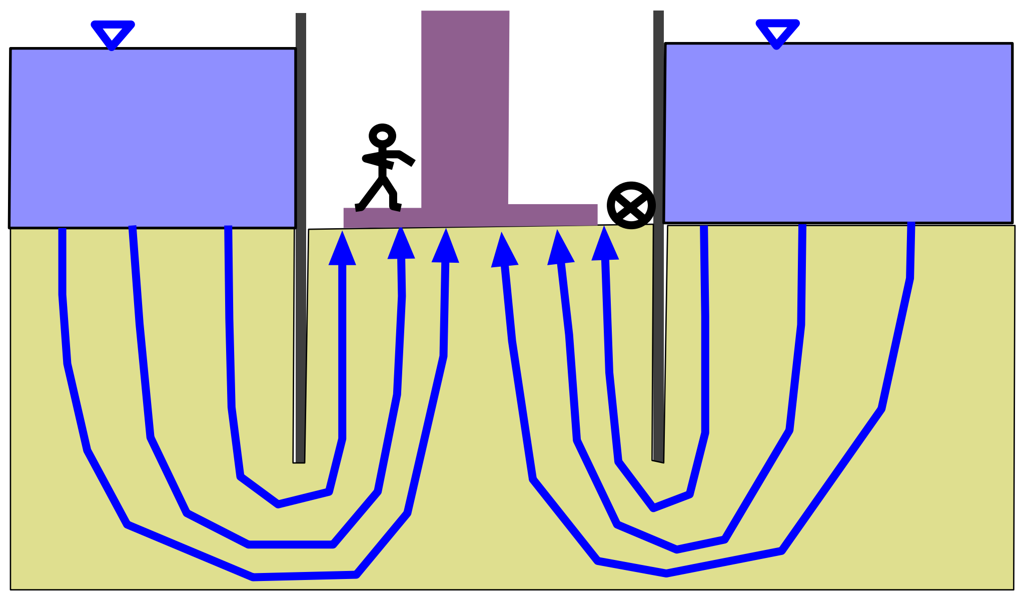
- --> At what rate is toxic fluid escaping the holding lagoon?
- --> How long might it take the fluid to reach the ground water table?
- --> What can be done to slow down the rate of escape of the pollutant?



ii) construction engineering:

