Effect of slope reinforcement of an embankment on global stability and effect of traffic loads

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ABSTRACT: It is common practice for a basal reinforcement to be used to stabilize an embankment on soft soil. However, in many cases also the slope of the embankment needs reinforcement due to increased slope angle. In this study the contribution of the slope reinforcement to global stability was investigated. It is a generally accepted definition that the main load for a reinforced soil is the traffic load and for an embankment, it is the self-weight of the embankment. In this study, also the effect of traffic load on the stability has been investigated. Safety factors were analyzed using the finite element technique for long and short-term. The embankment on soft clay that was unstable without reinforcement could be stabilized by reinforcing the slopes and safety factors of models were increased for different conditions. Additionally, it was seen that the use of geosynthetic reinforcement stretching from side to side contributes to the stability more than increasing the number of reinforcements. As a result, it was shown that reinforcement of the slope can be enough to provide the stability of an embankment with steep slopes on soft clays.

Keywords: traffic load, geosynthetic, reinforcement, embankment, finite element

1 INTRODUCTION

Safety of an embankment constructed on soft subsoil is one of the important factors which control the design life as well as the maintenance cost of a road. Several factors affect safety factor values, namely, the strength and deformation characteristics of soft subsoil, the type of embankment fill and the magnitude and number of applications of traffic load. In the literature some design methods are proposed, in one of which, the study of Kutara et al. (1980), an equivalent static load represents the traffic load, and a one dimensional consolidation theory is used to predict the settlement. Fujikawa et al. (1996) proposed a method to estimate the distribution of traffic-load-induced consolidation settlement in the subsoil. In the method by Fujikawa et al. a triangular distribution pattern of traffic-load-induced stress increments is assumed, i.e., maximum at ground surface and a linear decrease to zero at the depth of influence. Additionally, a number of empirical equations can be seen to predict the permanent deformation of cohesive soil under repeated loads (Monismith et al., 1975; Li and Selig, 1996; Chai and Miura, 2002). Additionally, geosynthetic-reinforced embankments are generally used in civil engineering and their behavior is an important research subject. Since the 1980s, conventional limit equilibrium methods for unreinforced models have been modified to include the stabilizing force contribution of geosynthetic reinforcement layers in embankments

(Luo et al., 2016). Alternatively, however, the finite element method (FEM), which gives practical and fast results, has been used in recent years.

The use of a geosynthetic reinforcement for an embankment constructed on soft soils can significantly enhance stability and allow construction to heights substantially higher than could be achieved without reinforcement (Rowe and Soderman, 1987; Smith and Tatari, 2016). A similar result may be achieved by reinforcing the slope alone. The optimum length of a reinforcement and number of layers for an embankment are unknown factors.

In this study, the following concepts were tested for a geosynthetic reinforced embankment on soft clay foundation with steep slopes: *i)* Can the reinforcement used to stabilize the slope also have the function of providing global stability, *ii)* Will laying the slope reinforcement continuously from side to side increase the stability, *iii)* Will the number of reinforcement layers have a significant effect on the stability, *iv)* is the traffic load a significant parameter, or is it negligible beside the self-weight of the embankment.

These concepts were investigated with the help of FEM analysis where the Factor of Safety results are compared. To investigate the first question two different concepts were used for reinforcement. The first option investigated was to use just the reinforcement necessary to keep the slope itself stable, hence the reinforcement lengths were chosen as L=6m. The other option was to use a continuous reinforcement, stretching from one side to the other of the embankment. Two different numbers of reinforcement layers (N=10 and 20) were investigated. Furthermore, the comparison of safety factors was conducted for different types of traffic loads. The magnitude of traffic loading was chosen from the literature to simulate normal to heavy traffic status as 10kPa, 20 kPa and 30 kPa. Both short-term and long-term conditions were considered.

