Overview of Stability and Failure Characteristics of Expansive Soil Bank Slope

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Abstract: Expansive soil is a type of special clay that expands and softens after water absorption and shrinks and cracks after water loss. It tends to cause engineering accidents such as slope deformation and landslide damage. This paper summarizes the interaction between three engineering properties of expansive soil as well as the slope failure characteristics based on case analysis. In this way, this paper can contribute its share to the design, construction and operation management of the expansive soil bank slope.

1. Introduction
At present, the expansive soil is influencing more than 40 countries worldwide, including more than 20 provinces and regions with an area of over 100,000 square kilometers in China [1]. The expansive soil has high particle dispersion and is mainly composed of hydrophilic clay minerals. In the natural state, the expansive soil has high strength. After water absorption, it expands and softens and its strength becomes lower. After water loss, it shrinks and cracks and its strength becomes higher. According to incomplete statistics, the annual economic losses caused by the expansive soil in the development of public facilities, water conservancy projects and houses in the 1970s and 1990s were as high as 10 billion US dollars [2]. For half a century, scholars at home and abroad have made remarkable achievements in the study on physical properties, deformation characteristics and prevention methods of expansive soil. This paper analyzes and summarizes the important engineering properties of the expansive soil and their mutual effect, and explores the failure characteristics of the expansive soil.

2. Engineering properties of expansive soil
The engineering properties of expansive soil mainly include the swelling-shrinkage property, fracture property, over-consolidation property and intensity attenuation property.

Swelling-shrinkage property is an important feature of expansive soil. There are many internal and external factors leading to this feature.

Among the internal factors, the soil microstructure is an important one. Under the same precipitation condition [3], it is found that the plain soil and lime soil that have suffered from long and heavy rainfall show different swelling-shrinkage behaviors: the compaction of the plain soil decreased by about 15% while that of lime soil remains essentially the same. This paper uses the lyophilization method to study the microstructure of the soil [4] and arranges the strength of common soils in China according to their microstructural swelling-shrinkage property: laminar flow structure> turbulent
particle structure> matrix particle structure> skeletal particle structure> spongy particle structure> cellular particle structure. This paper also points out that the high Mg$^{2+}$ content exchanged in the expansive soil modified by lime can change the soil microstructure and promotes the formation of cement between the particles, thereby inhibiting the expansion and shrinkage of the soil to a certain extent.

Changes in water content are recognized to be important among all the external factors. A large number of engineering cases show that the bulking failure of the expansive soil bank slope often occurs during and after the rainfall period. The soil swells after absorbing water, which leads to: 1) lower negative pore pressure of the surface, and the effect force decreases with the decrease of the surface suction; 2) softer soil and lower shear strength. Under the above influence, the soil strength is reduced, causing landslide instability.

The fracture is the key factor leading to the instability of the expansive soil. Fractures can not only break the integrity of the soil, but also provide a channel for water infiltration, leading to a rapid increase of water content of the soil near the fracture, a rapid decrease of effective stress, and a great decrease of shear strength. The fracture surface becomes the weak surface of the soil, which further becomes the cause of landslide accidents.

Under the effect of gravity, the expansive soil repeatedly expands, shrinks, and solidifies during the deposition process, leading to over-consolidation property. The over-consolidated expansive soil is featured with low water content, small void ratio, large dry density and high structural strength.

The engineering properties of expansive soil interact with each other. The swelling-shrinkage property causes soil water loss and secondary cracks. The infiltration of water along the fracture accelerates the softening of the internal soil. The over-consolidation property increases the development of the fracture and promotes the softening of the soil. Therefore, swelling-shrinkage property is an internal factor; the fracture property is the key factor affecting the mechanical properties of the soil and the slope stability; the over-consolidation property is the factor stimulating the failure. In this way, the three properties interact with each other.

3. Failure characteristics of expansive soil

Pull-type shallow damage: The front edge of the slope body firstly undergoes sliding deformation, and then gradually develops upward to pull the rear slip mass. According to the statistics of landslide cases, the slope surface shows faulting of steps and sometimes multi-layer sliding surface. This is because secondary cracks begin to develop during the drying and watering cycle [5], gradually destroying the integrity of the soil, leading to lower shear strength of the slope. If the soil strength continues to decrease after the first sliding, subsequent damage will also occur. Sliding will stop only after a new balance is reached.

Generally speaking, the soil 3m beneath the surface layer is significantly affected by the external climate. In a hygrothermal environment, multiple drying and watering cycles destroy the overall soil structure and develop fractures, leading to the shallow damage with the depth of the landslide surface between 2 to 4 meters in the expansive soil slope. Anchor bolt support can be used for reinforcement. The numerical simulation [6] shows that a certain number of anchors arranged at the foot of the slope can deliver a satisfactory supporting effect and reduce the shallow damage.

Seasonal Law: Based on the cases of expansive soil slope landslide, it is not difficult to find that most of these damages occur during the rainfall period. The first heavy rain after drought tends to cause large-scale landslide damage in the expansive soil area, indicating that the soil water content is closely related to the mechanical properties of the expansive soil. Lei et al. [7] found that strong rainfall can cause severe sliding of the bank slope, the rainfall was closely related to the landslide development, and that power function can be used to fit the relationship between the superficial displacement of the monitoring point at the expansive soil bank slope and the amount of rainfall based on the observation of surface displacement of the expansive soil bank slope during the construction period. If the fitting function of the expansive soil in the monitoring section is to be found through experiments, we can set monitoring points at the top, middle and bottom of the bank slope, and predict
the amount of landslide displacement of each part based on rainfall monitoring.

Structural characteristics: The fractures of different genesis and occurrence are gradually connected to each other, forming a weak structural layer with a certain thickness inside the soil. Under the external loads (such as excavation unloading) and the change of moist heat conditions, progressive failure occurs, which results in crack penetration and a sliding surface. Under this circumstance, the slope slides under the action of gravity. For example, the excavation unloading changes the stress state of the over-consolidated soil and makes the soil structure more relaxed. The unloading crack is generated on the slope, and the shear strength of the soil is reduced.

4. Conclusion
Deformation and failure of expansive soil pose great difficulties on engineering construction. Since there are many factors affecting soil stability, appropriate preventive measures should be taken in the stages of planning, design, construction, and operation management so as to reduce landslide damage. When the economy and technology permit, soil backfill or improved soil can be adopted in the planning and design stage so as to eliminate or reduce the influence of soil expansion and shrinkage. Anti-seepage measures can be taken at the foundation to prevent external water infiltration, while anchors can be used at the foot of the slope to prevent shallow landslide damage. During the construction, the excavation speed and the foundation and joint treatment should be controlled to ensure that the soil is fully compacted so as to prevent the occurrence of uneven settlement, cracks or seepage channels in the later stage. In the weak structural surface and areas with high landslide possibility, we should use equipment to monitor the seepage pressure and deformation and strengthen daily inspection. Once an abnormal phenomenon is found, we should take effective measures in time to avoid further damage.

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