A Method of safety factor for Slope consider the anti-sliding property of geotextile

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ABSTRACT

For the engineering of laying geotextile at the bottom, the stress of geotextile is mainly caused by the internal force of the embankment; it is assumed that the internal force of the embankment is borne by the reinforced cushion; the analysis method of slope stability is proposed. The results show that the simple slice method and the logarithmic spiral surface method of circular slip surface can well reflect the anti-sliding effect of the reinforced cushion, but the simplified circular slip surface method of the BISHOP has less evaluation effective; the anti-sliding effect of the reinforced cushion is related to the depth of the sliding surface in the foundation, and the anti-sliding effect is obvious when the slip surface is shallow; Conversely, the anti-sliding effect is small.

Keywords: stability of slope; geotextile; anti-sliding property; soft soil;

1 INTRODUCTION

When embankments are built on soft soil foundation, the construction of geotextile is often used in Engineering in order to improve the overall stability of the foundation. How to consider the effect of geotextile and analyze the stability of the slope, which is a great concern for engineers when the designing of this kind of dam.

So far, most methods of slope stability analysis are commonly used in engineering is based on the limit state design method. There are two ways to analyze the stability of slope with geotextile. One is the safety factor calculated by the circular arc sliding method, and the anti-sliding moment produced by the tensile force of the geotextile at the sliding surface is counted. The safety factor calculated by this method is very small, and it cannot objectively reflect the anti-sliding effect of the geotextile. The other method is the safety factor which is defined as the ratio of the ultimate load to the design load. As we all know, there is no good method to calculate the ultimate load for the foundation of layered soil when the difference of the strength index of each layer of soil. In addition the engineering safety factor of slope stability is defined by the strength reduction, which is unsuitable to compare with the ratio of the ultimate load. So these two ways have a lot of inconvenience in practical engineering.

Shen Zhujiang (1998) suggests a kind of distribution form of tensile force on the soil interface of reinforced cushion, and the safety factor according to the simplified circular slip surface method was calculated. Huang Chuanzhi and Miao Zhonghai (1999) suggest that the bearing force of the reinforced cushion bottom is ultimate frictional resistance and the ultimate load of the foundation is calculated. The safety factor is defined as the ratio of the ultimate load to the design load. It is suggested that the tensile force on the reinforced cushion is the sum of the following two parts: the earth pressure generated by the embankment and the ultimate frictional resistance of the reinforced cushion bottom. Huang Chuanzhi and Zhang Jing (1999) suggest that the bearing force of reinforced cushion is the internal force produced by the embankment, and the safety factor should be calculated according to the conventional slope stability analysis method.

At present, it has become a consensus that the influence of the tensile force of the reinforced cushion on the stability should be considered. However, it is necessary to further study how to consider the stress of reinforced cushion at the soil interface. This article is the continuation of Huang Chuanzhi and Zhang Jing (1999).

2 SLIDING MECHANISM OF GEOTEXTILE REINFORCED CUSHION

The authors of the paper hold that the forces sustained by the geotextile lay at the bottom of embankments and dams are internal forces, on the basis of which, an analytical method for the stability of slope is given.

When an embankment has built on the soft soil foundation and the geotextile are laid on the bottom of the embankment. We assume that geotextile have sufficient tensile strength and the geotextile are not broken or pulled out because of friction between embankment bottom and the foundation. So the overall damage should occur begin with the foundation of soil, so the part of sliding surface in the foundation can be considered only. As shown in Figure 1.

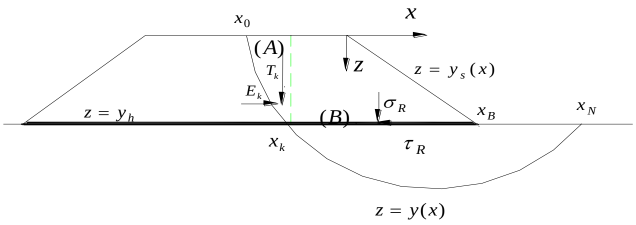

Fig.1 The possible sliding area of the foundation

The surface of the embankment is $z = y_s(x)$, Sliding surface is $z = y(x)$, embankment and foundation is $x_0 < x < x_N, y_s(x) < z < y(x)$,The area surrounded by the sliding surface and the slope surface is divided into two parts: (A) and (B).

In the region (A), besides gravity, there are horizontal force E_k and vertical shear force T_k on the interface produced by the embankment. In the region (B), there are horizontal tensile stress τ_R and vertical stress σ_R at each point of Geotextile reinforced cushion.

