

Design and Limitations of Using Limited Life Geotextiles

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ABSTRACT

The concept of the Limited Life Geotextiles refers to the ability of the geotextile in providing additional stability to an embankment erected on soft ground until the foundation soil achieves the desired shear strength over time. In this paper an analytical method is used to investigate the short term and long-term stability of basal reinforced embankment erected on soft soil. The amount of Limited Life Geotextiles(LLGs) required to achieve a specific Factor of Safety on varying Foundation depth (D) and Embankment Height (He) (D/He ratio) as well as slope angle is investigated.

KEYWORDS: Limited Life Geotextiles, free drain embankment, soft soil, reinforcement, Factor of Safety, Time Factor.

INTRODUCTION

The concept of limited life geotextiles seeks to emphasize on a clear definable working life, where materials used to manufacture geotextiles are designed so that progressive loss of their capability with time is match by the improvement in the ground conditions with time [1], [2]. Limited Life Geotextiles (LLGs) are reinforcing fabrics that are only required to perform their duty for a short time. In the case of reinforcing embankment erected on the soft soil, LLGs are required at the end of construction. However the need of geotextiles diminishes with time as pore water pressure dissipates. The process dissipation of pore water pressure the foundation gain shear strength and the need for reinforcement diminish with time. [3], [4][5][6] have recommended the use of Vegetable Fibre Geotextiles for the reinforcement of an embankment erected on soft soil due to their initial high strength.

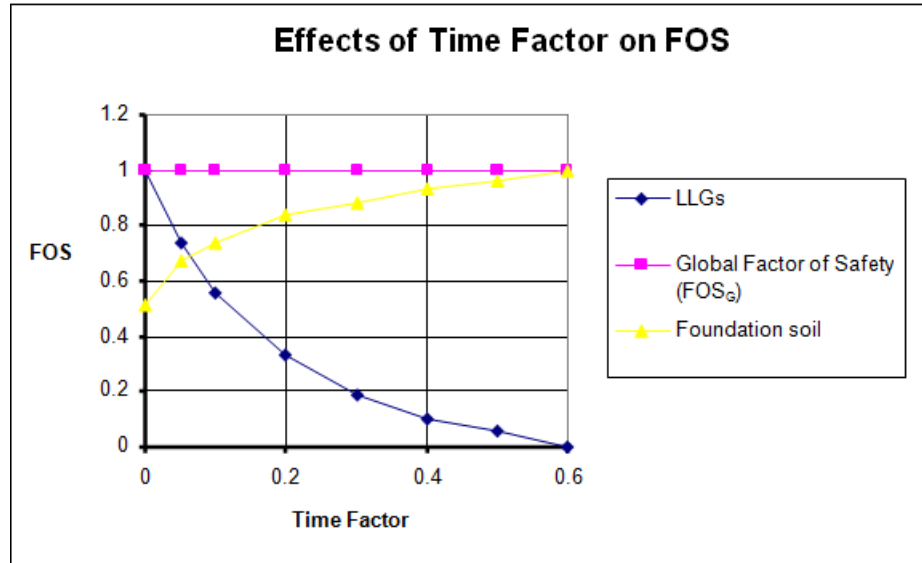


Figure 1: Schematic diagram showing the concept of Limited Life Geotextiles (LLGs)

In Figure 1 A schematic diagram showing that the shear strength increasing in foundation soil while LLGs strength diminishing. At Time factor (T_v) = 0.6 the shear strength in foundation soil is able to maintain global Factor of Safety (FOS_G) of unity and no need for extra reinforcement for that particular situation. Depending on the uncertainty of soil parameters and geotextiles properties and damages during construction, a partial factor should be assigned.[7], [8]. In the first part of this paper foundation titled “Designing bio-based geotextiles for reinforcing an embankment erected on the soft soil” Foundation (D)/ embankment height (H_e) ratio of unity for slopes V:He 1:2; 1:3 ; 1:4 and 1:5 were considered. In this paper the long-term and short –term stability on reinforced embankment on soft soil on varying foundation depth (D) and embankment heights (H_e) is considered D/He equals to 1, 2 and 3. Besides varying D/He ratio steeper slope V:He = 1:1 is considered.. In this analysis two objectives are to be met:

1. To determine the required tensile/stabilizing force from the geo-textile to maintain a global factor of safety equal to 1 from 1% to 90% consolidation. on varying D/He
2. To validate the effectiveness of using existing equation for designing equation for Limited Life Geotextiles on varying D/He and for steeper slopes.

DEFINITION OF MODEL FOR ANALYSIS

Analytical Model

The model to be considered is an embankment constructed over soft soil that is fully saturated, and the embankment fill consist of free drain material. This idealized situation that will be analyzed is shown in Figure 2.

