Experimental research of correlation on static and dynamic strength of clay

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Abstract

The LoadTrac II triaxial apparatus was employed to performed static, and the dynamic triaxial tests on Haikou red clay under consolidated undrained condition. The properties of static and dynamic strength were comparative studied. It obtained static and dynamic strength parameters of Haikou red clay, and established the relation between them. It turned out that: the result could benefit for accumulation of basic data which includes the seismic design, seismic safety evaluation of Haikou city, and completing theoretical system and engineering properties of Haikou red clay.

Keywords: triaxial, static, dynamic, strength, seismic safety

1. Introduction

China lies on the middle of the two seismic activities in the world, and the earthquake occurs frequently. Haikou City is the highest seismic intensity capital city in our country. China will construct the fourth astronautics launching base in Wenchang of Hainan, and also construct highway in the Hainan median line, but there is no literature of the Haikou red clay on the dynamic characteristics, therefore, it is necessary to obtain the soil property under the effect of earthquake (Guang-Xin Li, 2004; Shen Zhujiang, 1999).

Shear strength is one important subject of soil mechanics. The dynamic strength can be defined as: under a certain vibration times N, to make the soil up to a certain failure criteria demanded dynamic stress amplitude (Wang Wenshao, 1997). Current research is more about dynamic and static strength, but lack of analysis of the association (Hyodo et al, 1999). In this paper, the characteristics of static and dynamic strength are studied on Haikou regional special red clay. The test results and conclusion could accumulate basic data for which includes the seismic design, seismic safety evaluation of Haikou, and could complete theoretical system and engineering properties of Haikou red soil, providing reference data for earthquake prevention measures.

2. Experiment process

2.1 Test material

The project site is located on the Gao-Po Village of Haikou in Hainan province. Using thin-walled sampler to take undisturbed soil at the scene, and sealing it with tape could keep the integrity of the soil. According to soil test method standard, the soil was carried back and sampled preparation in the laboratory. From the routing soil tests, the properties of the physical and mechanical indexes were made a systematic study in table 1. And in the figure 1 was showed the thin-walled sampler and horizontal earth-moving. In order to have the sample matched the dynamic triaxial apparatus, the undisturbed soil sample diameter was made into 35mm, and the height was 77mm.

Fig. 1 Undisturbed soil field sampling equipment and horizontal bulldozing

Table 1 Physical properties of natural undisturbed red clay

Water content ω(%)	specific gravity d_s	Liquid Limit I_l (%)	Plastic limit I_p (%)	Specific Weight γ (kN/m^3)
35.5	2.74	56.9	31	16.9

2.2 Test Equipment

The LoadTrac II triaxial apparatus was made by GEO-COMP Company in picture 2; it could make triaxial tests under static and cyclic load.

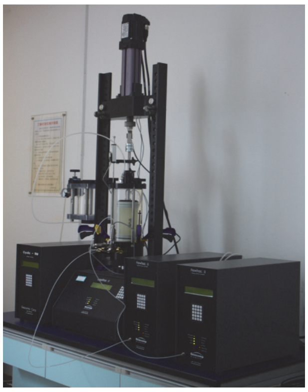


Fig. 2 LoadTrac II triaxial apparatus

2.3 Test procedure

Saturation: The undisturbed sample first saturated by the outdoor exhaust, followed by carbon dioxide led to saturation of the sample, then the instrument back-pressure saturated;

Consolidation: Specimens consolidated with isotropic consolidation. The numerical size of confining pressure were determined by the depth of overburden undisturbed soil, the confining pressures were followed by 50, 75, 100, 150 kPa. When the excess pore water pressure mainly dissipated, it was the end of consolidation.

Load: In the static load, set the shear rate as 0.5%/minis until strain was up to 15%. When dynamic loading, in order to prevent the triaxial chamber from driven, some measures were needed to fix in figure 3. It made axial strain of soil samples up to 5% as vibration destroyed (Mitchell and King, 1977).

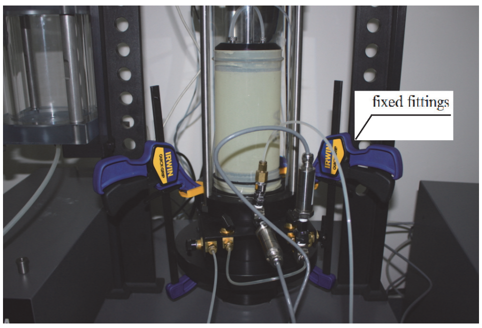


Fig. 3 Consolidation process

3. Characteristics of static strength

The deviator stress can be expressed as $\sigma_1 - \sigma_3$. During the shear test, deviator stress increased with the increase of strain, and then reached the peak value $(\sigma_1 - \sigma_3)_f$. It can be seen from figure 4 that the deviator stress increases dramatically when the confining pressure goes up.

