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Relationship between water saturation and hydraulic conductivity of a sandstone

Naoki Nishiyama[1]*, Tadashi Yokoyama[1]

[1]Dept. Earth & Space Sci. Osaka Univ.

Evaluation of hydraulic conductivity in the earth surface environment is important for considering the transport of dissolved matters and groundwater balance. Because the rock above water table is unsaturated, it is necessary to consider not only saturated hydraulic conductivity but also the relationship between water saturation and unsaturated hydraulic conductivity. In order to construct a model that can predict the unsaturated hydraulic conductivity of a rock, we measured the hydraulic conductivities of sandstone under various water saturations. It was found that the hydraulic conductivity (K) exponentially decreased with decreasing water saturation (S), and a proportional relationship between K and S^{3-4} was observed. In addition to the permeability test, we measured the size distribution of water-bearing pores by a water expulsion porosimetry, in which the water contents in each size of pore are determined by expelling pore water under various gas pressures. Based on the experimental results, we evaluated the applicability of Katz and Thompson model (K-T model), which has been often used for predicting a saturated hydraulic conductivity of sedimentary rock, to the prediction of unsaturated hydraulic conductivity. In the K-T model, the saturated hydraulic conductivity of a rock can be calculated by using the pore size distribution measured by the mercury intrusion porosimetry, without using fitting parameters. Although the original K-T model has been derived based on the data of mercury intrusion porosimetry, we can estimate unsaturated hydraulic conductivities under various water saturations if we use the size distribution of water-bearing pores measured by the water expulsion porosimetry. However, for calculating an unsaturated hydraulic conductivity, both the effect of the decrease of the volume of water flow paths and the effect of the decrease of connectivity of water flow paths need to be considered. In the present study, we attempt to formulate the unsaturated hydraulic conductivity by incorporating the above effects into the K-T model with the use of the percolation theory.

Keywords: unsaturated hydraulic conductivity, water saturation, vadose zone, sandstone