FEASIBILITY STUDY OF VENTILATION DESIGN FOR UNDERGROUND FACILITIES

Naoki Katsumata[1], Ryoji Yahagi[2], Hiromi Kurosaki[2], Shigeru Kubota[1]

Nuclear Waste Management Organization of Japan (NUMO)[1]
1-23, Shiba 4-chome, Minato-ku, Tokyo 108-0014 Japan

SHIMIZU CORPORATION[2]
2-16-1, Kyobashi, Chuo-ku, Tokyo 104-8370 Japan

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Abstract

NUMO considers not only post-closure safety but also pre-closure safety is important to ensure the safety of DGR (Deep Geological Disposal). Radiation safety is important to ensure safety during the pre-closure phase, but occupational safety is also important as well. Functional requirements for ensuring occupational safety are three requirements, such as maintaining the working environment, prevention of occurrence of accident and its enlargement and securing of evacuation routes. In the DGR, in order to maintain the working environment, supplying ventilation air flow rates to the underground and keeping the ambient temperature below 37°C should be attained (Ordinance on Industrial Safety and Hearth). The underground facility has very long disposal tunnels and it forms an extensive repository. Therefore, to confirm the feasibility of design for ventilation system essential to the workers during construction and operation is important. NUMO conducted a case study to confirm the feasibility of the ventilation system to the example of preliminary design in the underground facility at the DGR, so the outline is introduced.

1. Introduction

It is important to maintain a good working environment by studying the preliminary design method of ventilation system in the DGR (Deep Geological Repository). The ventilation system should satisfy the following three requirements to maintain the working environment.

i. Supplying fresh air for the workers in tunnels.
ii. Dilution and elimination of harmful gas and dust.
iii. Cooling the air generated by geothermal and mechanical heat.

In order to satisfy the requirement i and ii, the minimum wind velocity is preset with reference to the guidelines [1]. Also, it is necessary to note the maximum wind velocity prescribed by Enforcement Ordinance of the Mine Safety Act (Ordinance No.16). In order to satisfy the requirement iii, it is necessary to maintain the temperature in the tunnel prescribed by Ordinance on Industrial Safety and Health (Ordinance No.611).

Table 1 shows the requirements and criteria for designing the ventilation system.

Table 1 Design requirements and criteria of ventilation system.

Design requirements	Criteria	Regulations and guideline
Ventilation air flow rates	7.2 $m^3/s \leq$ (Crystalline rocks) 5.5 $m^3/s \leq$ (Sedimentary rocks without methane) 8.8 $m^3/s \leq$ (Sedimentary rocks with methane)	Ventilation technical guideline of tunnel construction (In Japanese) [1]
Maximum wind velocity	$\leq$ 7.5 m/s	Enforcement Ordinance of the Mine Safety Act (Ordinance No.16)
Temperature in the tunnel	$\leq$ 37°C	Ordinance on Industrial Safety and Health (Ordinance No.611)

The ventilation air flow rates are the air quantity required to dilute and eliminate the harmful gas and dust generated by the tunnel excavation work. The detail setting methods are described in 3.3.

The maximum wind velocity is a requirement for safety of the work environment. It was set to 7.5 m/s or less by reference to an Enforcement Ordinance of the Mine Safety Act (Ordinance No.16).

Temperature in the tunnel is a requirement for maintaining a good working environment. It was set to 37°C or less with reference to Ordinance on Industrial Safety and Health (Ordinance No.611). The ventilation system and the air cooling system should be planned to satisfy these design requirements.

Firstly, the air quantity required to maintain the working environment was calculated. It is required to dilute the dust and to exhaust the gasses generated by excavation work and necessary for the exhalation of workers.

After conducting the ventilation network analysis, the result should be checked whether the air quantity satisfies its requirement or not. And the maximum wind velocity should also be checked for its criteria.

If the temperature of working environment is higher than its criteria, a cooling device should be installed in the tunnel.

2. Design method of ventilation system

2.1 DGR layout and ventilation access

DGR layout and the ventilation access in the excavation area in crystalline rocks are shown in Fig. 1 and one in sedimentary rocks is shown in Fig. 2. An excavation area is the target one of the case study.

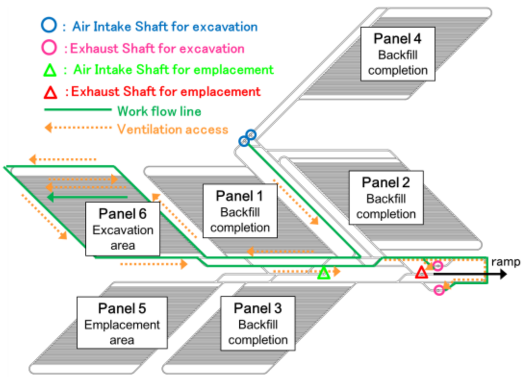

Fig. 1 DGR layout and ventilation access for the period of construction in crystalline rocks.

