Module 4: Water in soils (part 2)

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Spring 2022

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COURSE CONTENTS AND SCHEDULE

Department of
Civil and Environmental Engineering

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Tentative schedule

Day	Date	Topic	Lab.
W	1/19/2022	Class introduction, syllabus, policies	Soil
F	1/21/2022	Invited speaker: Topic TBD	components
M	1/24/2022	Introduction: The geological cycle, soil origin	Grain size
W	1/26/2022	Introduction: Site investigation	dist.
F	1/28/2022	Index properties: Phase relationships	
M	1/31/2022	Index properties: Grain size distribution, Atterberg limits	Atterberg
W	2/2/2022	Index properties: Soil classification	limits
F	2/4/2022	Compaction	
M	2/7/2022	Quiz 1: Introduction, index properties, compaction, in-situ testing	Visual
W	2/9/2022	Water in soils: Groundawater table, pore pressure, total and effective stresses	classification
F	2/11/2022	Water in soils: Darcy's law	
M	2/14/2022	Water in soils: Permeability and hydraulic conductivity	Compaction
W	2/16/2022	Water in soils: One-dimensional seepage	
F	2/18/2022	Water in soils: 2D-3D seepage, flow nets, pore pressure, uplift force, seepage force	
M	2/21/2022	President's day: no class	In-situ
W	2/23/2022	Water in soils: piping	density
F	2/24/2022	Quiz 2: Water in soils	
M	2/28/2022	Induced stress: Approximations, Bousinesq's elastic solution	Permeability
W	3/2/2022	Induced stress: Bousinesq's elastic solution, superposition	
F	3/4/2022	Induced stress: Stress tensor, elastic deformations	
M	3/7/2022	Consolidation: Oedometer test, primary and secondary consolidation	Site
W	3/9/2022	Consolidation: Preconsolidation pressure, OCR	investigation
F	3/11/2022	Consolidation: Primary consolidation parameters	
M	3/14/2022	Spring break: no class	
W	3/16/2022	Spring break: no class	
F	3/18/2022	Spring break: no class	
M	3/21/2022	Consolidation: rate of consolidation	Bonus
W	3/23/2022	Consolidation: preloading, radial consolidation	
F	3/25/2022	Quiz 3: Induced stress and consolidaiton	
M	3/28/2022	State of stress: 2D stresses and Mohr's circle	Consolidation
W	3/30/2022	State of stress: principal stresses, stress invariants, rotations	
F	4/1/2022	State of stress:: Usage of Mohr's circle	
M	4/4/2022	State of stress: stress paths, simple shear, triaxial compression	Settlement
W	4/6/2022	Quiz 4: State of stress	estimates
F	4/8/2022	Shear strength: Mohr-Coulomb failure criteria	
M	4/11/2022	Shear strength: drained and undrained behavior	Unconfined
W	4/13/2022	Shear strength: Shear strength of clays	compression
F	4/15/2022	Shear strength: Shear strength of sands	test
M	4/18/2022	Quiz 5: Shear strength	Direct
W	4/20/2022	Lateral earth pressure: at-rest, passive, and active conditions [2]	shear
F	4/22/2022	Intro to slope stability [2]	
M	4/25/2022	Intro to bearing capacity [2]	Direct
W	4/27/2022	Maine's day: no class	shear
F	4/29/2022	Classes end: Q&A session	
M	5/2/2022	Final exam (1:30 PM- 3:30 PM) Williams Hall 110	

M: Monday - W: Wednesday - F: Friday

[2] This items may or may not be covered. It will be determined by how far the course has progressed.

RECAP

- We learned about capillary rise.
- We learned about shrinkage/swelling of soils due to water content changes.
- We learned about the ingredients needed for frost action in soils.
- We learned about the principle of effective stress.
- We learned how to calculate geostatic total and effective stress and pore pressure.
- Today 1D water seepage trougth soils.

