Anti-slide piles reinforcement of expansive soil landslides

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2011 Pan-Am CGS Geotechnical Conference

ABSTRACT
The problem of expansive soil landslide has long been a concern of geotechnical researchers. Basis of the characteristics of expansive soil landslides, the slide mechanism of the expansive soil slope is studied. And then the anti-slide pile is designed to improve the slope stability of expansive soils in Zhenjiang City, Jiangsu province, China. In order to evaluate the effectiveness of the anti-slide pile, the horizontal displacement of soils in both front and back of piles is monitored and studied. The results show that the anti-slide pile can keep the landslide stable effectively.

RÉSUMÉ
Le problème de glissement de terrain sol expansif a longtemps été une préoccupation des chercheurs géotechnique. Fonction des caractéristiques des glissements de terrain sol gonflant, le mécanisme de coulissement de la pente du sol est étudiée expansive. Et puis la pile anti-dérapant est conçu pour améliorer la stabilité de la pente des sols gonflants à Zhenjiang Ville, province du Jiangsu, en Chine. Afin d'évaluer l'efficacité de la pile anti-dérapant, le déplacement horizontal des sols à l'avant et l'arrière de piles est surveillée et étudiée. Les résultats montrent: la pile anti-dérapant peut garder le glissement de terrain stable efficacement.

1 INTRODUCTION

The expansive soil contains high expansive minerals of kaolinite, illite, and montmorillonite (smectite group). It is the “calamitous soil” with special characteristics (i.e. swelling and shrinking, fissures, the strength reduction and over-consolidation etc.). It swells upon absorption of water and shrinks upon evaporation of water. Fissures in expansive soils are well developed and cause great damage to engineering projects. Railway, highway and buildings in the expansive soil area severely suffer from ground deformation hazards of such soil (*YIN*, 2010). In China, there were 125 landslide accidents during the construction of Jiaozhi-Yaguan railway in 1970s, and 521 failures of subgrade in Yang’an line. And many landslides of the expansive soil cut slope also occurred, such as 195 landslides in the 1385km (that is 1.4 landslides per 10km) canal of Bi-shi-hang in Anhui province, 55 in the canal of Yin-dan in Huibei province. The landslides often occur in the slope of 1:4~ 1:5, for instance, 13 landslides happened in the 2 km canal of Tao-qia-yin-dan after one year of construction. Some landslides occur in a few years, ten years, or decades. Therefore, the expansive soil slope could not be designed to be gentler to improve stability like a usual slope. The gentler slope needs more areas of cultivated land and higher cost. In addition, the gentler slope could not keep the expansive soil slope stable. Therefore, the problem of the expansive soil slope is an issue in Geotechnical Engineering. The South-to-North Water Transfer Project goes through 300-km-long expansive soil region, and the stability of the expansive soil cut slope causes a great risk of safety of the Project. Thus, it is important to study stability of expansive soil slopes (*YIN*, 2010).

There are many Engineering measures to improve the slope stability, such as anti-slide piles, retaining walls, geogrid and soil nails. The anti-slide pile is socked in stable soil layer, and provides by the passive soil pressure to balance the landslide force. It plays a great role in improvement of the slope in the world. It is also proved that the anti-slide pile has many advantages of safety construction, more power to keep the slope stable. Therefore, the anti-slide pile is regarded as “heave weapon” to control landslides, especially for the big and larger landslides. Thus, it is important to study anti-slide piles to improve the slope stability of expansive soils.

2 CHARACTERISTICS AND MECHANISM OF EXPANSIVE SOIL LANDSLIDES

2.1 Characteristics of expansive soil landslides

The expansive soil landslide is a special landslide problem. And the characteristics of the expansive soil landslide (*YIN*, 2010) are: (1) Shallowness. The slip face of expansive soils is shallow and the landslide is regarded as a shallow landslide. In Xiang-yu railway in China, there are 28 landslides of expansive soil, and there is 53% of the slip face of expansive soils of 0.5~3.0m, and 29% of 3.0~6.0m, and less of over 6.0m. (2) Traction. The landslide begins from the foot, then the upper slope begins to slide, finally the whole slope begins to slide. Therefore, there are often many continuous landslides developing like many ladders, or tiles. (3)Gentle. The landslide often happens to the slope of 1:3 ~ 1:5, or gentler slope of 1:6. (4) Long-term. Many expansive soil landslides happen in one or two years, or tens years after construction. (5) Seasonality. The landslide happens because of infiltration and large displacement. (6) Direction. More cracks and more landslides happen in the

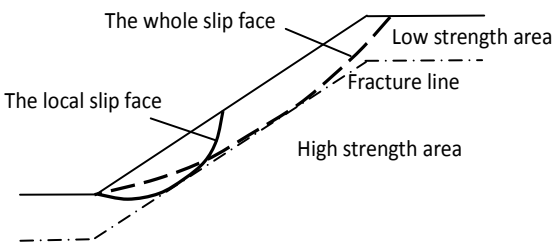
sunny slope, e.g. the northern slope of the canal, because of longer sunny time, larger range of temperature.

