LESSONS LEARNT FROM STAGED DRY RUN OF PERFORMANCE ASSESSMENT AND REPOSITORY DESIGN

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Abstract

Nuclear Waste Management Organization of Japan (NUMO) has proceeded with repository siting, since 2002, based on an "open solicitation procedure". While waiting for volunteer municipalities and having no specific site geological information, NUMO has been preparing for expected assessments and designs at the investigation stage. One of the efforts for preparation is the dry run using hypothetical site information. This paper introduces lessons learnt through this dry run.

Introduction

Nuclear Waste Management Organization of Japan (NUMO), the implementer of Japanese HLW geological disposal, has proceeded with repository siting, since 2002, based on an "open solicitation procedure". And it proposes stepwise investigations to find the final repository: the literature survey (LS) stage, the preliminary investigation (PI) stage and the detailed investigation (DI) stage. While waiting for volunteer municipalities and having no specific site geological information, NUMO has been preparing for expected assessments and designs at these investigation stages. One of the efforts is a dry run using hypothetical site information as a hands-on training mainly for safety assessment and repository designing. It does not only train NUMO staff but also brings various suggestions to the investigation planning and R&D strategy. And dry runs of the hypothetical sites of various geoenvironment such as mountainous site, costal site, crystalline rock, sedimentary rock etc. also enable us to brainstorm the way to build a safety case and a repository concept for generic and specific sites.

This paper shows suggestions to investigations and further R&D from the viewpoint of designing panel layout. The design of panel layout is one of the most important decision-making processes at the early stage of the repository designing because the location of panel directly affects the decision of locations of the following investigations. Especially the decision of panel layout in the surface-based investigation stage is very important, since the change of the location of panel after the detailed investigation stage using the underground facility would be extremely inefficient and would cause significant environmental disturbance.

Firstly, we briefly introduce the method of design of panel layout. And then, it is applied to the hypothetical site based on the stepwise dataset that corresponds to the NUMO stepwise approach of repository siting. And finally, suggestions to investigations and further R&D are presented through the discussion. In the dry run, we create hypothetical site dataset by modifying a set of investigations of an actual civil engineering project.

Method for design of panel layout

The method of repository designing is fundamentally based on the JNC second progress report (hereinafter the H12 report) (JNC, 2000), and the practicality is taken into account from the implementer's viewpoint. The main elements in designing panel layout are location, depth and size of panels (Table 1).

Table 1. **Main elements and methods for design of panel layout**

Main elements of panel layout	Basis of decision making	Method
Location	Groundwater travel time to the biosphere	A groundwater flow analysis
Depth	Tunnel stability	A three-dimensional elasto-plastic analysis (same as the H12 report)
	Temperature	An analysis of heat conduction
Size	A ratio of volume of suitable domain of the host rock	Rock classification

In the H12 report, the location of a panel was given. However, we need to determine the suitable location in an application area in a volunteer municipality in practice. Although political and social aspects may strongly affect the location of repository including the panel layout, we should show the strategy to determine the suitable location from the technical viewpoint. The panel should be located at the area where the groundwater travel time to the biosphere is expected to be relatively large, because groundwater scenario is one of the most important scenarios in the safety assessment.

On the other hand, the depth of the panel is determined from both tunnel stability and thermal constraint of up to one hundred degrees in centigrade in buffer materials following the H12 report, under the legal constraint of below 300 m in depth. Tunnel stability is estimated by a three-dimensional elasto-plastic analysis using the finite element method based on the H12 report, where support systems are not considered. The groundwater travel time will be also taken into consideration.

The panel size in the H12 report was restricted only by the number of vitrified wastes, waste package pitch, and disposal tunnel spacing because of the assumption of the homogeneity of the host rock. In practice, however, the host rock must be heterogeneous and there would be domains not suitable for the disposal, which means the panel size is influenced also by the ratio of volume of suitable domain to the total volume of the host rock. In this paper, the following equation is proposed to estimate the size of the panel.

$$A=A_0/r$$

where A is the total horizontal area of the panel, A_0 is the area in case the host rock is perfectly suitable (same as the H12 report), r is the ratio of the volume of suitable domain to the total volume of the host rock. In this paper, the rock classification widely used in Japan is adopted to identify the suitable/unsuitable domain for the repository; it is assumed in the dry run that CH class rock (hard) is suitable and that CM class rock (slightly soft) is unsuitable.

