Journal of Engg. Research Vol. 7 No. (3) September 2019 pp. 1-12

An instrument for wetting-drying cycle of expansive soil under simulated loads and experimental research

Jun-gui Dong*, Guo-yuan Xu*, Hai-bo Lv** and Jun-yan Yang**

*School of Civil Engineering and Transportation, South China University of Technology, Guangzhou 510641, China

**College of Civil Engineering and Architecture, Guilin University of Technology, Guangxi 541004, China

*Corresponding Author: dhunter110@163.com

ABSTRACT

The alternating effect of rainfall and evaporation in nature causes great damage to the shear strength of expansive soil. To study the effect of wetting-drying cycle experiencing loads on the strength of expansive soil, an instrument is developed in this paper, and its testing error is verified as well. Helped by this instrument, specimens that experienced 0~6 cycles under 0kPa, 5kPa, 15kPa, and 30kPa are carried out; direct shear test is performed for those samples. The results show that the instrument accurately controls the water content (within 1%), simulating an actual cycle for soil at different depths. Wetting-drying cycle shows a significant impact on the cohesion, although the friction angle is not sensitive to the cycles. An additional parametric study suggests that the decrease of shear strength can be attributed to cracks caused by wetting-drying cycles. The existence of load effectively restricts the shrinkage crack and the attenuation of shear strength and especially greatly inhibits the attenuation of cohesion. Limited by load, specimen density also narrows the attenuation of shear strength to a certain extent.

Keywords: expansive soil; wetting-drying cycle; instrument; load; shear strength.

INTRODUCTION

Expansive soil, a high plasticity clay, contains montmorillonite, illite, and other hydrophilic minerals and is extremely sensitive to the change of water content (Chen, 1974; Liao, 1984). Obviously the expansive soil will expand when it comes into contact with water and shrinks due to water evaporation. Furthermore, the expansion and shrinkage of volume are partly reversible and repeatable (Nayak, 1974; Gens and Alonso, 1992; Murad et al., 1995; Kleinfelter et al., 2006). Expansive soil is widely distributed over 40 countries and regions all around the world, including India, America, Canada, and Spain. When it comes to China, more than 100 thousand square kilometers of expansive soil is distributed among about 20 regions, which seriously troubled buildings founded on it (Liu, 2000).

Change of water content shows great influence on the properties of expansive soil. With the increase of water content, expansive soil hazards show paroxysm because of the rapid decrease of shear strength (Yang et al., 2003; Qi and Vanapalli, 2016; Chen, 1988). Being studied by experts for nearly sixty years, expansive soil hazards still happen frequently (Pupple et al., 2006). The annual cost of damage is more than $5 billion worldwide, which is higher than that caused by earthquakes and hurricanes (Gourley et al., 1993). Millions of square meters of buildings is damaged in China every year, and the direct losses of money are as high as hundreds of millions. Apart from the damage above, maintenance cost for structures founded on expansive soil is also up to tens of millions every year (Liu, 1997; Zhang et al., 2014). It is of great importance for practice engineering to study the influence of wetting-drying cycle on the shear strength of expansive soil. Rainfall and evaporation in nature inevitably cause wetting-drying cycle of shallow soil (Li et al., 2010; Yang et al., 2007). Consequently, the matric suction, pore-water pressure, deformation, and other parameters greatly changed after various wetting-drying cycles (Zhang et al., 2015). The influence of cycles on cohesion is more obvious than that on the friction angle (Zeng, 2007). The emergence and development of cracks in the wetting-drying process are considered to be the main inducer for the attenuation of shear strength (Yin et al., 2014; Wang et al., 2016).

Current researches indicate that the wetting-drying cycle of expansive soil is mainly based on laboratory tests, and testing methods are divided into two types. Method one is taking cutting sample ring specimen as research object, and the different cycles are performed under no load. Water content of the specimen is calculated by weighing during the testing process so as to control the range of wetting-drying cycle. Direct shear test or triaxial test is performed after a number of wetting-drying cycles scheduled before (Lv et al., 2012; Pierrot et al., 2016; Faith et al., 2016). Method two stacks weights on specimens to simulate vertical load during wetting-drying cycle. To control the range of water content (range of wetting-drying cycle), however, vertical load (the weights) has to be unloaded when the water content is calculated by weighting method (Yang et al., 2014; Huang et al., 2014). In short, both methods are found quite effective in controlling the water content in expansive soil, while previous researches failed to consider the actual load of practice engineering, because it is always loaded for a certain depth of soil in practice engineering, and it shows no unloading during the whole process of wetting-drying cycle.

Despite the valuable discoveries, the impact of wetting-drying cycle on the shear strength of expansive soil under actual load remains virtually unexplored. Based on the limitations of the previous studies, our work focuses on a good simulation of the actual load as close as possible. Essential factors of practice engineering complied with an instrument, which accurately controls the water content of the specimen, simulating the lateral load and vertical load of a certain depth without the smallest effort. Furthermore, no unloading in the whole process of wetting-drying cycles and direct shear tests is found. Thus, this method is more closer to practice engineering. With the help of this instrument, 0~6 cycles under 0 kPa, 5 kPa, 15 kPa, and 30 kPa are carried out before direct shear test, which could be conducive to discuss how the wetting-drying cycle under actual load affects the shear strength of expansive soil. We believe this work could obviously provide novel evidence for engineering design and hazard prevention in expansive soil areas. So far, this instrument has been given patent for invention in China.

