

DETERMINATION OF OPTIMUM TENSILE STRENGTH OF GEOGRID REINFORCED EMBANKMENT

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ABSTRACT: Soil-reinforcement interaction is a key issue in the design of geogrid-reinforced soil structures. Therefore, it is important to analyze the interaction mechanism between the soil and geogrid reinforcement. A multi-layered geogrid-reinforced embankment with steep slope was proposed for this study. This embankment was reinforced by five layers of biaxial geogrids. According to the stability of reinforced earth structures and the mechanical interaction between geogrid and soil analysis, the optimum tensile strength of geogrid for each of layers was determined. This must consider the factor of safety, soil-geogrid interface shear stress and the horizontal and vertical displacements of soil and the mobilized geogrid. Consequently, a series of soil-geogrid interaction numerical models were developed to simulate the reinforcing systems. Simulation was performed using finite difference-based software FLAC version 4.00 (Itasca, 2000). Since the displacements of soil and geogrid reinforcement are relatively small in this study, the determination of optimum tensile strength of geogrid was strongly influenced by factor of safety and soil-geogrid interface shear stress.

KEYWORDS: embankment, reinforcement, geogrid, tensile strength, finite difference analysis

1. INTRODUCTION

It has been found that the interaction property between soil and geogrid is an important factor for the design of these structures. A geogrid, because of its structural characteristics, especially its aperture structure, exhibits a significant mutual effect with the surrounding soil. This mutual effect is due to friction between the geogrid surface and soil particles, as well as the passive resistance of cross direction ribs of geogrid. To be effective, the geogrid reinforcements must intersect potential failure surfaces in the soil mass. Strains in the soil mass generate strains in the reinforcements, which in turn, generate tensile loads in the reinforcements. These tensile loads act to restrict soil movements and thus impart additional soil shear strength. This results in the composite soil/reinforcement system having significantly greater shear strength than the soil mass alone.

Existing literature shows that laboratory and analytical studies performed in the past have shown promising results. The use of geogrid reinforcement can significantly increases the factor of safety of the embankments [1] and the bearing capacity of foundation [2] also reduces the settlement due to transient loading [3]. Soil reinforcement interaction is a key issue in the design of reinforced soil structures. Therefore, it is important to analyze the interaction between the soil and geosynthetic reinforcement. The use of numerical techniques, such as the finite difference method, for examination of the mechanical response of geosynthetic-reinforced soil structures has become increasingly popular.

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The objective of the research reported in this paper is to establish a rational design method to determine the optimum tensile strength of geogrid as reinforcement in embankment. Attention is also focused on the mechanical behavior of soil-geosynthetic interaction.

2. GEOMETRY OF MODEL

The 13 m of embankments with slopes as 45 degree as presented in Figure 1 was being investigated in this study. This embankment was reinforced by five layers of biaxial geogrids. The vertical spacing of geogrid is varied from 1.5 m up to 3 m. A nominal surcharge of 50 kPa has been used for modeling the traffic load as commonly adopted in practice.

