Experimental Study on the Influence of Permeability Coefficient of Granite Residual Soil

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Abstract: In order to study the influence of void ratio, seepage flow, confining pressure and principal stress difference on the permeability coefficient of granite residual soil samples, four groups of seepage tests of 16 samples were designed. The test results show that with the increase of initial void ratio, the permeability coefficient increases gradually, and the final increase trend of permeability coefficient slows down; with the increase of confining pressure, the permeability coefficient decreases gradually, and the decrease trend of permeability coefficient slows down; with the increase of main stress, the permeability coefficient decreases gradually, and the decrease trend of permeability coefficient slows down; with the increase of seepage flow rate The permeability coefficient increases gradually, and the increasing trend of permeability coefficient becomes larger.

1 INTRODUCTION

Granite residual soil is mainly distributed in the southeast region with abundant rainfall in China, where there are many granites. The granite in contact with rain and air has changed its mineral composition after weathering for a certain period of time, and the internal structure of the soil has cracks. Under the influence of the surrounding environment, the granite has formed residual soil over time. Underground geotechnical engineering is growing more and more significant as the economy grows. The study of the mechanical properties of granite residual soil is inextricably linked to projects like subways, tunnels, foundation pits, slope protection, and so forth. Residual soil is easy to soften and disintegrate when encountering water. Water will alter the internal skeleton structure of the particles as it infiltrates, and the penetration may have an impact or drag effect on the soil particles. The more fine particles the percolation force can carry away the larger the percolation pores will be and the direction of the percolation force is fixed to induce a rearrangement of the particles. Additionally, more orderly pore channels can also make the infiltration more smooth and enhance the permeability characteristics of soil. Seepage characteristics are of great significance for many working conditions such as rainfall, water level change and foundation pit drainage in practical projects.

Liao Hongjian(Liao et al., 2005) et al. considered the research of slope stability caused by the speed of water level decline and the permeability characteristics of soil, and combined with the simulation calculation of seepage field in actual working conditions, obtained the influence law of water level decline and soil permeability coefficient on the stability coefficient.Lu Yulin(Lu, 2018) et al. consider the influence of coupled seismic and seepage fields on the change of slope stability, combining the common limit equilibrium theory with both earthquake and percolation conditions to study and refine the calculation method of stability coefficients. Yan Fangfang(Yan et al,. 2019) et al. considered the effect of different rainfall duration on the variation of the water level line of the seepage field and the slope instability slip surface. The simulation results showed that the longer the rainfall duration the higher the water level line the larger the slope slip surface, and the rainfall had a greater effect on the surface layer of the soil. Shi Zhenming(Shi et al,. 2016) et al. considered the changing law of slope stability during rainfall infiltration on multi-layered soil slopes, improved the seepage field model, calculated the strength parameters in the seepage process of

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different soil layers and carried out numerical simulations, and the results showed that the stability coefficient of soil decreases as the depth of rainfall infiltration increases. Liu Caihua(Liu et al, 2005) et al. considered the influence of slope water level rise on slope stability change, and the simulation results showed that the slope stability coefficient first decreased and then increased due to the effect of pore water pressure during the water level rise, which was also related to the attenuation of shallow strength parameters. Liu Caihua(Liu et al, 2005) et al. considered the impact of groundwater changes on slope stability changes during the sudden drop of reservoir water level, and analyzed a large number of practical cases. The results showed that there was a certain delay time for groundwater to drop after the sudden drop of reservoir water level, which had an impact on slope instability.Ma Mengxiang(Ma et al, 2018) et al. considered the effect of the rate of change of water level rise and fall on the change of reservoir slope stability, and the simulation study results showed that the rate of change of water level has a greater effect on slope stability, and the effect of water level rise and fall on stability is different. However, there are few research results on the influence of various internal and external factors on the permeability coefficient of residual soil. Therefore, this paper mainly studies the influence of pore ratio, seepage flow, confining pressure, principal stress difference and other factors on the permeability coefficient of granite residual soil samples under constant waterhead.

2 EXPERIMENTAL PROGRAMME

To investigate the effects of pore ratio, seepage flow , confining pressure and main stress difference on the penetration coefficient of granite residual soil specimens, four sets of seepage tests with a total of 16 specimens were designed, in which specimens 1-4 were tested to study the effects of initial pore ratio on the penetration coefficient, specimens 2-8 were tested to study the effects of seepage flow rate on the penetration coefficient, specimens 9-12 were tested to study the effects of confining pressure on the penetration coefficient, and specimens 13-16 were tested to study the effects of different main stress differences on the penetration coefficient. Table 1 displays the test conditions for each group of tests.

