Barrier of near-surface LILW disposal facility in Korea : hydraulic model development

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Abstract

The primary objective of the engineered barrier of Low-and Intermediate Level radioactive Waste (LILW) disposal facility is to limit the amount of water ingress that passes through the engineered barrier and to protect waste packages. From the mid of 2015, the silo type disposal facility for LILW started for its operation as the first stage. As the second stage, the vault type of near-surface disposal facility is being prepared in Korea. The second stage facility is composed of the multiple engineered barrier cover system so that the effects by rainfall are reduced and thus leakage of radioactive substances can be minimized. The cover system is composed of several different layers including surface, protective, drainage and barrier layer. In this paper, Hydro-geological concept modeling to predict the rainfall infiltration through the cover system is performed by using Finite Element subsurface Flow code (FEFLOW).

1. Introduction

Currently, the operation of LILW disposal facility is ongoing in Gyeongju Wolsong. In December 2014, the near-surface disposal facility of silo type below ground level was completed as the first stage, and the license for the construction and operation of the near-surface disposal facility as the second stage is being prepared.

For the second stage of near-surface disposal facility, concrete storages for keeping disposal containers on the surface will be constructed and then the multiple engineered barrier cover system installed on their top so that the influences by rainfall are reduced, and thus leakage of radionuclide substances can be minimized [1].

In this paper, rainfall infiltration through the multiple engineered barrier cover system was adapted and assessed by using the two-dimensional groundwater flow model with FEFLOW to assess the performance of the cover system of the second stage near-surface disposal facility at ground level [2].

2. Design concept of the cover system

The primary objective of cover of LILW disposal facility is to limit the amount of water that passes through the cover system and the amount of water potentially coming into contact with waste. There are only a few ways in which the cover can limit the passage of water: by evapotranspiration and diversion of water into runoff or subsurface lateral drainage. Since precipitation cannot be controlled, seepage can only be minimized by maximizing the sum of evapotranspiration, runoff and subsurface lateral drainage. Other objectives that have a direct impact on water flow through the cover system are also important. For instance, it is often necessary for the cover to minimize wind and water erosion and to prevent plant and animal intrusion.

The second stage of the Wolsong LILW disposal facility was designed as the near-surface disposal.

The cover system is composed of multiple layers (surface layer, protective layer, drainage layer and barrier layer) as engineering barrier elements. The inclination of each layer should be set to more than 3 % gradient in order to minimize rainfall infiltration into the disposal vault. The permissible infiltration rate is 32 mm/year, and this rate was calculated taking into consideration the permeability of the barrier layer. Fig.1 shows the configuration of the cover system.

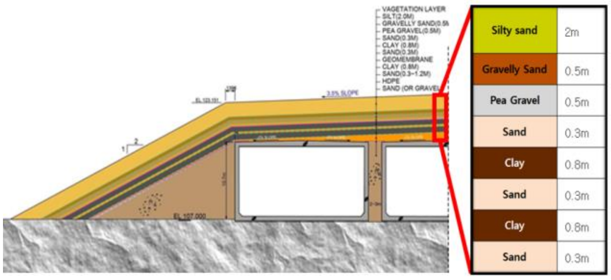


Figure 1. Configuration of multi-layer cover concept in the second stage LILW disposal facility

Table. 1 shows the composition and functional requirement of each layer. The function of each layer is as follows [3]:

- Surface layer
  The functions of surface layer are to manage runoff, minimizing erosion, maximizing evapotranspiration. It consists of silty sand.

- Protective layer
  A protective layer is placed directly below the surface layer. The combined layers function to protect underlying layers from degradation, which can occur by repeated freeze/thaw cycles, repeated excessive wetting/drying, plant, animal, or human intrusion.
  The protective layer consists of gravelly sand and pea gravel.

- Drainage layer
  The function of the drainage layer is to collect water infiltrated through the surface and protective layers and to divert this water laterally. The drainage layer is composed of sand.

- Barrier layer
  The barrier layer is the most critical component, because this layer plays a role to limit water infiltration into disposal vault. Functional requirement of this layer is on the order of a few cm/year or less: 10^{-7}cm≈3.2cm/year.
  The barrier layer is composed of clay.

