EMBANKMENTS ON SOFT SOIL DESIGN CONSIDERING TIME EFFECTS ON GEOSYNTHETICS AND ON SOIL PROPERTIES

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ABSTRACT: The design of geosynthetic reinforcements for high embankments on soft subground is traditionally performed by the analysis of stability conditions of the structure through methods that consider limit equilibrium principles. The analysis through such methods requires some input parameters; two of them are the object of the paper: the soft soil undrained shear strength and the design (or available) geosynthetic tensile strength. The foundation soft soil, in most cases, is a type of fine and saturated soil. Hence, its shear strength is normally estimated from site tests, and is treated as undrained strength. The geosynthetic design strength, the available strength during the reinforcement service period, is mainly affected by the creep behaviour of the reinforcement material. The work aims to establish analysis criteria to consider the variation of these parameters through the time. So, aims to propose a less conservative procedure for designing geosynthetic reinforcements for embankments on soft subground, through the identification of the real critical moment of the structure in terms of stability, along its service life. In general, this moment is taken in project as it was the instant of the end of execution. The proposed procedure considers simple and usual concepts of soil mechanics and geosynthetics science, for an easy and quick analysis using limit equilibrium concepts and tools, allowing a more economic (but not less safe) project.

1 INTRODUCTION

The embankments built over soft soil may present stability deficiencies. In these cases, geosynthetics acting as reinforcement elements are an interesting option to prevent global failure and other failure potential factors.

The stability analyses to global rupture in these problems are generally made considering the limit equilibrium of a circular edge.

In fact, two of the most important parameters of these traditional analyses: the soft soil undrained shear strength and the geosynthetic tensile strength are time dependent. The first one increases during consolidation and the second decreases during this time, mainly, due to creep factors. Figure 1 illustrates some of these time effects.

The soft soil undrained strength is a very important parameter, once the stability condition is very sensitive to its magnitude. In the case of the geosynthetic reinforcement, in such application, its tensile strength is the most important parameter.

In design time, these parameters are normally considered as the following: the soil shear strength is estimated according to the initial condition (before the embankment construction), and the reinforcement design strength is estimated for a predetermined reinforcement service time. This is a simple and conservative way of considering the problem, once the strengths of foundation soil and reinforcement are both parameters time dependents in such cases.

Vidal et al (2002) discuss the soil and the geosynthetic parameters considered in consolidation and stability analysis. They analyse the hypotheses and concepts from Terzaghi´s consolidation theory (Lambe & Whitman 1979, f.ex.), adopted to evaluate the undrained soil strength increase considering their limitations, and compare results obtained by conventional and numerical analysis. The performed analysis show that, for the example studied, the Terzaghi's Theory underestimated consolidation time (as expected) but it is on the safe side and it is a practical tool on the collection of parameters to be input in stability analysis considering soil consolidation with consequent resistance increase. About the stability analysis, the results suggested a less conservative analysis when compared to traditional ones, once it really takes the soil resistance increase into account and do not penalise in excess the reinforcement strength value in terms of decreasing due to creep susceptibility.

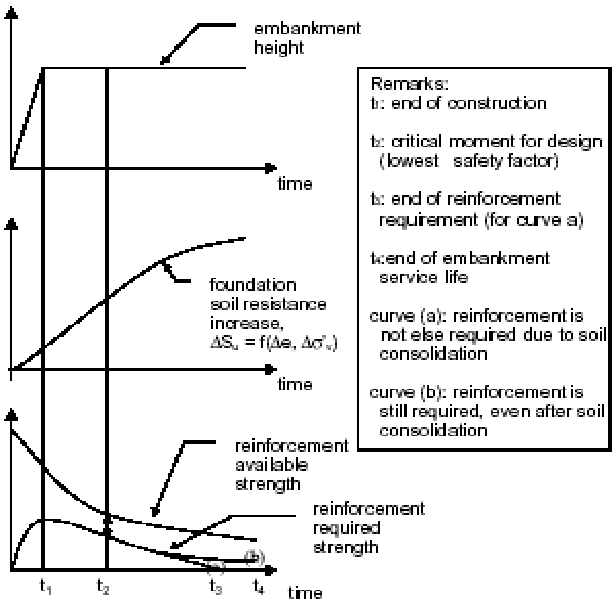


Figure 1 Time effects acting on embankments over soft soils (Vidal et al 2002).

