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Dynamic Characteristics of Saturated Soft Clay under Constant Confining Pressure Cyclic Loading

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Abstract. The research on the dynamic characteristics of soft clay under cyclic loading has high value. This paper takes Ningbo saturated soft clay as the research object and uses the GCTS true triaxial test system to analyze the effects of consolidated confining pressure and cyclic deviator stress on the axial cumulative strain. The experimental results found that when the number of vibrations and the cyclic stress ratio are the same, the axial cumulative plastic strain increases with the increase of the consolidation confining pressure. When the dynamic stress amplitude is the same, the axial cumulative strain decreases with the increase of the consolidation confining pressure. Under different confining pressures, as the number of vibrations increases, the cumulative axial strain increases. The development law of axial cumulative strain under different cyclic stress ratios is inconsistent, and there is a critical cyclic stress ratio. The experimental results provide a certain reference for engineering seismic design.

1. Introduction

At present, with the construction of large buildings and infrastructure, the underlying soft soil layer will inevitably be subjected to long-term cyclic loading. On the one hand, under the long-term cyclic loading, the settlement of soft clay soil foundation and the structural damage have become increasingly prominent[124,128,251]. For example, Miura [251] et al. obtained the additional settlement of 10-15cm within 2 years of the operation period of Sage Airport in Japan based on the measured data. On the other hand, under the action of cyclic loading, when the effective stress principle is used for dynamic analysis, the change rule of pore water pressure of soft clay will have an important influence on the deformation and strength of the soil.

As one of the important mechanical indexes of soil dynamic characteristics, dynamic strength of soil has very important research value and practical application value. The value of dynamic strength of soil under dynamic load is closely related to the stability and safe use of overlying buildings. It not only reflects the bearing capacity of soil directly, but also provides reference for seismic design of engineering. Therefore, the study of dynamic characteristics of soft clay under cyclic loading has high value. In order to analyze the influence of consolidation confining pressure and cyclic deviator stress on the axial cumulative strain and the change law of pore pressure. This paper uses the GCTS true triaxial test system to perform cyclic triaxial tests on Ningbo saturated soft clay under different drainage conditions.

2. Properties of soil sample

The test soil samples are taken from Ningbo area, the buried depth is about 28.0-30.0m, and the soil samples are dark gray. The basic physical and mechanical properties are shown in Table 1. It can be seen from Table1 that Ningbo soft clay has the characteristics of large void ratio and high moisture content. The compressibility is 0.81MPa-1, and the sensitivity is 3.5-5.0. It shows that Ningbo clay is a medium-sensitive and highly compressible clay.

Table 1 Physical and mechanical properties of testing soils

Severe γ/kN.m^{-3}	17.6
Moisture content w/%	43.9
Liquid limit W_L/%	51.5
Plastic limit W_p/%	23.3
Plasticity Index I_p	28.2
Permeability coefficient K/（10^{-8}cm/s）	5.18
Void ratio e	1.25
Unconfined compressive strength q_u/kPa	50
Sensitivity S_t	3.5~5.0
Compression factor a_v/MPa-1	0.81

3. Test scheme

In order to study the dynamic characteristics of Ningbo remolded saturated soft clay under unidirectional cyclic loading, undrained uniaxial cyclic triaxial tests are carried out under different consolidation confining pressures and different dynamic stress levels. This test was carried out on spax-2000 static and dynamic true triaxial test system manufactured by GCTs company of USA. The test system consists of true triaxial pressure chamber, pressure control panel, confining pressure / back pressure volume computer servo controller, general signal regulating board, digital servo controller and acquisition system, and control system, etc.