DESIGN OF THE INSTRUMENT

The instrument, with small density and high strength, is made of aluminum alloy that can be found convenient and cheap. It is composed of circulating device, lever, and special shear box. The circulating device, which includes nut, fixed collar, cover plate, column, cutting ring, hoop, and base plate, is the most important part of this instrument (Fig. 1). The nut can be rotated up and down along the column because its whole length attached to the base plate is screwed. A free sliding between the fixed collar and the column is permitted. The upper part of the cover plate, named cross beam, is about 1.0cm longer than the outer diameter of the fixed collar and is used to measure the vertical deformation of samples through a dial gauge. To accelerate the process of wetting and drying, drainage holes are evenly distributed on both the cover plate and the base plate. The diameter of the cutting ring is slightly larger than that of the cover plate and is slightly shorter than that of the straight distance between the columns in the diagonal position. The cutting ring, with the upper half height being 15.0mm and the lower being 10.0 mm, is divided into two parts in the vertical. Therefore, it guarantees the vertical expansion of the specimen will not exceed the cutting ring and does good to cut sample apart without disassembling. The lower edge of cutting ring with screw can be screwed to the base plate. A hoop is prepared to fix the two parts of cutting ring, making the samples remain a whole during wetting-drying cycle.

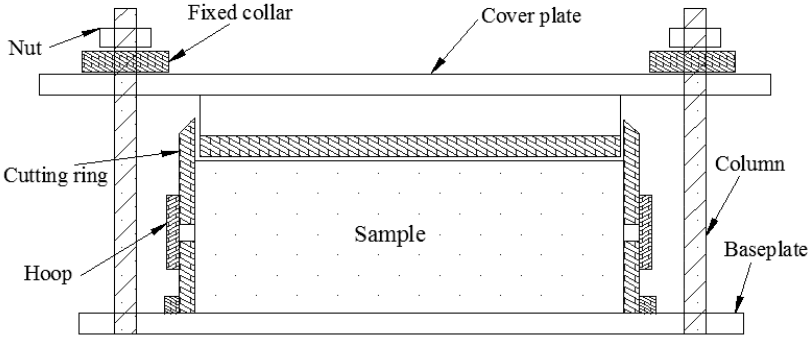


Fig. 1. Device for wetting-drying cycle.

In this study, the simulated vertical load is applied by a lever (Fig. 2), while lower load can also be directly provided by weights placed on the device. The lever, with a length of 50.0cm and lever ratio of 1:10, achieves the simulation of various loads of different soil depths by changing weights or lever ratio. It is very convenient for us to measure the vertical expansion of the specimen by a dial gauge installed on the lever. During the testing process, the instrument is placed in a temperature-humidity controlled box, and the circulating device and specimen are immersed in a water tank with a diameter of 15.0cm and a total height of 10.0cm. When simulating the wetting process, the water tank is filled with water to cover the upper surface of the specimen. On the contrary, before drying, water is released from the bottom of the water tank.

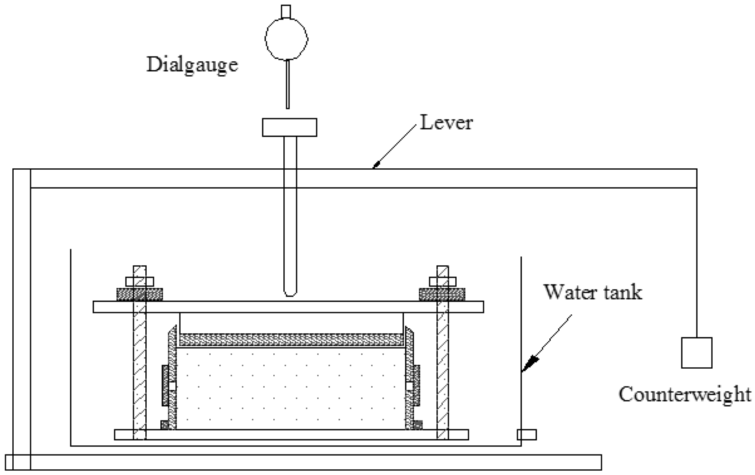
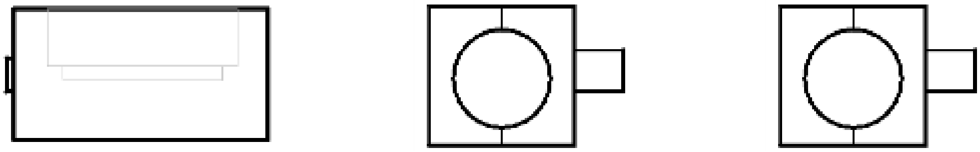


Fig. 2. Device for wetting-drying cycle under load.

As illustrated in Figure 3, the shear box is specially designed to cater to the demands of circulating device, and it consists of three parts: the pedestal, the upper shear box, and the lower shear box. A groove conforms to the circulating device on the bottom of the pedestal, so as to put the device directly into the pedestal after various wetting-drying cycle. In the case of lateral load and vertical load, the whole process from specimen installing to breakdown is completed without disturbing.



