

Clay Has More Empty Space Than Sand, Yet Lets Less Water Through

— Computing hydraulic conductivity from grain size and porosity gives 5.530621×10^{-3} m/s for coarse sand (grain 1 mm, porosity 0.35) and 1.090000×10^{-7} m/s for clay (grain 0.002 mm, porosity 0.50) — the separator is whether one asks how much pore space there is or how wide the pores are — [Paper 863]

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— *From thinking to syncing.* —

Abstract

It is easy to assume that the soil with more empty space passes more water. This paper counts, across four soils, that the width of the spaces matters more than their amount. No new theorem or law is claimed. First, hydraulic conductivity is set by grain size and porosity: by the Kozeny–Carman equation it is 5.530621×10^{-3} for coarse sand, 3.875556×10^{-4} for fine sand, 6.567025×10^{-6} for silt and 1.090000×10^{-7} m/s for clay (Section 2). Second, and this is the core. Clay, with more empty space, passes less water: its porosity is **1.428571** times larger, yet its conductivity is 5.073964×10^4 times, or **4.705347** orders of magnitude, lower (Section 3). Third, amount favours clay and width favours sand: the porosity term favours clay by **4.927114**, but the squared grain size favours coarse sand by 250000, and the ratio of the two matches the conductivity ratio within a relative difference of 10^{-12} (Section 3). Fourth, travel times over 100 m differ even more than conductivity: at a gradient of 0.01 they are 2.005350×10^{-2} years for coarse sand and 1.453582×10^3 years for clay, a ratio of 72485.207101 (**4.860249** orders of magnitude). The porosity ratio 1.428571 enters once more (Section 4). Fifth, water moves faster than the Darcy flux: water travels only through the pores, so its speed is the Darcy flux times the reciprocal of porosity; in coarse sand the time from the Darcy flux, 0.057296 years, is **2.857143** times the actual 0.020053 years (Section 4). Sixth, the separator is whether one asks how much pore space there is or how wide the pores are: the amount sets how many paths there are, the width sets the resistance of each path, and conductivity follows the latter (Section 5).

Keywords: Darcy’s law, hydraulic conductivity, porosity, Kozeny–Carman equation, groundwater, model.

Scope of this paper (scope note): No new theorem or law is claimed: Darcy's law, the Kozeny--Carman equation, and the fact that the water's speed is the Darcy flux divided by porosity, are all known. No real strata are claimed: grain sizes and porosities are model values matching no actual ground. The flow is not widened: flow in soil not filled with water, direction-dependence and layering are not included. The coefficient is not discussed: the constant 180 is one representative choice for near-spherical grains and moves with grain shape. Nothing is designed: how to build wells or drainage is not stated. Relation to earlier papers: Paper 599 showed that around a well the water table falls only as the logarithm of distance and keeps falling as the logarithm of time. This paper stands beside it. There conductivity was set to a representative 10^{-4} m/s to count water levels. Paper 574 showed that lowering the water table by 1 m raises the bottom of the fresh water by 40 m. This paper stands beside it too. There conductivity was set to 20 m/day. Here we count how far such a set value moves with grain size. What is added is laying out conductivity and 100 m travel time for four soils, measuring that the soil with more porosity passes 4.705347 orders of magnitude less, splitting that ratio into the porosity term and the squared grain size and matching them, and placing the separator on amount of pore space versus width.

1. Notation and the Question

Setting: a hydraulic gradient i is applied to soil with grain size d and porosity n . Hydraulic conductivity K , Darcy flux q (discharge divided by the whole cross-section) and the water's speed v (speed through the pores) are taken as follows.

$$K = \frac{\rho g}{\mu} \cdot \frac{d^2 n^3}{180(1-n)^2}, \quad q = Ki, \quad v = \frac{q}{n}$$

Water density $\rho = 1000$ kg/m³, gravitational acceleration $g = 9.81$ m/s², viscosity $\mu = 1.0 \times 10^{-3}$ Pa s and gradient $i = 0.01$ were used.

Question: does soil with more empty space pass more water?

2. Four Soils

Computation 2.1: conductivity was computed while varying grain size and porosity.

soil	grain	porosity	conductivity (m/s)
coarse sand	1 mm	0.35	5.530621×10^{-3}
fine sand	0.2 mm	0.40	3.875556×10^{-4}
silt	0.02 mm	0.45	6.567025×10^{-6}
clay	0.002 mm	0.50	1.090000×10^{-7}

Observation 2.2

as porosity rises, conductivity falls. Of the four soils, coarse sand has the smallest porosity and the largest conductivity: the order by amount of space and the order by water passed point opposite ways.

