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Status of rock dynamics study in horonobe underground research laboratory, Japan

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ABSTRACT: Rock dynamics is one of key issue for research and development of techniques for safe geological disposal of high-level radioactive waste. Horonobe Underground Research Laboratory (URL) is off-site URL constructed in soft sedimentary rock to the depth of 350 m with three shafts and three level experimental galleries. Earthquake-resistant design of underground openings, observation of seismic records and groundwater pressure change due to earthquakes, and excavation disturbed zone experiment have been performed relating to the study of rock dynamics in URL project. This paper shows current status of Horonobe URL project and results of earthquake-resistant design of shafts, observation of seismic records and groundwater pressure change due to the 2011 off the Pacific coast of Tohoku Earthquake.

1 INTRODUCTION

One of the features of the geological disposal policy in Japan is the establishment of Underground Research Laboratories (URLs). The URLs must be distinct from an actual disposal facility, which will be selected by NUMO (Nuclear Waste Management Organization of Japan). Research on deep geological environments, and development of instrument and methodologies will provide the basis for R&D on geological disposal of high-level radioactive waste. 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 (OECD/NEA, 2001), and are distinct from on-site (site-specific) URLs to be constructed at potential waste disposal sites. In order to cover the general geological environment in Japan, two URLs, one for sedimentary rock and another for crystalline rock have been planned, one is the Horonobe Underground Research Laboratory the other is the Mizunami Underground Research Laboratory (JNC 2001; 2002). One purpose of this plan is to confirm the technical reliability of the geological disposal methods, as indicated by the Second Progress Report (JNC 2000).

The site of the URL project for sedimentary rock is located at Horonobe, in the northern part of Hokkaido, north of Japan. The geology consists of Tertiary and Quaternary sedimentary rocks. Conceptual design for the Horonobe URL at present is as follow:

- Two 500 m access shafts and one Ventilation Shaft; and
- Experiment levels, at 140 m, 250 m, 350 m and 500 m depths.

In 2012, excavation of the Ventilation Shaft and East Access Shaft reached 350 m depth, and the experiment gallery at 350 m depth was excavated between 2012 and 2014. In 2012, excavation of the West Access Shaft started, and reached 350 m depth in 2013. Countermeasures against rock bursts and large volume/high-pressure inflows of water or inflammable gas are important issues to be addressed during excavation of shafts and research galleries. Figure 1 shows the layout of the Horonobe URL.

The site of the URL project for crystalline rock is located in Mizunami City, Gifu prefecture. The regional geology consists of Tertiary and Quaternary sedimentary rocks overlying a Cretaceous granitic basement. Current design for the Mizunami URL is as follows:

- Two shafts, the Main Shaft (6.5 m ϕ) and the Ventilation Shaft (4.5 m ϕ); and
- Two experimental levels, at the 300 m level and the 500 m level.

In 2012, excavation of the Main and Ventilation Shafts reached 500 m depth, and an experiment gallery at 500 m depth was excavated between 2012 and 2014.

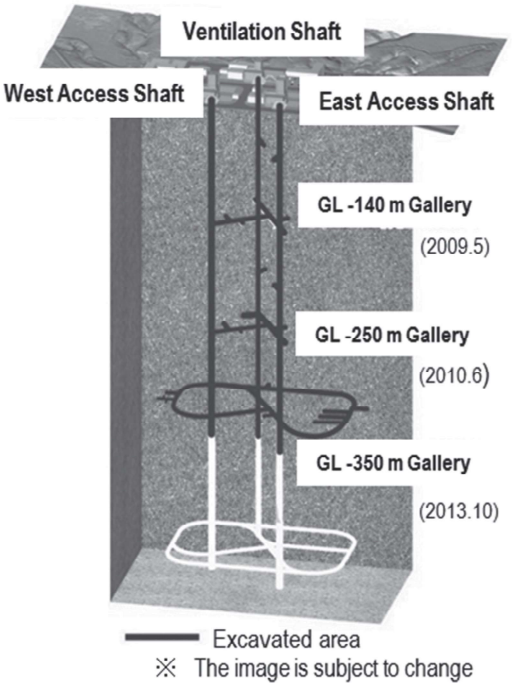
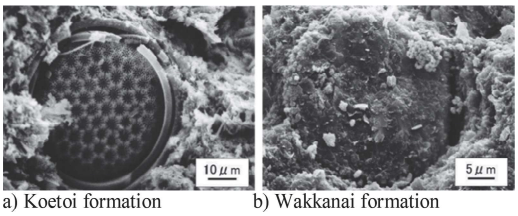


Figure 1. Layout of Horonobe URL.



a) Koetoi formation b) Wakkanai formation

Figure 2. Microphotograph of formations.

