Retraction Notice

Title of retracted article: Research on the Permeability Characteristics of Granite with Different Weathering Degrees before and after the Influence of Mining Method Construction

Author(s): Serges Mendomo Meye, Zhenzhong Shen

* Corresponding author. Email: sergesmendomo@yahoo.fr

Journal: Engineering
Year: 2020
Volume: 12
Number: 6
Pages (from - to): 382-400
DOI (to PDF): https://doi.org/10.4236/eng.2020.126029
Paper ID at SCIRP: 101170
Article page: https://www.scirp.org/journal/paperinformation.aspx?paperid=101170

Retraction date: 2023-02-23

Retraction initiative (multiple responses allowed; mark with **X**):
☐ All authors
X Some of the authors:
☐ Editor with hints from
- O Journal owner (publisher)
- O Institution:
- O Reader:
- O Other:

Retraction type (multiple responses allowed):
☐ Unreliable findings
O Lab error O Inconsistent data O Analytical error O Biased interpretation
O Other:
☐ Irreproducible results
☐ Failure to disclose a major competing interest likely to influence interpretations or recommendations
☐ Unethical research

☐ Fraud
O Data fabrication O Fake publication O Other:
X Plagiarism ☐ Self plagiarism ☐ Overlap ☐ Redundant publication *
☐ Copyright infringement ☐ Other legal concern:

☐ Editorial reasons
O Handling error O Unreliable review(s) O Decision error O Other:

☐ Other:

Results of publication (only one response allowed):
X are still valid.
☐ were found to be overall invalid.

Author's conduct (only one response allowed):
X honest error
☐ academic misconduct
☐ none (not applicable in this case – e.g. in case of editorial reasons)

* Also called duplicate or repetitive publication. Definition: "Publishing or attempting to publish substantially the same work more than once."

Scientific Research Publishing

History
Expression of Concern:
☐ yes, date: yyyy-mm-dd
X no

Correction:
☐ yes, date: yyyy-mm-dd
X no

Comment:

The paper does not meet the standards of "Engineering".

This paper has been retracted to straighten the academic record. In making this decision the Editorial Board follows COPE's Retraction Guidelines. The aim is to promote the circulation of scientific research by offering an ideal research publication platform with due consideration of internationally accepted standards on publication ethics. The Editorial Board would like to extend its sincere apologies for any inconvenience this retraction may have caused.

Editor guiding this retraction: Prof. David L. Carroll (Editor-in-Chief of ENG)

Engineering, 2020, 12, 382-400
https://www.scirp.org/journal/eng
ISSN Online: 1947-394X
ISSN Print: 1947-3931

RETRACTED

Research on the Permeability Characteristics of Granite with Different Weathering Degrees before and after the Influence of Mining Method Construction

Serges Mendomo Meye[1,2*], Zhenzhong Shen[1,2]

[1]State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing, China
[2]College of Water Conservancy and Hydropower Engineering, Hohai University, Nanjing, China
Email: *d2016010@hhu.edu.cn, *sergesmendomo@yahoo.fr

How to cite this paper: Meye, S.M. and Shen, Z.Z. (2020) Research on the Permeability Characteristics of Granite with Different Weathering Degrees before and after the Influence of Mining Method Construction. *Engineering*, **12**, 382-400.
https://doi.org/10.4236/eng.2020.126029

Received: February 8, 2020
Accepted: June 26, 2020
Published: June 29, 2020

Abstract

The influence of mining method tunnel construction on the groundwater environment is a very important and complex engineering environment problem, and the strong differential weathering of water-rich granite strata increases the difficulty of this problem. In this paper, the mineral composition and microstructure characteristics of granite with different weathering degrees before and after the influence of mining method were studied by *in-situ* and indoor seepage tests and theoretical calculation, and the impact of mining method tunneling on granite permeability was also analyzed. Calculation results revealed that the permeability coefficient of surrounding rock at 1.1 m away from excavation face increased 41.6 times as much as the original. The permeability coefficient of moderately and strongly weathered granite increased by 6.12 and 3.33 times, respectively and the permeability also increased. The variation of the permeability coefficient of fully weathered granite was the smallest, increasing by 1.67 times, which is due to mechanical excavation of a fully weathered layer on-site, and the disturbance was far less than that caused by blasting. The scale of the excavation damaged zone (EDZ) induced by mining method was determined by wave velocity test, which provides a basis for subsequent seepage field calculation and research.

Keywords

Mining Method, Granite Permeability, EDZ, Groundwater Environment, Weathered Granite

1. Introduction

The permeability of granite surrounding rock is closely related to its weathering degree. For granite with different weathering degree, mining method construction will have different effects on its permeability. Differential weathering of granite strata and the influence of mining method construction bring great difficulties to the negative effect evaluation of groundwater environment. Nowadays, there are few studies on the impact of mining method construction on groundwater environment in weathered granite tunnels, and there is a lack of systematic research results. Taking this into consideration, this paper investigates the geological environment of the typical granite tunnel engineering research area. The variation law of permeability of weathered granite surrounding rock and the scope of excavation damaged zone (EDZ) under the effect of tunnel construction with mining method are also considered. This research aims to reveal the influence of tunnel construction with mining method on the groundwater environment in weathered granite. The research results can provide some reference for the negative effect evaluation of groundwater environment in tunnel construction by mining method and the design of tunnel waterproof and drainage structure, which is of great practical significance for the protection of groundwater environment in similar tunnel construction projects.