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CONTENTS

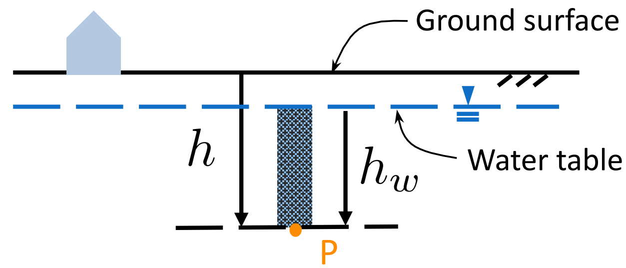
- Total head and Bernoulli's equation.
- Hydraulic gradient.
- Discharge and seepage velocity.
- Darcy's law.
- Hydraulic conductivity and permeability of soils.
- Permeability tests.
- Flow in series and parallel.

More in chapter 7 of Holtz et al. (2013)

WATER IN MOTION

- In this module, we will assume saturated conditions .
  - $\longrightarrow$ all voids are fully filled with water
  - $\longrightarrow$ water pressure $u > 0$
- In the last class, we learned how to calculate the water pressure in saturated soils under static conditions (no flow).

$$u = \gamma_w h_w$$



- In this part, we will study what happens when WATER MOVES!

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TOTAL HEAD

From fluid mechanics, the most important variable to study the behavior of water is the TOTAL HEAD h, which comes from Bernoulli's equation .

TOTAL head h measures the total energy per unit weight of water of a reference volume.

$$h = \frac{u}{\gamma_w} + z$$

- $z =$ elevation

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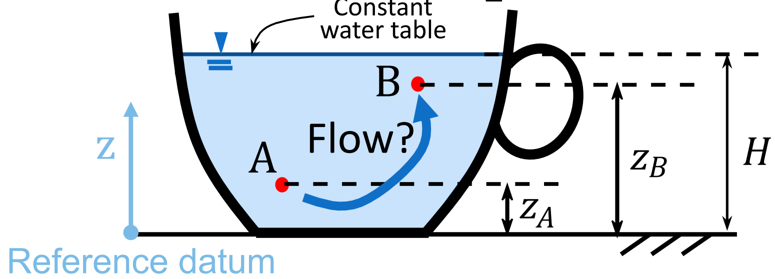
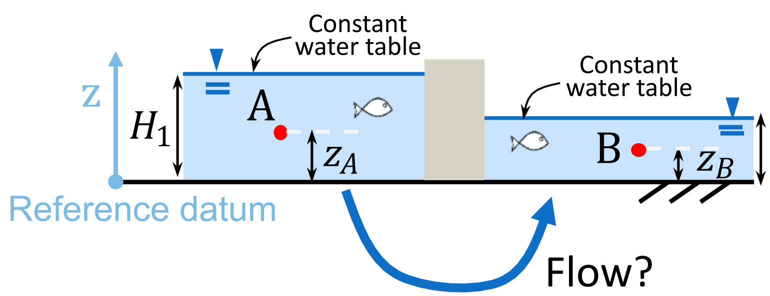
WATER IN MOVEMENT

- To have flow, there needs to be a difference in total head $\Delta h \neq 0$
- Water flows from point of higher h to points of lower h.



Example: dam



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HYDRAULIC GRADIENT

Is the gradient or change of total head over a length L of flow path.

$$i = \frac{\Delta h}{L}$$

Where $\Delta h = h_a - h_b$ with $h_a > h_b$.

- $i = 0 \longrightarrow$ no flow.
- $i \neq 0 \longrightarrow$ flow between the two points.