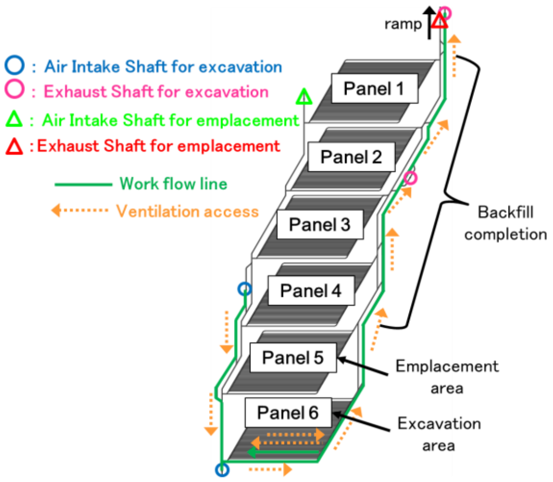

Fig. 2 DGR layout and ventilation access for the period of construction in sedimentary rocks.

The final disposal plan requires to disposing 40,000 vitrified waste packages for HLW. NUMO planned the conceptual DGR that consists of 6 panels. The total extension of tunnels is about 30 km. It also has 6 shafts and 1 ramp.

Two kinds of geological environment, crystalline rocks and sedimentary rocks, was assumed. The depth of the underground facility was set at 1,000 m of crystalline rocks and 500 m of sedimentary rocks.

The surface temperature was preset to 15°C and the geothermal gradient is set to 3°C/100m [2]. In other words, it means the temperature of rocks in the underground facility is estimated 45°C for crystalline rocks and 30°C for sedimentary rocks.

Furthermore, in the case of sedimentary rocks, there is a possibility that methane gas will be discharged.

Fig. 1 shows that panel No.6, the farthest panel from the exhaust shaft, is under excavation. At the same time, panel No.5 is under emplacement of HLW and backfilling of the disposal tunnels. For the other panels backfilling are completed.

Fig. 2 shows that panel No.6 is under excavation. At the same time, panel No.5 is under emplacement of HLW and backfilling of the disposal tunnel. For the other panels backfilling are completed.

Although the excavation and emplacement works are carried out in parallel, the work flow lines are set in order that these works can be done separately.

2.2 Concept of basic design

In order to ventilate the working tunnels, it is necessary that the ventilation access forms a circuit as shown in Fig. 3.

The underground facility is connected to the surface through the air intake shaft and the exhaust shaft. These tunnels and shafts form a circuit. Therefore, it is possible to ventilate by installing an exhaust fan at the outlet of the exhaust shaft.

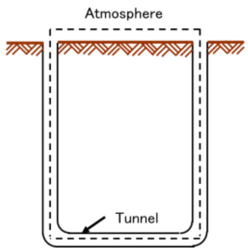

Fig. 3 Conceptual diagram of ventilation circuit [3]

Ventilation fans should be installed not only at the outlet of the exhaust shaft, but also in the tunnels. For the reason mentioned above, the total extension of the tunnels and shafts which needs ventilation access becomes long and many fans have to be installed and it is necessary to balance the air quantity, velocity and direction (vector of wind velocity). This should be studied by using ventilation network analysis.

2.3 Basic policy of dead-end disposal tunnel

Fig. 4 (a) shows the situation during excavating the disposal tunnel. In this case, the disposal tunnel forms a dead-end. In order to form a ventilation circuit, the ventilation ducts and fans should be installed inside the disposal tunnel as shown in Fig. 4 (b).

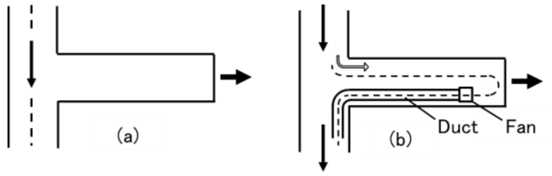

Fig. 4 Ventilation schematic illustration for dead-end tunnel [3]

2.4 Design of excavation completion disposal tunnels

There is no person at always in the excavation completion area. However, there is a possibility that response to emergency works may occur, so it is necessary to ventilate.

There are many excavation completion disposal tunnels and a large air quantity is necessary due to above reasons.

Therefore, the many disposal tunnels are connected by a duct and ventilation by a high pressure fan. By this ingenious ventilation policy setting, air quantity can be reduced.