The present paper discusses the effects of the polymer geosynthetic composition and geomorphologic soil constitution and properties, on the design of geosynthetic reinforcement by limit equilibrium analysis, considering the foundation soil strength increasing due to consolidation. The embankment construction time is not considered in this work because the main subject is show that with simple analysis it is possible to reduce the reinforcement cost, allowing a more economic (but not less safe) project. All the discussions and results presented are based on a master thesis work presented at Aeronautical Institute of Technology of Brazil in 2003 (Silva 2003).

2 DESIGN PROCEDURE

2.1 *Undrained soil strength analysis*

The undrained soil strength increase is calculated considering the relationship between this parameter and the effective vertical stress evaluated as function of the time and the position on soil foundation.

The literature proposes empirical and semi-empirical correlations to evaluate this relationship (Jamiolkowski et al 1985 and Mesri 1975, for example) or it may be determined from laboratory tests. In fact, this value is generally equal or superior than 0,22, being largely affected by the over consolidation ratio of the soil foundation.

To evaluate the effective vertical stress the soil foundation is divided in three zones as summarized in Figure 2. In zone 3, out of the embankment, no increase on the soil strength is considered. In zone 1, under the embankment platform, the effective vertical stresses are calculated by Terzaghi´s Theory considering 100% of the embankment weight acting as an uniform surcharge. The stresses in zone 2 could be calculated considering 50% of the zone 1 surcharge or to be subdivided in two other zones, having 1/3 and 2/3 of the surcharge applied on each one.

Figure 3 presents one example of results obtained in zone 1.

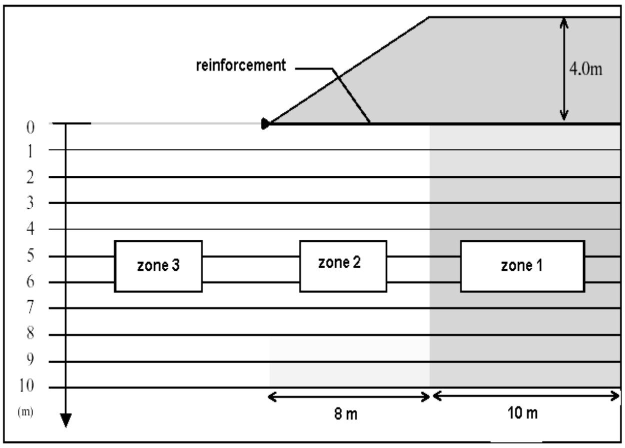


Figure 2 Typical transversal sections.

2.2 *Stability analysis*

Stability analyses are performed on software suitable for soil structures stability analysis, GGU-Slope (Buβ 1999). This is a German commercial package that calculates limit equilibrium analysis by five different methods, allowing the inclusion of geosynthetic reinforcements, being adopted the Simplified Bishop Method, that considers a circular failure surface (Lambe & Whitman 1979).

The reinforcement material properties required by GGU-Slope are a design tensile strength value and a parameter of reinforcement/soil interaction, like an interaction coefficient. The soft soil is treated as a Mohr-Coulomb material (c = S_u and σ = 0) and it may be horizontally stratified in order to simulate a variation of the soil resistance with depth.

Figure 4 presents an example of GGU-Slope results.