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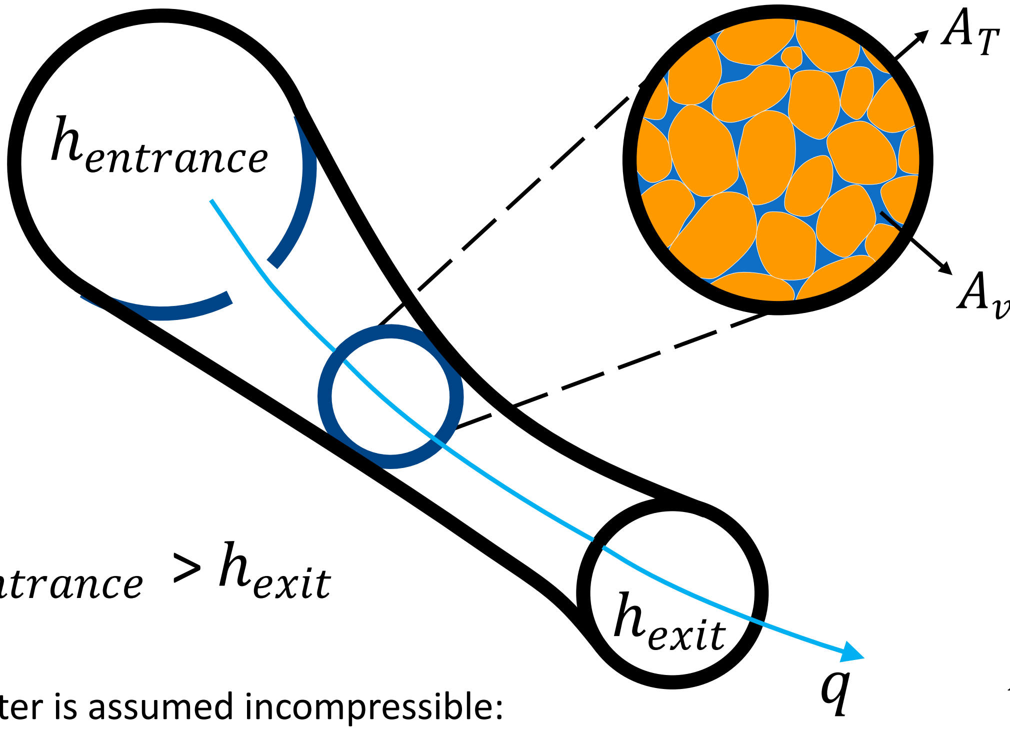
WATER IN MOVEMENT

Flow tube or "Pipe"



$h_{entrance} > h_{exit}$

If water is assumed incompressible:

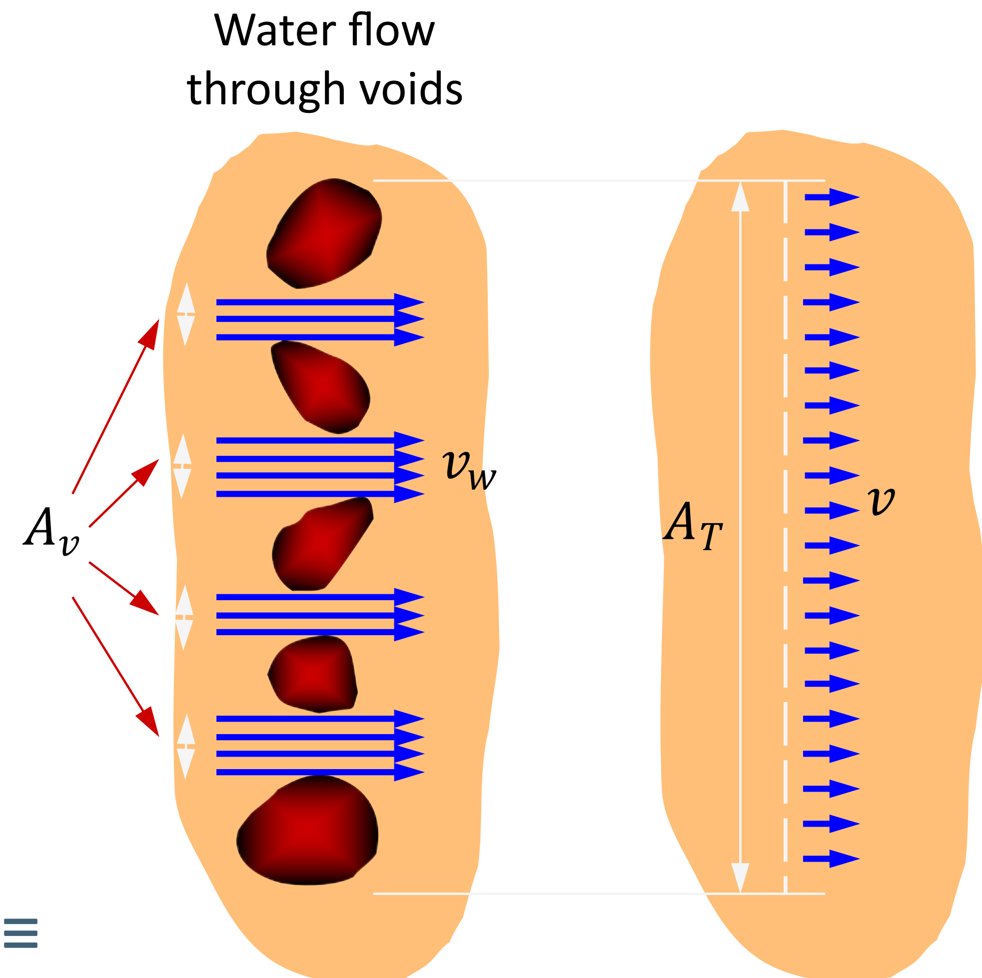
$$q_{entrance} = q_{exit} = q$$

A_v = area of voids

A_t= total coss section

q = water flow rate

TRUE SEEPAGE VELOCITY



Water flow rate q:

$$q = v_w A_v = v A_t$$

"Discharge" velocity (or Darcy velocity) v

$$v = v_w \frac{A_v}{A_t} = v_w n$$

- A_v = area of voids
- A_t = total area
- v_w = seepage velocity (real velocity)

DARCY'S LAW

- Proposed by Henry Darcy (1803-1858), french engineer.
- He designed pressurized water distribution system to supply fresh water to Dijon.
- Proposed the Darcy's law , which describes the flow of fluid trough porous media based on experimental results on the flow water in sands.


Henry darcy

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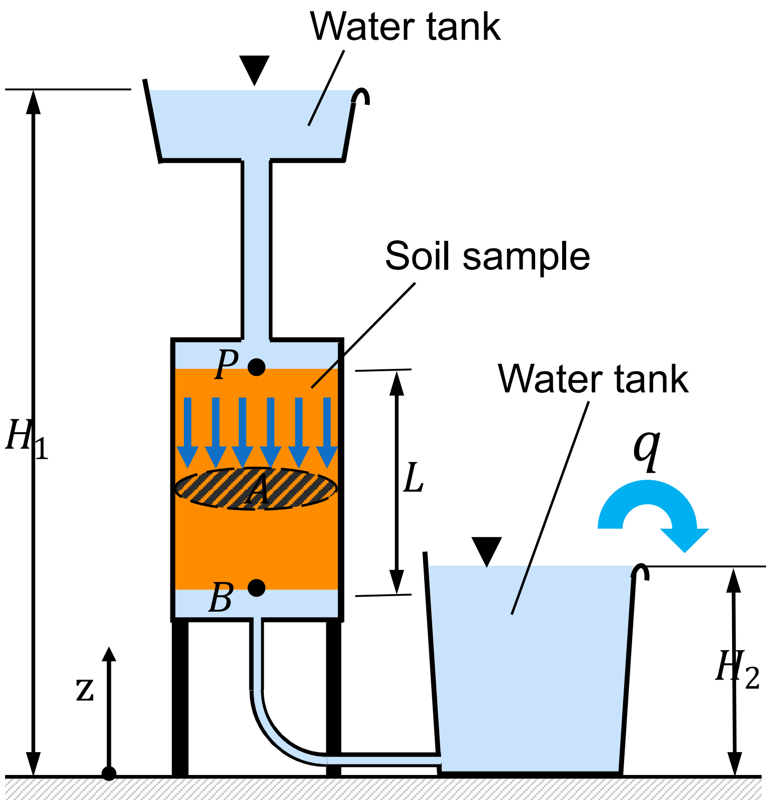
DARCY'S LAW



He observed that the flow rate q was:

- Proportional to A and Δh.
- Inversely proportional to L.

$$q = k\frac{\Delta h}{L}A$$

$$q = kiA$$

$$q = vA$$

- $k =$ permeability coefficient.

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DARCY'S LAW

Darcy's law is valid if:

- The water flow is slow, laminar, not turbulent .
- Kinematic energy is negligible.
- The soil is homogeneous (i.e., properties do not depend on the location of measurement).
- The soil is isotropic (i.e., properties do not depend on the direction that you measure them).