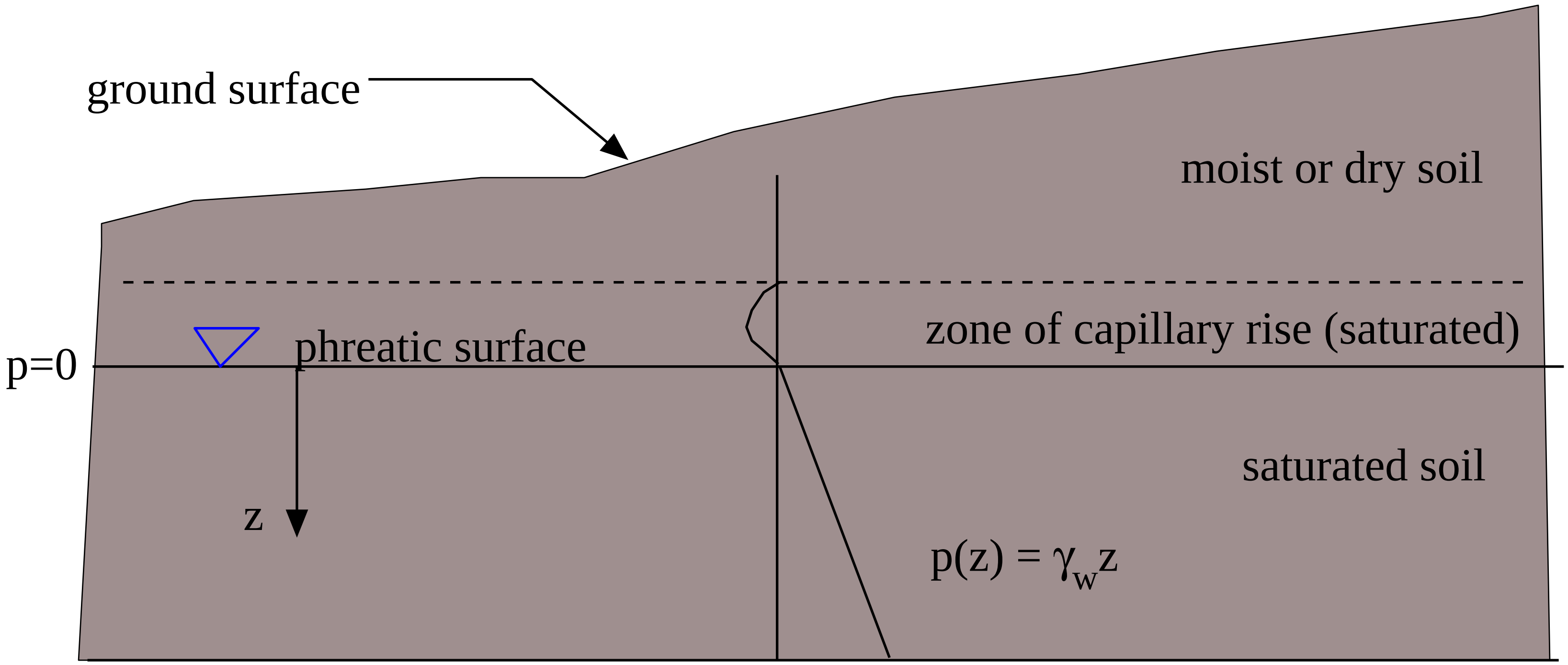
When building structures in relatively shallow bodies of water, it is fairly common construction practice to build a temporary sheet−pile cofferdam structure around the site and to pump the water out.

Important questions that would need to be answered are:
−−> What will be the rate of water inflow to the site ? (so that the pump can be sized)
−−> Is it possible that the soil will liquify and endanger construction workers?



Our objective is to gain an understanding of the mechanics of fluid flow in soils so that engineering problems of this type can eventually be addressed.

B. Fluid at Rest in Soil (No Flow Occurring)



- Beneath the water table:
  - Fluid pressure is hydrostatic: $p(z) = \gamma_w z$
  - This fluid pressure is really a "gauge" pressure in that the atmospheric pressure has been substracted out.

- Immediately above the water table is the capillary zone:
  In the capillary zone, water pressure is less than atmospheric pressure.
  −−> Thus, we say that the fluid pressure is negative in this region.

C. Fluid Flow in Soil

- From fluid mechanics, you might know that the Bernoulli head measures the total energyof a fluid at a fixed spatial point.

$$h = h_z + p/\gamma_w + v^2/2g$$

- The Bernoulli head has three additive contributions:

h_z represents the elevation w.r.t. an *arbitrary* datum. The value is the *distance* of the point at which head is being measured *above the datum.* This number can be either positive if the point is above the datum, or negative if the point is below the datum.

p/γ_w represents the pressure head of the fluid and has units of length.

$v^2/2g$ represents the kinetic head of the fluid and also has units of length. Since water flowing in soil typically has very small velocities, the kinetic head is typically negligible compared to that of the pressure and elevation energies. For this reason, the velocity head is neglected in soil mechanics.

Therefore, the so−called piezometric head used to measure the elevation and pressure energies of fluids in soils is simply: $h = h_z + p/\gamma_w$

The actual value of the piezometric head in fluids is naturally dependent upon the choice of the reference datum.