Geo-environment of hypothetical site

The hypothetical site was assumed to be located at a steep mountainous area. The potential repository area of 7 km × 3 km was given in the site. The tomography and the geology in and around the potential area are shown in Figure 1. And the locations of the main investigations such as borehole investigations and geophysical surveys are also displayed. It can be seen that the survey lines and boreholes were located in almost a straight line. These restrictions on the locations of the investigations were caused due to the fact that the hypothetical site was based on the actual civil engineering project site. Since the strategy of the investigations of the project was different from that of HLW disposal in principle, we slightly modified the order of the investigations.

Figure 1. **Geological map (DI) and investigation points in and around the hypothetical potential area**

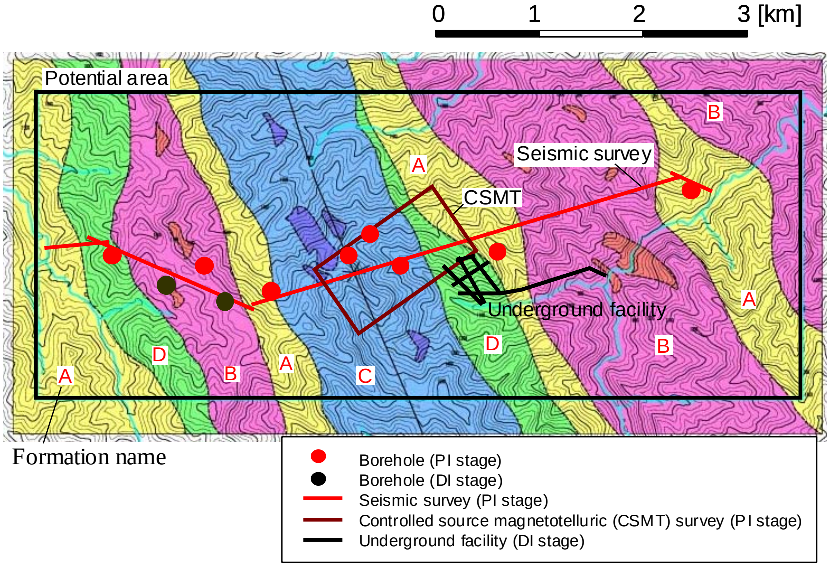


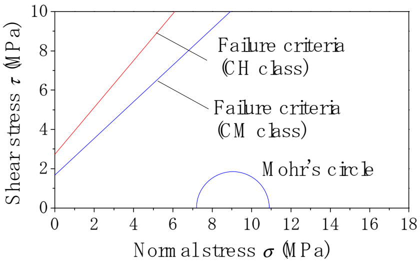
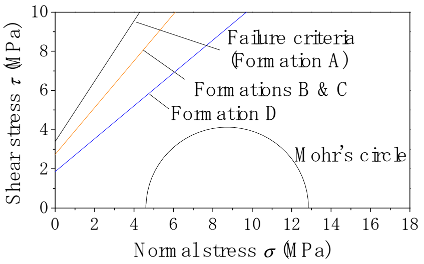
Table 2 shows the main investigation items and the results in the PI stage and the DI stage that are considered to strongly affect the panel layout. The investigations in the PI stage included surface exploration, geophysical surveys, borehole investigations (BTV, Lugion tests, rock stress measurement by sleeve fracturing method) and laboratory tests using the core samples. On the other hand, the investigations in the DI stage were mainly conducted in the underground facility including investigations of cutting face, plate loading tests and borehole investigations (short-distance permeability tests and rock stress measurement by overcoring method).

According to the estimated geo-environment, main differences between the PI stage and the DI stage were existence of faults and rock mechanical properties including rock class, initial rock stress and failure criteria. No fault was identified in the PI stage, while two faults, F1 fault and F2 fault, were detected by means of the investigation of cutting face of the underground facility in the DI stage. The faults were so large as to be avoided for the repository panel, although their continuities were so poor as not to outcrop to the ground surface.

Regarding to the rock classification, the ratio of the volume of CH class rock to that of CM class rock was 85% to 15% in the PI stage, while the ratio in the DI stage was 100% to 0%. It was considered to be due to the uncertainty of core investigation. In terms of the initial rock stress, the overcoring method conducted in the DI stage was considered to be more accurate than the sleeve fracturing method conducted in the PI stage. The main difference of the initial rock stress between two stages was that the deviator stress estimated in the DI stage was larger than that estimated in the PI stage. On estimating the failure criteria, the host rock was classified into CH class rock and CM class rock according to the rock classification in the PI stage, while that was classified into formations A, B, C and D in the DI stage. It was because the failure criteria were not considered to depend highly on the formations in the PI stage. Therefore, rearrangement of the uniaxial tests in PI stage was performed in addition to the rock shear tests in order to obtain the failure criteria of the formations in the DI stage. As the results, the formation A was stronger than the average of the CH class rock and the formation D was slightly weaker than the average of the CM class rock.

