Mechanical behavior of an underground research facility in Korea Atomic Energy Research Institute

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SUMMARY

An underground research facility (KURF) is under construction at KAERI for the in situ studies related to the validation of a HLW disposal system. For the safe construction and long-term researches at KURF, mechanical stability of the facility should be evaluated. In this study, 3D mechanical stability analysis using the rock mass properties determined from various in situ as well as laboratory tests was carried out. From the analysis, it was possible to predict the rock deformation, stress concentration, and plastic zone developed before and after the excavation. A test blasting was performed to characterize the site dependent dynamic response, which can be used for the prediction of the blasting impact on the facilities in KAERI.

1. INTRODUCTION

In order to develop a reasonable disposal system, it is necessary to validate the system in a rock similar to the host geological formation. In Korea, a small scale underground research tunnel, KURF, for validating the design of the underground high-level waste (HLW) repository is being planned. The KURF will be a major infrastructure for the HLW disposal program and various in situ studies such as rock behavior, in situ stress change, influence of discontinuities, excavation disturbed zone study, fluid flow in rock mass, heater test at different scales, Thermo-Hydro-Mechanical experiment, generation and migration of colloids, and the validation of the processes for the transportation, emplacement, retrieval operation, and closure will be carried out at KURF. The construction of the facility was started in May 2005 and the first stage of the construction of the access tunnel was successfully completed in Aug. 2005. The tunnel length to be excavated in 2005 is about 110m.

2. GEOLOGICAL SURVEY AT THE SITE

In order to determine the geological condition of the site, a surface survey, seismic survey, electric resistivity survey, borehole drilling, borehole observation, and laboratory tests were carried out in 2003 (Kwon et al., 2004).

A geophysical survey was carried out to estimate the location and size of the lineaments and to obtain the thickness of the overburden. The survey lines for the geophysical survey were decided on with a consideration of the expected tunnel length and tunnel direction. For the direct investigation of the geological characteristics, a 160 m long vertical borehole and a 252 m long declined borehole along the expected tunnel direction were drilled. Figure 1 shows the fault zone, fracture zone, water conducting zone, as joints detected from the geological survey.

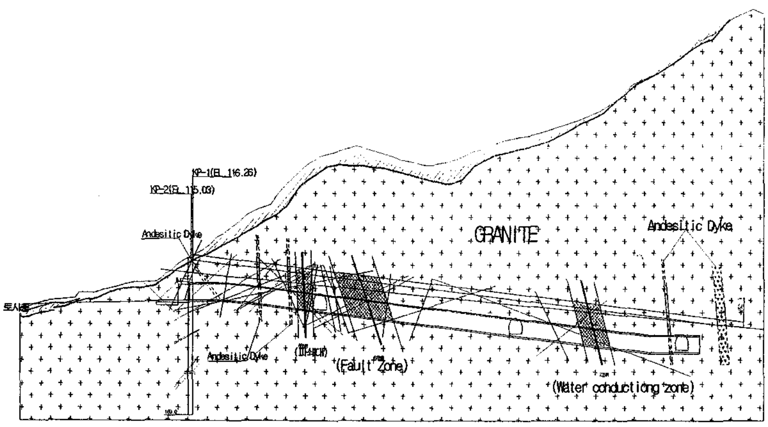

Fig. 1. Geological conditions expected during the excavation of the KURF

The poor rock condition nearby the entrance becomes better at the 82-125 m range. After the poor rock shown briefly at around 125 m, good and hard rock is likely to be met until 177 m. There is another fracture zone at the range of 177-192 m. After that the rock conditions become better. The variation of the rock condition along the declined borehole could be described with a variation of the Rock Mass Rating (RMR). The ranges with the RMR higher than 41 are 85 % of the whole range. About 24 % of the whole range shows the RMR at over 81, which can be classified as "Very good rock".