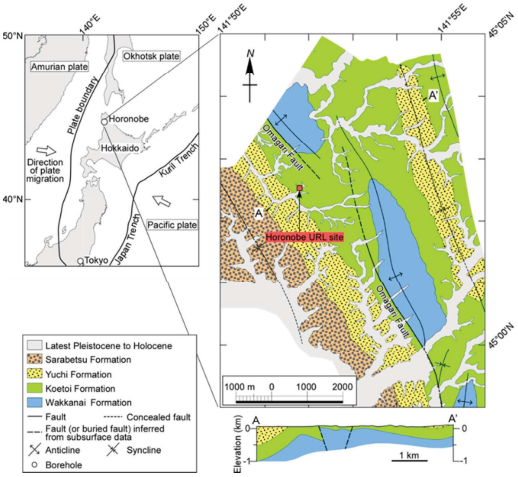


Figure 3. Geological map and NE–SW geological cross-section of the Horonobe area.

It will be necessary to evaluate direct and/or indirect influence of large earthquakes to design and construction of repository, and safety of geological disposal system during long period in safety assessment. Even in Sweden, where large earthquakes have not occurred, implementation organization SKB (Swedish Nuclear Fuel and Waste Management Co) recognized large earthquakes induced by influence of glacier is one of key issue to evaluate in the safety assessment of repository at Forsmark (SKB 2011a,b).

This paper shows current status of Horonobe URL project and results of earthquake-resistant design of shaft, observation of seismic records and groundwater pressure change due to the 2011 off the Pacific coast of Tohoku Earthquake.

2 HORONOBE UNDERGROUND RESEARCH LABORATORY

2.1 *Location*

The Horonobe URL is located in Horonobe Town, Hokkaido Prefecture, in the north of Japan. The Horonobe URL facility and related surface plant are constructed on the land in suburb of central Horonobe town.

2.2 *Geology, mechanical and physical properties of rock*

The shafts and galleries have been excavated through overlying Neogene sedimentary rocks named Koetoi formation (diatomaceous mudstones with opal-A) and into the Wakkanai formation (siliceous mudstones with opal-CT) (Figure 2). The Koetoi formation and upper part of Wakkanai formation have been faulted and have undergone several episodes of uplift and subsidence from the Miocene to the Pliocene, indicated by the presence of lacustrine and marine sedimentary formations unconformably overlying the basement (Hayano and Ishii 2016) (Figure 3). Table 1 shows properties of the formations and groundwater.

2.3 *R&D in Horonobe URL*

The Horonobe Underground Research Laboratory (Horonobe URL) Project was commenced in March 2001 by JAEA. This planned to extend over 20 years and comprises three phases: Phase 1: Surface-based investigations, Phase 2: Construction

Table 1. Properties of rock and groundwater.

Property	Koetoi F.	Wakkanai F.
UCS* (MPa)	1.44–9.80	8.90–34.9
Young's modulus (GPa)	0.38–1.03	1.41–6.35
Poison's ratio	0.22–0.47	0.17–0.34
Effective porosity (%)	60–65	40–50
Unit weight (kN/mm^3)	14–16	15–19
Hydraulic conductivity (m/s)	10^{-8}–10^{-9}	10^{-6}–10^{-11}
Swelling pressure index (MPa)	0.04	0.03
Slake-durability index (I_{d2}) (%)	>90	>95
Dissolved gas	Methane dominant	
Groundwater	Saline water	

*Unconfined compressive strength

Phase (investigations during construction of the underground facilities), and Phase 3: Operation phase (research in the underground facilities) (JNC 2005). The URL Project is currently in Phase 3.

In Phase 1, several hundred meters boreholes were excavated, and geological, hydrological, geochemical and mechanical investigations were performed to predict deep geological environment. Based on the results of borehole investigations models were developed and excavation disturbance were analyzed. Mechanical stability of the shaft and gallery, ventilation analysis, countermeasures against high-pressure water inflow and earthquake-resistant were analyzed for construction planning. Mechanical excavation method were selected for main part of shaft and gallery. Figure 4 shows some results of development of hydrogeological model and groundwater flow simulation.