2.2 Mechanism of expansive soil landslides

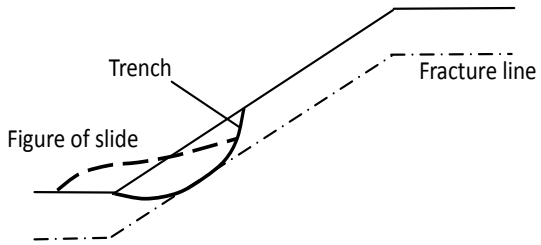
The permeability of expansive soils is very low (10^{-8}~10^{-7} cm/s), when a new slope is excavated or filled. The duration of rain has less influence on the slope stability because of less infiltration. *Chen et al*.(2007) proved the safety factor of the expansive soil slope was more than 2 by geo-centrifuge model experiments. On the other side, many landslides happen in a few months or years after excavation, during heavy rain.

2.2.1 The fracture is the essential factor of expansive soil landslides

There are many fractures in expansive soils after a few cycles of swelling and shrinking. The large amount of fractures not only cause soil mass broken, strength down, but also increase the permeability of the shallow soil layer, the amount of infiltration rainwater. Therefore, the slip face of expansive soils is shallow, as Figure 1. *Chen et al*.(2007) showed the dry-wet cycling was the main cause of the problem. The dry-wet cycling led to cracks in soils. With the increasing times of the dry-wet cycling, the width and the depth of the cracks got larger and deeper. The crack not only broke the soil structure of the slope, but also provided passage for water infiltration, which further led to the soil softening and the strength decreasing. Therefore, the fracture is the essential factor of expansive soil landslides.



(a) the whole landslide and a local landslide



(b) After local sliding

Figure 1. Shallowness and traction of expansive soil landslides

2.2.2 Heavy rain causes expansive soil landslides

Many landslides happen in rain seasons. *Pierson et al.*(1992) observed that landsides in Hawaii coincided with or followed an extremely heavy rainfall. Studies of slope failures in Hong Kong (*Brand*,1992) and in Singapore (*Rahardjo et al.*, 2001) also showed the effects of short duration, high intensity rainfalls. Some studies have also shown the effects of fall on residual soil slopes by pore-water pressure measurements using piezometric and matric suction monitor devices. *Zhan et al.* (2003) reported artificial rainfall simulation tests on an 11 m high cut slope in a typical medium-plastic expansive clay in Hubei of China, and showed that rainfall infiltration led to a significant increase in the pore-water pressure and the water content within the top 2 m soil layer, which resulted in a reduction of shear strength due to a decrease in effective stress and wetting-induced soil softening.

2.2.3 Strength reduction is a direct factor causing expansive soil landslides

Rainfall infiltration leads to a significant increase in the pore-water pressure and water content which results in a reduction of shear strength. Then there is a relatively small displacement at the foot of the slope, which makes the strength decrease to the fully softened value (*Skempton*,1964), that is the residual shearing strength. Or a local passive failure happens and triggers a progressive slope failure, then the strength decreases to the residual shearing strength (*Bjerrun*,1967). The results of experiments showed: the strength of expansive soils decreased with cycles of wetting-drying; *Miao et al.*(1999) reported the strength of expansive soils was closely relative to its water content. The slope stability of expansive soils is also relative to fissures, caused by wetting-drying cycles. The fissures lead to strength reduction, permeability increase, and provide passage for infiltration.

Therefore, the shallow landslides happened because of fissures, reduction of strength and heavy rain

3 ANTI-SLIDE PILES REINFORCEMENT FOR EXPANSIVE SOIL SLOPES

Anti-slide piles reinforcement is one of techniques to control landslides, especially on the gentle slope. There is a typical example of the expansive soil landslide to demonstrate the technique.

