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An Overview of the Mechanics of Disaster Rock Masses

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Abstract

Rock mass mechanics can be characterized into designing stone mass mechanics and calamity rock mass mechanics in light of science and application. They were developed in terms of their concept, object, scientific essence, and application. Disaster rock mass mechanics' meaning, research method, and theoretical framework were discussed. Fiasco rock mass mechanics is an unequivocally nonlinear discipline that is serious areas of strength for a to concentrate on regular and misleadingly prompted calamities. In its critically unstable state, the rock mass system where disasters occur exhibits extreme spatial and temporal nonlinearity. Therefore, a statistical analysis of highly probable events is necessary for disaster prediction and forecasting to be effective. Finding the quantitative or semi-quantitative relationship between physical and biological information and the instability of rock mass systems could be the direction of disaster prediction efforts.

For a deep geological repository of high-level radioactive waste, the mechanical behavior of the host rock is crucial to its isolation as a natural barrier in the multi-field coupling environment. For a superior comprehension of stone in China's Beishan pre-chosen region for geographical removal of significant level radioactive waste, a progression of examinations were completed on in-situ pressure field of rock mass at profundity, strength and misshapening qualities of rocks under various pressure and temperature conditions, and rock boreability and flexibility to Passage Exhausting Machine (TBM) innovation. The findings indicate that Beishan granite is suitable for geological disposal because it possesses the typical characteristics of a hard, brittle rock with a low permeability. In the interim, another stone mass appropriateness assessment framework was proposed, and the stone mass fundamentally made out of Beishan rock was shown to be reasonable for geographical removal. Additionally, the constructability of Beishan stone at designing scale was tried and confirmed through field tests in the Beishan Investigation Passage (BET). In this section, we present the most recent developments in the Beishan underground research laboratory (URL) for geological disposal as well as a summary of the main findings of rock mechanics research on Beishan granite over the past few years.

Keywords: Beishan granite; High-level radioactive waste; High-level radioactive waste; Exhausting machine

Introduction

Safe removal of significant level radioactive waste (HLW) is a central question for the economical improvement of the atomic business. Deep geological disposal is now accepted as the most feasible method for the final disposal of HLW after roughly 50 years of research. At several hundred meters below the surface of the ground, a host rock can be used to build a deep geological repository (DGR) [1]. A multi-barrier system, which typically consists of a natural geological barrier and an engineered barrier system, is frequently used in the design of DGRs. As the last safeguard to the biosphere, the regular geographical obstruction (i.e., the host rock) assumes a basic part in guaranteeing the drawn out wellbeing of the HLW vault [2]. This objective can only be accomplished with a thorough comprehension of the host rock's mechanical behaviors.

China's strategy for HLW disposal is divided into three phases in accordance with the Guidelines on Research and Development (R&D) Planning for Geological Disposal of High-Level Radioactive Waste, which were by the China Atomic Energy Authority (CAEA), the Ministry of Science and Technology (MOST), and the former Ministry of Environment Protection (MOEP). 1) laboratory-based research and the selection of the disposal facility's location from 2006 to 2020; 2) underground testing and research from 2021 to 2040; and 3) construction of the disposal facility from 2041 to 2050. In addition, the thirteenth Five-year Plan of China (2016-2020) expressed that "the development of China's URL for HLW removal ought to begin before 2020", demonstrating that the Chinese government connects extraordinary significance to the improvement of the URL.

Site determination for China's DGR begun in 1985. Extensive exertion has been committed to the choice of likely destinations in stone developments [3].Due to the fact that granitic rocks are suitable for hosting repositories and the widespread presence of granite formations in China, granite formations received the most attention. China's DGR was recommended to prioritize the Beishan region in northwestern China in 2011. In 2016, the Xinchang site in the Beishan not entirely set in stone as China's URL site. Thus, we call China's most memorable URL for HLW removal as the Beishan URL.

The Beishan URL site is in the middle of the 22-kilometer-long and 7-kilometer-wide Xinchang granite intrusion, which is in the middle of the Beishan area. The Gobi Desert's relatively flat topography of the URL site is characterized by a few small hills. The stone sorts predominantly incorporate monzonitic rock and granodiorite. The fact that 86.2% of the total drill cores have RQD values greater than 90% indicates that the rock mass at the site is very well-integrated. In addition, the rock cores that were taken out of seven engineering exploration boreholes that were dug during the URL's initial design phase exhibit exceptionally high integrity.

