Paper Number: 4423

Experimental Studies on the Smooth Parallel Plate Model Addressing the Validity of the Cubic Law under Conditions of Variable Saturation.

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Generally determining regional scale fluxes through the intermediate fractured vadose zone involves conceptualising flow as bulk flow through the system. This black box approach loses important factors that influence variably saturated flow through discrete fractures. Current key research questions identified by Berkowitz [1] and Neumann [2] is the influence of fracture or discontinuity geometry, as well as partial saturation. The aim of the research is to investigate the fundamental concept of the cubic law under conditions of variable saturation and the influence on flow regimes.

A series of physical models incorporating individual discrete fractures and orthogonal intersections were created. This involved using smooth clean parallel plates with a vertical and horizontal orientation, under conditions of intermittent and continuous input fluxes. The parallel plate model was thereafter extended to include an orthogonal fracture intersection in order to validate the findings to theory on unsaturated flow at fracture intersections. Furthermore, the influence of inclination of the fractures and the subsequent intersections were also explored and the findings of these tests are expected to provide insight into the validity of the cubic law in unsaturated conditions.

Results show that despite the basic clean smooth parallel plate model used in these experiments, the basic assumptions of the cubic law cannot be obtained and its use in numerical models should be queried. Although full saturation was observed in the horizontal experiments, the validity of the cubic law can be questioned from the results occurring during the remaining experiments as:

a) Full saturation is not ever truly achieved, regardless of water supply input;
b) Flow remains as oscillating rivulets and, occasionally localised sheets with capillary islands;
c) Flow achieved is neither uniform, laminar nor saturated;
d) Draining of the saturated horizontal fracture occurs along a vertical face as non-uniform separate rivulets exiting at discrete points along the fracture; and
e) The orientation of fractures may have a more critical role in governing flow through fractures compared to other fracture geometry properties.

Important conclusions drawn from this research regarding understanding flow through discrete fractures include:

a) Failure of the cubic law in non-horizontal fractures as saturated sheetflow is not achieved;
b) Preferential flow still occupies the vast minority of cross-sectional area in a vertical fracture;
c) Movement of water through the intermediate fractured vadose zone becomes a matter of the continuity principle, whereby transport can occur at significantly higher rates given the very low degree of water saturation;
d) Quantifying discrete fracture flow, notably at sub-saturation, is implicitly inaccurate;

e) An improved qualitative understanding of variably saturated fracture flow will improve the understanding in conceptualising flow through the fractured vadose zone.

References:

[1] Berkowitz, B. (2002). Characterizing flow and transport in fractured geological media: a review. Advances in Water Research. *25*(8) 861-884.

[2] Neuman, S. P. (2005). Trends, prospects and challenges in quantifying flow and transport through fractured rocks. Hydrogeology Journal. *13*(1) 124-147.