Journal of Zhejiang University SCIENCE A
ISSN 1009-3095 (Print); ISSN 1862-1775 (Online)
www.zju.edu.cn/jzus; www.springerlink.com
E-mail: jzus@zju.edu.cn

The stability analysis of expansive slope in Jing-Yi Expressway

ZUO Chang-qun†, CHEN Jian-ping

(*Engineering Faculty, China University of Geosciences, Wuhan 430074, China*)

†E-mail: helenzz@126.com

Received Mar. 20, 2006; revision accepted Oct. 10, 2006

Abstract: This paper firstly introduces the distribution of weathered layers, and then presents the relationship between water content and expansive force and the working model of expansive forces in expansive soil slopes. Taking the expansive soil slope of Jing-Yi Expressway as example and applying the Slices Method, this paper puts forward the stability calculation method considering the effect of expansive forces, and also proposes the treatments.

Key words: Expansive soil, Stability analyses, Slices Method, Weathered layer
doi:10.1631/jzus.2007.A0270 **Document code:** A **CLC number:** TU4; U41

INTRODUCTION

Jing-Yi Expressway (95 km) is the Jingmen-Yichang section of the Hangzhou-Lanzhou Expressway line. The embedment slopes along the line are mainly expansive slopes causing many inconveniences for engineering. With longtime exposure, water accumulated in widespread sections because of bad drainage measures, and constructions collapsed. In this work, a selected representative sector's stability is analyzed and the corresponding reinforcement measures are presented.

DISTRIBUTION RULE OF EXPANSIVE FORCE

Expansive soil is a special clayey soil which expands and softens upon contacting water, and shrinks and cracks during shortage of water. The bane of embedment slope stability is the existence of expansive force, the causative reason of which is intensive hydrophilicity in the clayey soil (mainly containing montmorillonite). The alteration of water content directly causes expansive force alteration (Liu, 1997; Kong and Tan, 2000). The diversity of moisture movement in different sections of embedment slope alters the working rule of expansive force which influences greatly the slope stability, so that considering the influence of expansive force is very necessary in practical engineering.

Delaminating of weathering

The fluctuation of water content and the repetitive expanding lead to crack expansion and development in the deep soil layer and great reduction of soil strength, and also form the weathered layer. The direct consequence of deformation and destruction of expansive slope is the minimal variability of the influence of depth on soil strength caused by weathering action so that the soil mass forms different weathered layers. Liao (2003)'s study showed that expansive soil can be separated into surface layer, shallow layer and deep layer. The surface layer weathering is intensive with the crack quite developed; the swelling-shrinking deformation is also quite intensive, and belongs to the heavy weathered layer. The shallow layer weathering is relatively weak compared with surface layer, in which the crack is relatively small and not developed, swelling-shrinking deformation is not like that of the surface layer, and belongs to the weak weathered layer. While the deep layer almost has no weathering, swelling-shrinking deformation and strength attenuation, and belongs to undisturbed soil. The soil in each layer has its own particular physical quality, structure and strength.

Variation rule of expansive force in weathered layer

In the surface weathered coat, the weathering is intensive, the water content changes dramatically, with the expansive force change following along. With the extension from sloping surface to sloping interior, the restraining force of inner soil intensified gradually. Therefore the working rule of superficial force is an increasing process from 0 (in the sloping surface) to maximum value.

In shallow weathered layer, the weathering is not as intensive as that of the surface coat, while the water content still changes. The soil body receives the bilateral restraining from the surface coat and deep layer, and also encounters a rather large expansive force in this layer. Because of the homogeneity of moisture movement, the expansive force can be regarded as a constant.

In the deep weathered layer, there is almost no weathering, just like that of the moisture movement. The expansive force decreases with increasing of depth, while the gradient is smaller compared with the superficial weathered coat.