On the other hand, regarding to the hydraulic properties, there was no large difference between two stages, owing to the limited amount of data obtained in the DI stage. In practice, however, we should have more detailed investigations on hydrogeology in the DI stage since the range of hydraulic conductivity available in a Lugion test is limited.

Table 2. **Main dataset at each stage**

	Preliminary investigation (PI) stage	**Detailed investigation (DI) stage**
Main investigation items	• Surface exploration • Geophysical survey – Airborne EM survey – Seismic survey – CSMT survey • Borehole investigation (8 boreholes) – Fracture distribution (BTV) – Hydraulic conductivity (Lugion test) – Rock stress (sleeve fracturing method) • Laboratory test – Deformation and strength properties (uniaxial test)	• Borehole investigation from the surface (2 boreholes) • Investigations using the underground facility – Investigation of cutting face – Borehole investigation (13 boreholes) • Hydraulic conductivity (short- distance permeability test) • Rock stress (overcoring) – Deformation and strength properties (plate loading test, rock shear test, measurement of tunnel deformation)
Fault and fracture	No major fault was identified in the potential area.	• F1 and F2 faults were newly identified (the tunnel excavation).
Rock mechanics	• CH: 85%, CM: 15% (core investi- gation) • Initial rock stress (sleeve fracturing method) and failure criteria (uniaxial tests)  	• CH: 100% (plate loading test) • Initial stress (overcoring method) and failure criteria (rock shear test and rearrangement of the uniaxial tests in the PI stage) 
Hydrogeology	• Hydraulic conductivity (Lugion test) 1.0×10^{-6} m/s at 0 to 50m in depth 1.0×10^{-7} m/s at 50 to 200m in depth 1.0×10^{-8} m/s (lower limit of Lugion test) at deeper than 200m	• Hydraulic conductivity (short-dis- tance permeability test) 1.0×10^{-9} m/s at deeper than 200m

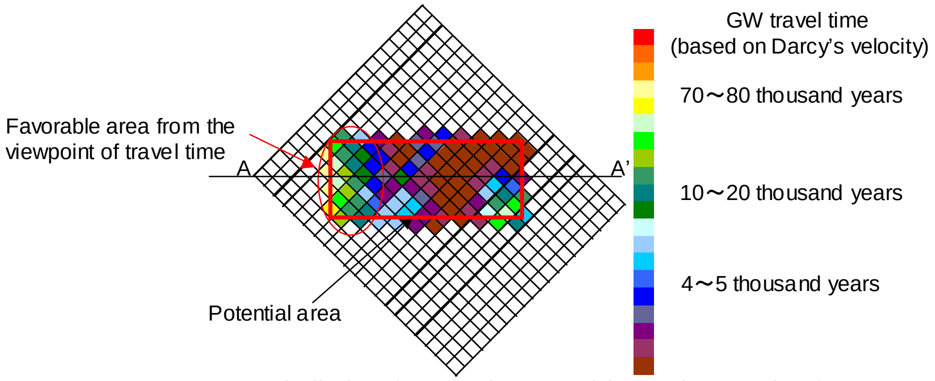
Disposal panel layout

In this section, the panel layouts are designed through groundwater flow analyses and a tunnel stability analyses based on the dataset of the PI stage and the DI stage.

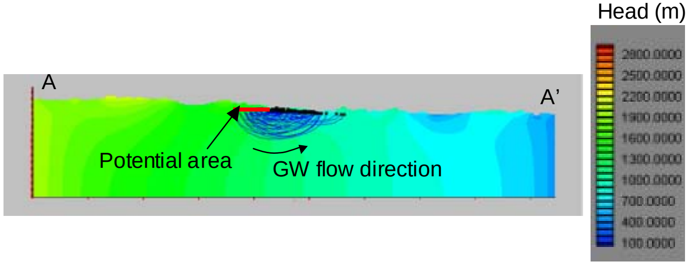
Groundwater flow analysis

As mentioned in the previous section, a groundwater flow is taken into account for the decision of the locations and the depths of disposal panels. In order to understand the groundwater flow system in and around the potential repository area, a regional groundwater flow analysis was performed based on the dataset of the PI stage. It was not performed in the DI stage because the update of the dataset of hydraulic conductivities was limited. Figure 2 shows the distribution of total hydraulic head and the groundwater streamlines from the potential area to the biosphere as a result of the analysis. The figure also shows the distribution of the expected travel time. It can be seen that the groundwater flows mainly from left-hand side to right-hand side and that the expected travel time from the left-hand area is larger than that from the other area. It means that the left-hand area is more favorable for location of panels from the viewpoint of the regional groundwater flow system. The analysis also indicated that the dependence of the travel time on the depth was limited.