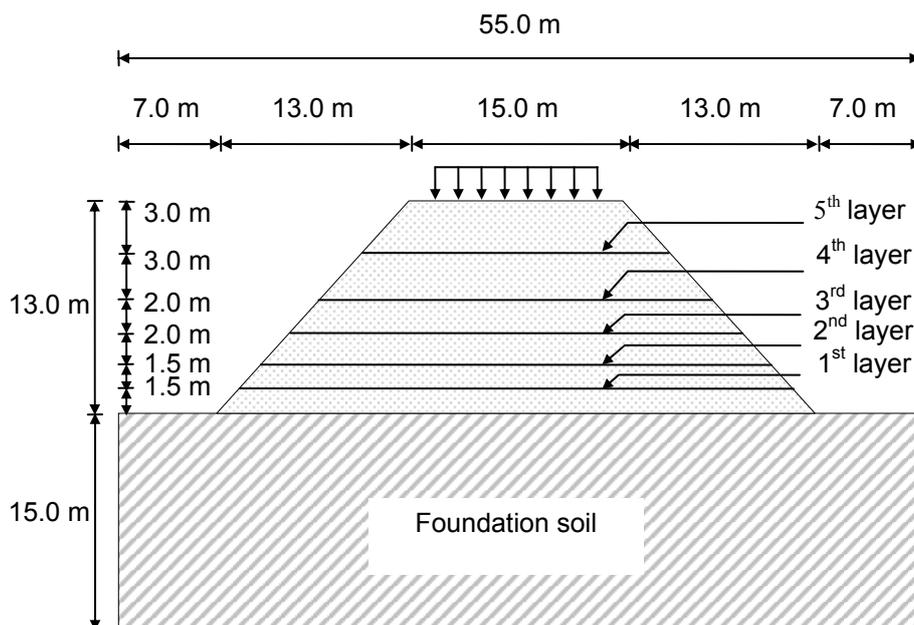


Figure 1. Geometry of model of reinforced steep embankment slope

3. MATERIAL PROPERTIES

The fill and the foundation soil materials were both represented by Mohr-Coulomb elements. Table 1 summarizes soil properties used in the modeling.

Table 1. Physical properties of soil material

Property	Type	
	Earth structures	Foundation soil
Mass density, γ_d (kN/m ³)	19	20
Wet density, γ_t (kN/m ³)	24	25
Cohesion, c (kPa)	1	3
Friction angle, ϕ (deg)	30	35

The reinforcement was modeled as a series of cable elements that have no flexural rigidity and can only resist tension. Biaxial geogrids were used as reinforcement in this study. The reinforcement properties used in the modeling is summarized in Table 2.

Table 2. Mechanical properties of the geogrid reinforcement

Property	Value
Mass/unit area, M_A (g/m^2)	340
Aperture size, length (mm) x width (mm)	16 x 16
Thickness, t (mm)	5
Stiffness modulus per unit width, J (N/m/m)	1.8×10^9
Tensile strength per unit width, T (kN/m)	20~240
Bond strength, τ (N/m)	5000
Bond friction angle, δ (deg)	35

4. CONCEPT OF REINFORCEMENT DESIGN

The solution of installation of the reinforcement layer inside the embankment favors better reinforcement anchorage strength, particularly for geogrid, for which all the grid bearing members will be buried inside the good quality of fill material [4].

In order to determine the optimum tensile strength of geogrid in reinforced embankments, the tensile strength of geogrid reinforcement is varied from 20 up to 240 kN/m and also it was assumed that each layer of geogrid has same tensile strength. Based on the assumption that foundation soil is strong enough to receive the load from upper structure, slope or shallow slope failure will occur in the embankment structure [5].

In this study, the numerical modeling of geogrid-reinforced slopes is performed using the FLAC (Fast Lagrangian Analysis of Continua) program version 4.0. FLAC is an explicit finite difference program that performs a Lagrangian analysis. Numerical mesh was created as a user selected-grid model to meet the soil-geogrid interface analysis. The fineness of zoning affects the accuracy of the factor-of-safety calculation; the finer the zoning, the better the accuracy of the solution [6].

5. RESULT AND DISCUSSIONS

5.1. INFLUENCE OF FACTOR OF SAFETY

The slope stability factor of safety is taken from the critical surface requiring the maximum reinforcement. Detailed design of reinforced slopes is performed by determining the factor of safety with sequentially modified reinforcement until the target factor of safety is achieved. When factor of safety is equal to 1, the slope is in a state of impending failure. Generally, a value of 1.5 for the factor of safety with respect to strength is acceptable for the design of a stable slope.

When reinforcement of various tensile strengths is installed, strain and stress of soil-geogrid reinforcement and its safety factor change will be measured for optimized reinforcement design. The failure plot is displayed as the filled contour plot of shear strain-rate contours as shown in Figure 2. For unreinforced embankment, it has the slope failure type (Figure 2 a). While, for geogrid-reinforced embankment with tensile strength of 100 and 240 kN/m, it is shown the shallow slope failure type was occurred (Figure 2 b and c).