(a) Pedestal (b) Upper shear box (c) Lower shear box

Fig. 3. Shear box specially designed.

USE OF THE INSTRUMENT

To facilitate understanding and use of the instrument in this research, a succinct introduction to the specific steps of the device is given as follows.

Step one. To improve the accuracy of testing data, attached water and vertical deformation of the device are calibrated; we actually studied the weight of water adhered to the inner surface of circulating device as well as the vertical deformation of device itself under different loads during a whole cycle.

Step two. As shown in Figure 1, the cutting ring and base plate are tightened together, and two filter papers are then placed on both surfaces of the specimen to prevent soil particles slipping away. The mass of circulating device together with filter papers is weighed and recorded as M_0. For the consideration of later calculation, the specimen whose initial water content and dry density are clearly recorded is made according to the testing scheme, covering the cover plate to the sample and screwing the nut at the column top after the fixed collar is placed through the column. The mass of circulating device and specimen is weighed and recorded as M_1. Therefore, the mass of the specimen in the device is $M_2= M_1-M_0$. If the water content of the specimen is given as ω_1, and the mass of soil particles in the sample is $M_3=M_2/(1+\omega_1)$, and the mass of the water in the specimen is $M_4=M_2-M_3$. According to the initial weight and height of the specimen, the porosity and initial saturation are accurately calculated by comprehensive analysis.

Step three. The circulating device and specimen are placed into the water tank. The dial gauge, which is used to measure the vertical deformation and contraction, is installed on the lever, and its initial reading is recorded. Based on the testing scheme, different vertical pressures are applied on the specimen by adjusting the weights. At this moment, the vertical aspect of the specimen is subjected to a compression load, and the lateral pressure of the cutting ring is available too. Thus, the stress condition of the specimen is close to that in practice engineering.

Step four. Distilled water is poured into the water tank to cover the top of the specimen during the simulating process of wetting, so that the water can fully infiltrate the specimen. For precise control of the range of wetting-drying cycle, the reading of the dial gauge is recorded at a regular time, and the total mass of specimen and circulating device is weighed as well. During weighing process, the nut is screwed to close contact with the fixed collar and is stopped when the reading of the dial gauge just happened to change. At this point, before removing the lever, the nut tightened already makes the pressure of the specimen equal to that provided by the lever before. Since the specimen is nipped by the cover plate and the base plate, it successfully prevents the rebound of specimen after unloading the vertical load. The circulating device, which is taken out of the water tank and dried, is put upon the electronic balance to weigh the mass and recorded it as M_5. The mass difference between two weighing (M_5-M_1) is the quantity of water absorbed into the specimen. Therefore, water content, which is $\omega_2=(M_5-M_1+M_4)/M_3$, is calculated effortlessly. The specimen, restrained by the cover plate and the base plate when weighed, is still under loaded condition, which guarantees no unloading at all during the whole weighing process. According to the weight and height of the specimen, the porosity and saturation are accurately calculated at each time. We preferred to increase the frequency of measurement when the specimen is close to the water content scheduled.

Step five. The simulation of the drying process is practically completed in a temperature-humidity controlled box. For the sake of freely evaporating of specimen, the lever and circulating device are placed in the temperature-humidity controlled box where the temperature is 40°C and the relative humidity setting is 35%. By using the similar method mentioned in step four, the reading of the dial gauge is recorded at a regular time, and the total mass of the specimen and circulating device is weighed as well. Thereby, the water content of the specimen at these moments is calculated. Only in this way can the drying process be carried out under lateral load and vertical load and can the changes of water content be precisely controlled.

Step six. Following the scheme, the circulating device is put into the shear box after completing the scheduled cycles and is then installed on the direct shear instrument together with the shear box. Similar to the weighing method, the nut is screwed along the column to close contact with the fixed collar and stopped when the reading of the dial gauge began to change. In light of the requirements of the direct shear test, corresponding loads such as 100 kPa, 200 kPa, 300 kPa, and 400 kPa are applied on the crossbeam of the cover plate as soon as the lever is removed. The nuts, fixed collar, and hoop are moved away, and the lower shear box is secured by screws to fix the circulating device at the base of the shearing box. Finally, the upper shear box is installed. So far, direct shear specimen installation is completed.

Step seven. The initial reading of the dial gauge of direct shear instrument is adjusted and recorded before completing the direct shear test guided by relevant standards.

ERROR CALIBRATION

(1) Error calibration of water adhered on the circulating device

In this research, the mass of water adhered to the inner surface of the circulating device is calibrated so as to deduct it when calculating water content during the wetting-drying cycle. Therefore, accurate calculation of water content is achieved. After the results of five experiments are, respectively, analyzed, the mass of water adhered is determined as 1.49g and the test error is about 0.52g, for which the influence on water content is about 0.5% (Tab. 1).

Table 1. Calibration of water adhered on the inner surface.

