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Analysis of Fissured Expansive Soil Slope Stability and Its Reinforcement with Anti-Slippery Piles

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Abstract. Fissure is one of the most important characteristics in expansive soil. It's an important factor affecting slope stability in the expansive soil area. With the study of expansive soils typical channel slope fissured characters in the South-to-North Water Diversion Project, different impaction on slope stability such as location and inclination of the fissure are analyzed. By using the limit equilibrium method, the stability of expansive soil slope is analyzed; the most adverse condition of expansive soil slope is concluded. Then anti-slippery pile reinforcement in expansive soil channel slope is studied by using finite difference method. The research is of great significance to the construction and reinforcement of expansive soil slopes in South-to-North Water Diversion Project.

Introduction

Expansive soil is special soil which is multi-fissured, and can be swelling or shrinking in different condition. Expansive soil is found extremely broad in China, and it does great harm to constructions. The South-to-North Water Diversion Project involves cumulative length of about 340km of the main canal, which 1/4 of the total length contains expansive soil. Because of its special engineering properties and mechanical properties of expansive soil [1], channel slope instability is one of the major technical problems of South-to-North Water Diversion Project. In "Eleventh Five-Year" period, Yangtze River Scientific Research Institute [2-3] associate with the relevant domestic institute, company, universities, and engineering management units, establish a joint research group, has constructed two field test base in Nanyang and Xinxiang section. Study on failure mechanism and mechanical properties of expansive soil are carried out by use of large centrifuges, high-precision CT triaxial apparatus scan .

Currently, the studies of strong expansive soil slope stability are focused on the damaging effects of rainfall infiltration on expansive soil slope, and few are focused on expansive soil slope instability caused by fissures. Most works are concentrated in the shallow surface due to the wet and dry cycle irregular fissure. GONG Bi-wei et al [4] explore the process of slope instability on shallow drying shrinkage fissures under the wet and dry cycle conditions associated with rainfall infiltration. Yaohai Lin et al [5] analyses expansive soil fissured slope stability on the study of the fissure's impact on the overconsolidated and intensity of expansive soil. Lin Yuling et al [6] study the expansive soil fissures development under wet and dry cycle climate, then a new and effectual slope stability analysis method of discontinuous deformation is established which divide the fissures of expansive soil into block system. Meng Qianling [7] carries out the fissure of expansive soil slope stability analysis. Above of fissured expansive soil slope stability research, mainly focused on shallow surface fissures caused by the wet and dry cycle, and few are focused on impaction of location and inclination of the natural fissure, which is formed by geological process, to expansive soil slope stability.

Based on the field test section of Nanyang and limit equilibrium theory, Zhanlin Cheng et al [2] of Yangtze River Scientific Research Institute propose a new analysis method which analyses the fissures location and inclination of the expansive slope stability. The expansive soil slope stability safety factor in the different fissures traits and working conditions is obtained by using of this limit

equilibrium theory. Leqiu Chen et al [9] already use the finite difference method to simulate the stability of slope reinforcement with anti-slippery piles. Anti-slippery pile reinforcement channel slope is studied by using finite difference method in the next sections.

Calculation model and parameters

Fissure is one of the most important characteristics of expansive soil. Fissure research in this paper, does not refer to the general light level fissure caused by wet and dry cycles, which is secondary fissure; the "natural fissure", on the other hand, is inherent in the natural soil which is not produced by the expansion and contraction deformation, and it is formed due to the complex role of geological process. Yongyu Fong, QU Yongxin [8] has studied the macro-structural features of expansive soil in Nanyang city, and outlined the structure of the Nanyang natural fissured expansive soil slope, as shown in Figure 1. In Figure 1, the top of the slope there is a short, messy and random secondary fissure. As the depth increases below atmosphere impact, the secondary fissure gradually disappear with depth increasing, while natural fissure appear, and the length of natural fissure is significantly longer than the secondary fissures, the natural fissures has certain inclination. The dashed line in Figure 1 shows the slope of potential sliding surface. According to the typical geologic feature and actual fissure occurrence, several typical fissure distributions are shown in Figure 2. The angle between steep inclination fissures and the horizontal axis is 30 degree. The angle between gentle inclination fissures and the horizontal axis is 0 degree, as shown in Figure 2. The strength parameters are carried out by triaxial tests, using different parameter in respective area.

Table 1 Calculation parameters

name	dry density （g/cm3）	saturation density (g/cm3)	moisture content (%)	friction angle （° ）	Cohesion (kPa)	elastic modulus (MPa)	Poisson ratio
fissure	1.62	2.04	21.0	10	9	30	0.3
expansion soil	1.65	2.04	23.0	21	18	30	0.3

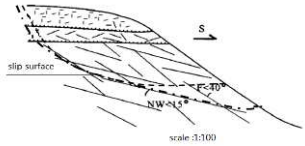

Figure1 Natural expansive soil slope (cited in Yongyu Fong, Yongxin Qu, [8])

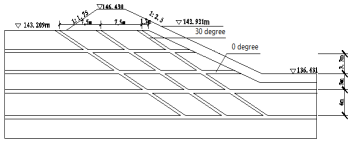

Figure 2 The inclination 0 degree and 30 degree combination fissures expansive soil slope calculation model

Calculation results and analysis

Considering fissure occurrence and using the limit equilibrium analysis method to calculate expansive soils typical channel slope in the South-to-North Water Diversion Project. Study the fissure in different locations (channel bottom elevation, several meters above and below the channel bottom elevation), different fissure inclination and different duration on expansive soil slope stability. The calculation results are shown in Table 2.

