Research on expansive soil characteristics – taking Ankang Tunnel as an example

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Abstract. This paper takes the Ankang Tunnel as an example to conduct research on the mechanical characteristics of swelling and shrinkage deformation of expansive soil, such as the free swelling ratio, unloaded swelling ratio, axial load swelling ratio, and swelling pressure, hoping to provide guidance for the construction of similar expansive rock and soil tunnels. The research shows that: (1) The free swelling ratio of the expansive soil in the Ankang Tunnel is relatively low, at 49.7 %, with weak-medium expansiveness. (2) The unloaded swelling process of the expansive soil can be divided into the rapid swelling stage in the initial swelling stage, the swelling transition stage and the slow swelling stage in the middle swelling stage, and the swelling stable stage in the later swelling stage. (3) With the increase of the water content, the swelling pressure of the soil gradually decreases.

Keywords: Ankang tunnel, expansive soil, swelling and shrinkage deformation.

1. Introduction

Expansive rock and soil are widely distributed in more than 20 provinces and regions in China, such as Henan, Hebei, Yunnan, and Shaanxi. Expansive soil is a special type of soil that contains a large amount of hydrophilic minerals such as montmorillonite and illite [1]. When encountering water, it will cause the volume of the surrounding rock to expand, and when constrained by the tunnel lining, it will generate swelling pressure, leading to diseases in the tunnel structure.

Many scholars have done a lot of research on the characteristics of expansive soil. Ye et al. [2] found through one-dimensional indoor expansion characteristic tests that the expansion force increased exponentially with the increase of initial dry density, while the expansion force increased first and then decreased with the increase of initial moisture content. Qin et al. [3] used an improved triaxial swelling apparatus to investigate the law of change of expansion force with time. Guo [4] studied the relationship between the ultimate swelling pressure of the medium - expansive soil in Nanyang and the initial water content and dry density. Ding et al. [5] studied the change law of the natural swelling pressure with the degree of humidification and proposed the concept of natural swelling pressure. Zhou et al. [6] used an improved torsional ring shear system to study the correlation between residual strength and composition characteristics of expansive soils with different swelling potential. Duan et al. [7] studied the influence of temperature and moisture fields on the swelling behavior of expansive subgrade and the mechanical and deformation characteristics of the ballastless track foundation. Zhang et al. [8] studied the evolution and physical mechanism of suppressing frost heaving in expansive soils with different water contents and dry densities using soil bags. Fang et al. [9] used an improved unsaturated soil true triaxial apparatus to study the three-dimensional swelling changes of expansive soil. Duan et al. [10] conducted triaxial shear tests to compare the shear behavior and nonlinear characteristics of expansive soil under high cell pressure and low cell pressure. Lin et al. [11] analyzed the law of water content variation with depth in natural environments and established an equation for the relationship between water content and cover load. Feng and Zhan [12] discovered through wet-dry cycling tests that the expansion force during the moisture absorption process exceeds that of the drying process. Wen et al. [13] found the expansive soil that the initial water content and dry density of the soil sample have a significant impact on the swelling pressure of the soil. Li et al. [14], Wang et al. [15] and others found through indoor tests that the unloaded swelling ratio is negatively correlated with the water content of the soil.

This paper will focus on the experimental research on the influence of the two factors of the initial water content and the overlying load on the swelling ratio and the swelling pressure, analyze the evolution law of the experimental values under the influence of different factors, and thus provide a scientific basis for guiding engineering practice.

2. Material and research method

According to the actual situation, the sampling point is selected near the tunnel face of DK171 + 010 - DK171 + 050. According to the design requirements, the sampling point is 1 m in front of the tunnel face and 2 m below the vault on the upper step of the tunnel face.

In order to avoid the soil sample being in contact with the surrounding environment for too long, the sampling barrel is sealed in time after sampling to reduce the risk of deformation and loss of the original state. Seal with wax at the joints of the upper- and lower-barrel lids and the barrel body to ensure that the wax liquid is firmly fixed on the sampling barrel without any gaps after solidification. Finally, use tape to wrap the sampling barrel and mark the soil sample at each sampling point.

2.1. Free swelling ratio test

The free swelling ratio is an important mechanical characteristic index of expansive soil, which is the ratio of the volume increment of the natural expansive soil after drying, grinding, sieving, and immersion and swelling to the original volume, expressed as a percentage. Select an appropriate amount of soil sample, 100 g, crush it and sieve it through a 0.5 mm sieve, dry it to a constant weight at 110 °C, and then take it out and cool it to room temperature in a drying cylinder. Use a soil sampling spoon to take an appropriate amount of sample and pour it into a funnel, stirring with an iron wire while pouring. After the measuring cup is filled with soil sample, weigh the mass of the sample in the measuring cup. Take another measuring cup and repeat the above operation to weigh the mass of the second sample. The difference between the two measurements shall not be greater than 0.1 g, See Fig. 1.