Simplified working model of expansive force

Expansive force is the internal stress generated by volume enlargement in the process of absorbing water. In the experiment, the test used undisturbed soil sample, and brought pressure to bear on the soaking sample in order to measure the maximum pressure of unit area when the steady state is reached. A large number of experimental researches on expansive soils were made in this region (Zhong and Wang, 2004). The experiment was done as follows.

Draw the curve diagram of experimental data (Fig.1). Regression analysis showed that the expansive force and water content had linear relation, with the expression of the two elements being represented as follows:

$$P_s = a\omega^3 + b\omega^2 + c\omega + d, \tag{1}$$

where P_s, ω are expansive force and water content, and a, b, c, d are experimental parameters.

Fig.1 shows that water content has big influence on the expansive deformation, and that minimal water content change can also create a rather large changing of expansive force. According to the experimental data, the relationship between expansive force and water content can be described with a simplified mathematical function.

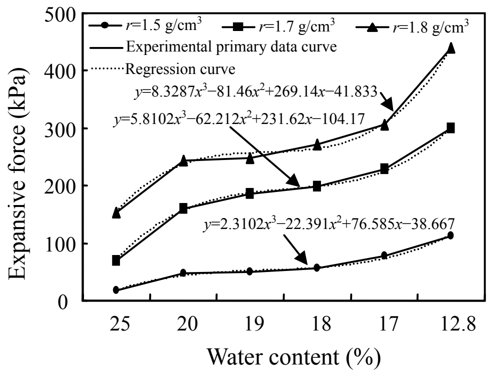

Fig.1 The diagram of expansive force and water content

Xiao (2001) chose the straight line equation to describe the variation rule of expansive force to analyze the slope. According to the analysis mentioned above and the practical conditions, the superficial coat weathering was worst; the expansive force increases with distance, while the increasing rate reduces gradually.

The mathematical model adopted in this paper is the conic line model, as shown in Fig.2. The expansive force P_s was determined by the experiment, where L was the superficial layer depth, L_1 was the shallow depth; x was the distance from sloping surface to the random position of the slope, the slope ratio was 1:m, so that the expression of expansive force and horizon distance can be represented as follows:

$$\begin{cases} x = P_e^2 L\sqrt{1+m^2}\,/\,P_s^2, & 0 \le x \le L\sqrt{1+m^2}; \\ P_e = P_s \text{ (constant)}, & L\sqrt{1+m^2} \le x \le (L+L_1)\sqrt{1+m^2}. \end{cases}$$

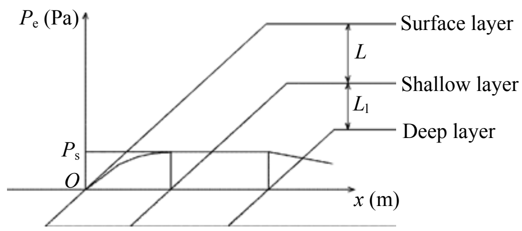

Fig.2 Distribution map of expansive force in slope

PRINCIPLE OF SLICE METHOD IN EXPANSIVE SLOPE

The Slice Method was the major method for the slope stability analysis in which the concrete process divided the sliding mass into some vertical soil stripes, considered as rigid bodies, calculated the respective sliding moment and anti-slide moment applied to the circle center in each of the stripes, then resolved the whole assurance coefficient (Ling, 2005). For the expansive slope, the analysis must take the transverse and longitudinal expansive forces into account. The principle of Slice Method is represented in Fig.3.