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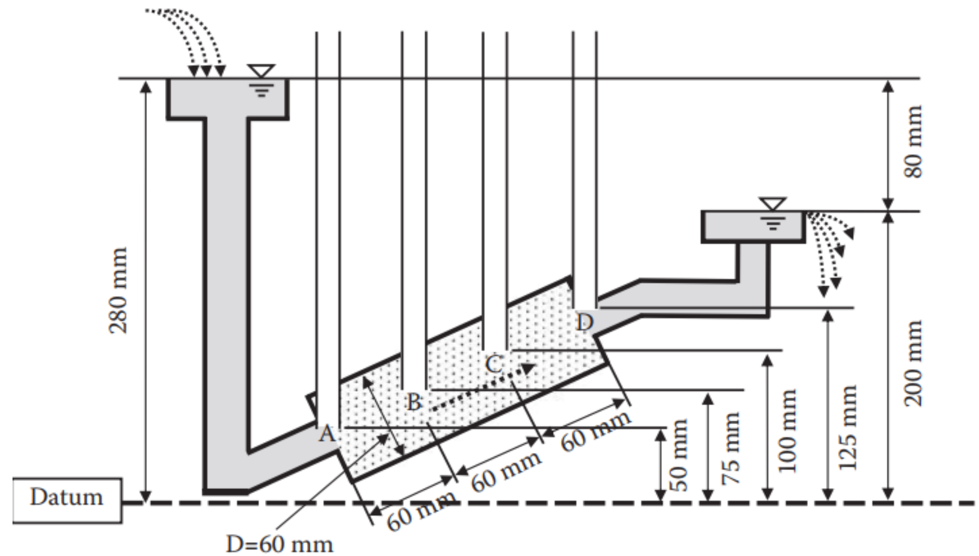
EXAMPLE 4.3

The figure shows water flow trought the soil specimen in a cylinder. The specimen's k is 3.4×10^{-4} cm/s.



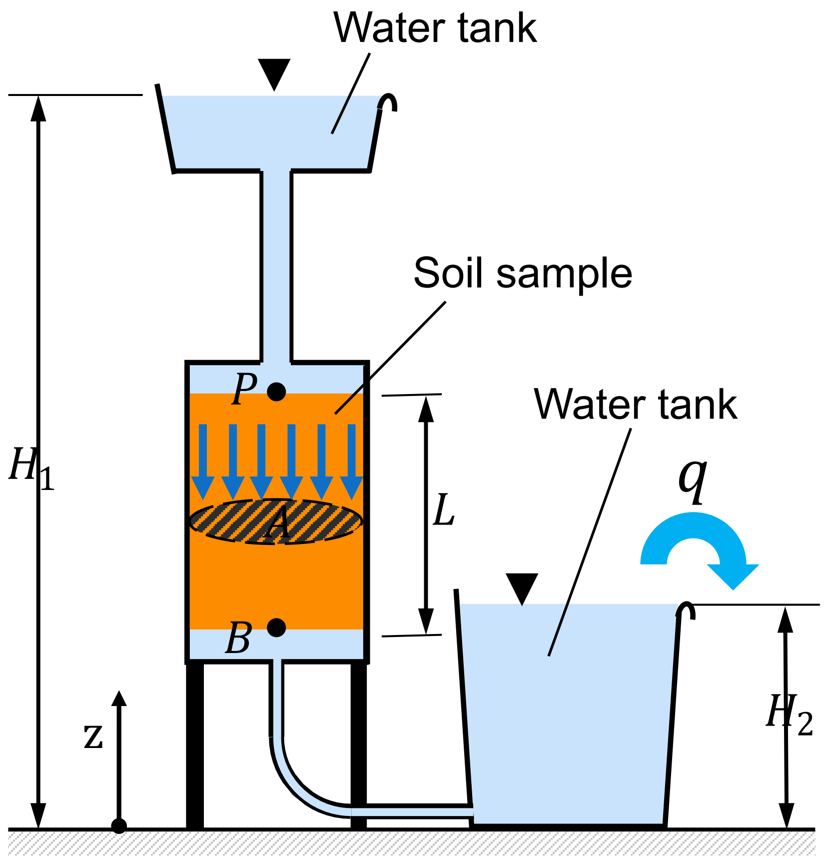
1. Calculate total head, pressure head, and pore pressure at point A and B.
2. Draw the levels of water in standpipes.
3. Compute the amount of water flow q through the specimen.

MEASUREMENT OF PERMEABILITY

Recall:

- Is the ability of water to flow trough soil.
- Depends on void ratio, GSD, voids connectivity, viscosity of the fluid,...
- One of the most variable parameters of soils and difficult to determine in the field accurately.
- Different methods and between most popular we have:
  1. Constant head test
  2. Falling head.