2. Literature Review

The hot and rainy climate makes the rock mass suffer strong weathering. With the change of weathering degree, the micro-structure and mineral composition of granite also has a series of changes. Which further show the changes of physical and mechanical properties, including the permeability of granite. It is of great significance to clarify the variation law of the permeability characteristics of weathered granite in order to study the change of seepage field. Today, scholars have made a thorough study of the permeability characteristics of granite. Zhao [1] revealed the relationship between permeability and burial depth of granite based on a large number of borehole water pressure test data in three typical granite areas in Singapore. The analysis results show that with the increase of burial depth, the permeability of granite decreases gradually, and the permeability is closely related to the quality of its rock mass. Oda *et al.* [2] carried out transient impulse tests on Inada granite samples and studied the relationship between rock permeability and damage growth. Kranzz *et al.* [3] studied the permeability of barre granite, analyzed the relationship between joint roughness and permeability coefficient, and established the empirical relationship between permeability coefficient and normal stress. Shao *et al.* [4], established a damaged model of granite and revealed the relationship between permeability and damaged tensor of granite based on meso-damaged mechanics. Brace [5] studied the permeability of granite under high confining pressure and water pressure. The results showed that the permeability of granite decreased with the increase of effective confining pressure. Morrow *et al.* [6] studied the effect of effective stress on the permeability of granite under cyclic loading. Pratt *et al.* [7] studied many physical and mechanical properties of granite through long-term in-situ tests and analyzed the relationship between permeability and stress direction. In response to a need for a more accurate porosity measuring method for small solid samples, the porosity measurement sensor using the sensitive capacitive-dependent crystal was developed by M. Vojko [8] [9]. The experimental results of the porosity determination in volcanic rock samples were presented. The uncertainty of the porosity measurement is less than 0.1% (Temp = 10˚C - 30˚C). Wang [10] studied the variation of permeability of Beishan granite with burial depth by borehole water pressure test. Zhu *et al.* [11] studied the variation of permeability of granite under different confining pressures during the whole stress-strain process through indoor permeability tests. Hu *et al.* [12] based on the improved meso-damage model, simulated and analyzed the variation characteristics of granite permeability in the process of compressive failure. Li Wenliang *et al.* [13] by conducting seepage tests under different confining pressures, studied the variation of non-linear seepage characteristics of fractured granite with hydraulic gradient and confining pressures, and its physical genesis mechanism was analyzed. Wang *et al.*, [14] studied the effect of axial and circumferential strains on the permeability of granite in the whole process of stress-strain and clarified the permeability mechanism in the process of deformation and failure of granite. Chen *et al.* [15] by means of triaxial compression stress-strain permeability test and three-dimensional acoustic emission method, studied the evolution mechanism of mechanical damage of granite under different confining pressures and its influence on permeability. The experimental results show that under compressive stress, the damage evolution of granite begins with the generation and expansion of micro-fissures, and develops rapidly at the time of rock failure and at the post-peak stage. It is pointed out that the extension of fissures is the fundamental cause of deterioration of the mechanical properties of granite. Zhang *et al.* [16] introduced the basic characteristics of granite total weathering zone in the dam site area of the Three Gorges Project and the experimental results of its seepage parameters and analyzed the different reflections of different experiments on the seepage characteristics of granite total weathering zone.

According to the above literature review, experts and scholars have carried out a lot of research on the permeability characteristics of granite with different weathering degrees. The pointed out that the changes of rock fissures and mineral composition are important factors affecting the permeability of granite. But most of the research objects are single granite in a certain engineering, so the comparative study on the permeability characteristics of granite with different weathering degrees in the same project is rare. And the study considering the influence of mining method construction on granite with different weathering degrees is also rare. Therefore, it is necessary to carry out a comprehensive and systematic study on the permeability characteristics of granite with different weathering degrees before and after the impact of mining method construction based on specific projects. So as to provide more accurate parameters for evaluating the impact of weathering granite tunnel construction on groundwater environment and enhance the reliability of the evaluation results.

3. Methods and Materials

3.1. Variation Law of Permeability Coefficient

3.1.1. *In-Situ* Test

The permeability of rock mass is not only determined by its genesis but also closely related to its fracture development and connectivity. According to the actual situation of the strata in the study area, the permeability coefficient of the strong and medium weathered granite (not affected by the construction) has been obtained through the borehole pumping test. Four pumping holes were arranged in the pumping test, among which ZK1 and ZK2 carried out the pumping test with two observation holes. The observation holes were mainly vertical and parallel to the ground water flow direction. Then, according to the characteristics of underground structures, they were in the shape of the "one" section with the main hole. The distance between the observation hole and the pumping hole met the requirements of the recharge boundary and calculation formula of the groundwater in the pumping test in the bedrock area. The distance between the observation hole and the pumping hole was 1 - 2 times of the aquifer thickness. The plan is depicted in **Figure 1**. ZK3 and ZK4 were limited by terrain conditions, so only a single hole pumping test was carried out.

In the pumping test, the steady flow method was adopted, and the drawdown was divided into three times (falling process), for each time the drawdown was greater than 1 m. The permeability of different aquifers was evaluated respectively, and the water level was restored after pumping. According to the field conditions, a mixed pumping test was carried out on the complete borehole for the borehole with larger bedrock depth or the borehole without the sand layer. Weathered and moderately weathered granite has the characteristics of confined water. According to the actual situation of well pipe structure and aquifer type, the formula in code for hydrogeological investigation of railway engineering (TB 10049-2004) was selected for calculation. The calculation formula of two observation holes and a single hole of confined water in the complete well zone of confined water is shown in Equations (1)-(4).

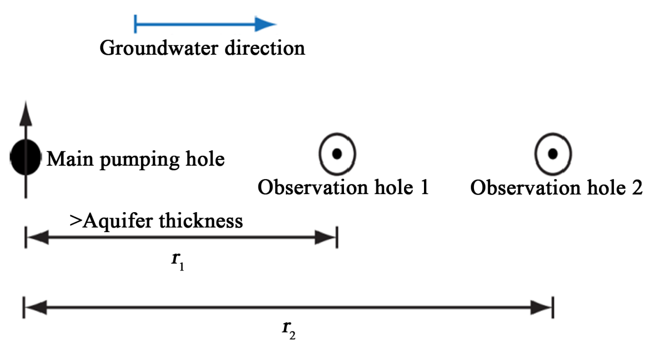

Figure 1. Plan of pumping test hole.

$$k = 0.366Q\frac{\lg r_2 - \lg r_1}{M(S_1 - S_2)} \tag{1}$$

$$\lg R = \frac{S_1 \lg r_2 - S_2 \lg r_1}{S_1 - S_2} \tag{2}$$

$$k = \frac{0.366Q}{MS}\lg\frac{R}{r} \tag{3}$$

$$R = 10S\sqrt{k} \tag{4}$$

where, k is the permeability coefficient (m/d); Q is the flow rate (m^3/d); R is the radius of influence (m); r_1 and r_2 are the distance (m) from observation hole 1 and observation hole 2 to the pumping hole, respectively; S_1 and S_2 are the water level drop depth (m) of observation hole 1 and observation hole 2, respectively; M is the thickness of the confined aquifer (m).