Number	Total mass adhered/g	Adhered by sample/g	Adhered by device/g	Mean mass of that adhered by device/g	Max error/g
1	3.73	1.98	1.75		
2	5.66	4.31	1.35		
3	4.84	3.29	1.52	1.49	0.52
4	3.68	2.45	1.23		
5	5.65	4.04	1.61		

(2) Error calibration of water content

The drying method, a method where water is evaporated by high temperature, is ordinarily used in the laboratory. In our work, however, water content is calculated by weighing method for the care of reuse of sample. Therefore, getting knowledge of the calculating error between weighing method and drying method is necessary to precisely control the range of water content during the wetting-drying cycle. The contrast curve of two methods of calculating water content during the wetting process is shown in Figure 4 while Figure 5 shows that during the drying process.

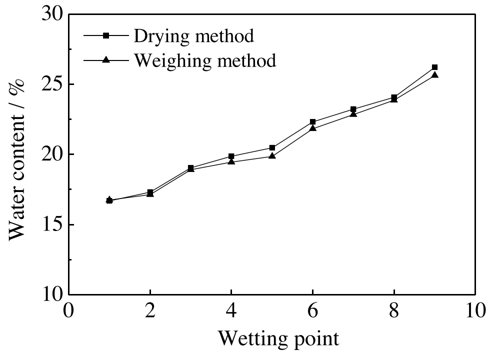


Fig. 4. Comparison of two methods in calculating water content during the wetting process.

Compacted tests are carried out on the calculating error of two methods during the drying process. Figure 4 shows the variation in drying method (actual values) and weighing method (calculated values) for water content. Observed from Figure 4, the calculating error of the two methods is within 1 % during the process of wetting. In most cases, the water content calculated by weighing method is slightly lower than that of the drying method, which may be contributed to the different mass of water adhered to the inner surface of the circulating device after different time. In addition, there are some errors in deducting the water differently absorbed by filter papers at each time when calculating the water content of samples.

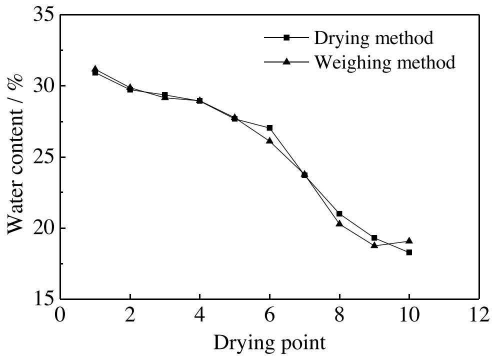


Fig. 5. Comparison of two methods in calculating water content during drying process.

In the drying process, the calculating error of the two methods also shows similar variation as that of the wetting process. Figure 5 shows that most points calculated by weighing method are slightly higher than those of the drying method except few abnormal data caused by experimental error. A good consistency between the two types of water content is achieved, and the error of them is within 1 %, making it possible to accurately control the range of wetting-drying cycle. The higher phenomenon of values calculated by weighing method might be mainly because the water adhered to the inner surface is classified into that absorbed by the sample.

In conclusion, a good consistency between the two methods is observed, and the error is negligible, which powerfully proofed that the calculation of water content by weighing method is feasible and has high precision.

DESIGN OF TEST

(1) Test materials

Expansive soil of a low free swell index (FSI) is chosen for this study (technical code for building in expansive soil regions, 2012). It is collected from a depth between 2.0 m and 4.0 m under the subsurface of Nanning city, China. The properties of the expansive soil obtained are given in Table 2.

Table 2. Selected geotechnical properties of the soil obtained by testing.

Liquid limit/%	Plastic limit/%	Plastic index/%	Free expansion rate/%	Specific gravity of soil particles	Expansion pressure/kPa	Gradation/%	
						< 0.005mm	< 0.002mm
45.30	22.10	23.20	57.00	2.72	169.00	47.20	31.70

(2) Specimen preparation

Wetting-drying cycle and direct shear test are performed on disturbed expansive clay specimens under both loaded condition and unloaded condition to study the effect of wetting-drying cycle on cohesion and the friction angle. Learned from the undisturbed soil test at sampling site, the dry densities are all around 1.7 g/cm^3 fluctuated gently (Liu, 2013; Wang, 2014), and the maximum dry density given by the compaction test is 1.78 g/cm^3; therefore, the dry density of the circulating specimen is identified as 1.8 g/cm^3. Vertical loads, usually between 0 and 75 kPa, can efficiently inhibit the attenuation of shear strength of expansive soil (Yang et al., 2014). The destruction depth of expansive soil is less than 2.0m where the vertical stress is generally not greater than 40 kPa (Li et al., 2010; Yang et al., 2007). Accordingly, the vertical loads in the process of wetting-drying cycle are divided into four levels: 0 kPa, 5 kPa, 15 kPa, and 30 kPa. The range of water content of expansive soil is ordinary less than 5% at the depth of 2.0 m. Consequently, the range of wetting-drying cycle in this research is determined as ± 5 %(Yang and Zhang, 2008). Six specimens are divided into one group prepared for wetting-drying cycle, among which four specimens are taken out for the direct shear test.

(3) Testing procedure

With the help of special shear box, the saturated specimen experienced scheduled cycles are conducted by employing the quick shear method. In this way (Test Methods of Soils for Highway Engineering, 2007), the direct shear test is performed with a velocity of 0.8 mm/min, and the vertical loads are 100 kPa,200 kPa,300 kPa, and 400 kPa. Testing data are collected as a curve whose peak is determined as the shear strength under this level of load.