In Phase 2, groundwater pressure monitoring were performed in the deep boreholes during shaft sinking (Figure 5). Excavation disturbed zone (EDZ) experiments were also performed in the shafts and galleries. Low-pH cement were developed and used as shotcrete for the support system of the gallery and used for grouting materials as countermeasures for large amount of inflow.

In Phase 3, three main issues; near-field performance study including full-scale EBS (Engineered Barrier System) experiment (Figure 6), overpack corrosion test and in-situ mass transport test, demonstration of repository design options, and verification of the crustal-movement buffering capacity of sedimentary rocks, have been performed in the 350 m depth research gallery. Heating test of the full-scale EBS experiment was commenced in January 2014, and T-H-M-C coupled data were cor-

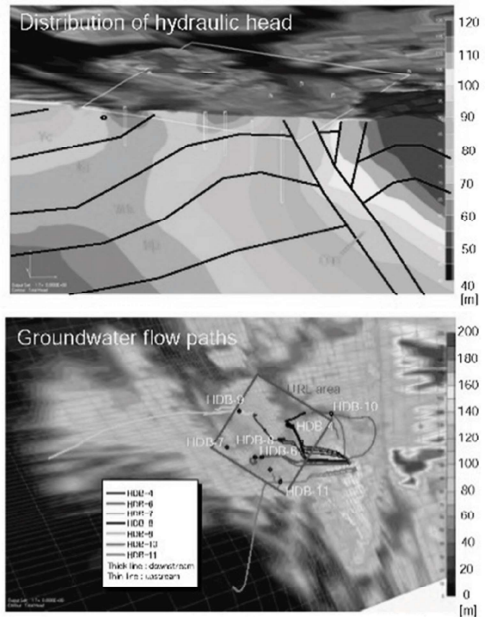


Figure 4. Distribution of hydraulic head and groundwater flow paths obtained by the optimization analysis.

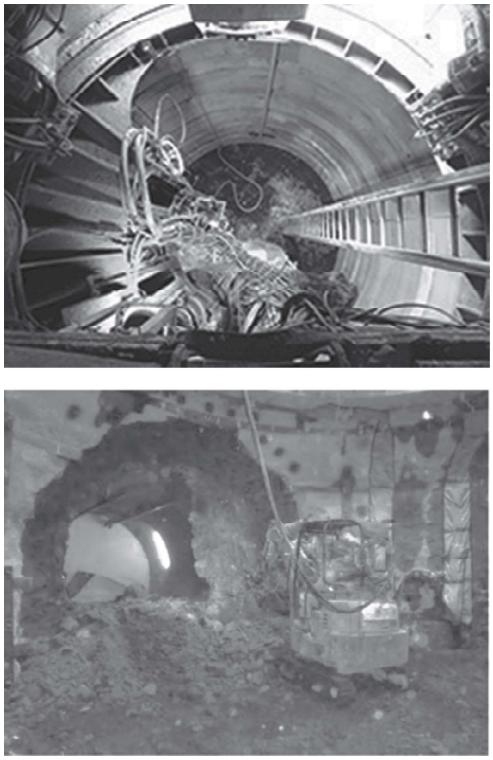


Figure 5. Photos of excavation of shaft and gallery.

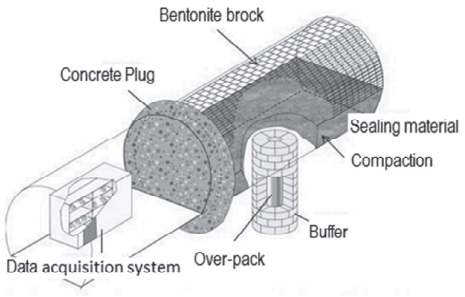


Figure 6. Conceptual design of full-scale EBS experiment.

rected by 200 sensors of thermometer, strain meter, displacement meter, pressure meter, moisture meter, pH meter, platinum electrode, etc. Resistance tomography could show the distribution and its change with time of moisture content of buffer material. Single-hole tracer test for intact rock, and cross-hole tracer test for single fracture and fault have been performed, and sorption coefficient and adsorption coefficient were obtained.

3 STUDY ON ROCK DYNAMICS

3.1 *Earthquake-resistant design*

To ensure safety during construction of the underground facility, it is essential that the shafts and galleries are not only stable during excavation but also remain stable and resistant to damage with respect to earthquakes. Numerical analysis using static techniques were performed in Phase 1 to understand stress on the concrete liner and the surrounding rock mass under static loads, and for comparison to intensity of a dynamic load, assuming a significant earthquake generated by movement on the nearest active fault in North—West area in the Sea of Japan, having a maximum ground acceleration equal to 230 gal. Calculations of the principal stresses, the major shear strains and the local safety factors in the excavated shafts and arising from an earthquake after shaft excavation showed that the changes in these parameters are very small. The stresses induced in the design supports induced by an earthquake are lower than the allowable value.

