Investigation of the Stability of Geosynthetic Reinforced Soil Retaining Structure

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ABSTRACT: This paper utilizes numerical method to simulate the application of geosynthetic reinforced soil retaining structures. The SLOPE/W computer program is employed in this study to introduce the calculation of the reinforcement forces and the strengthening mechanical behavior of the soil structure as well as the failure mode. When using SLOPE/W program for analyzing geosynthetic reinforced soil retaining structure, each layer of the reinforcement is considered with the identical tensile force on the sliding surface on the same slice. Once the reinforcements committed pull-out failure, they bear different tensile forces. While the reinforcement committed break-off failure, the reinforcement tensile forces are the same. The unique component is the neat consideration for making the different required length of reinforcement. Under the circumstance of the failure surface not cutting through the reinforcement, it does not provide any resistance force. In addition, SLOPE/W is used for the slope stability analysis of the geosynthetic reinforced soil retaining structure built in FoGuang University, Ilan County, Taiwan. Slope condition in the absence of the reinforcement gives the factor of safety as 0.93, which does not meet the requirement of slope stability at all. While with the support of reinforcements, the safety factor is increased to 2.19, which matches the specification under normal condition.

INTRODUCTION

The application of geosynthetic reinforced soil retaining structures results in many advantages, such as reducing time and cost of construction, allowing larger deformation and settlement, reaching earthwork balance in the construction site, etc. However, despite of numerous advantages, the interaction mechanism between the soil and the reinforcement remains unclear. As a result, there are still many unsolved issues waiting for further study comprehensively.

This paper focus on studying the mechanical behaviors of geosynthetic reinforced soil retaining structures utilizing the SLOPE/W computer program, which has been commonly used in the field of geotechnical engineering. More specifically, the theoretical basis for evaluating the safety factor of the slope with the help of reinforcements is explored in detail. The contribution of reinforcing material is divided into two parts: the reinforcing approach theory adopted by the program and the reinforcing material parameters input in the program.

Using the SLOPE/W program for analysis of geosynthetic reinforced soil retaining structure, each layer of reinforcement is considered with the identical tensile force on the sliding surface on the same slice. In addition, once reinforcements committed pull-out failure, they bear different tensile forces. While the reinforcement committed break-off failure, the tensile forces are the same. The unique component is the neat consideration for making the different required length of reinforcement. Under the circumstance of the failure surface not cutting through the reinforcement, it does not provide any resistance force. As a result, the SLOPE/W computer program can predict the factor of safety for slope stability more rigorous and conservative than other computer programs.

This study also makes use of the SLOPE/W program for slope stability analysis to simulate the FoGuang University case for the purpose of understanding the system of strengthening slope stability and to further discuss the application of the computer program as well as the useful results from the prediction.

NUMERICAL COMPUTER PROGRAM SLOPE/W

SLOPE/W has been applied for decades in North America and thus accumulated a large number of application experience. The characteristics of the integrated problem formulation enable it to bring into play with eight assumptions for the method of slices to analyze and calculate either simple or complex slope stability problems. We can use SLOPE/W to analyze simple or complex shape of the slip plane, the pore water pressure, the nature of the soil, different loading methods and other geotechnical conditions, etc. SLOPE/W follows the limit equilibrium theory to model the analysis of different soil types, complex slip surface shapes of the slope, and the pore water pressure distribution. SLOPE/W provides a variety of different types of soil models, and the choice of deterministic and random input parameters as well. It can adopt a variety of method of slices, such as Morgenstern-Price, Spencer, Ordinary, Bishop, Janbu, Sarma, Corps of Engineering, and Lowe-Karafiath, to analyze all kinds of geotechnical conditions. For instance, the slip surface shape change, the pore water pressure conditions, the nature of the soil, different load mode, and so on.

The principle of SLOPE/W program analysis is the use of two-dimensional limit equilibrium theory, the method of slices for slope analysis and calculation of safety factors. Among them, the general limit equilibrium method (GLE) theory is the key analysis method recommended by the SLOPE/W program. The GLE method can more or less summarize the characteristics of the various limit equilibrium methods.

