

Analysis on Long-term Settlement of Soft Soil under Subway Dynamic Load in Wuhan Area

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Abstract. Through conducting the GDS dynamic triaxial test, this paper makes an analysis for the deformation characteristics of soft soil and its settlement mechanism under the subway traffic traveling load in Wuhan area. The test result shows that the cumulative plastic strain and pore water pressure of the soft clay soil samples are all experiencing the rapid growth stage, the slow growth stage and the stationary stage. The sandy soil samples' stages are similar to the clay, but its strain value is smaller and pore water pressure value is greater. The total settlement under subway traveling load is consist of settlement caused by the undrained cumulative plastic strain and settlement caused by the dissipation of undrained pore water pressure. Also through the test we can find that the main settlement has completed during the first 3 years, later it becomes stable gradually.

Introduction

At present the subway has become the important means of transport in big cities. But with the increasing of subway operation time, a series of problems are exposed such as the settlement of ground foundation and vibration problems surrounding the environment [1]. Soft soil is widely distributed in Wuhan area, thus subway tunnel will inevitably cross the soft soil layer which has properties of low strength, high compressive strength and high sensitivity. How to accurately predict the long-term settlement and effectively reduce the subsidence has become an urgent problem in the construction of subway system. Because of its complex properties, soft soil has its own specific engineering characteristics, and effects of the strength and deformation are also complicated. This paper takes samples of soft soil in the process of engineering construction in Wuhan area and studies the relationship between cumulative plastic strain and pore water pressure of the clay with its vibration number under different confined pressure and dynamic stress ratio by GDS dynamic triaxial test. Based on this, a long-term settlement under the subway traveling load in the operation period can be calculated and predicted.

Deformation Characteristics of Clay under the Dynamic Load

The GDS Dynamic Triaxial Test Plan

At present it is common that multifunctional dynamic cyclic triaxial test system is used to study dynamic characteristics of soft soil. Before the test, cylindrical samples need to be back pressed until they are saturated. In order to simulate the actual situation, samples should be consolidated under the condition of K0. According to relevant research results and investigation data, K0 is defined to be 0.6. The geotechnical engineering investigation of Wuhan rail transit line No.2 [2] points out that the initial consolidation confining pressure of soft soil around the tunnel generally distributes from 100kpa to 300kpa. Considering the effect of different tunnel depths on test results, the initial consolidation confining pressure is taken 170kpa, 280kpa respectively. According to the research achievements of Tang Yi-qun [3], we take the cyclical stress amplitude of 40kpa as the maximum additional stress in this test. By investigating the frequency response of the holes, the

vibration frequency of 0.5 Hz is adopted in this experiment.

Tab. 1 Test Program

Number	Density(g/cm-3)	natural water content (%)	confining pressure (Kpa)	cyclical stress amplitude(Kpa)	Frequency (Hz)	the cyclic number
A1	1.67	34.1	170	40	0.5	2000
A2	1.67	34.1	280	40	0.5	2000
B1	1.63	16.7	170	40	0.5	2000
B2	1.63	16.7	280	40	0.5	2000

Growth Characteristics of Pore Water Pressure

According to the classic consolidation theory, the external load is borne by the pore water when load imposes, with penetration consolidation process going on, external load gradually transfers from the excess pore water pressure to the effective stress, thus the strength and the deformation of soil mainly depending on effective stress. For analyzing the mechanical properties of soil, change rules of the pore water pressure under external load must be studied firstly. Through the time trend table of pore water pressure in the confining pressure of 170kpa, 280kpa under the same dynamic stress ratio, it can be seen that pore water pressure increasing trend is divided into three distinct phases: the rapid growth stage, the slow growth stage and the stationary stage. At stage one the duration is short, pore water pressure increases sharply and the growth rate decreases gradually, but overall maintain a rapid rate. It has a slightly longer duration at stage two; pore water pressure increases at a slow speed, the growth rate gradually continue to decrease. At stage three the duration is the longest; the growth rate of pore water pressure gradually decreases toward zero and finally becomes stable.