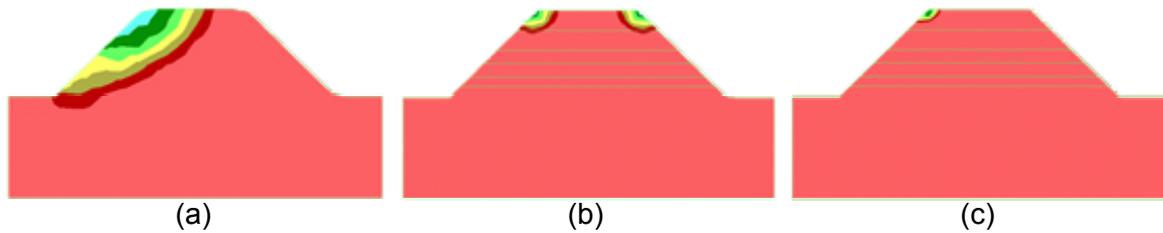


Figure 2. Shear-strain rate contour for (a) unreinforced embankment, (b) reinforced embankment T=100 kN/m, and (c) T=240 kN/m.

For the embankment structure in this study, factor of safety have been analyzed for various tensile strength of geogrid, from 20 kN/m of low-strength reinforcement up to 240 kN/m of high-strength reinforcement and the result is shown in Figure 3.

For unreinforced embankment, the safety of factor was 0.79 and 20 kN/m low-strength reinforcement was 0.98. Factor of safety was tended to increase linearly with the reinforcement strength increase. In this case, factor of safety was kept constant at 160 kN/m. According to the USACE, the minimum allowable factor of safety of 1.5 was satisfied by tensile strength at least 100 kN/m for factor of safety as 1.63.

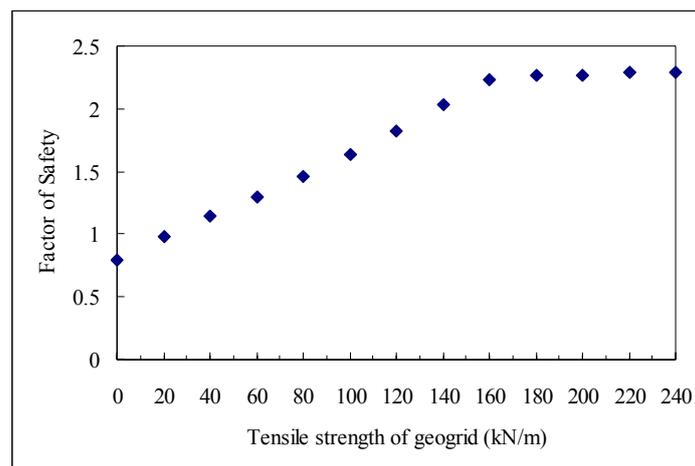


Figure 3. Factor of safety

5.2. INFLUENCE OF STRESS DISTRIBUTION

The main target of reinforcement is to inhibit the development of tensile stresses in the soil and, consequently, to support the tensile stresses that the soil cannot withstand. The tensile stress supported by geogrid improves the soil mechanical properties by reducing the shear stress that has to be carried by the soil and by increasing its available shearing resistance. Hence, total stress of soil at the soil-reinforcement interfaces has been reduced.

Soil at the location of geogrid reinforcement installed has the variety of shear stress distribution for each layer as shown in Figure 4 ~ Figure 6. At the first layer, soil has shear stress at most 69.1 kN/m² at the center. For the second until fifth layer, soil has shear stress at most respectively as 62.7, 56.6, 51, and 32.6 kN/m² at the center. The reinforcement has variety of stress depend on its material strength. The stress in reinforcement is as high as tensile strength but if it is below the shear stress in soil, reinforcement is to be failure. The optimum tensile strength of geogrid was analyzed for each layer and it tended decreasing for the upper layer of reinforcement.

Considering the requirement that stress of reinforcement is higher than soil shear stress, as depicted in Figure 4 ~ Figure 6, geogrid reinforcement at the first layer with tensile strength at least 100 kN/m is considered good, as it is higher than soil shear stress. The second and third layer reach the optimum tensile strength at 80 kN/m and for the fourth and fifth layer at 60 kN/m.

