Demonstration Test of Cavern-Type Disposal Facility and Its Progress-10116

Takahiro Nakajima*, Yoshihiro Akiyama*, Kenji Terada*, Masahiro Negi*
*Radioactive Waste Management Funding and Research Center
1-15-7, Tsukishima, Chuo City, Tokyo, 104-0052, Japan

ABSTRACT

There have been some feasibility studies in Japan on cavern-type disposal facilities for low-level waste (LLW) with relatively high radioactivity mainly generated from power plant decommissioning and for part of transuranic (TRU) waste mainly from spent fuel reprocessing. The facilities in these studies are designed to be constructed in a cavern 50 to 100 meters below ground, and to employ an engineered barrier system (EBS) of a combination of a bentonite low percolation layer and a cement-based layer. In order to advance the research further, a government-commissioned research project named *Demonstration Test of Cavern-Type Disposal Facility* started in fiscal 2005, and since fiscal 2007 a full-scale mock-up test facility has been constructed under an actual subsurface environment.

The main objective of the test is to establish construction methods and procedures which ensure the required quality of the EBS on-site. By fiscal 2008 some component parts of the facility had been constructed in an underground cavern, and the test has so far demonstrated both practicability of the construction and achievement of the required quality. This paper covers the project outline and the test results obtained by the construction of some parts of a bentonite low percolation layer and a cement-based layer.

INTRODUCTION

Classification of radioactive waste in Japan

Radioactive waste is roughly classified into two categories in Japan. One is the high-level radioactive waste that contains fission products separated from spent fuel during the reprocessing. The other is low-level radioactive waste. The low-level radioactive waste is classified by the difference of generation and the level of radioactivity.

There are four disposal methods for radioactive waste, depending on the Radiation level. They are as follows:

- Near Surface Disposal without Engineered Barriers
  - Near surface trench disposal
- Near Surface Disposal with Engineered Barriers
  - Near surface pit disposal
- Intermediate Depth Disposal
  - Disposal at a depth deep enough (50 – 100 meters below the surface) to avoid overlap with general underground use

- Geological disposal
  - Disposal in geological formations deeper than 300 meters below the surface

These disposal methods are shown in Figure 1.

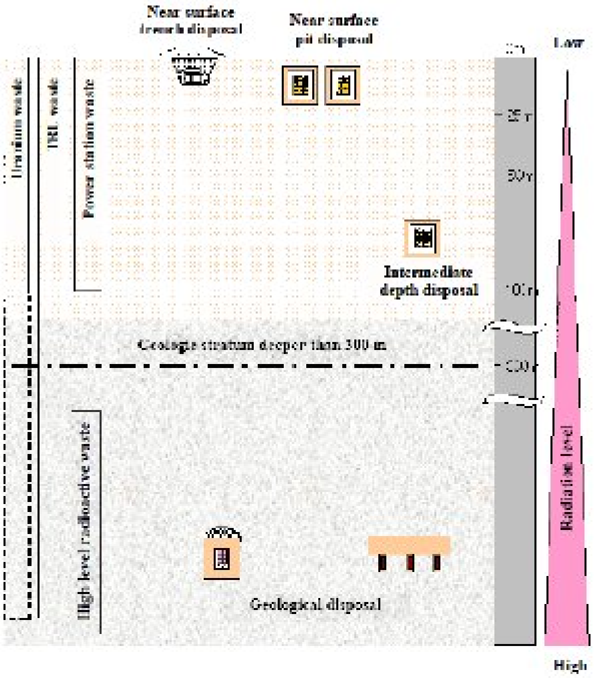


Fig.1 Categorization of radioactive waste disposal methods in Japan [1]

The concept of intermediate depth disposal system

The facilities of intermediate depth disposal are constructed 50 meters or deeper below surface, therefore, requiring designing of construction methods unlike the construction of near surface disposal facilities [2]. The concept of the intermediate depth disposal with engineered barriers is shown in Figure 2

The engineered barrier system works to reduce migration of radioactive substances from disposal facilities through groundwater flow. Main engineered barriers are as follows:

- The low percolation layer of bentonite material which reduces groundwater inflow through facilities
- The low diffusiveness layer of cement material inside the low percolation layer, and which contains any groundwater that seeps from the inner diffusion area.

