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Change of Adsorptive Bound Water of Soft Soil in Hangzhou under Typical Loading Conditions

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Change of Adsorptive Bound Water of Soft Soil in Hangzhou under Typical Loading Conditions

Qingqing Zheng*

College of civil engineering, Zhejiang University, Hangzhou, China

*Corresponding author e-mail: 19440708@163.com

Abstract. Adsorptive bound water can reflect the physical properties of soil and affect its mechanical behaviour. Based on the important function of adsorbed water, the change of adsorbed water under three types of load is studied. The undisturbed samples nearby subway in Hangzhou is selected as criterion. Via the volumetric flask method, the content of the adsorbed water and the specific surface area are measured. Compared with the results of undisturbed specimen, this paper evaluated the effect of the impact, vibration and remolded and vibration. The results show that after loading the adsorption water content decreases. Among three types of load, the remolded vibration made the most significant change.

1. Introduction

One of the typical features of soft clay is its high water content, and bound water is an important part of pore water in soil. The bound water includes osmotic bound water (also called weak bound water) and adsorption bound water (strongly bound water), which are distributed in Fig. 1[1]. On the left side of Fig. 1 is the clay flake particle with negative charge. To the right is a diffusion layer consisting of surrounding water molecules, positive ion cloud and so on. It is called a diffusion double layer, and the water in the double layer is called bound water. Adsorbed bound water (abbreviated as adsorbed water) is closely attached to the particle's surface that can be attracted by particles up to 109 kPa. Its physical properties are different from those of weak bound water and free water, which has certain viscous, elastic and shear strength, and is closely related to macro-mechanical properties of the soil [2].

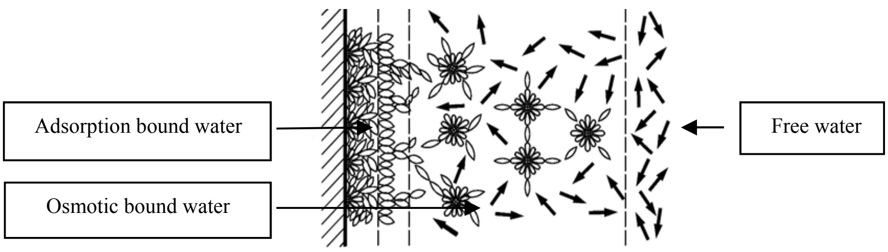

Figure 1. Distribution of adsorption bound water in pores

Currently, the research on the mechanical behavior of soft clay focuses on the apparent law, such as pore pressure, deformation and stiffness development law. Relatively speaking, there are few researches on the nature of pore water from micro and micro perspectives, and literature shows that pore, pore size and particle shape are mainly discussed in this study, while little attention is paid to pore water [3].

Soft soil has typical regional differences. Based on the fact that soft soil is widely covered underground in Hangzhou and many metro tunnels have been built in recent years, this paper takes Hangzhou soft soil as an object to study the change of adsorbed bound water under several typical loading conditions, as to provide micro-basis for evaluating the macro-mechanical properties the soft soil in Hangzhou. Considering the impact of shield construction method for metro tunnel on soil, this paper exerts the impact load on the soil sample, which through comparing the undisturbed soil sample to analyze the change of adsorbed water. In view of the long-term impact of subway train vibration during the operation period, the soil samples are loaded to simulate the vibration of the metro traffic law, and analyze the change of adsorbed water. In view of the construction disturbance and the operation of subway train, the vibration is applied to the samples after remodeling to analyze the adsorbed water changes.

2. Test

2.1. Soil sample

The soil samples come from the saturated silty soft clay close to the No. 2 Metro Line in the west of Hangzhou City, which has the features of high water content, high compressibility and low permeability. The soil sample are selected strictly in accordance with the original soil sampling standard of JGJ 89-92 Grade I. Its basic physical properties are in Table 1 as follows:

Table 1. Physical properties of soil

gravity kN/m^3	Water content w/%	Specific gravity	plastic limit wp/%	liquid limit /%	Plasticity index	Liquid index
17.6	47%	2.74	16.4	37%	17.8	1.59

There are three types of loads in this paper, as shown in Table 2. Loading tests are carried out on GDS dynamic tri-axial apparatus, saturated and consolidated before loading. Table 2 is the main parameter of formal loading. Due to the limited space, the parameters of saturation and consolidation process are referred to the standard. In Table 2, the reason why the impact load is loaded once is that under 200 kPa impact loads, the axial strain of the sample has exceeded 25% after one impact, which can be regarded as failure, so the loading is not continued. The vibration loading of soil sample has the feature of time interval to simulate train operation. It adopts the form of 10 seconds stop after per vibration, and the waveform adopts half-sine wave. The vibration frequency is 1Hz and the amplitude is 20kPa. The vibration process is without drain, and it stops after 10^4 accumulation. The manufacturing process of remolded soil samples is strictly in accordance with geotechnical specifications, and vacuum negative pressure drainage is used for consolidation.