The pumping test results are as follows: the permeability coefficient of ZK1 strongly weathered granite is k = 1.59 - 1.81 m/d, the average permeability coefficient is k = 1.67 m/d, medium permeability. ZK2 moderately weathered granite permeability coefficient k = 0.66 - 0.80 m/d, the average permeability coefficient k = 0.73 m/d, weak permeability. ZK3 moderately weathered granite permeability coefficient k = 0.58 - 0.76 m/d, the average permeability coefficient k = 0.67 m/d, weak permeability. ZK4 strongly weathered granite permeability coefficient k = 1.37 - 1.59 m/d, the average permeability coefficient k = 1.46 m/d, medium permeability.

In order to obtain the permeability coefficient of slightly weathered granite (not affected by construction), a multi-stage conventional single plug water pressure test was carried out in ZK1. According to the code for water pressure test in boreholes of water conservancy and hydropower engineering (SL 31-2003), the permeability of slightly weathered granite test section is calculated by the following formula

$$q = \frac{Q_3}{LP_3} \tag{5}$$

where q is the permeability of the test section (Lu); L is the length of test section (m); Q_3 is the calculated flow in the third stage (L/min); P_3 is the pressure in the third stage (MPa).

Since the medium layer is located below the groundwater level, and $q < 10$ Lu, the $p - Q$ curve is laminar flow. The following equation can be used to calculate the permeability coefficient

$$k = \frac{Q}{2\pi HL}\ln\frac{L}{r_0} \tag{6}$$

where k is the rock mass permeability coefficient (m/d); Q is the inflow rate (L/min); H is the test head (m); L is the length of the experimental segment (m); r_0 is the borehole radius (m).

The test results show that the permeability coefficient k of slightly weathered granite ranges from 0.008 to 0.03 m/d.

3.1.2. Laboratory Permeability Test and Theoretical Calculation

The permeability coefficients of fully weathered granite before and after the influence of mining method construction were measured by the variable head permeability test. Eight groups of fully weathered granite (sandy clay) were tested before and after construction. TST-55 permeameter is used in the test instrument, which is composed of upper cover, base, socket, ring knife, permeable stone, and screw. It is suitable for measuring the permeability coefficient of fine soil. The indoor permeability test is shown in Figure 2.

The variable head penetration test is carried out in accordance with the procedures specified in the "geotechnical test method standard" (GB/T 50123-1999). First, put the sample ring knife into the soil and tighten the screw. It is required to be sealed until there is no seepage of air and water. Then the water inlet is connected with the variable head pipe, water and exhaust are injected until there is no bubble in the overflow water, the infiltration container is leveled and the water inlet closed. The pure water is injected into the variable head pipe to raise the water head to a predetermined height (not more than 2 m). After the water level is stable, the water source is cut off and the intake is opened. When the overflow of the outlet is overflowed, the initial water head height and the starting time of the variable head pipe are recorded, and the records are recorded according to the predetermined time interval. The water level is changed in the variable head pipe to a higher level, the water head and time change are recorded after the water level is stable, the test is repeated 5 - 6 times until the permeability coefficient is within the allowable range, and the test is completed.

The variable head permeability coefficient of each group of soil samples is calculated according to the following formula

$$k_T - 2.3\frac{aL}{A\left(t_2 - t_1\right)}\lg\frac{H_1}{H_2} \tag{7}$$

where a is the cross-sectional area (cm^2), 2.3 is the transformation factor of ln and lg, L is the height of the sample (cm), A is the cross-sectional area of the sample (cm^2), t_2 and t_1 are the starting and ending time (s), H_1 and H_2 are the start and end water head (cm).

The results of variable head permeability test show that the average vertical and horizontal permeability coefficients of completely weathered granite (not

Figure 2. Indoor permeability test.

affected by construction are 0.31 m/d and 0.28 m/d respectively, and the average vertical and horizontal permeability coefficients of completely weathered granite affected by construction) are 0.52 m/d and 0.49 m/d respectively. It can be seen that the permeability of completely weathered granite increases under the influence of mining method construction disturbance.

For strong, medium and weak weathered granite, drilling and blasting excavation will not only produce new cracks in the rock mass, but also further expand and connect the original cracks in the rock body, and the strength parameters and permeability of the rock mass will be affected.

Due to the limitation of field working conditions of the tunnel, the permeability coefficient of the surrounding rock of strong, medium and light weathered granite after the mining method construction is difficult to be determined by the field in-situ test, so the theoretical formula in literature (Liu Yongsheng (2010)) is used to calculate the permeability coefficient of the fissured rock mass considering the blasting effect. Read. R [17], after studying the formation of EDZ, it is believed that the existence of the tensile stress area in the surrounding rock of the tunnel under the excavation condition is one of the reasons for the formation of EDZ. Liu Yongsheng (2010) analyzed the law of rock fracture expansion under the action of stress wave and deduced the calculation formula of the change multiple n of rock permeability coefficient under the condition of tension shear stress under the action of stress wave as follows

$$n = \frac{k}{k_0} = \frac{\left[b_0 - \frac{(1-2\mu-\cos 2\beta)}{} P_0 \left(\frac{r}{r_0} \right)^{-\alpha} \right]^3}{b_0^3} \tag{8}$$

where, k_0 and k are the permeability coefficient of surrounding rock before and after construction (m/d); b_0 is the initial opening degree of rock fracture (m); μ is the Poisson's ratio of rock mass; β is the azimuth angle of the fracture (˚); k_n is the normal stiffness of the fracture (MPa/mm); P_0 is the hole wall pressure (GPa); r is the distance between the measuring point and the hole wall (m); r_0 is the radius of charge (m); α is the attenuation coefficient of stress wave.

According to the site investigation and blasting special construction plan, the calculation parameters of the change multiple of the permeability coefficient of strong, medium and light weathered granite after construction are shown in Table 1. The value of r in the table is the depth of EDZ inferred from the P-wave velocity test, and the change multiples of permeability coefficient of strong, medium and light weathered granite after blasting are 3.33, 6.12, and 41.60, respectively.

4. Discussions and Results

4.1. Comparison of Permeability Coefficient of Weathered Granite before and after Construction

Through the *in-situ* test of rock permeability, indoor permeability test, and

Table 1. Calculation parameters of change multiple of rock permeability coefficient after blasting.