CONSTANT HEAD PERMEABILITY TEST

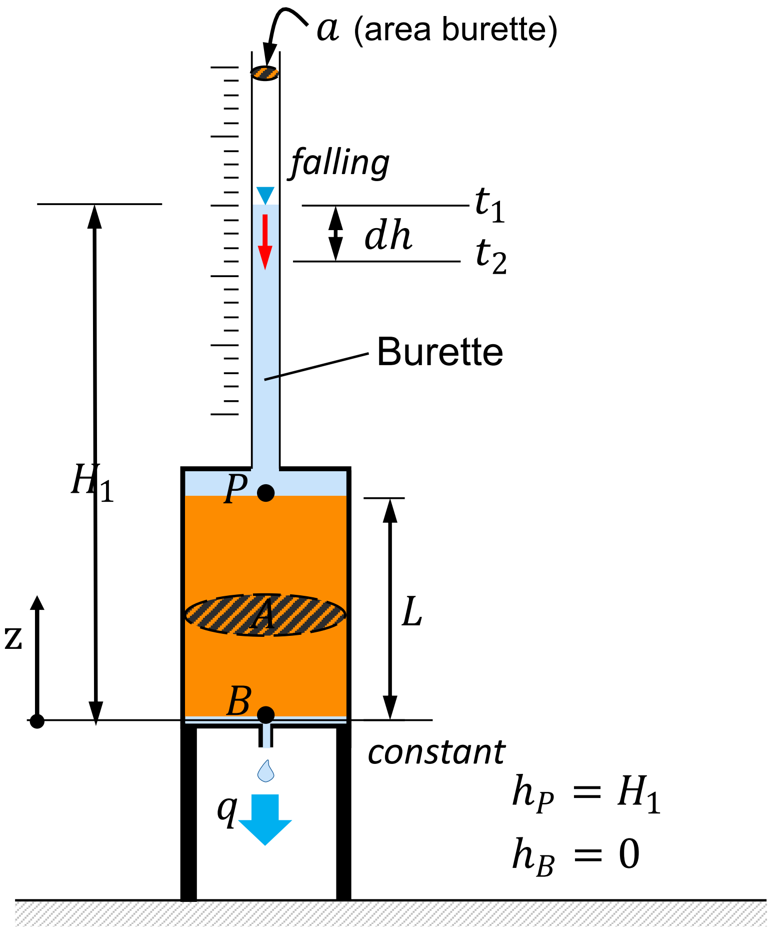


- Δh constant

$$k = \frac{QL}{A\Delta h t}$$

- $t =$ elapsed time of measurement.
- very slow test.
- Darcy used this test in his experiments.

FALLING HEAD PERMEABILITY TEST



- Δh not constant

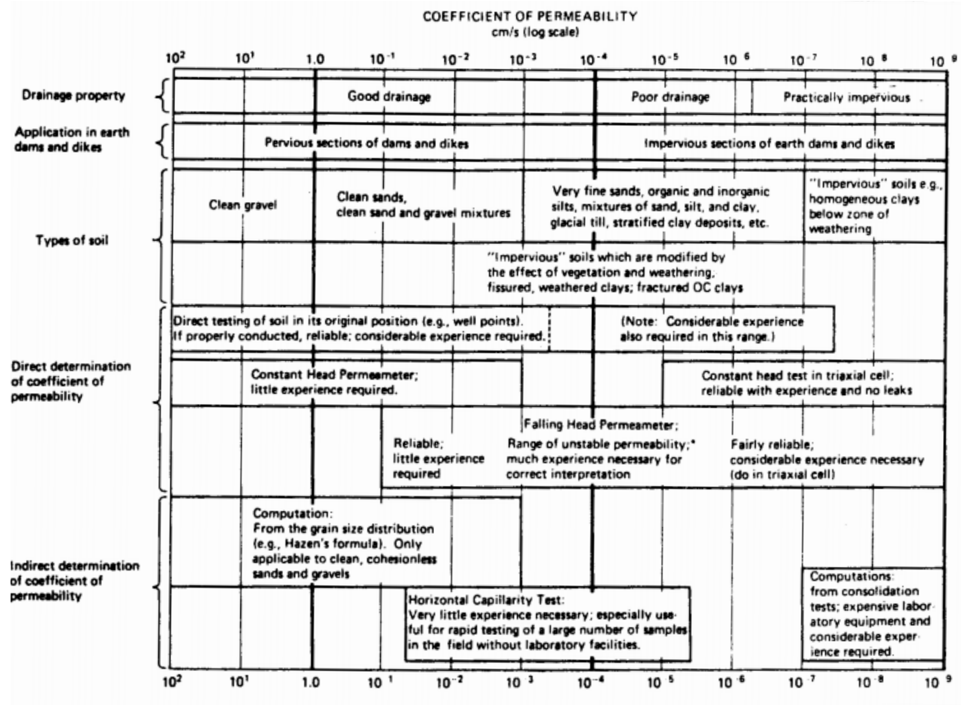
$$k = \frac{a}{A}\frac{L}{\Delta t}\ln\left(\frac{H_1}{H_1 - \Delta h}\right)$$