2 NUMERICAL MODEL

It can be seen from Figure 1 that the model sand slope made from sand soil is on the clay subsoil and the water table is 3 m below the surface. Clay soil parameters were taken from Hammouri et al. (2008) and sand soil parameters were taken from Laman and Keskin (2004). Clay soil was modeled as Mohr-Coulomb and for sand the Hardening soil model was used to represent the model better. The properties of the clay and sand soil models can be seen from Tables 1 and 2. The height of the embankment is 5 m and its slope angle is 45°. As the geosynthetic reinforcement a geogrid was chosen. The properties of the geosynthetic properties were taken from the literature as: Elasticity modulus J=465 kN/m, Poisson ratio ν=0.3. Since the selected reinforcement was a geogrid and the soil is a granular soil, it was foreseen that good contact would be present between sand and geogrid, so no interface elements were used in the study.

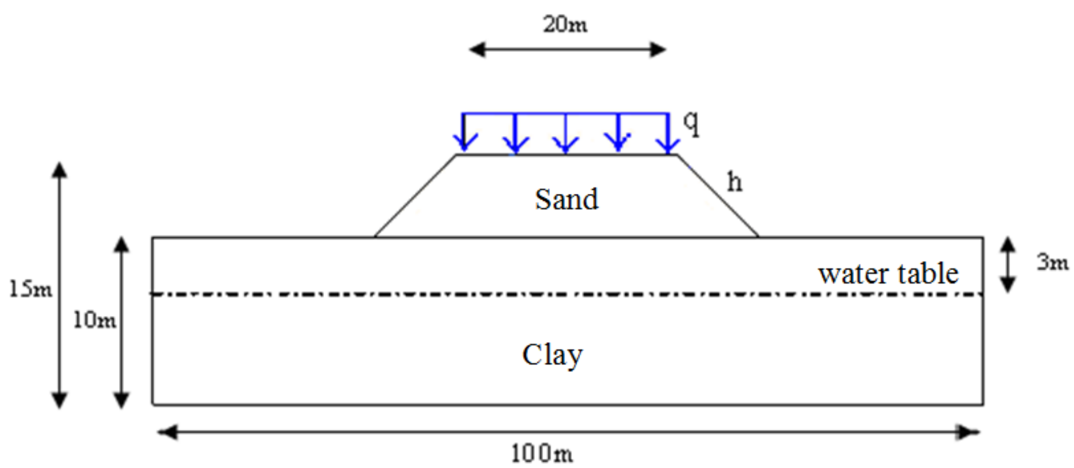

Figure 1: Geometry of the model

As can be seen from Figure 1, the system is symmetrical, so in finite element analysis only half of the model was used. Very fine mesh was chosen and element number for the space between the reinforcements was further increased. The size and mesh types were kept constant for all analyses to prevent the mesh size and type from affecting the results. Movement at the bottom of the model was solved with boundary elements with horizontal and vertical fixities and the vertical boundary was given only horizontal fixity.

The sand was laid in layers to construct the embankment and the time interval of the placement between subsequent layers was defined as 5 days. Two numbers of reinforcement layers were investigated, namely N=10 and 20. Reinforcement length was chosen to represent two conditions, namely reinforcement length L=6m and geosynthetic reinforcement stretching from side to side as L=slope lengths. Figure 2 shows the reinforcement placement system for this study.

