STUDY ON PIPING AND EROSION OF BUFFER MATERIAL DURING THE RE-SATURATION PERIOD

Takayuki ABE*[1], Ichizo KOBAYASHI *[2], Masahiro KAWAKUBO*[1], Masataka IMAI*[1], Tomoko ISHII*[1]

*1 Radioactive Waste Management Funding and Research Center
Nichirei Akashicho Bldg. 12F, 6-4, Akashicho, Chuo-ku, Tokyo, 104-0044, Japan
*2 Kajima Corporation
2-19-1, Tobitakyu, Chofu City, Tokyo, 182-0036, Japan

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Abstract

The state transition of buffer material (clay) composing the engineered barrier system (EBS) for the geological disposal of high-level radioactive waste is most intense during the re-saturation period after emplacement into the disposal pit. For evaluating and predicting long-term evolution of buffer material, it is important to grasp the behavior of the buffer material during the re-saturation period. The buffer material has to be maintained within a range of density in order to perform its long-term safety function. However, there is concern that buffer material might flow out by piping and erosion during the re-saturation period. In this study, several laboratory tests for piping and erosion of buffer material during the re-saturation period were conducted with various conditions, e.g., material form, interface condition, liquid type, water flow, and water pressure. As a result, knowledge was obtained on the outflow of buffer material, and on engineering countermeasures.

1. Introduction

The method of geological disposal in Japan consists of multiple barriers combining engineered barriers and natural barriers. For buffer materials constituting the engineered barrier, performance such as suppression of migration of radioactive substances is required, and this performance is brought about by maintaining a predetermined buffer material density. However, at the time of re-saturation, there is a possibility for water channels to form due to the groundwater flowing on the surface of the buffer material, and of the buffer material eroding [1]. If the density of the buffer material greatly decreases due to the erosion, there is a fear that the long-term performance will be affected. Therefore, it is necessary to investigate the phenomenon of piping and erosion of buffer material, and to consider countermeasures to piping and erosion.

In this study, we investigated the piping and erosion phenomenon near the surface of the buffer material when conditions, e.g., material, interface condition, liquid type, water flow, water pressure, are changed, and as a part of countermeasures to piping and erosion of buffer material, an indoor test was conducted to ascertain the countermeasure effect by pre-swelling (a method of swelling the buffer material in advance by the water supply before the test). In this research, as a preliminary step of the full-scale test, a small- scale test using a small cell was carried out in order to investigate the piping and erosion phenomenon by various parameters.

2. Piping and erosion test

In the case of the buffer material block emplacement construction method (hereinafter referred to as the pellet filling method) which is the vertical emplacement of geological disposal, the existence of clearance is expected at the boundary between the buffer material block and the surrounding bedrock. As a current construction method, a method of filling pellets into the clearance area is considered. Therefore, in this study, we investigated the piping and erosion phenomenon on a test system simulating the pellet filling method by indoor test.

2. 1 Test method

A schematic diagram of the test cell and the test image are shown in Fig. 1. We simulated the pellet filling method and tested a case filled with pellets in a small cell and a case filled with half blocks and pellets. The test cell has an inside diameter of 110 mm and a height of 50 mm, and porous disks were arranged at the top and bottom of the cell in order to distribute water from a plane surface. The water flow direction is from the bottom to the top, and the drainage is through a cell provided on the top cover from a slit of 5 mm width provided between the upper lid of the cell and the side ring.

The test cases are shown in Table 1. Pellets were used at 100 wt.% Kunigel V1 combined with

10 to 20 mm of particle size and 1 to 3 mm of particle size examined in a previous study [2]. Blocks were used at 70 wt.% Kunigel V1 and 30 wt.% silica sand. The water flow rate was basically 0.1 L/min with reference to the upper limit value set as required performance of disposal pits such as by SKB and Posiva Company [3]. In order to check the influence of water flow rate, the water flow rate was also measured for cases of 0.01 L/min and 0.001 L/min. We used distilled water, simulated Horonobe groundwater (0.18 M [hereinafter referred to as simulated groundwater]), NaCl (0.5 M), $CaCl_2$ (0.5 M) as liquid type. Water supply was carried out at a constant flow rate from the start of the test. Simulated groundwater was analyzed and simulated groundwater composition collected from 350 m underground in Horonobe. The simulated groundwater composition is shown in Table 2.