Table 1.

number	Initial void ratio	confining pressure （kPa）	Seepage flow （ml/min）	Principal stress difference （kPa）
1	1.0	70	0.02	0
2	1.1	70	0.02	0
3	1.2	70	0.02	0
4	1.3	70	0.02	0
5	1.0	70	0.02	0
6	1.0	70	0.04	0
7	1.0	70	0.06	0
8	1.0	70	0.08	0
9	1.0	70	0.02	0
10	1.0	120	0.02	0
11	1.0	170	0.02	0
12	1.0	220	0.02	0
13	1.0	70	0.02	0
14	1.0	70	0.02	20
15	1.0	70	0.02	40
16	1.0	70	0.02	60

3 EXPERIMENTAL EQUIPMENT AND TESTING

3.1 Experimental Equipment

The instrumentation used in this test is the SLB-1 type stress-strain controlled triaxial shear permeability tester, which can be used to conduct seepage shear tests under constant water head and constant flow conditions, respectively. The test equipment is shown in Figure 1. The parameters that can be adjusted or displayed for each function of the instrument are: the controllable range of specimen axial pressure is 0-20kN (±1%), the controllable range of strain in shear test is 0.002-4mm/min (±10%), the controllable range of stress in shear test is 0kN-20kN(±1%), the controllable range setting value of specimen circumferential pressure is 0.01-1.95MPa, the set value of counterpressure in percolation test can be controlled in the range of 0.01-0.99MPa(±0.5%FS), the volume flow rate in constant flow percolation test can be controlled in the range of 0.02-30ml/min, the volume deformation ignores positive and negative and the maximum deformation is 480ml.

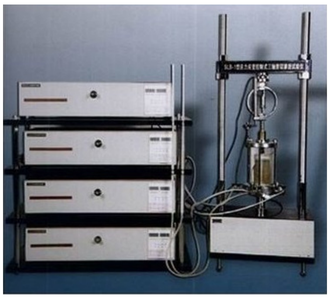

Figure 1: The stress-strain control shear penetrant triaxial test apparatus

3.2 Experimental Testing

The test soil samples were taken from a granite residual soil slope, firstly, all the soils were dried and crushed, and then the soil was sieved with a maximum particle size of 2mm sifter. The main physical properties are shown in Table 2. The specimen models used for the test were all Φ39.1×80mm models. In order to prepare soil samples with a specific initial pore ratio, the dry density of the soil can be calculated based on the required pore ratio, and then the mass of the required soil can be calculated based on the already prepared soil samples with a certain moisture content. The specimen is saturated by means of vacuum pumping and later solidified, and the solidification end condition is set to be zero pore water pressure.

Table 2: Main physical property indexes of granite residual soil.

Restricted particle size (mm)	Median size (mm)	proportion	Liquid limit (%)	Plastic limit (%)	I_p Plasticity index
0.006	0.0008	2.7065	46.5	23.1	23.4

The seepage test adopts the constant waterhead seepage method. In the test, open the back pressure valve and set the back pressure at the upper and lower ends, and the numerical difference is the constant head value. Set the back pressure at the upper end to 0 and the lower end to 50kPa. The constant waterhead value is 50kPa.

4 EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Influence of Seepage Flow on Permeability Coefficient

Triaxial seepage shear tests were conducted under different initial pore ratio conditions according to the experimental scheme. The permeation coefficients obtained from the seepage tests are shown in Table 3. The variation of the penetration coefficient with the initial pore ratio is shown in Fig. 2.

Table 3: Effect of initial void ratio on permeability coefficient.

number	Initial void ratio	confining pressure （kPa）	Seepage flow （ml/min）	Principal stress difference （kPa）	Permeability coefficient （cm/s）
HLL1	1.0	70	0.02	0	8.34E-07
HLL2	1.1	70	0.02	0	4.91E-06
HLL3	1.2	70	0.02	0	8.48E-06
HLL4	1.3	70	0.02	0	8.95E-06

According to the trend shown in the data in Fig. 2 and table 3, it can be seen that when the confining pressure, flow rate and main stress are the same and the initial pore ratio is within the range of 1.0-1.3 in the test, the permeability coefficient increases with the growth of the initial pore ratio, but the increasing trend gradually slows down. The initial pore ratio from 1.0 to 1.3 corresponds to an increase in the permeability coefficient from 8.34E-07cm/s to 8.95E-06cm/s. The order of magnitude increases by one level, thus showing the importance of the initial pore ratio on the permeability coefficient.

