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Interaction between clay-based sealing components and crystalline host rock

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ABSTRACT

The results of hydraulic–mechanical (H–M) numerical simulation of a shaft seal installed at a fracture zone (FZ) in a crystalline host rock using the finite element method are presented. The primary function of a shaft seal is to limit short-circuiting of the groundwater flow regime via the shaft in a deep geological repository. Two different stages of system evolution were considered in this numerical modelling. Stage 1 simulates the groundwater flow into an open shaft, prior to seal installation. Stage 2 simulates the groundwater flow into the shaft seal after seal installation. Four different cases were completed to: (i) evaluate H–M response due to the interaction between clay-based sealing material and crystalline host rock in the shaft seal structure; (ii) quantify the effect of the different times between the completion of the shaft excavation and the completion of shaft seal installation on the H–M response; and (iii) define the potential effects of different sealing material configurations. Shaft sealing materials include the bentonite–sand mixture (BSM), dense backfill (DBF), and concrete plug (CP). The BSM has greater swelling capacity and lower hydraulic conductivity (K) than the DBF. The results of these analyses show that the decrease of the pore water pressure is concentrated along the fracture zone (FZ), which has the greatest K. As the time increases, the greatest decrease in pore water pressure is found around the FZ. Following FZ isolation and the subsequent filling of the shaft with water as it floods, the pore water pressure profile tends to recover back to the initial conditions prior to shaft excavation. The majority of the fluids that ultimately saturate the centre of the shaft seal flow radially inwards from the FZ. The time between the completion of the shaft excavation and the completion of shaft seal installation has a significant effect on the saturation time. A shorter time can reduce the saturation time. Since most of the inflow comes from the FZ, application of the BSM for extended distances above and below the FZ does not significantly affect the saturation time of the volume adjacent to the FZ. The application of BSM near the FZ rather than a low swelling capacity, more permeable filling material is very significant. This study assumed a perfect contact between seal materials and host rock. Limited to the assumptions used in this study, use of BSM near the FZ was found to increase the time before the centre of the shaft seal became fully saturated from between 4 and 30 years (when the DBF is used) to between 90 and 100 years (when the BSM is used).

1. Introduction

The Government of Canada has accepted the Nuclear Waste Management Organization's (NWMO) recommendation of Adaptive Phased Management (APM) as the long-term management approach for Canada's used nuclear fuel (NWMO, 2005; NRCan, 2007). APM ultimately involves the isolation and containment of used nuclear fuel in a deep geological repository (DGR). On completion of the waste placement operations, and during repository closure, shaft seals will be installed at strategic locations, such as, where significant fracture zones (FZs) are located. These shaft seals are expected to be composed of both clay-based and concrete-based sealing components. The primary function of a shaft seal is to limit short-circuiting of the groundwater flow regime via the shaft.

As part of the closure of Atomic Energy of Canada Limited's (AECL) Underground Research Laboratory (URL), a full-scale shaft seal has been constructed at the intersection of a low dipping thrust fault with the access shaft (Dixon et al., 2009). The geometry and sealing material configuration for a repository shaft seal is not fixed and will vary depending on the host rock type and local conditions. Both crystalline and sedimentary rocks are considered potentially suitable host rock formations for a DGR (NWMO, 2005). However, modelling of the evolution of the shaft seal at the URL will provide a valuable opportunity to calibrate models and evaluate what environmental parameters are critical in the hydration process. In this paper, the host rock is assumed to be crystalline rock. The condition and properties of the host rock at the URL, which is sparsely to moderately fractured rock (MFR), is used to provide input for this study.

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Beyond the hydraulic, mechanical and geological parameters, the time between the completion of the shaft construction and the installation of the shaft seals may affect the hydraulic–mechanical (H–M) response occurring in the shaft sealing system. The notation $t_{install}$ is used to define the time between the completion of the shaft construction and the installation of the shaft seals. Numerical analyses using different $t_{install}$ can be used to define which case is more conservative for further study.

The main objectives of the paper are to: (i) evaluate H–M response due to the interaction between clay-based sealing material and crystalline host rock in the shaft seal structure; (ii) quantify the effect of different $t_{install}$ on the H–M response; and (iii) define the potential effects of different sealing material configurations.

In order to address these objectives, four cases of H–M numerical simulation of a shaft seal installed in a crystalline host rock have been conducted. A finite element computer code (i.e., COMSOL) is used to solve the H–M transient problem. Three different sealing components are considered in this study, including bentonite–sand mixture (BSM), dense backfill (DBF), and concrete plugs (CP). The cases in this paper include two different $t_{install}$ (1 year and 100 years) and three different configurations of shaft sealing materials.

This study did not attempt to predict the responses of the shaft sealing components. This study focused on the relative comparison of the hydraulic responses between different cases to address the objectives of this study. More rigorous constitutive models, calibration of parameters, boundary conditions, geometry of the actual shaft seals are required in order to predict the actual response of the shaft sealing components.