2. 2 Test Results and Discussion

Figure 2 shows the piping in the pellet case (P-1 to P-3) with different flow rates using distilled water. In the case of 0.1 L/min and 0.01 L/min, one day later, a water channel was confirmed in both cases. However, the water channel width is thinner at a flow rate of 0.01 L/min than 0.1 L/min. In the case of 0.001 L/min, no water channel was observed until after 210 minutes, and the water pressure increased to 3 MPa of the limit pressure of the cell, so the test was terminated.

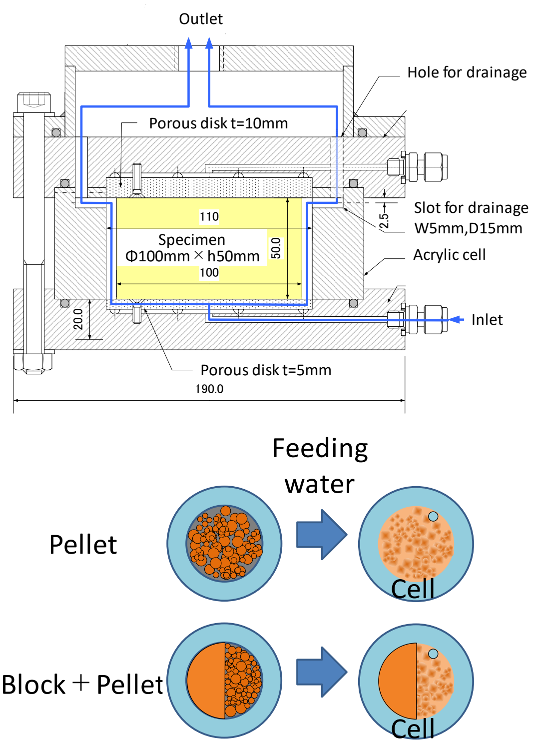


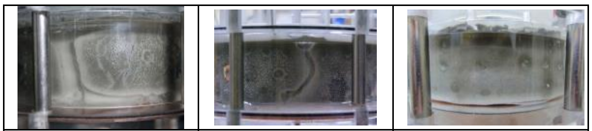
Fig. 1 Schematic diagram of small cell and test image

Table 1 Piping and erosion test case using small cell

Specimen	No.	Flow rate (L/min)	Type of Liquid	Initial dry density (Mg/m^3)	Max injection pressure (MPa)
Pellet	P-1	0.1	Distilled water	1.5	3
	P-2	0.01			
	P-3	0.001			
	P-4	0.1	Simulated groundwater		
	P-5	0.1	NaCl		
	P-6	0.1	$CaCl_2$		
Block＋Pellet	BP-1	0.1	Distilled water	Block：1.6 Pellet：1.5	
	BP-2	0.1	Simulated groundwater		
	BP-3	0.001	NaCl		
	BP-4	0.001	$CaCl_2$		

Table 2 Simulated groundwater composition

Reagent	ppm	Mol/L
NaCl	5,200	8.9E-02
$NaHCO_3$	3,000	3.6E-02
$CaCl_2$	180	1.6E-03
KCl	230	3.1E-03
$MgCl_2$	190	2.0E-03
H_3BO_3	410	6.6E-03



P-1（0.1 L/min）（After 24 hr）	P-2（0.01 L/min）（After 24 hr）	P-3（0.001 L/min）（After 210 minutes）

Fig. 2 Forming situation of piping (distilled water, flow rate)

Fig. 3 shows the piping in the pellet cases (P-1, P-4 to P-6) with the same flow rate and different liquid types. In the case of distilled water, a large amount of buffer material eroded out of the cell after 15 days. In the case of simulated groundwater, one water channel was formed one day later and the width and position did not change much until 16 days later. Even simulated groundwater with 0.18 M was thinner in water channel than in the case of distilled water, and a large amount of buffer material did not erode out of the cell. In the case of NaCl, the shape of the water channel formed after one day did not change much even after 16 days, but deposition of sediment was observed in the water channel. It is thought that this is aggregation of montmorillonite contained in the cushioning material due to the influence of ionic strength and precipitation of silica sand. In the case of $CaCl_2$, one water channel formed after one day and formed a zone like a fracture zone after 16 days. This is because the swelling performance of the buffer material was greatly reduced due to the influence of Ca type in the initial Na type bentonite in addition to the influence of the ionic strength, and the erosion substance became lumpy and easily precipitated in the water. It is inferred that the range to be scoured was expanded in order to change the shape of the water crest by the precipitate.