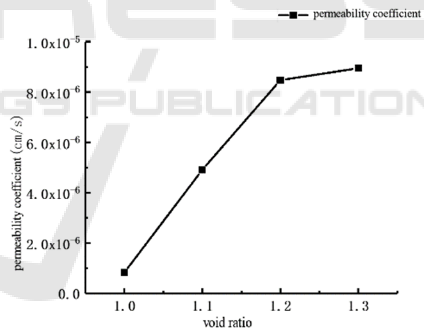

Figure 2: Relationship between initial void ratio and permeability coefficient.

The larger the pore ratio, the better the connectivity of the percolating pores and thus the larger the contact surface of the percolating water with the particles around the pores. With the gradual increase of percolation force, the directional percolation force promotes the orderly arrangement of particles. The more orderly pore channels also lead to smoother infiltration. The initial pore ratio in the test increased from 1.0 to 1.3, and the corresponding permeability coefficient increased from 8.34E-07cm/s to 8.95E-06cm/s, but the increasing trend was gradually slowing down.

4.2 Influence of Initial Pore Ratio on Permeability Coefficient

Triaxial seepage shear tests of remodeled soils were conducted according to the test protocol at different flow, the obtained permeability coefficients are shown in Table 4, and the variation of permeability coefficients with flow is shown in Fig. 3.

According to the data in Fig. 3 and table 4, when the void ratio, confining pressure and principal stress are the same in the test and the flow rate is within the range of 0.02ml/min-0.08ml/min, the permeability coefficient also increases with the growth of the flow rate. The permeability coefficient varies from 8.34E-07cm/s to 2.97E-06cm/s in the flow variation range. The overall variation of the permeability coefficient changes greatly, which is an order of magnitude higher. The permeability coefficient gradually increases with the increase of the seepage pressure, because the seepage flow directly affects the seepage pressure. The faster the rate of change in osmotic pressure, the faster the rate of change in penetration force and the increased ability to influence the skeletal structure of the soil particles, resulting in better pore connectivity.

Table 4: Effect of seepage flux on permeability coefficient.

number	Initial void ratio	Confine-ng pressure （kPa）	Seepage flow （ml/m-in）	Principal stress differen-ce （kPa）	Permeabili-ty coefficient （cm/s）
HLL5	1.0	70	0.02	0	8.34E-07
HLL6	1.0	70	0.04	0	1.25E-06
HLL7	1.0	70	0.06	0	1.96E-06
HLL8	1.0	70	0.08	0	2.97E-06

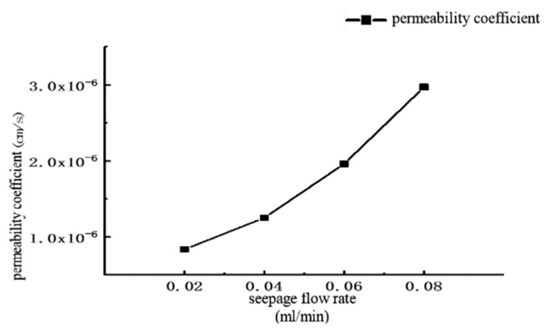

Figure 3: Relationship between seepage flux and permeability coefficient.

4.3 Influence of Confining Pressure on Permeability Coefficient

Triaxial seepage shear tests of remodeled soils under different confining pressure conditions were conducted according to the test protocol, and the obtained permeability coefficients are shown in Table 5, and the relationship between the permeability coefficient and the change of confining pressure is shown in Figure 4.

According to the data in Fig. 4 and table 5, when the pore ratio, seepage flow and principal stress are the same and the confining pressure is in the range of 70kpa-220kpa, the permeability coefficient decreases with the increase of confining pressure. When the confining pressure changes from 70kpa to 220kpa, the corresponding permeability coefficient decreases from 8.34E-07cm/s to 9.66E-08cm/s, and the downward trend gradually slows down.

In the seepage test, an increase in confining pressure can restrict the evolution of seepage channels, shrink soil pores, boost soil compactness, and weaken soil permeability. Confining pressure's capacity to alter the internal particle skeleton structure of soil during consolidation is waning as it increases. The pore space is already quite small due to the addition of some confining pressure, thus it is challenging to further shrink the vacuum by raising the confining pressure.