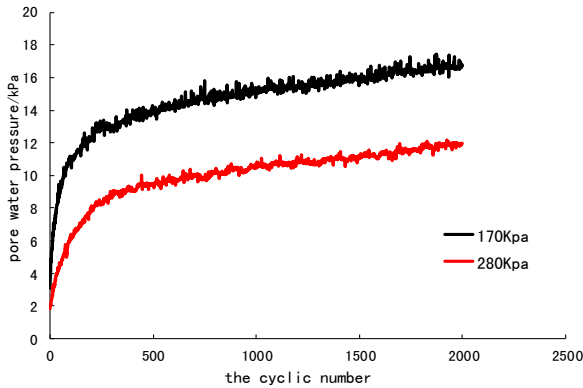


Fig. 1 Curve of Cumulative Pore Water Pressure Changing along with Cyclic Number

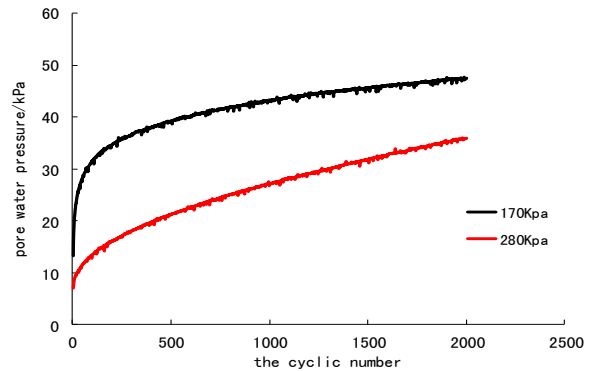


Fig. 2 Curve of Cumulative Pore Water Pressure Changing along with Cyclic Number

Through comparing the fig1 with the fig2, both the initial value and the growth rate of sandy soil are significantly greater than clay's. Combining with the engineering characteristics and engineering background of the soft soil in Wuhan area and according to the research results of Zhang Xi [4], we use equation (1) to determine the model parameters which are illustrated on Table 2:

$$u = u_t - \frac{u_t - u_0}{1 + C * (N / N_0)^p} \quad (1)$$

Where N is number of vibration; u_0 is the average annual hydrostatic pressure values; u_t is the limit value of the ultra pore water pressure; N_0 , p are regression parameters; C is Corrected Parameter.

Tab. 2 Fitting Parameter of Pore Pressure Model (clay samples)

confining pressure(Kpa)	u_t	u_0	N_0	p	C	R^2
170	30.4557	13.73	0.7251	0.1876	0.4918	0.9874
280	14.3509	0.0658	11.3293	0.5759	0.2162	0.9861

The sandy soil samples are fitting according to ExpDeacy2 formula:

$$u = A_1 e^{-N/N_1} + A_2 e^{-N/N_2} + A_3 \quad (2)$$

Where N is number of vibration; A_1 , A_2 , A_3 , N_1 , N_2 are regression parameters.

Tab. 3 Fitting Parameter of Pore Pressure Model (sandy samples)

confining pressure(Kpa)	A_1	N_1	A_2	N_2	A_3	R^2
170	13.1247	45.1553	17.48	910.8816	49.0639	0.9969
280	54.7186	120.4344	40.5215	2608.4521	54.7186	0.9995

Dynamic Deformation Characteristics of Clay

Even the soft soil foundation which has suffered a long consolidation process can also produce different degrees of settlement when the foundation subjects to continuous train traveling load. The curve of the figure 3 shows that when the load frequency and stress level maintain a certain level, the cumulative plastic strain of clay will increase with the growth of vibration frequency, and it is also affected by the confining pressure. When load frequency maintains a certain level, the greater initial consolidation confining pressure is, the smaller cumulative plastic strain value will be. The figure also shows that curve rises rapidly firstly, then it rises in a incline growth, and finally it rises gradually into relatively flat. It suggests that accumulated strain characteristic is similar to the growth characteristics of pore water pressure under the long-term load which experiences the 3 same stages. Combining with actual situation, cumulative deformation of soil surround the tunnel is large under traffic load of the subway in early operation of the subway. Then clay gets consolidated and its deformation rate reduces gradually with the increasing of the operation. Finally the cumulative deformation will become stable. As can be seen from Figure 4, the cumulative strain curve of sandy samples is similar with the clay ones, but its strain value is a little smaller.

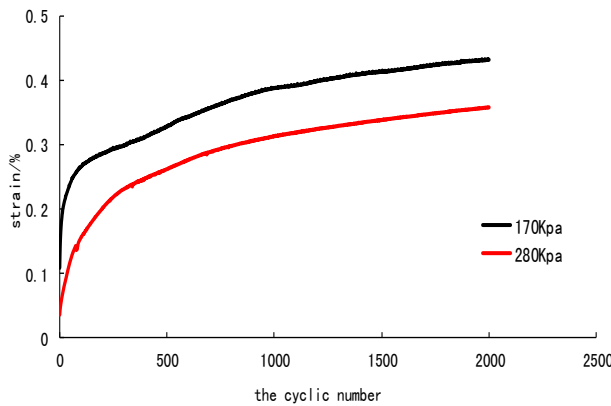


Fig. 3 Curve of Cumulative Plastic Strain Changing along with Cyclic Number (clay samples)