Figure 4 shows the piping in half block + pellet case (BP - 1 to BP - 4). The flow rate of the NaCl and the $CaCl_2$ was set at 0.001 L/min at which water channel was not generated in the tests of the P cases with different flow rate. In all cases, the piping was confirmed. At the initial stage of flow, a plurality of water crests were formed at the interface between the specimen and the cell, and converged on one water channel, and gradually grew. In all the cases, water channels were formed at the interface between the cell at the pellet side and the cell at the boundary between the block portion and the pellet portion, and were not formed at the interface with the cell on the block side. This is considered to be due to the low density on the pellet side with respect to the block side.

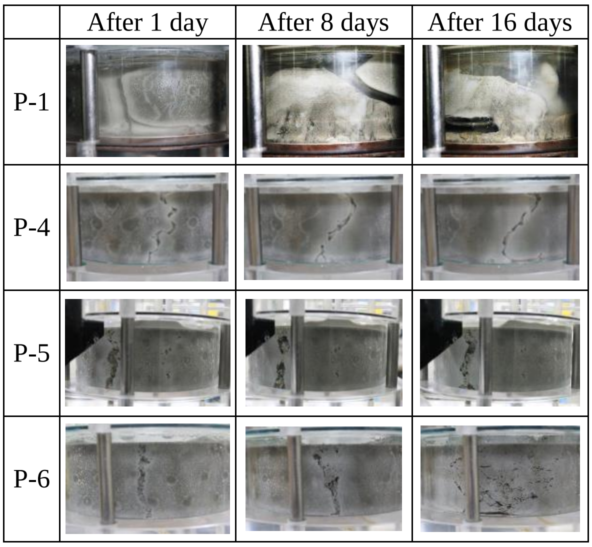


Fig. 3 Forming situation of piping (distilled water, flow rate)

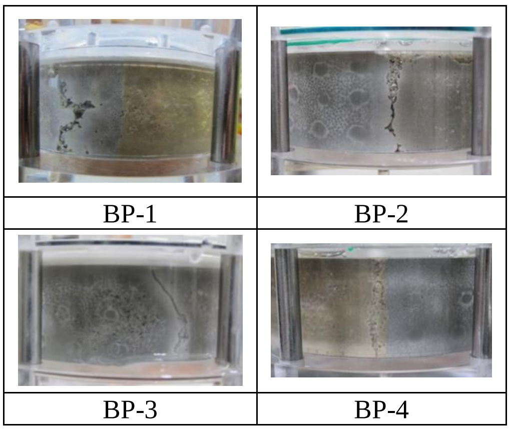


Fig. 4 Status of piping formation (after 1 day)

3. Suppression of piping by pre-swelling

If water is supplied while controlling so that a water channel is not formed in the buffer material and the buffer material swells sufficiently, there will be no gaps at the interface. In that way, even if ground water invades afterwards, it can only infiltrate into the buffer material by diffusion, which is considered to be unconducive to piping. Therefore, in this study, a test for confirming the effect of pre-swelling was performed on the half-block and pellet as described above.

3. 1 Test method

Table 3 shows the test cases of pre-swelling. Simulated groundwater was used as the type of pre-swelling liquid, and the flow rate was 0.1 L/min and 0.01 L/min. In addition, distilled water was used as the liquid type of pre-swelling, and distilled water, NaCl, and $CaCl_2$ were used as the liquid type at the time of the test. The water flow direction was from bottom to top. The method of pre-swelling was as follows: (1) simulated groundwater and distilled water were passed through the specimen after preparation at 0.1 L/min, (2) water stopped when water reached the upper surface of the specimen, (3) and a viewlet was connected to the lower mouth of the specimen. During the pre-swelling, the drain hole of the cell was closed. As a result, the interior of the cell became a diffusion field, so it could swell without forming a water channel. After pre-swelling, it was confirmed by visual inspection that no piping phenomenon occurred. When shifting to piping and erosion tests, drain holes were opened to make the same conditions as the piping and erosion test described above.