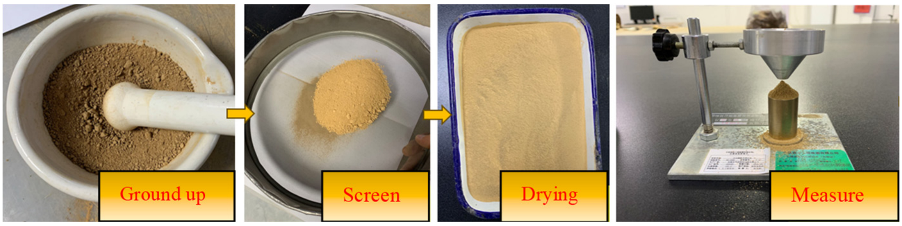

Fig. 1. Free expansion rate test procedure

2.2. Unloaded swelling ratio test

For the unloaded swelling ratio test, first make a sample with a height of 20 mm using a ring knife, and then install the sample into the unloaded swelling test instrument. Place the perforated cover plate on the top surface of the sample, align the center, install a dial gauge, and record the initial reading, as shown in Fig. 2. Then slowly add water for the test. When the deformation of the dial gauge reading is not greater than 0.01 mm within 6 h, the soil sample is considered to have reached stable swelling deformation. Then remove the dial gauge and suck out the excess water in the container. Push out the sample from the ring knife, weigh it, put it into an oven and dry it to a constant weight, take it out and cool it, and then weigh it again.

Fig. 2. Uncharged expansion test

Fig. 3. Charge expansion rate test

Fig. 4. Expansion force test

2.3. Axial load swelling ratio test

For the axial load swelling ratio test, four different water contents (13.4 %, 15.9 %, 18.4 %, 20.9 %) and four different overlying loads (25 kPa, 50 kPa, 75 kPa, 100 kPa) were considered, with a total of 16 test schemes, See Fig. 3. First, put the sample into the container, place a permeable plate and a cover plate, install a scale, first apply a pressure of 1 kPa to make all parts of the instrument in contact, and record the initial reading. Then apply the load in stages. When the difference in the dial gauge reading per hour is less than 0.01 mm, the compression deformation is considered to be stable. Then pour water into the water tank to make the water level about 5 mm higher than the sample. When the difference in the dial gauge reading exceeds two hours is less than 0.01 mm, the swelling deformation is considered to be stable.

2.4. Swelling pressure test

For the swelling pressure test, the loading balance method was used. Four groups of soil samples with water contents of 13.4 %, 15.9 %, 18.4 %, and 20.9 % were prepared, and the compaction degree was controlled at 95 %. Ring knife samples were prepared according to the compaction degree of 95 %, and two ring knife samples were prepared for each water content. By continuously applying load to keep the volume of the water - absorbing and swelling sample unchanged, when the sample no longer swells under a certain load, the load value is considered to be the swelling pressure. When using the loading balance method, the volume of the ring knife sample of the expansive soil is kept unchanged by pouring dry sand into the small bucket. After the test, the mass of the small bucket and the dry sand is weighed, as shown in Fig. 4.

3. Referencing

3.1. Free swelling ratio test

When the height of the soil particles in the test tube remained unchanged for 2 h, it was considered stable. After the swelling was stable, the readings on the top surface of the soil particles were 15.1 mL, 14.8 mL, and 15.0 mL, respectively, as shown in Fig. 5.

The calculated average free swelling ratio of the expansive soil is 49.7 %. According to the expansion potential classification standard of expansive soil in the “Code for Special Geotechnical Investigation of Railway Engineering” (TB10038-2012), combined with various reports and indoor test results, the free swelling ratio of the sampled expansive soil in this test is weak expansive soil.

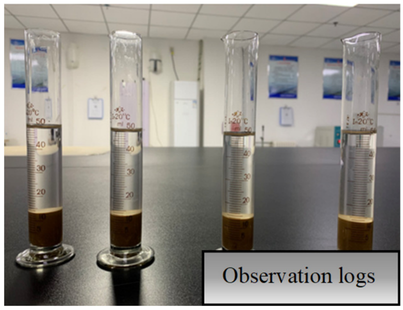

Fig. 5. Free expansion rate test

3.2. Unloaded swelling ratio test

As shown in Fig. 6, the first 60 minutes is the rapid swelling stage, and the deformation amount of the soil sample in the ring knife due to water absorption and swelling accounts for 70 % of the total deformation. From 60 minutes to 480 minutes is the swelling transition stage, and the swelling rate of the ring knife sample gradually decreases. The swelling deformation in this stage accounts for 20 % of the total deformation. From 480 minutes to 2520 minutes is the slow deformation stage, and the swelling rate in this stage further decreases to stability, accounting for about 10 % of the total deformation. After that, it is the swelling stable stage.