DISCUSSION OF TESTING RESULT

Effect of cycles and loads on cohesion

To better compare the effect of cycles under different vertical load on the shear strength (cohesion and friction angle), the testing data of four kinds of different loads are arranged together. As shown in Figure 6, the number of wetting-drying cycle is the horizontal coordinate-axis and the cohesion under different vertical loads is the vertical coordinate-axis. Compared with the unloaded condition, the cohesion is greatly improved with a small vertical load applied, but the continued increase of the vertical load (from 5 kPa to 30 kPa) made no sense in increasing the cohesion linearly. Accordingly, a slight increase of lateral and vertical load improves the strength and stability in practice engineering, which observably improves the soil cohesion. Besides, excessive lateral or vertical load is economically unreasonable.

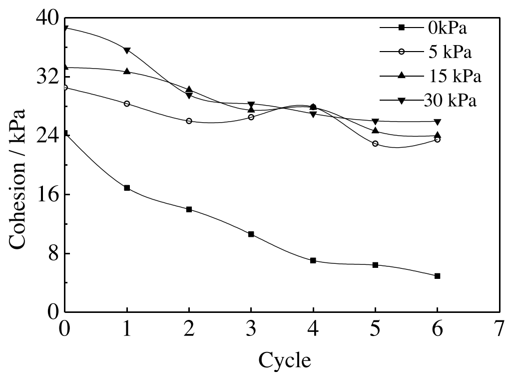
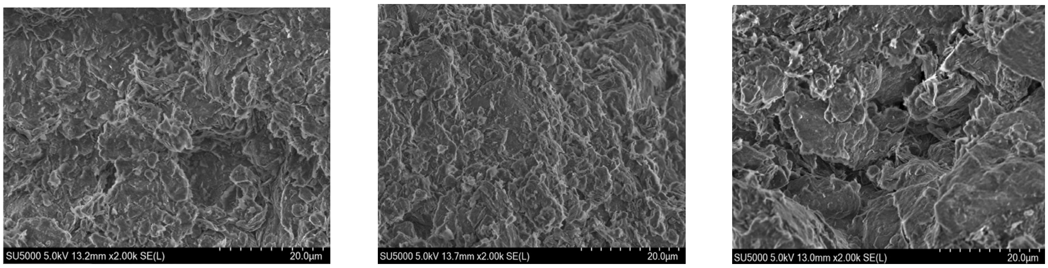


Fig. 6. Relationships between cohesion and cycle number under different vertical load.

Cohesion under different vertical load conditions shows a downward trend and a different rate of decline with the increase of wetting-drying cycle, indicating the presence of load and cycle (Skempton, 1964; Griffiths and Lane, 1999). Moreover, the rate of decline for cohesion was also found to be in accordance with the above factors, which showed diverse characteristics in different stages of the curves even under the same vertical load. This can be attributed to the effect of porosity and to the cracks generated by shrinkage. Widely agreed in the field of engineering, the shear strength of soil is inversely related to the development of cracks (Li, 2004; Yin and Xu, 2011; Liu et al., 2016; Wu and Yang, 2017). The fractured soil of the cracks has no strength at all, and the presence of cracks certainly leads to a decrease of shear strength when in terms of the whole sample (Li et al., 2015; Wan et al., 2015a). Without vertical load, the volume of expansive soil will drastically shrink during the process of losing water. Let us say that its contraction trend provides a shrink stress named σ_s; the tensile strength of soil is σ_d, and the lateral pressure caused by soil self-gravity is σ_z. If σ_s is less than $(\sigma_d+\sigma_z)$, no crack in the soil is observed, and if σ_s is greater than $(\sigma_d+\sigma_z)$, the soil began to crack soil. After a number of wetting-drying cycles, the shrinkage of the specimen is free to occur, and the stress concentration in the broken bodies is not big enough to produce cracks anymore; therefore, the decrease of shear strength tends to be stable. When there is a vertical load, the lateral self-gravity stress σ_z is increased, which also causes a friction force from circulating device σ_n. Only when σ_s is greater than ($\sigma_d+\sigma_z+\sigma_n$), cracks will appear. Obviously, the existence of vertical load effectively inhibits the occurrence and development of crack, which improves the shear strength of soil (Vanapalli, 2016; John and Hendra, 2017).

The SEM (Scanning Electron Microscope) is ordinarily used to reflect the impact of the load on the development of crack (Fig. 7) (Wen et al., 2014). Under the unloaded condition, cracks can be seen clearly after cycle 4; however, clear cracks are found after the 10^{th} cycle under the vertical load of 15 kPa.



(a) cycle 1 (b) cycle 2 (c) cycle 10

Fig. 7. SEM test experienced various cycle under 15 kPa.

