Countermeasures Planned for Reducing Water Inflow into Deep Shafts at the Mizunami Underground Research Laboratory*


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Abstract
The Mizunami Underground Research Laboratory (MIU) is currently being constructed. The MIU design consists of two 1,000 m-deep shafts with several research galleries. The goals of the MIU project are to establish techniques for investigation, analysis and assessment of deep geological environments, and to develop a range of engineering expertise for application in deep underground excavations in crystalline rocks such as granite. The diameter of the Main and the Ventilation Shafts are 6.5 m and 4.5 m, respectively. Horizontal tunnels to connect the shafts will be excavated at 100 m depth intervals. The Middle Stage, at about 500 m in depth, and the Main Stage, at about 1,000 m in depth, will be the main locations for scientific investigations. The Main and the Ventilation Shafts were 180 m and 191 m deep, respectively, in November 2006. During construction, water inflow into the shafts has been increasing and affecting the project progress. In order to reduce the water inflow into the shafts, pre- and post-excavation grouting has been planned. A post-excavation grouting test has been undertaken in the Ventilation Shaft and the applicability of several techniques has been evaluated. This paper describes an outline of the MIU project, its work plan and the results of the post-excavation grouting test.

Key words: Geological Disposal, URL, Shaft, Water Inflow, Grouting

1. Introduction

One of the features of the geological disposal policy in Japan is the requirement for the establishment of Underground Research Laboratories (URLs). The URLs are distinguished from an actual disposal facility, as outlined in the Atomic Energy Commission (AEC) report. Research on the deep geological environment will provide the basis for R&D on geological disposal of high-level radioactive waste. The AEC also stipulated that research at the URLs should contribute to Japan's scientific research on the geological environment.

JAEA's URL projects are directed towards improving the reliability of geological disposal technologies and developing advanced safety assessment methodologies. It will ensure that the implementation of geological disposal is based on a thorough scientific and technological basis. The URLs in these projects are classified into purpose-built generic URLs as described in the OECD/NEA report, and are distinct from site-specific URLs to be constructed on-site at potential waste disposal sites. In order to cover the
general geological environment in Japan, two URLs, one for crystalline rock and another for sedimentary rock have been planned; one is the Mizunami Underground Research Laboratory (MIU), the other is the Horonobe Underground Research Laboratory (Hnb-URL)\(^3\)\(^-\)\(^4\). One purpose of this plan is to confirm the technical reliability of the geological disposal methods, described in the Second Progress Report\(^5\).

The results of the geoscientific research carried out in the MIU project will provide establishment of the technological basis for safety regulations set by the government and for the HLW disposal project to be carried out by the Nuclear Waste Management Organization of Japan (NUMO).

2. Outline of MIU

2.1 Location

The MIU is located in Mizunami City, Gifu Prefecture, in the central part of Honshu, the main island of Japan (Fig.1). The MIU excavations and related surface facilities are constructed on the land leased from Mizunami City. The site has an area of about 7.8 hectares and located in the Intergarden of Tono Frontier Science Research City. This area has a number of public facilities, which draw many people to the area. This situation constrains traffic flow to the site during execution of the project, for example, at this time, heavy vehicle traffic to the construction site is only permitted on weekdays during daylight hours.

2.2 Geology and Rock Mechanical Properties

The regional geology encompassing the MIU project site consists of Tertiary and Quaternary sedimentary rocks overlying a Cretaceous granitic basement.

The shafts and galleries of the MIU are excavated in the late Cretaceous, Toki Granite. The Toki Granite has been faulted, and subjected to several episodes of uplift and subsidence from the Miocene to the Pliocene, indicated by unconformities in the lacustrine and marine sedimentary formations unconformably overlying the granite. The thickness of the sedimentary formations is about 170 m.

The average P-wave velocity, uniaxial compressive strength and Young’s modulus of intact rock of Toki Granite are approximately 5.5 km/sec, 150 MPa and 50 GPa, respectively.

2.3 Function of Shafts and Design Constraints

The principal feature of the MIU is to access to the geological environment down to 1,000 m-deep by the two vertical shafts. The Main shaft has a 6.5 m in diameter and the Ventilation Shaft has a 4.5 m in diameter. Horizontal galleries, known as Sub-stages, will be excavated at 100 m depth intervals. The Middle Stage, at about 500 m depth, and the Main Stage, at about 1,000 m depth, will be the main locations for scientific investigations.

