Study on Permeability Characteristics of Granites with Different Degrees of Weathering

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Abstract. In Guangzhou Metro line 21 tunnel construction process, weathered granite shows diversification in strength, deformation characteristics and permeability characteristics. The rock mass permeability coefficient is the core parameter necessary in the construction, and the definition of its value directly affects the accuracy of the calculation in design of tunnel anti-drainage structure and the negative effect evaluation of groundwater environment. With on-site and indoor tests, theoretical calculations, microstructure observations and mineral analysis, the permeability characteristics of granites in different degrees of weathering is studied. The variation of the final permeability characteristics is described. The permeability of granite does not increase unidirectionally as the degree of weathering deepens.

1. Introduction
Granite is a kind of rock with uniform and fine particles, small gap and granular structure. It is composed of quartz, feldspar and mica. It is a hard rock with good engineering mechanics. However, due to the large difference in the expansion coefficient between mineral components, granite is prone to cracks during thermal expansion and contraction, so it is susceptible to be weathered. With the increase of weathering degree, the mineral composition and microstructure characteristics of granite will change, which will manifest in macroscopic physical and mechanical properties, including rock mass permeability. Differences in engineering properties of granites with different degrees of weathering become obstacles to tunnel construction in Metro Line 21.

A. Tuğrul believes that the physical and mechanical properties of rock are a function of its mineral composition and fabric characteristics, also studies the relationship between the engineering properties of granite and the specific mineral composition in the study area [1]. Keith et al. demonstrates the effects of geological structure of water pressure conditions and the influence of specific mineral composition on the evolution of internal fissures in surrounding rock through comparative experiments, obtains a series of important rock mechanics parameters [2]. Zhao Bin et al. uses X-ray diffraction to determine the mineral composition of the corresponding rock sample. Scanning electron microscopy is used to observe the microstructure of the corresponding rock samples, the qualitative relationship between mineral composition, microstructure and mechanical properties is analyzed [3]. Lindqvist et al. studies the mineral composition of rock materials, particle size, shape, distribution, porosity, and
the influence of internal properties such as microcracks on physical properties and mechanical properties of rock [4].

The variation law of granite permeability coefficient of different weathering degrees is studied through indoor and outdoor experiments and theoretical calculations, as well as its relationship with the microstructure characteristics and mineral composition changes of granite.

2. Characteristics and variation on permeability coefficient of weathering granite

2.1. Weathering products of granite.
In most cases, the weathering in rock is the result of a combination of physical, chemical and biological effect [5]. Weathering not only changes the rock structure, but also the mineral composition of rock, even the physicochemical properties.

The main minerals of granite include quartz, potash feldspar and plagioclase, and minor minerals include mica, hornblende and a small amount of pyroxene. Quartz is a mineral that is very stable both physically and chemically. Therefore, mechanical disruption usually occurs during its weathering. Potash feldspar is a relatively stable mineral. Muscovite owns the best stability in the secondary minerals, which is common in residual soil. The biotite is easily weathered into chlorite and water black mica, and finally decomposed into clay minerals such as kaolinite. Minerals such as hornblende and pyroxene are much less stable than feldspar and easily weathered. The main components of weathered granite are quartz, feldspar and various clay minerals.

2.2. Determination of the degree of weathering of granite.
In general, the deeper the strata are buried, the less affected by weathering. Therefore, the weathering degree of granite usually presents certain vertical zoning characteristics.

China’s construction department has formulated a number of regulations, including the division of the rock weathering zone, as detailed in Table 1, Code for Geotechnical Investigation (GB 50021-2009). The indicators commonly used to characterize granite weathering strength include point load strength, standard strike number and rebound value. The correspondence between the granite weathering zone and the basic quality classification of the rock mass is established, as shown in Table 2. On account of the complexity and diversity the factors affecting the degree of weathering of granite are, the combination of qualitative description and multi-quantitative indicators could be more objective [6,7].

| Weathering degree | Field characteristics                                                                 | Wave velocity ratio $K_v$ |
|-------------------|---------------------------------------------------------------------------------------|---------------------------|
| Not weathered     | Fresh rock, occasional weathering traces                                              | 0.9−1.0                   |
| Micro-weathering  | Structure basically unchanged, only the joint surface rendered or slightly discolored, with a small number of weathered cracks | 0.8−0.9                   |
| Medium (weak)     | Structure partially destroyed, secondary minerals along the joint surface. Weathered fissures developed, rock mass cut into rock masses. Difficult to dig with the core, core drill can be drilled | 0.6−0.8                   |
| Strong weathering | Most of the structure destroyed, the mineral composition changes significantly. Weathered fissure developed, rock mass broken, able to dig, hard to dry drill. | 0.4−0.6                   |
| Full weathering   | Structure basically destroyed, but still identifiable, residual structural strength, can be digged and dry drilled. | 0.2−0.4                   |
| Residual soil     | Structure completely destroyed, already weathered into plasticity soil, easy to excavate, easy to drill with dry drill. | <0.2                      |
Table 2. Quantitative zoning index of granite weathering zone and its relationship with basic mass grading of rock mass. [9]

