Seepage improvement test and analysis of granite residual soil

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Abstract. The influence of slag powder, cement and bentonite on the permeability coefficient of granite residual soil at different incorporation ratios was analyzed by means of seepage test with variable head. Meanwhile, the permeability coefficient was compared with that of the original granite residual soil. It is found that the effect of slag powder on reducing the permeability coefficient of granite residual soil under non-alkaline environment is limited. The effect of cement on decreasing permeability coefficient of granite residual soil is obvious. Bentonite has the best effect on reducing permeability coefficient of granite residual soil.

1. Introduction

It has become an important research topic in the field of civil engineering to improve the engineering performance of soil by adding certain proportion of modified materials. Granite residual soil has relatively large pores and is generally used as engineering soil directly. When a large amount of rainwater infiltrates into the granite residual soil, it is easy to cause seepage, which is potentially destructive to the project. Therefore, improvement of granite residual soil is a good solution. It is of great significance to study the influence of modified materials on the permeability of granite residual soil.

Liu Sheng, Chen Zhibo, Chen Weiwen et al. [1] studied improved granite residual soil with fly ash. The study showed that the incorporation of fly ash could effectively improve the shear strength of granite residual soil and reduce its permeability coefficient and disintegration rate. Li Zili, Chen Zhibo, Hu Ping et al. [2] studied the compression characteristics of fly ash and lime-improved granite residual soil. Fei Lun Lin, Xu Lihong, Qian Jinsong et al. [3] studied the cement improvement effect of granite residual soil subgrade. Tan Wangsheng [4] studied the construction technology of cement and lime improvement scheme for the granite residual soil subgrade of Airport Avenue. Tian Pengfei et al. [5] conducted compaction performance test, shear test, CBR test and circular disintegration test to explore the improvement effect and reasonable mixing amount of industrial waste calcium carbide slag on granite residual soil. Xu Yunshan et al. [6] used thermal probe method to study the effect of temperature on the thermal conductivity of compacted bentonite samples. But at present, most of the research on soil improvement starts from the strength characteristics of improved soil, and so far there are few research achievements related to the improvement of impervious property of granite residual soil. This paper mainly studies the influence of slag powder, cement and bentonite on the permeability coefficient of granite residual soil under different incorporation ratios.
2. The scheme of experiment
On the permeability of the modified granite residual soil seepage test, turn head to slag powder, cement, bentonite respectively by 5%, 10%, 15%, 20% of the mixed granite residual soil, moisture content control 33%, density of 1.67 g/cm³ are controlled, the preparation of 61.8 mm in diameter, high 40 mm ring specimen, under the condition of constant temperature and humidity curing 7 d after saturation, at the same time the preparation contains no modification of the same moisture content and dry density materials saturated remodeling of granite residual soil specimen. In order to study the influence of various modified materials on the permeability coefficient of granite residual soil samples and granite residual soil samples mixed with 5%, 10%, 15% and 20% slag powder, cement and bentonite, variable head seepage test was carried out with TST-55 permeometer. The content of each component in each sample is shown in table 1.

| Mix proportion | 0% | 5%   | 10%  | 15%  | 20%  |
|----------------|----|------|------|------|------|
| The weight of the soil (g) | 150 | 140.5| 131.8| 123.9| 116.6|
| The weight of modified material (g) | 0   | 9.5  | 18.2 | 26.1 | 33.4 |
| The total weight of modified soil (g) | 150 | 150  | 150  | 150  | 150  |
| The weight of the water (g) | 50  | 50   | 50   | 50   | 50   |
| The total weight (g) | 200 | 200  | 200  | 200  | 200  |
| Density (g/cm³) | 1.67| 1.67 | 1.67 | 1.67 | 1.67 |

3. The equipment and raw materials of test

3.1. The equipment of test
The main equipment of this test is the TST-55 type variable head seepage flow test device, as shown in figure 1.

![Variable head seepage test device](image)

Figure 1. Variable head seepage test device.

During the seepage test with variable head, the seepage head changes dynamically with time. By measuring the scale values of the water level inside the head at two different times, the permeability coefficient of the sample during the seepage period can be calculated based on Darcy's Law principle[7].

3.2. Basic properties of residual soil and modified raw materials
The materials used in this test mainly include granite residual soil, slag powder, ordinary Portland cement and bentonite.