The size and shape of shafts and galleries were determined based on considerations of mechanical stability, excavation budget, the size and type of equipment and materials to be
transported in the shafts and in the galleries, and needed for the investigations. Fig.2 shows the layout of the MIU facilities, although this layout may be revised depending on the geological condition, etc.

In summary, the functions of shafts and galleries at the MIU are as follows:

- **Main shaft**: Transport route for personnel, construction and research materials necessary for excavation of galleries, and for investigations, and for transport of muck from galleries to the surface.
- **Ventilation shaft**: Ventilation and including space for fans and for new hoist cage installed after excavation to depth at 1,000 m.
- **Sub stages**: Galleries that will connect the Main and the Ventilation shafts and provide space for pumps, water supply, air conditioning, electrical equipment, refuge shelter, and space for investigations intended to understand depth-dependency of geological condition and excavation disturbance.
- **Main and Middle stages**: Research galleries for Phase III (Operation Phase) investigations including TBM tunnel, loop galleries, refuge shelters and drilling stations.

### 2.4 Access Method

Access methods to underground are basically grouped into vertical shaft type and inclined ramp type. The vertical shaft type was selected as the access method for the MIU, because of the shape and size of the construction site, schedule, and excavation budget.

### 2.5 Number of Shafts

In general, the ideal number of shafts is three or more, one for ventilation and others for transport of personnel and materials, air supply, and escape routes in emergencies such as a fire or accidents. Because of the schedule and excavation budget, the basic concept for the MIU is that, in case of emergency, personnel can take refuge in the shafts and in the refuge stations excavated in each gallery, and return to surface after the emergency is over. Therefore, the number of shafts in the MIU layout is two, the Main and the Ventilation Shafts.

### 2.6 Shape and Size of Shafts

The cross-section geometry of the shafts is circular selected after consideration of mechanical stability, workability, safety and budget for construction and maintenance.

The inner diameter of the Main and the Ventilation Shafts were determined to be 6.5 m and 4.5 m, respectively, for the following reasons.

- **Space requirements**: Ease of transport of materials and equipment needed for excavation of galleries and investigations, installation space for equipment, and plumbing.
- **Workability** (minimum space for excavations): Applicable short-step shaft sinking
2.7 Depth of Shafts

One of the purposes of the MIU project is to confirm the technical reliability of the geological disposal methods described in the Second Progress Report (JNC, 2000). In this report, the maximum depth of a geological disposal facility is estimated to be 1,000 m in the case of crystalline (hard) rock. Therefore the target depth of geoscience research at the MIU is also 1,000 m. So, the MIU shafts are expected to extend to 1,000 m depth and the Main Stage is also expected to be constructed as deep as 1,000 m as specified in the Master Plan of the MIU project (JNC, 2002).

2.8 Excavation Progress

Excavation of the shafts began in July, 2003 and reached GL.-10 m in September, 2003. Concrete work for collars at the shaft entrances and construction of surface facilities around the shafts were subsequently carried out.

In April, 2004, excavation of the lower part of the shaft entrances resumed and reached GL.-50m in November, 2004. Following this, facilities for shaft sinking such as head frames, scaffolds, hoists, concrete plant, etc., were constructed.

In February, 2005, shaft sinking was resumed below GL.-50 m with the short-step shaft sinking method. A single shaft sinking cycle comprises two consecutive drill, blast and mucking steps (1.3 m + 1.3 m), and one concrete lining step (2.6 m). One cycle requires 1.5 to 2.0 days including investigations such as geological observations and mapping, stereoscopic imaging, infrared thermography, etc.

 Depths of the Main and the Ventilation shafts were 180 m and 191 m, respectively, in December 2006. Fig-3 shows the geological model and current depth of each shafts.

3. Water Inflow into the Shafts

During construction, water inflow into the shafts has been increasing and affecting the project progress.

Fig. 4 gives an indication of the water inflow during shaft sinking for each shaft. The left and right hand graphs show major inflow points and the volume of water pumped as shaft sinking progressed. The water inflow increased significantly at about GL.-118 m in the Ventilation Shaft, in sandstone, and at about GL.-123 m in the Main Shaft. The water inflow into the Ventilation Shaft was especially large. The rock with the highest water inflow was
the sandstone and the basal conglomerate in the Toki lignite bearing formation. The hydraulic conductivity of these formations is in the order of 1E-6 meter per second, which is about 20 Lugeons. The large water inflow resulted in the increased pumping and water treatment costs, and affected the shaft sinking rates.

