Study on New Method of Accelerated Clay Creep Characteristics Test

Étude d'une nouvelle méthode d'évaluation accélérée des caractéristiques de fluage des argiles

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ABSTRACT: Long-term creep tests, dynamic triaxial tests and corresponding scanning electron microscope(SEM) test were carried out for remolded saturated clay to study the way of rapid acquisition of the creep characteristics. The creep deformation and permanent deformation under the cyclic loading of soil with same initial state were analyzed. Based on the principle of static stress and dynamic stress equivalent, and the creep time and the cyclic number equivalent, a method using the relationship between stress-strain-cyclic number to predict the creep deformation was established. The SEM test results showed that the clay microstructure changing trend of creep test and dynamic triaxial test were similar. The multilevel stress and long-term creep deformation can be predicted by the proposed method.

RÉSUMÉ :Des essais de fluage à long terme, des essais triaxiaux dynamiques ainsi que des observations correspondantes faites au microscope électronique à balayage (MEB) ont été réalisés sur une argile saturée remaniée pour étudier la possibilité d'acquérir rapidement les caractéristiques de fluage du matériau. On a analysé comparativement les déformations de fluage et les déformations permanentes obtenues sous chargement cyclique à partir du même état initial. En se basant sur le principe d'équivalence entre contrainte statique et contrainte dynamique, ainsi que sur l'équivalence entre le temps de fluage et le nombre de cycles, une méthode de prévision des déformations de fluage a été établie, basée sur la relation entre contrainte, déformation et nombre de cycles. Les images obtenues au MEB ont montré que les évolutions de microstructures obtenues dans les essais de fluage et dans les essais triaxiaux dynamiques étaient similaires. Les déformations de fluage à long terme peuvent donc être évaluées à partir de la méthode proposée.

KEYWORDS: Remolded Saturated Clay; Creep; Acceleration; Equivalent efficiency; Dynamic triaxial test
MOTS-CLÉS : argile saturée remaniée, fluage, accélération, efficacité équivalente, essai triaxial dynamique.

1 INTRODUCTION.

Because of the great deep and long draining path, there are the characteristics of chronicity and complexity in composite foundation substratum deformation. So the deformation of substratum is the main resource of foundation deformation. The creep has been the key problem of the infrastructure with high standard including high-speed railway (Liu Junfei ZhaoJian ZhaoGuotang et al. 2011, Cai Degou Ye Yangsheng Yan Hongye et al. 2010) . For the purpose of ensuring foundation stability and meeting the requirement of engineering design, it is very vital to research the method which can obtain creep characteristic of foundation soil quickly.

According to related reference, there are two reasons for creep. One is that deviator stress leads to viscous shear flow; the other is that spherical stress leads to viscous body flow (Li Xiao 2011). Clay grains are connected by hydrated film, so it has inherent cohesion and rheological behavior. Only the hydrated film is extruded under low stress level, so the deformation is elastic. When the stress level is raised, stress concentrations will happen among grains. Soil grains will contact directly dislocation and rearrange. So the permanent deformation generates (He Kaisheng and ShenZhujiang 2003). The deformation of soil under load is the synthetic result of microstructure change, such as structure bond failure, dislocation and porosity change (Zhang Xianwei Wang Changming and Li Junxia 2010).

The evident characteristics of soil stress-strain are nonlinear, hysteretic and cumulative under dynamic load. When dynamic stress level is low, elastic deformation is dominating. With the increasing of dynamic stress level, the permanent deformation increases gradually. Under different cyclic number and dynamic stress level, the soil grain adjusts and rearranges to some degree. In nature, there is correlation between microstructure change and macrostructure deformation (Liu Sha 2008). It is concluded that the deformation in macrostructure is a pattern of appearance of microstructure change.

2 CREEP AND DYNAMIC TRIAXIAL TEST AND RESULTS ANALYSIS

2.1 *Parameters of Soil*

Remolded saturated clay is used to experiment. Its parameters can be seen in Table 1 and Figure 1.