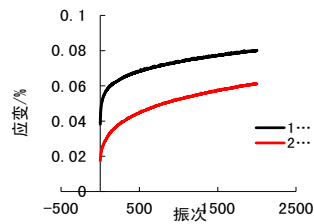


Fig. 4 Curve of Cumulative Plastic Strain Changing along with Cyclic Number (sandy samples)

Use equation (3) to determine the model parameters which is gotten in Table 4 and 5.

$$\varepsilon_p = \frac{A * N^B}{1 + C * N^B} \quad (3)$$

Where N is number of vibration; A , B , C are regression parameters.

Tab. 4 Fitting Parameter of Strain Equation (clay samples)

confining pressure(Kpa)	A	B	C	R ²
170	0.0867	0.0727	-0.3773	0.99178
280	0.0184	0.543	0.0354	0.9995

Tab. 5 Fitting Parameter of Strain Equation (sandy samples)

confining pressure (Kpa)	A	B	C	R ²
170	0.0097	0.0167	-0.7595	0.99922
280	0.0122	0.1519	-0.1172	0.99934

Prediction for the Long-term Settlement in Subway Operation Period

Due to the Cumulative plastic strain values of clay samples are significant greater than the sandy ones, the clay ground foundation is adopted to study the settlement deformation characteristics under the long-term load. According to the relevant studies, the main settlement areas are distributed concentratedly within the range of about 10m beneath the bottom of the tunnel, so this range is chosen for the next settlement calculation. It is generally accurate to use layer-wise summation method (taking 0.5m for layer thickness) to calculate the undrained cumulative plastic strain of clay and the pore water pressure respectively. The settlement caused by the undrained cumulative plastic strain of clay is calculated according to equation (4):

$$S_d = \sum_{i=1}^n \varepsilon_{pi} h_i \quad (4)$$

Where ε_{pi} is i-layer cumulative strain; h_i is the thickness i-layer; n is sum of Compression layer.

The settlement caused by the dissipation of undrained pore water pressure is calculated according to equation (5):

$$S_v = \sum_{i=1}^n m_{vi} h_i u_i U \quad (5)$$

Where n is the total number of layered clay; h_i is the thickness of i-layer; u_i is i-layer undrained pore water pressure m_{vi} is volume compressibility factor of the clay; U is i-layer degree of clay consolidation. Add the settlement caused by the undrained cumulative plastic strain of clay to the settlement caused by the dissipation of undrained pore water pressure can get the total settlement. The relationship between the three settlements and time are shown in Figure 5. It can be seen from calculation result that the total settlement caused by train traveling load will reach about 28.5mm after an operation of 3 years, the figure also can be found that the settlement caused by the dissipation of undrained pore water pressure is the main reason of total settlement.

Through using the results of GDS dynamic triaxial test to calculate the long-term clay foundation settlement, we can find that the main settlement has completed during the first 3 years. At this time dynamic strain value increases faster within the increasing number of vibrations. Then the strain increment decreases with the operation period, the settlement value is stabilized gradually, and the

effects of train traveling load to the clay settlement become very small.

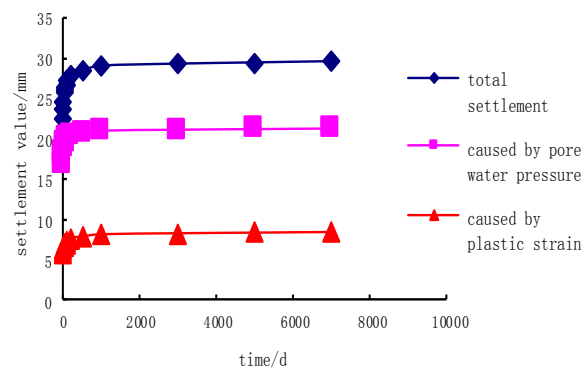


Fig. 5 Relationship between Settlement and Operation Time

Summary

(1) It can be seen from GDS dynamic triaxial test that under long-term cyclic load the strain and pore water pressure of the soil samples are all similarly experiencing the rapid growth stage, the slow growth stage and the stationary stage, each stage has its own growth characteristic.

(2) The main clay settlement has completed during the first 3 years, later the settlement value is stabilized gradually. For this feature the prevention of geological disasters during the operation of subway should be focused on the initial operation period to improve the efficiency of prevention of geological disasters.

Acknowledgement

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