

Modelling Limited Life Geotextiles For Reinforcing An Embankment On The Soft Soil

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Increasing environmental awareness has led to the investigation/consideration of a substitute using Limited Life geotextiles for the man-made material in situations where there is a requirement for the short-term reinforcement. The overall aim of the paper is to develop a comprehensive model of the required strengthening behaviour of Limited Life Geotextiles which have a limited (but definable) working life. To achieve this aim an analytical model for soil reinforcement, which incorporates change of foundation soil strength with time due to consolidation, has been created. The tensile force to be provided by a geotextile to ensure specific Factor of Safety against potential embankment failure as a function of time and soil properties has then been determined. A backanalysis method has been developed to estimate a global factor of safety representing the Factor of Safety of soil alone and that of the reinforcement. The analytical model has shown that geotextiles with limited life, e.g. 'Vegetable Fibre Geotextiles', can be used provided that the strength requirement decreases with time.

1. Basal Reinforcement Of Embankments

One particular situation where geotextiles are used in a soil-strengthening role is in the construction of temporary roads to facilitate exploration of energy fields, electrical power lines, and rescue operations etc. These critical operations are usually required on short term and sometimes executed in most harsh environmental conditions such as marshy, swampy grounds. On construction of an embankment on the soft soil, the weight of the embankment fill increases the tendency for failure by movement of a large body of the embankment. The failure may be rotational along a circular arc through the embankment and the underlying soil or as wedge involving horizontal movements of the soil masses along the embankment-geotextiles-foundation interface. (Mwasha 2005) found that rotational failure is more critical on homogenous soft soil.

With time the pore pressure in the foundation soil decreases and the shear strength of the soil will increase and the stability of the embankment will improve with time due to consolidation. However if the underlying soft soil does not have sufficient shear strength to resist the applied shear stresses at the time of embankment construction then rotational failure will occur. Incorporation of basal reinforcing geotextiles provides an additional resisting force. Figure 1 shows a schematic diagram demonstrating that, while the shear strength is increasing in foundation soil the LLG is diminishing. For example at $T_v = 0.6$ the shear strength in foundation soil is able to maintain global Factor of Safety of unity and no need for extra reinforcement for that particular situation.

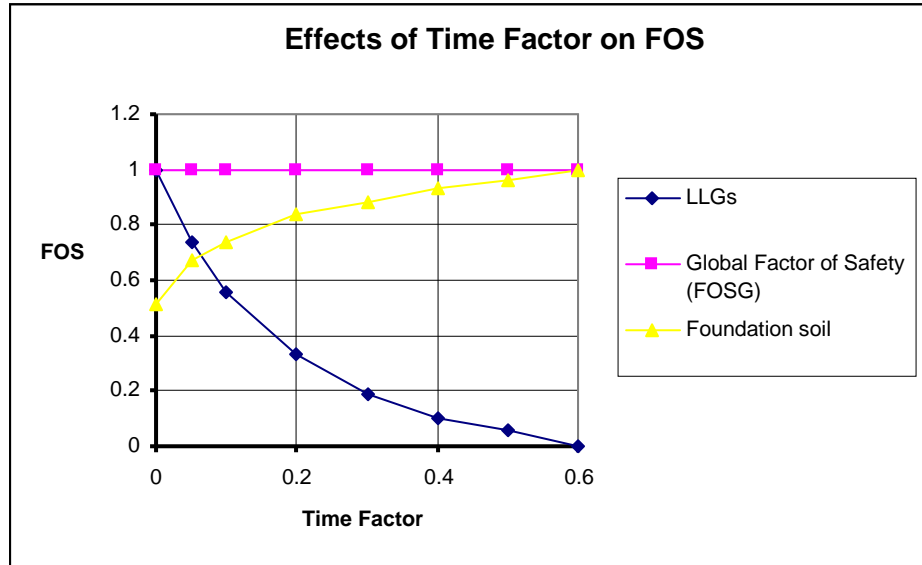


FIGURE 1: Schematic diagram showing the concept of Limited Life Geotextiles (LLGs)

On designing LLGs a reinforcing force is simulated as a single restoring force acting at the point of intersection of the free-body boundary and the reinforcement plane (Bailey 2000, Basset and Yeo 1988; Ingold, 1986; Nakamura *et. al*, 1988 and Tandjiria, *et al* (2002). The effect of the reinforcement can be incorporated into one of limit equilibrium equations (Duncan and Wright (2005) expressed in equation 1. These equations yield the same amount of required tensile force to achieve the Factor of safety of unity. (Mwasha 2009)

$$M_R + T_R R \geq M_D \quad (1)$$

Where

M_R - Resisting moment

M_D - Disturbing moment

$T_R R$ - Resisting force supplied by geotextiles

R- lever arm.