Effect of cycle and load on friction angle

The relationship between the friction angle and cycle under different loads is characterized in Figure 8. The data suggest that the friction angle decreases about 200 % after undergoing the first cycle, but floats slightly within 4° with an increasing cycle number. Based on the present researches, the friction angle of clay is divided into basic friction angle Φ_0 and $\Delta\Phi$. The Φ_0 value, which is statistically good in relation to the plastic index, relies upon the mineral composition of soil. The $\Delta\Phi$, the difference value between the actual friction angle and the basic friction angle, is closely correlated with soil density, water content, sample history, and other factors. The arrangement and composition of soil particles are changed during the process of wetting-drying cycle, and the Φ_0 is little changed while the $\Delta\Phi$ fluctuates within a certain range. Thus, the friction angle shows a trend of fluctuation with an increasing cycle number.

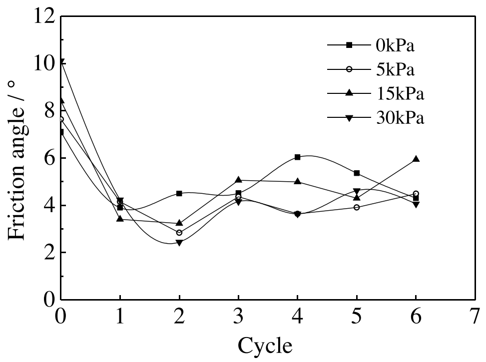


Fig. 8. Relationships between friction angle and cycle under different vertical load.

Discussion of electric double layer

The change of the electric double layer is reported previously to be an effective inducer of the decrease of strength with an increasing cycle number. After experiencing different number of cycles, the composition and arrangement of specimen particles are varied, causing significant differences in pore composition and matrix suction. During the wetting process, the matrix suction has an important influence on the formation and shape of the soil surface, which further affects the thickness of the electric double layer (Sun and Huang, 2015). The electric double layer of flat particles is thinner, so the adsorption force of the soil particle and the electrostatic suction between the soil particles become larger. Experienced repeated wetting-drying cycle, the specimen gradually breaks into thin pieces, and the electric double layer is relatively thick, which finally leads to the reduction of adsorption force of soil particle to the water and the electrostatic suction between the soil particles.

Discussion of density

Because of the repeated expansion and shrinkage during the process of wetting-drying cycle, the absorption of water surely results in a space increase among the soil particles, which decreases the friction between particles under the condition of unconstrained specimen volume (Sopheap et al., 2017; Wan et al., 2015b; Elbadry, 2016). As shown in Figure 9, swelling rate (relative rate of expansion) is about 10% under unloaded condition while it is about 6 % under a vertical load of 5 kPa, indicating a constraint on the full play of swelling potential. Quite evidently, as the vertical load increased, the relative rate of expansion continues to decrease, although it fluctuates slightly after different number of cycles. Generally, the expansive soil has some irreversible volume deformation and local flocculation among soil particles during the process of drying. Moreover, the existence of load accelerates the process of local flocculation, which increases the particle size. That is the reason why the shear strength under load is also improved.

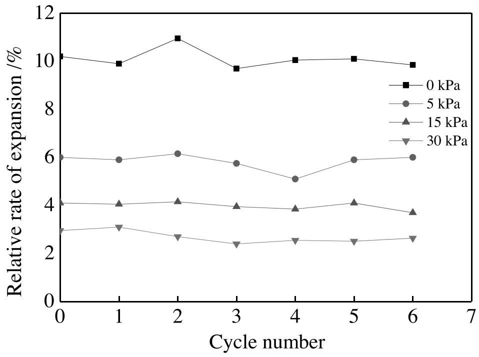


Fig. 9. Relationships between expansion and cycle number under different load.

CONCLUSIONS

In this paper, an instrument, which is used to simulate wetting-drying cycle, direct shear test of expansive soil under actual load, is developed. The instrument simulates the lateral load and vertical load of a certain depth in practice engineering, and it always keeps the specimen under load during the whole cycle. Therefore, the instrument simulates a reasonable condition that is more consistent with the practice engineering. Light, as the circulating device, can be placed on a high-precision electronic balance to calculate the water content changed during wetting-drying cycle. Verified by test, the calculating error of water content is within 1% in both the wetting and drying process, which powerfully proofs the advantage on controlling the range of cycle. With vertical loads such as 0 kPa, 5 kPa, 15 kPa, and 30 kPa, the cohesion decreases with the increase of cycle number, though the range of attenuation is different among various loads. Compared with the specimen that experienced no cycles, the friction angle undergone cycles is greatly reduced. Nevertheless, friction angles of the specimens that experienced 1~6 times wetting-drying cycle are relatively stable.

Stress concentration and cracks in the specimen are found to be the main inducer of strength attenuation during wetting-drying cycle, and the crack develops with the increase of the cycle number. In addition, the decrease of sliding resistance of particles is blamed on that the specimen gradually breaks into thin pieces and the electric double layer is relatively thick after cycles. The existence of load effectively restricts the shrinkage crack and the attenuation of shear strength, which particularly plays an important role in suppressing the attenuation of cohesion. Moreover, the attenuation of density is restricted by load, which partly restricts the decrease of shear strength. Some useful improvements are made to test the instrument in this paper, but there remains much room for improvement regarding its automation as well as the reduction of the human factor.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support provided by the National Natural Science Foundation of China and Guangxi Key Laboratory of Geomechanics and Geotechnical Engineering.