3. KURF DESIGN

The KURF will be utilized for various in situ experiments. The research modules, at which major research will be performed, should be located at a depth of more than 100 m to obtain the low-oxide-condition. Also good rock conditions are required for maintaining the underground tunnel for a long time with a limited rock support mainly consisting of rock bolts and wire mesh. Drill and blasting will be applied to make the horseshoe shape access tunnel and research modules. Considering the requirements, the basic design could be made. Figure 2 shows the schematic drawing of the conceptual design of the KURF.

The access tunnel size was selected as 6 m x 6 m after a consideration of the disposal tunnel size, which is 6 m and 7 m in the referenced disposal concept (Kang et al., 2000). The tunnel size was also recommended to allow for the use of a jumbo drill and other equipments typically used for a tunnel construction.

A downward tunnel slope is recommended to achieve the required depth. After a consideration of the workability and efficiency of achieving the required depth as well as the geophysical survey results, a -10 % access tunnel design was suggested. By placing the research modules below the 208 m high mountain, the required depth can be easily achieved with a short access tunnel. Based on the local topography and boundary of the KAERI site, a tunnel direction of N56^{o}W was chosen. When the tunnel direction is N56^{o}W, the major joint sets are almost perpendicular and a tunnel stability would be achieved more easily.

Two 25 m long research modules will be made at the end of the access tunnel. Fortunately the rock mass at the end of the access tunnel can be classified as "Good rock" according to the borehole investigation. The tunnel size is exactly the same as the access tunnel to simplify the construction and maintenance processes. For the research modules, it is recommended to apply a cutting-edge blasting technique in order to minimize the damage on rock.

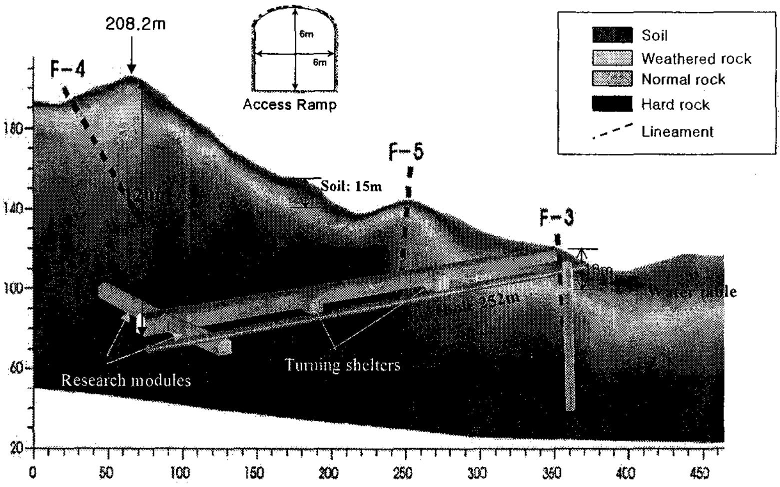

Figure 2. Schematic drawing of the URT

4. ROCK MASS PROPERTIES

In order to determine the rock properties at the site, the following in situ tests have been carried out:

- Hydraulic pressure test : Total 36 hydraulic pressure tests were carried out to determine the hydraulic conductivity of the rock mass.
- Goodman jack test: The deformation modulus at the site was measured in the vertical borehole with a Goodman Jack test.
- Borehole shear test: The cohesion and friction angle of the upper soil layer were measured using a borehole shear test.
- BIPS and BHTV : The distribution and aperture of the discontinuities were determined by using BIPS(Borehole Image Processing System) and BHTV (Borehole Televiewer).
- Hydraulic fracturing test: In the vertical borehole, hydraulic fracturing tests were performed to measure the in situ stress.

From the tests, the representative rock and rock mass properties in the research modules and the variation of the rock properties along the access tunnel could be determined(Kwon et al., 2005). It was also possible to estimate the representing rock properties in different ranges along the tunnel(Table 1). The variation of the rock properties was used in the mechanical stability analysis.

