Experimental Study on the Relationship between Three-dimensional Stress Attenuation Value and Strain of Remolded Expansive Soil

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Abstract. This paper studies the characteristic of remolded expansive clay in Hefei. A series of three-dimensional swelling tests were conducted for cubic expansive soil of different initial moisture contents and dry density as well as the swelling pressure tests under the control of the vertical strain and the lateral strain. The research results show that: (1) Under the same initial water content, the vertical displacement of the soil sample is released. At this time, the attenuation value of both the horizontal and vertical expansion force of the soil sample increases with the increase of the initial dry density. (2) The horizontal displacement of the soil sample is released. At this time, the attenuation value of the horizontal expansion force of the soil sample increases with the increase of the initial dry density. Moreover, the horizontal displacement of the soil sample is released in the case of the same initial dry density. And the attenuation value of the horizontal expansion force of the soil sample decreases with the increase of the initial water content.

Keywords: Remolded expansive soil, three-dimensional stress attenuation value, vertical expansion force, horizontal expansion force.

1. Introduction
Expansive soils in our country are widely distributed, and its water absorption and loss will cause expansion and contraction deformation. Under the action of atmospheric forces, repeated rainfall infiltration and dry-wet cycles will cause cracks in the soil and reduce the strength of the expansive soil, which are the important factors that cause instability of shallow slopes of expansive soils.

At present, scholars have done a lot of research on expansibility of expansive soils. However, these research are often limited to one-dimensional state and only focus on the vertical expansive force of expansive soil [1-8]. Actually when expansive soil swells in water, it will inevitably produce expansion force if this expansion deformation is restricted and its stress state is three-dimensional. When the slope soil body expands in the project, its upper part will deform, causing the release of...
vertical expansion force. Similarly, the vertical expansion force will also produce horizontal expansion force, causing the damage of retaining walls, pile foundations, underground pipelines, and culverts [9-11].

Based on this, in this paper, a strain-controlled swelling force test was conducted to explore the relationship between the attenuation value of swelling force and deformation of expansive soil. In addition, 6 samples of Hefei expansive soil are configured in this test according to different initial water content and dry density, and the improved "three-way expansion and shrinkage instrument" [12-13] is used.

2. Test Equipment and Test Plan

2.1. Three-way Expansion and Contraction Instrument

The test was carried out by using the three-way expansion and contraction instrument. This instrument is improved on the basis of the three-way expansion and contraction instrument of the Northwest Research Institute of the Ministry of Railways and the School of Logistics Engineering. It can simultaneously measure and control the expansion force under the three-way arbitrary strain.

![Figure 1. The test apparatus](image)

2.2. Physical and Mechanical Properties of Soil Samples and Sample Preparation Plan

The physical and mechanical properties of soil samples are shown in Table 1.

| Liquid limit \( W_L/\% \) | Plastic limit \( W_P/\% \) | Plasticity index \( I_p/\% \) | free swelling ratio \( f/\% \) | particle density \( G_s \) |
|---|---|---|---|---|
| 72 | 30 | 42 | 44 | 2.68 |

2.3. Test Plan

Two sets of three-way expansion force tests under the control of deformation were carried out. The test plan is shown in Table 2.

| Test type | Sample Number | Moisture content/\% | Dry density /g·cm\(^{-3}\) |
|---|---|---|---|
| Three-dimensional expansion force test under controlled deformation | 1-1 | 9.84 | 1.6 |
|  | 1-2 | 1.65 |
|  | 1-3 | 1.7 |
|  | 1-4 | 1.6 |
|  | 1-5 | 1.65 |
|  | 1-6 | 1.7 |
When doing a three-way expansion force test with the deformation control, a three-way expansion force test should be done in advance. After the swelling force of the sample is stabilized, the longitudinal restraint is continuously released to obtain the relationship between the three-directional swelling force and the longitudinal strain; after the longitudinal swelling force is 0, the horizontal restraint is continuously released to obtain the relationship between the horizontal swelling force and the horizontal strain.