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In the meantime, a 2016 pilot engineering for Beishan URL, the Beishan Exploration Tunnel (BET), was built, and the engineering-scale constructability of Beishan granite was tested and confirmed [4]. All of the aforementioned accomplishments provided an important foundation for the selection of the location for the Beishan URL and demonstrated the suitability of Beishan granite for geological disposal.

China began constructing the Beishan URL in 2021. June 2022 marked the beginning of the ramp and personnel shaft excavations. The personnel shaft will have been excavated to a depth of 160 meters by the end of 2022, and the drill-and-blast method will have been used to excavate the ramp to a length of 495 meters to make room for the TBM assembly [5]. The excellent quality of the rocks in the area suggests that the shaft and ramp excavations have already provided preliminary confirmation of the rock mass's good integrity at the URL site. At the moment, in-situ tests and the Beishan URL construction are working well together. The Beishan URL is wanted to be developed in 2027.

Stress field in situ at the URL Site for Beishan

At a potential DGR site, the in-situ stress state should be known with enough certainty to provide stress boundary conditions for the design of underground excavations and the evaluation of long-term stability. Because it has a direct impact on the layout of the DGR, it is necessary to accurately determine the orientation of the maximum principal stress in addition to the magnitudes of the components of the in-situ stress. An in-situ stress measurement campaign was carried out as part of the Beishan URL site characterization procedure. In five boreholes ranging from 60 to 600 meters below the surface, 102 hydro-fracturing in-situ stress measurements were carried out. The estimation results show that the in-situ burdens show a rising propensity with expanding profundity (H), despite the fact that there is a disperse in the most extreme level chief pressure (σH) values. When compared to the core sample's uniaxial compressive strength (UCS) values, the magnitudes of H are all less than 25 MPa [6]. Meanwhile, the measured H is typically greater than the estimated vertical stress (v), indicating that the horizontal tectonic stress controls the majority of the regional in-situ stress field at the URL site. Take note of the fact that the magnitudes of H measured in borehole BS37 are greater than those measured in the other four boreholes at depths ranging from 400 to 550 m. One reason might be the borehole BS37 is more like a shortcoming, which impacts the extents of σH got from borehole BS37.

The principal stress variations with depth are further demonstrated by the linear regression analysis. The 95% confidence limits for the linear regressions of the two horizontal principal stress components are depicted by the shaded zones. It is evident that the in-situ stress level at the Beishan URL site is relatively low because the magnitude of H at the depth of 450 m is approximately 15 MPa, which is approximately 50% and 25% of the maximum horizontal stresses measured from the crystalline rock-based Spö Hard Rock Laboratory (HRL) in Sweden and the URL in Canada at the same depth [7]. The predominant orientation of the stresses H is the NEE direction, with an average value of N55°E, which is in general agreement with the orientation of the Beishan area's crustal velocity vectors. The stresses H obtained from all measurement points are all oriented in the NE direction. Due to a small stress difference between the minimum horizontal stress (h) and v, the obtained in-situ stress state favors the stability of the surrounding rocks when the excavation axis is parallel to H for the construction of a DGR.

Compressive qualities

One of the most important stresses in the compressive rock deformation process is the crack initiation stress (ci). For the purpose of describing the mechanical properties of rocks and estimating brittle failure in the vicinity of deep underground excavations, it is practical to test for this characteristic stress threshold. By breaking down the acoustic emanation (AE) reactions of rock examples exposed to uniaxial compressive circumstances proposed another strategy utilizing combined AE hits (CAEH) to decide σci. Uniaxial compressive tests with AE measurement on 77 granitic rock samples were carried out so that the proposed approach could be confirmed. Using the CAEH method and the previously established lateral strain response (LSR) method, ci values of all specimens were identified based on recorded stress–strain relationships associated with AE data. According to statistical analysis, the outcomes of the two distinct approaches are comparable [8]. In addition, the mean ci values obtained from a number of well-established strain-based and AE-based methods and those obtained from 20 specimens, for instance, were comparable. Thus, the CAEH technique can be utilized as an elective strategy for σci assurance. To assess the mechanical properties of Beishan granite, additional uniaxial compressive tests have been performed on rock samples collected from various boreholes at the Beishan URL site.