Figure 2. **Distribution of groundwater travel time to the ground surface**



Distribution of expected GW travel time to the ground surface



Distribution of total hydraulic head and GW streamlines at section A-A'

Analysis of tunnel stability

Tunnel stability is a requirement in design of the panel depth. In this hypothetical site, it is a unique constraint to decide the panel depths because the groundwater travel time is not strongly dependent on depth and the thermal condition is moderate: both the average atmospheric temperature and the temperature gradient were much smaller than those in the H12 report. Therefore, analyses of tunnel stability were performed to find the suitable depth of the panel and the suitable distance of the tunnel interval. Figure 3 shows the finite element mesh and the distribution of safety factor as an example of the analyses. Tables 3 and 4 show the results of the analyses of the tunnel stabilities in the PI and the DI stages, respectively, where the host rock is classified into CH class rock and CM class rock in the PI stage and it is classified into formations A, B, C and D in the DI stage. In the PI stage, CH class rock was the target rock for the disposal and the tunnel was stable at the depth from 300 m to 1 300 m. In the DI stage, it was found that the formation D was not suitable at every depth below 300 m due to instability.

Figure 3. **Finite element mesh and the distribution of safety factor of an example**

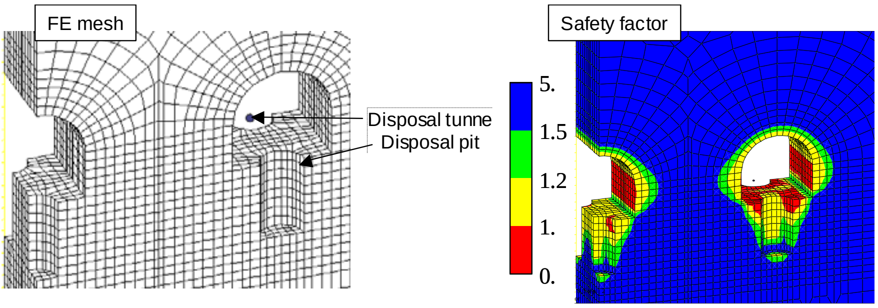


Table 3. **Tunnel stability in the PI stage**

Formation	**Rock class**	**Stability**	**Depth (m)**	**Distance (m)**		**Panel depth (m)**
A, B, C, D	CH	NG	Every depth	10.0	SF<1.5	300-1 300
		OK	300-1 300	12.5		
		NG	1 300-	12.5	Strain>critical strain	
	CM	NG	Every depth	10.0	SF<1.5	300-450
		OK	300-450	12.5		
		NG	450-	12.5	Strain>critical strain	

Table 4. **Tunnel stability in the DI stage**

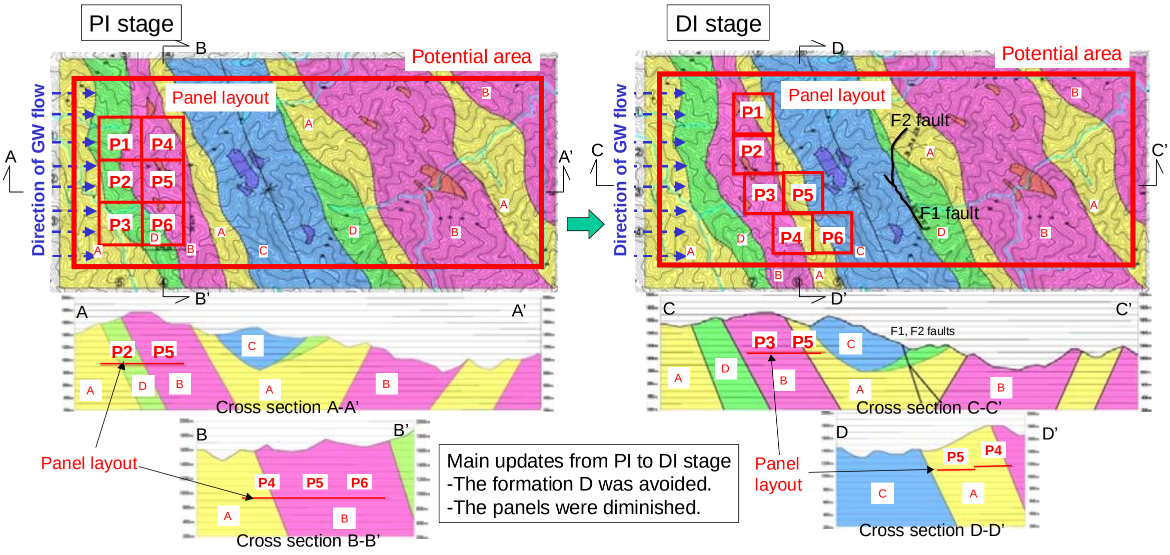
Formation	**Rock class**	**Stability**	**Depth (m)**	**Distance (m)**		**Panel depth (m)**
A	CH	OK	300-1 000 (at least)	12.5		300-1 000
B, C		OK	300-600	12.5		300-600
		NG	600-	12.5	SF<1.5	
D		NG	Every depth below 300m	12.5	SF<1.5	Not suitable