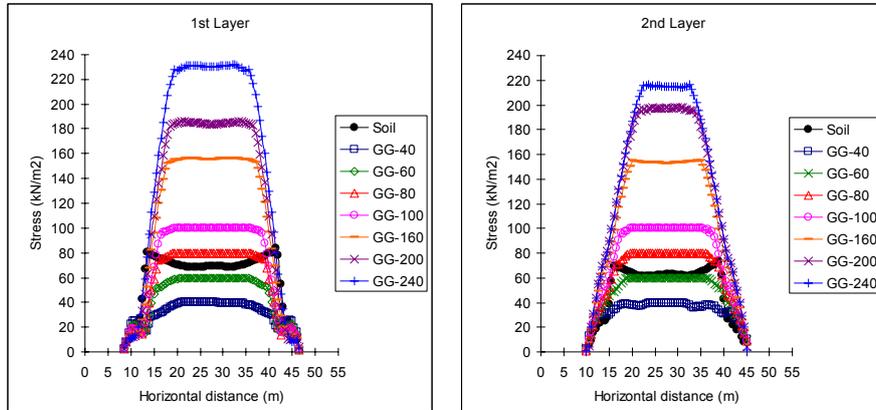


Figure 4. Stress distribution along the first (a) and the second (b) layer of geogrid reinforcement

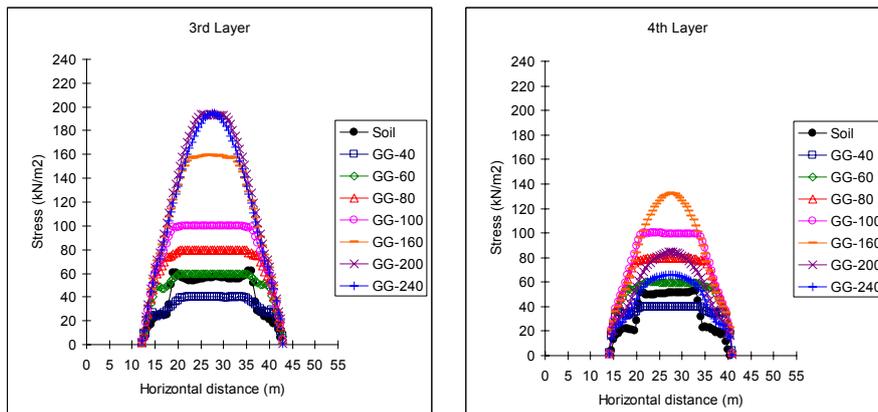


Figure 5. Stress distribution along the third (a) and the fourth (b) layer of geogrid reinforcement

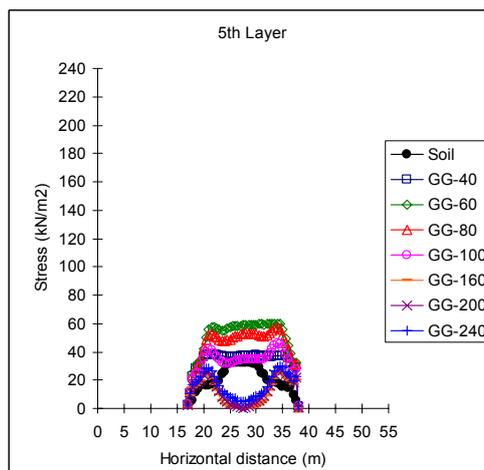


Figure 6. Stress distribution along the fifth layer of geogrid reinforcement

5.3. INFLUENCE OF DISPLACEMENT

Steep embankment slopes reinforced with less stiff or weaker geogrids tend to experience more displacement, compared to slopes with more stiff or strong reinforcement.

Installation the geogrid inside the embankment was reduced the soil displacements significantly. The soil horizontal displacements at the location of soil-geogrid interfaces, from the first to the fifth layer, are relatively small which is lower than 1 cm. These figures also show that horizontal displacements decreased as the larger tensile strength of geogrid was applied but increasing the tensile strength of geogrid has relatively small effect in the vertical displacement.