Weathering degree	b_0	μ	β	K_n	P_0	r	r_0	α
Strong weathering	0.005	0.3	0	20	0.23	2.0	0.025	1.65
Medium weathering	0.0035	0.25	0	50	0.54	1.5	0.025	1.65
Light weathering	0.0015	0.20	0	100	1.10	1.1	0.025	1.65

theoretical formula calculation, the permeability coefficient of granite with different weathering degrees before and after the mining method construction was obtained. Combined with the hydrogeological survey data collected, the permeability coefficient of each rock and soil layer in the study area is shown in Table 2. According to Table 2, the permeability of strongly weathered granite was the strongest (1.59 m/d), followed by moderately weathered granite (0.69 m/d), then fully weathered granite (0.3 m/d), and slightly weathered granite was the weakest (0.02 m/d).The permeability of slightly weathered granite changed greatly after the influence of the mining method. The formula calculation results revealed that the permeability coefficient of surrounding rock at 1.1 m away from the excavation face increased 41.6 times as much as the original. The reason is that the initial crack width of slightly weathered granite was very small, the change of crack gap after blasting was very significant, and the permeability coefficient also increased sharply. The permeability coefficient of moderately weathered granite and strongly weathered granite increased by 6.12 and 3.33 times, respectively and the permeability also increased. The variation of the permeability coefficient of fully weathered granite was the smallest, increasing by 1.67 times. This is due to the mechanical excavation of a fully weathered layer on-site, and the disturbance was far less than that caused by blasting.

4.2. Variation and Influence of Microstructure and Mineral Composition

With the deepening of weathering, the microstructure and mineral composition of granite will change accordingly, which will affect the permeability of the rock. In this section, the mineral composition and microstructure characteristics of granite with different weathering degrees before and after the influence of mining method construction were studied by micro test, and the influence on the permeability of granite was analyzed. The research idea was to carry out a polarized microscope test of rock slices, analyze the microstructure, mineral particle arrangement and mineral composition change of granite with different weathering degree before and after the influence of mining method construction, reveal the variation law of granite microstructure and mineral composition and its influence on permeability.

Eight (08) groups of granite samples with different weathering degrees were collected from the research area. The rock samples collected on-site are depicted in Figure 3, and the micro test type and rock sample number are shown in Table 3.

Table 2. Permeability coefficient of the rock soil layer.

Stratigraphic numbering	Geotechnical name	Indoor penetration test		Permeability coefficient range of *in-situ* test (M/D)	Permeability coefficient (M/D)
		k_V (m/d)	k_H (m/d)		
<1>	Artificial fill	-	-	-	1
<3-1>	Silty sand	-	-	-	3
<3-2>	Medium coarse sand	-	-	-	10
<3-3>	Coarse gravel	-	-	-	15
<3-4>	Pebble	-	-	-	25
<4-2B>	Muddy clay	-	-	-	0.001
<4-3>	Silty clay	-	-	-	0.1
<4N-2>	Plastic silty clay	-	-	-	0.2
<5H-1>	Plastic granite residual (upper level)	-	-	-	0.1
<5H-2>	Hard plastic granite residual (lower level)	-	--	-	0.15
<6H>	Completely weathered granite	0.31	0.28	-	0.3
<6H>	Completely weathered granite (after construction)	0.52	0.49	-	0.5
<7H>	Strongly weathered granite	-	-	1.37 - 1.81	1.59
<7H>	Strongly weathered granite (after construction)	--	--	--	5.29
<8H>	Moderately weathered granite	-	-	0.58 - 0.80	0.69
<8H>	Moderately weathered granite (after construction)	-	-	-	4.22
<9H>	Slightly weathered granite	-	-	-	0.02
<9H>	Slightly weathered granite (after construction)	-	-	-	0.83

Table 3. Micro test types and sample numbers.

Construction effect	Weathering degree	Test type	Rock sample number
No	Full weathering	Polarization microscope test	P-1
	Strong weathering		P-2
	Moderate weathering		P-3
	Breeze		P-4
Yes	Full weathering		P-5
	Strong weathering		P-6
	Moderate weathering		P-7
	Breeze		P-8

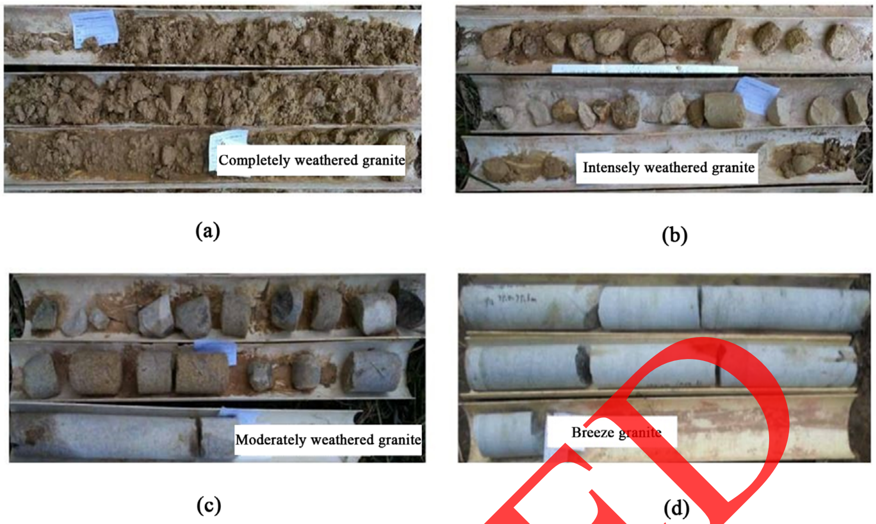

Figure 3. Field rock samples in the research area. (a) Fully weathered granite; (b) Strongly weathered granite; (c) Medium-weathered granite; (d) Weathered granite.

The microstructure and mineral composition of granite with different weathering degrees before and after the influence of the mining method was studied by a polarized microscope test. The rock slices were sent to the microscope laboratory for observation by a polarized microscope. The test instrument is Leica normal binocular metallographic microscope. The main technical indexes were as follows: the microscope was equipped with 12 V, 50 W light source, and the travel distance was 20 mm, the rock slices are depicted in **Figure 4**. The microstructures of weathered granite samples before the influence of mining method construction were observed by a polarized microscope as depicted in **Figure 5**. **Figure 6** depicts the microstructures of weathered granite samples affected by mining method construction.