REFERENCES

R. H. Chen. 1974. Foundation on expansive soil, Elsevier Scientific Publishing Co, Netherlands.

S. W. Liao. 1984. Expansive soil and railway engineering, China railway Press, Beijing.

N. V. Nayak & J. C. Christensen. 1974. Swelling characteristics of compacted expansive soil. Clay Miner. 19(4): 251-261.

A. Gens & E.E. Alonso. 1992. A framework for the behavior of unsaturated expansive clay Can. Geotechnical Journal, 29(6): 1013-1032.

N. Kleinfelter, M. Park & J. H. Cushman. 2006. Mixture theory and unsaturated flow in swelling soils. Transp.Porous Media. 68(1): 69-89.

M. A. Murad, L. S. Bennethum & J. H. Cushman. 1995. A multi-scale theory of swelling porous- media: I. Application to one-dimensional consolidation Transp. Porous Media. 19(2): 93-122.

C. Z. Liu. 2000. Geological disaster survey guide, Geology Press, Beijing.

Q. Yang, J. He & M. T. Luan. 2003. Comparative study on the shear strength of unsaturated red clay and expansive soil. Rock and Soil Mechanics. 24(1): 13-16.

C. Q. Shun & S. K. Vanapalli. 2016. Influence of swelling behavior on the stability of an infinite unsaturated expansive soil slope. Computers and Geotechnics. (76): 154-169.

F. H. Chen. 1988. Foundation on expansive soil. Elsevier Scientific Publishing Co, Amsterdam.

A. J. Pupple, K. Punthutaecha & S. K. Vananpalli. 2006. Soil water characteristics curves of stabilized expansive soil. Geotech. Eng.Geo-environ.Eng.,Am.Soc.Civil Eng. 132(6): 736-751.

C. S. Gourley, D. Newill & H. D. Shreiner. 1993. Expansive soil: TRL's research strategy. In: Proceedings of 1st International Symposium on Engineering Characteristics of Arid Soils.

T. H. Liu. 1997. The problem of expansive soil in engineering construction. China Architecture & Building Press, Beijing.

G. Q. Zhang, B. Song & S. D. Zhou. 2014. Landslide genesis of expansive soil slope and slope stability analysis method. Yangtze River. 45(6): 20-24.

X. W. Li, L. W. Kong, J. B. Chen & A. G. Guo. 2010. Field test on atmosphere influence depth on newly excavated expansive soil slope. Journal of Liaoning Technical University (Natural Science). 29(1): 99-102.

Y. H. Yang, W. Guo, M. Zhao & F. Li. 2007. The atmosphere influence depth of the expansive soil of Nanyang basin and its engineering significance. Yangtze River. 38(9): 11-13.

Y. Zhang, L. J. Wang, S. H. Liu & Y. W. Lin. 2015. Model test on the performance of the expansive soil slope during wetting-drying cycles.Journal of Zhengzhou University (Engineering Science). 36(6): 114-118.

Z. T. Zeng. 2007. Research on the wetting-drying effect and micro-mechanism of expansive soil. Guangxi University, Nanning.

Z. Z. Yin, J. P. Yuan & J. Wei. 2014. Influence of fissures on slope stability of expansive soil. Chinese Journal of Geotechnical Engineering. 34(12): 2155-2161.

X. Y. Wang, Z. H. Yao, F. N. Dang & Z. J. Dong. 2016. Meso-structure evolution of cracked expansive soil. Transaction of the Chinese Society of Agricultural Engineering. 32(3): 92-100.

H. B. Lv, Z. T. Zeng & Y. L. Zhao. 2012. Preliminary study on the cumulative damage of expansive soil in alternation of wetting-drying environment. Journal of Natural Disaster. .21(6): 119-123.

L. Y. Pierrot & G. Herve. 2016. Effect of biomass management regimes and wetting-drying cycles on soil carbon mineralization in a Sudano-Sahelian region. Journal of Arid Environments. (127): 1-6.

Z. Faith, J. L. William & M. Asce. 2016. Alternative methods for wet-dry cycling of geosynt-hetic clay liners. Journal of Geotechnical and Geoenvironmental Engineering.142(11): 1-9.

H. P. Yang, X. Z. Wang & J. Xiao. 2014. Influence of wetting-drying cycles on strength characteristics of Nanning expansive soil. Chinese Journal of Geotechnical Engineering. 36(5): 949-954.

Z. Huang, H. L. Fu, B. X. Wei & J. B. Zhang. 2014. Low stress shear strength characteristics of expansive soil under constant amplitude dry wet cycle conditions. Journal of Sichuan University(Engineering Science Edition). 48(1): 0-77.

GB 50112-2013. 2012. Technical code for building in expansive soil region, China Architecture and Building Press, Beijing.

H. W. Liu. 2013. Numerical analysis on slope excavation and experimental study on reinforced slope protection applied in expansive soil district at Yun Gui railway. Central South University,Changsha.

X. Z. Wang. 2014. The research of shear strength tests of expansive soil with dry-wet cycle simulation and lower stress condition. Changsha University of Technology, Changsha.

P. Yang & G. F. Zhang. 2008. Appropriate wrapping width of expansive soil embankment built by enveloping method. Journal of Highway and Transportation Research and Development. 25(7): 37-42.