Table 1. Characteristics of cover materials for the second stage LILW disposal facility

Layer	Characteristics
Surface layer (silty sand)	**Slope : 3 ~ 5 % (humid), 2 %(arid) Thickness : > 60cm [60~100 cm(humid), 200 cm(arid)] Erosion rate : < 2 ton/acre/year Resistant repeat freeze/thaw cycles**
Protective layer (gravelly sand, pea gravel)	
Filter layer (flexible membrane liner)	**Slope : > 3 % Thickness : > 30 cm K : > 10-2 cm/s Hydraulic transmissivity : > 3.0×10-9 cm2/s**
Drainage layer (sand)	
Barrier layer (clay)	**Thickness : > 60 cm Slope : > 3 % K : < 1.0 ×10-7cm/s(=3.2 cm/year)**

3. Modeling concept

Two-dimensional analysis was performed on the cross-section as a full scale, which is in the short axis direction of the second stage near-surface disposal facility and a multiple engineered barrier disposal cover installed on top of the disposal storages.

The model was set up by extending 20 m to both the left and right sides of the model area and 50 m to the bottom where the groundwater was located in order to exclude external influences in assessing the rainfall infiltration through the disposal cover as follows Fig. 2.

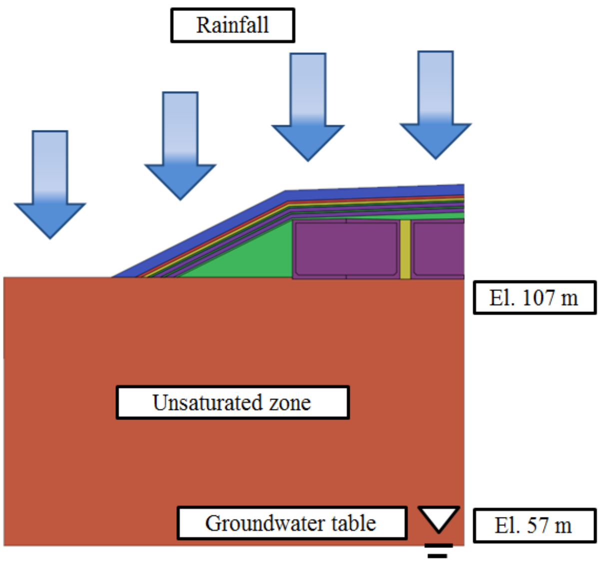


Figure 2. Concept model of ground water flow modeling for the second stage LILW disposal facility

4. Input parameters for concept modeling

4.1 Mesh generation

Fig. 3 shows that meshes are composed of a total of 29,194 elements using triangular elements of various sizes ranging from fine to coarse mesh in reflection of the design of the cover system. The model domain for cover system is subdivided into 9 areas reflecting the design so that characteristics of each layer can be applied. Base on the cover design, the second stage disposal facility has two-dimensional symmetry structure and for the numerical safety and computational efficiency, only the half of model area was simulated.

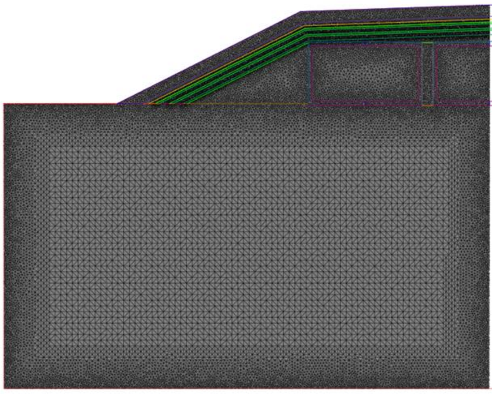


Figure 3. Mesh structure of numerical simulation

4.2 Boundary conditions

The ground water flow model requires information about the head or head gradient at the boundaries of the model domain. To set the rain conditions, the rainfall data for 30 years of weather station located near the second stage LILW disposal facility was applied.

The recharge amount excluding evapotranspiration and surface runoff from rainfall was assumed to penetrate through the disposal cover, and thus estimated amount was 469 mm/year, which was 36.5 % of the average annual rainfall as follows Fig. 4. The rainfall reflected recharge rate was set as the top boundary condition of domain.