2. Limited Life Geotextiles

2.1 Vegetable Fibres

Limited life Geotextiles could manufactured from different types of materials which do not harm flora and fauna, such as vegetable fibres. Many of the developing countries of the world can make effective use of vegetable fibre for making local geotextiles. Pritchard (1999) manufactured novel designer geotextiles made

from vegetable fibres which could be used for soil reinforcement. The principal criterion for soil reinforcement is to have sufficient tensile strength to provide tensile force to the ground.

2.1.1 The problem of using vegetable fibre products as technical material

The problem of using vegetable fibre products as technical material is that they are perceived to have inherently low tensile strength and poor durability when in contact with the soil and ultra-violet rays. However ropes composed of vegetable fibre have been employed for over 60 years in marine situations. Consequently the durability of vegetable fibre ropes has been documented in the hostile marine environment. The coir fiber is relatively water-proof and is one of the few natural fibers resistant to damage by salt water. The imperial Institute conducted trials in 1927, 1931 and 1932 at Southend Pier to determine the competitiveness of sisal to abaca for marine applications (Imperial Institute, 1932). Sets of 76.2 mm diameter ropes were made of sisal and abaca and fixed to a pier in such a manner that they were either completely submerged or completely uncovered for a period of time. It was found that sisal initially lost a higher degree of strength than abaca but with time the rate of deterioration of abaca increased to such an extent that by the end of 4 months the

percentage loss in strength of sisal and abaca was the same.

2.1.2 Using Limited Life Geotextiles as a sustainable solution for ground improvement

There are four predominant polymer families used as raw material for manufacturing Geosynthetics. These are mostly polyester, polyamide and polypropylene. The impacts of using manmade geosynthetic in construction industry are:

- The manufacture of plastics requires finite resources,
- Manmade geotextiles can create environmental pollutants.
- As litter it defiles private and public land and poses a serious threat to wildlife often causing death through suffocation or entanglement.

Using Biobased geotextiles such as Vegetable Fibre Geotextiles (VFGs) could highly reduce the pressure on the environment especially where these geotextiles are required for only short term.

2.1.3 Durability of limited Life geotextiles

The durability of geotextiles is the influence of the environment which has on the properties of these geotextiles with the passage of time. There are numerous factors, which could affect the ageing processes such as chemical (acid and

alkaline) and biological (micro-organisms) deterioration. The main question is how long a particular material can withstand the given degradation process whilst maintain the requisite properties throughout the design life. Since weak grounds vary greatly, it is important to develop LLGs products as per end user requirement with design and specifications criteria. A review of the strengths and weakness of the LLGs in relation to the competition with manmade geotextiles is essential for its competitive positioning. In order to win this competition careful analysis and appropriate designing of the reinforced embankment parameters must yield significant improvement in cost effectiveness and energy efficiency. Limited Life Geotextiles can provide an invaluable solution to the problem of constructing embankments over soft compressible ground at the same time acting as environmentally friendly material after its service life. (Mwasha 2009)

3. Analytical Model

To investigate the geotechnical aspects of an embankment containing LLGs reinforcement, a typical configuration of an embankment over soft ground has been defined and typical values have been assigned to the relevant parameters. From the review of typical cases of embankments built on soft clays, the idealized situation that will be analysed is as shown in Figure 2. Where H_e is embankment height, D_{cr} crust depth and D_{cl} soft soil depth. The ground water level (GWL) is at the ground surface.