Strengthening mechanism of geosynthetic reinforced soil retaining structure in other computer programs are generally presumed reducing instability, which is based on the assumption that the reinforcement is already complete revision eventually and not being divided by the overall factor of safety during calculation. The safety factor may be used to limit the reinforcement with allowable loading, but the safety factor can't be directly applied to the calculation of the safety factor. Nevertheless, specific or allowable reinforcement coefficient can be directly used in the SLOPE/W calculation, by the option of reinforcing material labeled as "F of S dependent". The option allows the reinforcement factor of safety to be included in the stability calculation. This option is achieved through the Yes or No options: selecting YES will increase the shear calculation to consider the factor of safety. That is to say, reinforcement coefficient will be divided by the overall factor of safety in order to obtain the revised reinforcement coefficient. Alternatively, option No is used to define the reduction reinforcement factor directly. In conclusion, the equation for calculation the factor of safety (S_m) can be expressed as

$$S_m = \frac{S_{soil}}{FS} + \frac{S_{reinforcement}}{FS} \tag{1}$$

FOGUANG UNIVERSITY CASE DESCRIPTION

FoGuang University is located in southeast piedmont of Chonan Mountain in Choshi, Ilan, Taiwan. The location is 7km north of the downtown Ilan City and 6km south of Touchen Town. The area of this project site is about 56.6 hectares entirely. The terrain inclines from the west to the east. The elevation is about 120m in the southeast side and 435m in the northwest side. The average slope is about 46.7%. The proposed case of the inclination angle of the GRSRS is 63°~73° vertical per 10m to set up a platform, corresponding to the site condition and the requirement of traffic system. Basically, a berm is located every 10m in vertical direction and a flow catch basin is installed along it. The horizontal drainage pipes are installed 5m~8m spacing within the permeable filter for the dewatering purpose.

In this case, the allowable long-term reinforcement tensile strength for the standard design of the GRSRS built in FoGuang University is 100kN/m. The material type of the geosynthetics is polymer-fiber and the failure extension strain must be less than 15% corresponding to the ultimate reinforcement tensile strength.

This study analyzes the geosynthetic reinforcement for the purpose of strengthening the slope structure built in FoGuang University by using SLOPE/W computer program. This structure is designed with the reinforcing material with tensile strength of 100kN/m. In this study, 0.5m layer thickness of reinforcement is carried out for the stability analysis of GLE method of slices. In addition to considering the impact of slice lateral force, and assuming that the normal force and shear force in the opposite direction, shear force $X = f(x) E\lambda$ empirical formula is included in the calculation to be taken into account.

The soil employs the Mohr-Coulomb model, which is considered as the simple and commonly used in soil shear strength parameters of nonlinear model. The profile of geosynthetic reinforced soil retaining structure built in FoGuang University is designed with three platforms. The appearance of the reinforced structure and the geometry model are shown in Figures 1 and 2.

FIG. 1. Site condition of FoGuang University case

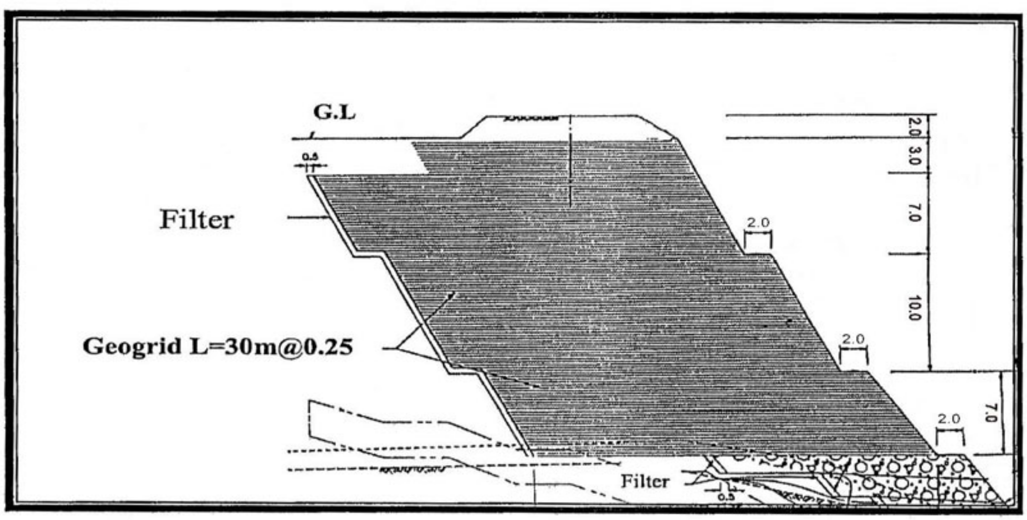

FIG. 2. Slope schematic diagram of FoGuang University case

In the simulation for the geosynthetic reinforced soil retaining structure built in FoGuang University, the parameters are chosen as follows: soil unit weight is 19.6 kN/m^3, cohesion is 10 kN/m^2, and friction angle is 31°; rock unit weight is also 19.6 kN/m^3, cohesion is assumed to be 200 kN/m^2 and the friction angle is 45°. SLOPE/W program analysis in this study selected the option "F of S Dependent" as Yes, and the option "Load Distribution" as Even Along Reinf. The simulation is performed for the case without reinforcement first. The predicted result from the analysis shows that the case in absence of the reinforcing circumstance, the safety factor is merely 0.92. After that, the case of considering the reinforcements of the soil retaining structure, the safety factor is increased to 2.19 as expected. The predicted sliding surface diagram is shown in Figure 3.