- $\Delta t =$ elapsed time of measurement.
- Rapid test.
- An operator is not always required in place.

PERMEABILITY OF SOILS

Rule of thumb:

1. Gravel $\longrightarrow k > 10^{-1}$ cm/s.
2. Sand $\longrightarrow 10^{-3}$ to 10^{-1} cm/s.
3. Silt $\longrightarrow 10^{-5}$ to 10^{-3} cm/s.
4. Clay $\longrightarrow 10^{-9}$ to 10^{-5} cm/s.



*Due to migration of fines, channels, and air in voids.

Fig. 7.6 Permeability, drainage, soil type, and methods to determine the coefficient of permeability (after A. Casagrande, 1938, with minor additions).

Holtz et al. (2013)

PERMEABILITY OF SOILS

Empirical correlations

- Hazen's (1911) equation:

$$k[cm/s] = CD_{10}^2$$

  - D_{10} in mm
  - $C =$ empirical coefficient between 0.4-10.0. 1 is a good value for clean poorly graded sands.

- Chapuis's formula

$$k[cm/s] = 2.4622 \left(D_{10}^2 \frac{e^3}{1+e} \right)$$

- Kozeny and Carman's formula:

$$k[cm/s] = \frac{\gamma_w}{\eta_w} \frac{1}{C_{k-c} S_s^2} \frac{e^3}{1+e}$$

  - γ_w in kN/m^3
  - $\eta_w =$ viscosity of water 1.002×10^{-3} Ns/m^2
  - $C_{k-c} =$ Kozeny-Carman's empirical constant (2 is usually used).
  - $S_s =$ specific surface 1/cm

EXAMPLE 4.4

A sample of sand, 5 cm in diamenter and 15 cm long, was prepared at porosity of 60% in a constant-head apparatus. The total head was kept constant at 30 cm and the amount of water collected was 40 cm^3. The test temperature was 20°. Calculate the permeability and the seepage velocity.

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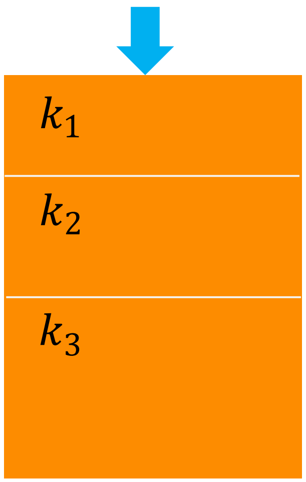
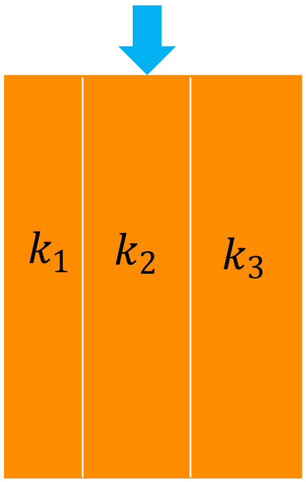
EQUIVALENT PERMEABILITY

If the soil is conformed of layers with different permeability, we need to calculate an equivalent permeability in order to apply Darcy's law.

