Numerical Analysis of Thermo-Hydro-Mechanical Coupled Behavior in Korean Reference HLW Disposal System (KRS)

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1. Introduction

Decay heat can influence temperature distribution at Engineered Barrier System (EBS) and at Natural Barrier System (NBS) in Korean Reference HLW disposal System (KRS). Water inflow from the rockmass can influence thermal conductivity of buffer materials. It can affect the thermal behavior. And thermal stress due to decay heat and swelling pressure due to the water inflow can change the stress condition at the disposal system and at the rock mass near the system. Therefore, the understanding of the THM coupled behavior is essential for the site selection, design, as well as the operation of the repository. In this study, numerical modeling was performed to enhance the understanding of THM coupled processes in the KRS.

2. Numerical model

2.1 Numerical code

TOUGH2-MP [1] was used to perform TH analysis using 60 processors in Linux system and FLAC3D [2] was used to conduct M analysis using 8 processors in Window system. Data can be exchanged through an internet hub.

2.2 Initial and boundary conditions

Fig. 1 presents the initial and boundary conditions for a coupled THM simulation. The initial conditions are defined at the pre-excavation stage. The vertical gradients of temperature, fluid pressure, and in-situ stress applied as shown in Fig. 1. In the numerical model, tunnel spacing and disposal holes interval was set to be 40 m and 8 m, respectively.

2.3 Input parameters

Decay heat was applied as a function (Eq. 1) and 30 years cooling time was assumed in the model. Van Genuchten model was used to consider capillary pressure. Power law was applied for relative permeability function. Mohr-coulomb model was used for mechanical analysis of buffer, backfill and host rock. Physical, thermal, hydraulic, and mechanical properties are listed in Table 1.

$$\mathrm{power} = 1.844 \times 1.455 \times 10^4 \times (\mathrm{t} + 30)^{-0.758} \quad (1)$$

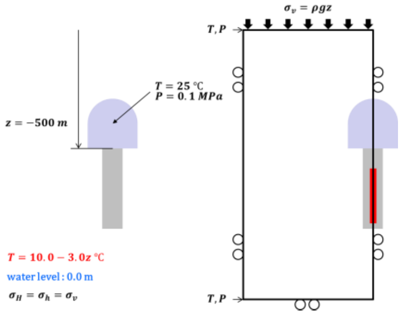

Fig. 1. Initial and boundary conditions in the model.

Table 1. Input parameters in the model

Parameters	Buffer	Back fill	Rock	Waste
Dry density (kg/m^3)	1,600	1,600	2,650	6,577
Porosity (-)	0.41	0.40	0.01	0.001
Thermal conductivity (W/mK)	0.72 – 1.20	1.09 – 2.149	2.853 - 3.165	49.02
Specific heat of solid (J/kg/K)	966.0	981.0	820.0	1000.0
Linear expansion coefficient (1/K)	2.5 E-5	2.5E-5	7.5 E-6	1.7 E-5
Intrinsic Permeability (m^2)	1.5E-20	1.6E-19	1.0E-18	0.0
λ	0.2941	0.5	0.6	-
1/P$_0$	2.6E-7	3.3E-7	5.0E-7	-
Klinkenberg parameter	1.0E09	1.0E08	6.86E5	-
Young's modulus (GPa)	0.59	0.59	33.34	155.0
n for relative permeability function (S^n)	1.9	1.9	3.0	-
Poisson's ratio(-)	0.20	0.20	0.3	0.285
Maximum swelling stress (MPa)	5.0	3.0	-	-
Friction angle (°)	37.0	37.0	46.66	-
Cohesion (MPa)	1.0	1.0	10.4	-
Tensile strength (MPa)	3.0	3.0	3.75	-
Dilation angle (°)	10.0	10.0	10.0	-

2.4 Modeling procedures

The excavation sequence was simulated for 10 years, with the elements in the tunnel removed and with fixed fluid pressure (0.1MPa) and relative humidity (100%). After 10 years, the waste canister, bentonite buffer, and backfill are installed instantaneously and the post closure simulation can start. The post closure simulation was performed for 1,000 years. The monitoring points are shown in Fig. 2.

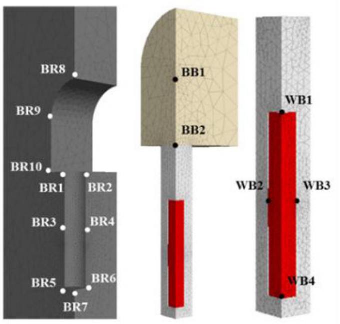

Fig. 2. Monitoring points of time dependent results.

3. Results

3.1 Thermo-hydraulic analysis

Fig. 3 presents temperature, fluid pressure, and degree of saturation evolutions with decay heat in the simulated waste canister. Maximum temperature is calculated below 100℃. Fluid pressure is slowly increased until several years, after then, the pressure is rapidly increased and becomes hydrostatic pressure after decades. The liquid saturation in the buffer decreases to a minimum of about 0.3 after a few years, after then saturation starts to increase and finally reaches 1.0 over 200 years.

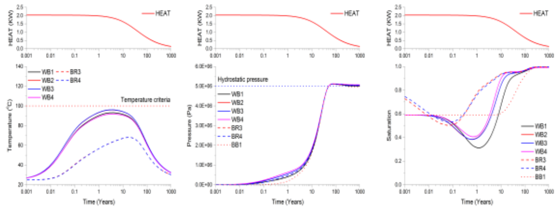

Fig. 3. Evolution of temperature, fluid pressure and saturation in KRS.

3.2 Mechanical analysis

In this study, the linear elastic (LE) swelling model was used and the model input parameters was be determined analytically to achieve a desired maximum swelling stress which is listed in Table 1. And Mohr-Coulomb criterion [3] is used to investigate the potential for rock failure. Fig. 4 presents the path of minimum and maximum principal effective stresses in relation to the Mohr-Coulomb failure envelopes. The stress state of rockmass stays below that required for failure.

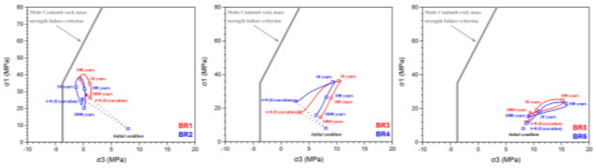

Fig. 4. Principal stress path in relation to Mohr-Coulomb failure criterion for rock mass.

4. Conclusions

Numerical modeling was performed to investigate influence of THM processes on KRS involving the interaction of multi-components including buffer materials, canister, and rockmass over 1000 years. The maximum temperature at the interface between canister and buffer can satisfy temperature criteria of 100°C. The stress state of rockmass stays below the failure criterion, but it is necessary to check that the stress state is below the spalling criterion based on the compressive strength.

Acknowledgements

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