3. Research on Attenuation Characteristics of Three-Dimensional Expansion Force Controlling Vertical Deformation

In engineering, when expansive soil slopes swell under the action of rain, the upper part will deform to a certain extent. Therefore, it is particularly important to understand the attenuation law of the three-dimensional swelling force of the soil when considering the deformation. Taking the characteristic vertical strain rate (0.125% and 0.375%, respectively) and the corresponding swelling force attenuation value, draw the relationship between the swelling force attenuation value of the test soil sample and the initial dry density under different initial water contents as follows:

![Graphs showing attenuation values for vertical and horizontal expansion forces](image)

(a) $\omega = 9.84\%$ (A is the attenuation value of vertical expansion force)

(b) $\omega = 12.60\%$ (B is the attenuation value of horizontal expansion force).

**Figure 2.** The relationship curve of vertical swelling force attenuation-dry density at different initial water content

It can be seen from the above figure that under the same initial water content, the vertical displacement of the soil sample is released. At this time, the attenuation value of both the horizontal and vertical expansion force of the soil sample increases with the increase of the initial dry density. Big.

Take the characteristic vertical strain rate (0.125%, 0.375% and 0.75%, respectively) and the corresponding expansion force attenuation value, and draw the relationship curve between the vertical expansion force attenuation value of the test soil sample and the initial water content under different initial dry densities The picture is as follows:
After taking the average of the attenuation values of the horizontal swelling force in the X and Y directions when the vertical strain rate is 0.125%, 0.375%, and 0.75%, respectively, plot the attenuation value of the horizontal swelling force of the test soil sample and the initial content under different initial dry densities. The relationship curve of water volume is as follows:

**Figure 3.** The relationship curve of vertical swelling force attenuation-water content at different initial dry densities

(a) $\rho_d = 1.60 \text{ g/cm}^3$

(b) $\rho_d = 1.65 \text{ g/cm}^3$

(c) $\rho_d = 1.70 \text{ g/cm}^3$
It can be seen from Figure 3 and Figure 4 that under the same initial dry density, the vertical displacement of the soil sample is released. At this time, both the horizontal and vertical swelling force attenuation value of the soil sample increases with the initial water content. Big and reduce.

4. Research on Attenuation Characteristics of Horizontal Expansion Force Controlling Lateral Deformation

After the soil has completely released the vertical expansion force, exploring the relationship between the lateral strain and the horizontal expansion force has important guiding significance for engineering practice. Take the characteristic horizontal strain rate and the corresponding horizontal swelling force attenuation value (take the data when the horizontal strain rate is 0.25% and 1.0% respectively for statistics) to plot the swelling force attenuation value and initial dry density of the test soil sample under different initial water contents The relationship curve is as follows:

It can be seen from Figure 5 that under the same initial water content, the horizontal displacement of the soil sample is released. At this time, the horizontal expansion force attenuation value of the soil sample increases with the increase of the initial dry density. Take the characteristic horizontal strain rate and the corresponding expansion force attenuation value (take the data when the horizontal strain rate is 0.25%, 0.375% and 1.0% respectively for statistics), and then average the horizontal expansion force attenuation values in the X and Y
directions to draw Under different initial dry densities, the relationship between the attenuation value of the horizontal swelling force of the test soil sample and the initial water content is as follows:

![Graphs showing the relationship between horizontal strain rate and B/Kpa for different initial water contents and dry densities.](image)

**Figure 6.** The relationship curve between the attenuation value of the horizontal expansion force and the water content at different initial dry densities

It can be seen from Figure 6 that under the same initial dry density, the horizontal displacement of the soil sample is released. At this time, the attenuation value of the horizontal expansion force of the soil sample decreases with the increase of the initial water content. In the data when the initial dry density is 1.60 g/cm³ and the horizontal strain rate is 0.375%, the horizontal swelling force attenuation value of the soil sample with a water content of 12.6% is greater than that of the soil sample with a water content of 9.84%. It is guessed here that it may be due to this stage In the test, the expansion force of the soil has become very small due to the release of deformation, which is caused by measurement errors.