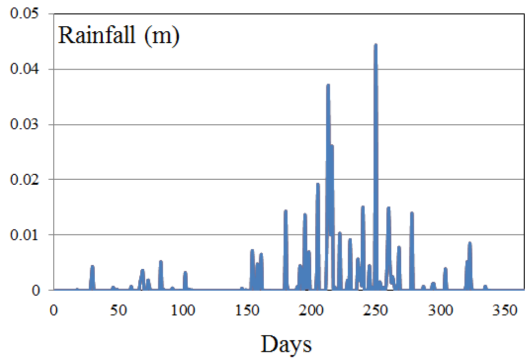


Figure 4. The average annual rainfall as the boundary condition

The bottom of domain was set as constant head boundary condition and the other boundary was set as no flow boundary. Fig. 5 shows the applied boundary conditions.

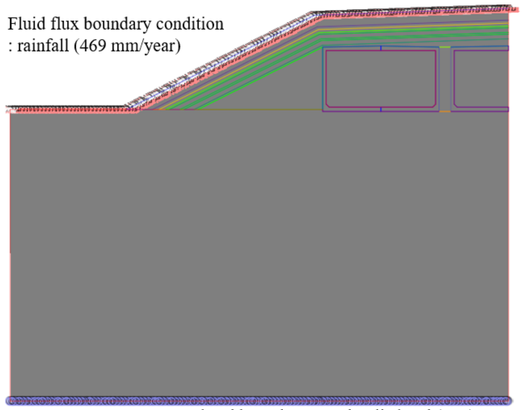


Figure 5. Applied boundary conditions for the calculation

4.3 Hydraulic properties of cover

In this study, the hydraulic properties of cover given in the reference were applied. The hydraulic properties listed in Table. 2 [4].

Table 2. Hydraulic properties considered for cover as a multi-layer

Layer	Water Content		Van Genuchten Parameters		Saturated Hydraulic Conductivity (cm/s)
	Residual (-)	Saturated (-)	α (cm^{-1})	n (-)	
Silty sand	0.1	0.47	0.044	1.523	1.00e-04
Gravelly sand	0.02	0.32	0.1008	2.922	1.00e-02
Pea gravel	0.03	0.26	4.695	2.572	1.00e+00
Sand	0.045	0.37	0.0683	2.08	3.00e-02
Clay	0.0001	0.36	0.0016	1.203	1.00e-07
Concrete Vault	0.08	0.40	0.0063	1.08	1.00e-8

The hydraulic property parameters were used as input data in numerical simulation. In order to reflect the fracture characteristics in unsaturated zone of the second disposal facility site, discrete fracture network modeling was conducted. The hydraulic conductivity derived from results of the discrete fracture network modeling was applied as the hydraulic conductivity of unsaturated zone. Fig. 6 shows the hydraulic conductivities of media.

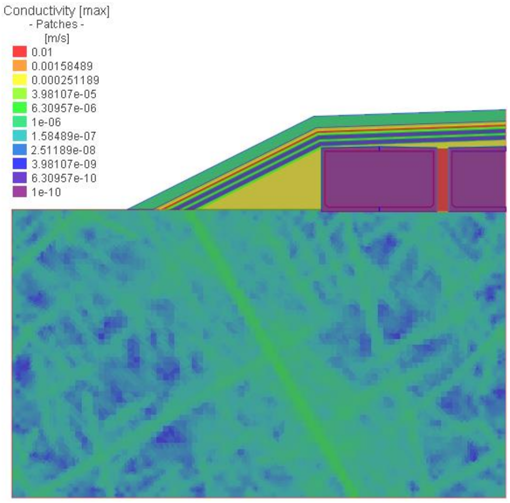
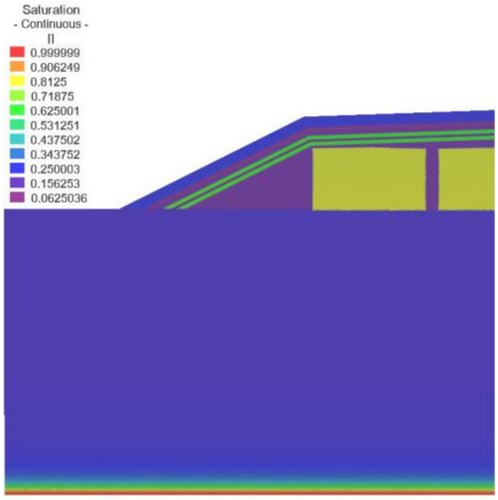