Table 1. Parameters of Soil

Specific gravity	Liquid limit (%)	Plastic limit (%)	Plasticity index
2.70	45.5	23.0	22.5

The samples used to creep and cyclic triaxial test were prepared as follows: Clay with moisture content over liquid limit was consolidated under certain load until 50kPa. That can ensure soil with the same stress history and the same consistency. The samples (Φ39.1 (mm) × H80 (mm) used to creep test and Φ50 (mm) × H100 (mm) used to dynamic triaxial test) were consolidated isotropically in chamber under 50kPa. The chamber pressure during test is 50kPa. Creep soil samples were sheared by respective loading in triaxial creep apparatus under drained and undrained condition. Dynamic triaxial test samples were sheared under undrained and 5Hz condition.

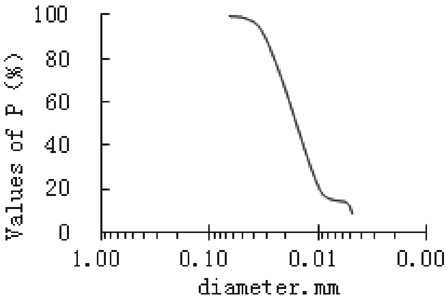

Figure 1. Semilogarithmic plot of results of grain analysis

Note: P means percentage by weight of grains smaller than the denoted size.

Creep test and dynamic triaxial test samples parameters can be seen in Table 3 and Table 4. The drained and undrained strength were 52.0kPa and 38.9kPa respectively under 50kPa chamber pressure.

Table 2. creep test samples index

No	Drainage lines	Deviator stress (kPa)	Density (g/cm^3)	Water content (%)
1	open	14.9	1.81	39.2
2	open	29.5	1.79	39.6
3	open	36.8	1.81	40.1
4	open	41.0	1.81	39.7
5	closed	14.9	1.85	39.8
6	closed	31.0	1.82	42.3
7	closed	40.5	1.84	42.3
8	closed	42.5	1.83	41.9

Table 3.. Dynamic triaxial test samples index

No.	Drainage lines	Deviator stress σ_d (kPa)	Density (g/cm^3)	Water content (%)
1	closed	20.0	1.80	42.1
2	closed	30.0	1.81	42.1
3	closed	35.0	1.80	43.0
4	closed	40.0	1.82	39.7
5	closed	45.0	1.81	40.7

2.2 *Test results analysis*

In creep test axial strain is generally denoted as the function stress level and time, for example . Exponential or hyperbolic function is used to express the influence of stress level. Power, logarithm or hyperbolic function is used to express the influence of time(Singh A. and Mitchell J.K. 1968, Mesri G. and Rebres-Cordero E. 1981, Wang BinWang ChangMingand Zhang Xianwei et al,2008, Zhang Wang 2009). It can be seen that logarithm function is reasonable for the correlation between strain and time (see Figure 3 and Figure 4). In Figure 3 and Figure 4 the origin is the deformation of 1h. Test data is expressed in the form of the dots of all kinds of shapes. The logarithm fitting curves are the black solid line.

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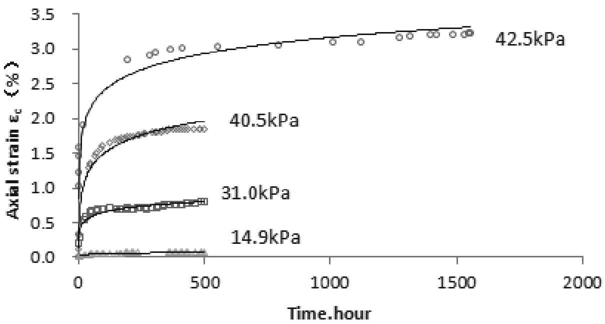