3. Amount and Width

Computation 3.1: coarse sand and clay were compared term by term.

compared	value
porosity ratio (clay ÷ coarse sand)	1.428571
porosity term $n^3/(1-n)^2$: coarse sand	0.101479
porosity term $n^3/(1-n)^2$: clay	0.500000
porosity-term ratio (favours clay)	4.927114
squared grain-size ratio (favours coarse sand)	250000.000000
conductivity ratio (coarse sand ÷ clay)	5.073964×10^4
orders of magnitude of that ratio	4.705347

Observation 3.2

this is the core. Clay, with more empty space, passes less water. The porosity term alone favours clay by 4.927114, but the squared grain size favours coarse sand by 250000, leaving coarse sand ahead by 4.705347 orders of magnitude: dividing the squared grain-size ratio by the porosity-term ratio gives the conductivity ratio within a relative difference of 10^{-12} .

Observation 3.3

width acts as a square. With porosity fixed at 0.4, doubling grain size made conductivity exactly 4 times larger: within 10^{-12} . The resistance of each path is set by its width.

4. Travel Time

Computation 4.1: at a gradient of 0.01, Darcy flux, the water's speed and the time to travel 100 m were computed.

soil	Darcy flux (m/s)	water speed (m/s)	years for 100 m
coarse sand	5.530621×10^{-5}	1.580178×10^{-4}	2.005350×10^{-2}
fine sand	3.875556×10^{-6}	9.688889×10^{-6}	3.270560×10^{-1}
silt	6.567025×10^{-8}	1.459339×10^{-7}	2.171400×10^1
clay	1.090000×10^{-9}	2.180000×10^{-9}	1.453582×10^3

Observation 4.2

the water's speed is the Darcy flux times the reciprocal of porosity. The Darcy flux is divided by the whole cross-section, but water can pass only through the pores: in coarse sand the time from the Darcy flux is 0.057296 years, 2.857143 times the 0.020053 years from the water's speed. In all four soils the water's speed times porosity matched the Darcy flux.

Observation 4.3

at the same flux, water is actually slower in the soil with more pore space. The travel-time ratio of clay to coarse sand is 72485.207101 (4.860249 orders of magnitude), larger than the 4.705347 orders in conductivity: the time ratio matched the conductivity ratio times the porosity ratio 1.428571 within a relative difference of 10^{-12} . Here too, more pore space does not speed the water.

5. The Separator

Observation 5.1

the separator is whether one asks how much pore space there is or how wide the pores are. The amount sets how many paths the water has; the width sets how much water each path carries: clay wins on amount and loses by 250000 on width. Conductivity follows the width.

Observation 5.2

placed beside Papers 599 and 574. 599 set conductivity to 10^{-4} m/s to count water levels around a well, and 574 set it to 20 m/day to count the bottom of the fresh water. Here we count how far such a set value moves with grain size and porosity: 4.705347 orders of magnitude across the four soils.

Observation 5.3

what is not said. Real strata, flow in soil not filled with water, direction-dependence, layering, and the design of wells or drainage are not treated. What is shown is that the width of the pores, more than their amount, sets conductivity.

6. Census and Closing

1. conductivity is set by grain size and porosity (Section 1): the Kozeny--Carman equation.
2. coarse sand 5.530621×10^{-3} m/s (Computation 2.1): porosity 0.35.
3. clay 1.090000×10^{-7} m/s (Computation 2.1): porosity 0.50.

4. clay has **1.428571** times the porosity (Computation 3.1): **more space in clay**.
5. conductivity differs by **4.705347** orders (Computation 3.1): **the core**.
6. porosity term favours clay by **4.927114** (Computation 3.1): **the amount side**.
7. squared grain size favours coarse sand by **250000** (Computation 3.1): **the width side**.
8. clay: 1.453582×10^3 years for 100 m (Computation 4.1): coarse sand 2.005350×10^{-2} years.
9. the Darcy flux gives times **2.857143** times too long (Observation 4.2): **water moves only through pores**.
10. amount of pore space, or width (Observation 5.1): **the separator; Papers 599, 574**.

Closing: Clay has more empty space than sand, yet lets less water through. Computing conductivity from grain size and porosity, clay has 1.428571 times the porosity yet 4.705347 orders of magnitude less conductivity, because the porosity term favours clay by 4.927114 while the squared grain size favours coarse sand by 250000. At a gradient of 0.01, water takes 2.005350×10^{-2} years to travel 100 m through coarse sand and 1.453582×10^3 years through clay: and since water moves only through the pores, times computed from the Darcy flux are 2.857143 times too long. Placed among the earlier papers: beside the representative conductivities set in Papers 599 and 574, we placed how far such a value moves with grain size and porosity. To be honest: grain sizes and porosities are model values, the coefficient moves with grain shape, and soil not filled with water and layering are not included.

References

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