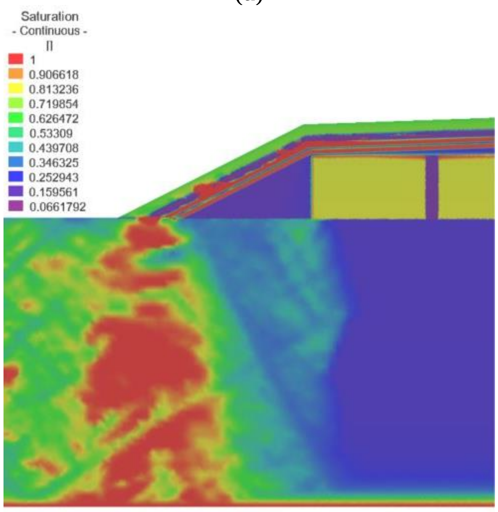
Figure 6. Distribution of hydraulic conductivity

5. Results of hydro-geological concept modeling

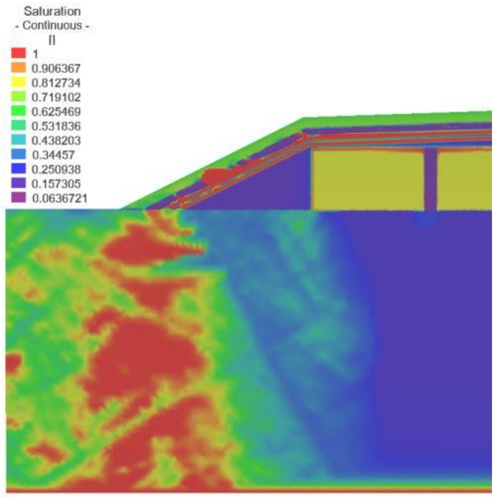
Fig. 7 show the change of saturation distribution over 300 years and it is possible to judge the behavior of infiltrated water based on simulation results (after 0, 100, 200, 300 years).



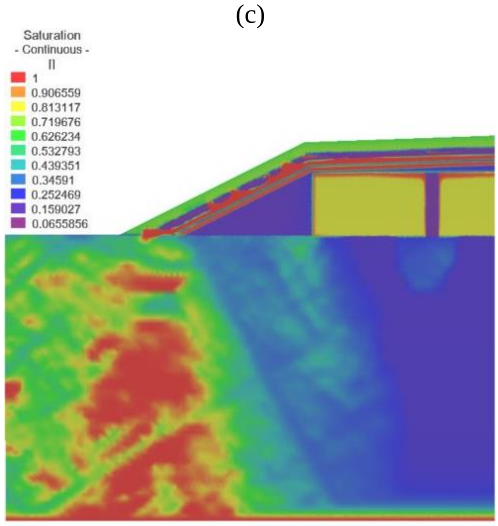
(a)



(b)



(c)



(d)

Figure 7. Saturation distribution after 0 (a), 100 (b), 200 (c), 300(d) years, respectively

The percolation of infiltrated water proceeded at a very slow rate along with time. Infiltrated water collected in the sand layer at the lowermost part of the drainage layer (gravelly sand, pea gravel, sand) and most of infiltrated water flow through the slope. Hence, the amount of infiltration into the clay layer forming the lower part of the cover layer within 300 years was simulated as extremely insignificant.

6. Conclusion

To assess the performance of the multiple engineered barrier cover system in the second stage LILW disposal facility in Korea, KORAD developed the hydro-geological concept model. The hydraulic evaluation of the cover was conducted using FEFLOW. As hydraulic evaluation result for the cover system, the infiltration rate into the sand layer forming the lower part of the cover system was satisfied with the permissible infiltration rate.

In order to improve reliability and validity of simulation results, various further studies such as cover properties suitable for KORAD's design, estimation of recharge amount and degradation of concrete are required.

The actual flow of rainfall passing through the facility will be three-dimensional. In this study, it has been limited to two-dimensional approach. Actual three-dimensional hydraulic studies will be carried out at a future date.

7. References

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