Figure 2. Undrained Creep Curve

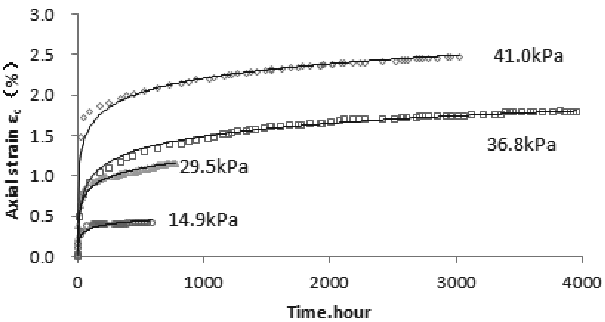

Figure 3. Drained Creep Curve

x

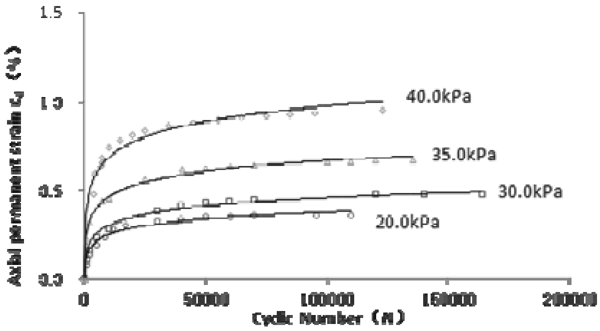

Figure 4. Dynamic Triaxial Test Curve

In this dynamic triaxial test logarithm function is used to express the correlation between axial strain and time. $f(D)$ is used to express the correlation between axial strain and stress level, (see Eq. 1).

$$\varepsilon_d = f(D)\ln N \quad (1)$$

ε_d——axial strain in dynamic triaxial test;
$D=\sigma_d/\sigma_3$, σ_d——deviator stress, σ_3——chamber stress.

A fitted coefficient under every stress level can be obtained by fitting the test data. f(D) can be solved by analyzing the correlation between the coefficient and stress level.

$$\varepsilon_d = 0.022e^{2.04D}\ln N \quad (2)$$

Because of the similarity between creep deformation and permanent deformation in dynamic triaxial test, it is raised that the stress-strain-cyclic number formula in dynamic triaxial test can be used to predict the creep deformation. In order to depict the influence on the difference between static and dynamic load and drainage condition, firstly ψ (D_r) is introduced.

$\varepsilon_c=\psi(D_r)0.0226e^{2.04D}\ln N$ (3)

Secondly, assume that static and dynamic stress level is equivalent. Static stress parameters are as follows:
$D_r=q/q_f$, $q=\sigma_1-\sigma_3$, σ_1—axial load , q_f---failure strength.

Thirdly, assume that time and cyclic number is equivalent.

N=t. N—cyclic number, t—creep time (h).

Finally, dynamic parameters are instead of static parameters. $\psi(D_r)$ is introduced. Then the creep strain formula can be obtained:

$\varepsilon_c=\psi(Dr)0.0226e^{2.04D}\ln t$ (4)

. $D=q/\sigma_3$

$\psi(D_r)$is a function of stress level. By analyzing the test data, the formula under different condition can be fitted as follows:

Drained condition: $\psi(Dr) = 1.52e^{0.67Dr}$ (5)

Undrained condition: $\psi(Dr) = 0.07e^{3.61Dr}$ (6)

The strain under different stress level and drainage condition can be calculated by Eq. 4, Eq. 5 and Eq. 6. The calculation and test results can be seen in Figure 6 and Figure 7.

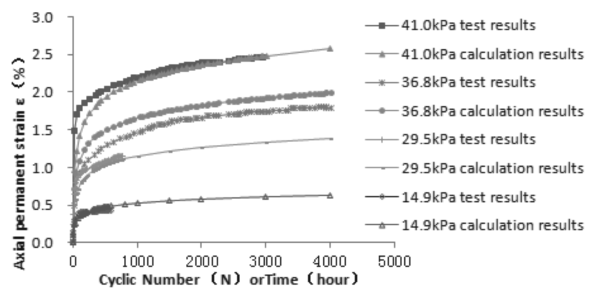

Figure5. Creep Test and Calculation Results under Drained Condition

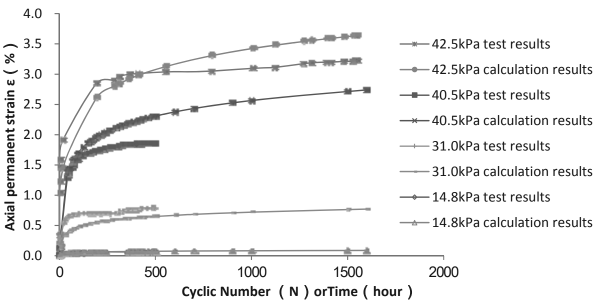

Figure 6. Creep Test and Calculation Results under Undrained Condition

The creep time under drained condition is longer than undrained. The developing trend and magnitude of strain which is calculated are in accordance with test results and the long-term creep deformation is predicted. The calculation results of 31.0kPa and 40.5kPa deviate from test results under undrained condition. The reason may be that the function ψ (D_r) is an approximate expression which comes from limited test data. There might be other factor or correlation. It is the next work to solve.

