Key Parameters and Distribution in Rock Mechanics for HLW Site Selection in Korea

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ABSTRACT: A step-by-step approach is being adopted worldwide with respect to site selection for the geological disposal of high-level radioactive waste (HLW). Korea also adopted a three-step approach. In order to conduct systematic and efficient site investigation and site evaluation, a classification system for evaluation elements by stage has been proposed, and it is subdivided into aspects, items, and parameters. Among a total of 17 items and 103 parameters, rock engineering-related items are 3 items and 33 evaluation parameters. Uniaxial compressive strength, in-situ stress are selected as key evaluation parameters, taking into account domestic and foreign cases, the importance of rock engineering, and the existence of international standard testing methods. Their characteristics and the distribution range of the domestic parameters are investigated. In this study, two types of granite were selected and regional distribution characteristics were analyzed based on the data obtained through drilling up to 750 m.

Keywords: HLW, Site investigation, Key parameters, Distribution, Uniaxial compressive strength, In-situ stress.

1 INTRODCUTION

According to the 1st (2016) and 2nd (2021) high-level radioactive waste management master plans announced by the government, site investigation and site selection for deep geological disposal of high-level radioactive waste follow a step-by-step procedure. The act related to deep geological disposal of high-level radioactive waste and site selection, which is currently being discussed in the National Assembly, also includes a step-by-step site survey procedure. A step-by-step site investigation procedure has been proposed by the International Atomic Energy Agency (IAEA, 1994). Similar to the IAEA and advanced countries, Korea's step-by-step site survey is planned for the third step, which is to conduct a nationwide survey, exclude unsuitable areas, and conduct basic and detailed surveys on the remaining candidate sites.

Based on domestic and foreign research cases, Kim et al., (2020a) proposed the geoenvironmental evaluation parameters necessary for site surveys at each step. The proposed classification system for investigation parameters was divided into evaluation aspects, items, and parameters, and a total of

17 items and 103 parameters were proposed, of which 33 were related to rock mechanics and engineering. The Korea Institute of Geoscience and Mineral Resources, which conducts research on geology and resources in Korea, is conducting deep drilling and multidisciplinary geoscientific surveys for the deep geological disposal of high-level radioactive waste on Korea's representative rock types, considering the geologic tectonic structures.

This study deals with the results of investigations on uniaxial compressive strength and in-situ stress, which are considered most important evaluation parameters in the field of rock mechanics and rock engineering, using drilling investigations on granite, one of Korea's representative rock types. In addition to the evaluation parameters studied here, it is clear that other rock mechanics evaluation parameters must also be investigated according to the stage.

2 STEPWISED SITE INVESTIGATION AND EVALUATION PARAMETERS RELATED TO ROCK MECHANICS

HLW site investigation is the process of selecting a site suitable for the purpose of high-level radioactive waste disposal and verifying that the site has characteristics suitable for the purpose. For systematic and efficient site investigation, IAEA (1994) proposed a step-by-step site investigation process (Table 1). The first stage is the disposal concept and planning stage, which includes the exclusion of unsuitable areas, followed by a basic or national-wide survey, followed by a detailed survey to propose two or three final candidate sites. According to Korean government 2nd Master Plan for High-Level Radioactive Waste, the social consensus process such as application for site by resident and referendum for site is included in the phase (Figure 1).

Table 1. Stepwise siting process for a HLW repository (IAEA, 1994).

	Stage	Remarks
1	Conceptual and planning	Define overall plan, guiding principles, and criteria
2	Area survey	Select one or more potential sites
3	Site characterization	Collect site-specific information and assess suitability of the site
4	Site confirmation	Select a final repository site

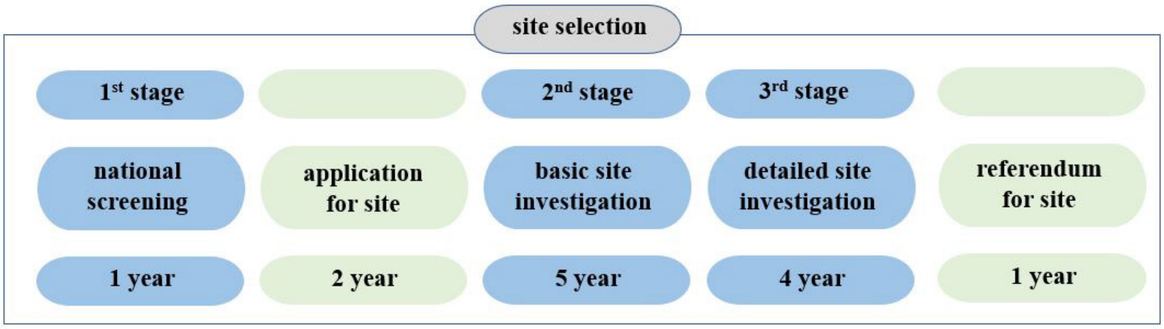

Figure 1. Site selection procedure in 2nd master plan in Korea.