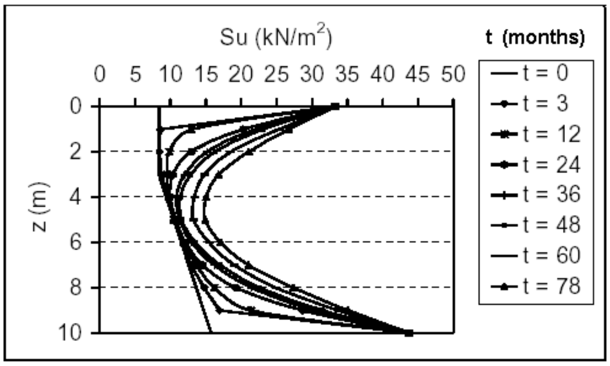


Figure 3 Example of the undrained strength of the soil foundation evolution in zone 1.

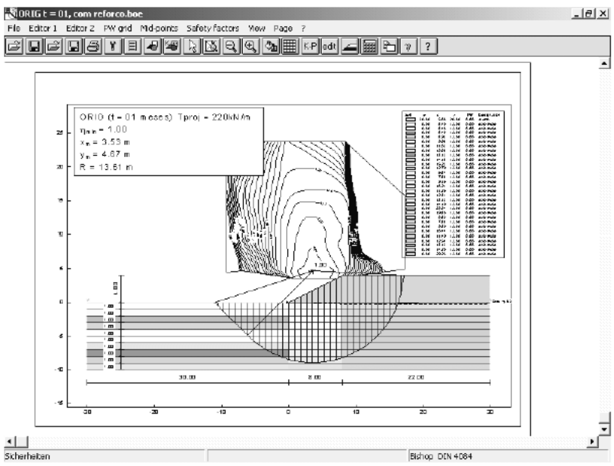


Figure 4 Example of stability analyses results.

2.3 *Effect of the surcharge consideration*

Considering Terzaghi´s Theory to evaluate the effective vertical stress time variation means to accept two opposite effects on real values:

- A conservative - due to the unidirectional flow consideration,
- A non conservative - due to the uniform surcharge discussed in 2.1.

This non conservative effect can be evaluated analysing the total vertical stress increment calculated, for instance, by Carothers proposition (Badillo & Rodrigues 1984):

$$\Delta\sigma_v = \frac{Q}{\pi}\left[\beta + \alpha\frac{x}{a} - \frac{z}{{r_2}^2}(x-b)\right] \quad (1)$$

with α, β, x, a, z and r_2 defined in Figure 5.

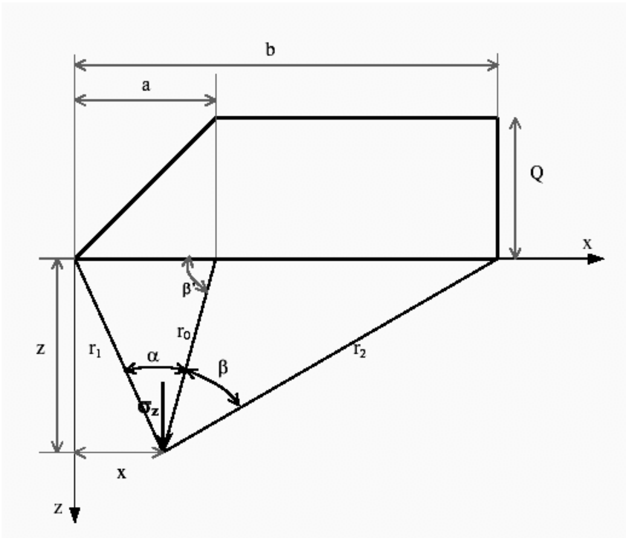
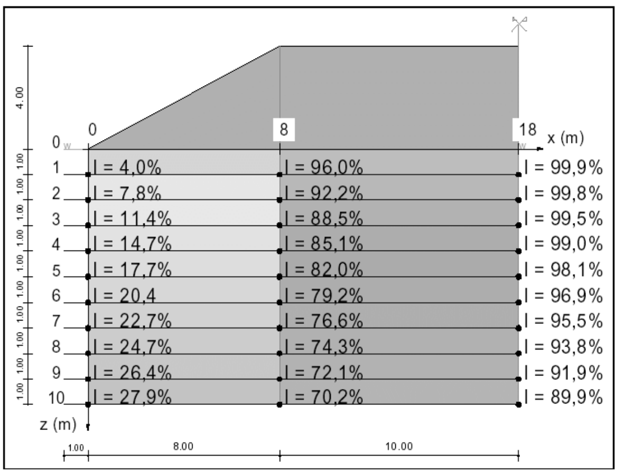


Figure 5 Parameters of equation 1.