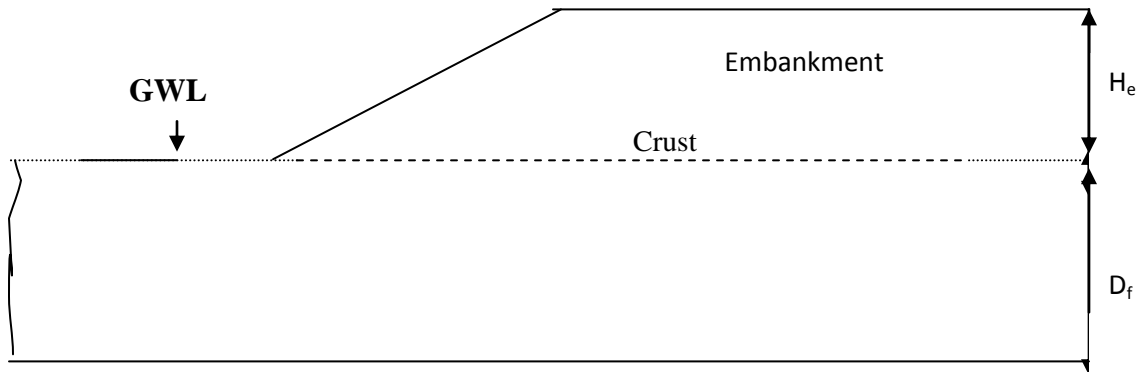


FIGURE 2: Typical Embankment

The practical situation considered is an embankment constructed over soft soil. In order to analyse this situation numerically it was necessary to assign physical quantities to the situation and the relevant parameters. This was achieved by selecting physical values for the situation considered. The embankment (He) was 3m high and composed of free-draining material. The soft clay of the foundation soil (Df) was taken as fully saturated and ground water was at ground level.

4. Parametric study

4.1 Full parametric study

For full parametric study the parameters for embankment, foundation soil was conducted by extracting data from existing projects conducted around the world. (Mwasha 2005). The final parameters obtained for this paper are shown in Table 1.

TABLE 1: Typical values of the relevant parameters for full parametric study

	Typical steepest slope	Slope range chosen for analysis V: H
Embankment	1:1 to 1:5	1:2 to 1:5
	Typical shear strength parameters	Selected shear strength parameters
	$c' = 0(\text{kN/m}^2)$, $\phi' = 35^\circ$ to 41°	$c'(\text{kN/m}^2) = 0$, $\phi' = 35^\circ$ and 41°
	Range of bulk unit weight	Selected bulk unit weight
	18 to 20(kN/m^3)	18(kN/m^3)
Soft soil	Typical shear strength parameters	Selected shear strength parameters
	$c' = 0$, $\phi' = 14^\circ$ to 26°	$c' = 0$, $\phi' = 14^\circ$ to 26°
	Range of bulk unit weight	Selected bulk unit weight
	15 to 20(kN/m^3)	15 to 22(kN/m^3)

5 Analytical Method

5.1 Analyses of Time Dependent Behaviour of slopes at various D/He

5.1.1 Factor of Safety of Embankment over Time

Using parameters shown in Table 1, the behaviour of system of foundation and embankment soils, the change in Factor of Safety (FOS) was investigated. Embankments with slopes V:H 1:1, 1:2, 1:3, 1:4 and 1:5. with time varying from $T_v = 0.00$ to $T_v=2$ was used

in this investigation. The process of determining the effects of Time Factor on Factor of Safety was conducted by initially inserting the transient pore water pressure (Mwasha 2005). into slope stability software GEO5. 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 Figures 3, 4. 5. For Df/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 For slopes 1:3; 1:4 and 1:5 FOS was acquired in excess of unity.

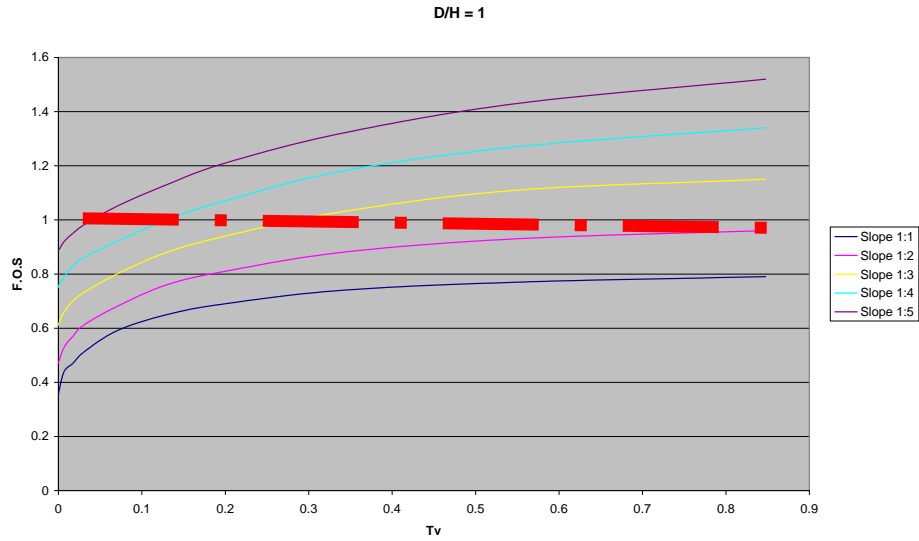


FIGURE 3: Factor of Safety for D/He equals to unity at given Time Factor (Tv) Time

