NUMERICAL ANALYSIS OF INFLOW CONTROL FOR QUALITY MANAGEMENT OF BUFFER MATERIAL USING DISCRETE FRACTURE NETWORK MODEL

Kazuhiko MASUMOTO*1 Makoto NAKAJIMA*1 Hayato NONAKA*1
Tomoko ISHII *2 Mayumi JO*2 Masataka IMAI*2 Hiroyuki ATSUMI*1

*1 Kajima Corporation
2-19-1, Tobitakyu, Chofu city, Tokyo, 182-0036, Japan

*2 Radioactive Waste Management Funding and Research Center
Pacific Marks Tsukishima, 1-15-7, Tsukishima, Chuo-ku, Tokyo, 104-0052, Japan

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Abstract

In the vertical disposal concept of high level radioactive waste, it is important to evaluate the influence of groundwater flow into disposal pits on the performance of buffer materials as an engineering barrier because the inflow might cause the erosion of the buffer materials. The purpose of this study was to evaluate the inflow control technique (e.g. grouting) around disposal pits using numerical analysis. The model for the simulation should be a discrete fracture network model when the groundwater mainly flows along fractures in a rock mass, therefore, the discrete fracture network model was selected to estimate the inflow control technique in this study.

The numerical flow analysis was conducted using LT-Flow, which is a groundwater simulation program using a pipe network structure, into which the fracture network was converted. Firstly, a single disposal tunnel was modelled for the simulation, and then five disposal tunnels were modelled by assuming disposal panels. The results of numerical flow analysis showed that the effectiveness of grouting for the disposal pits to control the inflow and the impact of grouting on other disposal pits or surrounding disposal tunnels could be evaluated quantitatively.

1. Introduction

In the repository for high-level radioactive waste, the groundwater inflow to the disposal pit impedes the emplacement of the buffer material at the operation phase. In addition, during the re-saturation period after the buffer has been emplaced, the groundwater inflow to the disposal pit may lead to piping and erosion, which may interrupt the self-repairing functions of the bentonite and affect long-term performance[1),2)]. Grouting and other engineering measures could be considered to reduce the flow of groundwater into disposal pits, but the hydrological properties of the surrounding rock may affect the effectiveness of these measures. In the case of a rock mass in which fractures control permeability, it is particularly necessary to evaluate effects using a fracture model that has been turned into the hydrogeological structure model. In this research, an analytical approach was conducted by creating a fracture network model based on actual investigation data of underground research laboratories, and variance in the volume of groundwater flowing into disposal pits due to the distribution of the fractures, and the influence of the engineering measures on the hydrological field around the disposal tunnel were evaluated. First, a study was made in a single disposal tunnel model, and then a study was made in multiple disposal tunnel models that assumed disposal panels. The following is a report of these studies.

2. Study of groundwater flowing into disposal pits based on the fracture network model

2-1 Creation of a hydrogeological structure model

Geological and hydrological investigation data from the Horonobe Underground Research Center[3)] were used to construct the hydrogeological model that was used in this research. The fracture data were the results of an investigation in the Horonobe URL 350m-level tunnel of two connection tunnels of roughly the same length, East and West, which orthogonally intersected each other. The hydrological data were derived from the results of a hydrological test at the boreholes conducted near a ventilation shaft, and the excavation damaged zone was from the results of a hydrological test conducted in the 350m-level tunnel. Table 1 shows the geometrical parameter set of these fractures, while Table 2 shows the parameter set used to create the hydrological model.

Based on the statistical data of these fractures, a 100m×100m×100m block scale geological structure model[4] was created using a probabilistic method. The number of realizations of the model was set at 10 based on the results of fracture network analysis[4] conducted at the Mizunami URL. At that time, the host rock of the Horonobe URL was sedimentary rock, so it was decided to create the model by considering matrix structure. Specifically, fractures with a minimum 1.25m to the set 3.82m radii were generated to model the matrix structure. The total number of fractures that were created was 77,813 as the average of 10 realizations, which were coordinated with the set intensity of the 3D fractures. The hydrogeological structure model was constructed by extracting 22% of the fractures from this geological structure model, which was the proportion of permeable fractures at the Horonobe URL. These fractures were given a transmissivity by the simulation analysis of hydrological test. Figure 1 is an example of realization. In this research, a model in which the fracture network structure was converted into a pipe network[5] was used for flow analysis.

