QUESTION 1

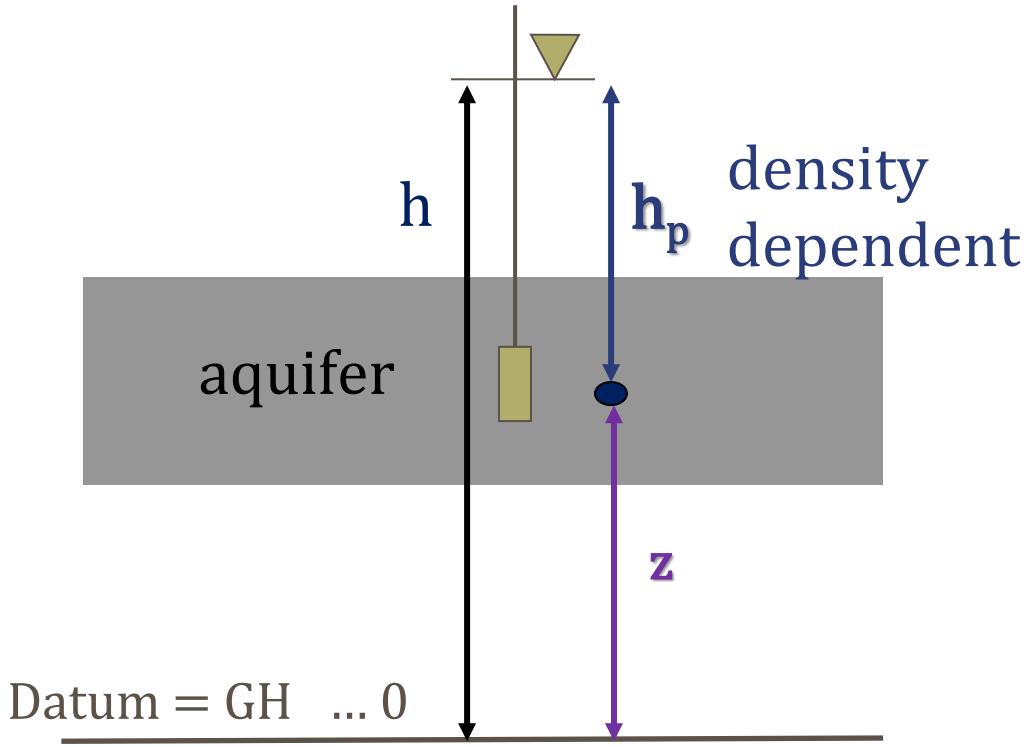
total (hydraulic)head = elevation head + pressure head

(pressure head: varying density fluids – important in contamination or salinity)