3.2.1. Granite residual soil. The main physical property indexes of granite residual soil are shown in table 2. In order to facilitate the calculation of soil sample allocation, the air-dried granite residual soil was dried in an oven for 10h and sealed for preservation before use.
Table 2. The main physical properties of granite residual soil.

| Property                  | Value   |
|---------------------------|---------|
| The water content /%      | 15.57   |
| Constrained grain size /mm| 0.006   |
| Median grain size /mm     | 0.0008  |
| Specific gravity          | 2.7065  |
| Liquid limit /%           | 46.5    |
| Plastic limit /%          | 23.1    |
| Plasticity index Ip       | 23.4    |

3.2.2. **Slag powder.** Slag is a by-product of steelmaking industry, and its main structure is vitreous structure, which is difficult to take hydration reaction when it meets water. Slag particles are relatively large, and after quenching, the slag is ground into fine powder by ball mill to obtain slag powder[^8-9^]. The main components are shown in table 3.

Table 3. The main component of slag powder.

| Component | Value     |
|-----------|-----------|
| CaO (%)   | 37.95     |
| SiO2 (%)  | 41.9      |
| Al2O3 (%) | 9.1       |
| MgO (%)   | 7.52      |
| Fe2O3 (%) | 3.42      |

This experiment studies the effect of slag powder mixed with granite residual soil in different proportions on the permeability coefficient.

3.2.3. **Ordinary portland cement.** Portland cement is a kind of widely used powdery hydraulic cementitious material. The basic components of Portland cement are shown in table 4.

Table 4. The basic composition of portland cement.

| Component | Value     |
|-----------|-----------|
| CaO (%)   | 62-67     |
| SiO2 (%)  | 20-24     |
| Al2O3 (%) | 4-7       |
| Fe2O3 (%) | 5-6       |
| MgO, K2O, TiO2, Na2O, etc. | <5 |

Compared with other common materials such as lime and fly ash, cement can obviously and rapidly improve the engineering properties of soil and its technology is more mature. However, the dosage should be controlled well in practical engineering to save engineering cost. Because the cement initial setting is faster, the construction requirements are higher.

3.2.4. **Bentonite.** Bentonite is white with waxy luster, often in the form of lumps or loose soils, and has good moisture absorption. The maximum water absorption capacity of bentonite can reach more than 10 times its own volume. Bentonite has very strong moisture absorption and expansion characteristics, and can expand to 20-30 times its own volume in water[^10^]. The bentonite has been widely used in improving the impervious performance of natural soil as lining material. The main technical indicators are shown in table 5.

Table 5. The main technical indicators of bentonite.

| Indicator              | Value     |
|------------------------|-----------|
| Whiteness s/%          | >75       |
| Viscosity P_s/mL15g    | >2.8      |
| Colloid value /%       | >90       |
| pH value               | 8-10.5    |
| Water content /%       | ≈10       |
| Swelling capacity /mL/g| ≈20       |
| Particle size / item   | 300-325   |

4. Test results and analysis

4.1. **Variable head seepage test**

The variable head pipe is filled with water and let stand until the water overflows from the outlet, then the measurement of permeability coefficient is started. After the head pipe is filled with water to a head less than 200 cm, close the water inlet of the water bottle and open the water inlet of the permeable container. At this moment, the stopwatch starts to clock and record the initial water head \( h_1 \). After the seepage time \( t \), read and record the final water head \( h_2 \). Repeat this procedure several times.
times. When the water level in the water head tube is low, refill the water through the water inlet of the water bottle for the test. Generally, the seepage test can be stopped if the test is recorded for about 6 times. At the beginning and end of the seepage test, the temperature of the seepage water is measured and recorded with a thermometer, and the average value is taken as the test temperature. The permeability coefficient $K_T$ of the sample at $T \degree C$ is calculated according to the following formula:

$$K_T = 2.3 \frac{aL}{At} \lg \frac{h_1}{h_2}$$

(1)

Where, $K_T$ is the permeability coefficient of the sample at $T \degree C$ (cm/s); $a$ is the cross-sectional area of the variable head pipe (cm$^2$); $L$ is the height of the sample (cm), and take 4 cm; $A$ is the cross-sectional area of the sample (cm$^2$), 30 cm$^2$; $t$ is the seepage time (s); $h_1$ and $h_2$ are initial head value (cm) and final head value (cm) respectively.

