Infiltration-Seepage Responses: Effects of Capillary Barriers on Flow Partitions

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RESEARCH OBJECTIVES

Possible water seepage into waste emplacement tunnels (drifts) in response to infiltration at the land surface is a major concern for performance evaluation of the proposed nuclear waste repository at Yucca Mountain, Nevada. To address this issue, investigators have recently conducted an infiltration seepage experiment at the site. However, data collected from this experiment showed complicated infiltration-seepage responses that were difficult to interpret, even with a sophisticated multiple-continuum numerical model. The objectives of this work are (1) to study the coupled effects of different processes on infiltration-seepage responses, and (2) to develop a more realistic 3-D numerical model that could quantitatively interpret the measured seepage into the alcove, as well as analyze the conditions under which seepage into drifts could occur.

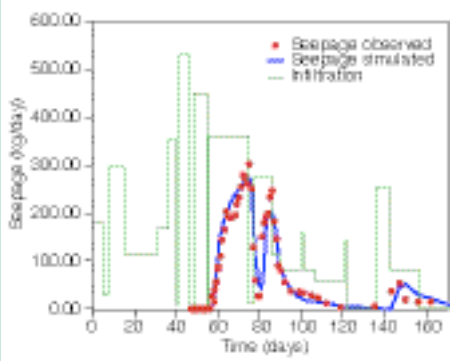

Figure 1. Comparison between the simulated (blue line) and the observed (red dots) seepage responses under given infiltration (light green line).

APPROACH

In the infiltration-seepage experiment, infiltration water was applied to the land surface through a drip irrigation system. The resulting seepage was collected and measured in an alcove 32 m below, sealed by a bulkhead (door). The basic approach for this study was to (1) incorporate site information about the flow system, and realistic experimental conditions into the previous model; (2) refine conceptual framework for the 3-D numerical model; (3) match model predictions to the observed seepage data, and to identify underlying key processes and mechanisms.

Specifically, the following new features were incorporated in the developed model:

- A sloping (about 40%) land surface with a soil cover of 30 cm is included in the numerical model. The soil layer is represented as a single continuum porous medium.
- A unique third L-continuum is introduced into the model to represent the portion of the fractured tuff that is not included in either F-continuum (the fast flow path) or M-continuum (the extremely slow flow path).
- The general flow simulator TOUGH2 was modified to accommodate the above features.

ACCOMPLISHMENTS

A 3-D, triple-continuum numerical model was developed to successfully simulate water percolation through fractured porous media. The simulated seepage compared well with the measured data. Furthermore, it was observed that seepage, in responding to the infiltration pulse, is highly nonlinear (Figure 1). When the internal saturation was low, even high infiltration pulses could be entirely damped, and no seepage occurs. After an adequate saturation condition was established, the peak seepage responses to the infiltration pulses could be very quick (e.g., <1 day). However, the slower responses in the tailing part, as a result of contributions from the L- and M-continua, were still visible. When the infiltration rate was reduced to a certain level, almost no seepage was observed. A likely explanation for the above phenomena is that, on the way from the land surface to the alcove, several "lateral" flow paths "compete" for the water from seepage. These paths are (1) the downslope flow in the soil layer, (2) imbibition to the L- and M-continuum, and (3) flow into the fracture network outside of the collection area. The capillary barriers at the soil/tuff interface and the alcove ceiling act as two "lower dams" that regulate the flow partitions between the competing flow paths, working with the suction forces in the unsaturated media.

SIGNIFICANCE OF FINDINGS

Our new approach shows significant improvement over previous methods in capturing the observed infiltration-seepage responses and the percolation processes behind them. The results also show that seepage into an emplacement drift (which would be located deeper than the test alcove) would not likely occur under the current local (i.e., desert) climate and geological conditions at Yucca Mountain. However, special attention should be paid to the strongly broken zones (i.e., the zones along the deep faults) where natural capillary barriers may be weak.

RELATED PUBLICATION

Pan, L., K. Zhang, Y.S. Wu, and G.S. Bodvarsson, Percolation through heterogeneous fractured porous media under transient infiltration: Reconciling measured and predicted seepage into a mined opening. The 68th Annual Meeting for Soil Science Society of America, Seattle, Washington. Agronomy Abstracts. American Society of Agronomy, Madison, Wisconsin, Oct. 31–Nov. 4, 2004.

ACKNOWLEDGMENTS

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