3. 2 Test Results and Discussion

Changes over time of water flow pressure and total flow rate of cases 1 and 2 are shown in Fig. 5, and the test situation is shown in Fig. 6. When the

Table 3 Pre-Swelling Test Case

No.	Pre-swelling Liquid type	Liquid type	Flow rate (L/min)	Initial dry density (Mg/m3)	Max injection pressure (MPa)
Case1	Simulated groundwater	Simulated groundwater 0.18 mol/l	0.1	Block : 1.6 Pellet : 1.5	3
Case2			0.01		
Case3	Distilled water	Distilled water	0.1		
Case4		NaCl 0.5 mol/l			
Case5		CaCl2 0.5 mol/l			

flow rate was 0.1 L/min, the water pressure increased to about 1.5 MPa at the beginning of water flow, and breakthrough occurred. Once breakthrough occurred, there was almost no increase in water pressure and a water channel was formed. On the other hand, in the case where the flow rate was 0.01 L/min, a water channel was not formed and the water pressure reached 3 MPa which is the upper limit pressure of the acrylic cell, so the test was terminated. In terms of the test situation, when the flow rate was 0.1 L / min, water was formed in the block part near the pellet part. If the piping is determined only by the magnitude relationship between the water pressure and the swelling pressure of the buffer material, it should occur in the pellet portion where the drying density is small like the above test results. The water channel was formed in the block rather than in the pellet part, because the pellets with low dry density tended to infiltrate during pre-swelling and it was considered that swelling pressure was more likely to be exerted than in the block part.

Changes over time of water flow pressure and total flow rate of cases 3 to 5 are shown in Fig. 7, and the test situation is shown in Fig. 8. In all cases formation of water channel was not confirmed until the water pressure reached 3 MPa, which is the upper limit pressure of acrylic cell. It was found that piping and erosion can be suppressed by pre-swelling the buffer material even if the liquid used is the liquid type with distilled water, NaCl, $CaCl_2$ at 0.1 L/min.

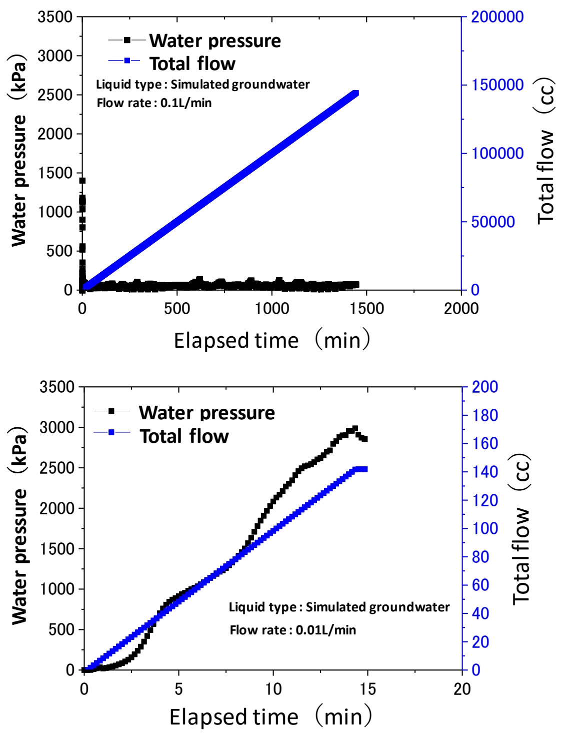


Fig. 5 Changes over time of water flow pressure and total flow rate (Cases 1, 2)

From these facts, it was found that there is a high possibility that piping and erosion can be suppressed by pre-swelling of buffer material. However, it was also revealed that the inhibitory effect is influenced by the ionic strength of the liquid type used for the pre-swelling. From now on it will be necessary to check the ionic strength of the liquid type used for pre-swelling, and the presence or absence of water channels.