Rock examples, with a width of roughly 50 mm, were ready as per the particulars suggested by the Worldwide Society for Rock Mechanics and Rock Designing (ISRM). The CAEH method-derived newly established ci data were incorporated into the previous database [9]. By fitting the 204 data using the least squares method, a linear relationship was found between ci and UCS. When the UCS value is known, the results suggest that ci = 0.46 UCS can be used to estimate ci. As of late, the CAEH technique has been utilized for σci assurance of Beishan rock under various moderate chief pressure (σ2) stacking conditions. Considering that the lab σci could be taken as a lower destined for the in-situ spalling strength, the likelihood of spalling close to exhuming limits for Beishan URL with a greatest profundity of 560 m is little on the grounds that the extent of the most extreme digressive weight on the removal limit is by and large not exactly σci of Beishan rock.

Toughness in fractures

The stone crack strength is a significant boundary required in the TBM execution expectation. As a result, the fracture toughness of five distinct varieties of Beishan granite with varying mineral compositions and grain sizes was experimentally examined [10]. In order to determine the fracture toughness (KIC) of dry and saturated specimens, 32 V-notched three-point bending tests were carried out on cylindrical specimens in accordance with the ISRM's recommendations.

The peak load, transition load, and fracture toughness of granite at different weighted average grain sizes in terms of their average values. Saturation causes the specimen to enter the plastic deformation stage more quickly because saturated specimens have lower transition loads and peak loads than dry specimens. The rate over the segments is the proportion of the typical KIC of the soaked examples to that of the dry examples, demonstrating that the immersion might prompt a diminishing in break strength of roughly 10% contrasted with the dry example. For both immersed examples and dry examples, the crack strength and the pinnacle load originally diminished, and afterward balanced out with expanding weighted normal grain size. One possible explanation is that smaller mineral grains crack more easily than larger ones when subjected to tensile stress. As a result, the macro-level strength and fracture toughness of specimens with small mineral sizes demonstrate higher energy requirements for the growth of the tensile crack.

The strength of the Beishan granite

The excavation technique is a crucial input for the URL and repository design. The TBM method is given priority for the excavation of the Beishan URL and future repository because it is the most advanced underground engineering technology. In recent years, a comprehensive feasibility study on the use of TBM for Beishan URLs has been conducted. Rock portability, which has a strong connection to the advance rate for TBM excavation, is one of the most important parameters for the feasibility study. TBM's advance rate will be slowed if the rock's portability is poor. In general, the index "penetration rate" is a crucial parameter for predicting the TBM advance rate and assessing rock portability. The expression "infiltration rate" is characterized as the exhuming distance of TBM per exhausting unit time [11]. It is a marker mirroring the communication among TBM and rock mass, and it is likewise utilized for the reasonableness assessment of the TBM technique in a particular undertaking. The excavation distance per cutter head revolution, also known as the basic penetration rate, is referred to as penetration (P) or penetration per revolution (PRev). Rock properties (UCS and Brazilian tensile strength (BTS)), in situ stress, cutter spacing, cutter dimension (size and tip width), thrust (represented by cutter force), and other machine parameters influence the maximum penetration value. However, for hard rock, the cutter tip width (CTW) has a significant impact on penetration and rock portability. In this paper, research on entrance and rock conveyability with various CTWs for TBM removal in Beishan stone ground is led by cutting test.

CTW's effect on cutter force

As demonstrated, the outcomes show that the shaper aspect affects the shaper force. The required cutter force typically rises significantly with CTW to achieve the same rock penetration with the same UCS. For instance, compared to cutters with CTWs of 8 mm and 16 mm, respectively, the cutter force required to reach a penetration of 3 mm for the cutter with CTW of 19 mm is 44.2% higher, or 7.6% higher. The explanation can be ascribed to that the stone pressure incited by the shaper is becoming lower with the CTW expanding under a similar shaper force, which makes it harder to part the stone and in this way decreases the entrance that can be arrived at by the more extensive tipped shaper.

