The Indoor Model Test on the Characteristic of Expansive Soil Slope under Climatic Conditions

ZHAI Ju-yun, MA Ming-jiang, HAO Xiao, ZHAO Jin, ZHAO Yu, YANG Qi-q
1 Henan University of Urban Construction, Pingdingshan, Henan, P.R. China
2 Henan urban comprehensive design and research institute, Pingdingshan 467000, Henan, China
*Corresponding author’s e-mail: 331626242@qq.com; zhaijuyun@hncj.edu.cn

Abstract An indoor model of expansive soil filling slope is tested in Pingdingshan city, Henan province, China. Using temperature and humidity detectors, earth pressure cells and so on, the static evaporation - rainfall infiltration cycles are tracked and monitored in the climate condition. The study suggests that atmospheric temperature is the direct cause of soil temperature. Due to the convection heat transfers, the surface temperature of the soil changes rapidly, and the temperature change of the heat transfer to the interior has a hysteresis phenomenon. Under surface evaporation conditions, the greater the depth is, the smaller the change range is in water content. Water loss rate is related to soil, air flow, temperature and humidity, cracks, soil water holding capacity, permeability and other factors. The change of stress in the expansive soil slope is the result of the joint action of soil water content, nature and climatic conditions. Due to the early erosion of rainfall, soil pressure is obviously attenuated. The soil pressure is on the rise due to the effects of rainfall infiltration and expansion force in the late rainfall. In the engineering, the key to prevent and cure engineering disaster of expansive soil is to improve the deformation characteristics and reasonable drainage of expansive soil.

1. Introduction
The water flow between atmosphere and soil is an important part of water vapor cycle. Moisture in the atmosphere enters the soil because of penetration, and liquid water changes into the gaseous water into the atmosphere because of evaporating. The expansive soil is a special soil for water sensitivity. The expansive soil expands when encountering water and contracts when losing water. The long-term climate change will cause the complex crack cuts and cracks in the expansive soil building foundation and the slope engineering and strength decreases. It often causes the slope collapse, pavement slurry and other engineering disasters. Therefore it is very important to study the water variation law of foundation under natural conditions. In order to obtain the characteristics of expansive soil slope, the model experiment of expansive soil slope was carried out under evaporation-rainfall condition in this study.

The foundation characteristics caused by climate change have been studied for a long time[1~7]. The law of water movement in unsaturated soil under evaporation conditions was studied[8]; The law of soil moisture change was studied according to simulated climate change[9]; The law of moisture distribution in expansive soil with geomembrane in rainfall evaporation process has been studied[10]. The effect of straw content on soil cracking was studied[11]. The characteristics of soil moisture and
heat change under radix puerariae mulch were studied \cite{12}. The model test of expansive soil filling slope in ankang city, Shanxi Province was carried out\cite{13}. The above research has obtained the change laws of temperature, moisture and pressure characteristic of slope soil under different climatic and environment conditions. However, there are few studies and reports on the characteristic distributions of the expansive soil slope in Pingdingshan under the condition of atmospheric influence and evaporation.

In this study, an indoor model test is conducted in Pingdingshan city for the expansive soil fill slope. According to the actual climate change, rainfall - stationary wet cycle is simulated, and the evolution rule of expansive soil slope is tracked and monitored. It deepens the understanding of the catastrophic process of the expansive soil slope.

2. Test site climate
The test is located in Pingdingshan city, which is subtropical monsoon climate. The average annual temperature is 14.80-15.40°C. The highest temperature appeared in July, with an average of 27.00°C. The lowest temperature appeared in January, with an average of 1.00°C. The average precipitation in Pingdingshan city is 726.1 mm, and the temperature and rainfall in each month are shown in table 1. According to the literature\cite{14}, the mean temperature and the average temperature of different depths in the experimental stage are shown in fig. 1.

| Month | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   |
|-------|------|------|------|------|------|------|------|------|------|------|------|------|
| ATM   | 3.0  | 4.0  | 5.0  | 6.0  | 7.0  | 8.0  | 9.0  | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 |
| RAIN  | 10.0 | 20.0 | 30.0 | 40.0 | 50.0 | 60.0 | 70.0 | 80.0 | 90.0 | 100.0| 110.0| 120.0|

3. The model test
3.1. Introduction of test expansive soil.
The test soil sample is taken from the intersection of the Jianshe road and the Dongfeng road in Pingdingshan. The fluorescence analysis of the soil is carried out. The chemical components and contents are shown in Table 2.

Through the geotechnical test, the plastic limit of the expanded soil is 22.85%, the 17mm liquid limit is 45.72%, 10mm liquid is 38.20%, and the free expansion rate is 55%.

