AMSE JOURNALS-AMSE IIETA publication-2017-Series: Modelling B; Vol. 86; N°1; pp 115-125
Submitted Jan. 2017; Revised March 15, 2017, Accepted April 15, 2017
https://doi.org/10.18280/mmc_b.860109

Application of Anchor Frame Beam in Expansive Soil Slope

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Abstract

Anchor frame beam is a method for strengthing expansive soil cutting slope, it can effectively prevent the shallow and deep sliding of the expansive soil slope, so as to prevent the further deformation of the slope mass. In this paper, combined with engineering example, the construction technology of anchor frame beam is described，the stability of the anchor frame beam protection system is calculated through using geo-slope software. The field monitoring data verifies that the anchor frame beam can effectively protect the expansive soil slope, this kind of protection method realizes the organic combination of traditional engineering protection and vegetation protection. The method has a good effect and is worthy of popularization.

Key words

Anchor frame beam，expansive soil，slope，reinforcement

1. Introduction

As a kind of special soil, the harmfulness of expansive soil is obvious to all in the engineering field. Excavation of foundation pit or slope is very easy to cause the slope collapse and landslide in the expansive soil area, which will bring no small trouble to the engineering construction. Some collapses and landslides may also occur after the operation of the road, causing inconvenience to the normal traffic. The stability of expansive soil slope has been the focus of engineers and technicians. Engineering and technical personnel have carried out a lot of scientific research work of expansive soil slope, and achieved a lot of research results with practical engineering value. However, due to the technical conditions and other aspects of the restrictions, people's understanding of the expansive soil has not reached a satisfactory level. Therefore, it is of great practical significance to improve the quality of engineering construction by using the new theories and methods of modern science and technology, and to develop the application of expansive soil slope protection technology.

2. Expansive soil slope reinforcement method

The traditional slope reinforcement methods are mainly the following: dry and mortar flag stone、retaining walls and concrete precast block etc. These methods can meet the safety design requirements of expansive soil slope, provide supporting and retaining reinforcement measures for slope, make the slope stability. But the traditional protection method is only concerned about the effect of engineering protection, and the lack of consideration on environmental protection. In recent years, greening protection concept was putted forward to achieve the organic combination of vegetation protection and engineering protection in the construction. Therefore, it is urgent to develop a new type of protective structure with stable and ecological landscape effect.

Anchor frame beam is an effective method to reinforce the slope of expansive soil; it has the following characteristics：good integrality、strong stiffness、 consideration to greening. In the anchor frame beam, the effect of anchor bolts is embedded in the expansive soil and fixed frame；the effect of the framework is to clamp the slope soil, and prevent the deformation of the slope；the grass shrub in the frame is used to reinforce the soil body with strong plant roots, so that the water content of the soil is relatively stable, and the swelling shrinkage of expansive soil is reduced. Frame beam, anchor and grass irrigation to form a three-dimensional strict protection system.

3. Engineering example

3.1 Engineering survey

Neixiang-Dengzhou Highway passing through Neixiang County, Xichuan county and Dengzhou City in Henan province，the total length is 90.693km. The special rock soil is mainly expansive soil along the highway. Expansive soil is composed of a great deal of strong hydrophilic clay minerals, such as montmorillonite and illite, it has much character, such as fracture development、swelling after water absorption、dry shrinkage after water loss, and has a large reciprocating expansion and shrinkage deformation capacity. According to geotechnical trial materials, the expansibility of soil is medium. The physical indexes of expansive soil obtained by drilling near the construction site are shown in Table 1.

Tab.1. Physical and mechanical parameters of expansive soil

depth (m)	natural water content (%)	specific gravity	density (g/cm3)	void ratio	saturation (%)	liquid limit (%)	plastic limit (%)	plasticity index	cohesion (kPa)	internal friction angle (°)
2.8	34.2	2.74	1.87	0.966	97.0	49.0	21.3	27.7	41.7	13.7
4.5	32.8	2.74	1.86	0.956	94.0	51.0	23.4	27.6	53.0	23.6
5.7	26.4	2.74	1.86	0.862	83.9	54.8	24.5	30.3	65.1	26.4

In the expansive soil test section, the terrain higher up to 12 meters, the two stage excavation has been used in deep cutting section. The skeletons of up and down slope are all cast-in-site reinforced concrete members. The slope rate of the up slope is 1:1.5, and the slope rate of the down slope is 1:1. The drainage type anchor frame beam was used in the protection of high expansive soil cutting slope, frame beam system using concave beams, which can not only play the role of reinforcement, but also can make the slope form a network of drainage system, so as to achieve the comprehensive benefits of ecological protection. As shown in Figure 1-2. Frame beam design figure shown in Figure 3.