Experimental results show that the slight granites collected in the study area were of medium and fine-grained granitic structure and massive structure, and their mineral composition mainly included quartz, potassium feldspar, plagioclase, and biotite. Quartz was irregular granular, a few of which were produced as agglomerated massive aggregate, showing slightly larger particle size, very low protuberance, no cleavage, no double crystal, some of which were wave-like extinction. Potassium feldspar was mostly irregular granular, with different particle sizes, mostly medium-sized, less fine-grained, very low protuberance, slightly argillaceous kaolinite. Plagioclase was mostly irregular granular, less irregular plate-shaped, with different particle sizes, mostly medium-sized, less fine-grained, weak medium argillaceous epidote, zoisite and sericites. Biotite was irregularly flaky, with different particle sizes, and had a very complete cleavage. It was light brown - dark brown, polychromatic, and absorptive. It had the highest dry color grade II, with parallel extinction. It contained magnetite, apatite and zircon microcrystals. Most of them were fresh, while a few were chlorite, hydrobiotite, and epidote. According to the mineral composition and

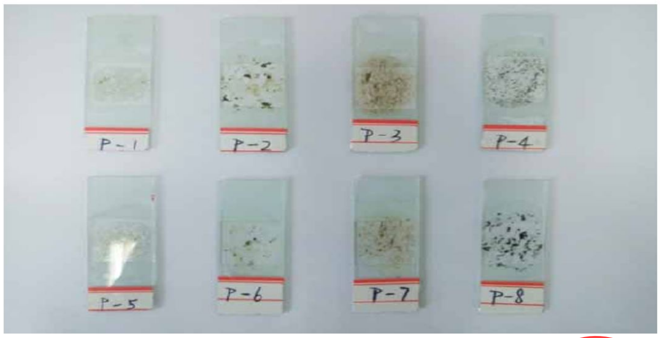

Figure 4. Slices of rock samples.

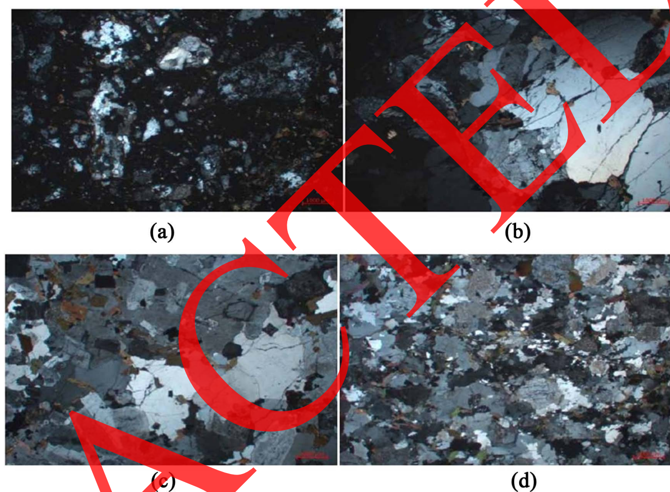

Figure 5. Microstructure of pre-weathered granite samples affected by mining method construction. (a) R-I (Orthogonal polarization, totally weathered granite); (b) P-2 (Orthogonal polarization, Strongly weathered granite); (c) P-3 (Orthogonal polarization, medium weathered granite); (d) P-4 (Orthogonal polarization, micro-weathered granite).

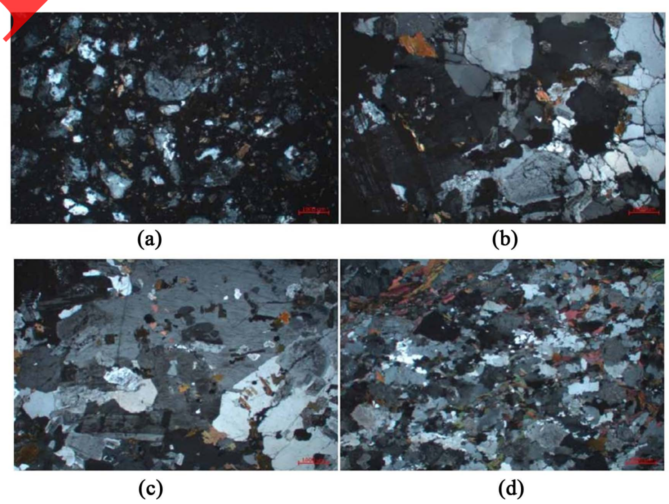

Figure 6. Microstructure of weathered granite samples affected by mine method construction. (a) P-5 (Orthogonal polarization, totally weathered granite); (b) P-6 (Orthogonal polarization, Strongly weathered granite); (c) P-7 (Orthogonal polarization, medium weathered granite); (d) P-8 (Orthogonal polarization, weathered granite).

microstructure of the rock, it was determined that the rock sample was medium fine-grained biotite monzogranite.

It can be seen from Figure 5 that with the deepening of weathering, the microstructure and mineral composition of granite changed significantly. Under the weathering, the K-feldspar and plagioclase in granite were gradually transformed into clay minerals, the structure changed from irregular granular to final clastic, the argillaceous kaolinization degree of K-feldspar gradually deepened, and the argillaceous epidote, zoisite, and argillaceous, microscale sericitization and clayization degree of plagioclase were gradually deepened. Combined with the field investigation, it was found that the weakly weathered granite was only slightly weathered and iron oxide impregnated in the joints and fissures, and most of the rocks were still fresh. The biotite in the moderately weathered granite was discolored obviously, the external ring of feldspar transformed into kaolinite, the mineral particles became smaller, and the micropore increased. The feldspar in the strongly weathered granite further decomposed into clay minerals, forming a large amount of kaolinite and a small amount of illite and chlorite. Only quartz and some potassium feldspar particles still maintained the original structure, and the micropore further increased. In the fully weathered granite, in addition to quartz with strong weathering resistance and a few potassium feldspars, most feldspar and biotite weathered into clay minerals.

The permeability of rock mass largely depends on the development degree of fracture and its filling material. According to the results of a polarized light microscope test, the micropore in granite increased with the deepening of weathering degree. Therefore, the permeability of granite increased gradually from weak weathering to strong weathering. However, with the further deepening of weathering, most of the original rock minerals, except quartz, have been weathered into clay minerals. The number of original permeable fissures did not increase but decreased inversely. In addition, the clay fillings had a certain degree of water resistance, which is averse to the seepage of water. Compared with the highly weathered granite, the permeability of completely weathered granite was weakened, which belongs to the relative aquiclude. The fragmentary strongly weathered granite had strong permeability, and the moderately weathered granite also had certain water permeability. The bedrock fissure water mostly stored in the strongly and moderately weathered layers of granite.

