New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)
© 2008 Taylor & Francis Group, London, ISBN 978-0-415-45775-0

Parametric study of geosynthetic reinforced soil retaining structures

S.J. Chao
National Ilan University, Ilan, Taiwan

ABSTRACT: Geosynthetic reinforced soil retaining structures (GRSRS) are composed of backfill materials and reinforcements, which are relatively complicated considering the soil-structure interaction. The complex soil-reinforcement system of GRSRS can be best analyzed by the finite element method (FEM). Finite element method is used in this study to analyze the geosynthetic reinforced soil retaining structures for more understanding. A parametric study is performed using the finite element model to comprehend the mechanical behavior of geosynthetic reinforced soil retaining structures. The factors affecting the wall performance, including backfill material, wall height, wall inclination, and offset for two-tiered construction technique are investigated. Last of all, design recommendations for GRSRS are proposed.

1 INTRODUCTION

Geosynthetic reinforced soil retaining structures (GRSRS) are used commonly in geotechnical engineering practices in Taiwan recently (Chou, 1992) as well as in the whole world (AASHTO, 1996; FHWA, 1997; CERF, 1998; GEO, 2000). Sand and gravel are preferred to be the backfill materials for constructing geosynthetic reinforced soil retaining structures. However, the soil deposits in the construction site can be any kind of materials. Following the principle of balancing the total amount of cutting and filling to avoid construction pollution, accepting cohesive soils as the backfill materials for the purposes of economical and ecological considerations is unavoidable today in Taiwan. Therefore, the range of the acceptable backfill materials covers between GW and CL nowadays.

On the other hand, GRSRS are composed of backfill materials and reinforcements, which are relatively complicated in considering of the soil-structure interaction. Fortunately, the complex soil-reinforcement behavior of GRSRS can be best analyzed by the finite element method (FEM). In this study, a commercial finite element analysis program PLAXIS is used as a numerical tool to capture the mechanism of GRSRS. PLAXIS is specifically intended for the analysis of deformation and stability in geotechnical engineering projects.

A parametric study is performed using the PLAXIS finite element program to understand the mechanical behavior of reinforced soil retaining structures. The factors affecting the wall performance, including backfill material, wall height, wall inclination, and offset for two-tiered construction technique are investigated. Finally, design recommendations for geosynthetic reinforced soil retaining structures are proposed.

2 PROBLEM DESCRIPTIONS

2.1 *FEM model*

In the finite element numerical model, the GRSRS are assumed to be plain strain condition. The backfill materials are simulated using the Mohr-Coulomb model while the reinforcements simply using the elastic tensile model. The boundary conditions are chosen to be fixed on the bottom for both directions and on the backside for horizontal direction.

A special option termed as ϕ-c reduction is available in PLAXIS to compute safety factors. In the ϕ-c reduction approach, the soil shear strength parameters $\tan \phi$ and c of the soil are successively reduced until failure of the reinforced soil retaining structure occurs. The strength of interfaces, if used, would be reduced in the same way.

The factor of safety (FS) of the GRSRS is used to define the value of the soil strength parameters at a given stage in the analysis:

$$FS = \frac{\tan \varphi_{input}}{\tan \varphi_{reduced}} = \frac{c_{input}}{c_{reduced}} \quad (1)$$

where the strength parameters with the subscript *input* refer to the properties entered in the material sets and parameters with the subscript *reduced* refer to the reduced values used in the analysis. The strength parameters are successively reduced repeatedly until failure of the structure occurs. At this point the factor of safety is given by:

$$FS = \frac{\text{available strength}}{\text{strength at failure}} \tag{2}$$

This approach resembles the method of calculation of safety factors conventionally adopted in slip-circle analyses. When using ϕ-c reduction in combination with advanced soil models, these models will actually act as a standard Mohr-Coulomb model, since stress-dependent stiffness behavior and hardening effects are excluded. The stress-dependent stiffness modulus at the end of the previous step is used as a constant stiffness modulus during the ϕ-c reduction calculation.