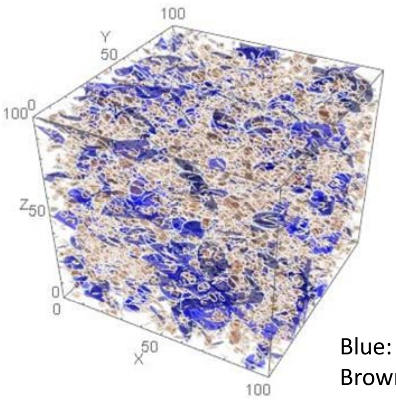
Table 1 Geometrical parameter set of the fracture

Set of fracture	Fracture orientation		Fracture size distribution		Fracture intensity	
	Dip Strike	Fisher coefficient	Power low	minimum radius (m)	P32 (m^2/m^3)	P32adj* (m^2/m^3)
NW	N69W 52N	16.9	3.5	3.82	0.54	0.94
NE	N51E 51N	13.6	3.5	3.82	0.25	0.44
Others	N78E 43S	5.2	3.5	3.82	0.20	0.34
total	-	-	-	-	0.98	1.71

*convert to 1.25m of minimum radius

Table 2 Parameter set for hydrogeological model

Parameter	Investigation data
Proportion of permeable fractures	22.2%
Permeability coefficient of interval including permeable fractures	6.0×10^{-9}m/sec (test interval 65m)
Permeability coefficient of EDZ	1.0×10^{-6}m/sec (width 65m)
Permeability coefficient of matrix	1.8×10^{-11}m/sec



Blue: permeable fracture
Brown: matrix structure

Figure 1 Hydrogeological structure model of discrete fracture network

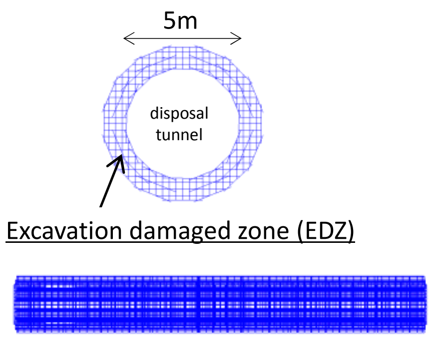


Figure 2 Modeling of Excavation Damaged Zone

2-2 Modeling the disposal tunnels and pits

One disposal tunnel and 10 vertical disposal pits were modeled in the model constructed in 2-1, and the flow analysis was conducted in the model. The disposal tunnel was a circular cavern having a length of 100m and diameter of 5m in the center of the model region. The excavation damaged zone was set with a thickness of 0.5m on the outer periphery of the disposal tunnel (Fig. 2). The boundary of the tunnel was set as the atmospheric pressure boundary. The disposal pits were turned into a model by setting pit intervals of 6.6m, radius of 1.5m, and 5.0m from the floor as the atmospheric pressure boundary. The conditions of the model boundary were a non-permeable boundary of the plane which orthogonally intersects with the axis of the disposal tunnel, with the other planes having a total head of 350m. In addition, the analysis was conducted in 3 steps: 1) at the time of disposal tunnel excavation, 2) at the time of disposal pit excavation, and 3) at the time grouting measures were implemented.

2-3 Estimations of amount of groundwater flowing into disposal tunnels and pits

Table 3 shows the results of calculating the volume of groundwater flowing into disposal tunnels for the time of disposal tunnel excavation. The tunnel inflow volume was the 10 realization average, which

Table 3 Results of flow analyses during disposal tunnel excavation

RZN	Single-tunnel inflow (L/min)	Multiple-tunnel inflow (L/min)				
		G1	G2	G3	G4	G5
HR01	7.10	0.03	2.49	3.43	4.49	6.02
HR02	10.35	0.98	1.38	4.52	8.14	27.83
HR03	2.84	0.65	0.56	1.05	4.11	4.09
HR04	3.76	1.43	1.63	1.06	1.11	3.70
HR05	3.20	15.57	6.04	1.74	0.09	7.89
HR06	8.15	5.36	3.60	4.63	0.61	14.25
HR07	10.78	5.84	1.95	7.37	4.08	5.78
HR08	48.25	2.501	4.91	30.77	20.51	11.65
HR09	2.06	117.60	24.44	1.01	0.77	6.79
HR10	10.77	9.93	2.50	6.83	1.69	3.74
Avg.	10.73	15.99	4.95	6.24	4.56	9.17
		-	5.25			-

