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The Pore Water Press of Granite Residual Soil with Different Consolidation Degree under Cyclic Loading

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Abstract: The underlying soil sometimes has different consolidation degree. Cyclic loading will result in the change of pore water pressure as well as the differential settlement. In order to study the effect of the consolidation degree on pore water pressure, a series of dynamic cyclic tests of saturated soils were carried out by dynamic triaxial test system. This study investigated the influence of the different initial consolidation degree 80%, 90%, 100% and the confining stress on pore water pressure with the same cyclic stress ratio. As the number of cycles increases, the pore water pressure increases. Under the same consolidation degree and cyclic stress ratio, the peak pore water pressure increased with increasing the confining pressure. During cyclic loading, the peak pore water pressure in not fully consolidation soil is found to be higher than in fully consolidation soil for the same cyclic stress ratio, frequency and confining stress. In order to simulate the development of the pore water pressure under the cyclic loading, a hyperbolic model has been proposed. The model can simulate the whole process for pore water pressure development under different initial consolidation degree of the soil. The results indicate that the theoretical value agrees well with the measured data.

Keywords: *Pore water pressure, Consolidation degree, Cyclic loads, Triaxial test, granite residual soil.*

1. Introduction

With the rapid development of urbanization, the high-speed railway, subway, etc has become a solution to the traffic congestion. But they also have vibration problem which should not be ignored. The vibration loading increases the pore water pressure which effects the deformation and strength of soil. The law of pore water pressure development is also the key to use effective stress theory for the dynamic analysis [1]. The correct predict of the pore water pressure is primary important.

In past few decades, experiments have been carried out to study the response of pore water pressure to cyclic loads [2-5]. Tang [1] studied pore water pressure in the saturated soft clay around the tunnel under vibration loading of Shanghai subway line No.2. Devi [6] researched the effects of cyclic stress ratios on the pore water pressure with confining stress of 100kPa by cyclic triaxial tests. Li [7] discussed the development of the post-cyclic pore water pressure and undrained strength after cyclic loading with consideration of cyclic disturbance on natural clay. Hyodo [8] tried to find the effect of different drainage conditions on the pore water pressure. Gu [9] studied influence of the confining pressure on the dynamic behavior of saturated clays. Hyde [10] presented the results of pore water pressure on different cyclic stress levels by tests. Researchers have proposed the formulation of undrained pore water pressure to predict its development [11-14]. But they did not consider the effect of the consolidation degree. They focused on the dynamic response of the saturated soil of consolidation degree 100%.

In order to rush deadline, the consolidation of subgrade soil sometimes did not wait the completion, the project was put into use. Displacement and other geological disasters will occur and threat life and property [15-16]. The increase in pore water pressure generated by cyclic loading, especially to the not fully consolidation soil, which will decrease the effective load bearing capacity of soil. Therefore, the research of the pore water pressure of the subgrade under cyclic loading is significant to the high-speed railway, subway, et al. This paper focuses on pore water pressure under the cyclic loading, considering the different initial consolidation degree 80%, 90%, 100%. A series of undrained tests were conducted by dynamic triaxial test system to investigate the development of pore water pressure with various initial consolidation degree and different confining stress. The development of pore water pressure was investigated. The suitable model was proposed to predict the pore water pressure buildup considering the consolidation degree.

2. Experimental program:

In order to investigate the influence of consolidation degree on the saturated soil, the experiments under cycle loading were conducted by dynamic triaxial test system in this study. The testing system is presented in Figure 1. The test samples were taken from Ganzhou city in Jiangxi province. The soils were collected at a depth of 0.3m below the surface. The soil was the granite residual soil and had a liquid limit of 40%, a plastic limit of 27.5, and the plasticity index of 12.5. The specific gravity was 2.73. The maximum dry density was 1.76 g/cm^3.