Panel layout

Based on the above analyses, panel layouts in the PI stage and the DI stage were designed as shown in Figure 4. The repository was divided into six panels following the H12 report. The panels were located at the depth of 600 m at the left-hand side of the potential area to maximise the expected travel times in both stages. The main changes of the panel layout from the PI stage to the DI stage were that the formation D was avoided for the panels due to instability of the tunnels and that the panels were diminished. The reason of the change of the panel size was the ratio of unsuitable domain of the host rock was estimated to be zero (100% of CH class) in the DI stage.

In this dry run, the panel layout was considerably changed from the PI stage to the DI stage. The main reason was the difference of the estimated initial rock stress. The rock stress was measured by means of the sleeve fracturing method in the PI stage. This method could not provide the accurate three-dimensional stress field because it assumed the vertical overburden pressure was one of the principal stresses. Especially, the fact that the stress deviation obtained in the PI stage was much smaller that in the DI stage brought a large impact.

Figure 4. **Panel layout in each stage**



Main updates from PI to DI stage
-The formation D was avoided.
-The panels were diminished.

Discussion

A redesign of panel layout strongly affects investigation planning. Especially, a significant redesign after a DI stage would be serious because it requires additional investigations aiming at the newly decided panel area. Therefore, panel layout after a PI stage (or after surface-based investigation stage) should be designed carefully for effective investigation planning in the following stages.

In this dry run, the panel layout was changed after the DI stage, since the formation D could not be found to be unsuitable in the PI stage. It occurred mainly because the investigations were limited due to the fact that these investigations were not aimed at the HLW geological disposal from the very beginning. However, flexibility is required in designing panel layout due to uncertainties of the results of the investigations and the estimation of the geo-environment using the results, although we could expect more data in actual sites. More specifically, the dry run suggested the needs of the further development of technique to obtain initial rock stress more accurately.

The faults F1 and F2 did not affect the panel layout. However, the fact that the faults that had not been identified by the surface-based investigations in the PI stage were detected in the DI stage brought important messages to us. Although these faults did not have such continuities as to outcrop to the ground surface, they were so large as to be avoided for the repository panel. It means that techniques to find such faults are required in the stage of the surface-based investigations. Otherwise, geological uncertainty should be taken into account appropriately for the repository designing.

Conclusions

This paper showed an example of dry run of designing panel layout using a hypothetical site information. Throughout the dry run, we proposed the method of designing panel size according to rock classification and showed its effectiveness. And the groundwater flow analysis was performed to find favorable location in the potential repository area from a broader point of view. These are important points for the implementer because panel location and its size have impact on construction cost and schedule.

From the discussion on the dry run, the following requirements to the future developments of designing method and investigation techniques were specified.

- Panel layout should be determined carefully before the construction of underground facility in the DI stage.
- Development of the techniques to obtain accurate initial rock stress from the surface is required.
- More accurate techniques to detect faults are expected from the surface.
- Settings of investigation area according to the panel size should be required.
- Uncertainty of geo-environment should be clarified by investigations. Otherwise, the repository design should be robust.

In this dry run, support systems were not considered in the design and it more or less resulted in considerable change of the panel layout. In practice, support systems will be expected to ensure the tunnel stability and the safety during the construction and the operation of the repository. Therefore, we need to develop more practical strategy of repository design including low pH cement, interaction between support systems and EBS, etc. In addition, it is necessary to take the effect of natural events and processes such as uplift, erosion and climate change on the groundwater flow system into consideration.

References

Japan Nuclear Cycle Development Institute (JNC), H12: Project to Establish the Scientific and Technical Basis for HLW disposal in Japan. Second Progress Report on Research and Development for the Geological Disposal for HLW in Japan – Project Overview Report, JNC TN1410 2000-001, 2000.