HYDRAULIC HEAD

$$\boldsymbol{h = z + h_p}$$

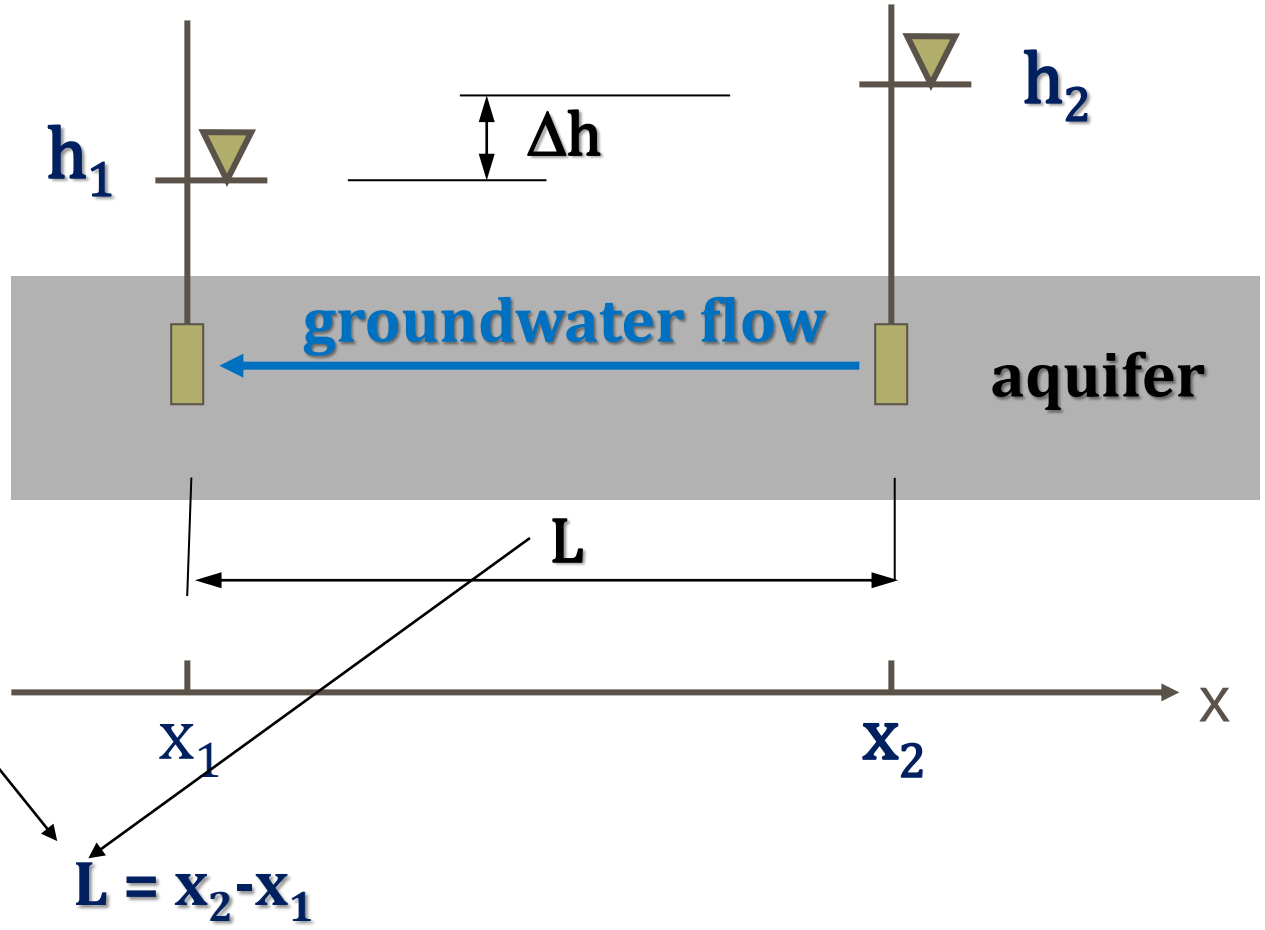
$$\boldsymbol{h} = z + \frac{p}{\gamma} = z + \frac{p}{\rho g}$$