Fig.1.Frame beam water shoot

Fig.2.Effect drawing of frame beam slope protection

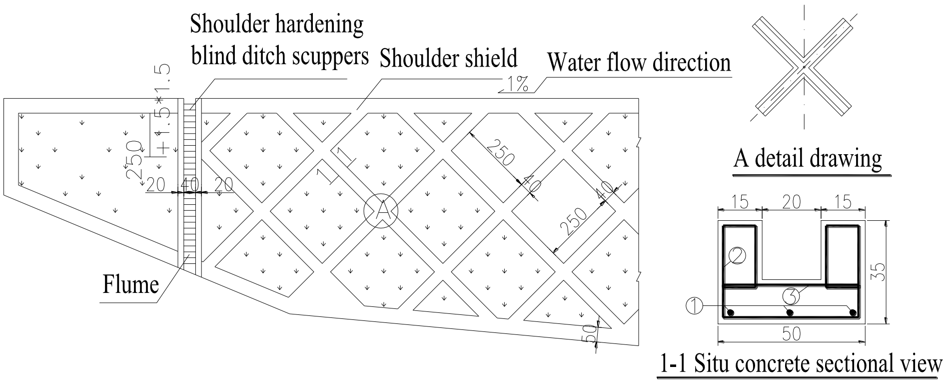

Fig.3. Design drawings of anchor frame beam

3.2 Construction procedures of anchor frame beam

The main construction process of anchor frame beam including：determine the exact location of the slope by construction lofting，brush slope from top to bottom，remove all loose soil on the slope，determine the location of the anchor hole，then drill holes，drill pipe should be perpendicular to the slope，first with short drill pipe, then use long drill pipe, and gradually drill to the design depth. In the process of drilling, it is forbidden to irrigation in the hole. Hole inspection should be carried out timely after the completion of drilling, then placed bolt fixed, after the anchor bolt is fixed, grouting can be carried out.

After anchor frame beam pouring finished, artificial excavation frame beam groove, binding reinforcement in the slot after inspection, steel banding and bolt head are connected as a whole, the concrete can be poured in groove after steel bar tied up, concrete pouring should be carried out from bottom to top, the soil at the bottom and two sides of the concrete is used as the formwork, the upper part of the concrete using the processing formwork.

After the concrete pouring is completed, sprinkling water for maintenance, ensure the strength of concrete to meet the design requirements. When concrete segmental construction is completed, then fill soil in the frame, and then hydroseeding. To ensure the survival rate of vegetation, maintenance needs to be carried out according to the weather condition. The technological process is shown in Figure 4.

Problems deserved attention in construction: the anchor should be driven in the direction perpendicular to the slope; anchor and frame beam joints should be welded; the bolt should be straight; the anchor should be removed the rust and oil, the anchor bolts should not be tapping after installation; grouting should be used in fine sand, and the sand particle size should be not less than 2.5mm, screen and clean before use.

Transplant the planting soil into the frame, planting turf use the form of mixed sowing, the grass bush includes: iris(30％), crown Vetch(15％), alfalfas(15％), fawn(40％), sowing with fertilizer, when planting should be accompanied by fertilizer, regular watering and maintenance.

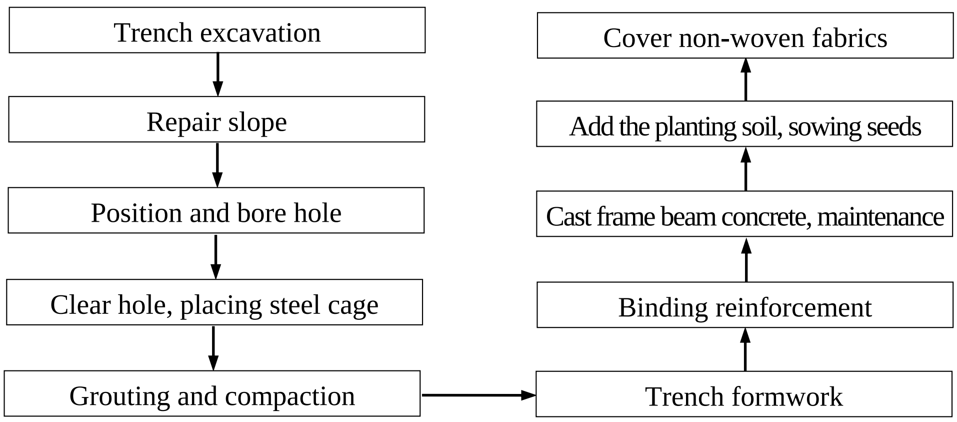

Fig.4. The flow chart of construction technology

4. Stability analysis of composite slope

4.1 Introduction of the geo-slope software

The project uses the geo-slope software to analyze the stability of the slope. The geo-slope software was developed by Calgary. Alberta Company in Canada, it includes slope analysis and calculation module、seepage analysis module、rock stress and strain field analysis module、temperature field analysis module and seismic stress and strain field analysis module，every module can be used separately.