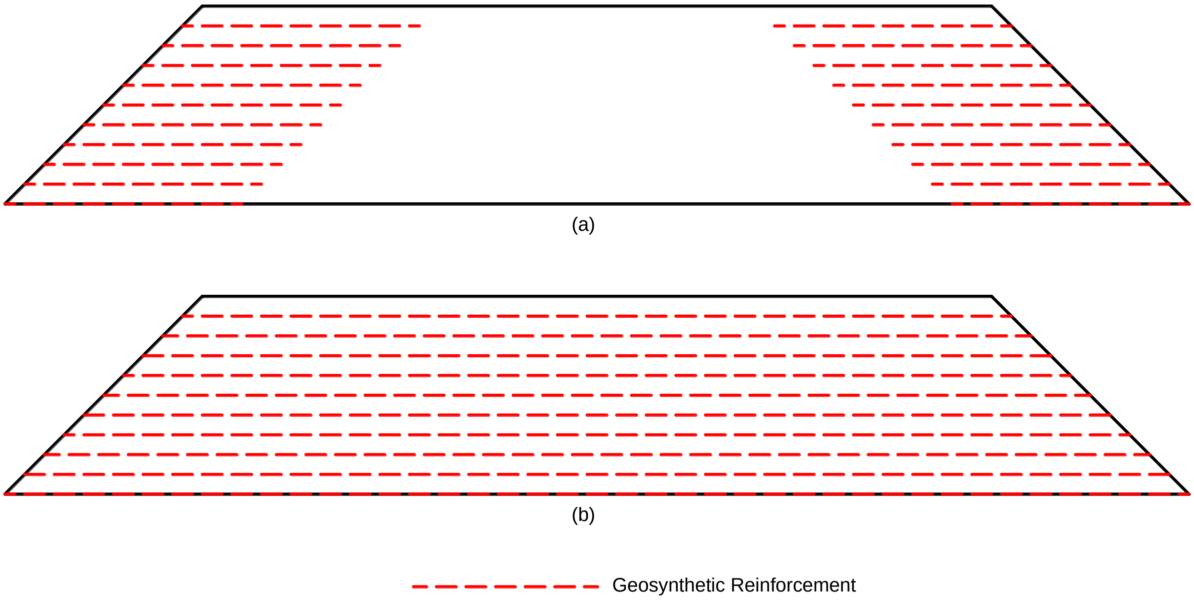

Figure 2: Reinforcement arrangement for analysis: a. reinforcement length is as L=6m, b. geosynthetic reinforcement stretching from side to side (L=slope lengths)

The traffic load was simulated by applying an equivalent static surcharge load of q=10, 20 and 30 kPa, which was applied right after the placement of an unpaved road. These loads were chosen based on literature such as Huang et al. (2009). In this study, two different conditions were compared, namely the short and long-term behavior. For long-term analysis, the safety factors were calculated after the completion of the consolidation.

Table 1. Properties of foundation soil

Parameter	Unit	Value
Dry unit weight (γ_{dry})	kN/m^3	16
Saturated unit weight (γ_{sat})	kN/m^3	18
Factor of permeability (k)	m/day	0,001
Young module (E)	kN/m^2	5000
Cohesion (c)	kN/m^2	5
Friction angle (ϕ)	(^{o})	28
Dilatation angle (ψ)	(^{o})	0
Poisson ratio (ν)	-	0,33

Table 2. Properties of embankment soil

Parameter	Unit	Value
Dry unit weight (γ_{dry})	kN/m^3	17
Reference pressure value (p^{ref})	kN/m^2	100
Triaxial stiffness (E_{50})	kN/m^2	28000
Triaxial unloading stiffness (E_{ur})	kN/m^2	72500
Oedometer loading stiffness (E_{oed})	kN/m^2	28000
Cohesion (c)	kN/m^2	0,30
Friction angle (ϕ)	(°)	41
Dilatation angle (ψ)	(°)	11
Poisson ratio (ν)	-	0,20
Failure ratio (R_f)	-	0,9

To determine the Factor of Safety, the so called phi-c-reduction method was used. In this approach, the cohesion and the tangent of the friction angle are reduced in the same proportion until failure. The reduction factor is given as:

$$\mathrm{Msf} = \frac{\tan\phi_i}{\tan\phi_r} = \frac{c_i}{c_r} \qquad (1)$$

where c_i and ϕ_i are input strength parameters and c_r and ϕ_r are the reduced strength parameters. The reduction of strength parameters is controlled by the total multiplier Msf. This parameter is increased in a step by step procedure until failure occurs. The safety factor is then defined as the value of Msf at failure.

