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Estimating hydraulic conductivity of the Opalinus Clay at the regional scale: Combined effect of desaturation and EDZ

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Abstract

A ventilation experiment (VE) was conducted in a non-lined microtunnel at the Mont Terri Rock Laboratory under well control conditions to evaluate *in situ* the consequences of desaturation induced by ventilation in consolidated Opalinus Clay rock. These investigations are carried out in the framework of the feasibility studies of radioactive waste underground repository. Specifically, from the point of view of long-term safety assessment in clay formations, it is crucial to estimate the evolution of the hydraulic conductivity. Yet, the combined effect of desaturation and the excavation damage zone is not well understood. We present the numerical hydrogeological modeling of the ventilation experiment based on measurements of water pressures and evaporation rates leaving the rock formation through the tunnel surface. It is found that, even though site characterization reveals that desaturation only occurs in a very small portion of the massif adjacent to the drift tunnel, nearfield water fluxes are still significantly driven by desaturation processes. In practice, this means that, even under minor desaturation conditions, routine characterization of effective saturated hydraulic conductivity ($K_{S,eff}$) based on scoping calculations that consider the ventilation experiment as a large pumping well will largely overestimate $K_{S,eff}$. An alternative conceptual model based on Kelvin's equation was able to capture the physics of the experiment and provide a more accurate estimate of $K_{S,eff}$.

Keywords: Subsurface hydrology; Hydrogeological modeling; Ventilation experiment; Effective hydraulic conductivity; Excavation damage zone

1. Introduction

Deep geological repositories are presently considered as the most feasible and safe solution for the management and disposal of radioactive waste. Clayey rock formations constitute a favorable potential host rock since they generally exhibit very low permeability, small molecular diffusion, and significant retention capacity for radionuclides. Yet, nearfield rock desaturation due to ventilation produced during the excavation and operational phases of underground repositories, which usually take place for long periods of time, can potentially perturb the natural-state of the host rock properties. The portion of the rock adjacent to the drift tunnel where hydromechanical properties are significantly perturbed due to excavation of the underground repository is known as the excavation damage zone (EDZ).

In this context, the VE project is a ventilation experiment (VE), performed within the European framework with several partners, that is being conducted at the Mont Terri Rock Laboratory to evaluate *in situ* the consequences of desaturation induced by ventilation in an underground radioactive waste repository with consolidated Opalinus Clay rock acting as a geological barrier. Specifically, from the point of view of long-term safety assessment of the disposal of radioactive waste in clay formations, it is crucial to estimate the desaturation and resaturation times in clayey rock, to evaluate the saturated hydraulic conductivity, and to investigate the evolution of the EDZ in terms of

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changes in hydraulic conductivity and displacements caused by the generation of cracks on drying.

A non-lined horizontal microtunnel was excavated and subjected to desaturation by ventilation while monitoring the evolution of hydromechanical parameters. In all, experimental results showed that, under real repository ventilation conditions, the desaturation of the Opalinus Clay rock is small. Desaturation was only appreciable in a very thin ring around the drift tunnel surface, extending after long periods of times no more than 30 cm, where water saturation ranged from 60% to 95% (Mayor et al., 2005). Further, the extensometers, which measured the relative displacements between drift tunnel surface and points located at a radial distance of 2 m inside the rock, measured small shrinkage (~0.9 mm) for desaturation phases and almost negligible swelling (~0.1 mm) for resaturation phases (Mayor et al., 2005). In these circumstances, minor desaturation conditions, the ventilation experiment is expected to behave as a large-scale pumping test by which regional scale saturated hydraulic conductivity ($K_{S,eff}$) can be estimated from measurements of water pressure and water evaporation rates. In doing this, routine scoping calculations and/or hydrogeological modeling used to determine the large-scale $K_{S,eff}$ requires the selection of boundary conditions. As it will be seen, the selection process of inner boundary conditions (boundary conditions at the drift tunnel surface) is a crucial step for the accurate estimation of $K_{S,eff}$ in a ventilation experiment. It will be shown that scoping calculations and hydrogeological modeling frequently used to determine $K_{S,eff}$ in a ventilation experiment can largely overestimate the $K_{S,eff}$ representative for the massif. Alternative $K_{S,eff}$ estimates calculated using Kelvin's equation and measurements of relative humidity and temperature at the drift tunnel surface provided a more reliable inner boundary condition.