The water inflow is expected to be large by the time excavation is completed. Left unmitigated, inflow will exceed the capacities of both the pumping and the water treatment facilities. Therefore, countermeasures to reduce the water inflow have to be taken.

4. Countermeasure Plan

4.1 Basic Concept of Grouting

4.1.1 Grouting Method for Countermeasure

Countermeasures to reduce the water inflow into the shaft have been considered and grouting has been selected. Grouting methods can be adapted to a variety of geological conditions. Grouting is performed to reduce rock mass hydraulic conductivity by injecting grouting materials. Two approaches to grouting are planned; pre-excavation and post-excavation grouting.

4.1.2 Basic Concept of Pre-Excavation Grouting

Pre-excavation grouting is used in advance of excavation. The injection region is below the shaft bottom. This method is applied for many shafts and tunnels worldwide.

This can be an operation in the general construction cycle. The main target structures for this method are single water bearing fractures or large zones with high hydraulic conductivity.

Two injection methods for pre-excavation grouting are considered. Fig. 5 shows the short injection method using a shaft jumbo. Fig. 6 shows the long injection method using a
drilling machine brought into the shaft. The methods to be employed will be selected based on the hydrogeological condition of injection area.

4.1.3 Basic Concept of Post-Excavation Grouting

Post-excavation grouting method will be used for grouting excavated regions above shaft bottom. The injection region in this method is close to the shaft wall. This method requires additional construction time and equipment. The main target regions for this method are the zones with large water inflow, i.e. high hydraulic conductivity and porosity.

In the case of the MIU shaft, the drainage material installed behind the concrete lining is used to collect water inflow and to discharge it into the shaft. Thus, water pressure is relieved from the shaft lining and therefore the concrete lining of MIU shaft is considered to have a zero pressure effect due to drainage material. For this reason, it is necessary to avoid plugging the drainage material by grout.

Post-excavation grouting is planned as in Fig.7. To avoid plugging the drainage material, three grouting zones are considered. The first 4 m into the rock mass from the concrete lining and shaft wall will not be grouted. The next 1 meter or so into the rock mass will be...
grouted to form a temporary grout curtain, using solution type water-glass grouting material. Next to the temporary grout curtain, the permanent grout curtain will be injected. It is designed to be about 5 m in thickness and comprised of suspension type calcium-silica grouting material.

The injection method for post-excavation grouting is performed as follows. Fig. 7 shows the horizontal drilling and injecting method using a drilling machine. First, full-length injection holes are drilled and perforated injection pipes are installed. Then, using double-packers, the solution type water-glass grouting material is injected at prescribed depths along boreholes for the temporary grout curtain. After injection of the temporary grout curtain, the suspension type calcium-silica grouting material is injected further from the shaft for the permanent grout curtain, using the same injection method. For the injection of the permanent grout curtain, injection holes are divided into first-step (odd number) holes and second-step (even number) holes. All the first-step holes are injected first.

5. Post-Excavation Grouting Tests

5.1 Test Grouting Plan

Before employing post-excavation grouting to reduce the water inflow from the sedimentary rock layers, it was necessary to evaluate the effectiveness of the post-excavation grouting method.

The test grouting area was selected in the basal conglomerate of the Toki lignite bearing formation. There are two reasons, one is that the major water inflow occurs there, and the other is that this area has one of the most difficult geological conditions for grouting. If the post-excavation grouting is successful in these geological conditions, this method should be applicable in other, possibly less severe, geological conditions.

The test grouting plan is shown in Fig. 8. There are two test zones at the same level, one is Zone-A, used for assessing the injection specifications, and the other is Zone-B, used for evaluating the effectiveness of post-excavation grouting. In Zone-A, the necessary amount of injected grout was estimated for several injection pressures. The injection specifications were then determined, including injection pressure and amount of grout to be injected. Then the test grouting to evaluate the feasibility and effectiveness of post-excavation grouting was performed in Zone-B using the injection specifications assessed.