Figure 1 GCTS true triaxial apparatus

The test in this paper uses saturated reshaped specimens to ensure the uniformity of the specimens. The reshaped soft clay sample was prepared by the kneading method, the sample size was 38mm in diameter and 76mm in height. First, the soft clay sample is saturated by the combined method of vacuum pumping and back pressure saturation. Next, all specimens are consolidated isotropically under a certain confining pressure. When the excess pore water pressure is completely dissipated, the soil sample is considered to be consolidated. After the consolidation of the specimen, the uniaxial dynamic loading test is carried out with the dynamic stress of different stress levels applied in the axial direction. Stress controlled loading method is used in the test. In addition, the semi sine wave is used to replace the complex dynamic stress caused by the subway train passing through[112].The loading frequency is 1 Hz. All specimens are subjected to 10000 cycles of cyclic loading under different dynamic stress levels. The specific test scheme is shown in table 2. In order to facilitate the analysis, according to Sakai et al.[253], the cyclic stress ratio is defined to characterize the dynamic stress amplitude under different confining pressures.

$$CSR = q^{ampl} / 2p_o^{'} = q^{ampl} / 2\sigma_3^{'} \tag{1}$$

Where $\sigma_3^{'}$ and $p_o^{'}$ represent the effective confining pressure and effective average normal stress after consolidation respectively.

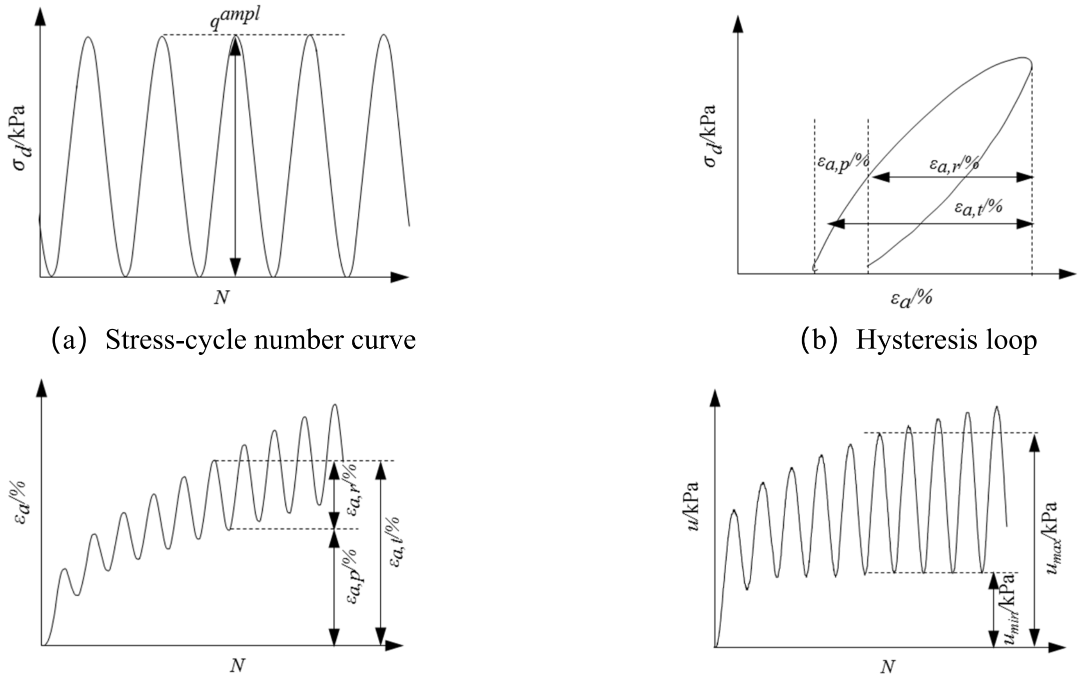
Table 2 Programs of cyclic loading tests

Sample number	Effective confining pressure $\sigma_3^{'}$ /kPa	Dynamic stress amplitude q^{ampl}/kPa	*CSR*	Loading frequency *f*/Hz	Loading times
CP-P101	100	20	0.10	1	10000
CP-P102	100	30	0.15	1	10000
CP-P103	100	40	0.20	1	10000
CP-P104	100	50	0.25	1	10000
CP-P105	100	60	0.30	1	10000
CP-P201	50	15	0.15	1	10000
CP-P202	50	20	0.20	1	10000
CP-P203	50	28	0.28	1	10000
CP-P204	50	36	0.36	1	10000
CP-P301	150	30	0.10	1	10000
CP-P302	150	45	0.15	1	10000
CP-P303	150	60	0.20	1	10000
CP-P304	150	70	0.23	1	10000
CP-P305	150	75	0.25	1	10000