QUESTION 1

HYDRAULIC GRADIENT

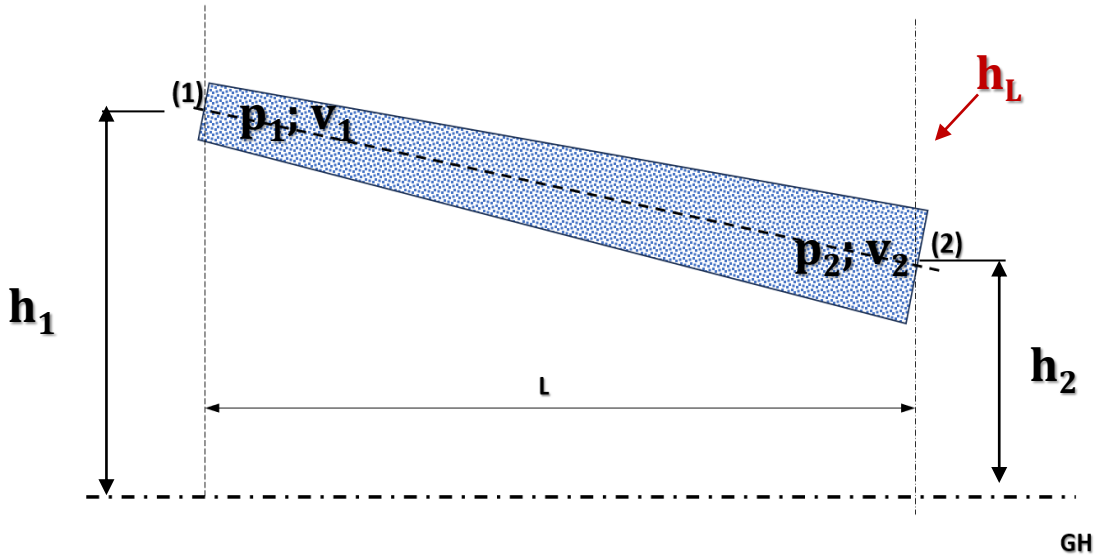
$$I = \frac{h_2 - h_1}{L}$$



$L = x_2 - x_1$

HEAD LOSS IN POROUS MEDIA

QUESTION 1



- Energy is **lost** in the flow through the porous medium **due to friction**
- **Energy equation Bernoulli eq.)** $\frac{v_1^2}{2g} + \frac{p_1}{\gamma} + h_1 = \frac{v_2^2}{2g} + \frac{p_2}{\gamma} + h_2 + h_L$
- Neglect velocity terms

$$h_L = \left(\frac{p_1}{\gamma} + z_1\right) - \left(\frac{p_2}{\gamma} + z_2\right) = h_1 - h_2 = \Delta h$$

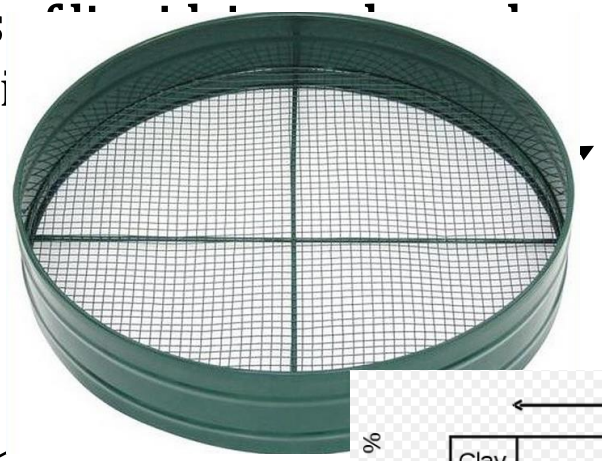
- **Flow** is always **from higher** head to **lower head**

QUESTION 2

LAMINAR and TURBULENT flow

- **laminar – particles of liquid move at parallel paths**
- **turbulent – motion of particles** inordinate, fluctuations of veloci space, mixing inside flow
- Criterion – **Reynolds number**