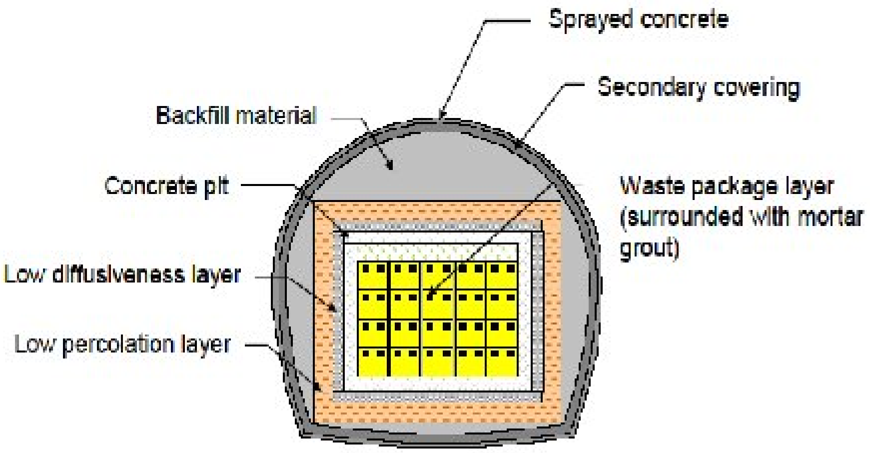


Fig.2 Vertical sectional view of disposal cavity [3]

Japan Nuclear Fuel Limited (JNFL), as a part of study on intermediate depth disposal of waste from power reactors, conducted research on geological features, underground water and ground from 2002 to 2006 at the site of uranium enrichment and waste disposal facilities [].

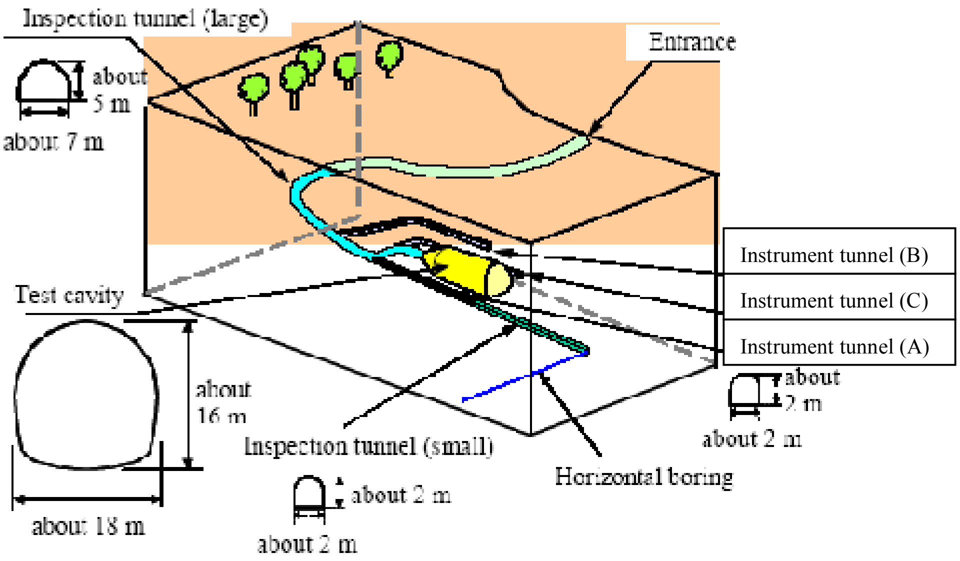


Fig.3 Inspection tunnel for the site investigation [5]

For the site investigation, a tunnel was excavated below the southern terrace (elevation of 30 - 40 meters). An image of the site investigation procedure is shown in Figure 3.

As a preliminary step, basic test data on intermediate depth disposal with engineered barriers has been mainly obtained by laboratory scale tests which were carried out to study waste disposal from power reactors decommissioning, trans-uranium waste, etc. As a next step, a demonstration test of intermediate depth disposal facilities is required to choose and clarify construction methods for an engineered barrier system.

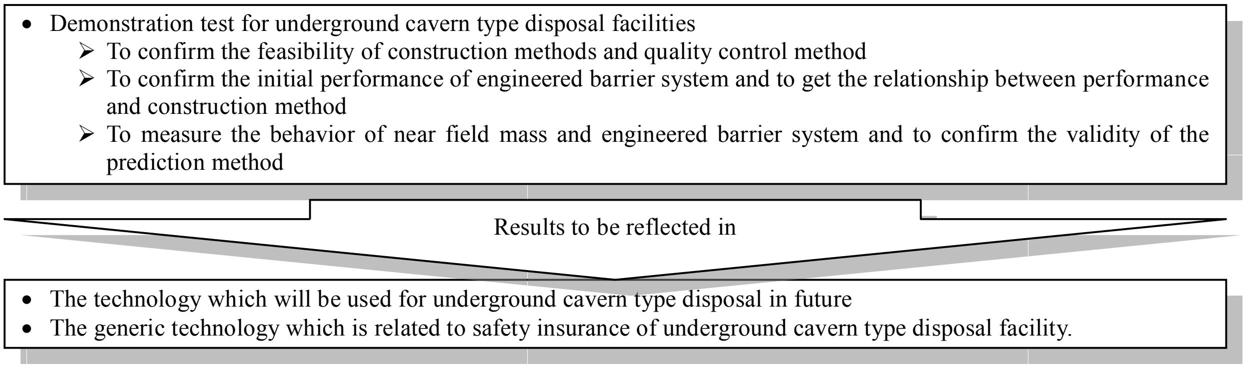
DEMONSTRATION TEST FOR CAVERN TYPE DISPOSAL FACILITY

Objectives

The demonstration test for cavern type disposal facility aims to construct a full scale engineered barrier system in-situ underground cavern. This test consists of three parts, which are construction test, performance test and behavior measurement.