3 MICROSTRUCTURE ANALYSIS

In order to explicit the microstructure change after the creep and dynamic triaxial test, the SEM test was carried out in low vacuum mode. The SEM test instrument is Quanta400 scanning electron microscope. The soil sample was cut to a cube of 1.5cm×1.5cm×1.5cm by wire saw. Both vertical and horizontal plane was test. The porosity parameters of soil including plane porosity, anisotropy and directional probability entropy were counted to analyse the microstructure change. The image of soil was magnified 2000 times, and the microstructure photographs before and after loading were shown as Figure 8 and Figure 9.

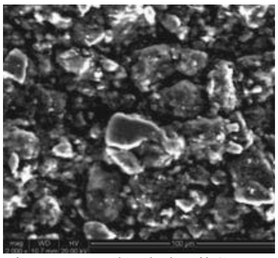

Figure 7. Unloaded soil SEM photograph

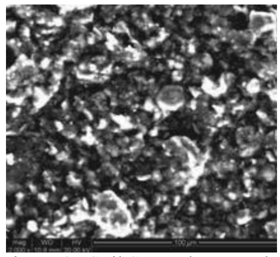

Figure 8. Soil SEM photograph after creep test

Figure 10, Figure 11 and Table 5 shows the microstructure parameter of different test. Both the vertical and horizontal plane porosity decreased after creep and dynamic triaxial test. The increasing anisotropy of porosity means that the porosity's shape trends to oval. The porosity directional probability entropy increases after creep and dynamic triaxial test. When the soil samples failure, the porosity directional probability entropy of creep soil sample is similar with dynamic triaxial test.

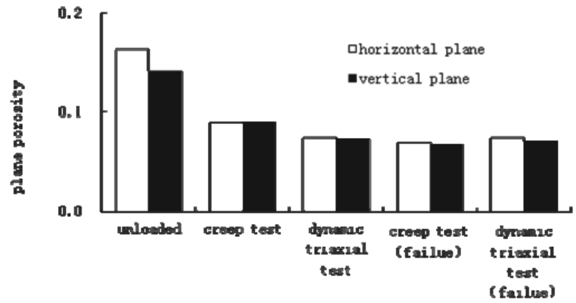

Fig 9. soil sample plane porosity of different test

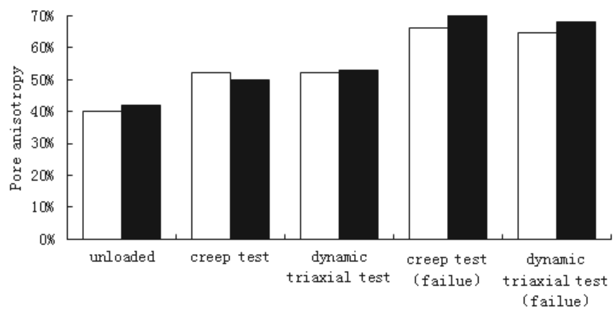

Fig 10. Porosity anisotropy of different test

Table 4. directional probability entropy of Porosity

unloaded	Creep test	dynamic triaxial test	Creep test (failure)	dynamic triaxial test (failure)
0.982	0.91	0.86	0.81	0.823

4 CONCLUSIONS

1. The creep deformation and permanent deformation of dynamic triaxial test are nonlinear. The deformation in macrostructure is a pattern of appearance of microstructure change.

2. The results of creep and dynamic triaxial test show that it is reasonable to use logarithmic function to describe the axial strain of creep and dynamic triaxial sample.

3. Based on the principle of static stress and dynamic stress equivalent, the stress-strain-cyclic number formula in dynamic triaxial test can be used to predict the creep deformation.

4. The SEM test results show that the change trend of plane porosity, anisotropy and directional probability entropy of both creep and dynamic triaxial test are similar. The microstructure status with equivalent condition is close.

5. The creep deformation under multilevel stress can be obtained with few samples by use of the method. The long-term creep deformation can be obtained within shorter time.

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