D. Fluid Flow and Head Gradients

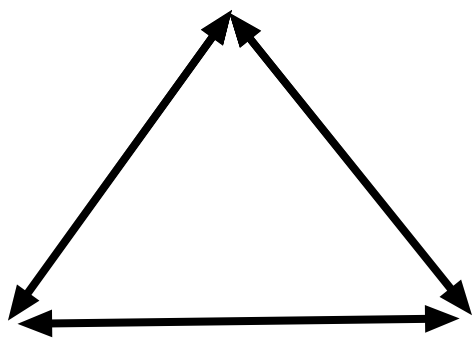
MAJOR CONCEPT:

1) Fluids flow in soils *only* when there is a *gradient* in piezometric head h.
   Lack of a gradient in piezometric head implies that fluid is *not flowing*

2) Whenever there is fluid flow in soils, there is energy dissipation.

3) In soils, fluids always flow *down* the gradient in piezometric head.
   That is, fluids flow from high energy regions to low energy regions.

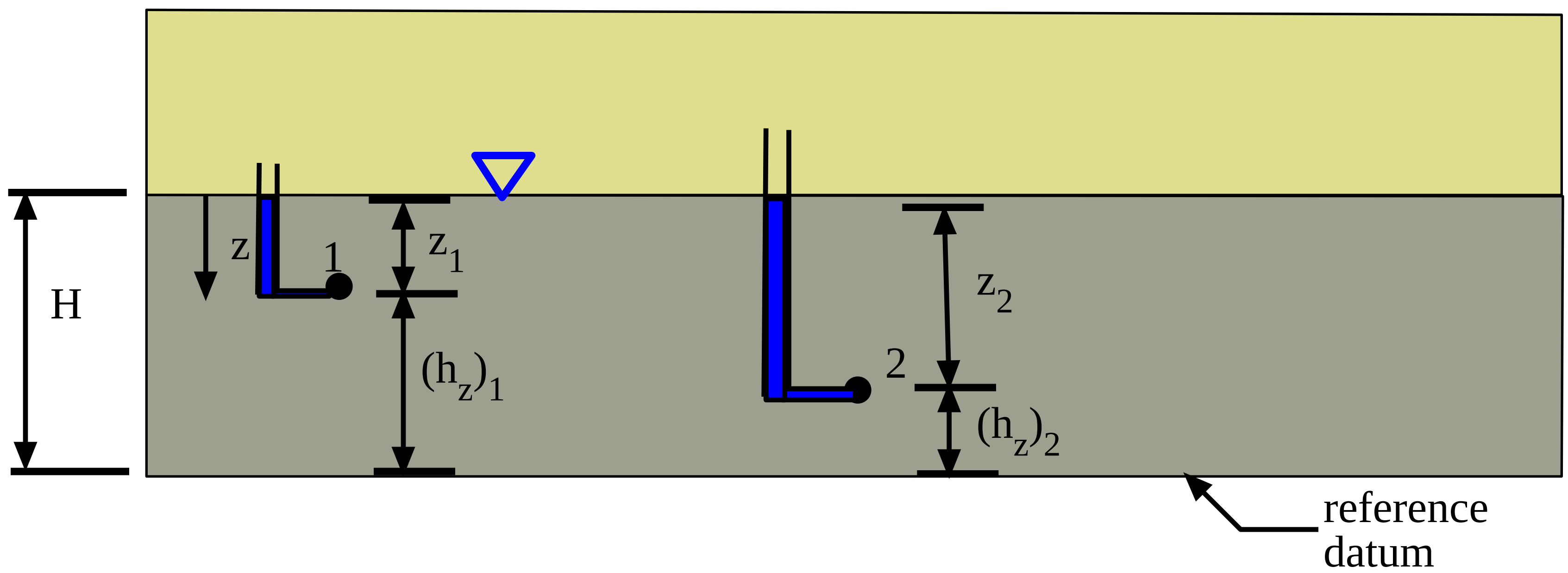
Fluid Flow in Soils



Gradient in head h

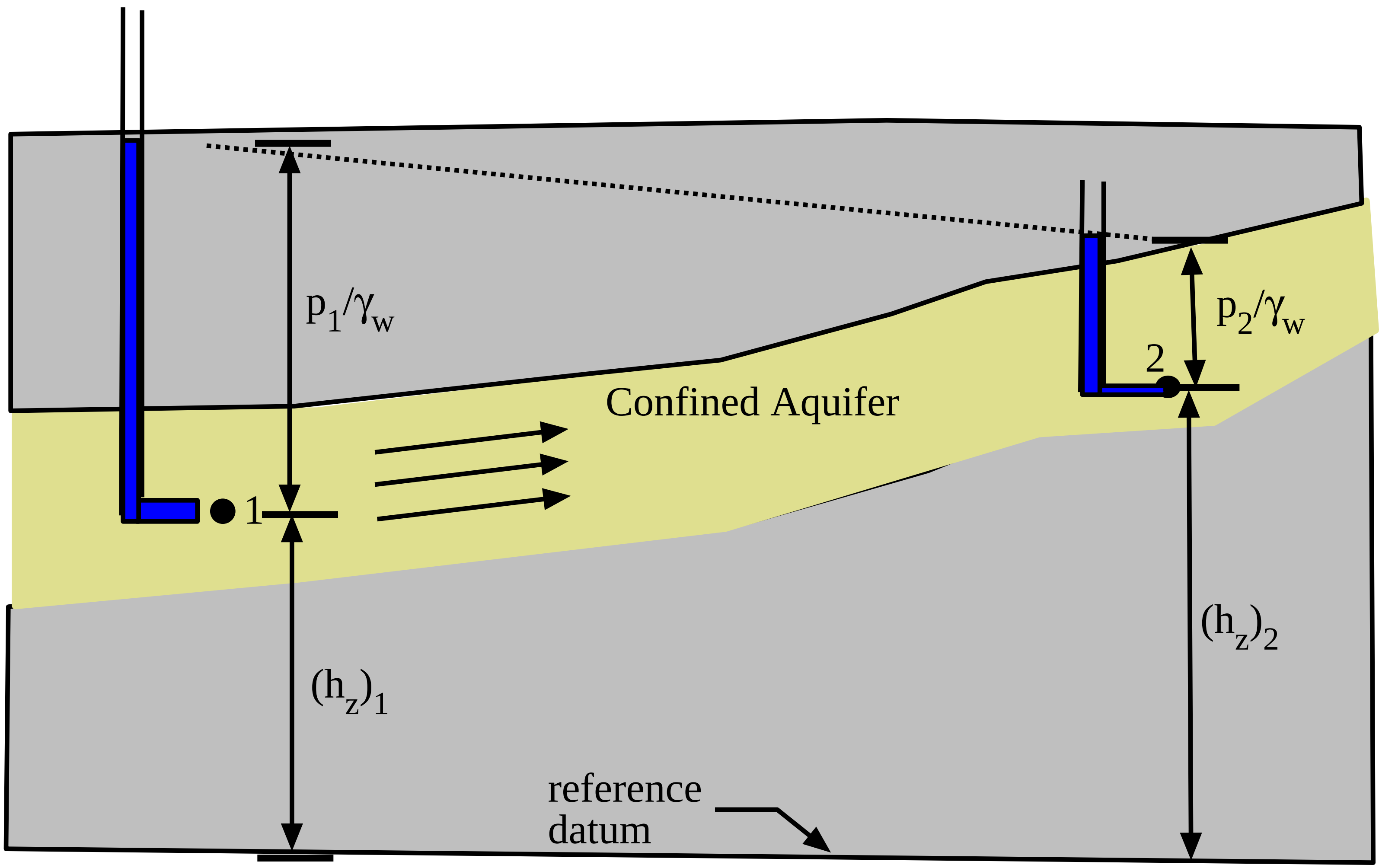
Energy Dissipation

Example #1: Uniform head distribution in a soil deposit.