The results of permeability coefficient of each group were calculated according to the test data, and the average value was taken as the permeability coefficient of the sample.

4.2. The results and analysis of test

4.2.1. Results and analysis of the influence of slag powder on permeability coefficient of granite residual soil. Figure 2 shows that the incorporation of slag powder can reduce the permeability coefficient of granite residual soil. When the incorporation ratio increases from 5% to 20%, the permeability coefficient of granite residual soil as a whole presents a linear decline trend with the increase of the incorporation ratio of slag powder, but the extent is not large. It is found in figure 3 that, relatively speaking, the sample soil with slag powder is relatively dense and the lumps are obvious. The particle size of slag powder is about 10-20 $\mu$m, smaller than the clay particle size.

Therefore, when slag powder is added into granite residual soil, its particles are distributed among the clay pores to fill in, effectively reducing the content of macropores and thereby reducing the permeability coefficient of soil. Although slag powder contains silicon, aluminum and other compounds with its own potential activity, the activation of slag powder requires a certain alkaline environment. However, in the absence of alkaline environment, the effect of simply adding slag powder on improving the permeability of granite residual soil is very limited, and the reason for improving the permeability of granite residual soil is mainly due to the filling effect of slag powder.
4.2.2. Results and analysis of the influence of cement on permeability coefficient of granite residual soil.

Figure 4 shows that the higher the cement content after curing for 7 days, the lower the permeability coefficient of the sample. When the cement incorporation ratio increased from 0% to 15%, the permeability coefficient showed a linear decline with a large range, from $1.47 \times 10^{-4}$ cm/s to $0.17 \times 10^{-4}$ cm/s, which decreased by an order of magnitude. However, when the incorporation ratio continued to increase from 15% to 20%, the permeability coefficient decreased slightly, only from $0.17 \times 10^{-4}$ cm/s to $0.12 \times 10^{-4}$ cm/s.

It is not difficult to find from figure 5 that, relatively speaking, the appearance of the cement mixed sample is relatively dense with a hard surface. After adding cement, a series of physical and chemical reactions take place between cement and water and some components in granite residual soil.

Figure 5. Comparison of the appearance of sample without cement and sample mixed with cement after seepage.
The hydration reaction of cement gel, gel contains more $Ca^{2+}$, they will and soil particles on the surface of the metal cation ion exchange, soil particles linked by colloid formation between the chain shape even group of flocculent structure, hydration products adhere to the particle surface, pore channel narrow, and part of the pore channel is colloid connection objects segmentation form enclosed Spaces; Calcium carbonate will be formed when $Ca(OH)_2$ generated by hydration reacts with $OH^-$ in water and $CO_2$ in air, and when $Ca^{2+}$ generated by hydration reacts with $SiO_3$, $AlO_3$ and other oxides in cement, crystals will be formed. Pores will be further filled, seepage channels will be reduced, and permeability coefficient will be reduced. In addition, during the curing period, the free water decreases, the crystallizing water increases, the soil becomes denser than before, and the permeability of the cement-mixed sample decreases further.

Due to the large original dispersion of soil particles and the large number of macropores, when the cement incorporation ratio is lower than 15%, the effect on the porosity of the sample soil is the most obvious, especially the sharp decrease in the number of macropores and the most obvious decrease in the permeability coefficient. With the gradual increase of cement content, part of hydration products began to fill the tiny pores between soil particles, but the effect of the tiny pores on soil permeability is far less than that of the large pores. Therefore, although the permeability coefficient continues to decrease, the decreasing range of the permeability coefficient has been significantly reduced.

4.2.3. Results and analysis of the influence of bentonite on permeability coefficient of granite residual soil. Figure 6 shows that with the increase of bentonite content, the permeability coefficient of granite residual soil decreases significantly. Mixed with 5% bentonite on the granite residual soil effect is very obvious, the improvement of the performance of the permeability coefficient of permeability drop to about 1/55 of the original, when mixing ratio increased to 10%, the permeability coefficient is still a relatively obvious continues to fall, to about 1/17 of 5% when the permeability coefficient ratio of mixed, increase when the dosage of bentonite, the coefficient of permeability reduction effect is smaller and smaller.