Figure 1: *Cyclic triaxial test system*

The soil particles were first sieved with a sieve with a 2 mm aperture size. Those particles with a dimension larger than 2 mm were discarded. The experimental specimens were prepared at two dry densities $1.55\ \mathrm{g/cm^3}$ and $1.60\ \mathrm{g/cm^3}$.Tests performed on remolded soil samples. The effect of consolidation degree on pore water pressure was also investigated with the three consolidation degrees of 80%, 90%, 100% based on the dry density $1.55\ \mathrm{g/cm^3}$ and $1.60\ \mathrm{g/cm^3}$. The specimens were first prepared at an initial gravimetric water contend $w = 20\%$ and a dry density. The specimens were prepared using the sample tube of 39.1 mm in diameter and 80 mm in height. In order to ensure uniform specimens with fewer clusters, the specimen 80 mm in height was statically compacted by 5 layers. The soil specimens were saturated using vacuum saturation method. Four group tests were made. The confining pressure of first group specimens T1, T2, T3, the second group specimens T4, T5, T6, and the third group specimens T7, T8, T9 were 100kPa, 150kPa, 200kPa respectively. The previous three groups were saturated allowing consolidation degree change (80%, 90%, 100%) in tests with the same dry density $1.60\ \mathrm{g/cm^3}$. The last group specimens T10, T11, T12 were saturated allowing consolidation degree change (80%, 90%, 100%) with the same dry density $1.60\ \mathrm{g/cm^3}$ and the same confining pressure 200kPa. The four groups were used to compare the influence of consolidation degree, confining pressure and dry density. The cyclic triaxial test has three phases of saturation, consolidation, and cyclic loading. The sample was consolidated under k_0 condition. The consolidation degree controlled three level 80%, 90%, 100%. The test used the frequency of 1.0Hz. All the tests were carried out under consolidation undrained condition. The loading waveform was a sine wave type. A cyclic stress ratio (CSR) of 0.2 was chosen. Detail testing schemes are shown in Table.1. The samples after test are presented in Figure.2.

Table 1: *Test schemes*

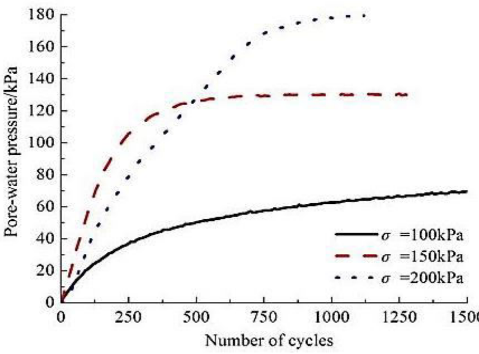
Sample	Confining Pressure (kPa)	Dry Density ($\mathrm{g/cm^3}$)	Consolidation degree (%)
T-1	100	1.60	80
T-2	100	1.60	90
T-3	100	1.60	100
T-4	150	1.60	80
T-5	150	1.60	90
T-6	150	1.60	100
T-7	200	1.60	80
T-8	200	1.60	90
T-9	200	1.60	100
T-10	200	1.55	80
T-11	200	1.55	90
T-12	200	1.55	100

Figure 2: *Cyclic triaxial test system*

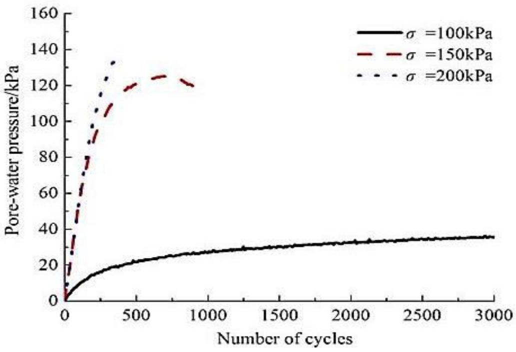
3. Test Results and Discussing:

3.1. Influence of confining pressure on pore water pressure:

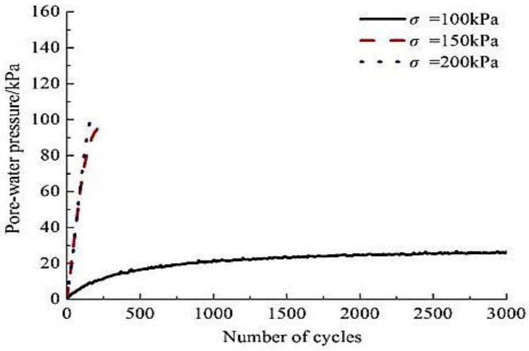
Through the test data of the dynamic triaxial test system, the relationships between accumulative pore pressure and number of cycles under different confining stress are shown in Figure.3. It can be noted that, for a given loading frequency 1Hz, under the different confining pressure, the pore water pressure increases with number of cycles quickly. The confining pressures were varied in the tests. When the consolidation degree was 80%, the peak values of the pore water pressure of the confining pressure 100kPa, 150kPa, 200 kPa were 84.1kPa, 130.6kPa, 179.5kPa, respectively. It can be seen in Figure.3(a). The samples were also tested at consolidation degree 90%, 100%. The results can be seen in Figure.3(b) and Figure.3(c), respectively. When the consolidation degree was 90%, the peak values of the pore water pressure were 36.3kPa, 125.9kPa, 135.3kPa for the confining pressure 100kPa, 150kPa, 200kPa, respectively. When the consolidation degree was 100%, the peak values of the pore water pressure of the confining pressure 100kPa, 150kPa, 200kPa were 26.8kPa, 99.4kPa, 104.7kPa,respectively.Under the same consolidation degree and cyclic stress ratio, the bigger the confining stress is, the greater the peak pore water pressure buildup is. Test results shown that the confining stress has strong influence on the response of saturated soils.



(a) U=80%



(b) U=90%

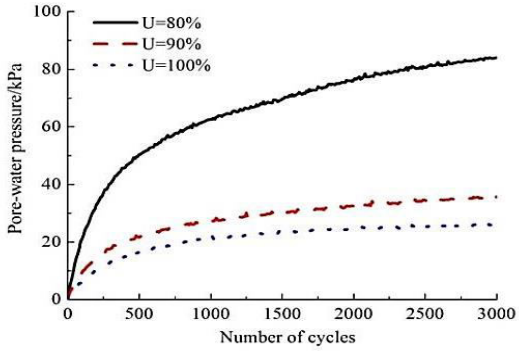


(c) U=100

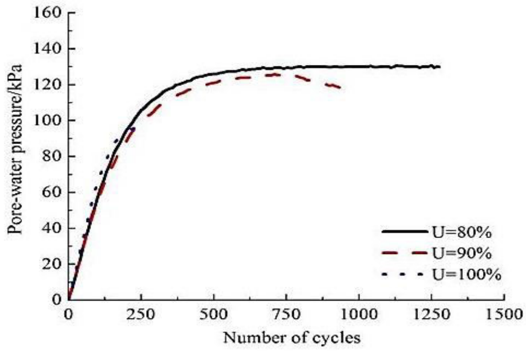
***Figure 3:** Relationships between pore pressure and number of cycles under different confining stress*

3.2. Influence of consolidation degree on pore water pressure:

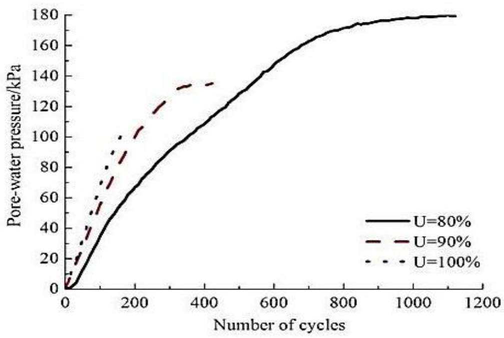
Figure.4 presents the pore water pressure versus the number of loading cycles under different consolidation degree 80%, 90%, 100%. Measured pore water pressure versus the number of loading cycles under the three confining pressure 100kPa, 150kPa, 200kPa were illustrated in Figure.4(a), (b), (c), respectively. For the same confining stress 100kPa, 150kPa, 200kPa, when the consolidation degree decreased from 100% to 80%, the increment of peak water pressure are 57.3kPa (from 26.8kPa to 84.1kPa), 31.2kPa (from 99.4kPa to 130.6kPa), 74.8kPa (from 104.7kPa to 179.5kPa), respectively. In general, when the consolidation degree decreased, the pore water pressure increased. For all soils, the pore water pressure increased rapidly with increasing number of loading cycles. During cyclic loading, the peak pore water pressure in not fully consolidation soil is found to be higher than in fully consolidation soil for the same cyclic stress ratio, frequency and confining stress. Because of the high degree of consolidation of the sample, the soil structure is denser, which is not conducive to the development of pore water pressure.