The experiment on sample from the landslide shows the soil is the weak-middle expansive soil with expansive ratio, δ_e=(11.5 ~ 78.5) %; for undisturbed sample soils, S_r=64 ~ 100%, shearing residual strength C_r =20.38kPa , φ_r=10.86º ; when saturated, C_{rs} =16.5kPa, φ_{rs}=9.0º. The slip surface is at depth of 4.0 ~ 5.0m, because of many fissures and much water in relatively loose soils, less than 4m depth. The result of back analysis shows: residual strength of soils at slip surface is C =(6 ~ 8)kPa , φ=8º。

Since the triaxial tests in the lab can not simulate the formation and process of the cracking and the water

infiltration process in the expansive soil, it is not proper to directly use the strength and deformation data obtained from the triaxial tests for the analysis of the deformation and stability of the expansive soil slope (*Chen et al*., 2007). The key measure of the expansive soil slope is to stop the soil water exchange with the outside. If water exchange could not stop, some drainage measures should be taken to prevent wetting the slope.

Therefore, the single row of anti-slide piles, diameter of (1.0~1.4)m, length of (8.0~12.0)m, socked in middle weathering rocks, are designed by residual strength. The drain is on the top beam of piles, which are embedded in soils.

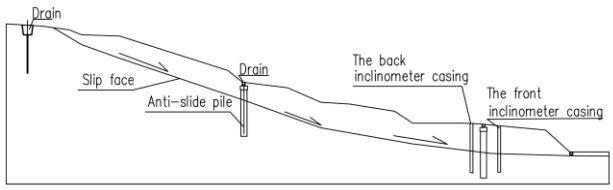


Figure .2 The scheme of the anti-slide pile in the landslide of expansive soils

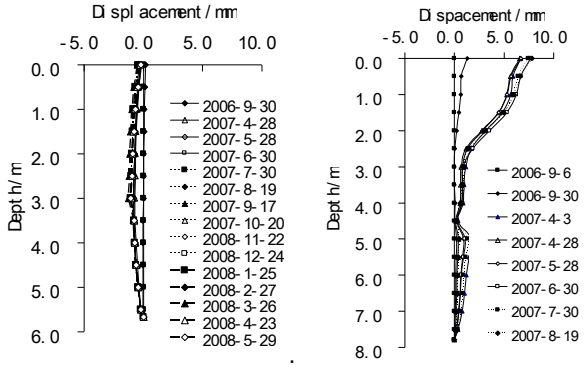
4 EFFECTIVENESS ANALYSIS OF ANTI-SLIDE PILES FOR LANDSLIDES

The anti-slide pile is a cantilever structure, socked in deep, stable and high strength soils. Fortunately, the displacement of swelling and shrinking of deep expansive soils is restrained by overburden, and the permeability of expansive soils is very low. The strength and displacement of deep expansive soils is stable with time. Therefore, the deep expansive soils can act as basement of piles. There are many advantages to use anti-slide piles in the gentle expansive soil slope, such as easy construction, a big area of the pile bearing.

In order to evaluate the effectiveness of anti-slide piles in the expansive soil landslides, the inclinometer casing is installed in the front and back of the single row anti-slide piles to measure horizontal displacement of soils (figure.2). Figure.3 shows the monitoring data of deep horizontal displacement of soils in one year. And the horizontal displacement deflection plot shows the soil behind the anti-slide pile is stable, and the maximum displacement of the soils is less than 3mm. Therefore, the anti-slide pile succeeded in keeping the slope stable. But the soil in front of piles is unstable, the displacement on the surface is more than 8mm, the shallow slide is obvious. The slip face is at 3m depth, which is consistent with that of geological exploration. Therefore, the anti-slide piles can effectively improve the stability of expansive soil slope, but need combine with the other measures to treat the front soils.

5 CONCLUSION

It is a big problem of the expansive soil landslides. The characteristics of the expansive soil landslide and the slide mechanism of the expansive soil slope were studied. The anti-slide pile was designed to improve stability of the expansive soil slope in Zhenjiang City, Jiangsu province, China. And the horizontal displacement of soils in the front and back of piles was monitored and studied. The results showed that the anti-slide pile can effectively keep the landslide stable.



(a) the back (b) the front

Figure 3. Horizontal displacement versus depth curves of anti-slide piles.

ACKNOWLEDGEMENTS

The work presented in this paper is supported by the Fundamental Research Funds for the Central Universities (No:2010B03414).

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