The slope analysis and calculation module is used to calculate the safety of slope and embankment. It has the following characteristics: (1) easy to model and easy to operate; (2) the AutoCAD base map can be used for modeling directly, and the calculation results can be output in a variety of formats; (3) the Carlo Monte reliability is used to analyze the reliability of the slope; (4) the reinforcement measures can be directly applied on the calculation section, even the length of the anchorage segment can be analyzed according to the input parameters; (5) for homogeneous soil, can find the most unfavorable slip arc.

4.2 Calculation method of composite slope stability and its parameter description

The expansive soil slope is different from the general clay slope, which is derived from the characteristic of expansive soil. The stability of the expansive soil slope is calculated by the parameters of water content and suction force, some research results have been obtained. Landslides often occur after long-term rainfall when the expansive soil is completely saturated. So the calculation of the stability of the expansive soil slope is back to the saturated expansive soil, however, it is important to take into account the influence of fracture, and the selection of long term strength parameters of expansive soil.

The anchor frame beam is a kind of way to reinforce the expansive soil slope. The design of the side bolt first need to determine the earth pressure, then the anchor length, spacing and other parameters are determined according to the experience or the corresponding formula. The earth pressure is calculated by the Coulomb formula, it is better to take the actual test of the soil earth pressure as the standard. The calculation formula of slope stability is:

$$F_s = \frac{\sum\left[(w_t + Q_t) sos\alpha_i \cdot tg\phi_f + \left(\frac{R_k}{s_{hk}}\right)\sin\beta_k \cdot tg\phi_f + c_f\left(\frac{\Delta_t}{\cos\alpha_i}\right) + \left(\frac{R_k}{s_{hk}}\right)\cos\beta_k\right]}{\sum(w_t + Q_t)\sin\alpha_t} \quad (1)$$

Where: w_i —the dead weight of the i soil strip, the dead weight is composed of dry weight and the gravity of groundwater.

Q_i —ground and underground load of the i soil strip;

ϕ_j —The internal friction angle of the jst layer soil of the ist sliding crack surface;

α_i —The angle between midpoint tangent line and the horizontal plane of the *ist* sliding crack surface

R_k —The maximum resistance of the kst row soil nail on the failure surface

β_k —The angle between the axis of the *kst* row soil nail and the tangent of the failure surface ;

s_{hk} —The Horizontal spacing of the kst row soil nail

The following formula calculates maximal pullout resistance of the soil nail, and takes the minimum value.

According to the subjected to tension condition of soil nail：

$$R = \pi d_0 l_a \tau \tag{2}$$

Where:

d_0 —the aperture of soil nail；

l_a — the length of soil nail into stable soil at the side of the failure surface;

τ —bond strength of interface between nail and soil.

It is controversial for the selection of slope parameters. The parameters obtained in the laboratory are much higher than the actual parameter values of the landslide. The main reason is that the expansive soil in the laboratory can not reflect the full saturation and softening of the landslide, and the effect of the crack on the strength of expansive soil is not considered, the strength of expansive soil decreased 60-70% because of fracture. The dry-wet cycle aggravate the formation and development of cracks. The landslide of expansive soil slope has the characteristics of shallow layer because of the existence of cracks. So it is necessary to take into account the effect of crack in calculating the stability coefficient of expansive soil.

The depth of the expansive soil cracks of the test section is about 2m, so the depth of the crack is set to 2m. Slope soil layer is divided into the influence of the atmospheric layer and the non atmospheric layer, the intensity of the atmospheric impact layer needs to be reduced by a certain degree. The influence depth of the expansive soils by the atmosphere in the project is 2.5-3.0m, $c = 20KPa$， $\phi = 20°$； and the strength below 3m is not affected by the atmosphere, it's parameters are taken from the laboratory, $c = 98KPa$， $\phi = 18°$。

4.3 Calculation result

In the Figure 5, the slope rate of the upper slope is 1:1.5, and the slope rate of the lower slope is 1:1. The safety factor is 0.988 in rainy days, which is in the unsafe condition and needs to be strengthened. In Figure 6, the anchor length is 5m, anchor spacing is 2.5m, and the safety factor after reinforcement is 1.246. In Figure 7, the anchor length is 3m, the safety factor is 1.244. The calculation results show that the actual effect of the anchor bolt in upper side slope is not obvious, but the anchoring effect of the anchor bolts in the lower slope is significant. In addition, the change of anchor length in the anchor frame beam is not obvious to the anchoring effect. When the bolt length is 3m, it can meet the safety requirements, so it is recommended to select the anchor length 3-4 meters