Figure 6 shows the increment of total vertical stresses calculated by eq.1 considering an embankment with the geometry indicated in Figure 2.



$$I = (\Delta\sigma_v)/(\gamma \times H)$$

Figure 6 Example of calculated increment of total vertical stresses in foundation soil.

3 PARAMETRIC ANALYSIS

3.1 *Geometry*

The adopted geometry considers the same embankment illustrated in Figure 6, with the soft soil foundation having the same thickness (10m). To evaluate the influence of the thickness of the soft layer one analysis considering the half of the original thickness value (5m) is presented.

3.2 *Soil foundation characteristics*

The relationship between the undrained strength and the effective vertical stress (S_u / σ_v') and the consolidation coefficient (C_v) are the soil foundation characteristics analysed. Default values are considered as 0,35 to this relationship and as 2 x $10^{-8}m^2/s$ to the consolidation coefficient. Two drainage faces are usually assumed, but one analysis considering only top drainage condition is presented.

3.3 *Geosynthetic properties*

The geosynthetic properties influence is analysed considering two geogrids chosen with different polymer composition. Figure 7 presents the rupture behaviour and Figure 8 presents the tensile strength at 5% of deformation, both determined in creep tests.

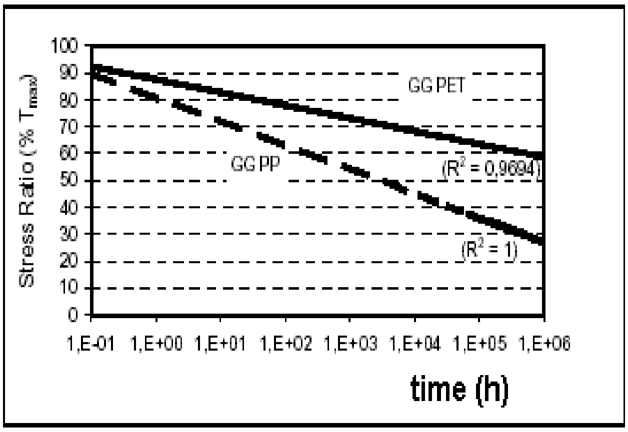


Figure 7 Rupture behaviour of the considered geogrids (BBA 1999).

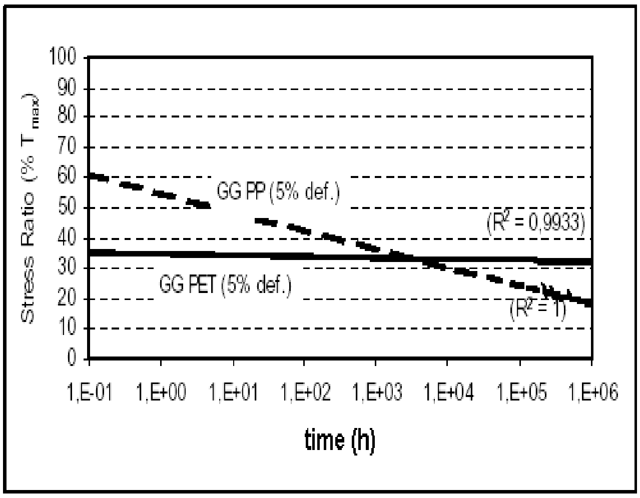


Figure 8 Tensile strength at 5% of deformation (creep tests) (BBA 1999).

3.4 *Other considerations*

Table 1 presents the constant properties adopted in the analyses presented in this work. They consider also the influence of the slope subdivision discussed in 2.1 and the horizontal subdivision of the foundation soil to take into account the undrained strength variation in the stability analyses.