Figure 6 depicts the microstructure of weathered granite samples after the influence of mining method construction. Compared with Figure 5, it can be seen that the microstructure of granite with different weathering degrees changed to some extent under the influence of mining method construction. For moderately weathered and slightly weathered granite, before the influence of mining method construction (Figure 5(c) and Figure 5(d)), the structure of medium and fine-grained granite was dense, and the mineral particles such as feldspar and quartz were closely arranged. After being affected by the mining method construction (Figure 6(c) and Figure 6(d)), the medium and fine-grained granite structure appeared loose, the different mineral particles appeared disorderly interspersed, the density of cracks and cracks increased, and the extension length also increased, which reflected that the mining method drilling and blasting excavation caused a certain degree of damage to granite, further expanding its original cracks and generating more new cracks, so the permeability also highly enhanced. For fully weathered and strongly weathered granite, before the influence of mining method construction (Figure 5(a) and Figure 5(b)), due to the high degree of weathering and loose of the overall structure, most of the mineral particles, except quartz, have been weathered into clay minerals and gravel. After the influence of mining method construction (Figure 6(a) and Figure 6(b)), the fully weathered granite mineral particles became more and more broken, the micro-cracks of strongly weathered granite mineral particles increased significantly, the interpenetration between different minerals was more obvious, the extension length and width of the cracks increased to a certain extent, and the overall structure of the two was more disordered, which showed that the mining construction had a certain disturbance effect on the granite with high weathering degree, and also enhanced its permeability to a certain extent. In brief, the influence of mining method construction on granite was mainly to change its microstructure, while the variation of weathering degree had a significant impact on the microstructure and mineral composition of granite.

4.3. Measurement of EDZ Based on Wave Velocity Test

4.3.1. EDZ

During the excavation of underground caverns, the damage and cracking of rock mass caused by stress redistribution together with the influence of excavation method, temperature, and groundwater, lead to significant deterioration of the physical and mechanical properties of surrounding rock in a certain range of excavation face, and finally form EDZ [18] [19], as shown in Figure 7. In the EDZ, not only a large number of new cracks will occur, but also existing cracks will further expand and penetrate, resulting in deterioration of strength and stiffness of the surrounding rock, an increase of permeability coefficient, and change of acoustic wave velocity [18].

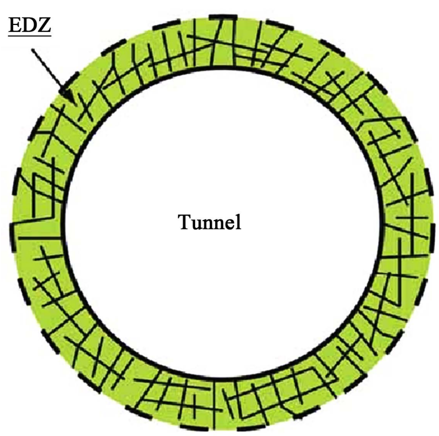

Figure 7. Diagram of EDZ.

The excavation method is an important factor affecting the scope of the EDZ and the nature of surrounding rock. Nowadays, tunnel excavation methods mainly include drilling and blasting method and mechanical excavation method, in which drilling and blasting method is the main excavation method [20]. The research results worldwide show that the surrounding rock under these two excavation methods will undergo different stress adjustment paths. When using drilling and blasting methods to excavate, besides bearing blasting load directly, the surrounding rock will also generate tension stress waves in the surrounding rock, forming a large number of radial and circumferential cracks, which will aggravate the damage degree of surrounding rock. Therefore, the damaged area and damage degree of surrounding rock formed by drilling and blasting excavation in surrounding rock are significantly larger than that of mechanical excavation. Sato *et al.* [21] found that after mechanical excavation, the permeability coefficient of surrounding rock changed little, while after drilling and blasting excavation, the permeability coefficient of surrounding rock increased by two orders of magnitude in the range of 0.5 - 1 m from the excavation surface.

For mining method tunnels in the research area, most sections were excavated by drilling and blasting methods, except some of the surrounding rocks with poor properties that needed to be excavated by manual or mechanical methods. It is important to determine the scope of the EDZ for establishing a reasonable seepage numerical calculation model and accurately evaluating the negative effect of the groundwater environment in tunnel construction. Nowadays, the main means to determine the scope of EDZ include the in-situ test [22] [23], empirical formula [24] [25], and numerical simulation [23]. This section measured the scope of EDZ through field acoustic testing, which provides a basis for subsequent seepage field calculation and research.

4.3.2. Test Principle and Device

For rock mass with undeveloped fracture and good integrity, it can be regarded as an elastic body approximately, and the propagation speed of the elastic wave in such medium is certain. With the development and expansion of joint fissures in rock mass under the influence of weathering or mining method construction, the propagation speed of the elastic wave in rock mass slows down and the amplitude decreases. A large number of theoretical research and engineering practice have proved that [26], the higher the fragmentation degree of rock media, the lower the density, the greater the acoustic resistance and the smaller the acoustic propagation speed. Based on the above principle, by measuring the acoustic wave propagation velocity of the granite surrounding rock, the EDZ of granite with different weathering degree can be accurately inferred.

The RSM-SY5 intelligent acoustic wave tester developed by Wuhan Institute of geotechnical mechanics, the Chinese Academy of Sciences was adopted. The test probe is RS-SD30 type longitudinal single-hole double-receiving transducer, and the test device is shown in **Figure 8**. The in-situ sonic test was based on the test method specified in the "geophysical prospecting regulations for water

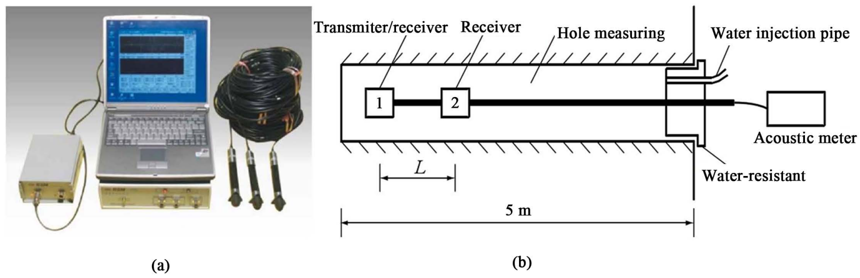

Figure 8. Field acoustic test. (a) Test instrument; (b) Acoustic test layout.

conservancy and hydropower engineering" (DL/T 5010-2005): first, the test hole with a depth of 5 m at the sidewall of the test section has been cleaned before drilling. Then, the probe was put into the test hole and connected to the water pipe, the air hole was blocked by the airbag, and water was injected into the test hole while the airbag was inflated. When the test hole was filled with water, the ultrasonic wave emitted by the transmitting probe was transmitted to the receiving transducer along with the hole wall through the coupling of the water in the hole, and then the P-wave velocity (m/s) of the granite at the measuring point have been obtained. The calculation formula is as follows

$$V_p = L/(t_2 - t_1) \tag{9}$$

where, L is the distance between two receiving probes (m), and t_1 and t_2 are the arrival time of ultrasound measured by two receivers (s).