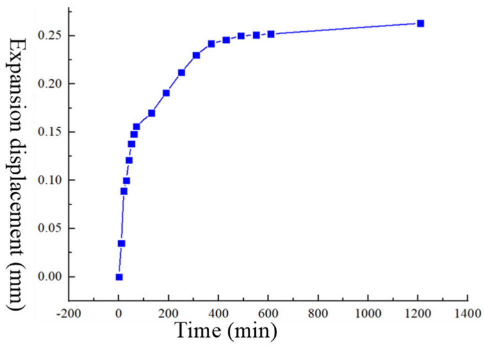

Fig. 6. Curve of uncharged expansion rate with time

3.3. Axial load swelling ratio test

The relationship curve between the swelling ratio of the Ankang expansive soil ring knife sample and the overlying load under different initial water contents is shown in Fig. 7. With the increase of the initial water content, the swelling ratio of the soil gradually decreases. With the increase of the overlying load, the swelling ratio of the ring knife sample of the expansive soil gradually decreases, and the amount of decrease in the swelling ratio also gradually becomes smaller. Taking the ring knife sample with an initial water content of 13.4 % as an example, when the overlying load is 25 kPa, the swelling ratio can reach 10.01 %; when the overlying load continues to increase to 50 kPa and 75 kPa, the loaded swelling ratios are 7.1 % and 5.5 %, respectively; when the overlying load increases to 100 kPa, the swelling ratio decreases to 4.8 %.

3.4. Swelling pressure test

Unlike ordinary clay, the expansive soil will exert swelling pressure on the supporting structure when it absorbs water and swells, resulting in additional deformation of the supporting structure. As shown in Fig. 8, when the compaction degree is 95 %, the swelling pressures of the soil samples with water contents of 13.4 %, 15.9 %, 18.4 %, and 20.9 % are 147.7 kPa, 134.6 kPa, 87.3 kPa, and 59.4 kPa, respectively. Combined with the test results of the swelling ratio, it is not difficult to find that there is a certain correlation between the swelling ratio and the swelling pressure of the expansive soil; that is, for the soil sample with a low water content, its swelling ratio is large, and its swelling pressure is also large.

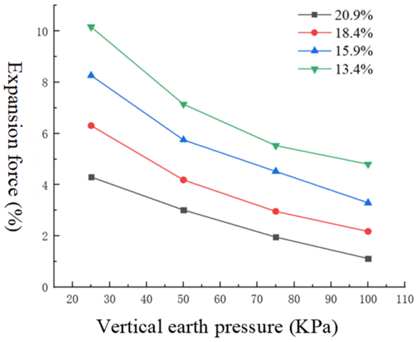

Fig. 7. Relationship between load expansion rate and vertical pressure of soil

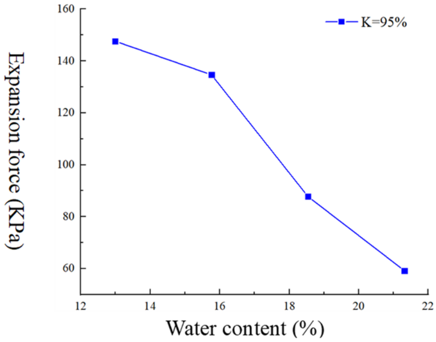

Fig. 8. The swelling force changes with moisture content at 95 % compaction

4. Conclusions

This paper determined the basic physical and mechanical properties of the expansive soil in the Ankang Tunnel through indoor geotechnical tests, studied the shear strength characteristics of the expansive soil in the Ankang Tunnel through direct shear tests, and explored the water absorption and swelling characteristics of the Ankang expansive soil based on the swelling ratio and swelling pressure tests. The following conclusions are drawn:

1) The free swelling ratio of the expansive soil in the Ankang Tunnel is relatively low, at 49.7 %, with weak - medium expansiveness.

2) The unloaded swelling process of the expansive soil in the Ankang Tunnel can be divided into the rapid swelling stage in the initial swelling stage, the swelling transition stage and the slow swelling stage in the middle swelling stage, and the swelling stable stage in the later swelling stage.

3) The swelling ratio of the soil is related to the initial water content and the overlying load. The increase of the initial water content leads to a decrease of the swelling ratio. With the increase of the overlying load, the swelling ratio of the ring knife sample of the expansive soil gradually decreases, and the amount of decrease in the swelling ratio also gradually becomes smaller.

4) With the increase of the water content, the swelling pressure of the soil gradually decreases.

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Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of interest

The authors declare that they have no conflict of interest.

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