4. Analysis of test results

4.1 Typical test results

Figure 2 shows the results of cyclic triaxial test under constant confining pressure. It can be seen from Fig. 2 (a) that the stress wave is stable with the increase of cycle number, and can reach the preset stress amplitude q^{ampl}. Fig. 2 (b) and (c) show the development curve of strain with vibration number and the stress-strain hysteresis curve respectively. It can be seen that the axial strain $\varepsilon_{a,t}$ produced by cyclic loading can be divided into two parts. One of them is the recoverable deformation during unloading, that is, the rebound strain $\varepsilon_{a,r}$. The other part is the strain which can not be recovered in the whole loading and unloading process and accumulates with the increase of the number of cycles, that is, cumulative strain $\varepsilon_{a,p}$. Fig. 2 (d) shows the variation of pore pressure of samples during cycling, in which some pore pressure can be dissipated during unloading.



(a) Stress-cycle number curve (b) Hysteresis loop

(c) Strain-cycle number curve (d) Pore pressure-cycle number curve

Figure 2 Results of cyclic triaxial test

Figure 3 shows the development curve of dynamic strain of the sample under the test conditions of CSR=0.15, σ_3'=100kPa and undrained conditions. It can be seen that as the number of cycles increases, the total strain of the sample exhibits an obvious cumulative effect. The cumulative strain increases rapidly at the beginning of cyclic loading. With the increase of cyclic vibrations, the growth rate of cumulative strain gradually slows down. The rebound strain remains basically constant after a certain cycle of vibrations.

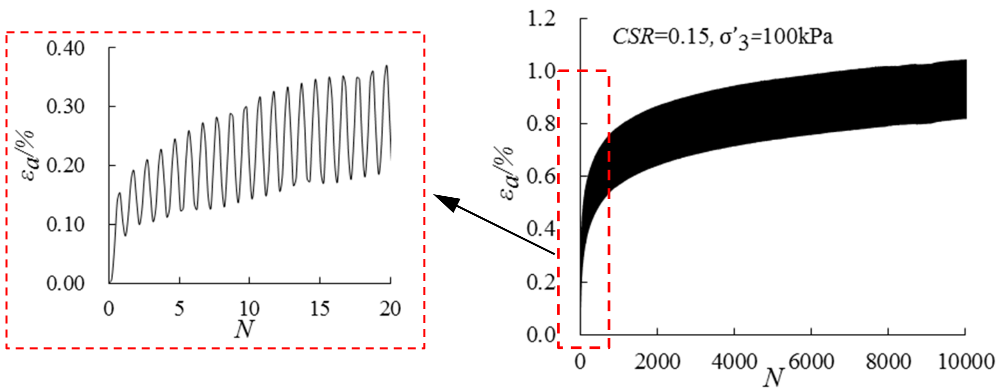


Figure 3 Development curves of dynamic strain

Under undrained conditions, the relationship curve between the resilient modulus of the sample and the cyclic vibration times is shown in Figure 4. It can be seen from the figure that in the initial stage of the cycle, the modulus of resilience decreases rapidly with the number of cyclic vibrations. After about 2000 times, the modulus of resilience finally tends to a stable value.

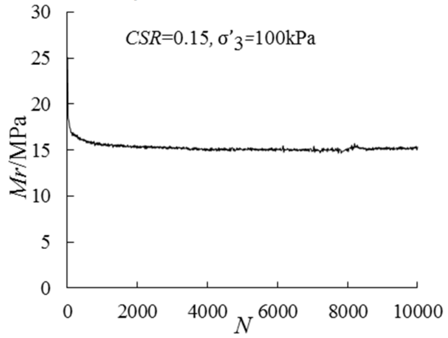
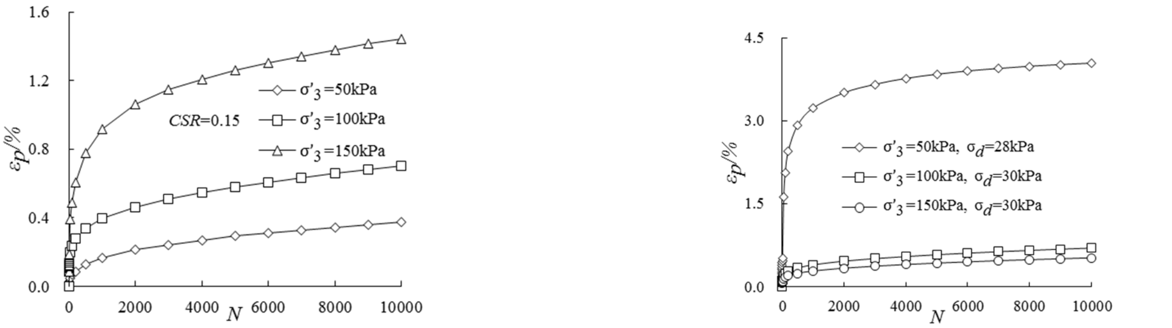