The construction test is carried out in the test cavity of JNFL to clarify construction methods of the engineered barrier by measuring accuracy of construction component, required time for construction, etc. The performance test is carried out at each stage of construction, and initial performance of engineered barrier about nuclide confinement is clarified by in-situ testing or laboratory tests using samples from the test area. The behavior measurement is carried out to measure the mechanical and hydrological behavior of test facilities and near field rock mass during and after construction of the engineered barrier.

The rationale for the demonstration test for cavern type disposal facility is shown in Figure 4.



- Demonstration test for underground cavern type disposal facilities
  - To confirm the feasibility of construction methods and quality control method
  - To confirm the initial performance of engineered barrier system and to get the relationship between performance and construction method
  - To measure the behavior of near field mass and engineered barrier system and to confirm the validity of the prediction method

Results to be reflected in

- The technology which will be used for underground cavern type disposal in future
- The generic technology which is related to safety insurance of underground cavern type disposal facility.

Fig. 4 Rationale for demonstration test for cavern type disposal facility [6]

Testing items

The test is the first of its kind in constructing in a cavern in Japan.

The performance of engineered barrier system depends on the construction method.

It is necessary that the behavior of each engineered barrier is evaluated for safety.

Technical points to be verified are:

Confirmation of appropriate construction method and procedure,

Establishment of testing methods and performance evaluation of engineered barrier system

Establishment of behavior measurement methods

Prediction of behavior for engineered barrier system and near field surrounding rock mass.

Accordingly, the test items include a construction test, a performance test and an engineered barrier system/ near field rock behavior measurement. The construction test is divided into low percolation layer (buffer), concrete pit, low diffusiveness (diffusion) layer, filler and backfill by construction material procedure, etc. These main contents are shown in Table 1.

Table 1. Testing items and contents [6]

Testing items	Main contents
1.Construction test ● Buffer ● Concrete Pit, Low Diffusion Layer ● Gap filling ● Back filling	By constructing the engineered barrier system in full scale under actual underground environment, applicability of construction method, construction procedure, and construction technique are clarified. At every component which constitutes disposal facility, multiple construction methods and construction techniques, are applied. Accuracy and efficiency of the synthetic facilities are clarified.
2.Performance test	Mechanical stability of engineered barrier system is clarified. Performance required in the safety evaluation of the nuclide confinement just after the construction (initial performance) is clarified.
3.Behavior measurement ● Engineered barrier system ● Near field rock	Mechanical stability of constructed engineered barrier system is measured. Mechanical and hydrological behavior of near field rock is measured.

Testing condition for the engineered barrier system

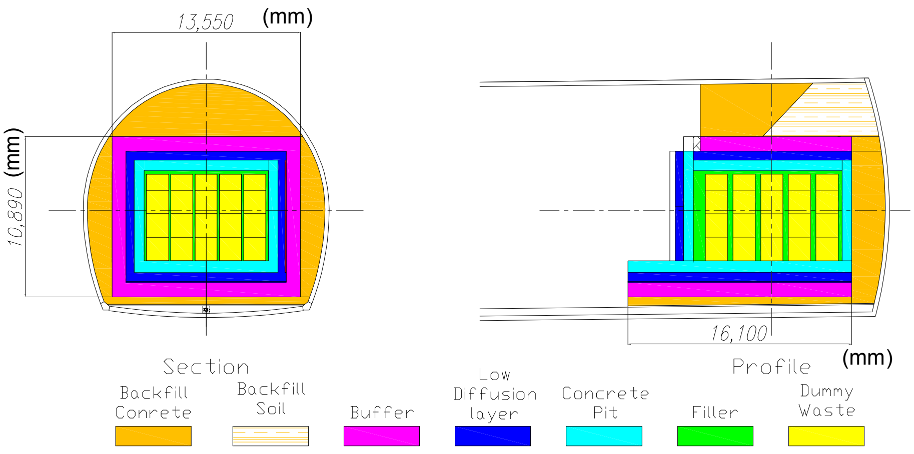


Fig. 5 Design of engineered barrier system [6]

Disposal facilities simulated in the demonstration test are to include various engineered barrier systems. After backfilling the cavern by cement based material, buffer of bentonite, low diffusion layer which consists of cement material, concrete pits, the filler and dummy waste are constructed. The design of the engineered barriers is shown in Figure 5. The function expected in each barrier is shown in Table 2.