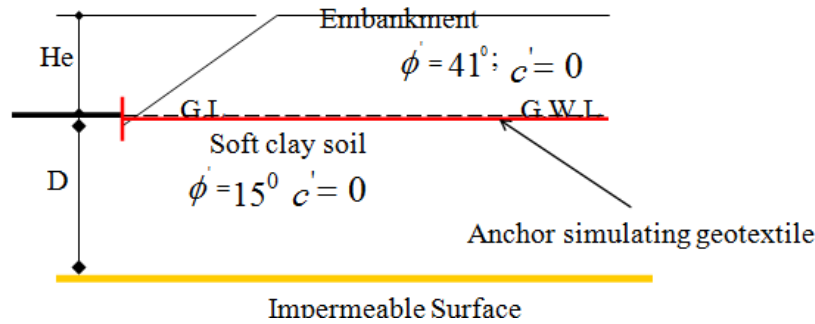


Figure 2: A typical Analytical Model

In order to analyze this situation numerically it was necessary to assign physical quantities for relevant parameters by selecting physical values. Embankment height ranged between 1 to 4m composing of a free-draining material such as sand was analyzed. The foundation soil consists of fully saturated soft clay. The water table was at ground level. The foundation depth D varied from 1 meter to 12 meters as shown in Table 1. Three D on He ratios, where analyzed with slopes configurations ranging between 1:1 to 1:5.

Table 1: Analyzed embankment and foundation depth.

Embankment height He (m)	Foundation depth D (m) at given D/He ratio		
		1	2
1	1	2	3
2	2	4	6
3	3	3	9
4	4	8	12

In order to analyze time dependent behaviour of an embankment transient pore pressure (Mwasha 2005) were inserted in the computer program GEO5 [9] It was assumed that the embankment fill was placed instantaneously, i.e. there was no consolidation during construction.

Pore Pressure Interface

Seven observation stations were positioned at various locations on the model as seen in figure.3. These stations were setup to determine the pore pressure in the foundation soil. Two stations, Sta. A and Sta. B, were positioned at the outer skirts of the embankment to determined the hydrostatic pore pressure from ground level to the impermeable surface.

Microsoft Excel's[10] iteration feature was then used to determine the depth, z, at each station where the hydrostatic pore pressure at stations A and B is likely to be located underneath the embankment over time.

$$u_{(z,t)} = z \cdot \gamma_w + \sum_{m=0}^{\infty} \left(\frac{2\Delta\sigma_v}{M} \sin(MZ) \exp(-M^2 T_v) \right) \tag{1}$$

where: $z \cdot \gamma_w$ = hydrostatic pore pressure.