Figure 4 Relationship between resilient modulus and vibration numbers under undrained condition

4.2 Influence of consolidation confining pressure

Figure5 shows the cumulative plastic strain development curve of remolded soft clay under the same dynamic stress amplitude or the same cyclic stress ratio and different consolidation confining pressure conditions. It can be seen that the axial strain of the sample accumulates and tends to be stable with the increase of the number of cycles, but the strain development rule under different confining pressures is obviously different. When the cyclic stress ratio remains the same, under the same number of vibrations, the axial cumulative strain has a positive correlation with the consolidated confining pressure. When the dynamic stress amplitude is the same, the axial cumulative strain corresponding to the same number of cycles decreases with the increase of the consolidation confining pressure.

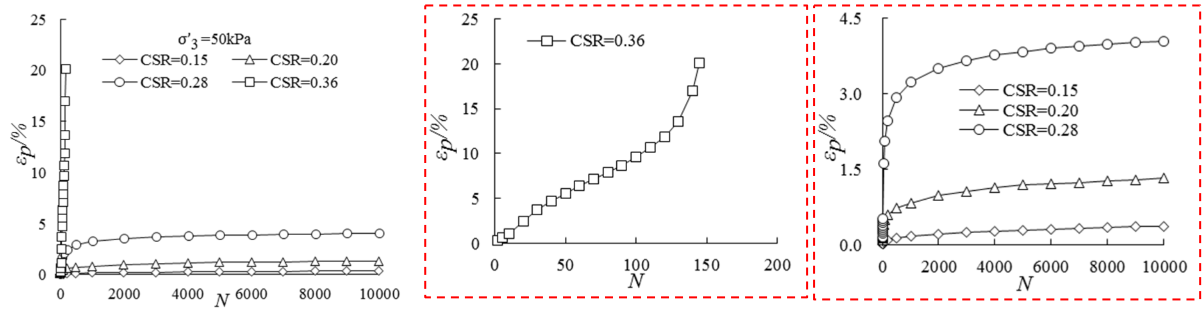


(a) Same cyclic stress ratio (b) Same dynamic stress amplitude

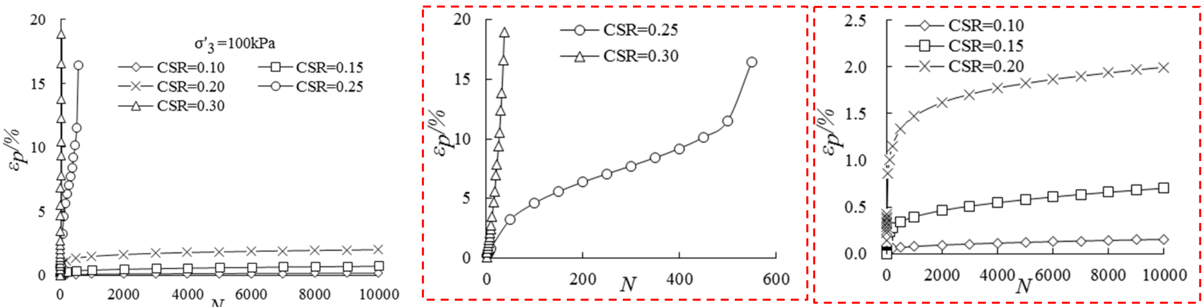
Figure 5 Relationship between cumulative axial strain and vibration numbers under different consolidate confining pressures