Effect of CTW on the maximum penetration that can be allowed

In light of the stone fracture component by the TBM shaper, two viewpoints ought to be examined while assessing the suitable most extreme entrance. (1) The cutter force required to reach low penetration is a measure of the difficulty levels for crushing rock with a cutter. For instance, as depicted in Fig. 27, for P = 1 mm, a CTW of 19 mm requires 28.2 percent more cutter force than a CTW of 16 mm, making it harder for the former to crush into the rock before chipping formation. 2) Expanding pace of shaper force with an increment of infiltration, which can be addressed by the power capability of the fitting bend. The outcomes outline that the elements of fitting bends bit by bit fluctuated from power capability to direct capability, and the capability power diminishes from 3.3329 to 1 as the CTW increments from 8 mm to 19 mm [12]. According to the tendency patterns of the three kinds of cutters, it will be much more difficult for the cutter with a CTW of 19 mm to significantly increase penetration. The cutter with a CTW of 19 mm has difficulty achieving high penetration, as discussed above.

Beishan's rock mass suitability assessment

Rock mass classification methods, such as the Q method and the RMR method, which focus primarily on constructability, should be used to assess the host rock's suitability for general underground engineering. The host rock's suitability for the geological disposal repository typically depends on the need for long-term safety, which is typically not taken into account by conventional rock mass classification methods. As a result, a brand-new quantitative rock mass classification system called QHLW was proposed. This new method can evaluate the repository's constructability as well as its long-term performance in the multi-field coupling environment. The suitability evaluation criterion at the repository scale of the QHLW system has been successfully utilized in the selection of China's URL.

In-situ test plan during Beishan URL development

The Beishan URL construction affords valuable opportunities for in-situ testing. A thorough field-testing program zeroing in on location portrayal, innovation improvement, and testing will be performed during URL development, including geographical planning, geophysical reviewing hydrogeological examinations, rock reasonableness assessment, TBM entrance test, in-situ pressure estimations, and unearthing harm zone (EDZ) portrayal, and so forth. The test areas along the incline [13-15]. Equipment for the URL operation stage, such as excavation equipment for the deposition hole, installation equipment for the buffer material, and equipment for radionuclide migration testing, will be developed in surface laboratories simultaneously with the above activities.

Conclusions

The mechanical attributes of Beishan stone were deliberately contemplated and the principal accomplishments are as per the following.

(1) Beishan granite has a tensile strength of about 11 MPa on average and a uniaxial compressive strength of up to 170 MPa on average. It suggests that Beishan granite is composed of brittle, hard rocks in the typical way. Beishan granite exhibits significantly lower strength under hydro-mechanical coupling conditions than under no coupling conditions. In the mean time, Beishan stone's versatile modulus, break harm pressure, and rock disappointment strength decline with the expansion in temperature. However, at various temperatures, the critical strain at the beginning of the accelerated creep stage appears to be constant. It is essential to conduct additional research on the thermo-hydro-mechanical coupling behavior of Beishan granite over a longer time scale in order to ensure the repository's long-term safety.

(2) The portability of Beishan granite was experimentally examined as one of the key parameters for the tunnel boring machine (TBM) methodology that is highly related to the advance rate. The relationships between the cutter tip width, the penetration depth, and the required force were discovered.

(3) A brand-new quantitative rock mass classification system known as QHLW was proposed in order to evaluate both the constructability and the long-term performance of Beishan granite. This system was successfully utilized in the selection of China's first URL site.

(4) The Beishan Exploration Tunnel (BET), a platform for field experiments, served as the pilot engineering for China's URL. The exhuming, disfigurement checking, and broke zone recognizing advances, which were intended to be utilized in the improvement of the Beishan URL, were tried and enhanced by different in-situ tests. In the meantime, the construction of BET confirmed the engineering-scale constructability of Beishan granite.

(5) The application for Beishan URL development was endorsed by CAEA in 2019. The Beishan URL has two experimental levels, three shafts, one spiral ramp, and a maximum depth of 560 meters. The development of Beishan URL has been begun in 2021 and it will persistently assume a part in the logical examination of land removal of HLW and the improvement of future DGR.

The selection, characterization, design, and construction of China's URL have all been based on the solid foundation established by rock mechanics research on Beishan granite. However, there are still difficulties in rock mechanics, such as the engineering-scale identification of mechanical properties of rock mass, the simulation and prediction of seepage in the host rock, and efficient excavation technology. In 2021, two examination projects, "concentrate on rock mechanics and long haul steadiness of the encompassing stone mass of URL" and "concentrate on key unearthing advances of URL", were all the while sent off alongside the development of China's URL to get a more profound comprehension of Beishan rock. It is anticipated that the Beishan URL's accomplishments will successfully advance China's DGR and other facilities of a similar nature worldwide.

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None

Conflict of Interest

None

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