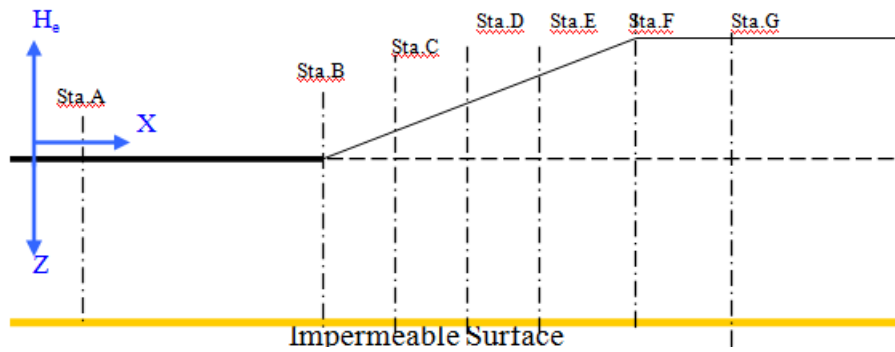


Figure 3: Positioning of Observation Points on Slope

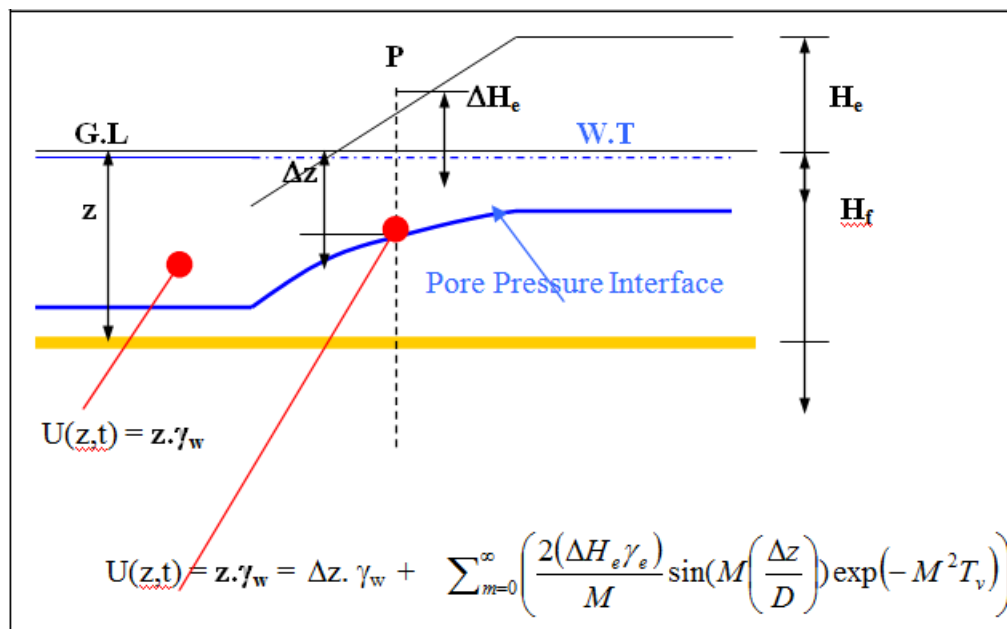


Figure 4: Interpolating pore pressure interface

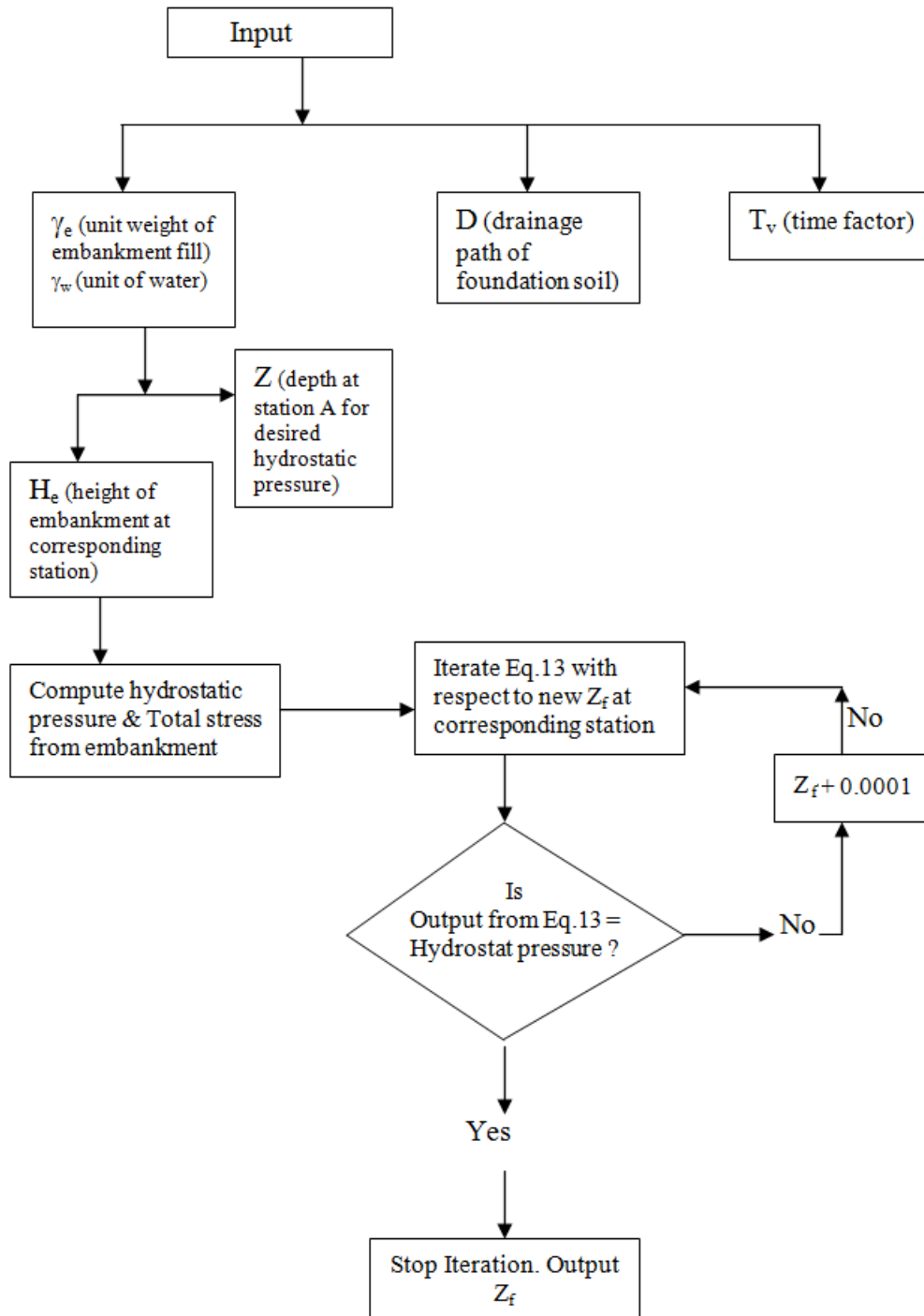


Figure 5: A schematic diagram showing the process of processing transient pore pressure in the foundation soil.

$$z \cdot \gamma_w = \Delta z \cdot \gamma_w + \sum_{m=0}^{\infty} \left(\frac{2(\Delta H_e \gamma_e)}{M} \sin\left(M \left(\frac{\Delta z}{D}\right)\right) \exp(-M^2 T_v) \right) \quad (2)$$