| Degree of weathering | Point load strength (MPa) | Standard hit number | Rebound value (times) | RQD (%) | BQ | Basic quality level of rock mass |
|----------------------|---------------------------|---------------------|----------------------|---------|----|----------------------------------|
| Residual soil        | -                         | 4~30                | <15                  | -       | -  | -                               |
| Full weathering      | <0.1                      | 30~50               | 15-17                | <25     | <250| V                               |
| Strong weathering    | 0.1~0.5                   | >50                 | 17-27                | 25~50   | 250~350| IV                              |
| Medium weathering    | 0.5~3                     | -                   | 27~47                | 50~75   | 350~450| III                             |
| Micro-weathering     | 3~7                       | -                   | 47~58                | 75~90   | 450~550| II                              |
| Not weathered        | 5.95                      | -                   | >58                  | >90     | >550 | I                               |

2.3. Change law of permeability coefficient
According to the actual situation of the stratum in the study area, the permeability coefficient of the strong and medium weathered granite is obtained through the on-site drilling pumping test. The permeability coefficient of fully weathered granite is determined by the penetration head penetration test. The permeability coefficient of micro-weathered granite is determined by a conventional single plug hydrostatic test. Combined with the collected hydrogeological survey data, the permeability coefficients of concerned geotechnical layer in the study area are shown in Table 3.

Table 3. Test results of permeability coefficient of granite with different degrees of weathering

| Granite type                  | Permeability coefficient (m/d) |
|-------------------------------|--------------------------------|
| Full weathering granite      | 0.15                           |
| Strong weathering granite    | 1.59                           |
| Medium weathering granite    | 0.69                           |
| Micro-weathered granite      | 0.02                           |

According to a series of experiments, strong-weathered granite has the strongest permeability, followed by medium weathering granite. The next one is fully weathered granite, while the micro-weathered granite shows the weakest permeability. It is known that as the degree of weathering increases, the increase rate of the permeability of granite changes from large to small and finally turns into a decrease.

3. Effect of microstructure and mineral composition changes

3.1. Microstructure observation
The micro-experimental study is carried out to study the changes of mineral composition and microstructure characteristics of granites with different weathering degrees.

A total of 4 groups of granite samples with different degrees of weathering is collected from the study area. The rock samples collected on site is as shown in Figure1. Microstructure of rock samples is shown in Figure 2.
3.2. Change in mineral composition

X-ray diffraction test (XRD) is used to further quantitatively study the variation of mineral composition of granites with different degrees of weathering. Figure 3 is the X-ray diffractometer (XRD).

![Figure 1. Site rock sample](image1)

![Figure 2. Microstructure of rock samples of pre-weathered granite](image2)
Figure 3. X-ray diffraction test

The XRD diffraction patterns of granites with different degrees of weathering is obtained by X-ray diffraction test in Figure 4. The mineral composition and content are shown in Table 4.

| Rock sample number | Mineral composition and content (%) |
|--------------------|-------------------------------------|
|                    | Illite | Kaolinite | Quartz | Feldspar | Black mica | Chlorite |
| X1                 | 17.7   | 33.0      | 23.2   | 24.0     | 0.0        | 2.1      |
| X2                 | 11.2   | 16.2      | 35.2   | 34.8     | 1.9        | 0.7      |
| X3                 | 7.2    | 6.3       | 36.6   | 45.7     | 4.2        | 0.0      |
| X4                 | 1.5    | 0.6       | 40.1   | 52.6     | 5.2        | 0.0      |

According to the above test results, as the degree of weathering increases, the mineral change mainly manifests as the feldspar weathering into clay minerals such as kaolinite and illite. The anti-weathering ability of quartz is strong so the content is slightly decreased. With the decrease of hard mineral content such as feldspar and quartz, the physical and mechanical properties of granite become worse, the number of fractures increases, and the scale becomes larger, which increases the water permeability of granite.

When the granite changes from a strong weathering state to a fully weathered state, the mineral composition changes greatly, and the clay mineral content surges to more than 50%. Macroscopically, the structural structure is completely destroyed, and the strong weathering is broken into a fully weathered loose soil [10]. The weathering products are mainly composed of clay, weathered sand and gravel. Water-permeable cracks in the structure are reduced. The clay filling in the crack has a certain water-tightness, which weakens the water permeability of fully weathered granite.

4. Summary

Through the analysis of macroscopic permeability characteristics and microstructure and mineral composition of granites with different degrees of weathering, it is known that the changes in mineral composition and microstructure caused by weathering directly affect the permeability characteristics.

With the increase of weathering degree, the potassium feldspar and plagioclase in granite gradually transform into clay minerals. The proportion of quartz becomes larger, the granite structure changes from irregular granular to final crumb. Mineral particles become smaller, microporosities increased in number, leading to the increase in water permeability of the granite. However, with further enhancement of the degree in weathering, the original internal structure in the granite is completely destroyed, and the clay filling in the fracture has a certain water-tightness, resulting in a decrease in water permeability. It explains why the rate of change in granite permeability has a turning point.
The research process verifies the known facts, preliminarily explains the variation of granite permeability with the degree of weathering. However, due to the limitations of research methods and sample size, follow-up work is still required for further verification and quantitative analysis.

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