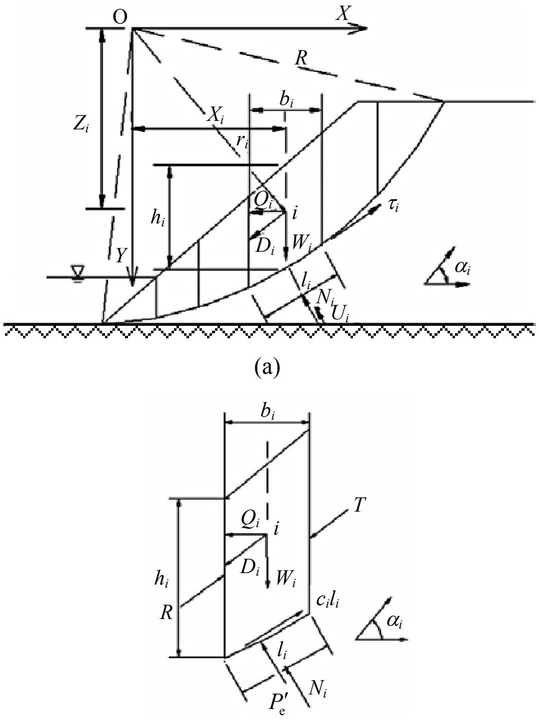

Fig.3 The picture of Slice Method principle
(a) Integral slice map; (b) Stripe stress map

For the stripe i, the glide force T included $W_i\sin\alpha_i$ and the anti-slide force R included $W_i\cos\alpha_i\tan\phi_i+c_il_i$. For the independent stripe, the bottom expansive force reduces bottom pressure force, and also reduces friction force subsequently. The composite expansive force direction would be altered, and the influence on each stripe would also be different. According to the different force direction, the corresponding assurance coefficient F_s can be defined as follows:

(1) If the composite expansive force was rightward, the component force had sliding resistance for the soil body, thus:

$$F_s=\frac{\sum W_i\sin\alpha_i}{\sum(W_i\cos\alpha_i-P_i'+P_i\sin\alpha_i)\tan\phi_i+c_il_i+P_i\cos\alpha_i};\qquad(2)$$

(2) If the composite expansive force was leftward, the component force had sliding effect for the soil body, thus:

$$F_s=\frac{\sum W_i\sin\alpha_i+P_i\cos\alpha_i}{\sum(W_i\cos\alpha_i-P_i'-P_i\sin\alpha_i)\tan\phi_i+c_il_i},\qquad(3)$$

where W_i, P_i, P_i' are the soil weight, composite force of transverse expansive force, composite force of transverse expansive force of stripe i, respectively; c_i, l_i, ϕ_i the cohesive strength, bottom length and friction angle; α_i is the bottom and the horizontal angle.

ENGINEERING PROJECT

The selecting slope calculated in this paper was located in K10+810~K11+600 section of Jing-Yi Expressway with whole length of 800 m. The slope is the second stage slope; the slope ratio is 1:1.5, with each height being 6 m. The slope surface is presented as loose condition; some section is presented as yellow shifting sand without bedrock exposure.

Slope slice calculation

According to the slope size, exploration and experiment material, determine the weathered layer located in the 3.5 m position below the slope surface, with the expansive force in the surface-shallow weathered layer being 50 kPa (Chen, 2004). As the slope was located above the water line, the influence of the pore water pressure could not be considered. Divided the slope model according to the practical conditions, calculate the acting force of each slice, and draw the stress exhibition map. The result is presented in Fig.4.

Stability calculation

The shear strength diversification of expansive soil was more complicated than that of normal clay soil. Because hydrophilic clay minerals soften in water, the strength decreased greatly. Multi-fissure characteristic was also the main reason of strength diversification. The shear parameter selection in stability analysis must consult experimental parameters and results, and also combine the outdoor observation, selecting the strength parameter of slope body as C=16 kPa, ϕ=6.5° (Zhang and Jiang, 2001). For each strip, the equivalent unit weight chosen for calculation of the unit weight is γ=20 kN/m^3.