It should be satisfied equations in the embankment and foundation:

$$\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xz}}{\partial z} = 0 \tag{1}$$

$$\frac{\partial \sigma_z}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} = \gamma \tag{2}$$

On sliding surface $z = y(x)$, it should be satisfied.

$$\sigma y' - \tau = \sigma_x y' - \tau_{xz} \tag{3}$$

$$\sigma + \tau y' = \sigma_z - \tau_{xz} y' \tag{4}$$

$$\tau = \frac{1}{F_s}(c + (\sigma - u) tg\phi) \tag{5}$$

The following discussion will start with the five equations mentioned above. From equation (1), on the top of reinforced cushion $z = y_{h-}$ and bottom of reinforced cushion $z = y_{h+}$,the tensile force of geotextile reinforced cushion is:

$$\tau_R = -\tau_{xz}\Big|_{y_{h-}} + \tau_{xz}\Big|_{y_{h+}} \tag{6}$$

From equation (2), ignoring the self-weight of reinforced cushion, there are:

$$\sigma_R = \sigma_z\Big|_{y_{h+}} - \sigma_z\Big|_{y_{h-}} \tag{7}$$

According to (6) and (7) two formulas: the tensile force on the reinforced cushion is composed of the shear stress of the soil above and below the reinforced cushion, and the vertical force is the difference between the vertical force of the soil below and above the reinforced cushion. The above force on the reinforced cushion is generated by the embankment body, and the below force is the counterforce of the foundation to the embankment. Because the reinforced cushion works with the embankment and the foundation, the tensile strength of the reinforced cushion will change the soil force, but the total internal force is balanced. That is to say, due to the tensile properties of the reinforced cushion, the total axial internal force generated by the embankment and foundation along the reinforced cushion is equal to that of the reinforced cushion in the opposite direction.

When considering problems according to limit analysis, only the forces acting on the foundation of the building are usually considered, and the reactions of the foundation to the building are not considered. Under these conditions, E_k 、 T_k and τ_R 、 σ_R are internal force in the region D (consisting of (A), (B)) which enclosed by the slope surface and sliding face. If the tensile force outside the boundary point (x_k, y_h) of the reinforced cushion is not considered. Considering that the geotextile reinforced cushion may be non-horizontal due to the influence of foundation deformation in practical engineering, the geotextile reinforced cushion may also have pore (geotextile without pore, geogrid with pore) and other reasons, part of the internal force generated by the embankment will be transmitted to the foundation. Therefore, it can be considered that the internal force produced by the embankment body is partly borne by the reinforced cushion, and the other part is transmitted to the foundation through the reinforced cushion, while the weight of the embankment is borne directly by the foundation. The bear ratio of the internal force of the embankment body to the geotextile reinforced cushion $\eta_t (0 \le \eta_t \le 1.0)$ is as follows.

$$\left.\begin{aligned} \tau_R &= \eta_t \frac{d}{dx}\int_{y_s}^{y_h} \sigma_x dz \\ \sigma_R &= \eta_t \frac{d}{dx}\int_{y_s}^{y_h} \tau_{xz} dz \end{aligned}\right\} \tag{8}$$

If $\eta_t = 1.0$, then $\sigma_z\Big|_{y_{h+}} = \int_{y_s}^{y_h} \gamma dz$ 、 $\tau_{xz}\Big|_{y_{h+}} = 0$.

Compared with the Huang Chuanzhi and Miao Zhonghai (1999), the vertical force is the same, but the horizontal force is different. The difference is that the internal force produced by the deformation of the foundation is not taken into account. In fact, consider the possible sliding area of the foundation shown in Fig.

1: $x_k < x < x_N$, $y_s(x) < z < y(x)$,If the tensile force of the geotextile reinforced cushion outside the boundary point (x_k, y_h) is not taken into account, the horizontal external force in the region (B)is only E_k ; as shown in Formula (6), this force is equal to the total horizontal shear force acting on the surface of the geotextile reinforced cushion. When the geotextile reinforced cushion has no pores, and the laying of the reinforced cushion is horizontal (without considering the deformation of the foundation), there is no doubt that the horizontal external force E_k is borne by the geotextile reinforced cushion. In addition, there is no other horizontal force from the embankment. If the horizontal force acting on the top of the foundation still exists, the force should be the internal force produced by the foundation, which cannot be determined by the limit analysis without considering the deformation of the foundation. Huang Chuanzhi and Miao Zhonghai (1999) assume that this force is the ultimate frictional resistance at the interface of the reinforced cushion, which obviously overestimates the anti-sliding effect of the reinforced cushion.