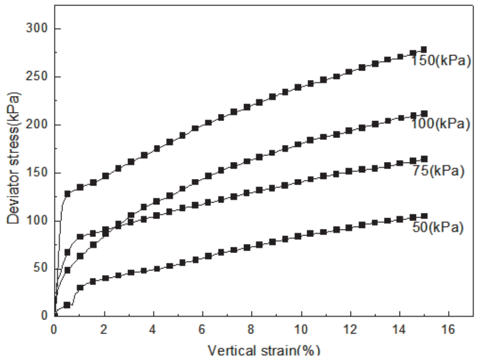
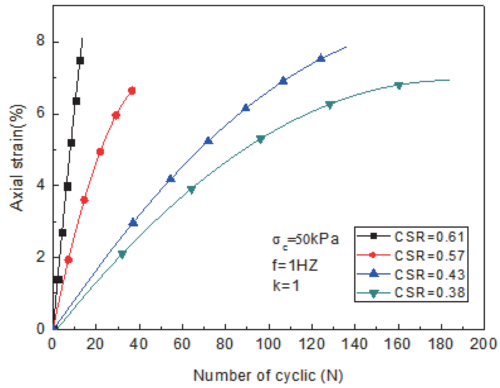


Fig. 4 Stress-strain curve under cu static

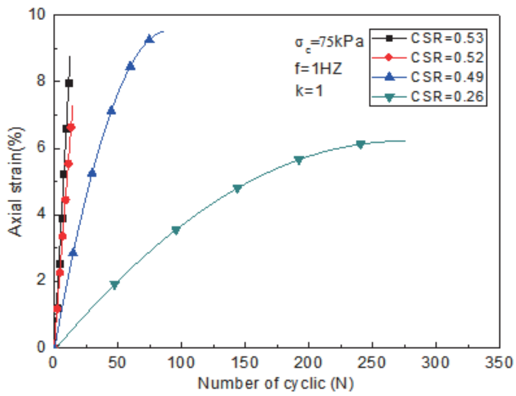
This paper chose 15% as the failure pressure to draw up the Mohr circle, and then obtains the CU strength parameter: $C_{cu} = 17\text{kPa}, \varphi_{cu} = 11^0$;

4. Analysis of dynamic strength

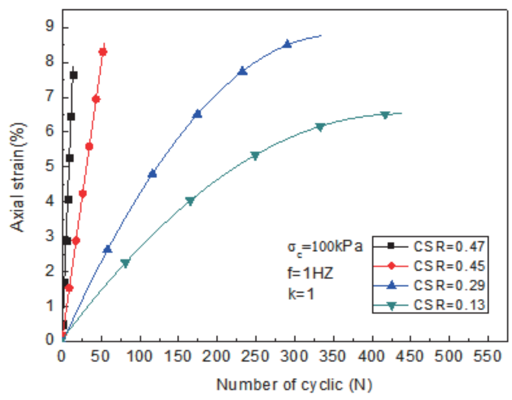
Cyclic test results are analyzed as follows:



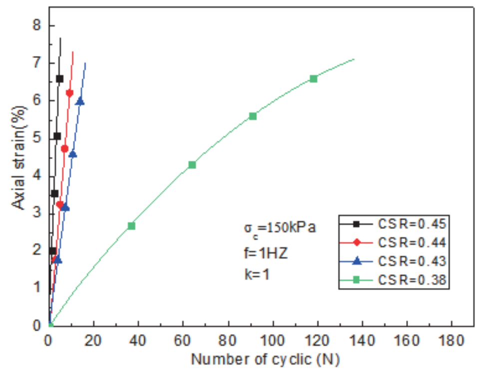
(a)



(b)



(c)



(d)

Fig. 5 Cyclic strain-vibration time curve under different confining pressure

The test data can be described through one fitting line of equation: $y = a + bx$, where a, b, R (correlation coefficient), parameter as follows:

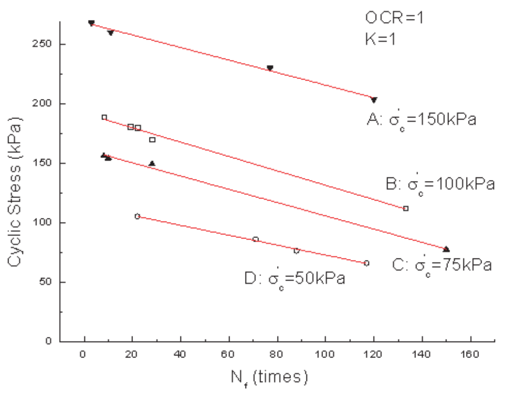


Fig. 6 Dynamic Shear stress - failure vibration time curve

Table 2 Form fitting line equation parameters

Straight line / Parameters	A	B	C	D
a	268.2	191.7	161.4	114.3
b	-0.53	-0.61	-0.56	-0.42
R	0.991	0.990	0.995	0.993

Many factors affect the soil strength can be divided into two categories. One is the soil itself, these factors such as soil composition, status and structure. The other is external factors, including stress state (confining pressure, the principal stress), stress history, the principal stress direction, loading rate and drainage conditions (Lee K L, 1979).

As can be seen from the figure, the higher the confining pressure, the greater the damage to the dynamic shear stresses. Points of attachment tend to parallel the fitted straight line.