According to the step-by-step evaluation parameters proposed by Kim et al. (2020a), evaluation parameters related to rock mechanics and rock engineering are used from the second step, and are largely divided into 3 items and 33 parameters: fracture, intact rock, and rock mass. In the case of Sweden, after classifying into discontinuities, mechanical properties of fractures/intact rock/rock mass, boundary conditions and supporting data as parameters, detailed properties were classified. In this study, the distribution characteristics of the uniaxial compressive strength and in-situ stress, which were considered to be the most basic and important among evaluation parameters related to rock mechanics, were studied based on the information of the granite area where deep drilling was performed.

Table 2. Evaluation parameters regarding rock mechanics and engineering in Korea and Sweden (Kim et al., 2020a, SKB, 1998).

	Korea			Sweden
item	Fracture	Intact rock	Rock Mass	
	Density	Water content	Deformation modulus	Discontinuities
	Magnitude	Specific gravity	Poisson’s ratio	Mechanical properties of intact rock
	Orientation	Porosity	Tensile strength	
Parameter	Aperture	Seismic velocity E	Compressive strength	Mechanical properties of rock mass
	Stiffness	Poisson’s ratio	Shear strength	
	Cohesion	UCS Tensile strength	Rock Mass Classification	Density and thermal properties
	Dilation angle	Cohesion, friction angle	In-situ stress	
	Joint roughness	Creep constant	Anisotropy and heterogeneity	Boundary conditions and supporting data
	JCS	Crack initiation /damage stress Fracture toughness Permeability		

3 UCS AND IN-SITU STRESS DISTRIBUTION ON THE KOREAN PENNINSULA

Kim et al. (2020b) built a database by collecting a total of 1,401 stress information measured by hydraulic fracturing and overcoring methods at depths of 10 to 880 m underground from 306 boreholes in Korea. Based on the DB, the stress information was classified according to the world stress map qualitative grade (A-E grade) and stress field (NF, SS, TF), and the Korean stress map 2020 was produced as shown in Figure 2(left). Overall, the direction of maximum horizontal stress in the Korean Peninsula ranges from northeast to southeast.

The spatial distribution of uniaxial compressive strength (UCS) on the Korean Peninsula was calculated by performing regular kriging based on more than 2000 data and location information. Since the data used have a large difference in sample size depending on the region or rock type, there is a limit in that they are concentrated in some specific regions, but a rough overview of the spatial distribution of the entire Korean Peninsula can be confirmed. The blue color in figure 2 (right) means that the UCS is high.

4 VALUES AND DISTRIBUTIONS OF EVALUATION PARAMETERS IN THE RESEARCH AREA

Korea's geological structure is composed of complex and diverse types of rock. Plutonic rock, metamorphic rock, and sedimentary rock according to the geological map published by the Korea Institute of Geological Resources account for 30%, 30%, and 25%, respectively. Among them, in this paper, Mesozoic Jurassic Granite in Chuncheon and Wonju area, which belong to the geological structure of Gyeonggi massif and Okcheon belt, was selected as the research area. The mechanical characteristics of the research area were obtained through surface geological surveys, deep drilling, field and laboratory tests.

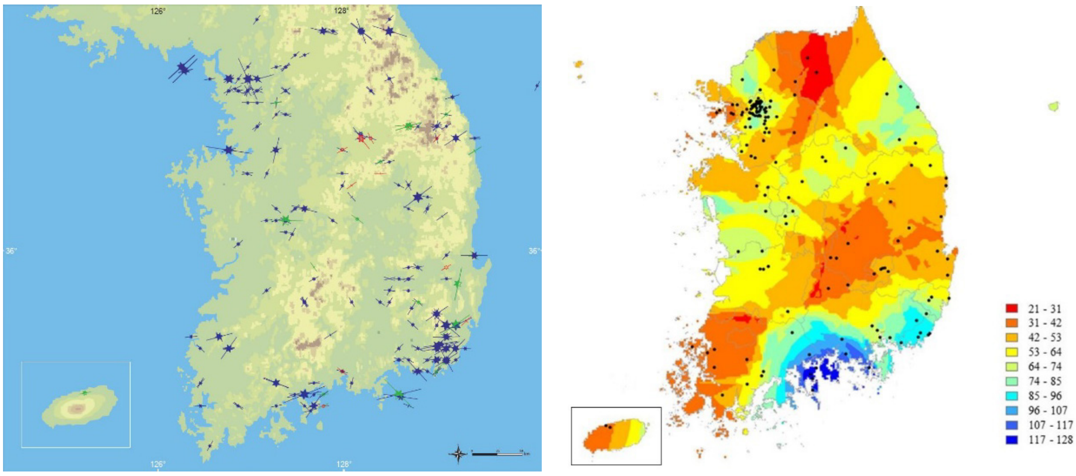

Figure 2. Korea stress map 2020(left) and UCS spatial distributions (Kim et al. (2020), Choi et al. (2021)).