2.2 *Material properties*

The typical properties of the backfill materials used in the simulation are chosen as follows (unless mentioned elsewhere in this paper): the unit weight of the sand = 19.5 kN/m^3, the Elastic modulus E = 18900 kN/m^2, the Poisson ratio $\nu = 0.3$, the friction angle $\phi = 27 \sim 48°$; on the other hand, the unit weight of the clay = 17 kN/m^3, the Elastic modulus E = 9800 kN/m^2, the Poisson ratio $\nu = 0.35$, the friction angle $\phi = 0°$, while the unconfined compression strength $c_u = 25 \sim 50$ kN/m^2. The typical backfill material properties of the sand and the clay used in the PLAXIS program are listed in Table 1.

The geosynthetic reinforcements are slender objects with a normal stiffness for tension but with no bending stiffness. That is to say, reinforcements can only sustain tensile forces and no compression. Finite element methods have been used extensively to study this type of elements. In PLAXIS program, the geosynthetic reinforcements are modeled as Geotextile elements. The only material property of the Geotextile element is elastic axial stiffness EA entered in units of force per unit width. Geotextile element cannot sustain compressive forces. The material property of geosynthetic reinforcement used in this study, based on the test conducting in the laboratory, EA = 6000 kN/m.

Table 1. Backfill material properties of the sand and the clay.

Parameter	Name	Sand	Clay	Unit
Material model	Model	Mohr-Coulomb	Mohr-Coulomb	–
Soil unit weight	γ	19.5	17	kN/m^3
Young's modulus	E	18900	9800	kN/m^2
Poisson's ratio	ν	0.3	0.35	–
Cohesion	c	0	25 ∼ 50	kN/m^2
Friction angle	ϕ	27 ∼ 48	0	°

3 PARAMETRIC STUDY

3.1 *Backfill material*

Taking into consideration the application of GRSRS, it would be the most benefit for using the site soil as the backfill materials. Therefore, a variety of backfill materials constructing the GRSRS are simulated by FEM to evaluate the influence on FS. A typical profile of the geosynthetic reinforced soil retaining wall is shown in Figure 1.

The influence on the factor of safety due to different values of cohesion of the backfill material is investigated first. According to Hunt (1985), the cohesion of clay ranges form 25 kN/m^2 to 50 kN/m^2. Therefore, 10 different cohesions with an increment of 2.5 kN/m^2 are used to perform the finite element analysis to predict the FS of the GRSRS.

The predicted results for different clayey backfill materials are shown in Figure 2. From Fig. 2, it can be seen that the FS for the reinforced clay wall is in the range of 2 ∼ 4. The values of FS of the GRSRS increase with increasing the values of cohesions.

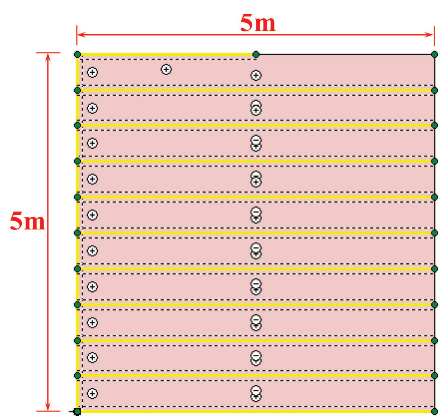

Figure 1. Typical profile of the geosynthetic reinforced soil retaining wall.

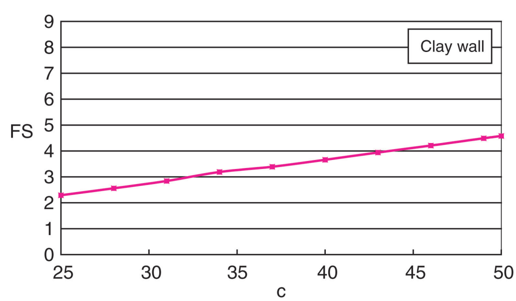

Figure 2. Effect of cohesion on FS for GRSRS.

The influence on the factor of safety due to different values of soil friction angles of the backfill material is also studied. According to Das (1994), the soil friction angle typically ranges between 27° ~ 48°. Similarly, 10 different friction angles with an increment of 2° are selected to perform the analysis to predict the FS of the GRSRS.

The predicted results for different granular backfill materials are illustrated in Figure 3. From Fig. 3, we can find that the values of FS of the GRSRS increase with increasing the values of soil friction angles quite linearly.

3.2 *Wall height*

The designed wall height of the GRSRS in the geotechnical practice in Taiwan are challenging worldwide all the time. Thus, the influence on FS due to wall height is necessarily to be considered.