![Figure 6. The relationship between permeability coefficient and bentonite incorporation ratio.](image)

Compared with the samples without bentonite, the appearance of the samples with bentonite doping is very dense, and it is difficult to see the existence of pores by naked eye. The surface is shiny, and the viscosity and plasticity are both large. This phenomenon can be clearly observed in figure 7.
It is concluded that bentonite has strong water-swelling characteristics: when bentonite meets water, water molecules enter between the mineral layers of bentonite, leading to the expansion of the interlayer spacing. Bentonite includes two types, sodium bentonite and calcium bentonite. The valence number of sodium bentonite containing $Na^+$ is lower than that of calcium bentonite containing $Ca^{2+}$. Therefore, the electrostatic attraction between particles is relatively weak, resulting in weaker bonding force between bentonite particles, easier dispersion of particles, and greater absorbency expansibility. After hygroscopic expansion, the volume of sodium bentonite particles reaches 20-30 times of the original volume, so that the pore ratio of soil is greatly reduced, the compactness is increased, and the permeability of soil is significantly reduced. When 5% and 10% bentonite are added, the volume expansion mainly reduces the number of macropores in the soil, and the number of macropores often plays a decisive role in the permeability of the soil, so the permeability coefficient drops sharply. When the incorporation ratio of bentonite continues to increase, under the condition that most of the macropores have been filled, the expansive effect of bentonite particles starts to act on a large number of tiny pores, so although the permeability coefficient continues to decrease, relatively speaking, its decreasing degree has been weakened.

4.2.4. A comprehensive comparison of permeability of improved residual soil by slag powder, cement and bentonite.

It is found in figure 8 that the incorporation of slag powder, cement and bentonite into granite residual soil will result in the decrease of permeability coefficient. The permeability coefficient of the three kinds of materials was smaller when they were added to eluvial soil, but the extent of permeability coefficient reduction was different. At the same incorporation ratio, the effect of adding bentonite on
the permeability coefficient of granite residual soil was the most obvious, followed by cement, and the effect of adding slag powder on the permeability coefficient of granite residual soil was the weakest.

When modifying materials are used to reduce the permeability coefficient of granite residual soil, the point with the greatest reduction of permeability coefficient is taken as the optimal incorporation ratio. Under non-alkaline condition, the effect of slag powder on the permeability coefficient of granite residual soil is not obvious. When the cement is added with 15%, the permeability coefficient of granite residual soil decreases the most. Considering the engineering cost, it is considered that the best cement incorporation ratio to reduce the permeability coefficient of granite residual soil is 6%-10%. The reduction of permeability coefficient of granite residual soil by adding 5% bentonite has been very large. However, because the test group with incorporation ratio of less than 5% bentonite is not set, and engineering cost is taken into account, it is considered that the best bentonite incorporation ratio to reduce the permeability coefficient of granite residual soil is within 5%.

5. Conclusion
In this paper, by adding slag powder, cement and bentonite to granite residual soil at 5%, 10%, 15% and 20%, respectively, saturated remolded ring knife samples were prepared. The influence law of various materials on the permeability coefficient of granite residual soil was studied through variable head seepage test. The main conclusions are as follows:

1) The residual soil sample with slag powder granite becomes compacted and agglomerates obviously; In the non-alkaline environment, the permeability coefficient decreases linearly with the increase of the incorporation ratio of slag powder, but the extent is not great.

2) The cementitious granite residual soil sample has reduced porosity, compact structure and hard texture. With the increase of cement incorporation ratio, the permeability coefficient decreases obviously, and the permeability coefficient decreases when the cement incorporation ratio exceeds 15%.

3) The structure of the bentonite-doped granite residual soil sample is very dense, and it is difficult to see the macropores with naked eye. With the increase of bentonite incorporation ratio, the permeability coefficient decreased significantly, especially when the incorporation ratio was 5%.

4) Based on the comprehensive comparison of the permeability coefficient of slag powder, cement and bentonite granite residual soil, it is concluded that the effect of slag powder on reducing the permeability coefficient of granite residual soil in non-alkaline environment is limited. The effect of cementing on the permeability coefficient of granite residual soil is obvious, and the optimal incorporation ratio is 5%-10%. The addition of bentonite has the best effect on reducing permeability coefficient of granite residual soil, and the best incorporation ratio is within 5%.

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