2. Shaft seal layout and case study

In this paper, the host rock is assumed to be a crystalline, sparsely to moderately fractured rock, similar to what is present at the URL. The simulated repository is located at a 500 m depth and a significant FZ is located at a 250 m depth (Fig. 1a), a layout relatively similar to the URL. As a result of the considerable distance from the shaft seal to the repository horizon and the expectation that the H–M evolution of a repository will likely occur before any temperature perturbations occur at the seal location, the shaft seal is assumed to be in an isothermal condition. Also like the URL, the FZ is assumed to be 4 m thick. The FZ is assumed to be a perfectly horizontal feature in order to simplify the analysis. This assumption allows the H–M simulation using a 2D-axisymmetric model.

The shaft seal layout considered in this numerical model has a diameter of 7.30 m, which is the assumed diameter of the main shaft in a DGR (Fig. 1b). The shape and height of the model shaft seal are similar to the shaft seal installed at the URL, but the seal has a larger diameter. Four different cases are presented in this paper. Table 1 shows the configuration of the sealing materials in components A–C for the four cases. Fig. 1b shows the components A–C discussed in Table 1.

Cases 1 and 2 are used to evaluate the effect of different $t_{install}$. Cases 1 and 2 have similar material configurations, but have different $t_{install}$ ($t_{install}$ = 100 years for Case 1, $t_{install}$ = 1 year for Case 2). In Cases 1 and 2, the seal consists of a 6-m-thick BSM component (A in Fig. 1a) that is constrained between two massive 4-m-thick CP components (C in Fig. 1a). The DBF components are installed above and below the CP (components B in Fig. 1a). The CP components are keyed into the shaft to provide shearing and rotational stability and restrain the swelling of the BSM component.

Case 3 has BSM (components A and B in Fig. 1a) and CP (component C in Fig. 1a) as sealing materials and Case 4 has only DBF (components A–C in Fig. 1a) as sealing materials. Cases 3 and 4 are completed to study the effectiveness of the shaft seal configuration. Cases 3 and 4 have $t_{install}$ of 1 year.

3. Material properties

3.1. Host rock

Table 2 summarizes the material properties used in the numerical modelling. Based on the observation by Read and Martin (1996), a Young's Modulus (E) of 60 GPa and Poisson's ratio (υ) of 0.25 for the host rock are selected. Since there is no specific

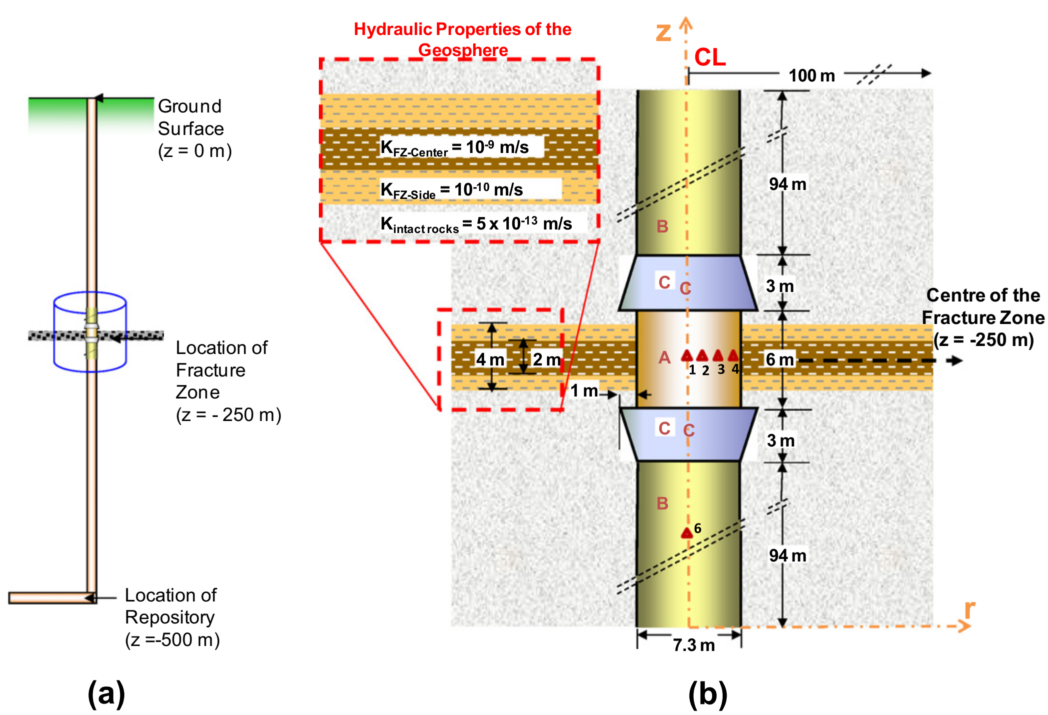

Fig. 1. Configuration of the shaft seal.