![Fig. 8 Test Layout - Post-Excavation Grouting](image-url)
The effectiveness of post-excavation grouting could be evaluated by the reduction in total water inflow into the shaft. But because any reduction is difficult to relate directly to the test region, lugeon values, hydraulic conductivity, water head, and inflow rate at the injected zone were assessed before and after injection and used to evaluate the effect of post-excavation grouting. Two pilot boreholes before injection and three evaluation boreholes after injection were drilled in the test grouting zone.

The two pilot boreholes, 10 m long, were located in the center of the test grouting zones. Sixteen meters long evaluation boreholes were drilled in the center (C-1 for Zone-A & C-3 for Zone-B) and the border (C-2 for Zone-B only) of the test grouting zones. For the three evaluation boreholes, the investigations were done within the permanent grout curtain zone and just to the outside of the permanent grout curtain, to evaluate the effect of post-excavation grouting and to assess the penetration of the grouting material.

Fig.9 shows the layout of pilot, evaluation and injection boreholes in Zone-A and Zone-B.

5.2 Results of Test Grouting

5.2.1 Pilot Boreholes

Two pilot boreholes were drilled and several hydraulic investigations were carried out in the boreholes. Table 1 shows the results of these hydraulic investigations. Lugeon value was estimated by lugeon test, inflow pressure and hydraulic conductivity were estimated by JFT test, and inflow rate was estimated by measuring of over flow water. These results are similar to each other. For this reason, it is considered that the hydrogeological conditions of the basal conglomerate are relatively homogeneous in this region.

<table>
<thead>
<tr>
<th>Borehole No.</th>
<th>Lugeon Value [Lu]</th>
<th>Inflow Pressure [MPa]</th>
<th>Hydraulic Conductivity [m/sec]</th>
<th>Inflow Rate [L/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>15</td>
<td>0.158</td>
<td>2.16E-06</td>
<td>9.9</td>
</tr>
<tr>
<td>16</td>
<td>20</td>
<td>0.169</td>
<td>2.78E-06</td>
<td>6.5</td>
</tr>
</tbody>
</table>
5.2.2 Assessment of the Grouting Specifications

Fig. 10 indicates the amount of injected grout in each injection hole and depths in the permanent grout curtain zone of Zone-A for assessing the required grouting specifications. The injected amounts varied because of different injection pressures and different injection procedures. There was no limitation on injection pressure below 3.5 MPa, which is much more than 10 times the inflow pressure. The average amount of injected grout is about 2.0% of the rock mass volume. The injection procedure followed was to inject from the shaft side outwards, which is more favorable than the reverse, because of low injection leakage rate.

The injection specifications are below:

- Injection Pressure: 3.5 MPa maximum
- Amount of grout to be injected: 2.0% of rock volume
- Injection procedure: From shaft side outwards

5.2.3 Evaluation of the Effect of Post-Excavation Grouting

Fig. 11 indicates the amount of injected grout in each injection hole and depths in the permanent grout curtain zone of Zone-B to evaluate the effect of post-excavation grouting. The distribution of these injected amounts is very regular, from a large amount to smaller from the shaft side outwards. The total amount of injected grout is about 1.5% of rock volume, 75% of the available 2.0%.

5.2.4 Evaluation Boreholes

Three evaluation boreholes were drilled and several hydraulic investigations were carried out in the holes. Table 2 shows the hydraulic investigation results of both the evaluation and pilot boreholes for comparison.
For Zone-A, No.3 indicates the initial hydraulic conditions before injection; C1-1 indicates hydraulic conditions after injection within the permanent grout curtain region; and C1-2 indicates hydraulic conditions after injection outside of the permanent grout curtain region. It is indicated that hydraulic conductivity decreased for C1-1 to less than one third of the initial conditions, but the lugeon value is about equal to the initial and greater outside of the injected region. The inflow rate in the permanent curtain is 6 times lower than the initial, and increases sharply outside of the curtain. The inflow pressure is higher than initial. From these results, the effect of post-excavation grouting shows significant results but some inconsistencies between Lugeon values and hydraulic conductivity need to be analyzed.