The nation norms proposed equivalent damaging vibration times, according to the formula of the earthquake department to promote：

$$M = 0.68 I_0 + 0.98 \quad (1)$$

Where M is the magnitude, I_0 is the intensity, for the degree of fortification of Haikou；

$M = 0.68 \times 8 + 0.98 = 6.42$, by checking the table, it is obtained that the equivalent failure vibration times in table 3 which equals 8 times in Haikou；

Table 3 Correlation of equivalent vibration times to failure and the seismic magnitude

Effective consolidation confining pressure/ kPa	50	75	100	150
Equivalent dynamic stress amplitude/ kPa	120	156	190	268

It is gained that dynamic stress in table 4 corresponds to 8 vibration times. Then, draw the Mohr circle to get dynamic strength parameters: $C_d = 19\text{kPa}$, $\varphi_d = 11^0$.

Table 4 Magnitude, equivalent failure vibration time relationship

the magnitude (M)	6.0	6.5	7.0	7.5	8.0
Vibration times the equivalent damage	5	8	12	15-20	26-30

5. A comparative study of dynamic and static strength

5.1 Overview

The static loads of limit equilibrium state can be described by limit stress circle Mohr. In the cycle, limit equilibrium state can also be used Moore limit stress circle, as shown in figure 7. According to Mohr-Coulomb failure criterion, it should be:

$$\sigma = \frac{2\sin\varphi}{1-\sin\varphi}\sigma_0^{'} + \frac{2c\cdot\cos\varphi}{1-\sin\varphi} \quad (2)$$

In the same confining pressure $\sigma_0^{'}$ of dynamic triaxial test, stress σ_d caused by the destruction of soil samples could also be used Mohr-Coulomb failure criterion, that is:

$$\sigma_d = \frac{2\sin\varphi}{1-\sin\varphi}\sigma_0^{'} + \frac{2c_d \cdot \cos\varphi}{1-\sin\varphi} \quad (3)$$

Combination (2) and (3):

$$c_d / c - 1 = (1 + \frac{\sigma_0^{'}}{c} \cdot \tan\varphi)(\sigma_d / \sigma - 1) \quad (4)$$

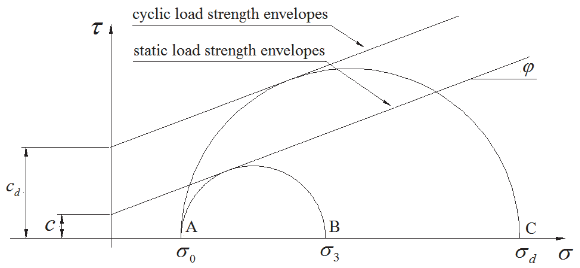


Fig. 7 Mohr-circle and failure envelope under static and dynamic load

Therefore, if know the static strength parameters c and φ, and dynamic strength of soils σ_d have been identified under the consolidation pressure $\sigma_0^{'}$, the dynamic cohesion c_d can be determined from the formula (4) ；

Table 5 shows the test condition and the result of Japan Shiroishi region volcano sedimentary clay, the soil particle composition: gravel particle13%, sand47%, powder particle 12% and clay particle 28%. Besides, some volcanic sediment of the cohesive soil test result of the Japanese Izu area is listed in the table 5 (Yasuhara et al., 1992).

Table 5 Static and dynamic test result of two kinds of clay

Test condition and result	Volcanic sedimentary clay （Izu）	Volcanic sedimentary sandy clay （Shiroishi）	Volcanic sedimentary sandy clay （Shiroishi）
Gravity γ (kN/m^3)	14.2	18.7	19.0
Water capacity w(%)	110－140	22－23	20－21
Plasticity index I_p	30	18	18
Static cohesive force c(kPa)	20	28	32
Internal frictional angle φ(°)	17	14	16
Dynamic cohesive force c_d(kPa)	48	52	51
c_d / c	2.4	1.86	1.59

Although it can not only obtain the unification conclusion from the two kind of cohesive soil experiments, but it turned out that the dynamic cohesive force was about 1.6-2.4 times the static cohesive force.

5.2 The analysis of strength comparative on Haikou red soil

According to the mentioned above, made static and cyclic triaxial test on Haikou red clay, taking the strain damage for failure criteria under isotropic consolidated undrained conditions.

It can be seen dynamic cohesive force slightly larger than the static cohesion.

Table 6 Comparison of dynamic and static strength of Haikou red soil

Test materials	Haikou red clay
Static cohesive force :C（kPa）	17
Internal frictional angle: φ(°)	11
Dynamic cohesive force : c_d (kPa)	20
c_d / c	1.17

6. CONCLUSION

The LoadTrac II triaxial apparatus which was made by GEOCOMP Company was employed to performed static and dynamic triaxial tests on Haikou red clay under isotropic consolidated undrained condition.

In the test procedure, in order to prevent the triaxial chamber from driven when dynamic loading, some measures were needed to fix.

Choose strain failure criterion to analyze the current results, get that there is a certain relation between the dynamic and static strength parameters. The cohesive is several multiple between the dynamic and static strength, and internal friction angle is decided by soil property, so dynamic and static condition basic unchanged; Comparative study of dynamic and static strength on Haikou red soil, the dynamic cohesive is 1.17 times than static cohesive.

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