This was achieved by imputing equation Terzaghi's one dimensional consolidation [11] equation 1 into excel and developing a loop command where iteration of the depth, z, will end until the corresponding pore pressure from equation 2 matches that of the hydrostatic pore pressure at stations A and B, as shown in Figure 3. The flow diagram shown the process of locating the transient pore pressure isoline at particular time and depth z is shown in Figure 4. The pore pressure interfaces for each ratio was determined from the end of construction to 90% consolidation of the foundation soil. These interfaces along with the geometric properties of the model were then manually inserted into GEO5

ANALYSES OF TIME DEPENDENT BEHAVIOUR OF SLOPES AT VARIOUS D/HE

Factor of Safety of Embankment over Time

The behaviour of complex system containing foundation and embankment soils parameters, the change in Factor of Safety (FOS) with time was investigated. It was found that as the Time Factor (T_v) increases the consolidation increases and the stability of all slopes increase regardless of the slope angle as shown in Figure 5, 6, 7.

For D/He equals to unity, it was found that all slopes are initially unstable at T_v equals to zero i.e. all have FOS less than unity, they subsequently acquire higher FOS and for slopes 1:3; 1:4 and 1:5 acquired FOS in excess of unity.

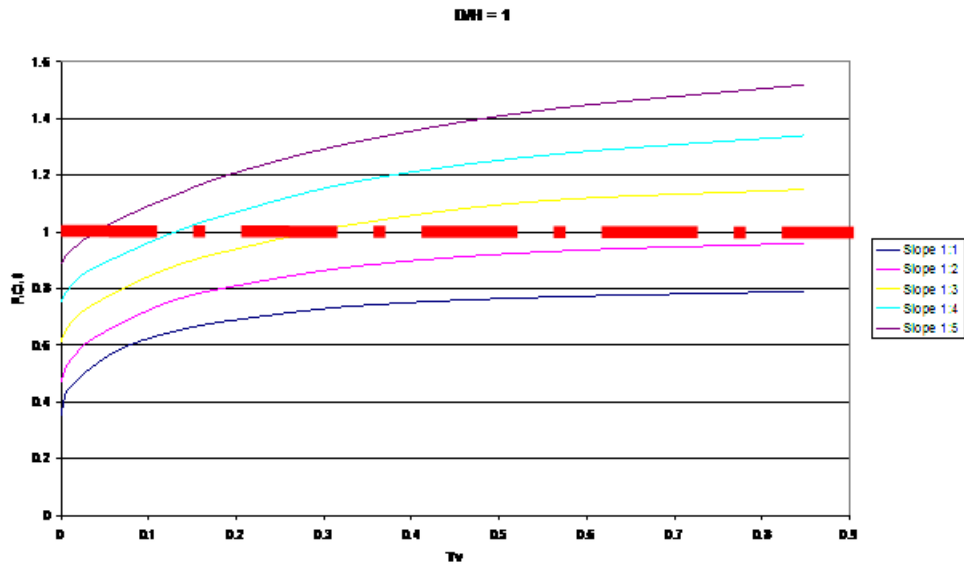


Figure 6a: Factor of Safety for D/He equals to 1 at given Time Factor (Tv) Time,

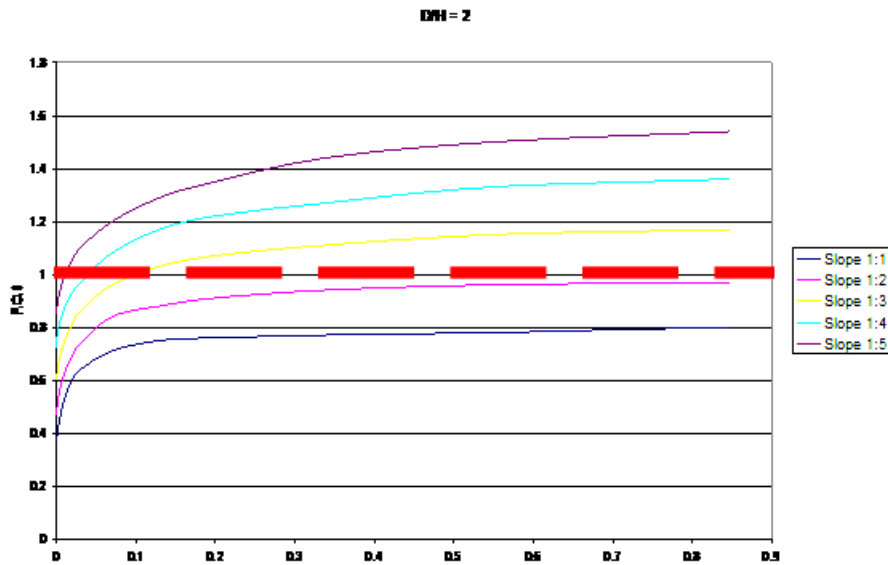


Figure 6b: Factor of Safety for D/He equals to 2 at given Time Factor (Tv) Time,

For D/He equals to 2 it was found that for steeper slopes V:H = 1:1 and 1:2 have FOS less than unity as shown in Figure 6