$$\mathbf{Re}_f = \frac{\boldsymbol{v d_{10}}}{\boldsymbol{\mu}}$$



v - velocity

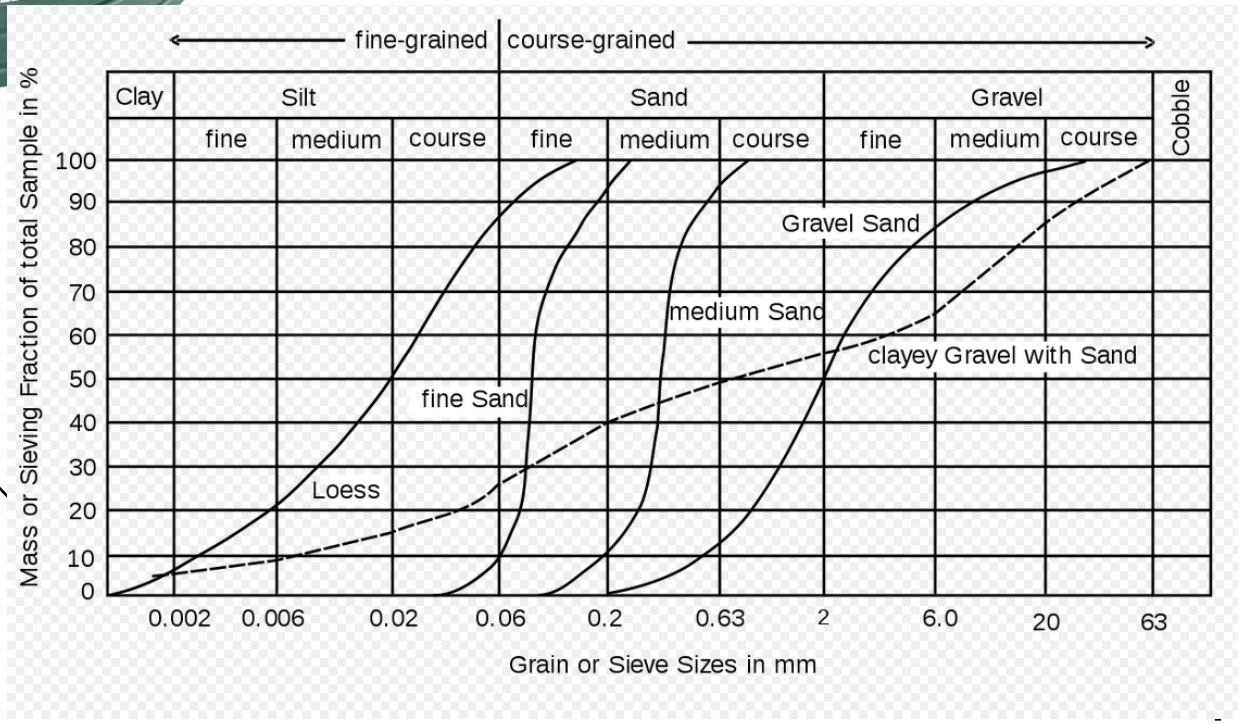
d_{10} = effective grain size diameter

CRITICAL REYNOLDS NUMBER