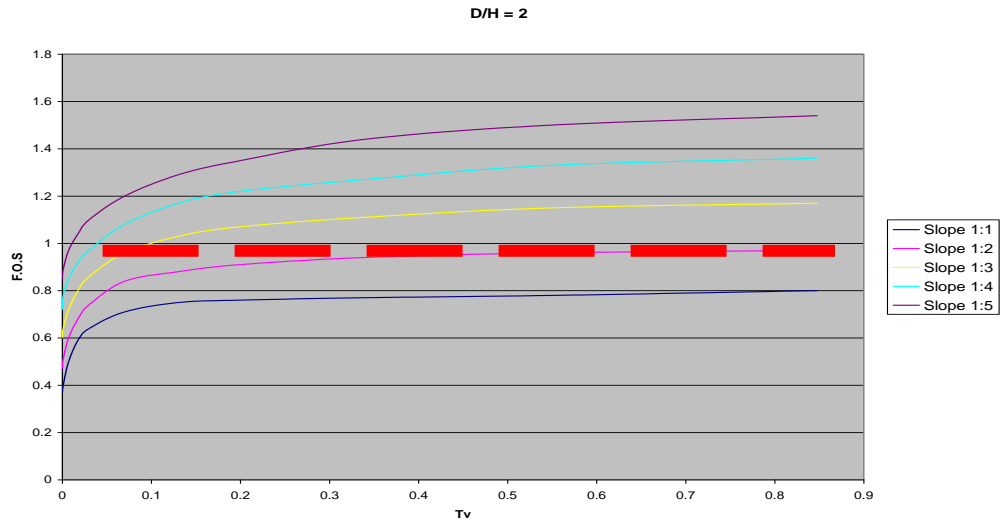


FIGURE 4: Factor of Safety for D/He equals to 2 at given Time Factor (Tv) Time

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 4

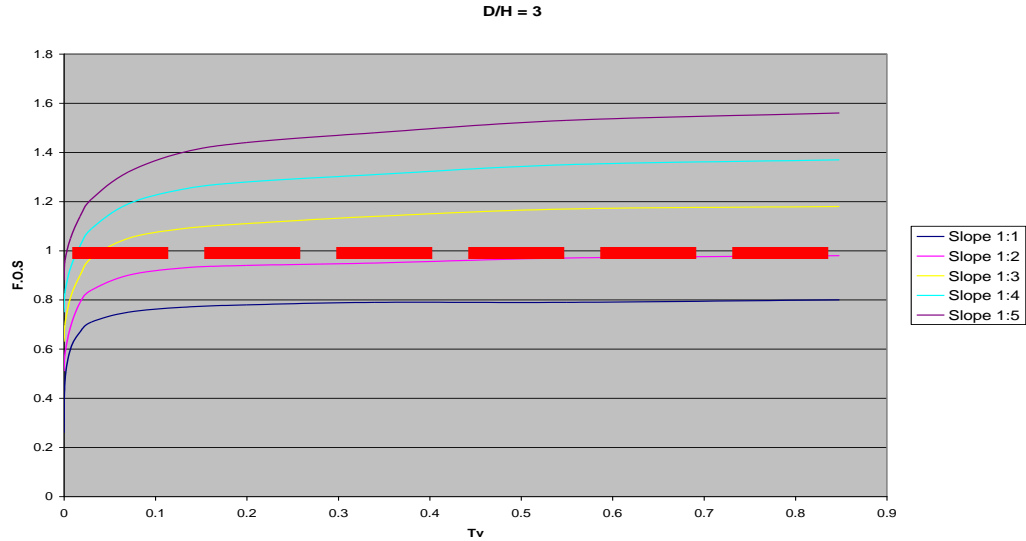


FIGURE 5: Factor of Safety for D/He equals to 3 at given Time Factor (Tv) Time

As shown in Figure 4 and 5 it was that for D/He equal 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 zero at the end of consolidation (Tv=2).