5. Conclusion

In this paper, the expansion force test of Hefei expansive soil under different initial water content and dry density is carried out to control the strain process, and the test results are analyzed. The main conclusions obtained are as follows:

1. Under the same initial water content, the vertical displacement of the soil sample is released. At this time, the attenuation value of both the horizontal and vertical expansion force of the soil sample increases with the increase of the initial dry density.

2. The horizontal displacement of the soil sample is released. At this time, the attenuation value of the horizontal expansion force of the soil sample increases with the increase of the initial dry density. Moreover, the horizontal displacement of the soil sample is released in the case of the same initial dry density.
density. And the attenuation value of the horizontal expansion force of the soil sample decreases with the increase of the initial water content.

Acknowledgments
This work was financially supported by national key research and development program (2017YFC1501206), National Natural Science Foundation of China Youth Science Fund Project (52008122).

References
[1] LIAO Lin-chang, ZHONG Xiao-chen, YIN Zong-ze. Test research of unsaturated expansive soil strain laws [J]. Dam Observation and Geotechnical Tests. 1999, 23(3): 36-39.
[2] DAI Zhang-jun. Analysis of deformation and stability of expansive soil slope considering swelling and strength softening [D]. Wuhan: Institute of rock and soil mechanics, Chinese academy of sciences, 5(2014).
[3] LIU Yue-miao, XU Guo-qing, LIU Shu-fen. et al. Study on compatibility and swelling property of buffer/backfill material for HLW repository [J]. Uranium Geology, 2001, 17(1): 44-47.
[4] YE Wei-min, SCHANZ T, QIAN Li-xin. et al. Characteristics of swelling pressure of densely compacted gaomiaozi bentonite GMZ01[J]. Chinese Journal of Rock Mechanics and Engineering, 2007, 26(S2): 3861-3865.
[5] KOMINE H, OGATA N. Experimental study on swelling characteristics of compacted bentonite[J]. Canadian Geotechnical Journal, 1994, 31(4): 478-490.
[6] BU Yong-fu, WU Zheng-gen, LIU Chuan-xin. Relativity between compaction conditions and swelling deformation of expansive soil[J]. Journal of Hohai University, 1997, 25(3): 57-60.
[7] TAN Luo-rong, KONG Ling-wei. Study on variation regularity of swelling behavior of expansive soil[J]. Rock and Soil Mechanics, 2004, 25(10): 1555-1559.
[8] LIU Quan-sheng, WANG Zhi-jiang. Influence factors of sand-bentonite mixtures on the swelling pressure [J]. Chinese Journal of Rock Mechanics and Engineering, 2002, 21(7): 1054-1058.
[9] ZOU Yue-qiang, LI Yong-kang, ZHU Meng-xin. Expansive soil lateral pressure research[J]. Journal of Hefei University of Technology(Natural Science Edition), 1993, 16(3): 109-114.
[10] YIN Zong-ze. The lateral expansion of soil and its influence on the deformation and stress of the earth-rockfill dam[J]. Journal of Hydraulic Engineering, 2000,(7): 49-55.
[11] ZHU Zhi-ze, LIU Song-yu. Active earth pressure analysis of unsaturated expansive soil [J]. Highway Traffic Science and Technology, 2001, 18 (5): 8-10.
[12] CHI Ze-cheng, CHEN Shan-xiong. Research on strain regularity of three-dimensional stress of Hefei remolded expansive clay[J]. Chinese Journal of Rock Mechanics and Engineering, 2018, 37 (S1): 3659-3665.
[13] CHI Ze-cheng, CHEN Shan-xiong. An experimental study of three-dimensional swelling pressure of Hefei remolded expansive clay[J]. Rock and Soil Mechanics, 2017, 38 (S1): 381-386.