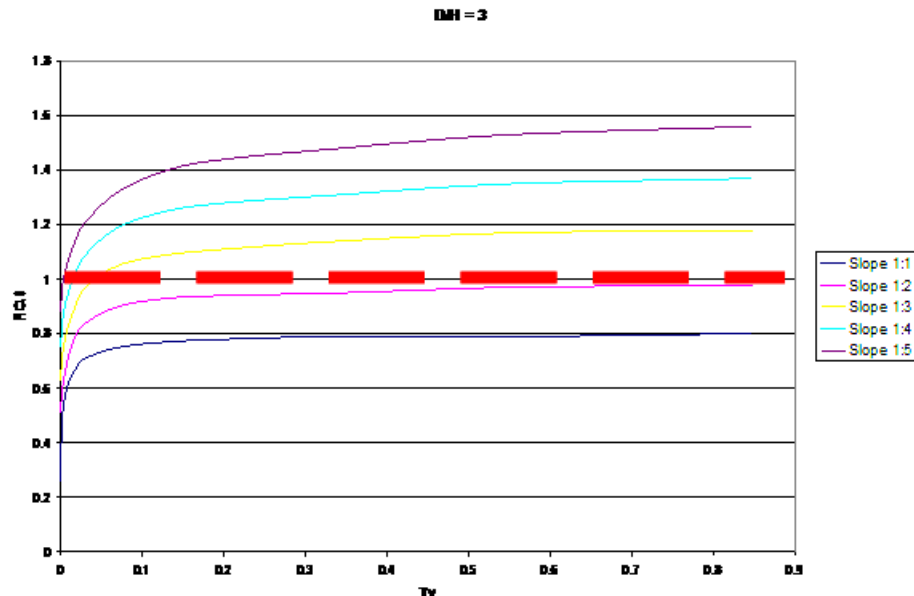


Figure 7: Factor of Safety for D/He equals to 3 at given Time Factor (Tv) Time,

For D/He equals to 2 and 3 there was steep increase in FOS during the early stages of consolidation and gradually stabilizes on increasing time factor. For these two cases steeper slopes V:H = 1:1 and 1:2 have FOS less than unity at Tv equals to unity.

Initial Tensile Force

The initial tensile force at the end of construction was determined for embankment heights ranging between 1 to 4m at D/He ratios of 1 and 2 as shown in Figure 7. Slopes 1:1 and 1:2 were omitted since these steep slopes do not conform to concept of Limited Life Geotextiles as shown in Figure 1.

The initial tensile force T_{RO} was determined by back analysis methods. To determine the stabilizing force back analysis measures were carried out by inserting reinforcement at the base of the embankment in GEO5. A method of trial and error was formulated in order to estimate the tensile strength required to achieve specific FOS according to [1]. The stages followed when conducting the trial and error analysis were:

- 1 Select a value of global Factor of Safety (FOS_G) for the case to be analyzed
- 2 Input slope geometry, foundation and embankment soil parameters and run the program to find the minimum Factor of Safety (FOS_U) with no reinforcement.
- 3 If the Factor of Safety determined was less than FOS_G required then incorporate an assumed value of force provided by horizontal reinforcement. Re-run the program and repeat the analysis to find the new minimum FOS. If this value is not equal to FOS_G then a new value of reinforcement force is assumed and the slope is re-analyzed.
- 4 The iteration process is repeated until the calculated Factor of Safety is on the range $FOS_G \pm 0.005$

When the calculated FOS_G corresponds to the required FOS_G the resultant output data gives disturbing and resisting moments as well as the critical slip circle parameters and amount of reinforcement required to achieve that specific global factor of safety