Figure 3 shows the distribution of UCS according to depth and statistical distributions of UCS in Chuncheon and Wonju. Whether the UCS properties followed a normal or lognormal distribution was tested. The Shapiro-Wilk test was performed because the number of UCS samples obtained from the two regions was less than 50. There was no normal or lognormal distribution in the Chuncheon area, but the UCS in the Wonju area showed that normality could not be rejected at the significance level of 0.05. When calculating the UCS representative value and range, Bayes' theorem is used to combine the test results obtained in this study area and the results of existing references, and a prior distribution is generated from UCS data conducted in Chuncheon and Wonju as prior information. Using the new UCS and prior distribution in the study area, the posterior distribution of the UCS mean was estimated with MCMC, and the results shown in Figure 4 were obtained. Estimated from the posterior distribution, the average of granite in Chuncheon area was 123 MPa and the deviation was 59 MPa, and the granite in Wonju area was 171 MPa and 46 MPa, respectively.

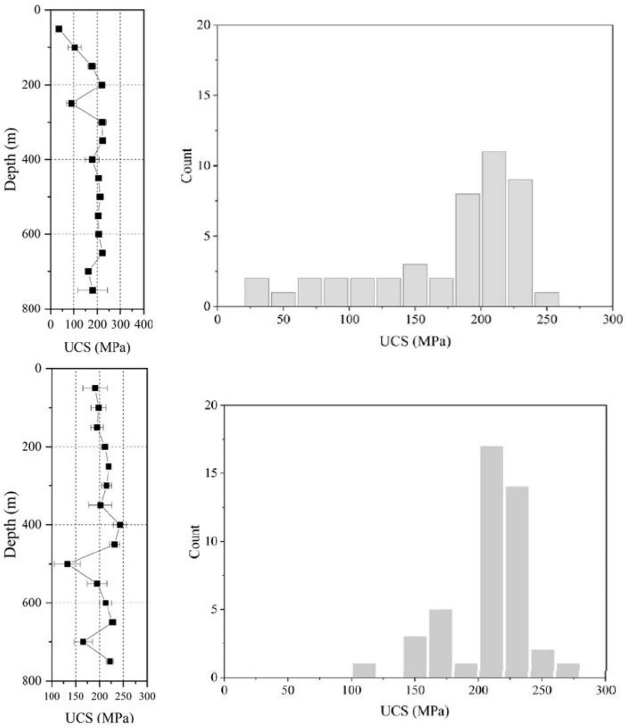

Figure 3. Distribution with depth and statistical distribution of UCS in Chucheon (up) and Wonju (bottom) (modified from Cheon et al., 2022).

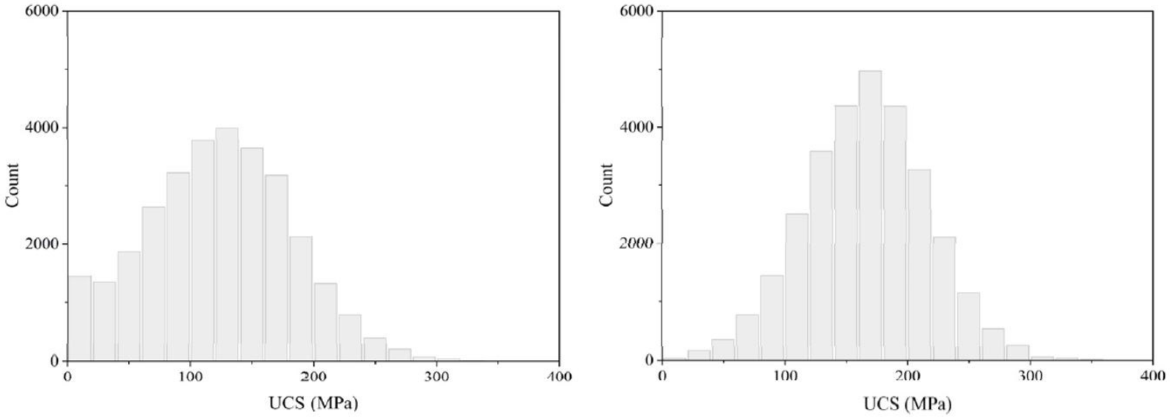

Figure 4. Posterior distribution of the UCS in Chucheon (left) and Wonju (right) (Cheon et al., 2022).