Table 2 Function of engineered barrier system [6]

Component / Function	Engineered barrier system				
	Filler (Mortar grout)	Low Diffusion Layer	Concrete Pit	Buffer	Backfill
Safety in construction work and operation	+	+	++	+	++
Sorption of nuclide	+	+	+	+	+
Low water permeability	+	+	+	++	+
Repression of diffusion	+	++	+	+	
Long term stability	+	+	+	+	+

++ : Main function, +: Expected function caused by the main function

In addition, the initial performance was set based on the function of the buffer and the low diffusion layer. Testing conditions and main contents are shown in Table 3.

Table 3 Testing conditions and main contents [6]

Component of EBS	Set value of performance	Testing condition	Main contents
Buffer	**Permeability:** 5×10^{-13}m/sec	**Material:** Bentonite(Kunigel GX) **Dry clay density:** 1.6Mg/m^3	**Construction method:** (Bottom area)In-situ compaction by large vibration roller. (Narrow side area, Upper area)In-situ compaction by small vibration roller, or construction using big bentonite block **Quality control:** Material, Construction method, etc.
Low Diffusion Layer	**Diffusion coefficient:** 1×10^{-12}m^2/sec	In-situ construction **Binder:** Low heat Portland cement and fly-ash **Water binder rate:** W/B=45%	**Crack control:** Effect by carbon fiber reinforcement. **Quality control:** Material, Construction method, etc.

CURRENT STATUS OF THE DEMONSTRATION TEST OF CAVERN TYPE DISPOSAL FACILITY

Construction test of buffer at bottom part

Testing conditions

In the construction test of the bottom part of the buffer, this part was compacted in-situ by large vibrating roller. Bentonite material was used for the buffer material. The density of buffer was set to 1.6 Mg/m^3. Through the construction test of the bottom part of the buffer, the construction method, workability, and required quality were clarified.

In FY2007, the bottom part of the buffer (thickness = 0.10m) was constructed.

In FY2008, the bottom part of the buffer (thickness = 0.90m) was constructed each a layer (thickness of the layer = 0.10m), and the performance of buffer was clarified.

The construction method was selected in each area by construction conditions. Bentonite was mainly compacted by using a large vibrating roller. Because the width of side area was as narrow as 1.0 meter, bentonite was compacted by using a small vibrating roller. The construction areas are shown in Figure 6. The construction machines used at each area are shown in Table 4.

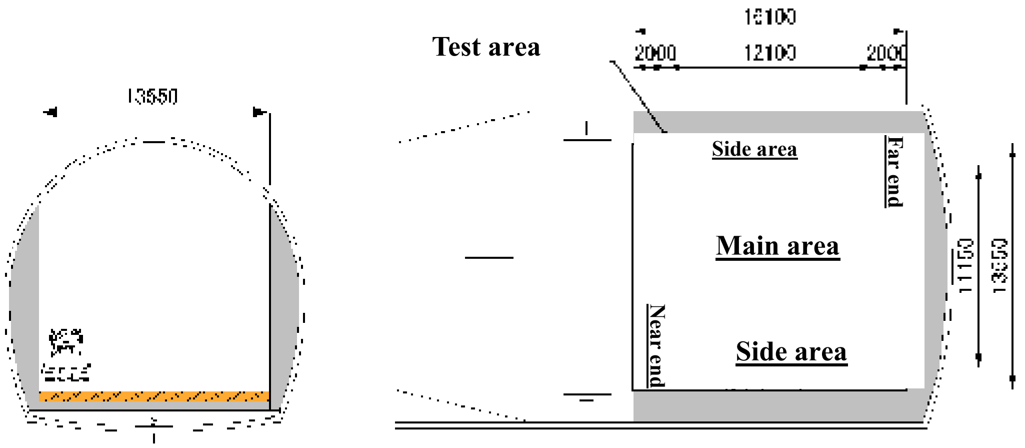


Fig. 6 Construction area[6]

Table 4. Principal construction machines

Step	Area	Machine		
		Type	Size (mm)	Weight (ton)
Spread	Except far end	Asphalt finisher	6,247x2,500x3,780	21.5
Compaction	Side Near end, Far end	Small vibrating roller	1,500x850x1,200	1.5
	Main(1st to 4th layer)	Large vibrating roller	5,808x2,250x2,972	11.0
	Main(5th to 10th layer)		6,250x2,530x2,910	19.4

Construction procedure

Water was added to Bentonite (Kunigel GX), with the target value of water content set from 19% to 23 % (mean 21%). The property of Kunigel GX is shown in table 5.

Table 5 Standard value of the material [7]

Test item	Standard value
Grain diameter size	Maximum 10mm
Water content	Under 10%
Plastic limit test	Under 30%
Methylemn blue adsorbent value	Over 63 mmol / 100g (45%)
Swelling test	Over 10 ml / 2g

The construction procedure is as follows:

1) At far end area (width approximately 2m), the bentonite was spread by manpower and mainly compacted by small vibrating roller. Manpower compaction using tamping rammer or vibrating compactor was tested in a few parts.
2) At main area and side areas, the bentonite was spread by an asphalt finisher. The width of the spreading lane was approximately 4.5m.
3) At the side and near end areas (approx. 2m width each), compaction was carried out by small roller.
4) Primary compaction was carried out by large vibrating roller. At this step, non-vibrating compaction was carried out in order to avoid destruction by strong vibration. The number of primary compaction times was different each a layer.
5) Main compaction was carried out by vibrating roller. The number of main compaction times was approximately four. The number of main compaction times increased by the result of measurement of dry density.