(a) σ =100kPa



(b) σ =150kPa



(c) σ =200kPa

***Figure 4:** Relationships between pore pressure and number of cycles under different consolidation degree*

Under the same dry density $1.55\ g/cm^3$, relationships between accumulative pore pressure and number of cycles under different consolidation degree of are shown in Figure.5. Figure.5 shows the results of cyclic triaxial test with varying consolidation degree at confining pressure 200kPa. With the number of cycles increasing, the peak pore water pressure of the consolidation degree 80%, 90%, 100% reached 174.3kPa, 153.2kPa, 146.2kPa. With the consolidation degree of the soil increased, soil is denser, the permeability of the soil becomes worse. Compared the results of different dry density Figure.4(c) and Figure.5, the dry density has influence on the development of pore water pressure of the soil. The dry density increased, the pore water pressure decreased. For a given frequency and confining pressure, larger peak values of the pore water pressures were generated at lower dry density as a general trend.

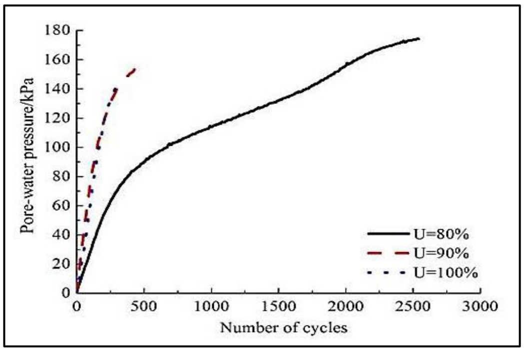


Figure 5: *Relationships between pore pressure and number of cycles under different consolidation degree*

4. Model for pore pressure:

Prediction of pore water pressure is important for understanding the behavior of soils under cyclic loading. Follow Ohara and Matsuda [13], a modified similar hyperbolic model is put forth as

$$\frac{u}{\sigma} = \frac{UN}{A + BUN}$$

Where, u is the pore water pressure; σ is the confining pressure; U is the consolidation degree; N is the number of cycles; A, B are the coefficient of model.

Based on the above model, the Matlab and nonlinear least-squares were used to algorithm to fit experimental data. The parameters of model used to fit the measured data of the tests are presented in Table.2. Table.2 shows that the coefficients of determination R^2 are more than 0.965. The R^2 value indicates that reasonable to good correlations are obtained for the model constants. It can be noted that all parameters match well with those obtained for individual specimens. The test date of confining pressure 100kPa is chosen as an example and comparison between measured and the fitted curves are shown in Figure.6. It is seen that the fitted data agree well with the measured data.

Table 2: *Model parameters*

Sample	σ (kPa)	U (%)	A	B	R^2
T-1	100	80	380.2496	1.0704	0.9870
T-2	100	90	912.87	2.5552	0.9888
T-3	100	100	380.961	3.4088	0.9970
T-4	150	80	98.76072	1.0026	0.9654
T-5	150	90	127.3148	1.005	0.9696
T-6	150	100	172.6627	0.8698	0.9852
T-7	200	80	206.4516	0.6384	0.9915
T-8	200	90	232.2581	0.7808	0.9892
T-9	200	100	1035.796	0.2653	0.9967
T-10	200	80	578.4944	0.941	0.9678
T-11	200	90	159.9493	0.8562	0.9963
T-12	200	100	561.4533	0.473	0.9917

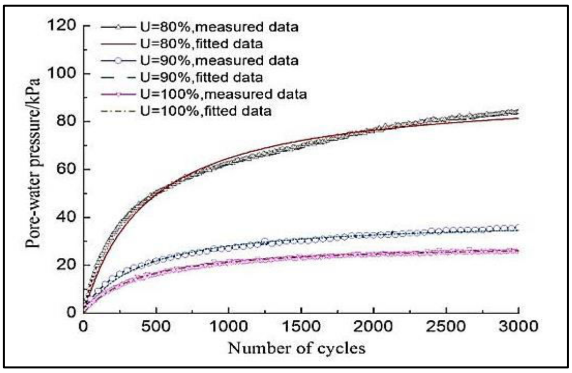


Figure 6: *Fitting of pore water pressure*

5. Conclusions:

In this paper, a series of dynamic triaxial tests were carried out on the granite residual soil with different consolidation degree and confining stress. The effects of the consolidation and confining stress on the pore water pressure were investigated. For the same cyclic stress ratio, during the application of cyclic loading, the peak pore water pressure increases with the decreasing of consolidation degree. The pore water pressures develop with increasing number of cyclic and decreasing consolidation degree, thereby decreasing the bearing capacity of the soil and inducing excessive settlement. The development of pore water pressure was influenced significantly by the consolidation degree and confining stress. A hyperbolic model considering the initial consolidation degree for prediction of pore water pressure has been proposed. The model was used to fit the experiment data of pore water pressure. The interesting agreements were obtained between fitted data and the measured data. The results can be referenced to construction of traffic engineering.