for groundwater flow $\mathrm{Re}_{fcr} = 1$

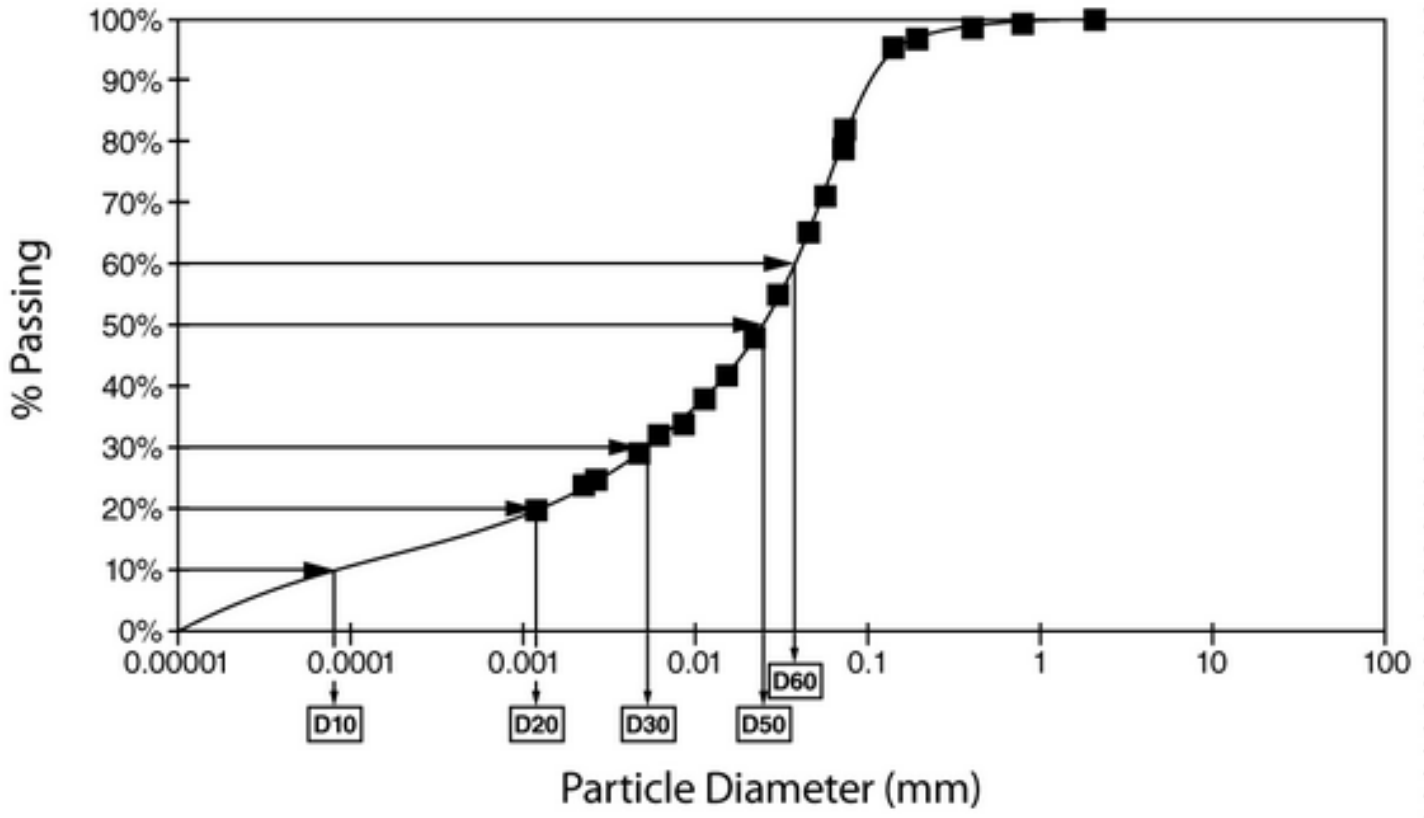
The *Reynolds number* can be used as a criterion to distinguish between laminar and turbulent flow:

A **sieve analysis** (or gradation test) is a practice or **procedure used** (commonly used in civil engineering) **to assess the particle size distribution** (also called gradation) of a granular material **by allowing the material to pass through a series of sieves of progressively smaller mesh size** and weighing the amount of material that is stopped by each sieve as a fraction of the whole mass...



QUESTION 2

Grain size **curve**



QUESTION 2

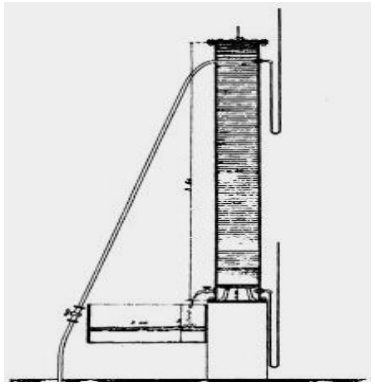
DARCY'S LAW

- Water **flow through an aquifer**.
- Darcy's law (conservation of momentum) **was determined experimentally** by Darcy, it can be derived from the Navier-Stokes equations
- Analogous to Fourier's law, Ohm's law, or Fick's law
- **Darcy's law** (conservation of momentum) **and** the **continuity equation** (conservation of mass) are used to derive the groundwater flow equation

QUESTION 2

DARCY'S LAW

Henry Darcy 1856



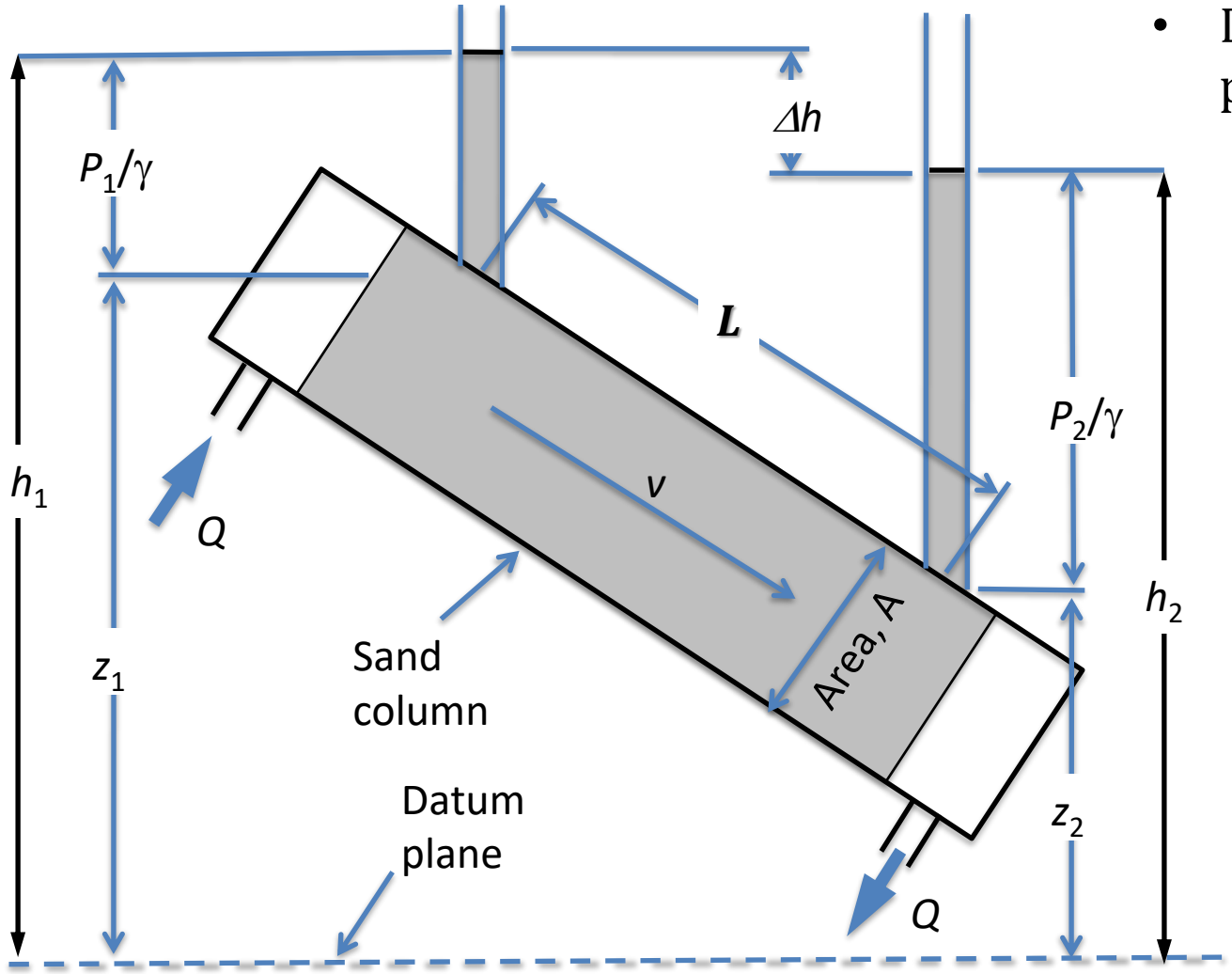
Experimental equipment

Darcy's Experimental Data

NUMÉRO de l'expérience	DURÉE.	DÉBIT MOYEN par minute.	PRESSION MOYENNE SUR LE FILTRE	PRESSION MOYENNE SOUS LE FILTRE	DIFFÉRENCE des PRESSIONS.	RAPPORT des VOLUMES aux pressions.	OBSERVATIONS.
1	2	3	4	5	6	7	8
		l.	m.	m.	m.		
1	15′	18,8	P + 9,48	P — 3,60	13,08	1,44	Fortes oscillations dans le manomètre supérieur.
2	15′	18,3	P + 12,88	P 0	12,88	1,42	*Id.*
3	10′	18,0	P + 9,80	P — 2,78	12,58	1,43	*Id.*
4	10′	17,4	P + 12,87	P + 0,46	12,41	1,40	Faibles.
5	20′	18,1	P + 12,80	P + 0,49	12,33	1,47	Assez faibles.
6	16′	14,9	P + 8,86	P — 0,83	9,69	1,54	Presque nulles.
7	15′	12,1	P + 12,84	P + 4,40	8,44	1,43	Très-fortes.
8	15′	9,8	P + 6,71	P 0	6,71	1,46	Très-faibles.
9	20′	7,9	P + 12,81	P + 7,03	5,78	1,37	Très-fortes.
10	20′	8,65	P + 5,58	P 0	5,58	1,55	Presque nulles.
11	20′	4,5	P + 2,98	P 0	2,98	1,51	*Id.*
12	20′	4,15	P + 12,86	P + 9,88	2,98	1,39	Assez fortes. On a déjà expliqué la cause de ces oscillations.

QUESTION 2

DARCY'S EXPERIMENT



- **Flow through sand filters**
- Discharge (Q) proportional to
  - Area, A
  - Head drop, h_1-h_2
  - Inverse of length, L