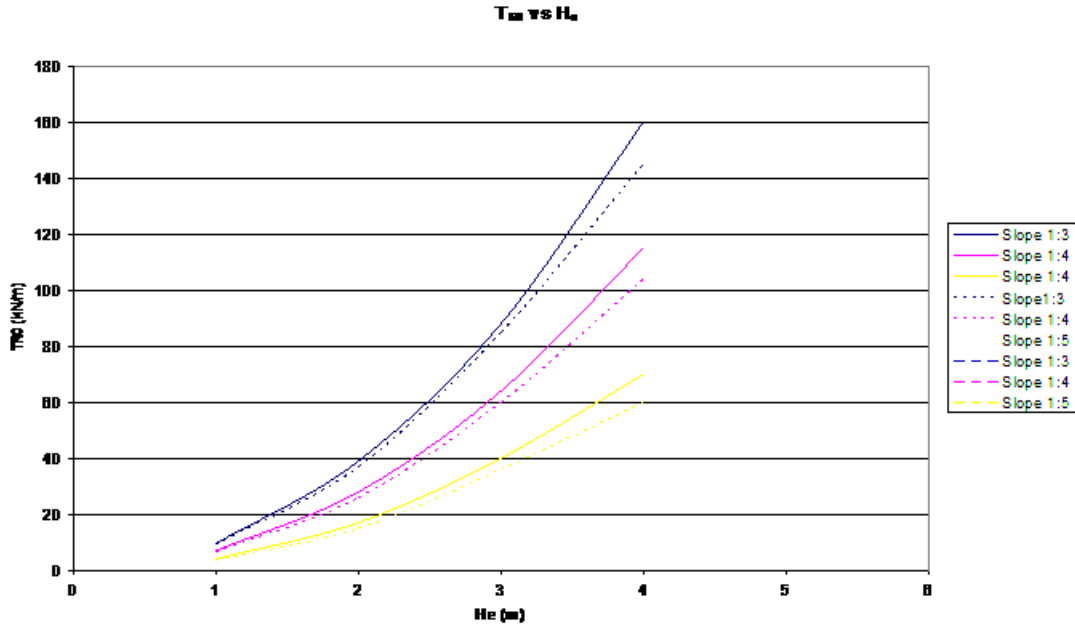


Figure 8: Initial Tensile Force, required to achieve a given FOS at T_v equals to zero. for $D/H_e = 1$ & 2 (Solid lines represent D/H_e at the ratio of unity while dash lines represent D/H_e ratio of 2).

Effects of Embankment heights on amount of tensile strength required to achieve a specific FOS

Using a backanalysis method the amount of required reinforcement for slopes V: H 1:3, 1:4 and 1:5 were investigated. It was found that on increasing embankment height and foundation depth there was exponential increase in amount of reinforcement required to achieve a global FOS of unity.

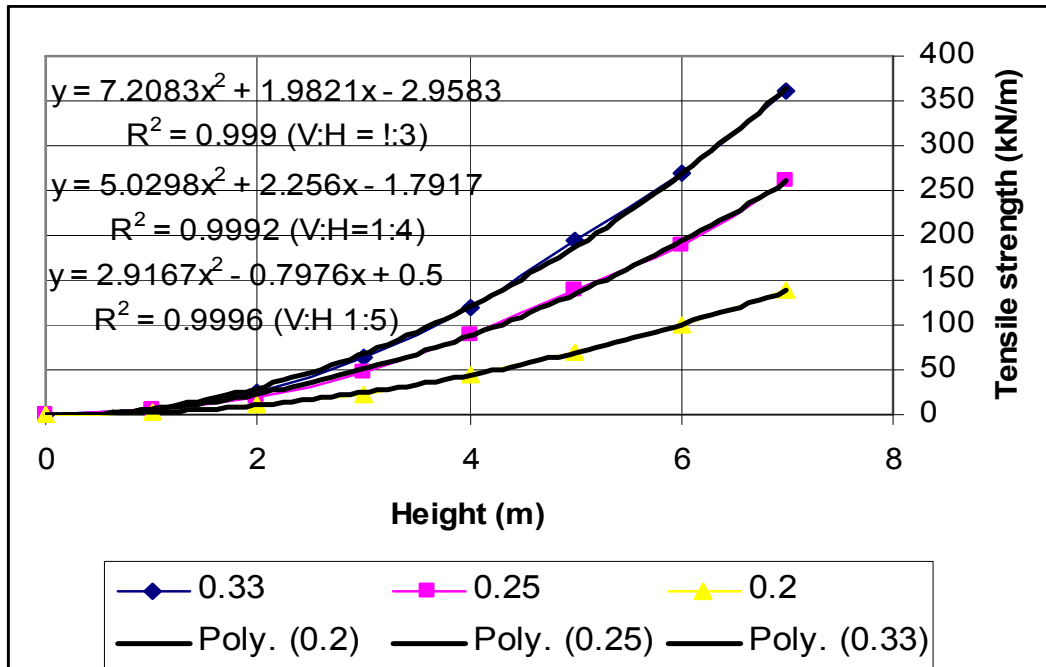


Figure 9: The effects of embankment height and foundation depth on amount of reinforcement required to achieve a global FOS of unity.

It was found that on increasing embankment height and foundation depth there was exponential increase in amount of reinforcement required to achieve a global FOS of unity. A chart for slopes 1:3, 1:4 and 1:5 having D/H ratio of unity is shown in Figure 8.

For Slope V:H = 1:3

$$T_R = 7.21 He^2 + 1.98He - 2.96 \quad (3)$$

$$R^2 = 0.9990$$

For Slope V:H = 1:4

$$T_R = 5.03 He^2 + 2.26He - 1.79 \quad (4)$$

$$R^2 = 0.9992$$

For Slope V:H = 1:5

$$T_R = 2.92 He^2 + 0.79He - 0.50 \quad (5)$$

$$R^2 = 0.9996$$

Displayed R- squared values for chart on equations were relatively high. Data extracted from this chart compares well with work done by Ingold [12].