- At point 1: $h_1 = (h_z)_1 + p_1/\gamma_w = (h_z)_1 + (\gamma_w z_1)/\gamma_w$
  $= (h_z)_1 + z_1 = H$
- At point 2: $h_2 = (h_z)_2 + p_2/\gamma_w = (h_z)_2 + (\gamma_w z_2)/\gamma_w$
  $= (h_z)_2 + z_2 = H$
- The head is identical at points 1 and 2. Thus there is no gradient of head h in the soil. Therefore, there is no flow of water in this situation.

Example #2: Fluid flows down the hydraulic gradient, not necessarily downhill.



•Observe that $h_1 > h_2$. Therefore water flows *down the head gradient* from point 1 toward point 2.

Question: If it is given that h_2=53m that $(h_z)_2$ = 33m. What is p_2?

Answer: Since $h_2 = (h_z)_2 + p_2/\gamma_w$ it follows that

$$p_2 = [h_2 - (h_z)_2]\gamma_w$$
$$= (53\text{m} - 33\text{m})\ 9.81\text{kN/m}^3$$
$$= 192.2\ \text{kN/m}^2$$

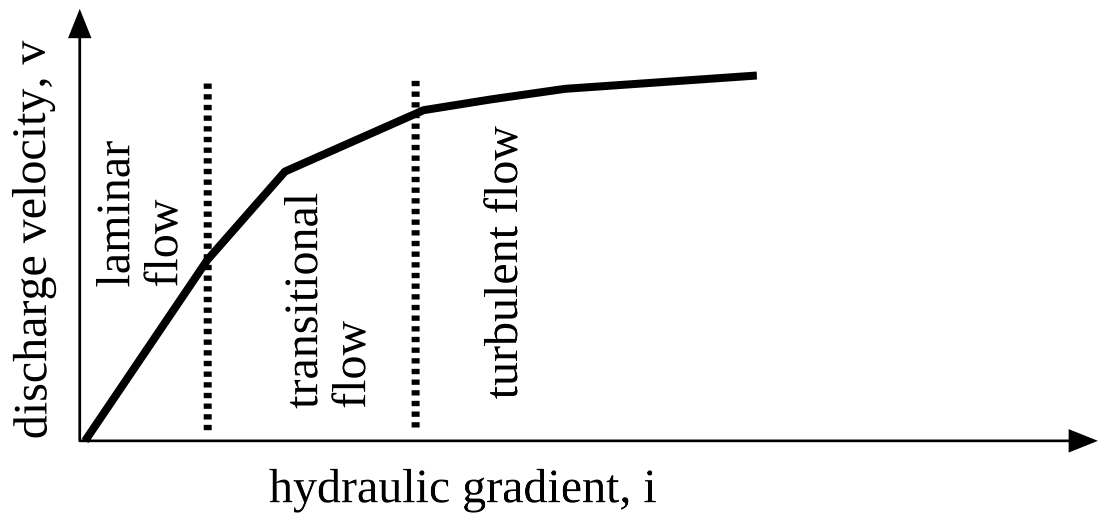
E. Darcy's Law (One−dimensional form)

- Typically, the larger the head gradient in soil, the faster fluid will flow.

- In one dimension, Darcy's Law gives a linear relationship between head gradient i and flow velocity v as follows:

$v = k\,i$ where: v = the *discharge* velocity of water flowing through soil;
k = the *permeability* of the soil; and
i = the *hydraulic gradient* in the direction of flow.

- Darcy's Law is typically valid for values of the hydraulic gradient i less than about 5, and for laminar flow in the voids.



F. Example Problem(s)

G. Measurement of Soil Permeabilities

- A number of tests can be used to measure or estimate the permeability of soils:

- Laboratory tests:
  - −−> the constant head test (used for highly permeable soils)
  - −−> the falling head test (used for relatively impermeable soils)

- Field tests:
  - −−> well draw−down tests.

- These tests will be discussed in more detail in the next period.