The limitation of the wall height is assumed to be 10 meter in this study. According to the general regulation, the length of the reinforcement has to be equal to 70% of the wall height at the least. Therefore, 10 different walls in height ranging from 10 m to 1 m with a constant width of 7 m are analyzed.

In order to study the effect of the wall height on the values of FS for the GRSRS, the value of soil friction angle is set to be 45° for sandy backfill material, while the value of cohesion is set to be 30 kN/m^2 for clayey backfill material at this point. The predicted results for the granular and the clayey retaining walls are both shown in Figure 4. From Fig. 4, it can be clearly seen that higher wall dimension obtains lower FS for the GRSRS.

In addition, the stability of sandy retaining wall is generally safer than that of clayey retaining wall by examining Fig. 4. It is noted that the value of FS of sandy retaining wall is lower than that of clayey retaining wall under the extreme condition with very low wall dimension. The reason for this result is that under such condition, the overburden pressure is not big enough to provide adequate frictional resistance for sandy reinforced wall comparing to the contribution of cohesion for clayey reinforced wall. Anyhow, the present regulation for the limitation of wall height for each individual tier (5 meter) is rather conservative according to the predicted results for both the sand walls and the clay walls.

3.3 *Wall inclination*

The effect of wall inclination of the GRSRS is also an interesting issue and worthy to do some research. Usually, we can separate the GRSRS from slope and wall by a boundary wall inclination angle as 70°. In this section, 10 different values of wall inclination angles between 70° and 90° are used. The predicted results with different wall inclination angles for both the sand and the clay retaining walls are shown in Figure 5. From Fig. 5, it can be seen that the steeper wall provides lower values of FS for sand wall. However, the values of FS for clay wall are almost remained unchanged with different wall inclination angle.

3.4 *Offset distance*

Due to the fact that tensile stresses in the reinforcements increase rapidly with height, current design requires multi-tiered system for high GRSRS (Leshchinsky and Han, 2004). Therefore, the effect of offset distance between adjacent tiers within a GRSRS

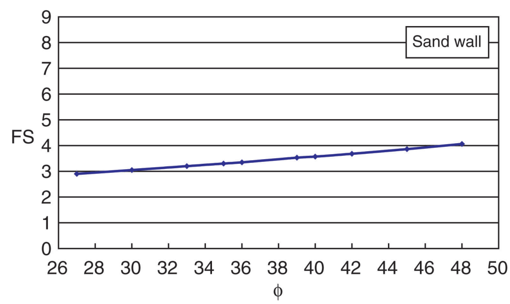

Figure 3. Effect of soil friction angle on FS for GRSRS.

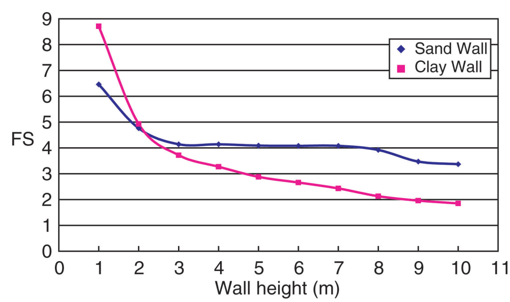

Figure 4. Effect of wall height on FS for GRSRS.

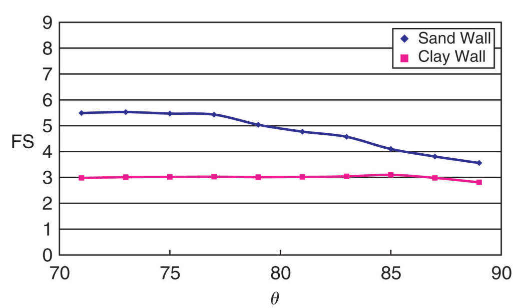

Figure 5. Effect of wall inclination on FS for GRSRS.

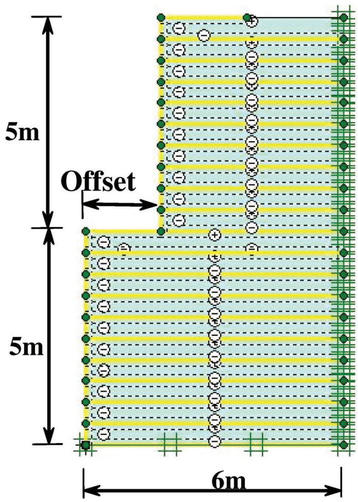

Figure 6. Profile of a two-tiered system for GRSRS.