Figures 7, 8, and 9 shows the spreading and compaction process described above.

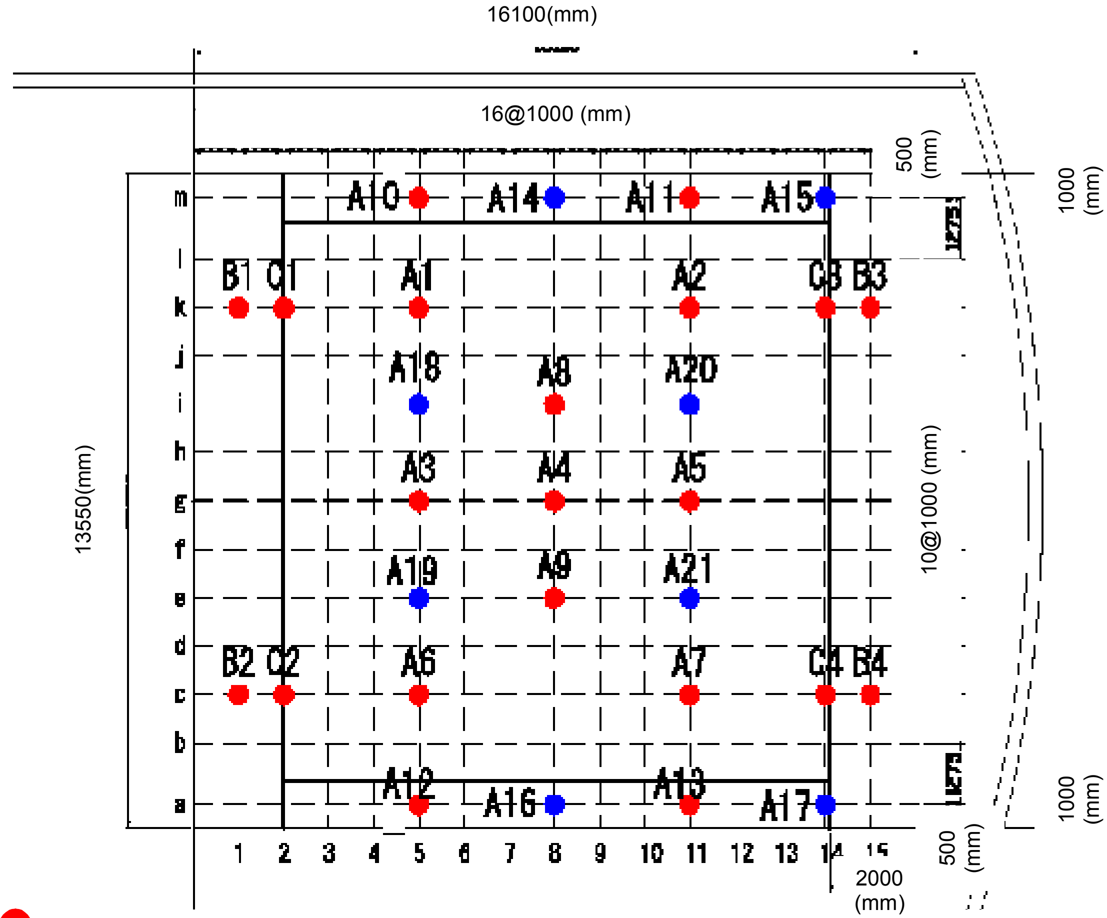
Fig. 7 Spreading by Asphalt Finisher

Fig. 8 Compaction by large vibrating roller at main area

Construction test results

After the construction test for each layer, the low percolation layer density was confirmed by core sampling. The density was calculated by weight and length of the core. The positions of sampling are shown in Figure 10. The sampling positions are divided into the main area, side area, far end area, near end area and its boundary.

Fig. 9 Compaction by small vibrating roller at side areas



🔴 : Core sampling point

🔵 : Additional core sampling point (after 7th layer)

Fig. 10 Positions at core sampling for dry density

The dry density histogram for all sampling cores is shown in Figure 11 below. The target value of dry density is set from 1.5 Mg/m^3 to 1.7 Mg/m^3. The mean is set 1.6 Mg/m^3. The results are as follows.

- Number of cores exceeding the upper limit is 12 (5% of cores).
- Number of cores exceeding the lower limit is 0 (0% of cores).

Therefore 95% of the samples are within the density target value. This result is useful for quality control at future construction processes.

