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Strength and Deformation of Unsaturated Compacted Clay under Wetting-Drying Cycles

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Abstract. Strength and deformation of unsaturated compacted clay under wetting-drying cycles considering different amplitudes and numbers have been studied in the present study. A non-suction controlled method was applied to carry out cyclic wetting-drying on the compacted clay, and the effect of wetting-drying cycles on confined compressive strength peak and deformation of specimens have been investigated. The results show that wetting-drying cycles can reduce the strength of compacted clay, and after 4-5 times of cycle the strength tends to be stable. The height and volume of compacted clay increase as the number of cycle increases. It can be indicated that under wet condition the influence of amplitude of wetting-drying cycle on the deformation is greater than that under dry condition.

1. Introduction

Soil compaction is an important process in foundation engineering (including highway, railway, retaining structures, etc.) and some ground stabilization methods. The behaviours of compacted soil directly affect the stability or safety of the related engineering structures. As exposed to natural environment, compacted soil could experience cyclic wetting-drying which may change the properties of the compacted soil. Thus, more and more attentions have been paid to this issue, especially on strength and deformation of compacted soil.

Du et al. [1] studied the influences of drying–wetting cycle on the dry density, pH, unconfined compressive strength (q_u) and secant modulus (E_{50}) of GGBS–MgO-stabilised kaolin clay. The results show q_u and E_{50} decrease with increasing drying-wetting cycles. Chittoori et al. [2] thoroughly investigated the volumetric strain and unconfined compressive strength of treated clay subjected to wetting-drying cycles. The volumetric strain is sensitive to the additive amount of lime and cement. Similar regulations are obtained by Li et al. [3] and Wang et al. [4] while after 3-5 cycles the unconfined compressive strength and secant modulus of soil tends to be constant. Researches have reported that wetting-drying cycles cause the decrease of swelling pressure and the development of crack width and depth [5, 6]. More recently, Tu et al. [7] and Yang et al. [8] both considered the effect of wetting-drying cycles under loading. The secant modulus and shear strength parameters show remarkable decline due to the wetting-drying cycles. Meanwhile, the external loading can efficiently avoid the strength and stiffness degradation of the compacted clay.

In the above studies, the effect of moisture change amplitude is not considered. So recently, Bian et al. [9] and Mu et al. [10] investigated properties of compacted clayey soil under different amplitudes of wetting-drying cycle, and the results are indicated that larger amplitude has greater impact on the strength and deformation of compacted soil under wetting-drying cycles. However, the literatures considered different amplitudes of wetting-drying cycles are rarely reported.

Thus, in this study wetting-drying cycles are performed on unsaturated compacted clay considering different amplitude and number of cycle. Then, the effect of wetting-drying cycles on the confined compressive strength peak and deformation are presented and discussed. Finally, main conclusions are drawn.

2. Experimental procedures

2.1. Experimental material

The clay is from Sanmenxia, China and the physical properties of the soil sample are listed in Table 1. For conducting triaxial compression test, the clay is remoulded into cylindrical specimens with 50mm diameter and 100mm height. The degree of compaction ($K=\rho_d/\rho_{dmax}$) is set as 0.92, so the initial dry density of specimens is $1.75g/cm^{-3}$. And the initial water content is set as optimal water content, i.e. 14.1%.

Table 1. Properties of the clay.

Natural moisture content	Saturated moisture content	Natural density	Specific gravity	Atterberg's limit (PL/LL)	Maximum dry density	Optimal moisture content	Permeability
%	%	g cm^{-3}	-	%	g cm^{-3}	%	cm s^{-1}
23.7	23.8	1.68	2.72	21.1/34.8	1.90	14.1	6.5×10^{-7}

2.2. Wetting-drying test

The subgrade is commonly compacted at the optimal moisture content (OMC), and then the water content of subgrade fillings will increase and change around a so-called "equilibrium moisture content (EMC)" in the natural environment. The EMC of subgrade is usually around OMC+7%~9% [11-12]. As mentioned before, the performance of subgrade soil tends to be stable after about 4 wetting-drying cycles. To simulate the actual condition, the water content path is set as illustrated in Figure 1. One wetting-drying cycle is from point A to point B. Note that the ending water content for all specimens is EMC. Then experimental program can be designed and listed in Table 2. In this study, the EMC is set as 17%, the maximum amplitude of cycle is considered as EMC±6% and the maximum number of cycle is 9. The temperature during the experiment is controlled at 25℃±2℃. The non-suction controlled method of wetting-drying is referred to Hu et al [13].