Table 5: Effect of confining pressure on permeability coefficient.

number	Initial void ratio	Confine-ng pressure （kPa）	Seepage flow （ml/m-in）	Principal stress differen-ce （kPa）	Permeabili-ty coefficient （cm/s）
HLL9	1.0	70	0.02	0	8.34E-07
HLL10	1.0	120	0.02	0	3.54E-07
HLL11	1.0	170	0.02	0	1.38E-07
HLL12	1.0	220	0.02	0	9.66E-08

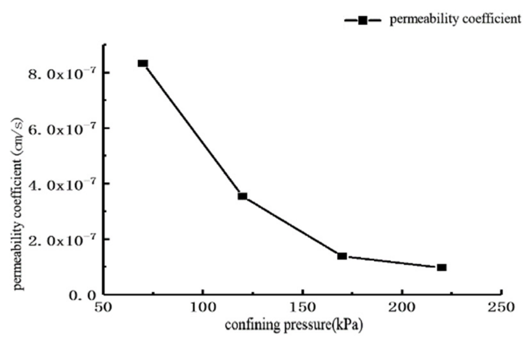

Figure 4: Relationship between confining pressure and permeability coefficient.

4.4 Influence of Principal Stress Difference on Permeability Coefficient

Triaxial seepage shear tests of remodeled soils under different principal stress differences were conducted according to the test protocol, and the obtained permeability coefficients are shown in Table 6, and the variation of permeability coefficients with principal stress is shown in Fig. 5.

The data in Figure 5 and Table 6 show that, in tests with the same pore ratio, seepage flow rate, and confining pressure, the permeability coefficient drops as the main stress differential increases. The main stress difference varies from 0 kPa to 60 kPa, and the corresponding permeability coefficient decreases from 8.34E-07cm/s to 3.38E-07cm/s, which is a small range of permeability coefficient reduction.

Table 6: Effect of principal stress difference on permeability coefficient.

number	Initial void ratio	Confine-ng pressure （kPa）	Seepage flow （ml/m-in）	Principal stress differen-ce （kPa）	Permeabili-ty coefficient （cm/s）
HLL13	1.0	70	0.02	0	8.34E-07
HLL14	1.0	70	0.02	20	5.76E-07
HLL15	1.0	70	0.02	40	3.98E-07
HLL16	1.0	70	0.02	60	3.83E-07

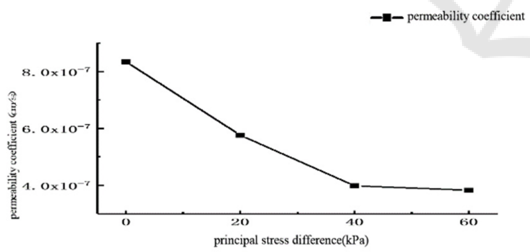

Figure 5: Relationship between principal stress difference and permeability coefficient.

On the one hand the applied principal stress difference increases the vertical pressure on the soil sample, and there will be less pore space after vertical consolidation. On the other hand, the principal stress difference may lead to local deformation of the soil, and the cross-sectional area of seepage will increase. The larger the principal stress difference is, the more obvious the effect from local deformation will be and the larger the area of seepage cross-section will be. Therefore, the permeability coefficient decreases with the increase of the principal stress difference.

5 CONCLUSIONS

(1) The permeability coefficient steadily rises as the initial pore ratio rises, and the final growth trend of the permeability coefficient slows down. The larger the pore ratio, the better the connectivity of the seepage pores, and the larger the contact surface between the seepage water and the particles around the pores. With the gradual increase of the seepage force, the directional seepage force promotes the orderly arrangement of particles, and the more orderly pore channels can also make the penetration more smooth.

(2) The permeability coefficient progressively rises as the seepage flow rate rises, and the trend of rising permeability coefficient quickens. Permeability pressure is directly influenced by the size of the seepage flow. The greater the rate of change in permeability pressure, the greater the rate of change in permeability, and the greater the ability to modify the skeletal structure of soil particles, resulting in improved pore connectivity.

(3) The permeability coefficient steadily drops as confining pressure rises, and the rate at which it is falling slows down. In the seepage test, an increase in confining pressure can restrict the evolution of seepage channels, shrink soil pores, boost soil compactness, and weaken soil permeability. Confining pressure's capacity to alter the internal particle skeleton structure of soil during consolidation is waning as it increases. The key point is that its pores are already quite small when the confining pressure is increased to a certain degree. It is challenging to minimize the pores, even while the confining pressure rises.

(4) The permeability coefficient steadily declines as the major stress rises, and this decline trend becomes slower. On the one hand, the application of the primary stress difference will result in an increase in the soil sample's vertical pressure ,and the pores for vertical consolidation will be less. On the other hand, applying the primary stress difference can cause localized soil deformation and expand the seepage's cross-sectional area. The influence of local deformation is more visible and the region of seepage cross-section is bigger as the major stress differential increases. As a result, the permeability coefficient similarly falls as the primary stress difference increases.

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