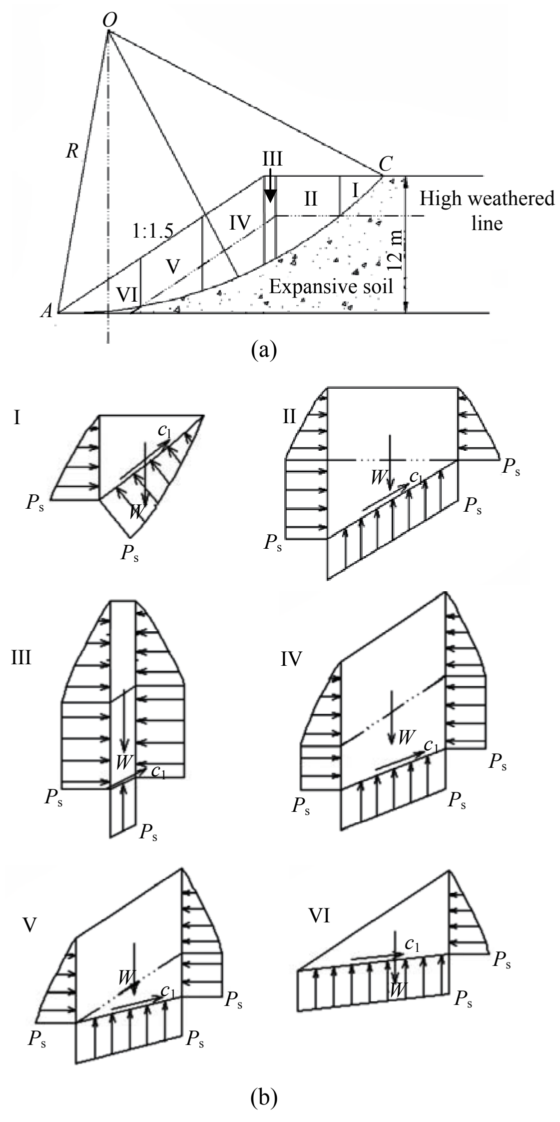

Fig.4 Slope slice map (a) and stress exhibition map (b)

Through the calculation, the stability coefficient F_s=0.7379. It was shown that the slope was in instability state, and fit the practical situation. Detailed calculation result is presented in Table 1.

Stability calculation that does not include the expansive force

Not considering the expansive force, calculate the stability coefficient applying the Swedish Circle Method. The calculation result is presented in Table 2, with F_s=0.7984.

At the same time, applying the General Slices Method and through four times iteration, calculate the stability coefficient as F_s=0.853.

To sum up, the stability coefficient including the expansive force is smaller than the ones not including the expansive force. It took great influence for slop stability and the calculation result also had differences when took different methods. The stability coefficient applied to Swedish Circle Method is usually smaller than that of the other methods, because this method neglects the mutual influence existing between stripes, satisfies the integral moment equalization qualification of sliding body, but does not satisfy the static equalization qualification of single stripe. Whereas the General Slices Method considers the influence of horizontal force among the stripes, and satisfies all the static equalization qualifications (Chen *et al.*, 2001), although this method does not consider the influence of expansive force, the final stability coefficient is still larger than the real state.

Table 1 The applied force calculation table of each stripe (considering the expansive force)

Number	α_i	W_i (kN)	P_i	P_i'	$c_i l_i$	T	R
1	39.00	150.26	52.50	83.09	88.62	139.63	138.81
2	31.00	694.08	114.00	221.40	118.08	357.45	265.04
3	26.00	160.02	4.50	35.28	18.80	70.15	35.43
4	21.00	742.62	−43.50	168.74	90.00	306.77	147.97
5	14.00	553.61	−64.50	162.26	86.54	196.50	127.46
6	6.00	388.32	−63.00	113.46	121.02	103.23	151.34
Composite force						1173.74	866.05
Stability coefficient				0.7379			

Table 2 The calculation stability table through Swedish Circle Method (not considering the expansive force)

Number	α_i	W_i (kN)	$W_i\sin\alpha_i$	$W_i\cos\alpha_i \times\tan\phi_i$	$c_i l_i$
1	39.00	150.26	139.63	13.30	88.62
2	31.00	694.08	357.45	67.77	118.08
3	26.00	160.02	70.15	16.38	18.80
4	21.00	742.62	266.16	78.97	90.00
5	14.00	553.61	133.92	61.18	86.54
6	6.00	388.32	40.58	43.99	121.02
Composite force			1007.89	281.59	523.06
Stability coefficient			0.7984		

REINFORCEMENT MEASURES OF EXPANSIVE SLOPE

The expansive slope has repetitive swelling-shrinking character when absorbing water, the reinforcement measure of expansive slope should be different from that of the other soil or rock slopes. The main measures included 3 kinds: drainage proofing, surface protection and sustainer proofing.