JTG E40-2007. 2007. Test Methods of Soils for Highway Engineering.People's Communications Press, Beijing.

A. W. Skempton. 1964. 4th Rankine lecture: Long term stability of clay slope, Geotechnique, 14(2):77-101.

D. V. Griffiths & P. A. Lane. 1999. Slope stability analysis by finite elements. Geotechnique. 49(3): 387-403.

G. X. Li. 2004. Advanced Soil Mechanic. Tsinghua University Press, Beijing.

Z. Z. Yin & B. Xu. 2011. Slope stability of expansive soil under fissure influence. Chinese Journal of Geotechnical Engineering. 33(3): 454-459.

X. R. Liu, D. L. Li, Z. Wang & Y. Zhang. 2016. The effect of dry-wet cycles with acidic wetting fluid on strength deterioration of shaly sandstone.Chinese Journal of Rock Mechanics and Enginee-ring. 35(8): 1543-1554.

J. H. Wu & S. Yang. 2017. Experimental study of matric suction measurement and its impact on shear strength under drying-wetting cycles for expansive soil. Rock and Soil Mechanics. 38(3): 678-684.

W. J. Li, Z. Y. Zhang, C. Wang, W. Y. Zhu & Y. Chen. 2015. Propagation and closure law of desiccation cracks of loamy clay during cyclic drying-wetting process. Transactions of the Chinese Society of Agricultural Engineering.31(8): 126-132.

Y. Wan, Q. Xue, L. Y. Zhao, Y. J. Du & L. Liu. 2015. Effects of wetting-drying cycles on permeability of compacted clay cover at landfill site. Rock and Soil Mechanics. 36(3): 679-693.

S. C. Qi & S. K. Vanapalli. 2016. Influence of swelling behavior on the stability of an infinite unsaturated expansive soil slope. Computers and Geotechnics. (76): 154-169.

T. H. John & S. Hendra. 2017. Shear behavior of calcium carbide eesidue-bagasse ash stabilized expansive soil. Procedia Engineering. (171): 476-483.

H. Wen, Q. Yang, X. W. Tang & W. G. Li. 2014. Mechanical behavior of soil with different initial dry densities under drying-wetting cycle. Journal of Hydraulic Engineering. 45(3): 261-268.

D. A. Sun & D. J. Huang. 2015. Soil-water and deformation characteristics of Nanyang expansive soil after wetting-drying cycles. Rock and Soil Mechanics. 36 (1): 115-119.

P. Sopheap, N. Satoshi & L. Suched. 2017. Deformation characteristics and stress responses of cement-treated expansive clay under confined one-dimensional swelling. Applied Clay Science. (146): 316-324.

Y. Wan, Q. Xue, Y. Wu & L. Y. Zhao. 2015. Mechanical properties and micro-mechanisms of compacted clay during drying-wetting cycles. Rock and Soil Mechanics. 36(10): 2815-2824.

H. Elbadry. 2016. Simplified reliable prediction method for determining the volume change of expansive soil based on simply physical tests. HBRC Journal, http://dx.doi.org/10.1016/j.hbrcj.2015.10.001

Submitted: 08/01/2018
Revised: 14/04/2019
Accepted: 14/04/2019

أداة لدورة الترطيب والتجفيف للتربة التمددية في ظل الأحمال المحاكية والبحث التجريبي

جون غوي دونغ، قوه يوان شو، *هاي بو المستوى و*جون يان يانغ
كلية الهندسة المدنية والنقل، جامعة جنوب الصين للتكنولوجيا، قوانغتشو، الصين
*كلية الهندسة المدنية والهندسة المعمارية، جامعة قويلين للتكنولوجيا، قوانغشي، الصين

الخلاصة

إن التأثير المتعاقب لهطول الأمطار والتبخر في الطبيعة يسبب أضراراً كبيرة على قوة القص في التربة التمددية. ولدراسة تأثير دورة الترطيب والتجفيف التي تواجه الأحمال على مقاومة التربة التمددية، تم تطوير أداة في هذا البحث، وتم كذلك التحقق من خطأ الاختبار. وبمساعدة هذه الأداة، تم تجربة عينات من 0~6 دورات في ظل 0 كيلو باسكال و 5 كيلو باسكال و 15 كيلو باسكال و 30 كيلو باسكال، وتم إجراء اختبار القص المباشر لتلك العينات. وأظهرت النتائج أن الأداة تتحكم بدقة في محتوى الماء (في حدود 1%)، مما يحاكي الدورة الفعلية للتربة بأعماق مختلفة. تبين دورة الترطيب والتجفيف تأثيراً كبيراً على التماسك على الرغم من أن زاوية الاحتكاك ليست حساسة للدورات. وتقترح دراسة معلمية إضافية أن انخفاض قوة القص يمكن أن يُعزى إلى الشقوق الناجمة عن دورات الترطيب والتجفيف. وجود الحمل يقيد بشكل فعال صدع الانكماش وإضعاف مقاومة القص، ولا سيما يمنع بشكل كبير إضعاف التماسك. اقتصاراً على الحمل، فإن كثافة العينة تؤدي أيضاً إلى التقليل من توهين مقاومة القص إلى حد ما.