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Testing of the Darcy-Buckingham Law for Unsaturated Flow in Porous Rocks using Centrifugal Force

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This work aims to test the applicability of the Darcy-Buckingham law to unsaturated flow in porous rocks. This law is widely assumed to govern essentially all unsaturated flow, though it has been experimentally shown to be applicable in only a few materials, all of them granular media and not consolidated rock. This law states that the flux density, q (LT-1), through an unsaturated porous medium is directly proportional to the force, F, driving the water flow. This implies that the ratio q/F, represented as the unsaturated hydraulic conductivity, K(θ), remains constant for a constant water content, θ. Different q values produced by different forces must depict a straight line passing through the origin and each one having the same θ. Some physical conditions, however, can cause deviations from this law. These conditions include: (i) partially filled macropores, (ii) particular flow regimes such as free-surface film flow, (iii) high fluid velocities, (iv) altered air-water interface configuration due to centrifugal force and (v) intergranular material such as the cement in consolidated rock which causes the pore shape to change, possibly affecting the air-water interface geometry and hence K. The likelihood of occurrence of such conditions depends on the texture, porosity, and structure of a given medium.

The experimental method chosen for this study is the Quasi-Steady Centrifuge (QSC) method, which has been applied to rock samples for the last 15 years. We conducted tests of the Darcy-Buckingham law on core samples from southeastern Italy, designated C and M, from the quarries Canosa di Puglia and Massafra, respectively. These are marine origin sedimentary carbonatic rocks, found widely in that area. The QSC method tested the law's validity in a centrifugal field, giving the measurements of q and θ for different centrifugal forces. This method allows large variations in force and flux without substantial change in water content. The Darcy-Buckingham law was confirmed for the conditions tested, as measured fluxes at a water content were found to vary in direct proportion to driving force. The law was found to valid for a range of K between 9.7E-09 and 1.8E-06 m/s, θ between 0.34 and 0.21, and force between 136 and 685 times earth gravity, exhibiting R2 between 0.912 and 0.998. The Reynolds number, ranged from 6.4E-09 to 2.6E-04 and 6.7E-09 to 3.4E-04 for C and M, respectively. The results suggest that, in addition to soils, as previously tested, the Darcy-Buckingham law is applicable to consolidated porous rock for conditions similar to those of our experiments.