Table 1 Assumed properties considered in the analyses.

	soft soils	embankment
Total specific weight (kN/m^3)	13	20
Cohesion (kN/m^2)		5
Friction angle (^{o})		30
Initial undrained strength (kN/m^2)	8,4 (z≤3) 8,4+0.73z (z>3)	

4 RESULTS

Table 2 summarizes the results of the analyses for verifying the influence of the slope (a) and foundation (b) subdivision; Table 3, the deth of the soft soil layer (a) and the drainage conditions (b); Table 4, the relationship (S_u / σ_v') and Table 5, the consolidation coefficient C_v . All the results are obtained considering unitary safety factors and Ultimate Limit State (BS 8006 1995).

Table 2 Influence of the slope and foundation subdivision.

	CA[3]	TDA[4]	(a)	(b)
slope		1 zone	2 zones	1 zone
Subsoil sublayers thickness[5]		1m	1m	2m
RESULTS				
PET Tmax[1] (kN/m^2)	408	310	314	324
PET tcr[2] (months)	409	4	6	8
PP Tmax[1] (kN/m^2)	786	445	455	482
PP tcr[2] (months)	409	8	6	12

[1] nominal tensile strength (ISO 10319 1993)
[2] critical moment for design as defined in Fig.1
[3] conventional analysis considering tcr at 90% of consolidation
[4] time dependent analysis with default parameters
[5] thickness of the soft soil horizontal divisions

Table 3 Influence of the soft soil deep layer and drainage conditions.

	TDA[4]	CA[3]	(a)	CA[3]	(b)
Soft soil (m)	10	5	5	10	10
Drainage faces	two	two	two	top	top
RESULTS					
PET Tmax[1] (kN/m^2)	310	312	200	428	324
PET tcr[2] (months)	4	102	0	1636	4
PP Tmax[1] (kN/m^2)	445	538	247	948	466
PP tcr[2] (months)	8	102	2	1636	8

[1] nominal tensile strength (ISO 10319 1993)
[2] critical moment for design as defined in Fig.1
[3] conventional analysis considering tcr at 90% of consolidation
[4] time dependent analysis with default parameters

Table 4 Influence of the S_u / σ_v' relationship (same initial S_u).

	CA[3]	TDA[4]	(a)[5]
S_u / σ_v'		0,35	0,22
RESULTS			
PET Tmax[1] (kN/m^2)	408	310	322
PET tcr[2] (months)	409	4	14
PP Tmax[1] (kN/m^2)	786	445	497
PP tcr[2] (months)	409	8	28

[1] nominal tensile strength (ISO 10319 1993)
[2] critical moment for design as defined in Fig.1
[3] conventional analysis considering tcr at 90% of consolidation
[4] time dependent analysis with default parameters
[5] same initial condition

Table 5 Influence of the consolidation coefficient C_v.

	TDA[4]	CA[3]	(a)	CA[3]	(b)
C_v (10^{-8} m^2/s)	2	1	1	4	4
RESULTS					
PETTmax[1](kN/m^2)	310	418	316	399	304
PET tcr[2] (months)	4	816	8	204	2
PP Tmax[1] (kN/m^2)	445	859	472	724	421
PP tcr[2] (months)	8	816	16	204	4

[1] nominal tensile strength (ISO 10319 1993)
[2] critical moment for design as defined in Fig.1
[3] conventional analysis considering tcr at 90% of consolidation
[4] time dependent analysis with default parameters

5 CONCLUSION

The parametric analyses performed show an important reduction in nominal tensile strength required, if the time effects in the soil and geosynthetics are taken into account, even if these analyses adopt simple design considerations.

Table 2 shows that refining the analyses do not means a remarkable change in calculated values but it could be better to work subdividing zone 2.

Table 3 shows that to thin foundation layer, the reduction of the required tensile strength of the geosynthetic is significant: 36% and 54%, to polyester and polypropylene, respectively.

Table 4 shows that even a conservative relationship between S_u / σ_v' means a reduction of 21%, for the polyester, and 36%, for the polypropylene, the required tensile strength of the geosynthetic.

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