The structure's lowest portion named as the first tier, the above portion is the second tier, and the highest portion is the third tier. The width of berm on the GRSRS is 2m. For every 0.5m, one layer of reinforcement was buried with the length of 30m. The tensile forces in the reinforcement of GRSRS are of importance for the safety design. The distribution of tensile force distribution in the reinforcement layers are shown in Table 1. The predicted results obtained from the simulation of SLOPE/W program show that the reinforcement tensile forces in the first tier are 45.87 kN/m; the distribution of the reinforcement tensile forces in the second tier are the same as 45.87 kN/m; and the distribution of the reinforcement tensile forces in the third tier ranges from 2.04 kN/m to 45.87 kN/m. The predicted values of the reinforcement tensile forces in the three tiers under normal condition are concluded in Table 1.

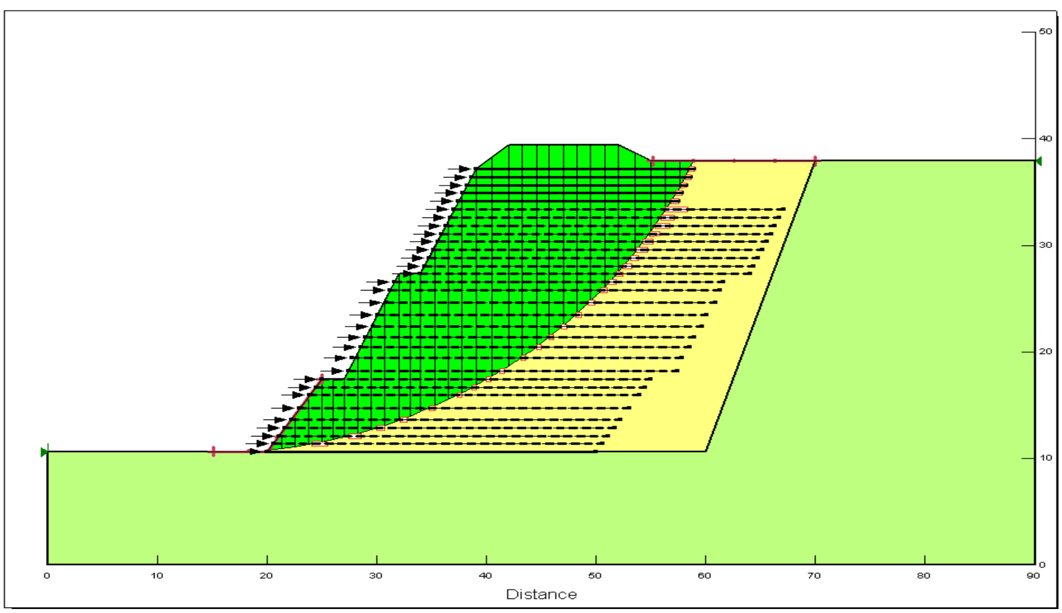

FIG. 3. Predicted diagram for FoGuang University reinforced soil retaining structure

Table 1. Predicted Values of The Reinforcement Tensile Forces in The Three Tiers

Geosynthetic Reinforced Soil Retaining Structure Layer	Layer	The First Tier	The Second Tier	The Third Tier
Reinforcement Tensile Force (kN/m)	Layer 20	45.87	45.87	5.46
	Layer 19	45.87	45.87	3.19
	Layer 18	45.87	45.87	3.19
	Layer 17	45.87	45.87	2.04
	Layer 16	45.87	45.87	2.04
	Layer 15	45.87	45.87	45.87
	Layer 14	45.87	45.87	45.87
	Layer 13	45.87	45.87	45.87
	Layer 12	45.87	45.87	45.87
	Layer 11	45.87	45.87	45.87
	Layer 10	45.87	45.87	45.87
	Layer 9	45.87	45.87	45.87
	Layer 8	45.87	45.87	45.87
	Layer 7	45.87	45.87	45.87
	Layer 6	45.87	45.87	45.87
	Layer 5	-	45.87	45.87
	Layer 4	-	45.87	45.87
	Layer 3	-	45.87	45.87
	Layer 2	-	45.87	45.87
	Layer 1	-	45.87	45.87

