Hydrogeological Evaluation of Unsaturated Zone In-situ Test Facility Designed for Small-scale Field Infiltration Test

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1. Introduction

The long-term stability of deep disposal facilities hinges significantly on reactive boundary interfaces formed along groundwater pathways. Rainfall seeps into the surface, moving through unsaturated zones and aquifers, undergoing geochemical changes as it progresses towards the deep subsurface. During this process, the migration of redox transition zones can weaken the natural barriers' buffering capacity. Therefore, a thorough understanding of groundwater flow characteristics from the surface to the disposal facility's surrounding bedrock is crucial. To achieve this understanding, we are planning small-scale field infiltration tests, in addition to long-term in-situ solute migration experiments, to investigate the movement of groundwater from the surface to the groundwater table. This paper provides a comprehensive analysis of the hydrogeological features of UNsaturated zone In-situ Test facility (UNIT), designed specifically for conducting small-scale field infiltration tests.

2. Methods and Results

In this research, as laboratory-scale experiments, particle size and soil texture analyses were performed to evaluate the background characteristics of UNIT. Field-scale investigations included measuring groundwater levels and conducting pumping tests to estimate the hydraulic properties of the study area.

2.1 Laboratory-scale Experiments

Soil samples, both disturbed and undisturbed, were collected at depths of 0, 30, 60, and 90 cm in the study area for particle size and soil texture analyses. Fig. 1 depicts the distribution of soil particles, with mean grain sizes ranging from 0.35 to 0.53 mm and uniformity coefficients exceeding 4, indicating heterogeneous medium sand [1, 2]. Based on these results and the borehole log, the hydraulic conductivity of the aquifer in the study area is expected to fall within the range of 1E-6 to 1E-2 m/s [3]. Consequently, a pumping test was determined as the suitable method for hydraulic testing in the research area [4]. The soil texture analysis results by depth indicate that the soil in the research area is classified as either sandy loam or loam.

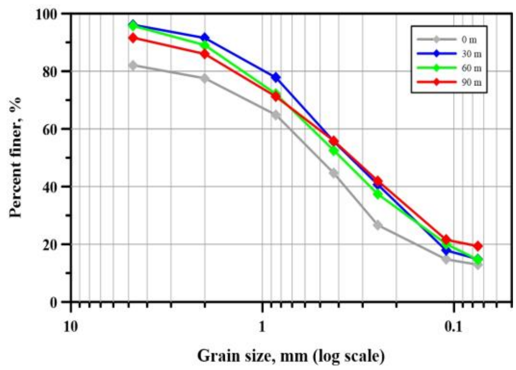

Fig. 1. The particle distributions of soil samples representing mean grain sizes and uniformity.

2.2 Groundwater Level

To conduct field experiments such as hydraulic testing or tracer tests for observing groundwater level fluctuations and assessing aquifer characteristics, a total of five boreholes were installed within UNIT, penetrating through weathered soil layers. The research area comprises landfill layers, sedimentary layers, weathered soil, and weathered rock. To accurately measure the groundwater level, automatic and manual measurements were performed concurrently to determine the elevation. As the boreholes were closely located, significant differences in groundwater levels were not observed. During the dry season, the groundwater level gradually decreased around an elevation of 61 m, while during the wet season, it sharply increased up to 64 m. The unsaturated zone consists of sandy loam and loam with relatively good permeability, and its thickness ranges from 2 to 4 m, causing rapid fluctuations in groundwater levels due to rainfall (Fig. 2).

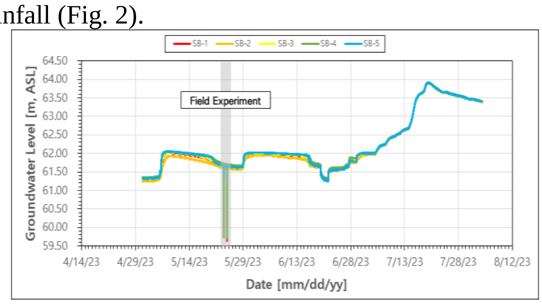

Fig. 2. Groundwater level fluctuations during the rainy season in the study area.