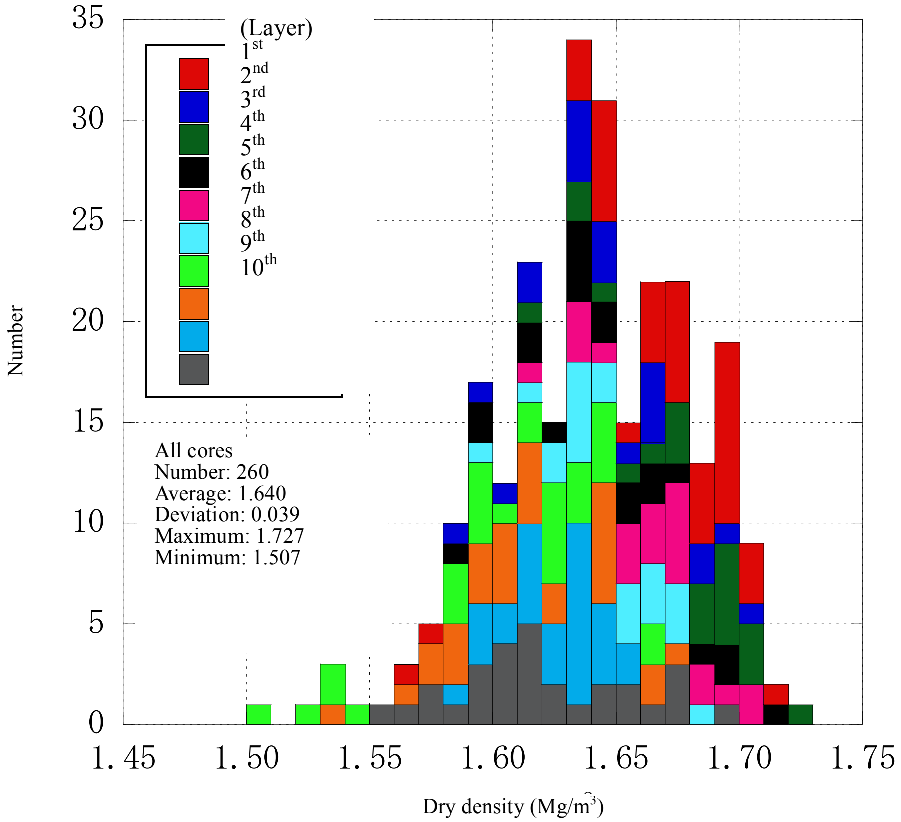


Fig. 11 Dry density histogram (All cores)

A study of suitable construction procedure and methods for bentonite compaction was performed in this test. The results are shown in Table 6, and Figures12 and 13.

In this study, dry density value was estimated by bentonite surface level surveying data.

- The suitable number of primary compaction by 19ton and 11ton size large vibrating roller is 4 times.
- The suitable number of main compaction by 19ton size large vibrating roller is 2 times.
- The suitable number of main compaction by 11ton size large vibrating roller is 4 times.

Table 6. Vibrating roller test results

Case#	Layer	Using machine				Dry density(Mg/m^3)
		Primary compaction		Main compaction		By cores
		19ton size	11ton size	19ton size	11ton size	
0	1st	8		6		1.669
1	2nd	4		4		1.645
2	3rd	4		4		1.678
3	4th	4		2		1.646
4	5th		4		6	1.665
5	6th		4		4	1.648
6	7th		4		4	1.605
	8th		4		4	1.614
	9th		4		4	1.625
	10th		4		4	1.621

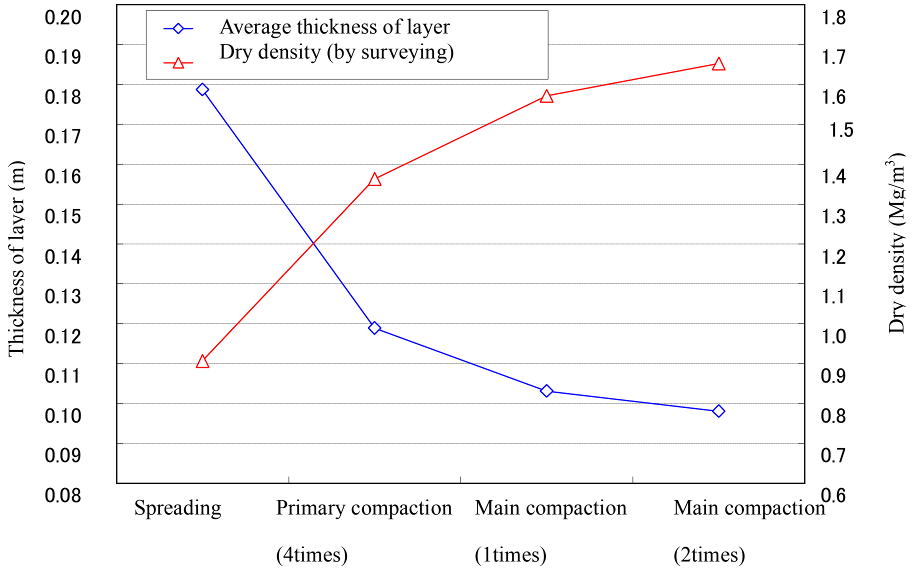


Fig. 12 Relationship for number of compaction and dry density (4th layer by 19ton vibrating roller)