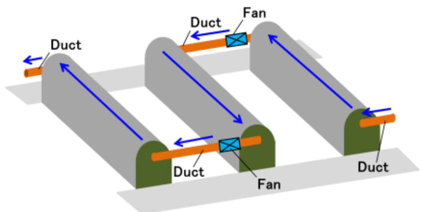

Fig.5 Ventilation access of a single stroke

3. Analytical studies

3.1 Outline of Ventilation network analysis

The ventilation network analysis is used to check the ventilation air flow rates and the maximum wind velocity at the all tunnels and shafts of calculation target area. Ventilation network analysis was conducted by two types of analysis code, “KAZEMARU” and “ONTA”.

A one-dimensional pipeline calculation code “KAZEMARU” is applied to the calculation of air quantity and wind velocity. In case of evaluating the thermal environment, “ONTA” is further applied. By the way the validation of “KAZEMARU” has been conducted and its applicability was verified in the actual mines [4].

“KAZEMARU” calculates the static pressure in tunnels based on Bernoulli's principle and outputs the air quantity in the tunnel.

The parameters to be input are the tunnel cross-sectional area, tunnel length, friction coefficient (parameters related to the roughness of the tunnel wall surface), and the additional length (equivalent tunnel length considering pressure loss at the corner of the tunnel, branching or confluent area) [5].

3.2 Condition of ventilation network analysis

Conditions of ventilation network analysis for each case were set as shown in Table 2.

Table 2 Conditions of ventilation network analysis for each case

	Geological condition	Methane	Target area	Panel No.
CASE-1	Crystalline rocks	No	Excavation area	6
CASE-2	Depth@-1,000m	No	Emplacement area	5
CASE-3	Sedimentary rocks	No	Excavation area	6
CASE-4	Depth@-500m	Yes	Excavation area	6

The CASE-1 can be defined as the reference case. The calculation results of the others were compared with CASE-1.

In the CASE-1, the ventilation access in the excavation area is set as shown in Fig. 1. In the crystalline rocks case, the disposal repository locates at the depth of 1,000 m. The ventilation access becomes longer than the case of sedimentary rocks. Because many construction machines are used at excavation area, the large air quantity should be required.

The CASE-2 represented the condition of an emplacement area as shown in panel No. 5 of Fig. 1. In accordance with our disposal plan, the process of emplacement would be carried out by remote works. The continuous ventilation is not necessary for the emplacement area. In this case, it is sufficient to ventilate only the tunnel of backfill. In this kind of situation, it can be expected that the air quantity can be reduced.

The CASE-3 represented the condition of a construction area as shown in panel No.6 of Fig. 2. In this case, the length of the shaft is shorter than the case of the crystalline rocks. It is expected that the capacity can be reduced.

In the CASE-4, it is assumed that methane gas is generated in the same area as CASE-3. In this case, the minimum wind velocity would faster than CASE-3.

3.3 Method for setting the ventilation air flow rates

In this section, the procedure for setting the ventilation air flow rates would be indicated.

The ventilation air flow rates are calculated by summing of the air quantity which is required to dilute the gas and necessary for exhalation of workers.

The main cause of dust generation is thought to be due to blasting and shotcreting. Exhaust gas is generated by drilling, chopping, mucking, haulage, shotcreting and installation of rock bolts. These volumes are specified in the guideline [1]. For information of guideline, because the dust is collected by the electric dust collector, it is not counted as the ventilation air flow rates.

Each ventilation air flow rates are calculated based on the method of the guideline. Fig. 6 shows the one example of calculation result of the ventilation air flow rates for CASE-1.

In this case, the ventilation air flow rates are the sum of the maximum value of the air quantity necessary to dilute for gas and the air quantity necessary for exhalation of workers.

The maximum value 6.7 m^3/s should be chosen as the ventilation air flow rates required to dilute the dust and gas. On the other hand, the ventilation air flow rates required for exhalation of workers are calculated to 0.5 m^3/s.

Therefore, the ventilation air flow rates are set to 7.2 m^3/s for each excavating tunnel in crystalline rocks.

Finally, the total volume is calculated by multiplying the ventilation air flow rates by the number of excavating tunnels.

In the same way, the ventilation air flow rates are calculated for each case.

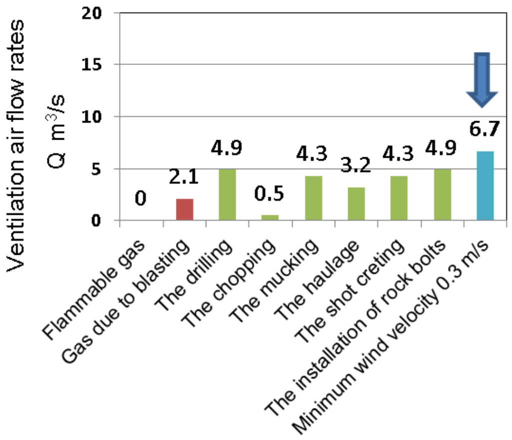

Fig. 6 Example of ventilation air flow rates at the time of excavation (crystalline rocks)

4. Results of Ventilation Network Analysis

4.1 Ventilation air flow rates

The results of the analysis are shown in Table 3.