It is noted that the different models presented in this paper consider an isotropic hydraulic conductivity tensor because our objective was to estimate a lamped parameter ($K_{S,eff}$) for the massif rather than describing the tensorial nature of the hydraulic conductivity. Yet, Opalinus Clay is in fact anisotropic due to well developed bedding planes (Nussbaum and Bossart, 2002). Laboratory experiments have determined intrinsic permeability values of 7.5×10^{-20} m^2 and 1.35×10^{-20} m^2 for core samples with bedding planes parallel to the hydraulic gradient and with an angle of 60°–55°, respectively (Muñoz et al., 2003).

2. Description of the ventilation experiment

The test section is a non-lined horizontal microtunnel, 1.3 m in diameter and 10 m long, sealed off and isolated by two double doors to perform the ventilation experiment under well-controlled conditions (Fig. 1a). A ventilation system formed by two ventilation pipes regulates the vapor

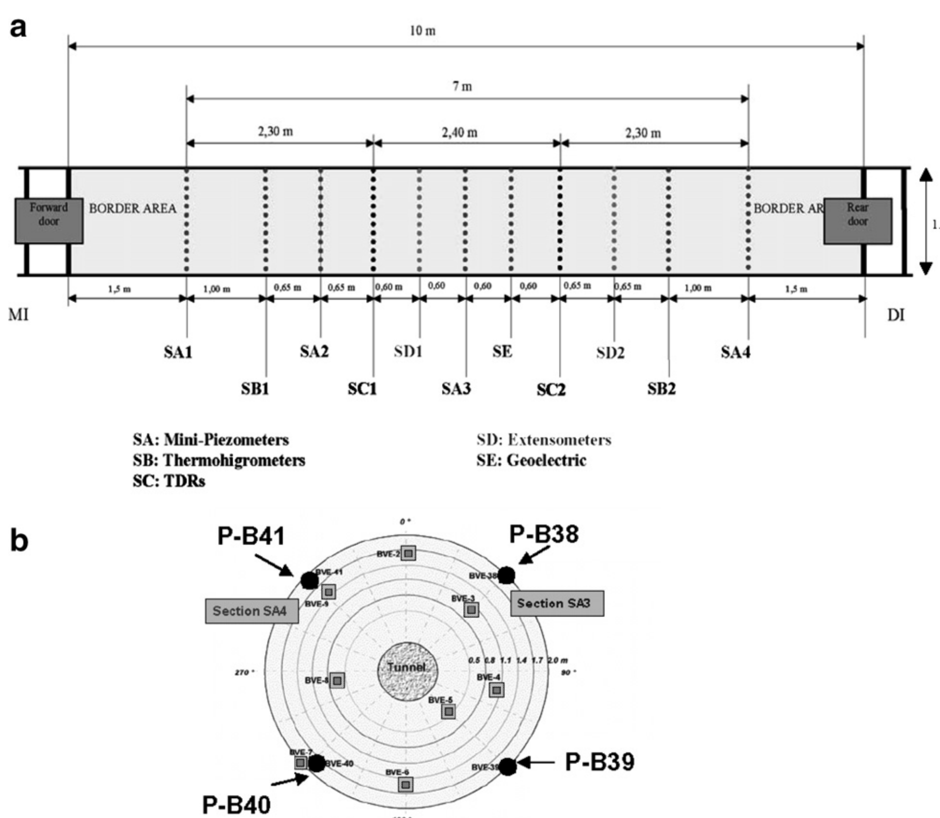

Fig. 1. Cross-sections with different types of instrumentation: (a) side view schematic of the ventilation experiment test section; (b) cross-section at mid-length of the microtunnel.