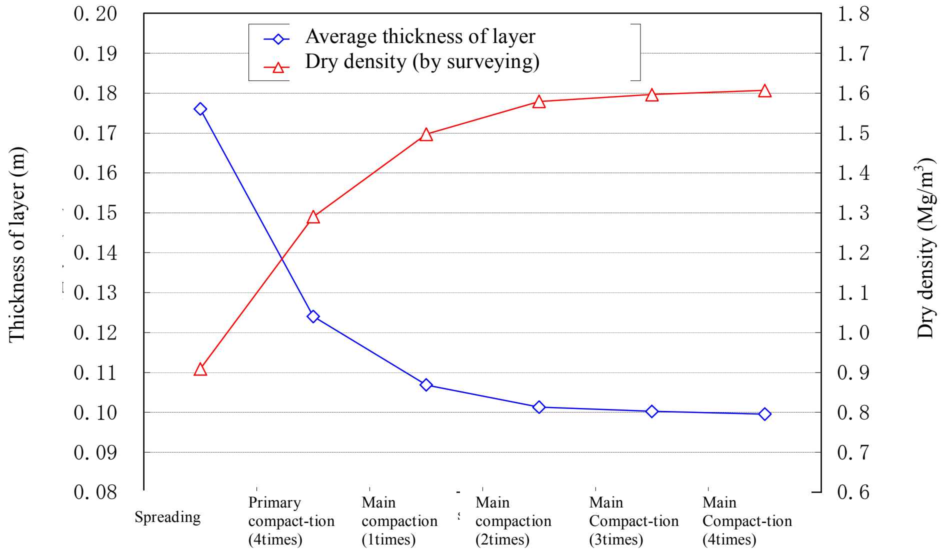


Fig. 13 Relationship for number of compaction and dry density (7th layer by 11ton vibrating roller)

Construction test of a cement-based layer

After the construction of a bentonite buffer was completed at the bottom of the facility, a low-diffusion layer made of self-compacting mortar (SCM) was constructed on the buffer. Subsequently, a concrete pit base and walls made of reinforced self-compacting concrete (SCC) were on the low-diffusion layer. To prevent water seepage, covering the surface of the buffer with a waterproof sheet was originally planned. But in an attempt to simplify the procedure, the mortar was placed directly on the bentonite. During placement of the mortar there was a significant lowering of the fluidity and thixotropic stiffening of the surface, as shown in Figure 14, which consequently required substantial compaction with the help of concrete vibrators. Interaction at the interface between the mortar and the bentonite will be examined by taking core samples. After placement of the 60-cm-high mortar layer the whole surface was lightly trowelled to an even finish and treated with a retarder for the preparation of the concrete joint.

Fig. 14 Mortar placed directly on bentonite

The concrete pit base, with a height of 80 cm, was placed on the mortar layer, and the concrete pit walls, with a height of 6.8 m and a thickness of 70 cm, were built on the concrete base. The concrete had relatively good fluidity during its placement. However, light vibrating compaction and earliest possible curing were needed to minimize the risk of plastic settlement cracking above the reinforcing bars and of early shrinkage cracking by moisture evaporation. Figure 15 shows a full view of the test facility with the concrete pit walls built on three sides.

Fig. 15 Test facility as of March 2009

Mix design of SCM and SCC

The primary requirement for the cement-based layer is low-diffusivity. Additionally, structural and radiation safety during construction and operation, radionuclide sorption capability, low-permeability, and long-term structural and chemical stability are also required. To satisfy these requirements, the material used for the cement-based layer should have the properties of:

- being dense in pore structure,
- being crack controlled,
- being self-compactable and
- being chemically stable.

Self-compacting material that is able to flow under its own weight and fill all spaces without the need for vibration is applied in order to decrease the possibility of human error and to increase the quality of the structure. To avoid temperature rise during hydration and to densify the hardened material after hydration, low-heat portland cement (LHC) and fly ash (FA) are used as binders, and the water-binder ratio (W/B) is set to 45%. An expansion agent (EA) is also used to compensate for shrinkage and improve crack resistance. The mix proportion of SCM and SCC specified through mix design is shown in Table 7.