4.3 Influence of dynamic stress amplitude

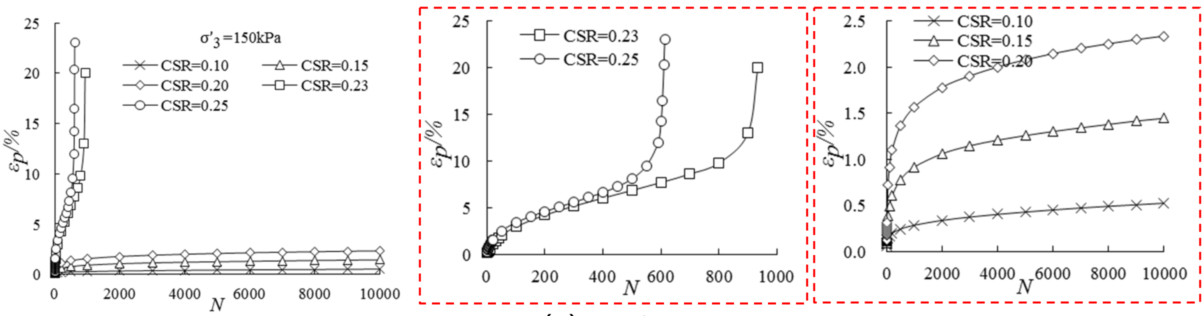
Figure 6 shows the development curve of the axial cumulative strain of Ningbo soft clay with the number of vibrations under different effective consolidation confining pressures. It can be seen that under a certain effective consolidation confining pressure, the axial cumulative strain of the sample increases with the increase of the dynamic stress amplitude. The shape of the development curve of axial cumulative strain with vibration numbers is obviously affected by the dynamic stress amplitude. Under a lower dynamic stress amplitude, the axial cumulative strain increases continuously with the increase of the number of cycles. After a certain number of vibrations, the increase rate of the axial cumulative strain gradually slows down, and the final cumulative strain tends to a stable value. Under a larger dynamic stress amplitude, the axial strain first slowly increases with the increase of the number of vibrations. Until a certain vibration frequency, the strain increases sharply, and the specimen is damaged at a small vibration number.



(a) 50kPa



(b) 100kPa



(c) 150kPa

Figure 6 Relationship between cumulative axial strain and vibration numbers under different dynamic stress amplitudes

The above experimental phenomena show that the characteristics of the axial strain development curve under different dynamic stress ratios are different under the same effective consolidation confining pressure. This shows the existence of critical cyclic stress ratio and the critical cyclic stress is not a constant value under different effective consolidation confining pressures. When the applied cyclic stress ratio is less than the critical cyclic stress ratio, the axial cumulative strain development curve is a stable curve. When the applied cyclic stress ratio is greater than the critical cyclic stress ratio, the axial cumulative strain development curve belongs to the damage curve.

5. Conclusion

This paper conducts constant confining pressure cycling triaxial tests on Ningbo remolded soft clay under undrained conditions. The effects of consolidation confining pressure and dynamic stress amplitude on the axial cumulative strain of saturated soft clay are analyzed. Get the following conclusions:

The relationship is analyzed between the axial cumulative strain and the consolidated confining pressure from the two perspectives of cyclic stress ratio and dynamic stress amplitude. The result shows that under the same number of vibrations, when the cyclic stress ratio is the same, the axial cumulative plastic strain increases with the increase of the consolidation confining pressure. When the dynamic stress amplitude is the same, the axial cumulative strain decreases with the increase of the consolidation confining pressure.

Under different confining pressures, as the number of vibrations increases, the cumulative axial strain increases. The growth rate of axial cumulative strain increases with the increase of cyclic stress ratio. At the same time, the development of axial cumulative strain under different cyclic stress ratios is inconsistent There is a critical cyclic stress ratio, and the critical cyclic stress ratio is not the same under different confining pressures.

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References

[1] SANGREY D A, HENKEL D J, ESRIG M I. (1969) The effective stress response of a saturated clay soil to repeated loading. Canadian Geotechnical Journal, 6(3):83-95.
[2] Zhou Jian, Tu Hongquan. (1996) A Model for Predicting the Cyclic Behaviour of Soft Clay. Rock and Soil Mechanics, 17(1):54-60.
[3] MIURA N., FUJIKAW K., SAKAI A. (1995) Field measurement of settlement in Saga airport highway subjected to traffic load. Soil Mechanics and Foundation Engineering, 43-6(449):49-51.