We will study two cases:

1. Flow is perpendicular to the layering.
2. Flow is parallel to the layering.





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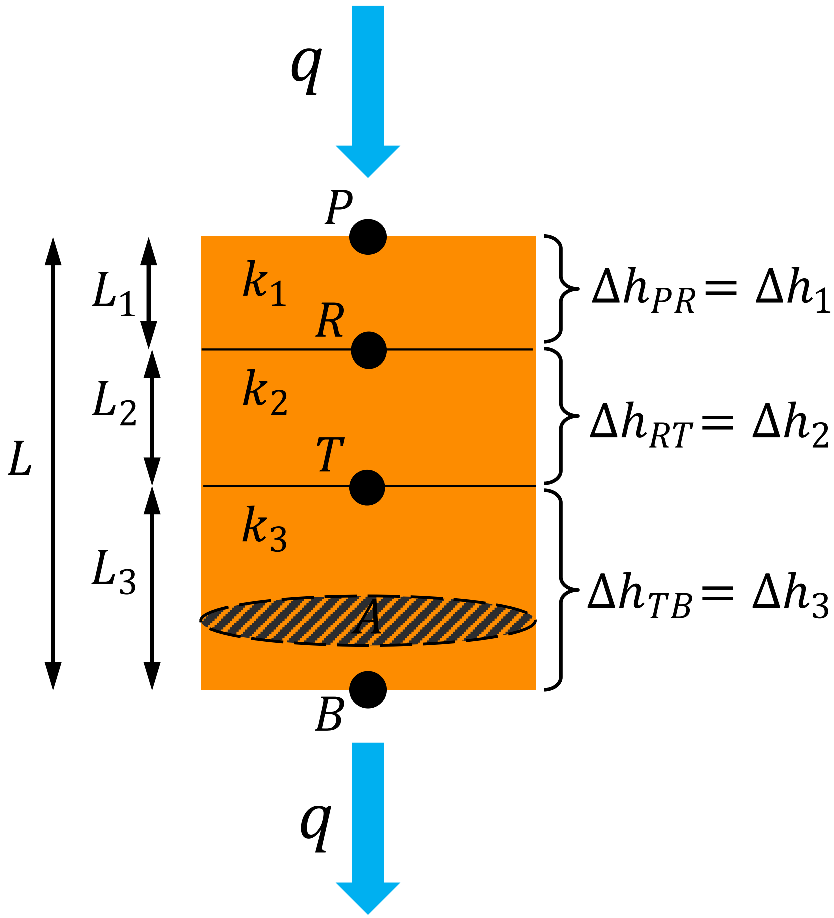
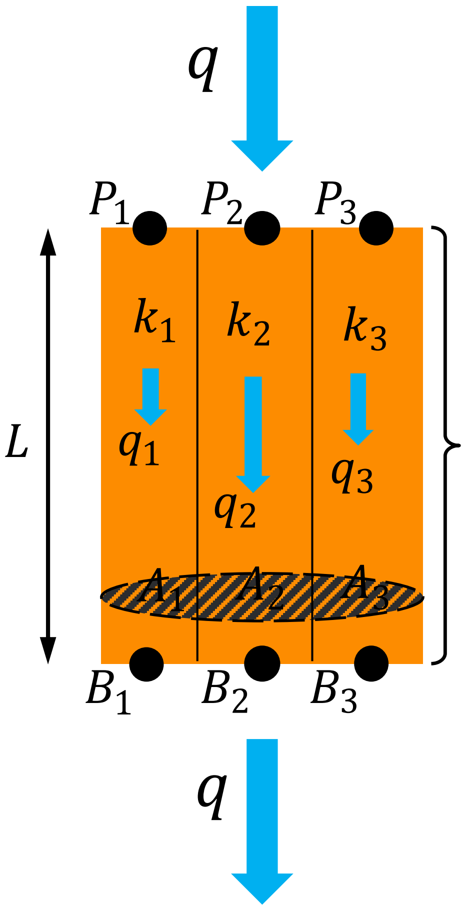
PERPENDICULAR FLOW



$$k_{eq} = \frac{L}{\sum_{i=1}^{n} L_i / k_i}$$

PARALLEL FLOW



$$\left.\begin{array}{l}\Delta h_{P_1B_1} = \Delta h_1 \\ \Delta h_{P_2B_2} = \Delta h_2 \\ \Delta h_{P_3B_3} = \Delta h_3\end{array}\right.$$

$$k_{eq} = \frac{\sum_{i=1}^{n} k_i A_i}{A}$$