CONCLUSION

In this study, the stability of the geosynthetic reinforced soil retaining structure built in FoGuang University is investigated. From the predicted results, it is found that the factor of safety is merely 0.92 under the condition in the absence of the reinforcement. This value does not meet the requirement of slope stability safety factor. With the geosynthetic reinforcements of 100 kN/m tensile strength, the safety factor increases to 2.19, which match the design specifications.

From the predicted results of the reinforcement tensile forces of the FoGuang University case, it is found that the reinforcements bear 45.87 kN/m while the ultimate tensile strength is 100kN/m. This value is obtained by selecting Yes for the option set in F of S Dependent, which can provide the shear strength reduction in F of S Dependent. On the other hand, the reinforcements can provide the strength with the same value of the ultimate strength to make the factor of safety moving up relatively. However, during the design process, selecting Yes option is more in line with the actual situation of the reinforced soil retaining structure and more conservative.

As a final point, for the geosynthetic reinforced soil retaining structure built in Fo-Guang University investigated in this study, the predicted maximum tensile forces obtained from the simulation of SLOPE/W program in the first tier are 45.87 kN/m; the distribution of the reinforcement tensile forces in the second tier are the same as 45.87 kN/m; and the distribution of the reinforcement tensile forces in the third tier ranges from 2.04 kN/m to 45.87 kN/m. The predicted maximum values of the tensile forces in the reinforcements of the geosynthetic reinforced soil retaining structure built in FoGuang University is valuable for considering the overall stability.

ACKNOWLEDGMENTS

The authors appreciate the support of the National Science Foundation.

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Anchoring Effect of Oblique Crack under Axial Tension Load

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ABSTRACT: The total improved potential energy of the system with anchor was modified by mesh-less method. The discrete equations of the system were derived. According to the variation principle, the anchorage problem of plate with oblique crack was studied by numerical under axial tension. Based on different elastic modulus of the anchor and various anchoring scheme, the equivalent elastic modulus of the system with anchor, the maximum stress at crack tip and the rupture loads were researched. The best solutions were provided for improving equivalent elastic modulus and rupture load of structure. The results show that elastic modulus of anchoring material has essential effect on inhibiting crack propagation and improving mechanical properties of jointed crack mass. The elastic modulus of anchoring material is 1-30 times as elastic modulus of the base material, which can achieve better anchoring effect.

INTRODUCTION

Jointed surface plays a very important role in the mechanical properties and stability of rock. To improve the stability of jointed rock mass and reduce the weakening on mechanical characteristics of jointed rock mass is urgent problems in engineering and theory.

Many scholars at home and abroad have conducted a lot of researches in reinforcement mechanism of jointed rock bolt (Ge and Liu 1988). Liu and Zhuo (1995) adopted finite element equivalent smooth method to derive the constitutive relationship of anchored rock mass and analysis stochastic stability of jointed rock mass. Li and Zhu (1998) constructed the constitutive relation of reinforced jointed rock mass from the point of view of the energy. This model was used in engineering practice and good results were obtained. Ye (1995) through simulation experiments of the jointed rock mass with several different angles, the bolt can not only improve the peak strength, elastic modulus of jointed rock mass, but also control the displacement of joint surface when bolt parallels the principal compressive stress or bolt and joint surface into 30^{o} angle. Zeng et al. (2004) carried out indoor model test. The results indicate that bolt can play a key role when bolt and joint into 90^{o} and the specimen deformation domain scope is the largest when the optimal anchoring angle. The results illustrate that this anchoring method makes full use of the mechanical properties of rock mass. Zhang (2009) made quantitative analysis of anchored jointed rock mass by model test. The results show the effect of different anchoring position and orientation on mechanical properties of jointed rock mass.

In this paper, the anchoring effects of different positions and orientations and elastic modulus of CFRP (Carbon Fiber-Reinforced Plastics) on mechanical properties of jointed rock mass will be researched by numerical.