Figure 7 shows the displacement gap in horizontal direction at the point where maximum displacement takes place. As soil and reinforcement has different modulus of elasticity, the displacement gap is occurred at the same location. The other influence on the displacement gap is the adhesion and friction between soil and reinforcement. The gap according to the tensile strength of reinforcement is linearly decreased as the increasing of tensile strength of reinforcement. In this case, both of horizontal and vertical displacements do not have significantly effect in determination of optimum tensile strength of geogrid reinforcement.

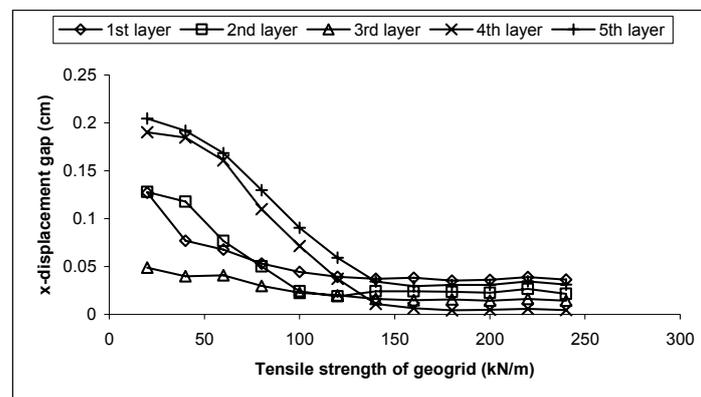


Figure 7. Displacement gap along the each of layers of geogrid reinforcement

5. DETERMINATION OF OPTIMUM TENSILE STRENGTH

Two-dimensional finite difference models were generated in this study. The models were analyzed using finite difference software developed by Itasca Consulting Group (FLAC). Analysis results included the safety factor, stress distribution, and displacement in horizontal and vertical direction of the geogrid reinforced embankment. In this model, the optimum tensile strength was determined for each of geogrid layers, which were installed in the predetermined vertical spacing.

By slope stability analysis, for tensile strength as and higher than 100 kN/m, the safety factor is 1.63. This meets the minimum safety factor requirement of 1.5 from USACE recommendation. Therefore, the optimum minimum tensile strength of geogrid reinforcement is 100 kN/m.

Determining the optimum tensile strength for each of geogrid layers becomes the objective of this study. In the comparison of soil-geogrid stress distribution in embankment, geogrid is considered good, as its stress is higher than soil stress at the unreinforced condition. It also must fulfill the requirement that in reinforced earth slope, the geogrid stress should be higher than soil stress at the same location. Therefore, considering in earth structure soil shear stress and cost-effectiveness, the geogrid tensile strength for first layer is optimum at least 100 kN/m. The second and third layer have optimum tensile strength at 80 kN/m and for the forth and fifth layer are at 60 kN/m.

The actual amount of convergence is related to the stress distribution carried by the soil mass and the geosynthetic. Since the displacement of soil and geogrid reinforcement are relatively small and do not have significantly effect by increasing the tensile strength, these can be negligible in determining the optimum tensile strength in this case.

6. CONCLUSION

In this study, factor of safety was tended to increase linearly with the reinforcement strength increase. In the comparison of soil-geogrid stress distribution in reinforced embankment model in this study, geogrid with tensile strength lower than the optimum tensile strength will have little reinforcement effects for that its tensile strength is lower than soil shear stress. Since the displacement of soil and geogrid reinforcement are relatively small and do not have significantly effect by increasing the tensile strength, these can be negligible in determining the optimum tensile strength in this case.

The economical design of the geogrid reinforced embankment is recommended in this study. The design of multi-layered geogrid-reinforced embankments with the optimum values of geogrid tensile strength is suggested as the following advantages: increase of reliable factor of safety, favorable stress distribution to the soil, allowance for use of soil with average mechanical properties, the entire system lead to a more cost-effective design of embankment.

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