In 2007, new fault names Sarobetsu fault zone in and around Horonobe town (L = 44 km, M = 7.6, Minimum distance = 6–7 km) was evaluated as active fault (The Headquarters for Earthquake Research Promotion, 2007).

SHAKE, a computer program for earthquake response analysis of horizontally layered sites

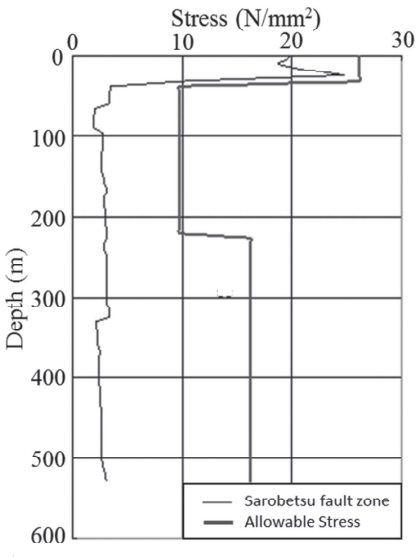


Figure 7. Calculated stress induced in the design supports induced by Sarobetsu fault.

was applied to calculate equivalent seismic intensity. Maximum share stress was also calculated and compared with allowable stress of supports. The results of calculation indicated that the stress induced in the design supports induced by Sarobetsu fault zone are also lower than the allowable value (Figure 7).

3.2 *Seismic records*

Seismic accelerations have been measured using seismometers installed on the ground surface and at the 250 m deep research gallery. Among all earthquakes observed in Apr. 2011 to Mar. 2013 (Table 2), this research relates to the one that occurred in Rumoi-chiho Chuhokubu on January 3, 2013 with the largest magnitude and maximum acceleration observed in Horonobe. Depth comparisons of the time history waveforms of the accelerations by direction are shown in Figure 8. Accelerations peaked first at the depth of 250 m, then on the ground surface, suggesting that seismic motions had moved from downwards. Accelerations are found to get amplified from the depth to the ground surface.

3.3 *Groundwater pressure change due to earthquake*

It is well known that large earthquakes induce groundwater level and pressure changes. In Japan, largest earthquake, the 2011 off the Pacific coast of Tohoku Earthquake (M_w 9.0), induced groundwater level and pressure changes in a wide area of

Table 2. Earthquakes observed in Horonobe (Apr. 2011 – Mar. 2013).

Observed at	Region Name	Depth (km)	Magnitude	Max. Acceleration (Gal) Surface	GL. –250 m	Surface/ GL. –250 m
2011/8/12 7:26	Hokkaido Hokusei-oki	28	3.9	–	4.0	–
2011/8/163:25	Hokkaido Hokusei-oki	28	2.6	–	0.8	–
2011/9/10 14:32	Soya-chiho Hokubu	0	2.2	–	2.6	–
2012/7/15 23:08	Kamikawa-chiho Hokubu	0	4.2	3.4	0.9	4
2012/7/166:49	Kamikawa-chiho Hokubu	0	4.3	4.8	1.5	3
2012/7/IS 4:39	Kamikawa-chiho Hokubu	0	4.1	4.0	1.3	3
2012/7/lS4:50	Kamikawa-chiho Hokubu	0	4.1	3.0	1.2	3
2012/8/14 11:59	Ohotsuku-kai Nanbu	654	7.3	–	1.2	–
2012/10'5 21:36	Soya-chiho Hokubu	12	2.3	4.0	2.4	2
2012/10'7 8:39	Soya-chiho Hokubu	7	3.4	5.5	1.7	3
2012/11/1011:26	Soya-chiho Hokubu	28	3	2.6	1.4	2
2012/12/1715:30	Soya-chiho Hokubu	29	3.7	13	6.0	2
2013/1/320:14	Rumoi-chiho Chuhokubu	24	4.8	17	6.6	3