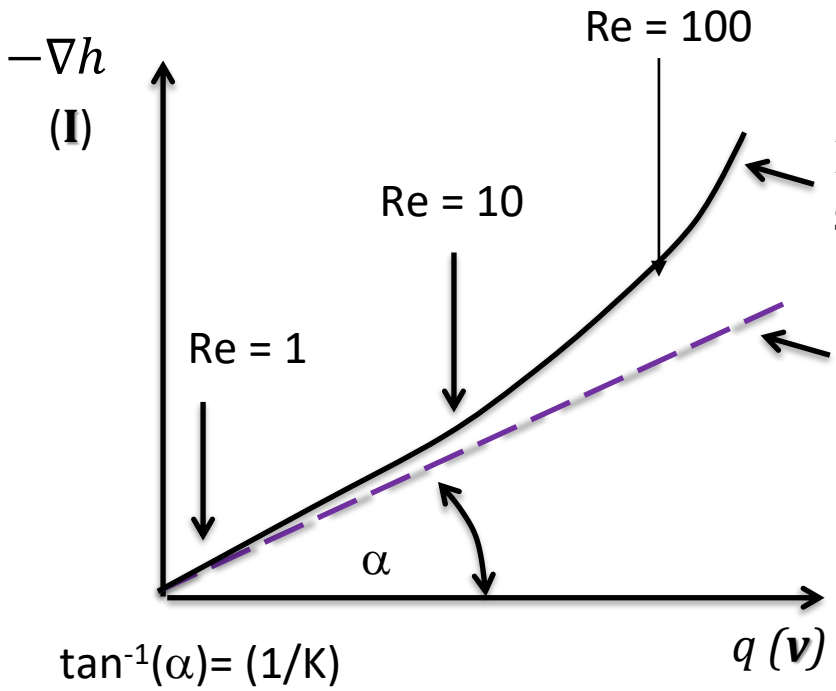
$$\boldsymbol{Q \propto K.A\frac{h_1 - h_2}{L}}$$

$$\Delta h = h_2 - h_1$$

$$q = \boldsymbol{v} = \frac{Q}{A} = \boldsymbol{-K\frac{\Delta h}{L}}$$

QUESTION 2

VALIDITY OF DARCY'S LAW



Re_f (0 ÷ 1) – Darcy eq. is valid

$$v = -K\,I \quad \Rightarrow \quad I = av$$

where **a** = 1/K

Re_f (1 ÷ 10) Darcy eq. is also valid

Re_f (10 ÷ 100) - Nondarcian flow (Darcy eq. is not valid)

$$I = av + b.v^m$$

where **m** = 1,6 ÷2,0

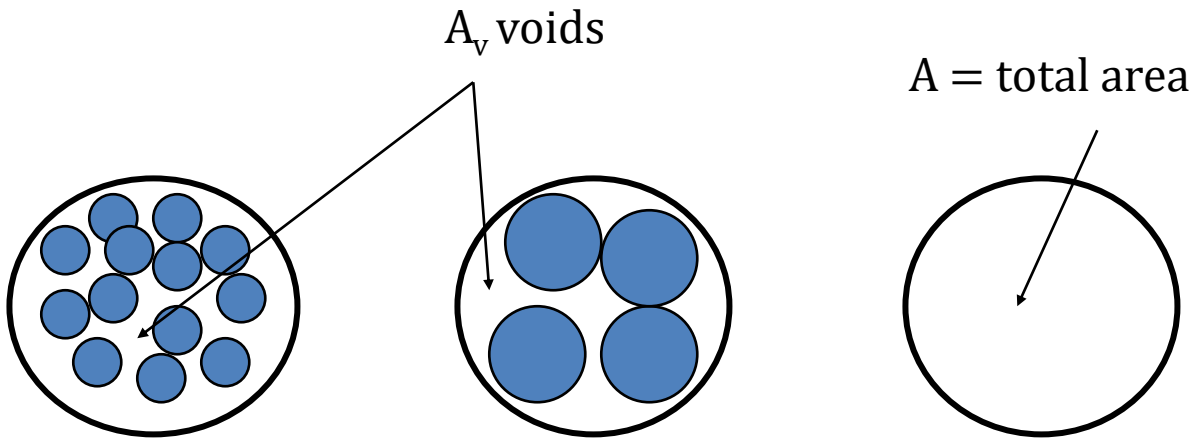
Re_f >100 **turbulent flow** (Darcy eq. is not valid)

$$I = b\,v^2$$

QUESTION 2

- **DARCY VELOCITY v_D** is a fictitious velocity since it assumes that flow occurs across the entire cross-section of the sediment sample. Flow actually takes place only through interconnected pore channels (voids), at the seepage velocity v_s
- Effective porosity, n_{ef} for

ACTUAL GROUNDWATER VELOCITY (seepage velocity) - v_s



$$v_D = n_{ef} v_S$$