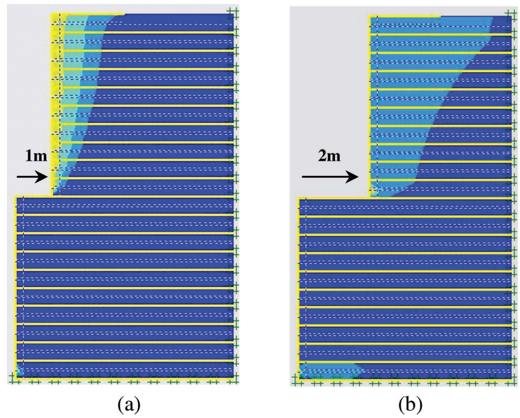

Figure 7. Typical upper tier failure conditions of (a) sand wall and (b) clay wall.

system is worthy examined in detail. For the purpose of simplification, a two-tiered system is used in this section for both the cases of the sandy reinforced walls and the clayey reinforced walls. Each tier height in this model is set to be a constant value of 5 m as shown in Figure 6.

The effect of offset distance is investigated by performing the finite element analysis to predict the values of FS for both the sand walls and the clay walls with various offsets distances. The offset distances are chosen from 0 m to 2 m with an increment of 0.25 m for each simulation process.

For the sand wall, it can be found that the failure surface always pass through the two-tiered system all the way down to the base of the wall for those cases with offset distance smaller than 0.75 m. when the offset distance increases to 1 m and further, the failure surface can only be found in the domain of the upper tier region as shown in Figure 7(a). On the other hand, for the clay wall, the offset distance needs to be as large as 2 m to reach the condition of purely upper tier failure as shown in Figure 7(b). The offset distance for a clay wall system is thus suggested to be larger comparing that for a sand wall system.

4 CONCLUSIONS

FEM can be utilized to simulate the complicated behaviors of geosysthetic reinforced soil retaining structures. In this study, a commercial finite element analysis program PLAXIS is used as a numerical tool to capture the mechanism of GRSRS and thus provides useful information in detail.

A comparative parametric study for GRSRS, including backfill material, wall height, wall inclination, and offset distance, is carried out and described in detail. Finally, design recommendations for geosysthetic reinforced soil retaining structures are proposed as follow.

1. The predicted results for different clayey backfill materials indicate the values of FS of the GRSRS increase with increasing the values of cohesions.
2. The predicted results for different granular backfill materials prove the values of FS of the GRSRS increase with increasing the values of soil friction angles linearly.
3. The predicted results for the granular and the clayey retaining walls both demonstrate that the higher wall dimension provides lower FS for the GRSRS.
4. Steeper wall provides lower values of FS for sand wall, but not the case for clay wall.
5. The offset distances for two-tiered GRSRS system are suggested larger than 1 m for sand wall, while 2 m for the clay wall. Adopting the suggesting values of the offset distance can guarantee the GRSRS to develop the purely upper tier failure condition and thus reduce the tensile stresses in the reinforcements within the lower tier.

REFERENCES

AASHTO, 1996. Standard Specifications for Highway Bridges, With 197 Interims, American Association of State Highway and Transportation officials, Fifteenth Edition, Washington, D.C, USA.

Chou, N.N.S. 1992. Performance of Geosynthetic Reinforced Soil walls, Ph.D. Dissertation, University of Colorado.

Das, B.M. 1994. Principles of Geotechnical Engineering, PWS Publishing Company.

FHWA, 1997. Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines, Pub. No. FHWA-SA-96-071.

Geotechnical Engineering Office, The Government of the Hong Kong Special Administrative Region, 2000. Technical Guidelines on Landscape Treatment and Bio-engineering for Man-made Slopes and Retaining Walls, GEO Publication No. 1/2000.

Highway Innovative Technology Evaluation Center, a service center of Civil Engineering Research Foundation, 1998. Guidelines for Evaluating Earth Retaining Systems, CERF Report No. 40334, March 1998.

Hunt, R.E. 1985. Geotechnical Engineering Techniques and Practices, McGraw-Hill Book Company.

Leshchinsky, D. and Han, J. 2004. Geosynthetic Reinforced Multitiered Wall, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 130, No. 12, pp. 1225–1235.