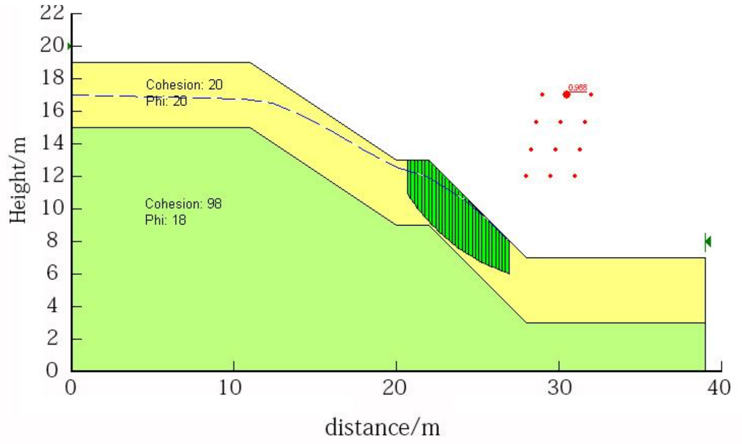

Fig.5.Stability of excavated expansive soil slope(rainy day)

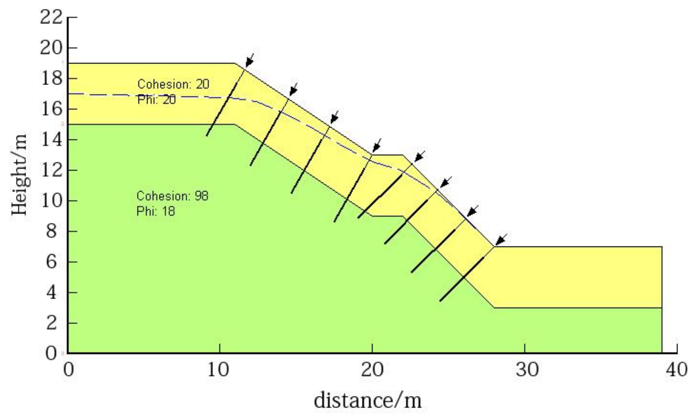

Fig.6.Stability of expansive soil slope after reinforcement(rainy day)

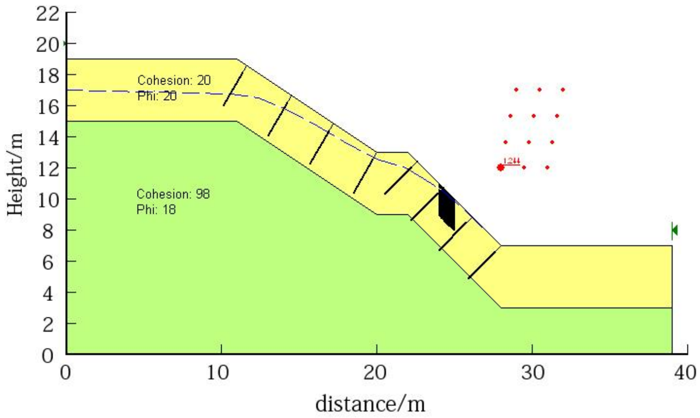

Fig.7. Stability of expansive soil slope after reinforcement(the length of anchor is 3m)

4.4 Monitoring effect

In order to monitor the stability of the expansive soil slope, we arranged the slope inclinometer on both sides of the slope. After experienced several large rain erosion, the monitoring data which was measured from the slope inclinometer show that the slope deformation is in stable condition, the slope deformation in the range of 2cm. Slope vegetation and the surrounding natural environment have formed a stable ecosystem. Facts show that the anchor frame beam is very effective for the protection of expansive soil slope.

5. Conclusions

(1) For expansive soil slope, anchor frame beam is an effective form of slope protection, and it is also a typical combination of vegetation protection and engineering protection, which is conducive to the stability of slope and the maintenance of ecological balance.

(2) The timely construction of slope excavation can effectively control the strength degradation caused by the swell-shrinking deformation of the expansive soil, and prevent the gradual change of the surface spalling became shallow landslide. The effect of the anchor mortar inclusion and the soil can prevent the slope from deep seated landslide.

(3) The anchor frame beam is an open system, which allows the soil to have a certain swell-shrinking and stress release, so as to achieve the purpose of slope stability.

(4) Planting turf in the framework, the plant roots are used to stabilize the slope, greening the environment， and the driver's visual fatigue can be improved, it does favor to the traffic safety.

Acknowledgements

The authors are grateful to the anonymous referees for their valuable remarks and helpful suggestions, which have significantly improved the paper. This research is supported by the national natural science foundation of China (Grant No: 41402267); the science and technology project of Henan Province (Grant No: 172102310748); the young backbone teacher support program of Henan province colleges and universities (Grant No: 2015GGJS-120);the key research project of the Henan education department (Grant No: 15B560008)； and the natural science basic research projects of the Henan education department (Grant No. 2010B410004)

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