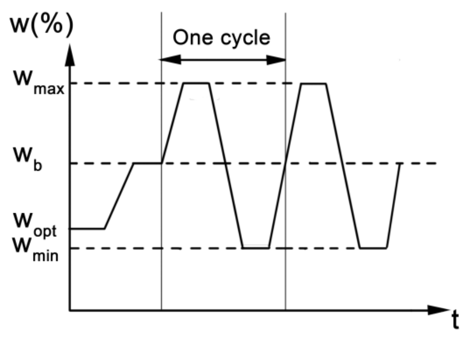

Figure 1. Wetting-drying path.

Table 2. Experimental program.

Specimen Number	Number of cycle	Amplitude of cycle (EMC±%)
A	0	0
B-2	2	2
B-4	4	2
B-6	6	2
B-9	9	2
C-2	2	4
C-4	4	4
C-6	6	4
D-2	2	6
D-4	4	6

2.3. Triaxial compression test for unsaturated soil
A non-suction controlled triaxial compression test is carried out on the unsaturated compacted clay. In the consolidation stage, the specimen is collected to atmosphere, so pore water pressure u_w is zero while pore air pressure u_a is the standard atmosphere pressure. Therefore, it can be assumed that the suction acted on the soil is $s=u_a-u_w=p_{atm}$=101.3kPa. During the compression stage, all valves are closed to offer an undrained and unexhausted condition and the vertical strain rate is set as 0.05%/min. The test is terminated as soon as obvious peak deviator pressure or total specimen vertical strain of 15% detected. In this study, the confining pressures for the compacted clay are 20kPa, 40kPa and 60kPa based on the buried depth of subgrade.

2.4. Deformation measurement
To obtain the deformation rule of compacted clay under wetting-drying cycles, a vernier caliper is used to measure the dimensions of specimens. The full range of the caliper is 200mm and accuracy is 0.02mm. The height and diameter are carefully measured and recorded in each wetting-drying cycle when the specimen reaches its maximum or minimum moisture content. Then the volume of one specimen can be calculated applying the cylinder volume formula. In order to reduce error, three diameter values in different heights and three height values in different locations for one specimen are recorded to calculate the average values.

3. Results and Discussion

3.1. Confined compressive strength peak
In order to investigate the influence of wetting-drying cycles on strength of unsaturated compacted clay, average compressive strength peak values under various confining pressure are plotted in Figure 2 and Figure 3. Note that the amplitude of cycle in Figure 2 is EMC±2% and the number of cycle in Figure 3 is two cycles.

From Figure 2, it can be seen that the strength of compacted clay soil decreases apparently with increasing number of wetting-drying cycles. While the strength for 4 cycles under a 20kPa's confining pressure reveals an abnormal increase. This may result from small size of specimen and large discreteness of soil. Overall, the strength of compacted clay tends to be stable after 4~5 cycles. For specimens under confining pressure of 40kPa, the strength after 6 wetting-drying cycles can be reduced by 20.7% than that without the cycle. Large confining pressure can reduce the effect of wetting-drying cycles, so it can be concluded that deep buried soil with larger geostatic stress can be less affected by wetting-drying cycles than shallow buried soil. The effect of amplitude of wetting-drying cycles has a similar regular based on Figure 3. It can be found that the strength of soil gradually falls down with larger amplitude of cycle.

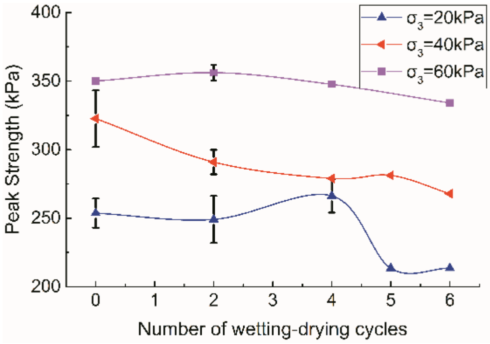

Figure 2. Variation of average peak strength with number of wetting-drying cycles.

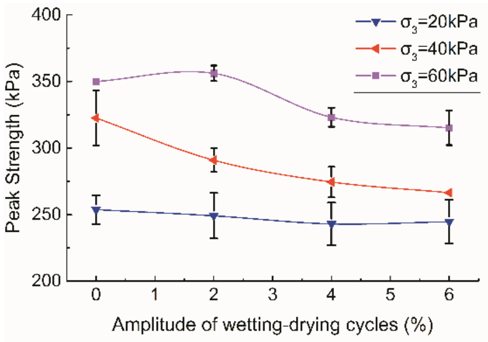

Figure 3. Variation of average peak strength with amplitude of wetting-drying cycles.

The wetting-drying cycles acted on the soil can lead to cyclic fluctuation of suction and some irreversible changes on the soil structure, thus this effect should be seriously considered in the design and construction of soil compaction, such as subgrade.

3.2. Deformation

Wetting-drying cycles can influence not only the strength but also the deformation of the unsaturated compacted clay. Figure 4 and Figure 5 present the variation of height and volume of three typical specimens under wetting-drying cycles.

