The analysis of dynamic pore pressure

Junhui Luo i), Linchang Miao ii) and Guangfan Li iii)

i) PhD Student, Institute of Geotechnical Engineering of Southeast University, Nanjing 210096, China
ii) Professor, Institute of Geotechnical Engineering of Southeast University, Nanjing 210096, China
iii) Professor, College of Civil Engineering of Hainan University, Haikou 570228, China

ABSTRACT

China is located in two biggest earthquake activity belts of the world; therefore, it is indispensable to research geotechnical dynamic properties. Cyclic loading tests had been constructed by LoadTrac II dynamic triaxial equipment for Haikou red clay. The dynamic pore pressure curves of Haikou red clay were calculated by a practical pore pressure model and test results showed that they have the high correlation compared with calculation results.

Keywords: earthquake; over-consolidated; dynamic characteristics; dynamic pore pressure model

1 INTRODUCTION

Earthquake is an epidermis vibration of the earth caused by sudden release of energy slowly accumulated in the core of the earth. The degree of earthquake damage is called intensity. Haikou is a city with the most fortification intensity city among provincial capital in China; therefore, it is essential to research dynamic property of the red clay in Hainan province. The clay would produce strain accumulation and softening phenomenon under cyclic load, because of the increasing excess pore water pressure; Therefore, if it revealed the dynamic properties of soil on the basis of the mechanism, it should focus on the law of development of dynamic water pressure.

The pore water pressure of soil will be occurred under cyclic loads, so it is also called dynamic pore water pressure. This paper based on the mechanism to analyze dynamic pore pressure characteristics, and it calculated by practical pore pressure model on pore pressure-time curves.

2 GENERAL SPECIFICATIONS

Up to now, many scholars presented lots of pore pressure models [i]. Zhang Jian-ming and Xie Ding-yi[6] (1991) established practical calculation method for question of pore pressure. With regard to dynamic triaxial test of stress control amplitude, pore pressure increment model was proposed, which had three changing forms, namely A, B and C-type.

As shown in figure 1, the upper part of these curves is known as A-type curve, the middle part is B-type, the lower part is C-type, it was experimentally showed that pore pressure increment processes of different types were determined by soil density, cell pressure and dynamic strength and so forth. While the corresponding expressions were:

\[
\frac{u^*}{u_j} = 1 - e^{-\beta t_j} \quad \text{(A Type)} \tag{1}
\]

\[
\frac{u^*}{u_j} = \frac{2}{\pi} \sin^{-1} \left( \frac{1}{t_j} \right)^\frac{1}{2} \quad \text{(B Type)} \tag{2}
\]

\[
\frac{u^*}{u_j} = \left[ \frac{1}{2} \left( 1 - \cos \frac{\pi}{t_j} \right) \right]^b \quad \text{(C Type)} \tag{3}
\]

Where \( \beta, a, b \) — Calculation parameters;

\( u^* \) — Dynamic pore water pressure with the action of dynamic load under completely undrained condition;

\( u_j \) — Limited pore water pressure, which is a maximum value of pore pressure increment during earthquake;

\( t \) — Total time of cycle duration;

\( t_c \) — Time of cycle duration corresponded to critical pore pressure.

Fig.1 Pore water pressure model of three types under the same stress amplitude
3 DYNAMIC TRIAXIAL TESTS

3.1 Test Materials

The soil site located at downward of Gao-po Village, Haikou City. Geotechnical engineering survey grade of the project was confirmed as B according to Geotechnical Engineering Specification [7] (GB50021-21).

3.2 Test Instruments

Triaxial apparatus of LoadTrac II made by GEOCOMP Company, it could make triaxial test by the means of cyclic load and static load.

3.3 Test processes

Saturation: It was saturated by outdoor air extraction, next inlet carbon dioxide, and then conduct back pressure by triaxial. Consolidation: The sample was conducted under isotropic consolidation. Loading: When test was loading, it loaded the force respectively corresponded to vibration of several, score and hundreds times when the strain of the soil sample was up to 5%.

The first page must contain the Title, Author(s), Affiliation(s), Abstract, and Keywords. The INTRODUCTION must begin 24pt (= 2 lines) below the keywords. The first line of the title is located 24pt from the top of the printing box.

4 ANALYSIS OF THE DYNAMIC PORE PRESSURE ON HAIKOU RED CLAY

4.1 Mechanism of dynamic pore water pressure

The variation of pore water pressure is related closely to soil internal factors and external conditions like earthquake, including cycle stress ratio, cell pressure, vibration frequency, and over consolidation ration.

4.2 Influence of different cyclic stress

In figure 2-figure 4, under specific dynamic shear stress or dynamic shear strain, the pore water pressure would be linear increase as cyclic number increase. The influence of cyclic vibration number on the pore water pressure, however, depends on the level of dynamic shear stress or dynamic shear strain, or loading rate, etc.

\[
CSR = \frac{\tau}{\sigma_c} = \frac{\sigma_d}{2\sigma_c}
\]  

Where \(\tau\) — Dynamic shear stress ; \(\sigma_c\) — Effective cell pressure level ; \(\sigma_d\) — Dynamic stress.