6. Acknowledgements:

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References:

[1] Yiqun Tang, Zhendong Cui, Xi Zhang and Shukai Zhao, "Dynamic response and pore pressure model of the saturated soft clay around the tunnel under vibration loading of Shanghai subway", *Engineering Geology,* Volume No.98, Issue No.3-4, PP.126-132,2008.

[2] H. A. M. Van Eakelen and D. M. Potts, "The behaviour of Drammen clay under cyclic loading", *Géotechnique*, Volume No.28, Issue No.2, PP.173-196, 1978.

[3] A. Sakai, L. Samang and N. Miura, "Behaviour of soft soils under undrained cyclic loading with initial shear stress", *Geotech. Eng. J. Southeast Asian Geotech. Soc.*, Volume No.27, Issue No.2, PP.1-22, 1996.

[4] G. G. Moses, S. N. Rao and P. N. Rao, "Undrained strength behaviour of a cemented

marine clay under monotonic and cyclic loading", *Ocean Engineering*, Volume No.30, Issue No.14, PP.1765-1789, 2003.

[5] A. M. Ansal and A. Erken, "Undrained behavior of clay under cyclic shear stresses", *Journal of Geotechnical and Engineering*, Volume No.115, Issue No.7, PP.968-983,1989.

[6] K. Devi, R. Sahu and S. Mukherjee, "Response of organic clay under cyclic loading", *International Journal of Geotechnical Engineering*, Volume No.8, Issue No.2, PP.130-143, 2014.

[7] Lingling Li, Hanbo Dan and Lizhong Wang, "Undrained behavior of natural marine clay under cyclic loading", *Ocean Engineering*, Volume No.38, Issue No.16, PP.1792-1805, 2011.

[8] M. Hyodo, K. Yasuhara and K. Hirao, "Prediction of clay behaviour in undrained and partially drained cyclic triaxialtests", *Soils and Foundations*, Volume No.32, Issue No.4, PP.117-127, 1992.

[9] Chuan Gu, Jun Wang, Yuanqiang Cai, Zhongxuan Yang and Yufeng Gao, "Undrained cyclic triaxial behavior of saturated clays under variable confining pressure", *Soil Dynamics and Earthquake Engineering*, Volume No.40, PP.118-128, 2012.

[10] A.F.L. Hyde, K. Yasuhara and K. Hirao, "Stability criteria for marine clay under one-way cyclic loading", *J. Geotech. Eng. ASCE*, Volume No.119, Issue No.11, PP.1771-1789, 1993.

[11] H. B. Seed and I. M. Idriss, "Simplified procedure for evaluating soil liquefaction potential", *J. Soil Mech. and Found. Div.*, Volume No.97, Issue No.9, PP.1249-1273, 1971.

[12] P. DeAlba, C. K. Chan and H. B. Seed, "Sand liquefaction in large scale simple shear tests", *J. Geotech. Engrg. Div.*, Volume No.102, Issue No.9, PP.909-927, 1976.

[13] S. Ohara and H. Matsuda, "Study on the settlement of saturated clay layer induced by cyclic shear". *Soils and Foundations*, Volume No.28, Issue No.3, PP.103-113, 1988.

[14] M. Paul, R.B. Sahu and G. Banerjee, "Undrained Pore Pressure Prediction in Clayey Soil under Cyclic Loading", *Int. J. Geomech.*, Volume No.15, Issue No.5, PP.04014082, 2015.

[15] Yimin Liu and Jie Wang, "The research and application of landslide surface crack monitoring method based on laser ranging mode", *Environmental and earth sciences research journal*, Volume No.2, Issue No.2, PP.19-24, 2015.

[16] Haidong Jiang, "Study on statistical characteristics of deep displacement of monitoring data for soil slope", *Environmental and earth sciences research journal*, Volume No.2, Issue No.4, PP.11-16, 2015.