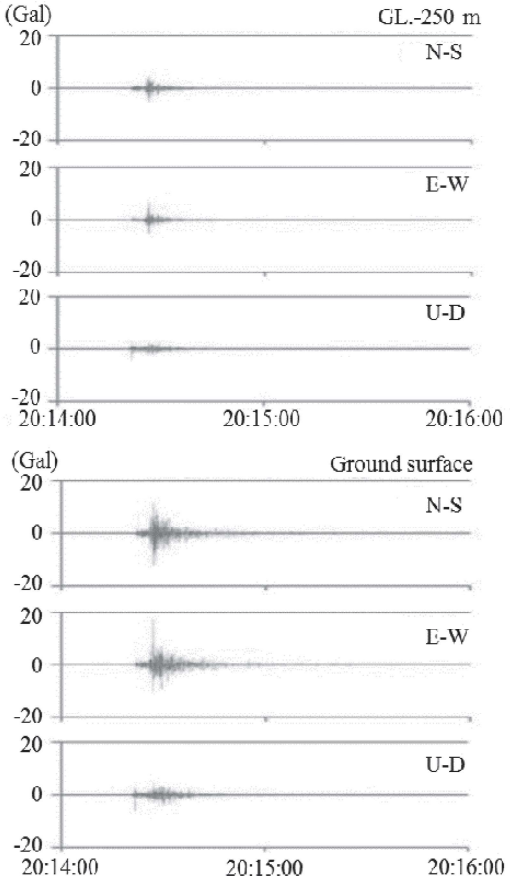


Figure 8. Seismic records of Rumoi-chiho chuhokubu earthquake (3 Jan. 2013, M =4.8).

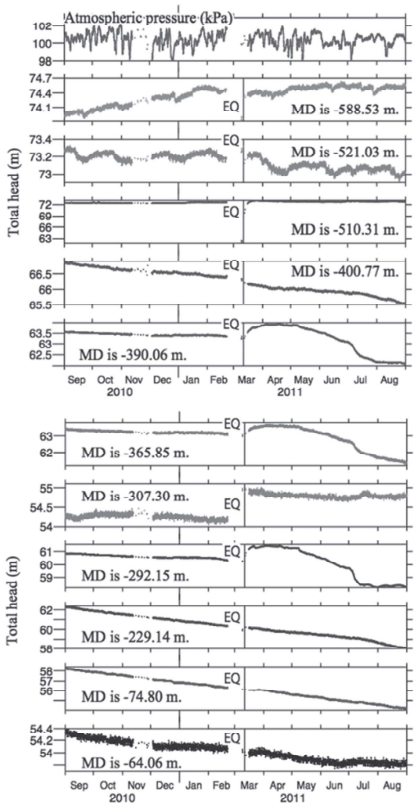


Figure 9. Groundwater level change in the HDB-6 borehole in Horonobe due to the 2011 off the Pacific coast of Tohoku Earthquake. Vertical line with EQ is the date of the Tohoku earthquake. MD is the monitoring depth below ground level.

Japan. Both in Horonobe and Mizunami URLs groundwater level and pressure changes were observed in almost boreholes (Miyakawa et al. 2011, Niwa et al. 2012) (Figure 9). Distance from the epicenter is about 825 km and 525 km, respectively. Maximum level changes were several 10 cm and 15 m, respectively. Variation of change, drawdown/elevation, urgency and quantity, were considered to be influenced by dilatation/constriction, geological setting, hydraulic conductivity, hydraulic gradient, etc. But, these changes had recovered and returned to an original trend in several months or one year. This phenomenon means inelastic behavior did not occurred. These changes due to large earthquake would not have a fatal influence to safety of geological dispos al system in the area several hundred far away from epicenter.

4 CONCLUSIONS

Horonobe Underground Research Laboratory is off-site URL constructed in soft sedimentary rock to the depth of 350 m with three shafts and three level experimental galleries. This URL project is 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.

Rock dynamics is one of key issue for research and development of techniques for safe geological disposal of high-level radioactive waste. This paper shows some results of earthquake-resistant design of shafts, observation of seismic records and groundwater pressure change due to the 2011 off the Pacific coast of Tohoku Earthquake. As results of calculation indicated that the stress induced in the design supports induced by Sarobetsu fault zone which was newly recognized active fault are lower than the allowable value of supports system of shaft. Seismic accelerations have been measured and accelerations are found to get amplified from the depth to the ground surface. Groundwater level and pressure changes due to the large earthquake were observed. These changes had recovered and returned to an original trend in several months or one year. These changes would not have a fatal influence to safety of geological disposal system in the area far away from epicenter.

Further development of rock dynamics in Horonobe URL project is necessary to continue observation of seismic records and develop methodology of earthquake-resistant design for deeper underground.

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