Predicting tensile force required to achieve a specific FOS at given (Tv)

In order to determining the required tensile force from the geo-textile over time ($T_{R(t)}$), The process of determining ($T_{R(t)}$) was conducted by initially inserting the transient pore water pressure at given Time Factor into GEO5. The backanalysis process was conducted for D/He equal to unity, two and three. The results of backanalysed values were compared with those obtained using equation 3 (Mwasha, 2005; Sasby, 2007)

$$T_{R(t)} = T_{R0} - 120Tv^{0.50} \tag{3}$$

where:

$T_{R(0)}$ - Initial tensile force required to achieve a specific FOS at Tv approximately zero.

$T_{R(t)}$ - tensile force required to achieve a specific FOS at $Tv > 0$

Tv - Time Factor

As shown in Figure 10 there was a good correlation between backanalysis and predicted tensile strength for D/He equals to unity. For steeper slopes V:H 1:2 and 1:1 showed good correlation at the initial stages of consolidation but under estimated the amount of reinforcement required at the higher stages of consolidation

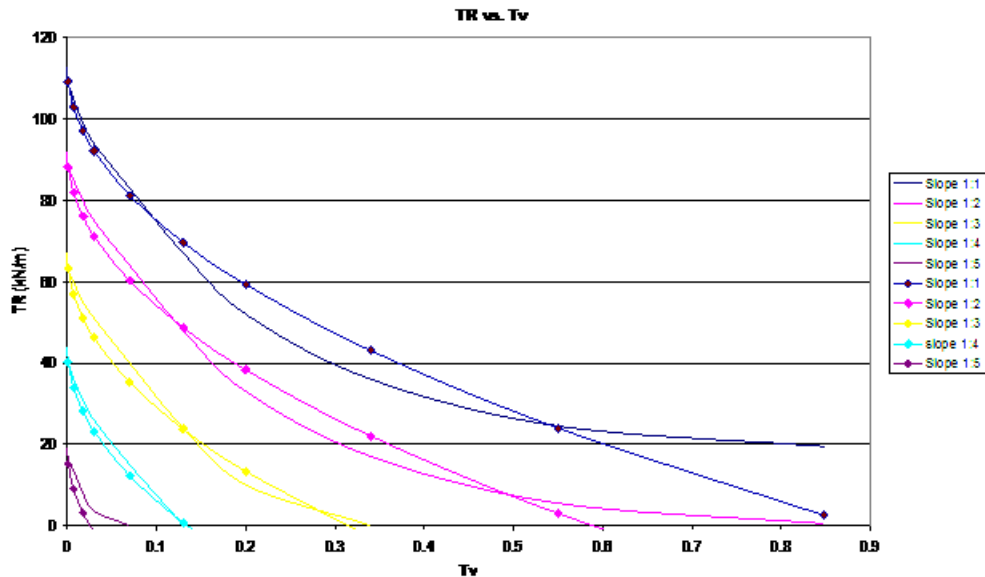


Figure 10a: Backanalysed Required Tensile Force, $T_{R(t)}$ at given Time Factor, (D/He = 1) (Predicted Tensile strength are shown in lines with dots)

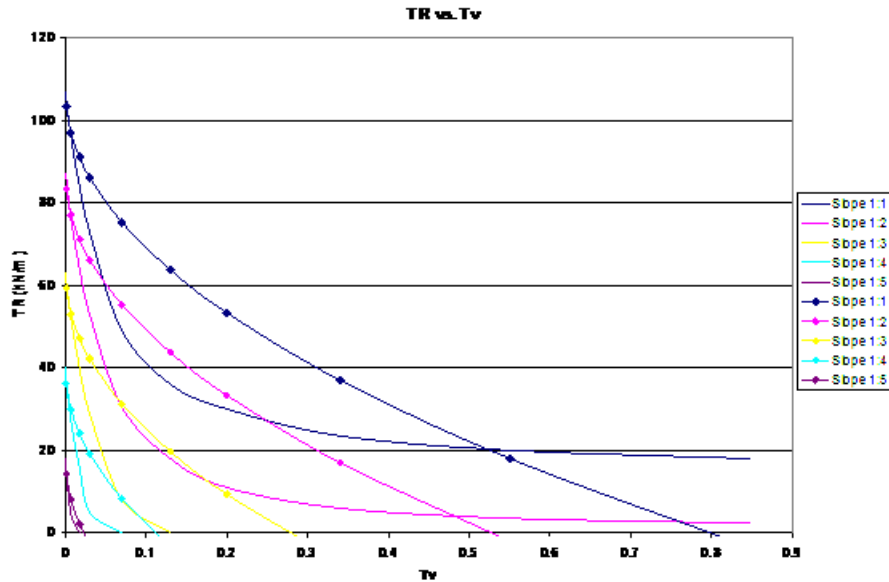


Figure 10b: Backanalysed Required Tensile Force, $T_{R(t)}$ at given Time Factor, (D/He = 2) (Predicted Tensile strength are shown in lines with dots)

When D/He was equals to two there was overestimation of reinforcement required to achieve a specific FOS for slopes 1:3; 1:4 and 1:5. There was underestimation of reinforcement for steeper slope V:H 1:1 and 1:2. as shown in Figure 11.