Table 2 Hydraulic Investigation Results of Evaluation Boreholes

<table>
<thead>
<tr>
<th>Zone</th>
<th>Bore-hole No.</th>
<th>Lugeon Value [Lu]</th>
<th>Inflow Pressure [MPa]</th>
<th>Hydraulic Conductivity [m/sec]</th>
<th>Inflow Rate [L/min]</th>
<th>Borehole Location</th>
<th>Before or After Injection</th>
<th>Within or outside of Curtain</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3</td>
<td>15</td>
<td>0.158</td>
<td>2.16E-06</td>
<td>9.9</td>
<td>Center</td>
<td>Before</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>C1-1</td>
<td>17</td>
<td>0.190</td>
<td>6.73E-07</td>
<td>1.6</td>
<td>Center</td>
<td>After</td>
<td>Within</td>
</tr>
<tr>
<td></td>
<td>C1-2</td>
<td>23</td>
<td>0.202</td>
<td>1.83E-06</td>
<td>14.0</td>
<td>Center</td>
<td>After</td>
<td>Outside</td>
</tr>
<tr>
<td>B</td>
<td>16</td>
<td>20</td>
<td>0.169</td>
<td>2.78E-06</td>
<td>6.5</td>
<td>Center</td>
<td>Before</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>C2-1</td>
<td>8</td>
<td>0.178</td>
<td>1.31E-06</td>
<td>12.0</td>
<td>Border</td>
<td>After</td>
<td>Within</td>
</tr>
<tr>
<td></td>
<td>C2-2</td>
<td>5</td>
<td>0.182</td>
<td>1.29E-06</td>
<td>16.0</td>
<td>Border</td>
<td>After</td>
<td>Outside</td>
</tr>
<tr>
<td></td>
<td>C2-3</td>
<td>4</td>
<td>0.170</td>
<td>7.52E-07</td>
<td>16.0</td>
<td>Center</td>
<td>After</td>
<td>Within</td>
</tr>
<tr>
<td></td>
<td>C3-1</td>
<td>4</td>
<td>0.219</td>
<td>7.79E-07</td>
<td>0.0</td>
<td>Center</td>
<td>After</td>
<td>Outside</td>
</tr>
<tr>
<td></td>
<td>C3-2</td>
<td>3</td>
<td>0.228</td>
<td>4.52E-07</td>
<td>1.1</td>
<td>Center</td>
<td>After</td>
<td>Outside</td>
</tr>
<tr>
<td></td>
<td>C3-3</td>
<td>11</td>
<td>0.254</td>
<td>1.76E-06</td>
<td>18.0</td>
<td>Center</td>
<td>After</td>
<td>Outside</td>
</tr>
</tbody>
</table>

For Zone-B, No.16 indicates initial hydraulic conditions before injection; C2-1, C2-2, C3-1, and C3-2 indicate hydraulic conditions after injection within the permanent grout curtain region, and C2-3 and C3-3 indicate hydraulic conditions after injection outside of the permanent grout curtain region. In the center of the zone (C3-series), the hydraulic conductivity and lugeon values decreased in the permanent grout curtain region (C3-1 and C3-2) to about one fifth of the initial conditions and are much less than the values outside of the injected region. The inflow rate within the curtain is significantly less than the initial conditions and in comparison to the higher flow rate outside the curtain region. The inflow pressure is higher than initial. However on the border of the zone (C2-series), the changes are not as clear. Lugeon values and hydraulic conductivity decreased, but inflow pressure and inflow rate increased. Observations from the evaluation boreholes indicated that the post-excavation grouting is more effective in the center of injected zones.

5.3 Conclusion of Test Grouting

Conclusions of the post-excavation grouting test are as follows:
- Testing post-excavation grouting was done in a restricted region of the conglomerate.
- Two test grouting regions were selected, one to assess grouting specifications, and the other to evaluate the effectiveness of grouting.
- Injection test specifications including injection pressure, injected volume, and procedure, were determined by assessing the test results.
- The effectiveness of post-excavation grouting under these specifications was evaluated and considered useful.
- The concept of post-excavation grouting is considered successful overall.

6. Final Remarks
The outline of the Mizunami URL and results of the post-excavation grouting test were described.

The post-excavation grouting test was successful overall. However, reduction of total water inflow into the shafts after the test was not confirmed; though reduced flow was demonstrated in specific grouted regions. It may be necessary to form a continuous grout curtain around the shaft to reduce water inflow.

This post-excavation grouting concept can be suitable for permeable sedimentary rock, but it is considered that it may be difficult to completely seal a single water bearing fracture in crystalline (hard) rock.

However the method is considered a good candidate countermeasure for reducing water inflow into shafts and tunnels.

References

(2) OECD Nuclear Energy Agency: The Role of Underground Laboratories in Nuclear Waste Disposal Programs, OECD, (2001)