After conducting the ventilation network analysis, the result should be checked whether the air quantity satisfies its requirement or not. And the maximum wind velocity should also be checked against its criteria.

Table 3 Results of the ventilation network analysis for ventilation air flow rates

	Air quantity at the outlet of shaft	Total of the ventilation air flow rates	The ventilation air flow rates	Number of the working tunnel
CASE-1	151.8 m^3/s	122.4 m^3/s	7.2 m^3/s	17
CASE-2	59.5 m^3/s	43.2 m^3/s	7.2 m^3/s	6
CASE-3	158.5 m^3/s	93.5 m^3/s	5.5 m^3/s	17
CASE-4	316.9 m^3/s	176.0 m^3/s	8.8 m^3/s	20

The results of the analysis suggested as follows.

- It is evident from the result of CASE-1 that several fans enable to supply enough air even though the ventilation air flow rates are very large.
- In the emplacement area, the capacity of the fan is smaller than the one in the excavation area. The cause of this result is the difference of the number of working tunnels (CASE-2).
- Even at the same depth, in case of assuming methane gas, should be required about doubled, therefore, far more capacity by many fans are needed for keeping the air flow.

4.2 Maximum wind velocity

CASE-1, 2 and 3 have resulted in that maximum wind velocity satisfied with the design requirement, below 7.5 m/s, as shown in Table 1.

CASE-4 has resulted in over the criteria of maximum wind velocity in this analysis condition. The cause of this result is that the large air quantity is required to ventilate the methane gas.

In this case, we should expand the width of a cross section of the tunnel from 5 m to 8 m.

It enable us to satisfy the maximum wind velocity as show in CASE-4', Table 4.

Table 4 Results of the ventilation network analysis for maximum wind velocity

	Maximum wind velocity	Cross-sectional area of the main tunnel
CASE-1	6.8 m/s	22.3 m^2
CASE-2	1.6 m/s	22.3 m^2
CASE-3	5.7 m/s	16.5 m^2
CASE-4	14.0 m/s	16.5 m^2
CASE-4'	4.4 m/s	52.1 m^2

4.3 Thermal environment analysis

In conducting the thermal environment analysis, it is also important to consider the heats generated by the construction machines in the tunnels.

Before conducting the thermal environment analysis, the heats generation rates generated by the construction machines in the disposal tunnels are calculated in accordance with the guideline.

In addition to the air quantity of tunnels obtained by ventilation network analysis and the temperature of the tunnel wall, the heats generated by the construction machines are preset on the "ONTA" code.

As a result, the temperature of working environment, increased to maximum 41°C as shown in Table 5, CASE-1.

Without considering the heats generated by the construction machines, the temperature in the tunnel increased to maximum 40°C due to geothermal.

These results indicate that the influence of geothermal is dominant as compared with the heats generated by the construction machines.

The result of CASE-3 where the disposal tunnels are located in the depth of 500 m and the thermal environment is lower than CASE-1 supports the fact that geothermal influence is the maximum consideration.

In order to maintain the good working environment, the temperature in the tunnel where the workers are working on must be kept below 37°C (Ordinance on Industrial Safety and Health No. 611). Therefore, it is necessary to install the air cooling system. The capacity of the air cooling system was calculated by ONTA. By the parameters input again based on the guidelines [1] relating to the air cooling system and the temperature calculation was carried out. As a result, it was possible to preliminary design an air cooling system to keep it below 37°C.

Table 5 Results of thermal environment analysis

	Temperature in the tunnel	Cooling capacity for the working tunnel
CASE-1	41°C	2,080 kW
CASE-2	41°C	650 kW
CASE-3	29°C	–
CASE-4	29°C	–

This study focused on maintaining a good working environment in the disposal tunnels. If the maintenance or repair work is required in the access tunnel, the local air cooling system or mobile rest station should be installed to maintain the good working environment.

5. CONCLUSIONS

Design method of ventilation system and air cooling system were prepared in order to maintain the working environment at excavation and operation of underground facilities. In this study of preliminary design of ventilation system, it was available to consider the balance of air quantity and position of fans by using KAZEMARU.

In addition, it was confirmed that their systems could be planned with generally equipment's by analytical studies of ventilation system and air cooling system for underground facilities which were designed in an assumed geological environment.

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