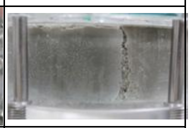
	Before the test	After water supply	Test situation on the side
Case1			
Case2			

Fig. 6 Forming situation of piping (after one day)

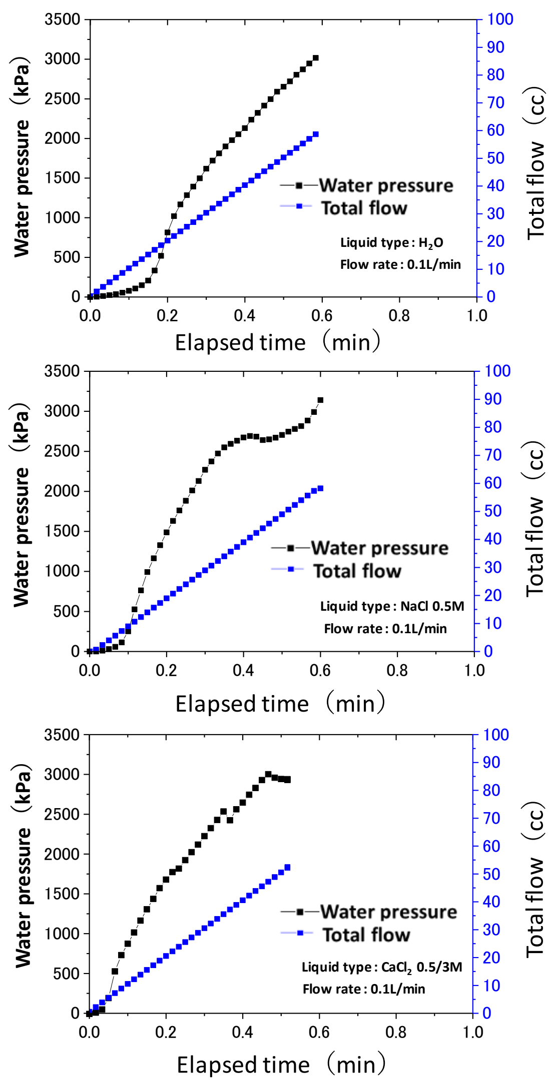


Fig. 7 Changes over time of water flow pressure and total flow rate (Cases 3 to 5)

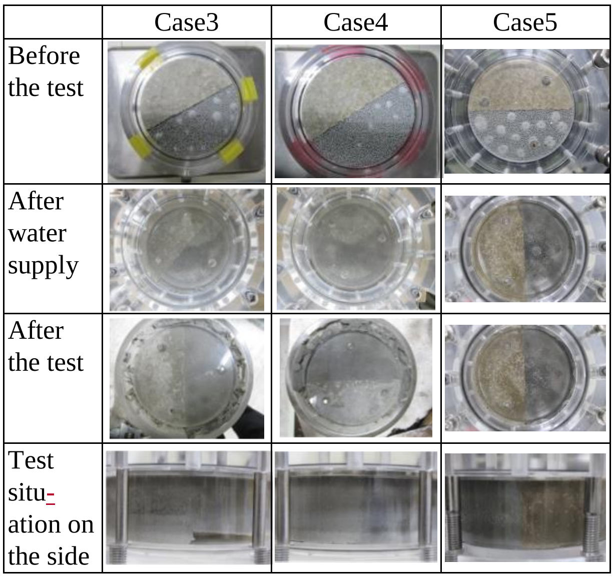


Fig. 8 Status of pre-swelling test (Cases 3 to 5)

4. Summary

We conducted a test using a small acrylic cell for the purpose of grasping the formation condition of water channels in the vicinity of the surface of the buffer material, and the effect of countermeasures against erosion of the buffer material due to pre-swelling. In the test simulating the pellet filling method of the block stationary construction method, formation of water channels was not confirmed if the water flow rate was 0.001 L/min. On the other hand, in the case of NaCl and $CaCl_2$, swelling performance of the buffer material decreased due to ionic strength and Ca type conversion, and phenomena such as precipitation of silica sand and expansion of washing range were observed.

It was also found that pre-swelling may be an effective countermeasure for suppressing water formation. However, in the case of pre-swelling with a liquid type with an ionic strength of 0.18, a water channel was formed, suggesting that the ionic strength of the liquid type used for engineered water supply affects the pre-swelling effect. For that reason, future study is necessary for the condition of piping with the ionic strength of the liquid type used for pre-swelling as a parameter.

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