Drainage proofing includes intercepting ditch, drainage ditch, lateral ditch, supporting leaching trench. Surface protection includes plaster proofing, biologic proofing, cement proofing, and so on. Sustainer proofing mainly includes retaining wall, friction pile, and so on. For the intense expansive embedment slope, the protecting can take anchor sock, reinforcing mat and sprayed concrete.

For K10+810~K11+600 embedment slope, repetitive rain invasion caused extensive surface soil collapse of slope, and the slope bed retaining wall was also removed and had crack distortion. Because the local expansive soil had high hardness and high dense characteristic in dry undisturbed environments, cement mixing pile could be chosen to improve the foundation to enhance the upper load bearing capacity. According to the practical conditions of this section, install the gravity retaining wall in bilateral subgrade to prevent the sliding of slope soil body. At the same time, backfill the slope by changing the 1:1.5 slope ratio to 1:2.5. For slope surface, apply lattice and vegetation protection.

CONCLUSION AND SUGGESTION

(1) For the expansive slope, the slope analysis must fully consider the working rule of expansive force. Because different depth has different weathering degree, the working rule of expansive force can be expressed by proper mathematical model in order to fit practical conditions.

(2) Through comparison of different results, expansive slope stability analysis must consider the influence of expansive forces; otherwise the calculation results will be different from the actual conditions. If the slope was located within the water level, the analysis must consider the pore water pressure.

(3) Water greatly influences the expansive slope and discharging engineering at the point of treatment. The reinforcement project must strengthen the design of the discharging structure.

(4) Backfilling is the important method in slope treatment, with proper slope ratio being very important. This project enlarged slope ratio to prevent slope sliding.

References

Chen, W.W., 2004. Test and treatment of expansive soil in Jingmen-Yichang Expressway. *Journal of Highway and Transportation Research and Development*, **2**(1):5-8 (in Chinese).

Chen, Z.Y., Zhou, J.X., Wang, H.J., 2001. Soil Mechanics. Tsinghua University Press, Beijing, p.246-252 (in Chinese).

Kong, L.W., Tan, L.R., 2000. Study on Shear Strength and Swelling-shrinkage Characteristic of Compacted Expansive Soil. *In*: Rahardjo, H., Toll, D.G., Leong, E.C. (Eds.), Unsaturated Soil for Asia, Rotterdam, Balkema, p.515-519.

Liao, S.W., 2003. Expansive Soil and Railway Engineering. China Railway Publishing House, Beijing, p.58-72 (in Chinese).

Ling, T., 1995. Soil Mechanics. China University of Geosciences Press, Wuhan, p.180-228 (in Chinese).

Liu, T.H., 1997. The Expansive Soil Problems in the Engineering Construction. China Architecture and Building Press, Beijing, p.30-64 (in Chinese).

Xiao, S.G., 2001. Stability analysis of expansive clay slope. *Rock and Soil Mechanics*, **22**(2):152-153 (in Chinese).

Zhang, J.X., Jiang, S.H., 2001. A brief discussion on properties of swell soil and stability of foundation in Dangyang Yichang Speedway. *Earth Science*, **26**(4):424-428 (in Chinese).

Zhong, X.C., Wang, J., 2004. The primary study on the expansive strain rule of unsaturated expansive soil. *Journal of Yancheng Institute of Technology*, **16**(3):71-72 (in Chinese).