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

The initial tensile force at the end of construction was determine for embankment heights ranging between 1 to 4m at D/He ratios of 1 and 2 The initial tensile force (T_{R0}) 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 [Mwasha 2009].

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 (Mwasha 2008) at given Time Factor into GEO5 The backanalysis process for determining required tensile strength to achieve a specific FOS (Mwasha 2005, in press) was conducted for D/He equal to unity, and two. The results of backanalysed values were compared with those obtained using equation 2 (Mwasha 2009).

$$T_{R(t)} = T_{R0} - 120Tv^{0.50} \tag{2}$$

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 6 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.

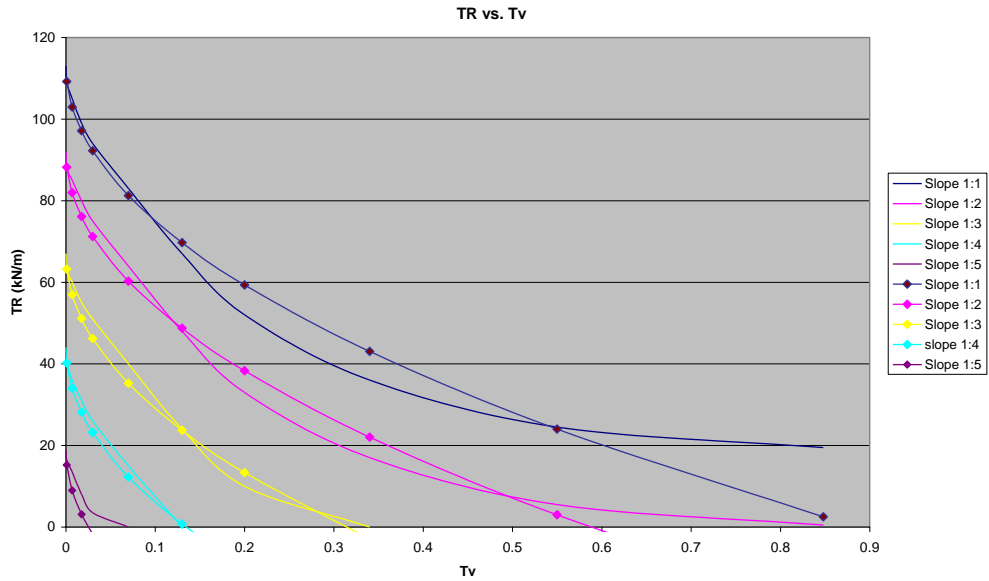


FIGURE 6: Backanalysed Required Tensile Force, $T_{R(t)}$ at given Time Factor, (D/He = 1)
(Predicted Tensile strength are shown in lines with dots)