Table 2. Detailed information of specimen

Sample number	Description	Loading steps
1	Undisturbed sample	①Saturation
2-A	Impact load	①Saturation②Consolidation③Impact load(200kPa, 0.1s, 1time)
2-B	Cyclic load	①Saturation②Consolidation③vibration (amplitude 20kPa for 10^4 times, 1Hz)
2-C	Remolding and cyclic load	①remolding②Saturation③Consolidation④Vibration (amplitude 20kPa for 10^4 times, 1Hz)

2.2. Water adsorption test

There're many methods to test the adsorbed bound water, such as: XIAO [4] used hygroscopic method and SEM method to test the bound water of soft soil in Hangzhou and Tianjin; TIAN [5] determined the adsorbed water content on clay surface by nuclear magnetic resonance and infrared spectroscopy, respectively. Because of the high cost of infrared spectroscopy and nuclear magnetic resonance (NMR) test, and hygroscopic method requires higher test environment, this paper selects volumetric flask to test the water adsorption content [6].

The volumetric bottle method is briefly introduced: In the cohesive soil, the water molecular density of bound water and the attraction of clay particles to water molecules are different from that of free water, so the average ratio of bound water to free water is 1.0 g/cm^3. It increases gradually with the distance decreases from the particle surface, and the average bulk density is about 1.8 g/cm^3. In contrast, the bulk density of osmotic bound water is closer to that of free water, which is about 1.3g/cm^3, and there is a big gap between the bulk density of osmotic bound water and that of adsorptive bound water. The theoretical basis of volumetric bottle method is that when the dried sample is immersed in water again and liquid free water is transformed into solid adsorbed bound water, the water density increases and the total volume decreases, which causes the volume change of the solution. This method is simple and easy to operate, which can measure the adsorbed bound water content more accurately.

If m_s (g) dry soil sample is added to a volumetric bottle containing a certain amount of water or solution and the free water is converted into adsorbed bound water, the water body is reduced to ΔV, and the expression of which is (1):

$$\Delta V = \frac{\gamma_{we} - \gamma_{wt}}{\gamma_{we}\gamma_{wt}} m_s w_g \tag{1}$$

In the formula, γ_{we} is the average bulk density of adsorbed bound water of 1.3; γ_{wt} is the volume weight in free water; w_g is the adsorbed bound water content, which is presented as percentage of dry soil weight.

From formula (1), the expression of adsorbed bound water w_g is obtained as follows (2):

$$w_g = \frac{\gamma_{we}\gamma_{wt}}{\gamma_{we} - \gamma_{wt}} \frac{\Delta V}{m_s} \tag{2}$$

In formula (2), the value ΔV can be calculated by the following formula (3) for the experiment:

$$\Delta V = \frac{m_s}{G_s} - V_t \tag{3}$$

The G_s in the formula is the solubility of soil samples tested with neutral liquids; and the water increment in volumetric bottle is actually measured by V_t.

The test steps are as follows:

I. Firstly, soil samples are dried at 200-250°C for 8 hours and then cooled in a dryer. In order to prevent uneven scale due to glass instrument being heated, the volumetric flask must be cleaned, without using the oven, so it must be dried by natural air. Soil samples and volumetric bottles are kept at the same temperature as the water and ambient temperature in this experiment, without other heat source.

II. The quantitative dried soil sample m_s (g) is put into the volumetric bottle, and then 500ml quantitative water is injected into the bottle and discharged with bubbles by shaking. Record the scale of the concave liquid surface on the page. After oscillation, fill the bottle with plug. The sample oscillates once or twice every 24 hours, and records the data. Stop the experiment till the water level becomes stable, and record the data of final liquid level.

III. The amount of adsorbed bound water is calculated according to the calculation formula.

IV. Each group of soil samples is carried out in the parallel test, and the relative error of experimental results is not greater than 3%.