4.3.3. P-Wave Velocity Test Results

Because the condition of the tunnel construction site was limited, the acoustic wave test could not be carried out for full and strong weathered granite. Therefore, the object of this site acoustic test was medium and slightly granite. The test was carried out at ZDK26 + 320 section (slightly weathered granite) and ZDK25 + 580 section (moderately weathered granite) of No. 2 tunnel, with 1 measuring hole on each side of the arch wall and arch foot, respectively. The acoustic wave test has been carried out after the surrounding rock converged and stabilized. Through the sorting and analysis of the test data, the P-wave velocity curve with a depth of moderate and slight weathered granite was obtained as shown in Figure 9 and Figure 10.

According to the field acoustic test results, the weathered granite tunnel formed a certain range of EDZ under the blasting action. The rock mass in this area was disturbed by the blasting excavation, and its P-wave velocity has been significantly reduced. For the moderately weathered granite surrounding rock, the depth of EDZ was about 1.5 m, the P-wave velocity of the test hole of arch foot decreased by about 1500 m/s, and the P-wave velocity of the test hole of the arch waist decreased by about 1100 m/s. For the slightly weathered granite, the EDZ depth was about 1.1 m, the maximum P-wave velocity of the test hole at the arch foot was reduced by about 1000 m/s, and the maximum P-wave velocity of the test hole at the arch waist was reduced by about 800 m/s. In contrast, the

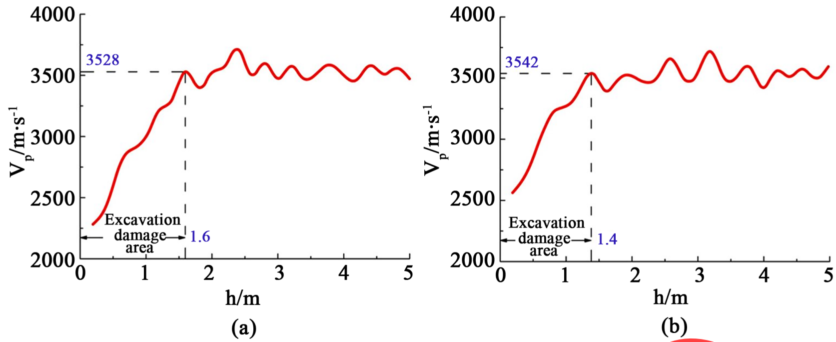

Figure 9. P-wave velocity-depth curve of moderately weathered granite. (a) The arches with a moderately weathered section; (b) The arch waist of weathered section.

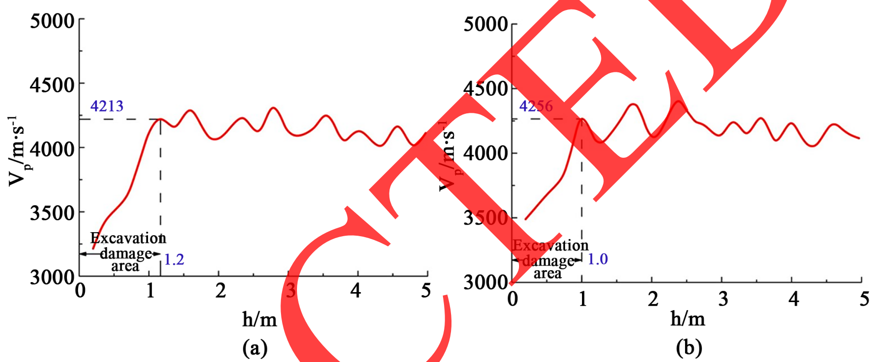

Figure 10. P-wave velocity-depth curve of slightly weathered granite. (a) The arch of foot of slightly weathered section; (b) The arch waist of slightly weathered section.

P-wave velocity of moderately weathered granite with lower initial integrity decreased more greatly, and the range of EDZ formed by construction was larger.

The development degree and connectivity of rock fracture are the key factors affecting the rock permeability. According to the analysis of the field wave velocity test results, it can be seen that the excavation disturbance of the mining method construction led to the further expansion and connection of the internal cracks of the weathered granite, the attenuation of the P-wave velocity of the rock mass, and the deterioration of the integrity, which increased the rock permeability coefficient within a certain range, induced the tunnel water gushing disaster, and had a negative impact on the groundwater environment.

5. Conclusions

In this paper, the weathering resistance, commonly used weathering degree classification criteria and discrimination basis of granite were introduced. Through the permeability test and theoretical formula calculation, the variation law of the permeability coefficient of different weathering degrees of granite before and after the influence of mining method construction was studied. From the perspective of rock microstructure and mineral composition, the change of weathering degree and the effect of mining method construction on granite permeability were analyzed. According to the influence of permeability and the field wave velocity test, the scope of EDZ formed by mining method construction was determined, and the following conclusions were obtained.

Without the influence of mining method construction, the permeability of strongly weathered granite was the strongest, followed by moderately weathered granite, then fully weathered granite, and slightly weathered granite was the weakest. Under the influence of the mining method, the permeability of slightly weathered granite changed greatly. This is because the initial crack width of slightly weathered granite was very small and the crack changed significantly after blasting.

The influence of mining construction on granite is mainly to change its microstructure. The construction disturbance made the granite structure lose, the mineral particles broken and displaced, the micro-cracks increased, the density increased, the extension length and width increased, and the permeability further enhanced.

The excavation disturbance by mining method construction will lead to further expansion and connection of the internal fissures of the weathered granite, the attenuation of the P-wave velocity of the rock mass and the deterioration of the integrity, resulting in the increase of the permeability coefficient of the rock mass within a certain range, inducing the tunnel water inrush disaster, which will have a negative impact on the groundwater environment.