The results show that: in the case of the same duration, gentle inclination 0 degree fissure locates in three different position, the corresponding soil skid resistance and sliding force ratio is different; under the conditions of the construction and operation period, as the depth of gentle inclination 0 degree fissure growth, the safety factor of slope increases gradually, the corresponding landslide

stabilizing force and sliding force ratio is gradually increases; In completion period, because the top of the slope is filling loaded, the safety factor is slightly smaller than the construction period. With the depth of gentle inclination 0 degree fissure growth, the safety factor shows a trend that it first decrease and then increase, when the gentle inclination 0 degree fissures in the channel bottom of 3 meters, the safety factor of slope is at the minimum; In operation period, due to the role of counter-pressure of the water level, the safety factor is more than 1.50.

Table 2 The different durations security coefficient under 30 degrees fissured the same position, 0 degrees fissures different depths, and whether the groundwater conditions

fissure depth	duration	no groundwater, steep fissure	groundwater, steep fissure
7 meters below the channel bottom	Construction	1.97	1.34
	Completion	1.60	1.18
	operation	3.11	2.49
3 meters below the channel bottom	Construction	1.43	1.12
	Completion	1.24	1.09
	operation	2.43	2.14
at the bottom	Construction	1.23	1.11
	Completion	1.26	1.16
	operation	2.16	1.95

Reinforced with piles analysis

Seen from Table 2, the 10 meters high expansive soil slope with groundwater in completion period is the most unfavorable condition. The schematic diagram of the calculated position of the slip surface and the safety factor of slope are received by the Limit equilibrium method. The safety factor of channel slope is 1.09. It does not meet the design requirements of the safety factor of 1.3. Therefore it needs to reinforce the channel slope in completion period.

In order to better guarantee the safety of the slope and maximize soil shear resistance, assumed that the soil has reached the limit equilibrium when use finite difference method to calculate the force of the anti-slippery pile. Elastic-plastic model of Mohr-Coulomb yield criterion in the numerical calculation of the finite difference method for the soil is assumed; by using fluid-structure interaction analysis to calculation of pore water pressure field; anti-slippery pile is simulated by PILE unit, and simplify the coupling interaction between the pile and soil as spring. The computational mechanics parameters of expansive soil and fissure are show in Table 1. The parameters of PILE unit are shown in Table 4. Finite difference grid are shown in Figure 4. The calculation results show that: the reduction of strength parameters of the sliding surface is 1.3 while the channel slope safety factor is 1.3 (reference strength reduction method). The anti-slippery pile can withstand the maximum bending moment of 811 （KN per meter）. The calculation results provide the basis for expansive soil slope reinforcement measures.

Table 4 The pile unit calculation parameters

concrete grade	elastic modulus (MPa)	Poisson ratio	density (kg/m3)	normal stiffness (kN/m3)	tangential stiffness (kN/m3)
C30	2.04×104	0.167	2.5×103	30000	13500

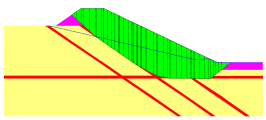

Figure 3 The slip surface location of the height 10 meters slope under the most unfavorable conditions

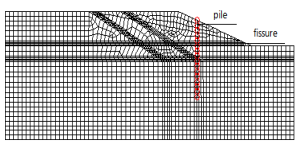

Figure 4 Schematic finite difference grids

Conclusions

By analysis the stability of the fissured 10 meters high expansive soil slope of different fissure occurrence and operating conditions, the most unfavorable condition of expansive soil slope is obtained , and the forces of the slippery pile which is reinforced for the expansive soil slope is analyzed and calculated by the finite difference method . The calculation result is of great significance to construction design and reinforcement expansive soil slopes of the South-to-North Water Diversion Project. The conclusion is as follows:

(1) Under the conditions of the construction and operation period, as the depth of gentle inclination 0 degree fissure growth, the safety factor of slope is gradually increased, and channel slope stability is the higher;

(2) In completion period, because the top of slope is filling loaded, the safety factor is slightly smaller than the construction period;

(3) The most adverse condition needs to be laid an anti-slippery pile which is above 4 meters the channel bottom, and anti-slippery pile shall not be less than the ultimate moment of 811 KN per meter. Then the safety factor of fissured expansive soil slope is 1.3 which meets the design requirements. It shows that the expansive soil slope reinforced with piles is effective.

Acknowledgements

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