A Numerical Study of Unsaturated Flow and Transport Through a Fractured Meter-sized Rock Block

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RESEARCH OBJECTIVES

Our work involves study of a meter-sized block of fractured rock to obtain experimental evidence in support of the active fracture concept (AFC). This concept assumes that only a portion of fractures in a connected unsaturated fracture network contributes to liquid water flow. Prior to this experimental evaluation, however, we needed to perform a preliminary numerical simulation in which we incorporated the AFC into a dual-continuum model (DCM) to create an enhanced DCM. Through this integration, we intend to identify the most effective way to quantify the AFC parameter in the laboratory.

APPROACH

The DCM was developed and then compared to a discrete fracture network model (DFNM) representing the meter-sized rock block, to see whether the DCM could accurately simulate flow and transport in the block. The DFNM, which contained an artificially generated 2-D fracture network, is based on statistical information from field observations at Yucca Mountain, Nevada (including fracture density, ranges of aperture and trace length, distribution of orientation, flow rate, and tracer transport data). As a preliminary step, DCM results obtained without incorporating the AFC were calibrated against the DFNM data. The AFC model was then integrated into the DCM to examine whether adding the AFC model could improve DCM predictions of discrete flow behavior.

ACCOMPLISHMENTS

At transient states, the DFNM showed distinctive preferential flow patterns, such as stepwise increases in water effluent flow rates and high water saturation along predominant flow paths (i.e., fractures). The DCM breakthrough curves did not initially capture the DFNM results because of their conceptual differences. But after the incorporation of the AFC, DCM predictions for flow-rate breakthrough curves were significantly improved. The flow rates from the AFC-enhanced DCM were calibrated against those of the DFNM to estimate the effect of including the AFC parameter.

SIGNIFICANCE OF FINDINGS

These numerical simulations imply that laboratory experiments incorporating a transient state in the flow field would provide a more sensitive approach for estimating the AFC parameter than steady-state experiments. Additionally, water breakthrough curves at low (rather than high) injection rates may be more appropriate for laboratory tests to determine the AFC parameter. The results also suggest that the DCM-AFC approach improves the prediction of unsaturated flow and transport, but may not be well suited for the current two-dimensional meter-scale model. Three-dimensional studies with detailed characterization of fracture networks have been proposed for more accurate estimation of the AFC parameter.

RELATED PUBLICATIONS

Seol, Y., T.J. Kneafsey, K. Ito, and S. Finsterle, Simulation of unsaturated flow and transport through a fractured meter-sized model block using the continuum approach. Water Resources Research, 2003 (submitted); Berkeley Lab Report LBNL-52818, 2003.

Ito, K., and Y. Seol, A 3-D discrete fracture network generator to examine fracture-matrix interaction using TOUGH2. Proceedings of the TOUGH Symposium 2003, Berkeley, California, May 12-14, 2003; Berkeley Lab Report LBNL-52465, 2003.

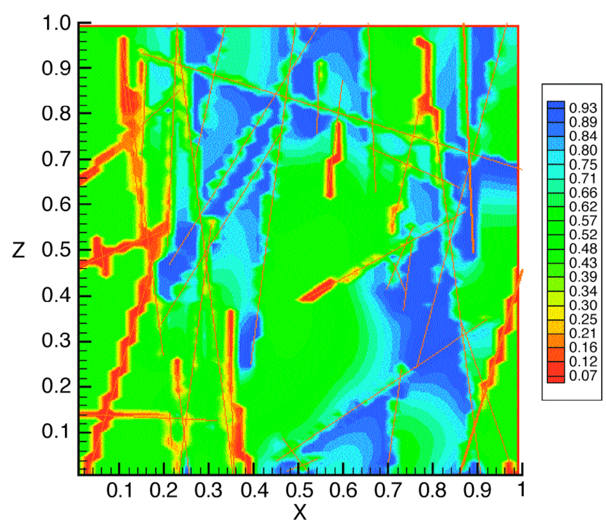

Figure 1. Distribution of water saturation in the DFNM, showing preferential flow patterns developed along major fractures in the transient state of the flow domain.

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