3. Test Result

In order to obtain more accurate test results, two groups of parallel tests are carried out, and the quality of soil samples is as below:

The first group of parallel test: undisturbed state: 21.9g, impact: 22.0g, vibration: 23.3g and remolded and vibration 24.4g;

The second group of parallel test: undisturbed state: 21.7g, impact: 20.1g, vibration: 20.1g and remolded and vibration 20.2g;

From Figure 2-a and 2-b, it can be seen that the formation rate of water adsorbed by soil samples decreases gradually. The test results of the first group is shown as Table 3 that before 2 days, the adsorbed water content of soil samples increased gradually from 3.5%/d to 7.5% per day, indicating that the larger diameter and the better patency of soil samples filled by pore water at this stage. On the 3rd day, the water content of adsorbed water in the undisturbed, impacted only, vibrated only and remolded and vibrated samples reached 15%, 10%, 8% and 6% accordingly, indicating that the order of the proportion of macro-pore is the same. It can be concluded that the loading will reduce the macro-pore in soil. Compared with the difference reduced by macro-pore proportion, the remolded and vibrated one has the greatest, followed by the impacted one, the vibrated one, the impacted one.

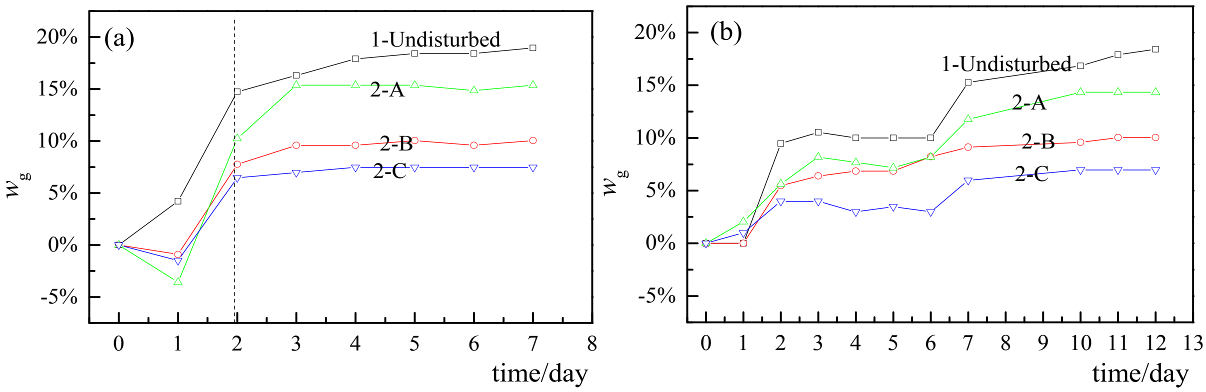

Figure 2. Development of adsorbed water

After 3 days, the average daily adsorbed water content of undisturbed soil and impact soil is similar, increasing by about 1% per day. The average daily increase of vibration soil is 0.4%, while the remolded and vibrated soil sample remained basically unchanged. At this stage, the pore water is mainly formed in small pore and aggregate. Therefore, the fine and aggregate retention of undisturbed soil and impact soil are better. There are still some small pores and aggregates in the vibrated soil. The content of remolded vibration soil is the smallest. Above results show that the load of remolding and vibration has the greatest influence on the adsorbed water content, followed by vibration and impact.

Table 3. Results of the content of absorbed water

Group number	Sample-1	Sample-2-A	Sample-2-B	Sample-2-C
(a)	18.95%	10.04%	15.36%	7.46%
(b)	18.59%	11.14%	15.69%	8.38%
Mean value	18.77%	10.38%	15.53%	7.91%
Deviation	1%	5%	1%	6%

Finally, the water content of adsorbed bound water of undisturbed soil sample measured by volumetric flask method is 18.77%, which is only 1.3% different from the plastic limit of the soil sample of 20%. According to the definition, the water content of soil fluid and plastic limit is the limit water content of precipitated free water and permeable bound water, so it can be regarded as the theoretical value of bound water content and adsorbed bound water content to a certain extent.

XIAO [4] has tested the water content of soft soil in Hangzhou by hygroscopic method, and SEM method. The results show that there's 5% difference with the liquid-plastic limit method. Compared with the results of volumetric flask method and the liquid-plastic limit method, the error of the volumetric bottle method is greater, indicating that the results of the volumetric flask method are more reliable.

4. Conclusion

In this paper, the change of adsorbed bound water of undisturbed soft clay in Hangzhou is tested by volumetric flask method under three typical loading conditions, and the following conclusions are drawn:

(1) The adsorbed water content of undisturbed soft soil measured by volumetric flask method is about 19%. After three different forms of loading, the adsorbed water content decreases. Among them, the remolded and vibrated soil has the most significant influence, followed by undisturbed soil, and the impact load is the smallest.

(2) The formation process of adsorbed water shows that the proportion of macro-pore volume decreases after loading, and the order of influence still is remolded and vibrated, vibrated only and impacted only. Under the circumstance of impact and vibration, fine pores and flocculent groups are still retained in the soil samples, while the small pores and flocculent groups are little left after remolded and vibrated.

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