3 ANALYSIS METHOD BASED ON LOGARITHMIC SPIRAL SLIDING SURFACE

For the sliding area shown in Figure 1, $x_0 < x < x_N, y_S(x) < z < y(x)$, Similar to the discussion in Huang Chuanzhi and Zhang Jing (1999) and Qian Jia Huan (1996), if the slip surface is taken as follows:

$$\left.\begin{aligned} x - x_R &= R_i e^{-\theta F_{\phi i}} \cos\theta \\ y - y_R &= R_i e^{-\theta F_{\phi i}} \sin\theta \\ R_{i+1} &= R_i e^{(F_{\phi i+1} - F_{\phi i})\theta_i} \\ x &\in (x_{i-1}, x_i) \quad i = 1, 2 \cdots \end{aligned}\right\} \tag{10}$$

The formula for calculating the safety factor is obtained.

$$F_s = M_r / M_0 \tag{11}$$

$$\begin{cases} M_\gamma = (1-\eta_t)\sum\limits_{i=1}\int_{x_{i-1}}^{x_i} [(w_{\gamma i} - u_i)tg\phi_i + c_i](y - y_R - y'(x - x_R))dx \\ +\sum\limits_{i=k+1}\int_{x_{i-1}}^{x_i} [(w_{\gamma i} - u_i)tg\phi_i + c_i](y - y_R - y'(x - x_R))dx \\ M_0 = (1-\eta_t)\sum\limits_{i=1}\int_{x_{i-1}}^{x_i} w_{\gamma i}(y - y_R)y'dx + \sum\limits_{i=k+1}\int_{x_{i-1}}^{x_i} w_{\gamma i}(y - y_R)y'dx \end{cases} \tag{12}$$

Comparing with the formula without considering the anti-sliding effect of Geotextile Reinforced cushion, the anti-sliding moment and sliding moment of geotextile reinforced cushion are multiplied by the factors $1-\eta_t$ considering the anti-sliding effect of geotextile reinforced cushion respectively when the sliding surface is located in the embankment body$[x_0, x_k]$. At that time $\eta_t = 0$, the anti-sliding effect of geotextile reinforced cushion was not considered. At that time $\eta_t = 1.0$, the internal force generated by the embankment was all borne by the geotextile reinforced cushion. At that time $0 \le \eta_t \le 1.0$, the internal force produced by the embankment was partly borne by the geotextile reinforced cushion and partly by the foundation.

4 ANTI-SLIDE EFFECT OF GEOTEXTILE REINFORCED CUSHION

The results are used for discussion. First, an example is analyzed: the embankment height is 6m, the slope is 1:2, and the top width is bigger. Foundation soil $\gamma' = 7(kPa/m^3)$, much strength was selected to calculate the safety factor. It is noted that the distance between the arc depth and the reinforced cushion is H_t , calculation is shown in Table 1. Simple slice method is shown as SSM, Bishop Simplified method is shown as BSM, This paper method is shown as TPM.

Table 1 Table of safety factor ($c = 10\ (kPa/m^2)^\circ\ \phi = 5^\circ$)

H_t (m)	η_t	0	0.5	0.75,	1.0,
2.0	SSM	0.863	1.024	1.167	1.414
	BSM	0.941	1.100	1.235	1.458
	TPM	0.937	1.107	1.247	1.469
4.0	SSM	0.795	0.867	0.914	0.969
	BSM	0.890	0.955	0.994	1.040
	TPM	0.911	0.982	1.015	1.051
6.0	SSM	0.789	0.829*	0.849	0.870
	BSM	0.892	0.927*	0.947*	0.967
	TPM	0.921	0.959*	0.972*	0.986*
8.0	SSM	0.802	0.830	0.840*	0.849*
	BSM	0.914	0.941	0.956	0.966*
	TPM	0.936	0.967	0.978	0.990

The results show clearly that the anti-sliding effect of geotextile reinforced cushion is related to the depth of the sliding arc, the shallower the depth of the sliding arc, the more obvious the anti-sliding effect; with the increase of the depth of the sliding arc, the anti-sliding effect becomes smaller and smaller.