Table 4 Results of flow analyses during disposal pit excavation

RLZ	tunnel inflow before pit excavation	tunnel inflow after pit excavation	disposal pit inflow (L/min)										tunnel and disposal pit inflow (L/min)	number of disposal pit of >0.5L/min
			No.1	No.2	No.3	No.4	No.5	No.6	No.7	No.8	No.9	No.10		
HR01	7.10	4.65	0.12	0.35	0.17	0.04	0.46	0.04	0.74	0.45	0.53	0.00	7.55	2
HR02	10.35	8.82	0.12	0.19	0.04	0.02	0.16	0.25	0.28	0.09	0.23	0.27	10.48	0
HR03	2.84	2.04	0.05	0.07	0.08	0.20	0.01	0.00	0.32	0.29	0.00	0.00	3.05	0
HR04	3.76	3.21	0.21	0.02	0.05	0.00	0.01	0.12	0.04	0.09	0.02	0.02	3.79	0
HR05	3.20	2.13	0.06	0.11	0.02	0.20	0.82	0.00	0.00	0.56	0.00	0.00	3.90	2
HR06	8.15	6.55	0.09	0.23	0.11	0.42	0.16	0.64	0.01	0.14	0.02	0.06	8.43	1
HR07	10.78	7.70	0.01	0.01	0.04	0.95	0.11	0.35	0.32	1.15	0.88	0.17	11.69	3
HR08	48.25	38.19	5.54	0.48	1.04	0.71	0.40	1.47	0.78	0.34	0.05	0.01	49.01	5
HR09	2.06	1.57	0.02	0.00	0.06	0.09	0.00	0.00	0.17	0.10	0.09	0.47	2.57	0
HR10	10.77	9.22	0.07	0.19	0.97	0.03	0.14	0.07	0.05	0.04	0.01	0.04	10.83	1
avg.	10.73	8.41	0.27										11.13	total 14

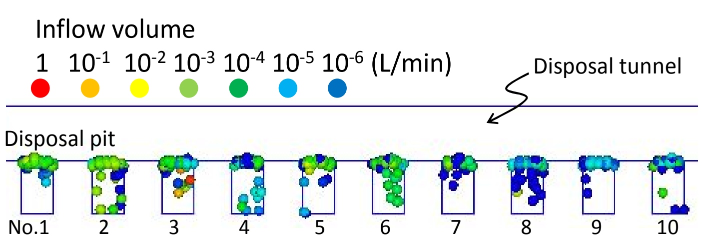


Figure 3 Distribution of disposal pit inflow

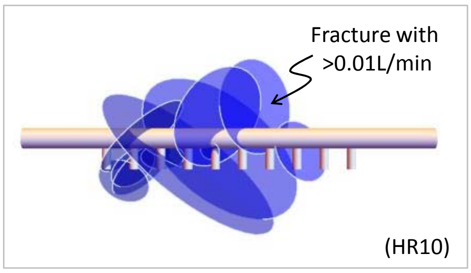


Figure 4 Distribution of fractures intersecting with disposal pit

indicated 10.73L/min. This roughly corresponded with the actual measured value of inflow for 100m of the 350m-level tunnel of Horonobe URL.

Table 4 shows the results of calculations made for the time of disposal pit excavation. The average inflow volume of the disposal pits was 0.27L/min, which varied depending on the realization and disposal pit. This can be said to be the result of inconsistencies in the fractures. For example, Figure 3 shows the distribution of disposal pit inflow locations, and Figure 4 shows the distribution of fractures having a flow volume of 0.01L/min or more that intersects with the disposal pits, for one realization (HR10). In addition to the inflow locations seen from the excavation damaged zone adjacent to the tunnel, groundwater inflow can be seen in places where fractures intersect with disposal pits. The number of disposal pits having an inflow volume per pit of at least 0.5L/min was a maximum of 5 pits /10 pits per realization. A total of 14 of the 100 disposal pits had a value of at least 0.5L/min.