Fig. 1 The average temperature of different buried soil varies with time

| Table 2 Chemical compositions and contents of expansive soil derived from Pingdingshan |
|---------------------------------|------|------|------|------|------|------|------|
| Chemical composition           | SiO₂ | Fe₂O₃ | CaO  | CuO  | Al₂O₃ | K₂O  | others |
| Content(%)                     | 53.260| 20.370| 11.020| 1.275| 3.460 | 0.840| 9.775 |
The test site is in the structure laboratory hall of Henan urban construction college. The expansion soil is layered and compacted. The average dry density of soil mass is 1.60g/cm³ and the average mass water content is 25.0%.

3.2. field expansion soil slope test
The width and height ratio of the expansive soil model slope is 1:1. The size of the model and the embedded location of the test elements are shown in fig. 2 and Fig. 3, with a total of 10 test points. The sensor location number is 1, 2, 3 and 4 from the top down. The temperature and humidity sensors and earth pressure cells are buried in each monitoring location. The bottom of the expansive soil slope is reinforced concrete floor, with the model back against the wall, and steel plate on both sides. The plastic film on the back and sides is separated from the surrounding area, so that the vertical friction between the soil and the surrounding area can be reduced, and the water loss can be reduced.

Temperature and moisture test use NHSF48 soil moisture (temperature) sensor. The output part adopts voltage output. The soil pressure is measured by the micro-earth pressure box, and the data acquisition adopts strain output.

![Fig. 2 The elevation of the probe buried position ( mm )](image1)

![Fig. 3 The floor plan of the probe buried position ( mm )](image2)

According to the actual weather conditions, the test process adopted static - rainfall (Spray water with sprinkler head) - static - rainfall- static three dry and wet circulations. The experiment began on November 18, 2016 and lasted 126 days. On the 16th day after the slope was made, the first rain fell on December 5, the water stopped raining when the water began to overflow. After the first rainfall, the static time went through 82 days. On February 27, 2017, the second simulated rainfall, after an hour of rain, The rain stopped when the water began to overflow, and then it evaporates for 28 days. The test method is shown in table 3.

During the test, the temperature, water content and stress of the expansive soil slope were tested. The distribution of the data in different positions and the changes with time were analyzed. At the same time, the fracture of slope soil is observed and described.

| Test phase       | Test schedule                      | rainfall /mm | Rainfall duration /h |
|------------------|------------------------------------|--------------|----------------------|
| static period    | The static time after completion was 16d | /            | /                    |
| Rainfall period  | The static time after the first rainfall was 82d | 45.0         | 1.5h in the morning, 1h in the afternoon |
|                  | The static time after the second rainfall was 28d | 28.2         | 1h                   |

4. Analysis of test results.

4.1. temperature distribution
The test sections of temperature test are located in three positions of the top, the middle and the foot of the slope. The temperature data of the temperature sensor are summarized, and the changes of soil temperature at different locations and depths during the monitoring period are obtained. The soil
temperature at the top of the slope is shown in Fig. 4. The change of soil temperature during the first rainfall is shown in Fig. 5.

![Fig. 4 The temperature varies with time in the top of the slope](image)

![Fig. 5 The temperature varies with time before and after the first rainfall on the top of the slope](image)

We can see from Fig.s 6 and 7. Atmospheric convection has a significant influence on soil and surface temperature distribution. The soil temperature changes with the atmospheric temperature. The change of soil temperature in different places is roughly the same. We take the top of the slope position as an example to analyze. The variation range of soil temperature in different depths is different. Shallow soil 1-1 has the largest variation range, and the greater the depth is, the smaller the range is. During the static period, the surface temperature of soil changes rapidly. The soil surface heat transfers to the soil, and the deeper the position is, the later the temperature changes. During the simulated rainfall period, because the water temperature is higher than the soil temperature, and the water permeates through cracks and pores. Shallow soil 1-1 temperature rises rapidly, but the influence time is shorter. After that, the temperature change is caused by the atmosphere environment. Because the water does not permeate into the deep soil, the soil temperature of 1-3, 1-4 is largely unaffected. The changes of soil temperature in the middle and the foot of the slope are shown in Fig. 6 and Fig. 7.

![Fig. 6 The temperature varies with time in the middle of the slope](image)

![Fig. 7 The temperature varies with time in the foot of the slope](image)

4.2. the variation distribution of moisture content.
The test sections are three test sections on the top, the middle and the foot of the slope. Water distribution data are summarized. The initial water content of the soil is the same. The volume water content at all times minus the initial volume water content, and the data relation with the time are shown in Fig. 10, Fig. 11 and Fig. 12. It can be seen that under evaporation conditions, the water loss of topsoil is the fastest, and the residual stable state is reached first. After that, evaporation has little effect. The deep soil which did not reach the residual water content is continuously dehydrated, and the water is constantly moving upward. The loss rate of water is related to soil, air flow, temperature and humidity, water holding capacity, permeability and so on. The variation range of surface soil moisture content is the largest, and with the increase of depth, the variation range of water content decreases. Before the first rainfall, the soil was intact. When the expansive soil loses water and contracts, and the initial cracking degree is slight. The volume of water content is only 5% lower than the initial water content. Because of the rainfall, the soil of the slope has experienced dry and wet
circulation, and the cracking is serious. The residual volume water content was 13% less than the initial water content. The residual volume after the second rainfall is the same as the first.