Acknowledgements

Sino-Cameroon Cooperation through the Chinese Scholarship Council Program and 108 Research Group (Hohai University) supported much of the work presented in this paper. The authors would like to express appreciation to the reviewers for their valuable comments and suggestions that helped to improve the quality of the paper.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Zhao, J. (1998) Rock Mass Hydraulic Conductivity of the Bukit Timah Granite, Singapore. *Engineering Geology*, **50**, 211-216. https://doi.org/10.1016/S0013-7952(98)00021-0

[2] Oda, M., Takemura, T. and Aoki, T. (2002) Damage Growth and Permeability Change in Triaxial Compression Tests of Inada Granite. *Mechanics of Materials*, **34**, 313-331. https://doi.org/10.1016/S0167-6636(02)00115-1

[3] Kranzz, R.L., Frankel, A.D., Engelder, T. and Scholz, C.H. (1979) The Permeability of Whole and Jointed Barre Granite. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, **18**, 225-234. https://doi.org/10.1016/0148-9062(79)91197-5

[4] Shao, J.F., Zhou, H. and Chau, K.T. (2005) Coupling between Anisotropic Damage

and Permeability Variation in Brittle Rocks. *International Journal for Numerical and Analytical Methods in Geomechanics*, **29**, 1231-1247. https://doi.org/10.1002/nag.457

[5] Brace, W.F., Walsh, J.B. and Frangos, W.T. (1968) Permeability of Granite under High Pressure. *Journal of Geophysical Research*, **73**, 2225-2236. https://doi.org/10.1029/JB073i006p02225

[6] Morrow, C.A., Zhang B.-C. and Byerlee, J.D. (1986) Effective Pressure Law for Permeability of Westerly Granite under Cyclic Loading. *Journal of Geophysical Research*: *Solid Earth*, **91**, 3870-3876. https://doi.org/10.1029/JB091iB03p03870

[7] Pratt, H.R., Swolfs, H.S., Brace, W.F., *et al.*, (1977) Elastic and Transport Properties of an *in Situ* Jointed Granite. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, **14**, 35-45. https://doi.org/10.1016/0148-9062(77)90560-5

[8] Matko, V. and Koprivnikar, J. (1998) Quartz Sensor for Water Absorption Measurement in Glass-Fiber Resins. *IEEE Transactions on Instrumentation and Measurement,* **47**, 1159-1162. https://doi.org/10.1109/19.746575

[9] Matko, V. (2004) Porosity Determination by Using Two Stochastic Signals. *Sensors and Actuators A*: *Physical*, **112**, 320-327. https://doi.org/10.1016/j.sna.2003.10.065

[10] Wang, J. (2010) High-Level Radioactive Waste Disposal in China: Update 2010. *Journal of Rock Mechanics and Geotechnical Engineering*, **2**, 1-11.

[11] Zhu, A.D., *et al.* (2002) Experimental Study on Seepage Characteristics of Brittle Rocks in the Whole Stress-Strain Process. *Rock and Soil Mechanics*, **23**, 555-559. (In Chinese)

[12] Hu, D.W., *et al.* (2008) Anisotropic Damage and Permeability Evolution of Brittle Rocks. *Journal of Rock Mechanics and Engineering*, **27**, 1822-1827. (In Chinese)

[13] Li, W.L., *et al.* (2017) Experimental Study on Nonlinear Seepage Characteristics of Fractured Granite under Different Confining Pressures. *Rock and soil mechanics*, **38**, 140-150. (In Chinese)

[14] Wang, H.L., *et al.* (2006) Experimental Study on Permeability Evolution in Rock Deformation and Failure. *Rock and Soil Mechanics*, **27**, 1703-1708. (In Chinese)

[15] Chen, L., *et al.* (2014) Damage Evolution Characteristics of Granite under Compression Stress and Its Influence on Permeability. *Journal of rock mechanics and engineering*, **33**, 287-295. (In Chinese)

[16] Zhang, L.F., *et al.* (2001) Study on Seepage Parameters of Granite Fully Weathered Zone in Three Gorges Dam Site. *Journal of Rock Mechanics and Engineering*, **20**, 705-709. (In Chinese)

[17] Read, R.S. (2004) 20 Years of Excavation Response Studies at AECL's Undergroung Research Laboratory. *International Journal of Rock Mechanics and Mining*, **8**, 1251-1275. https://doi.org/10.1016/j.ijrmms.2004.09.012

[18] Ji (2005) Analysis of Surrounding Rock Damage Disturbance Zone during Tunnel Excavation. *Journal of Rock Mechanics and Engineering*, **24**, 1697-1702.

[19] Li. *et al.* (2016) Study on the Excavation Damage Area of Brittle Rock Mass and Its Influencing Factors. *Journal of Geotechnical Engineering*, **38**, 190-197.

[20] Yan, P., *et al.* (2009) Study on the Loose Range of Surrounding Rock of Tunnel under the Condition of TBM and Drilling and Blasting Excavation. *Journal of Civil Engineering*, **42**, 121-128. (In Chinese)

[21] Sato, T., Kikuchi, T. and Sugihara, K. (2000) *In-Situ* Experiments on an Excavation Disturbed Zone Induced by Mechanical Excavation in Neogene Sedimentary Rock

at Tono Mine, Central Japan. *Engineering Geology*, **56**, 97-108. https://doi.org/10.1016/S0013-7952(99)00136-2

[22] Kaiser, P.K. (1996) Canadian Rockburst Support Handbook. Geomechanics Research Centre, Sudbury.

[23] Martin, C.D., Kaiser, P.K. and McCreath, D.R. (1999) Hoek-Brown Parameters for Predicting the Depth of Brittle failure around Tunnels. *Canadian Geotechnical Journal*, **36**, 136-151. https://doi.org/10.1139/t98-072

[24] Li, S., *et al.* (2010) Observation and Analysis of the Formation and Evolution of the Damaged Area during TBM Excavation of Deep Tunnel by Digital Borehole Photography. *Journal of Rock Mechanics and Engineering*, **29**, 1106-1112. (In Chinese)

[25] Li, Z.H. (2013) Study on the Evolution and Formation Mechanism of Excavation Damage Zone of Deep Tunnel. Shenyang Northeastern University, Shenyang.

[26] Kim, J.-S., Lee, K.-S., Cho, W.-J., *et al.* (2015) A Comparative Evaluation of Stress-Strain and Acoustic Emission Methods for Quantitative Damage Assessments of Brittle Rock. *Rock Mechanics and Rock Engineering*, **48**, 495-508. https://doi.org/10.1007/s00603-014-0590-0