4.3 Haikou Clay hydrodynamic model

The Zhang Jian-min model indicates continuous curve pattern of stress control, as shown in type A in figure 1. So it is feasible to assume the model expression of dynamic pore pressure of soil based on the formula. Then fitting could be made: Make conclusion by formula (1), and analyze the model of pore water pressure on the basis of figure 3. The figure indicates the fitting curve of four different dynamic stress ratio, namely a, b, c, d, after coordinate transformation under the effective cell pressure of 100 kPa of Haikou red clay in figure 5-figure 8.

The initial effective cell pressure of cyclic stress ratio and cyclic stress amplitude ratio is defined as:

\[
\text{CSR} = \frac{\tau}{\sigma_c} = \frac{\sigma_d}{2\sigma_c}
\]  

![Fig.2 Excess pore pressure-vibration relationship diagram under 50kPa cell pressure of Haikou red clay](image1)

![Fig.3 Excess pore pressure-vibration relationship diagram under 100kPa cell pressure of Haikou red clay](image2)

![Fig.4 Excess pore pressure-vibration relationship diagram under 150kPa cell pressure of Haikou red clay](image3)

![Fig.5 Haikou red clay Jian-min Zhang model curve a diagram](image4)
According to equation (1), the a, b, c, d types were fitting curve, and the following table 1 showed that the parameters of the fitted curve.

Table 1. Zhang Jian-min model parameters

| Parameters | a   | b   | c   | d   |
|------------|-----|-----|-----|-----|
| hf (kPa)   | 72.8| 124.4| 106.5| 94.4|
| \(\beta_{lf} \) | 1.4 | 3.04 | 3.45 | 5.88 |
| R          | 0.99| 0.98 | 0.95 | 0.91 |

Zhang Jian-min model was used as curve pattern of stress. The fitting correlation coefficient, in high value yet, reduces gradually and slightly with the decrease of dynamic stress ratio. And it means that the fitting results are preferably. Zhang Jian-min model cannot be used to describe the alternate phenomenon of shear shrinkage and dilatation in soil under the dynamic load. However, this model is practical to predict.

5 CONCLUSIONS

1. Through dynamic triaxial test in Haikou red clay, testing results indicates that the relationship between pore water pressure and cyclic number is almost the same under the same cyclic stress ratio, and that the pore water pressure would be linear increase with cyclic number under the same cyclic stress ratio. As the cell pressure rises, if the sample becomes denser before loading, the soil deformation rate and pore pressure rising rate become lower in high cell pressure than in low cell pressure, as well as the rising amplitude of pore pressure.

2. On the basis of the selected model of the dynamic pore water pressure to analyze, this study establishes the proper dynamic pore pressure increase model of Haikou red clay, and the model parameters are determined by dynamic triaxial tests. The value of correlation coefficient stays high. Zhang Jian-min model is used to verify growth form well. Although it disables to describe the alternate phenomenon of shear shrinkage and dilatation in soil under the dynamic load, it is practical to predict and calculate the dynamic pore pressure.

REFERENCES

1) Wu Shi-ming. Soil Dynamics, Beijing: Press of China Building Industry, 1998.
2) Li Zheng, Yuxiang Juan. Gravel under dynamic loading of Size Effect, Thesis of Hehai University, 2007. (5).
3) H.B. Seed, G.R. Martin, J. Lysmer. Pore-Water Pressure Changer During Soil Liquefaction, Journal of Geotechnical Engineering Division, ASCE, vol., 1976102(GT1).
4) Wang Wen-shao. The strength, liquefaction and destruction problem of Saturated sand under repeated loads, Hydraulic Engineering, 1980(1)
5) Zhang Keling, Tao Zhenyu. Prediction of pore pressure on saturated clay under cyclic loading in the, Rock and Soil Mechanics, 1994,(9): 9~17
6) Zhang Jian-min, Xie Ding-yi. Impact of pore pressure mode selector on the calculating of sand seismic boundary value problem, Numerical methods Symposium of second national geotechnical engineering applications, Press of Tong-ji University, 1999.
7) The People's Republic of China national standard "geotechnical engineering" GB50021-2001, Press of China Building Industry, 2009.
8) Ministry of Water Resources. Republic of China national standard "soil test method standards" GB/T50123-1999, Press of China Planning, 1999.
9) Zhou Jian, Gong Xiaonan. Research of strain softens under cyclic loading of saturated soft clay, Civil Engineering Journal, 2000(10): 75~82.
10) Wang Wen-shao. Characteristics of dynamic strength and liquefaction on soil, Beijing: China Electric Power Press
11) Zhang Jian-hong, HE Chang-rong. The law of pore pressure and liquefaction of strength under cyclic loads on unsaturated sandy soil, Science Technology of Chengdu University, 1994, (1): 1~8.