3 RESULTS

In this research, 25 different analyses were made and the stability of unreinforced and reinforced slopes was investigated. The slope of the embankment was of a height that impaired stability and ensured collapse in the case of reinforcement not being used. Figure 3 shows the failure pattern of the unreinforced embankment. Therefore, to provide stability, geosynthetic reinforcements were used in the embankment. By using the reinforcement, the embankment could be constructed and it could have safety factors bigger than 1. Additionally, the strain vectors could move into deeper layers due to the effect of the reinforcement.

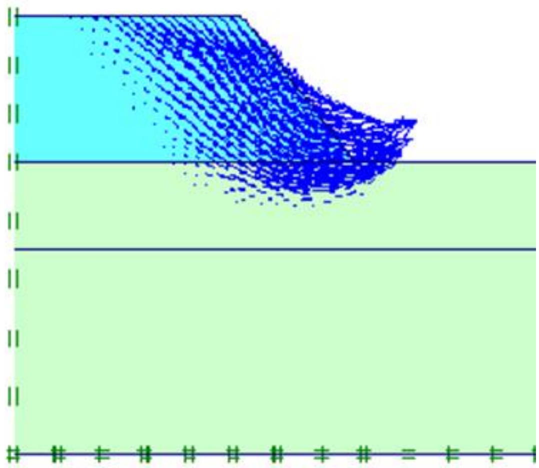

Figure 3: Unreinforced embankment

The effects of the different traffic loads were analyzed for geosynthetic reinforcement stretching from side to side as L=embankment width, the results of which can be seen for short and long-term analysis in Table 3. As can be seen from the Table 3, long-term analysis has greater safety factors than short-term analysis for both N=10 and N=20 and this is an expected result. However, the analyses show that the change in the traffic load has quite a significant effect on the factor of safety, especially in the short-term. The reduction in the factor of safety as the traffic load increases from 10 kPa to 30 kPa is in the order of 15% for both 10 and 20 layers of reinforcement.

Table 3. Safety factors of long reinforcement lengths for different traffic loads

Traffic load, q (kN/m^2)	10		20		30	
Number of reinforcement, N	10	20	10	20	10	20
Short term analysis	2,71	2,80	2,50	2,58	2,29	2,40
Long term analysis	3,76	3,78	3,60	3,62	3,43	3,44

The safety factors for the embankment with short reinforcement (L=6m) are given inTable 4. As can be seen from Table 4, again the traffic load causes a significant reduction (in the order of 13%) in the short-term and in the order of 9% in the long-term. The more interesting result in the case of using reinforcement of limited length is the fact that no significant difference is observed when the number of reinforcement layers is increased from 10 to 20. This statement is correct for both short-term and long-term analyses.

Table 4. Safety factors of short reinforcement lengths (L=6m) for different traffic loads

Traffic load, q (kN/m^2)	10		20		30	
Number of reinforcement, N	10	20	10	20	10	20
Short term analysis	1,47	1,50	1,37	1,39	1,29	1,30
Long term analysis	1,83	1,84	1,74	1,75	1,66	1,67

4 CONCLUSIONS

In this research, a numerical model was used in order to evaluate the effect of certain parameters for embankments with steep slopes on soft foundation soil. First a design was made which could not remain stable without the help of reinforcement and it was shown with the help of FE analysis that the factor of safety is below one.

The results were compared for two different reinforcement lengths for short and long term analysis. It was shown that placing reinforcement of limited length, enough to stabilize the slope alone, can be sufficient to provide overall stability

As the number of reinforcement layers is increased from 10 to 20, the Factor of Safety increases slightly for short-term analysis, but for long-term there is almost no increase in the – factor of safety results.

Instead of doubling the number of reinforcement layers, if the reinforcement is laid across the embankment, the increase in the overall Factor of Safety can be increased much more significantly.

As the traffic load increases, the safety factors decrease for both short term and long term analysis. This shows that the traffic load is an important parameter in the design of such embankments.

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