Fig. 8 The volume water content varies with time in the top of the slope
Fig. 9 The volume water content varies with time in the middle of the slope
Fig. 10 The volume water content varies with time in the foot of the slope

In the process of rainfall, the moisture content of the shallow soil 1-1 has been increased, and the water content losses after rainfall, and the volume water has dropped sharply, forming a sharp angle. The first rainfall lasts longer and the moisture content of the water increases. Because 1-3 is buried deep, the water content does not decrease at the end of the rainfall. The second rainfall duration is shorter, and the water content of 1-3 does not change, and the water is basically stable, indicating that there is no crack in the depth of 1-3. In the 1-4 detection point, the water content change is due to the bottom of the soil slope, which is the concrete bottom plate.

The foot of the slope can be seen by Fig. 10. The water content at the foot of slope elevates because of the seepage flow from high to low. The water flow along the sliding surface is larger, resulting in the largest increase of water content in the middle part 3-2 probe.

4.3 Soil pressure distribution
The pressure data of earth pressure cells is summarized. The relationship between pressure and time is shown in Fig. 9 and Fig. 10.

The earth pressure cells are placed at the top and the middle slope of the slope. The changes of soil pressure in different locations and depths during the monitoring period are shown in Fig. 11 and Fig. 12.

A. The changes of vertical pressure
B. The changes of level pressure

Fig. 11 The pressure changes with time in the top of the slope

The variation of soil pressure at the top of the slope is shown in Fig. 13. In the static period after the slope filling, the soil has the tendency of expanding rebound, because of the compaction of the expansion soil. Although the water evaporates, the vertical and horizontal earth pressures increase overall. In the first rainfall, due to the infiltration of rain water, soil moisture content increases, soil mass swells, cracks closes and soil pressure rises. The abrupt change of soil pressure during rainfall is due to the increase of water pressure in the fissure and the loss of moisture after rainfall. After rainfall, the vertical and horizontal earth pressure of shallow soil have obvious attenuation.
The changes of vertical pressure

A. The changes of vertical pressure

B. The changes of level pressure

Fig. 12 The pressure of each detection point changes with time in the middle of the slope

It is because the surface of the slope is washed by the rain, and the moisture along the fracture surface takes away the fine soil particles, so that the soil losess, the water holding capacity and the swelling reduce. 1-4 earth pressure cell is buried deeper. The soil pressure increases because the rainfall infiltration of the overburden soil is greater than that of the sediment erosion, and the upward expansion of the expansive soil causes the slope and the lateral wall to generate downward friction, which causes the vertical earth pressure to rise. After the rain ends swelling stability. Soil pressure decreases with the evaporation of soil water. The descending value is very small as the water content evaporates slowly.

It can be seen from Fig. 14. The depth of the 2-2 pressure box is 0.9m, In the first rainfall, the vertical pressure increased with the increase of water content, and then decreased due to evaporation of water. After the second simulated rainfall, the development of cracks and the erosion of rain water cause the soil particles to be taken away, the vertical pressure significantly reduced. The 2-3 earth pressure box is buried deeper. After rainfall, the pressure increases with the rain. Soil pressure increases later than 2-2. In 2-1, the horizontal earth pressure strength drops sharply because of the loss of moisture. After the first rainfall, the cracks close, the soil expands, and the horizontal soil pressure gradually increases.

The evaporation rate of soil water in the slope is different, which leads to the cracking of the expansive soil. The width and depth of the crack increases with the time.

5. Conclusion

1) The surface temperature of soil changes rapidly due to convection heat transfer and the soil surface heat transfer to soil. The deeper the position is, the later the temperature changes, and the temperature change lags behind.

2) Under evaporation conditions, the water loss of the surface soil is the fastest, and the deeper the soil is, the slower the water content changes. After the water content is close to the residual water content, evaporation has little effect. The water that has not reached the residual moisture content is still being lost. Water loss rate is related to soil, air flow, temperature and humidity, water holding capacity, permeability and so on.

3) The change of stress in soil slope is the result of the joint action of expansive soil moisture content, soil properties and climatic conditions.

4) In engineering, the key of preventing and controlling expansive soil engineering is to improve the deformation characteristics and reasonable drainage of expansive soil.

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