2-4 Changes in inflow volume due to grouting measures

Grouting measures as an inflow control technique for the disposal pits were turned into a model by reducing the permeability within a 1.5m area around the disposal pits that showed an inflow volume of at least 0.1L/min. When creating the model, the permeability coefficient of pipes that go through the area of grout improvement shown in Figure 5, was reduced to 13% for the initial model based on the improvement target value of pre-grouting. As a result of this calculation, the inflow volume to the disposal pits subjected to grouting was reduced by an average of 33%, and the number of disposal pits having inflow volume of 0.1L/min or less was increased from 51 to 76. Figure 6 shows an example of the analytical results. In the No. 2, 3 and 5 pits where grouting was taken, the inflow volume was significantly reduced. However, at No. 4, which was sandwiched between these grouting pits, it can be seen that the inflow volume had increased slightly due to changing groundwater flow paths.

3. Study of groundwater flowing into the disposal pits in the multiple tunnel model

3-1 Modeling the multiple tunnels

Assuming actual disposal panels, the presence or absence of a nearby disposal tunnel, the continuation of fractures into the tunnel, etc., may affect the groundwater inflow to the disposal pits. Therefore, the volume of groundwater flowing into disposal pits was analytically estimated by creating a model of multiple tunnels. When constructing this model, the 10 hydrogeological structure models created in 2-1 were each given 5 parallel disposal tunnels having a

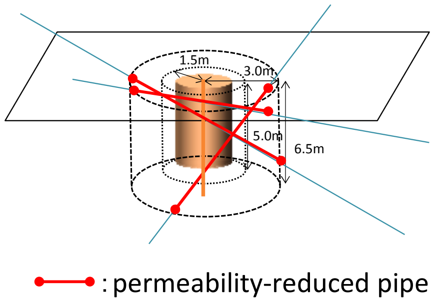


Figure 5 Modeling of grouting around disposal pit

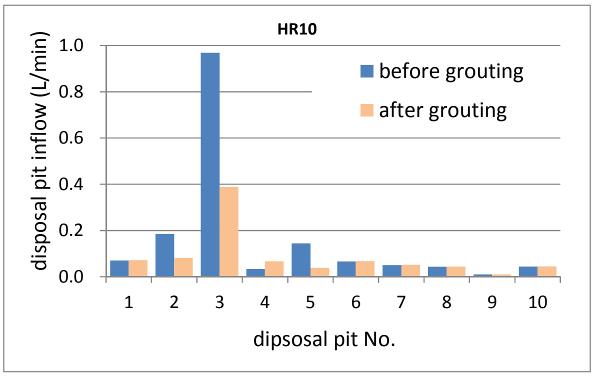


Figure 6 Results of flow analyses before and after grouting

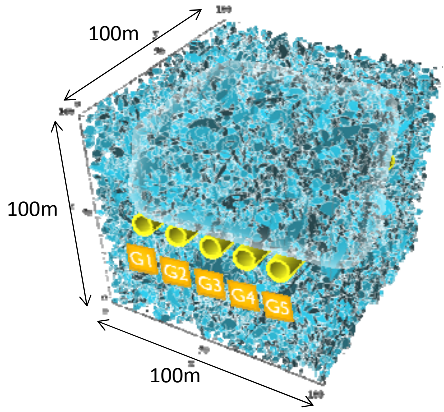


Figure 7 Multiple-tunnel model of discrete fracture network

Table 5 Summary of number of disposal pits with >0.5L/min inflow

RZN	Single-tunnel	Multiple-tunnel			
		G2	G3	G4	Total
HR01	2/10	0/10	0/10	1/10	1/30
HR02	0/10	0/10	0/10	1/10	1/30
HR03	0/10	0/10	0/10	1/10	1/30
HR04	0/10	0/10	0/10	0/10	0/30
HR05	2/10	1/10	1/10	1/10	3/30
HR06	1/10	0/10	0/10	0/10	0/30
HR07	3/10	0/10	3/10	2/10	5/30
HR08	5/10	0/10	6/10	7/10	13/30
HR09	0/10	1/10	0/10	0/10	1/30
HR10	1/10	0/10	0/10	0/10	0/30
Avg. per 100 pits	14.0/100	8.3/100			

diameter of 5.0m and spaced at 12m intervals. The floors of each of these disposal tunnels were given 10 disposal pits having a height of 5m and radius of 1.5m (Figure 7). As was the case with the single tunnel, the plane which orthogonally intersected with the axis of the disposal tunnel became the non-permeable boundary, while other model boundaries had a total head of 350m. It should be noted that the groundwater volume was evaluated using data from the middle 3 of the 5 disposal tunnels (G2 to G4 in Figure 7) in order to evaluate the influence of adjacent disposal tunnels.