In Figure 4, the heights of specimens under three amplitudes (EMC±2%, EMC±4%, EMC±6%) of cycle are plotted. It's obvious that under wet condition, the height of specimen increases with the increasing amplitude because of larger moisture content in specimens; while under dry condition, the amplitude change has little influence on the specimen's height. Moreover, the height of specimens increases as the number of wetting-drying cycles increases. After about four cycles, the height grows slowly and tends to be stable.

It can be observed from Figure 5 that the variation rule of specimen volume is similar to specimen height. The volume change on the compacted clay occurs as slight swelling, and the swelling is more apparent with larger amplitude and number of wetting-drying cycles. This can be related to the soil structure changes, and may cause the reduction of soil strength. Furtherly, the wetting mainly contributes to the soil swelling rather than drying.

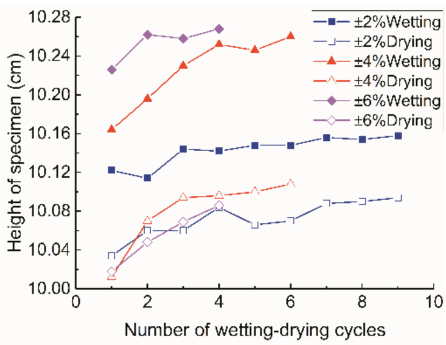

Figure 4. Variation of specimen height with number of wetting-drying cycles.

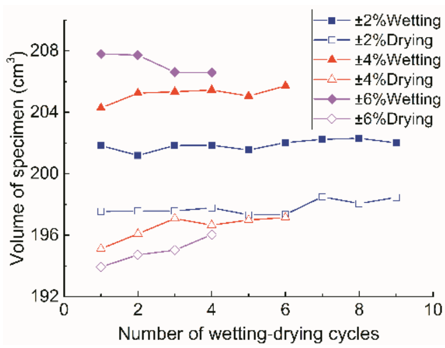

Figure 5. Variation of specimen volume with number of wetting-drying cycles.

To better understand relation between the moisture content and specimen deformation, the height and volume with different moisture contents are plotted in Figure 6 and Figure 7 respectively. The data are gathered around seven moisture contents corresponding to the design moisture contents for different amplitudes of cycle. Fitting curves to data points are drawn in the figures to reveal the rule more clearly. It can be seen from Figure 6, when moisture content is below 16% the effect of moisture content on specimen height can be neglected; when moisture content is above 16%, the height of specimen increases linearly with the increasing moisture content. For Figure 7, the volume of specimen increases proximately linearly with the increasing moisture content, while the volume change due to moisture content variation is more generally below 16%.

Thus, it is summarized that wetting-drying cycles have great influence on the deformation of the unsaturated compacted clay. In addition, the effect of wetting is greater than that of drying on the specimen deformation.

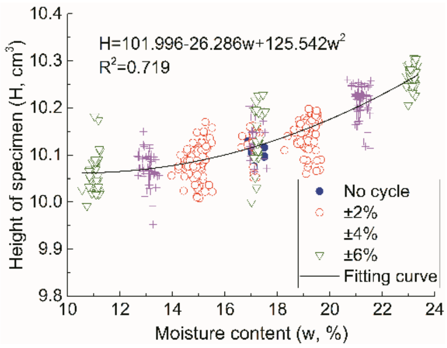

Figure 6. Variation of specimen height with moisture content.

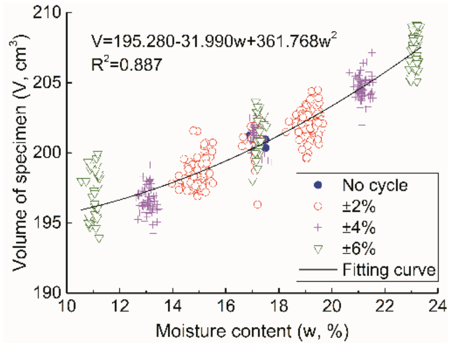

Figure 7. Variation of specimen volume with moisture content.

4. Conclusions

In this paper, triaxial tests and deformation measurements are performed on unsaturated compacted clay experienced wetting-drying cycles. The strengths of specimens under different amplitudes and numbers of wetting-drying cycles are studied and the heights and volumes of specimens are also investigated. The main conclusions for this study are summarized as following:

- The strength peak of compacted clay decreases with increasing amplitude and number of wetting-drying cycles. After 4-5 cycles, the strength of compacted clay tends to be stable.
- Increasing confining pressure can mitigate the impact of wetting-drying cycles on strength of compacted clay.
- The height and volume of compacted clay grow as the number of wetting-drying cycle increases.
- Under wet condition, the height and volume of compacted clay obviously increase with increasing amplitude of wetting-drying cycles; under dry condition, the amplitude change has little influence on the specimen's deformation.

Acknowledgments

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