2.3 Pumping Tests

The small-scale infiltration test involves injecting a tracer at the surface and monitoring concentration changes observed at the observation well while withdrawing water, aiming to evaluate the characteristics of the unsaturated zone over time. Therefore, to analyze the experimental results, it is essential to assess not only the unsaturated zone but also the characteristics of the saturated zone. Consequently, in this study, in-situ hydraulic tests were performed to evaluate the hydrogeological properties of the saturated zone. The pumping test conducted as a constant-rate test involves interpreting pressure decline over time measured in the test interval while maintaining a constant pumping rate, to evaluate the hydrogeological properties of the aquifer. The pumping test fundamentally assumes radial flow towards the pumping well, and initially experiences a significant pressure decline immediately after pumping, followed by diminishing pressure changes over time.

The pumping test conducted at IB wells installed in the research area for small-scale field infiltration tests can be classified into multi-well and single-well pumping tests. In the multi-well pumping test, pumping was conducted at the pumping well IB-4 at a rate of 27.87 m/d for approximately 2 hours. During this time, a drawdown of 5.729 m was observed at the pumping well. However, at the nearest observation well, IB-3, the maximum drawdown was only 0.680 m, and minimal changes in water levels were observed at other observation wells. The hydraulic conductivity of IB-3 is 1.917E-5 m/s, and the transmissivity is 2.013E-4 m^2/s, which corresponds well to the range of well-sorted sands [3]. Since it falls outside the range of applicability for other hydraulic testing methods, it confirms that the pumping test was an appropriate hydraulic testing method [4]. The transmissivity and hydraulic conductivity of IB-4 are only 2.514E-5 m^2/s and 2.394E-6 m/s, respectively, which are approximately 1/8 of those measured at IB-3. This indicates a lower hydraulic connection between IB-4 and the other observation wells.

Fig. 3 presents the analysis and diagnostic assessment results for the single-well pumping tests. The groundwater level changes observed at IB-1, IB-2, and IB-3 during the single-well pumping tests indicate rapid attainment of radial flow shortly after pumping. The single-well pumping tests were also analyzed using the unconfined aquifer model, revealing transmissivities ranging from 1.770E-4 to 2.355E-4 m^2/s and hydraulic conductivities ranging from 1.656E-5 to 2.138E-5 m/s (Fig. 3).

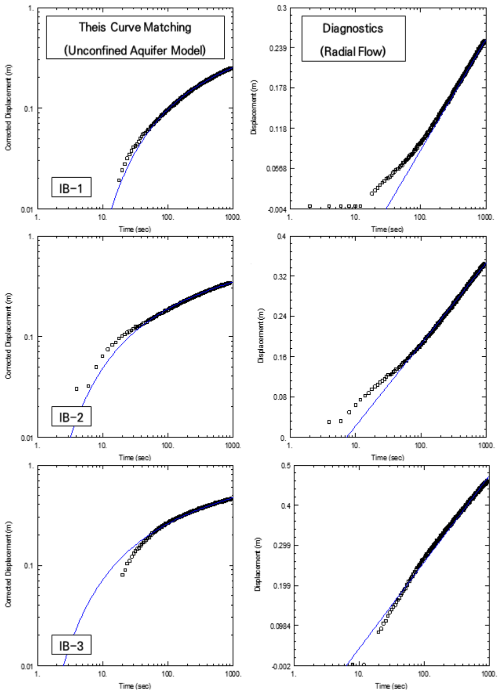

Fig. 3. Analysis and diagnostic evaluation of the single-well pumping tests conducted at IB wells.

3. Conclusions

In the context of the long-term stability of deep disposal facilities, reactive boundary interfaces along groundwater flow paths are crucial. Rainfall infiltrates the surface, moving through unsaturated zones and aquifers, engaging in geochemical interactions as it reaches the deep subsurface. The potential movement of redox transition zones during this process could diminish the buffering function of natural barriers. In this context, small-scale field infiltration tests are being prepared to understand groundwater flow from the surface to the groundwater table. This study provides a detailed background evaluation for the study area. Future studies will focus more on field-scale experiments, including tracer tests, with an emphasis on field infiltration tests, utilizing various tracers based on the results. These small-scale experiments will be utilized to derive methodologies for assessing the background characteristics of the study area, serve as input data for an integrated surface-subsurface hydrologic model to evaluate the long-term performance of natural barriers, and assess the performance of models simulating the unsaturated zone. Such research at a small scale will serve as a foundation for developing larger watershed-scale models, essential for evaluating the long-term safety of deep disposal repositories.

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