Table 7 Specified mix of SCM and SCC

	SF (cm)	Air (%)	Constituent materials (kg/m^3)							
			W	Powder				S	G	SP (%)
				Binder			LS			
				C	FA	EA				
SCM	65	2.5	230	338	153	20	307	1199	0	0.6
SCC	65	2.5	160	229	107	20	249	820	780	0.8

SF: slump-flow, W: water, C: cement (LHC), FA: fly-ash, EA: expansion agent, LS: limestone powder, S: fine aggregate (limestone sand), G: coarse aggregate (crushed limestone), SP: superplasticizer

Diffusion Coefficient of SCM

The diffusive property of the material is represented by its diffusion coefficient. In this test an effective diffusivity of tritiated water (HTO) in the mortar was measured by a through-diffusion experiment. The porosity of the material was also measured by the mercury intrusion technique. Measurements have been performed under varying conditions, as shown in Table 8. The test results that have been obtained so far are shown in Figures 16 and 17.

Table 8 Conditions of test specimens

	Test no.	W/B (%)	LS/B (%)	Air content (%)	Slump-flow (cm)
Base	#1	45	60	2.5	60
High W/B	#2	50	60	2.5	60
High air	#6	45	60	4.0	60
	#7	45	60	6.0	60
High porosity	#10	60	60	n/a	n/a
	#11	75	60	n/a	n/a
	#12	90	60	n/a	n/a

Figure 16 shows the relationship between the water-binder ratio (W/B) and effective diffusion coefficient (*De*). The white circle and the black circle markers stand for short-term (the first three months) and long-term (one year following) measurement values, respectively. The *De* shows a higher value as the W/B is higher, but it decreases with time and drops below 1E-12m^2/s within one year.

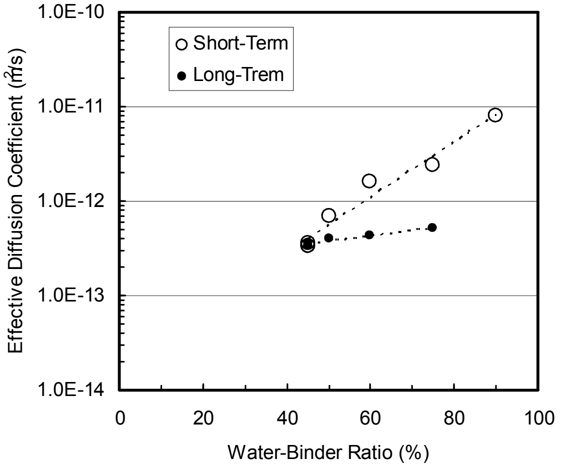


Fig. 16 Relationship between W/B and *De*

Figure 17 shows the relationship between total porosity and effective diffusion coefficient (*De*). Similarly, the white and the black markers stand for short- and long-term measurement values, respectively. As is the case with the above-mentioned relationship, the *De* increases with an increase of the porosity, but becomes lower in the long term.

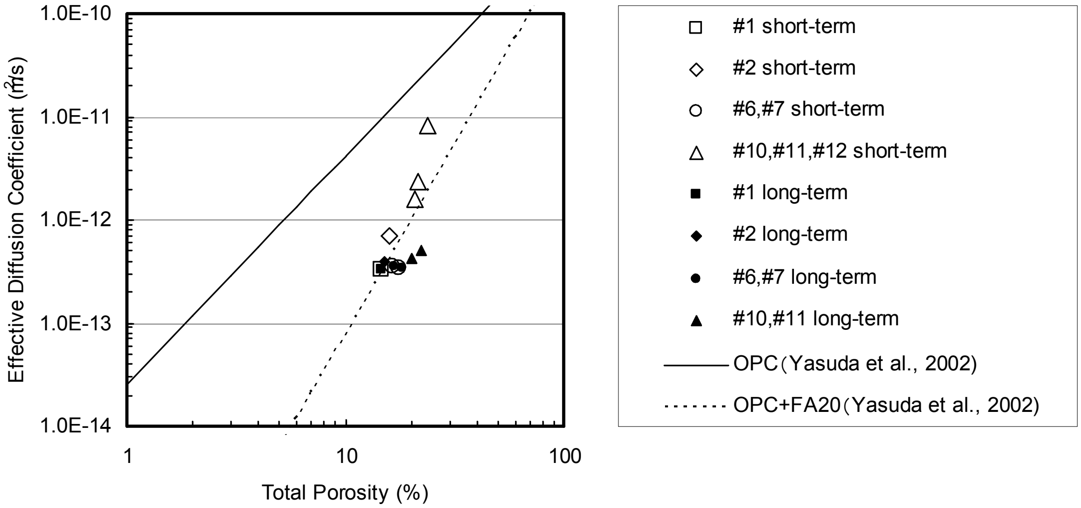


Fig. 17 Relationship between porosity and *De*

It is presumed that the decrease of the De with time results from pore structural change of the material because the total porosity has not changed throughout the experiment. The target value of diffusion coefficient is 1E-12 m^2/s or less at the time of construction completion, which is based on a safety assessment. The test results satisfy it under varying conditions on a long-term basis. Consequently, the mix proportion specified here is satisfactory to the required low-diffusivity on the premise that appropriate compaction and curing should be done. The diffusion test of core samples taken from the low-diffusion layer cast on-site is ongoing, and the results will be compiled later.

Acknowledgments

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