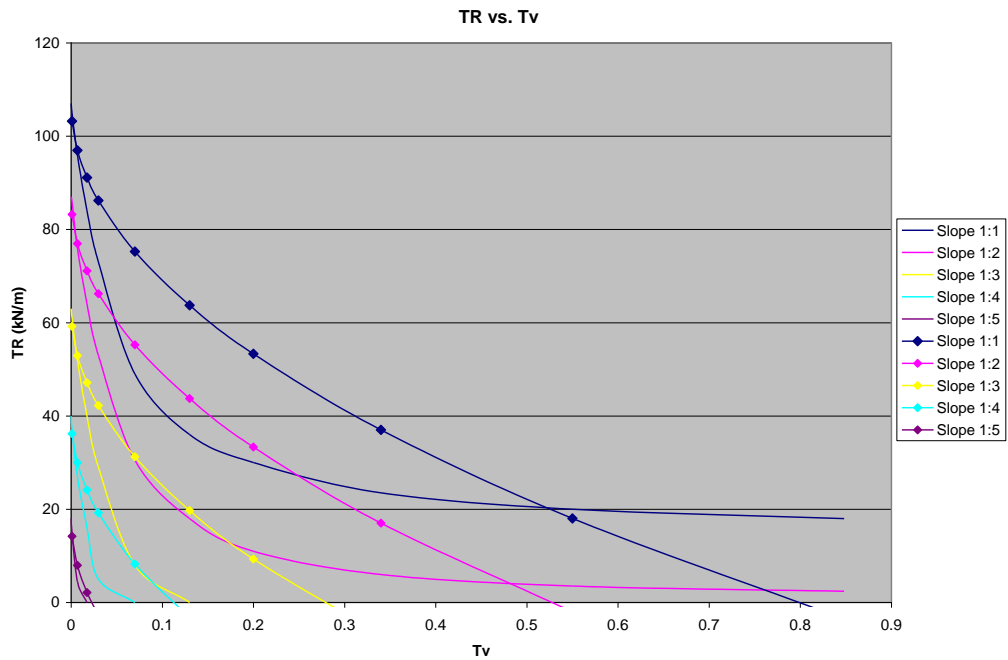


FIGURE 7: Backanalysed Required Tensile Force, $T_{R(t)}$ at given Time Factor, (D/He = 2)
(Predicted Tensile strength are shown in lines with dots)

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 8.

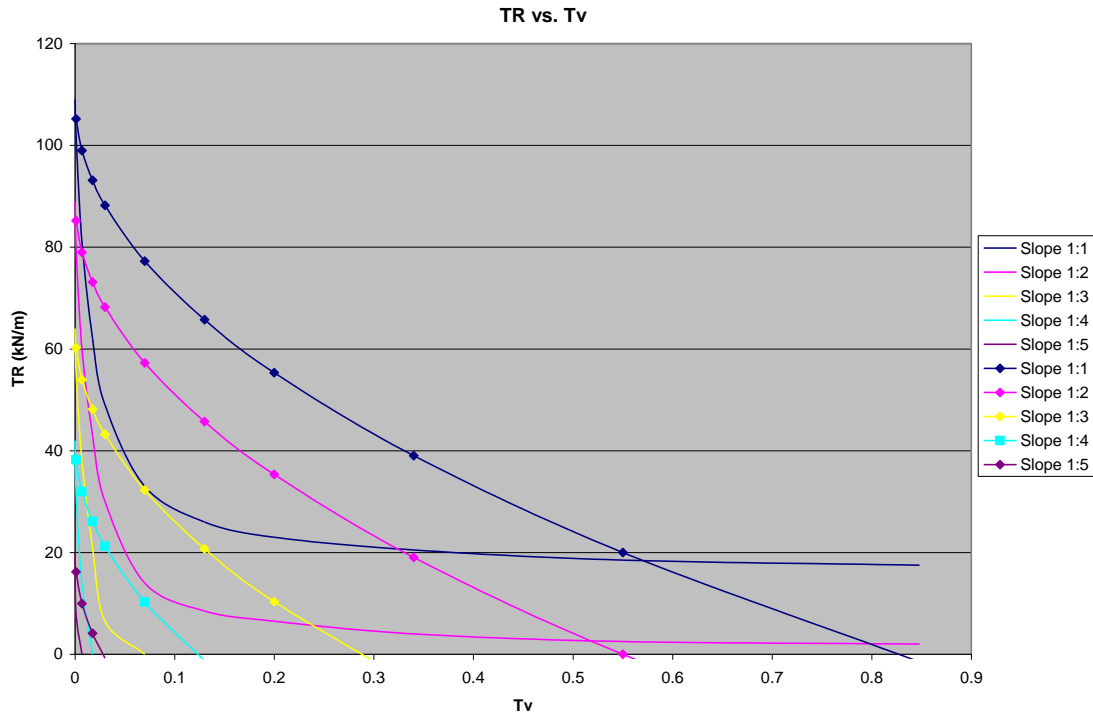


FIGURE 8: Backanalysed Required Tensile Force, $T_{R(t)}$ at given Time Factor, (D/He = 3)

(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 3.

6. Conclusion and Recommendations

- The use of a geotextile at the base of the embankment (between the underlying soft soil and embankment fill) will provide extra lateral forces. These will either prevent the embankment from splitting, or introduce a moment to resist rotation.
- As the underlying soil strength increases so the stabilizing force, which has to be provided by the geotextile, diminishes with time. A vegetable Fibre Geotextiles can be

selected wherein the loss in strength of the geotextile due to degradation. Corresponds to the reduction in the required stabilizing force.

- The analytical model has been successful and shows that geotextiles with limited design lives can be used in selected engineering situation.
- Further research is recommended for more complicated models and different foundation depth and embankment heights.

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