THE DISCRETE MODEL OF MESH-LESS METHOD

The total modified total potential energy of jointed rock mass with CFRP is as follows.

$$\Pi = U_{\Omega 1} + U_{\Omega 2} = \iiint_{\Omega_1} \frac{1}{2}\varepsilon^T \cdot \sigma \, d\Omega_1 + \iiint_{\Omega_2} \frac{1}{2}\varepsilon^T \cdot \sigma \, d\Omega_2 - \iiint_{\Omega_1} u^T \cdot f \, d\Omega_1$$

$$- \iint_{\Gamma_{\bar{t}}} u^T \cdot \bar{f} \, d\Gamma_{\bar{f}} + \iint_{\Gamma_u} \frac{\beta}{2}[q_s^T u - \bar{u}_\xi]^T \cdot [q_s^T u - \bar{u}_\xi] \, d\Gamma_u \qquad (1)$$

Where, θ is the direction angle at constraint boundary. q_s^T =[cosθ, sinθ] is a direction cosine array on constraint boundary.

For the 2-D problem, the generalized displacement array of node is as follows.

$$[u^*]^T = [u_1^*, v_1^*, u_2^*, v_2^*, \cdots, u_n^*, v_n^*] \qquad (2)$$

The approximate displacement u^h at any point in the elastic domain can be fit by the generalized node displacement u^* within the influence domain of this point.

$$u^h = \varphi u^* \qquad (3)$$

Where, $\varphi=[\varphi_1,\varphi_2,\ldots,\varphi_n]$ is shape function matrix. $\phi_I = diag[\varphi_I, \varphi_I]$, φ_I (I=1,2,…,n)are shape functions.

Strains at any point within the domain are as follows.

$$\varepsilon=[\varepsilon_x, \varepsilon_y, \cdots, \gamma_{xy}]^T=Cu^* \qquad (4)$$

Where, $C=[C_1, C_2, \cdots, C_n]$ is a derivative matrix of shape functions.

$C_I = \lfloor \varphi_{I,x} \quad 0;0 \quad \varphi_{I,y};\ \varphi_{I,y} \quad \varphi_{I,x} \rfloor$,(I=1,2,…,n)

Stresses at any point within the domain are as follows.

$$\sigma=[\sigma_x, \sigma_y, \cdots, \tau_{xy}]^T=DCu^* \qquad (5)$$

Where, D is a elasticity matrix.

The modified total potential energy of the system was put into the minimum potential energy principle to obtain discrete equations of the system.

$$K\,u^* = F \qquad (6)$$

Where, K and F are as follows. $R=q_s\,q_s^T$.

$$K = \int_\Omega C^T DC\, \mathrm{d}\Omega + \beta \int_{\Gamma_u} \phi^T R \phi\, \mathrm{d}\Gamma_u$$

$$F = \int_\Omega \phi^T f\, \mathrm{d}\Omega + \int_{\Gamma_\sigma} \phi^T \bar{f}\, \mathrm{d}\Gamma_\sigma + \beta \int_{\Gamma_u} \phi^T q_s \bar{u}_\xi\, \mathrm{d}\Gamma_u$$

REINFORCEMENT SCHEME

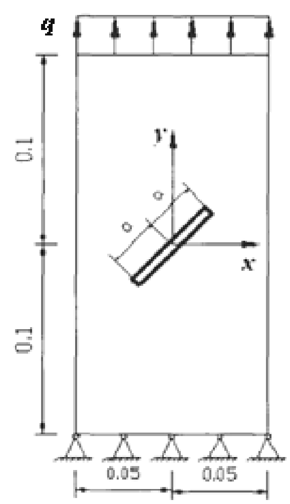

FIG. 1. Plate with a central oblique crack

The rectangular plate is 100mm×200mm, as shown in Fig.1.

The central inclined crack length is 10mm. Its inclined angle is 45°.

The upper boundary of rectangular plate bears uniform tension load q=l.0MPa/m, the lower boundary bears hinge constraint.

The anchoring effect of two positions and CFRP lying different angles on each position was compared to get the best anchor position.

THE MODIFIED TENSILE STRESS CRITERION

The modified maximum tangential tensile stress criterion (Zhang et al. 2012) is adopted, which can be depicted as follows: (1) It is assumed that cracks propagate only in the principal normal plane at a point along crack front in local coordinates. (2) The crack propagation direction can be determined along the direction of the maximum tangential tensile stress $\sigma_{\theta\max}$ in the principal normal plane. The local coordinates at crack front are shown in Fig.2. The symbols n, b, τ, θ, r are defined as principal normal, binomial, tangent, polar tangential and radial coordinates, respectively. The planes, $n\tau$, τb and bn, are defined as osculating plane, bi-normal