3-2 Estimations of amount of groundwater flowing into disposal tunnels and pits in the multiple tunnel models

Flow analyses were conducted at the time of the disposal tunnel excavation, and comparisons were made between the analytical results of the single- and multiple-tunnel models (Table 3). Although variance was seen in each realization, it could be concluded that inflow locations were dispersed when there was an adjacent disposal tunnel. In the multiple-tunnel model, the average inflow volume per disposal tunnel was 5.25L/min, which was only about half the value in the single-tunnel model.

Next, flow analyses were conducted at the time of the disposal pit excavation. Table 5 shows the number of disposal pits with an inflow volume of at least 0.5L/min per pit. Here it can be seen that only 25 disposal pits had a value of at least 0.5L/min of the 300 pits in the multiple-tunnel model, that is, 8.3 pits per 100 pits, about 60% of the number of pits in the single-tunnel model. From these results, we could confirm that the existence of adjacent disposal tunnels or pits helped to greatly reduce the amount of groundwater flowing into disposal tunnels and pits.

3-3 Changes in inflow volume due to grouting measures in multiple tunnel models

Using the multiple-tunnel model of HR08, which was the realization having the greatest volume of inflow during disposal pit excavation, a flow analysis was conducted when grouting measures were implemented. Figure 8 shows 6 disposal pits where the inflow value exceeded 0.5L/min and where grouting as an inflow control technique was conducted in the order of initial inflow volume ((1) to (6) in the figure). As with 2-4, grouting was modeled by reducing the permeability within an area of 1.5m around the target disposal pit, and the flow analysis was conducted. Figure 9 shows the results of the inflow volume reduction by the grouting, and the amount of inflow increase in disposal pits of around the grouting pits, arranged in the order of (1) to (6). Inflow volume decreased in all of the grouting pits, but in the disposal pits of adjacent tunnels, inflow volume increased slightly due to change of

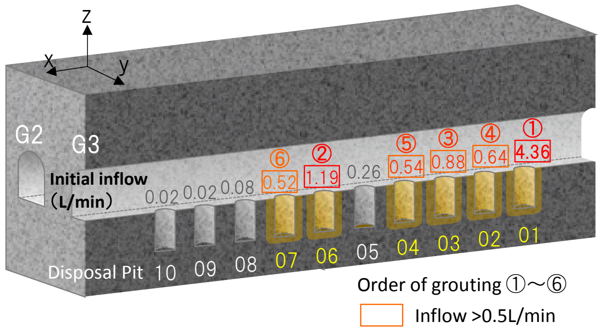


Figure 8 Grouting pits and order of grouting (HR08)

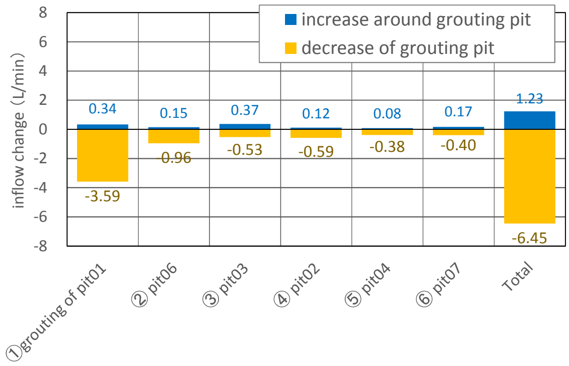


Figure 9 Results of inflow change of disposal pits in the order of grouting

groundwater flow paths. However, overall the amount of inflow reduction in grouting pits was 6.45L/min, while the amount of inflow increase in disposal pits of adjacent tunnels was limited to 1.23L/min, indicating that the grouting measures were effective in reducing the amount of inflow.

4. Concluding remarks

In a rock mass where fractures control permeability, variance in disposal pit inflow due to the distribution of fractures, and the influence of engineering measures on the hydrological fields around disposal tunnels could be quantitatively evaluated with analyses using discrete fracture network models. In addition, by creating a model of multiple disposal tunnels, it was possible to quantitatively evaluate the reduction of inflow volume by the dispersion of inflow locations due to the influence of adjacent tunnels, and the increase in inflow volume resulting from changing groundwater flow paths.

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