Table 1. Estimated rock mass properties at the specified ranges

Parameters	Range(m)				
	30-82	82-125	125-177	177-192	192-252
Interval(m)	52.9	42.6	51	15.2	60.1
Dip	88	68-88	68-90	90	90
σ_{ci} (MPa)	30.8	58.4	71.6	77.6	82.7
E_m(GPa)	3.2	12.1	37.9	6.21	20.4
Bulk modulus(GPa)	2.13	8.07	25.3	4.14	13.6
Shear modulus(GPa)	1.28	4.84	15.16	2.48	8.16
Cohesion(MPa)	1.7	4.2	6.7	4.6	6.4
Friction angle	35	40	46	36	42
Tensile strength(MPa)	0.014	0.102	0.49	0.047	0.23
Model type	Mohr-Coulomb				

5. STABILITY ANALYSIS USING FLAC3D

For the mechanical stability analysis of the underground facility, a three-dimensional continuum code, FLAC3D, was used. FLAC3D is an explicit finite difference program(Itasca, 1996). For the stability analysis of the access tunnel, a model mesh was made which considered the actual topography around the small scale URL site. Figure 3 shows the principal stress distributions, displacements, and plastic zone development after the excavation. A maximum principal stress of about 10 MPa was developed in the tunnel roof. The stress concentration in the roof was mainly due to the horizontal stress acting along the x axis. Along the tunnel wall, about 3MPa compressive stresses were developed. For the minimum principal stress distribution, tensile stresses up to 0.4 MPa were developed around the tunnel and the surface especially in the left region. According to the displacement plot, up to 9 mm is expected to be developed around the tunnel entrance part. The horizontal displacement from the tunnel wall was much higher than the vertical displacement from the roof and floor. This might be due to the higher horizontal stress than the overburden load. The stress redistribution after an excavation expands the plastic zone generated due to the erosion effect. In the tunnel roof close to the tunnel entrance, a plastic zone of about 1m was developed, while up to a 3 m plastic zone was developed in the floor. In the tunnel wall, about a 1m thick plastic zone was also developed after an excavation.

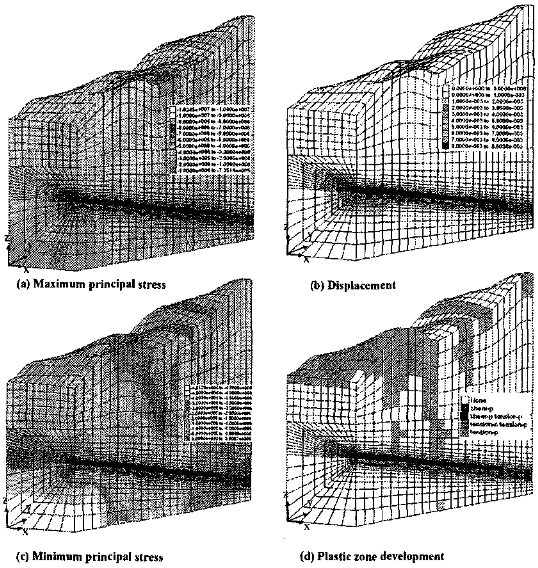

Fig.3. Modeling results after excavation

6. DYNAMIC CHARACTERISTICS OF THE SITE

To construct the KURF, it is necessary to assure that the blasting impact will not disturb the operation of the neighboring facilities including the research reactor, Hanaro, which is located at about 500m from the center of the access tunnel. The nearest facility is located at about 272m from the site. In order to check the blasting impact, a test blasting was performed and the vibration and noise were measured at 8 different locations. For the test blasting, total 31kg of explosives were installed in 92 blastholes. The explosives were blasted in several steps to reduce the vibration and nose. From the measured vibrations and noises, the following empirical equation could be suggested:

$$V = 83.24\left(\frac{D}{\sqrt{W}}\right)^{-1.45} \qquad (1)$$

where, V is vibration (cm/sec), D is distance (m), and W is the amount of explosives blasted simulataneously (kg). Using the equation, it was possible to estimate the blasting impact at different locations. Figure 4 shows the predicted blasting impact when the tunnel center is blasted with a maximum amount of explosives.