For the overall stability of mean soil, because of the anti-sliding effect of geotextile reinforced cushion, the sliding arc depth of the minimum safety factor increased. In the Qingdao embankment project, the quick shear strength index is used to calculate the safety factor, as shown in Table 2:

The results show that the SSM and t TPM are reasonable, and the anti-sliding effect of geotextile

	η_t	0.0	0.50	0.75	1.0
Regardless of strength growth	SSM	0.731	0.770	0.792	0.810
	BSM	0.977	0.995	1.005	1.057
	TPM	0.866	0.911	0.921	0.930
Consider strength growth	SSM	0.950	1.048	1.086	1.118
	BSM	1.302	1.344	1.365	1.388
	TPM	1.178	1.261	1.280	1.327

reinforced cushion is obvious. The increase of the safety factor calculated by the BSM is obviously smaller. The larger proportion η_t by the reinforced cushion, the more remarkable the anti-sliding effect of the reinforced cushion.

In addition, when η_t is determined, the greater safety factor, the more significant the anti-sliding effect of the reinforced cushion; and the safety factor is very small, the anti-sliding effect of the reinforced cushion is also small. This reminds that η_t may not be a definite number, but a quantity that should be related to the safety factor.

Table 2 calculation for Qingdao embankment project

5 DETERMINATIONS OF OVERALL STABILITY ANALYSIS METHODS

According to Eq. (12), the total tensile force of geotextile reinforced cushion is determined by $T_R = \int_{x_k}^{x_B} \tau_R = \eta_t E_k$, E_k is the earth pressure determined by the embankment. However, that when η_t is determined, E_k is not the horizontal force when the embankment is in the ultimate state along with the sliding surface, but the horizontal force when the safety factor is F_s, and that is the earth pressure when the strength index is $\bar{c} = c / F_s$、 $tg\bar{\varphi} = tg\varphi / F_s$, When F_s is small, $\bar{c}$、$\bar{\varphi}$ are increased, thus E_k is reduced, and the tensile force on the reinforced cushion is reduced, so its anti-sliding effect is small. On the contrary, when F_s is large, $\bar{c}$、$\bar{\varphi}$ are reduced, so E_k is increased, and the tensile force of the reinforced cushion is increased, so its anti-sliding effect is greater.

It is well known that the widely used calculation formulas (such as simple slice method) have been used in practical engineering for decades, and engineers have accumulated rich experience. If our formulas are not comparable to these formulas, it will be inconvenient for engineers to apply them. In view of this fact, we should seek formulas that are comparable to the commonly used ones, and the formulas given above are based on this principle.

In practical engineering, the safety factor is always required to be greater than 1.0. As stipulated in the Code for Foundation of Port Engineering, except that the safety factor calculated according to the index of quick shear strength can be selected according to experience, the safety factor is always required to be greater than 1.1. Generally speaking, as far as overall stability is concerned, the engineering of laying geotextile reinforced cushion is mostly unsafe, so when designing and calculating, the safety factor is less than 1.0 is not allowed, equal to or slightly greater than 1.1 can meet the requirements of the code. Therefore, it is not important to consider the phenomenon that the smaller the safety factor, the smaller the anti-sliding effect of the reinforced cushion.

Based on the above analysis, the suggest is as follow: (1) when the anti-sliding effect of Geotextile Reinforced cushion is considering, the simple slice method (SSM)and the method of logarithmic spiral (TPM) can be used to calculate the stability of Geotextile Reinforced cushion. (2) Before more practical engineering examples and more application experience are obtained, the ratio of the reinforced cushion bearing the internal force of the embankment is taken $\eta_t = 0.75$, and the safety factor is still determined according to the requirements the Code for Foundation of Port Engineering. The safety factor can be determined according to the simplified Bishop method in the Code for Foundation of Port Engineering when the method of logarithmic spiral (TPM) can be selected. (3) The safety factor for tensile strength of geotextiles can be calculated according to the method was given in Huang Chuanzhi and Miao Zhonghai (1999).

6 CONCLUSIONS

1. According to the limit analysis theory, a part of the internal force produced by the embankment was beard by the geotextile reinforced cushion, and the other part of the internal force is supported by the foundation. The bear ratio of the internal force of the embankment body to the geotextile reinforced cushion is $\eta_t = 0.75$.

2. The commonly used slope stability analysis methods can be used to calculate the anti-sliding effect of Geotextile Reinforced cushion. The anti-sliding moment and sliding moment produced by the sliding arc above the surface of geotextile reinforced cushion can be multiplied by coefficient $(1-\eta_t)$. However, the anti-sliding effect of reinforced cushion with simplified Bishop Method (BSM) is obviously smaller. It is suggested to apply the simple slice method (SSM) and the method of logarithmic spiral (TPM) can be used to calculate the stability of Geotextile Reinforced cushion.

3. The calculation shows that the anti-sliding effect of geotextile reinforced cushion is related to the depth of sliding surface. The effect of shallow sliding is remarkable, but that of deep sliding is very small.

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