As a result of analyzing the regression equation of the in-situ stress obtained by the hydraulic fracturing test by constructing y = ax + b, the maximum stress acting in the Chuncheon area was less than 40 MPa and less than 30 MPa in the Wonju area as shown in Figure 5. Since the stress ratio is generally inversely proportional to the depth, the regression equation is set to y = a/x + b. As a result of the analysis, there is stress anisotropy along the direction in Chuncheon, but the ratio is not large at 1.3. In the case of Wonju, the deeper the depth, the more converged to 1.

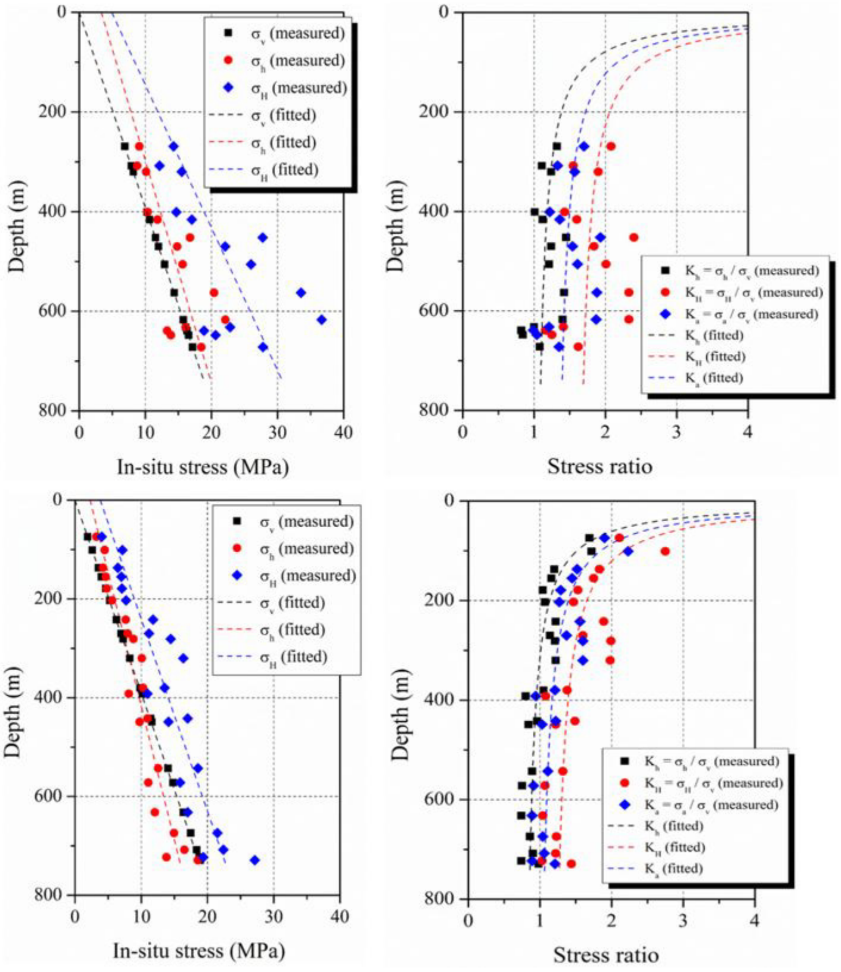

Figure 5. Magnitude and stress ratio with depth in Chucheon (up) and Wonju (bottom) (modified from Cheon et al., 2022).

5 CONCLUSION

In this study, uniaxial compressive strength and in situ stress, which are considered as key evaluation parameters among the evaluation parameters in the field of rock mechanics and engineering required in the site investigation for deep disposal of high-level radioactive waste, were evaluated. The subjects of the study were granite in Chuncheon and Wonju where deep drilling was performed. In advance, the spatial distribution of uniaxial compressive strength and the distribution characteristics of in situ stress, along with geological information such as the geologic characteristics of Korea and the area of distributed rock types, were investigated based on reference data. Afterwards, statistical processing using Bayesian theorem was performed to estimate the distribution and range of uniaxial compressive strength. In the case of the in-situ stress, the magnitude of the in-situ and the range of stress ratio with depth were estimated by setting a regression equation considering the change characteristics with depth. In addition to the two key evaluation parameters presented here, analysis of the others required in the site selection is continuously needed.

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