According to the design criteria for blasting in Korea, 0.2cm/sec is the limited ground velocity allowed for the most sensitive structures such as cultural assets and precision machinery. Compared to the criteria, the vibration levels at the locations are quite low and the excavation work by utilizing the blasting design was allowed.

The tunnel was blasted once a day during weekdays and 1m-2.5m advance could be achieved depending on the rock conditions. The vibration and noise level due to the blasting were recorded at about 200m from the tunnel entrance. Figure 5 shows the comparison between the predicted and measured vibration. The vibration increases with tunnel advance is mainly due to the increase of explosives to be blasted at once. The measured vibration is much lower than the prediction using Eq.(1). The difference would be due to the variation of the rock condition and rock type along the tunnel, but further study is necessary for understanding the difference.

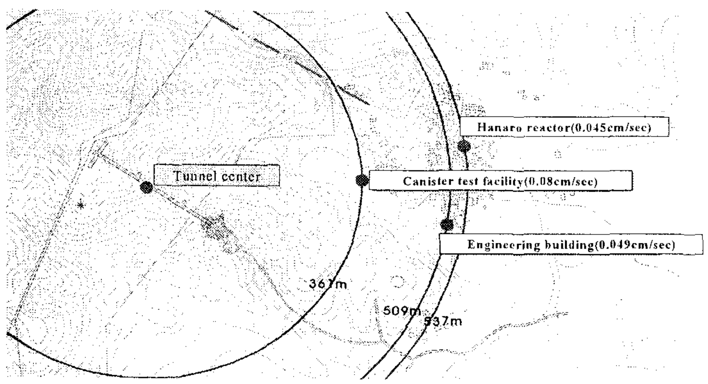

Fig. 4. Calculation of the vibrations at different locations when the blasting will be undertaken at the tunnel center.

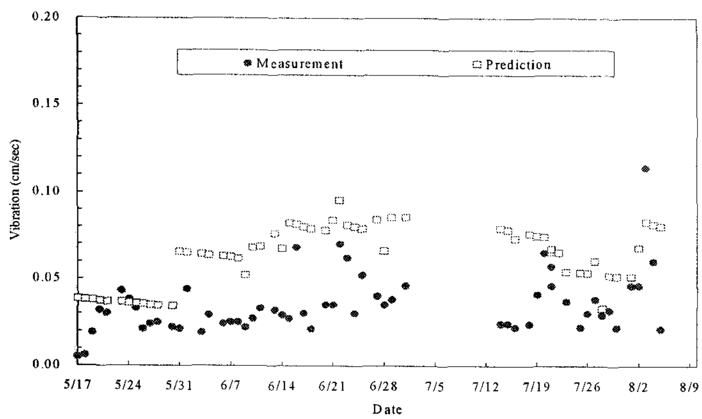

Fig. 5. Comparison of the measured and predicted vibration due to the blasting

7. CONCLUSIONS

For the safe disposal of HLW in a geological formation, validation of a disposal concept in an underground tunnel is essential. In this study, the rock mass properties at KURF site were determined from various in situ and laboratory tests and used for the mechanical stability analysis using a 3D modeling code, FLAC3D. From the computer simulations, the development of plastic zone and the displacement and stress change before and after tunnel excavation could be investigated.

From the test blasting at the site, an empirical equation, which can show the relationship between the amount of explosive and vibration at a location, was derived and used for the possible blasting impact on major facilities at KAERI. According to the daily measurement of the vibration and noise, the vibration increases with tunnel advance. The measured vibration was much lower than the predicted one using the empirical equation derived from the test blasting. Compared to the design criteria for blasting in Korea, 0.2cm/sec, the measured vibration is insignificant and thus it was concluded that the blasting work at the site would not disturb the neighboring facilities.

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