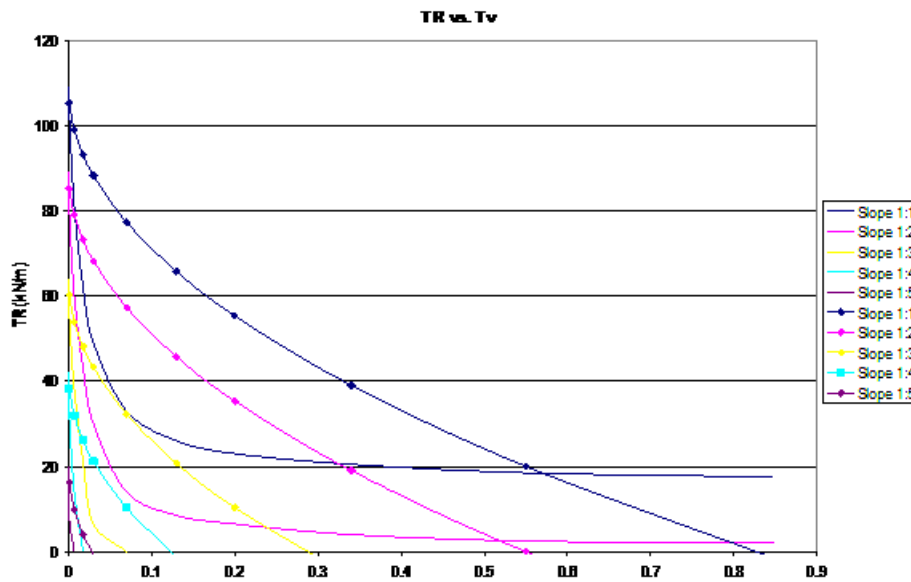


Figure 11: Backanalysed Required Tensile Force, $T_{R(t)}$ at given Time Factor, (D/He = 3) (Predicted Tensile strength are shown in lines with dots)

As for D/He equals to three it was found that there was an overestimation of reinforcement required to achieve a specific FOS for slopes 1:3; 1:4 and 1:5. There was underestimation of

reinforcement for steeper slope V:H 1:1 and 1:2 when backanalysis results were compared with empirical equation, Eq. 3.

DISCUSSION

The current results obtained from the parametric study have illustrated the concept of the design using limited life geotextiles. Initially a backanalysis was conducted to estimate the amount of required reinforcement at the end of construction. It was found that the amount of required reinforcement exponentially increases on increasing embankment height. These results coincide with those obtained by [12]. In this paper it has been found that by applying the concept of pore pressure, interfaces outline to simulate the dissipation of excess pore pressure, the time dependent behaviour of an embankment can be analyzed satisfactorily. Comparing results obtained using backanalyses in Figure 7, it was found that as the drainage path increases so does the shear strength of the foundation soil and hence less amount required reinforcement for constant embankment height. As was pointed out by Ingold, the importance in selecting embankment geometries, which gave an acceptable factor of safety in the long term. This importance can be seen in Figures 9, 10 and 11 where slope V:H equals to 1: 1 and 1:2 did not achieve the desired factory of safety 1 over time. Therefore, the tensile force required from the geo-textile to stabilize these slopes will have to be maintained until the end of consolidation and hence goes against the concept of limited life geo-textiles.

However, slopes equal to or greater than a 1: 3 slope cohere with Ingold on respect to the term “shorter geo-textile design life.” The Limit Life Geotextiles concept agreed well for slopes 1: 3 to 1:5. In this case the FOS of unity was achieved before the foundation soil had reach 40% consolidation. However it can be seen that as the gradient of the slope decreases so does the design life and the required tensile force from the geotextile. From this analysis four major factors can be identified, with respect to the physical and mechanical properties of both the embankment and foundation soils, that preside over the magnitude of the initial tensile force required to maintain a global factor of safety equal to 1. These factors are:

1. Slope of the Embankment
2. Height of the Embankment
3. Depth of the Foundation Soil
4. Pore water pressure

CONCLUSIONS AND RECOMMENDATIONS

In concluding this research it can be seen from the results obtained from the embankment and foundation parameters have a definable working life Limited Life Geotextiles. Steep slopes ranging from 1:1 to 1:2 do not validate the use of limited life geo-textiles since the working life of the geo-textile extends to the end of consolidation. For steep slope the combination of LLGs and traditional geotextiles should be used. Further study should be conducted to demonstrate the effect of crust strength and thickness on using Limited Life Geotextiles. Foundation and

embankment shear strength parameters should be varied and incorporated in to the designing empirical equation.

ACKNOWLEDGEMENT

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