Investigation on Geotextile Behavior under Railway Embankment

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ABSTRACT

Stabilization of railway embankment on soft to very soft clayey subgrades has major importance from railway construction and operation points of view. Amongst the variety methods of soft soil stabilization especially in the case of railway embankment construction, utilizing the geotextile material usually facilities track construction and lead to more economical design in major of case. Selection of suitable geotextile material for railway embankment stabilization directly relates on precise evaluation of tensile force which cab be assessed with various closed form or numerical solutions. In this study the behaviour of railway embankment on soft clayey subgrades reinforced with geotextile was investigated. For this purpose two commonly used limit equilibrium method for analyzing the geotextile tensile force compared with nonlinear FEM numerical results. The results comparison, show considerable difference in geotextile tensile force for numerical and limits equilibrium methods in soft to very soft subgrades.

KEYWORDS: geotextile, finite element method, limit equilibrium method, railway embankment.

INTRODUCTION

In recent years development of high-speed railways and increase in axle loads in modern rolling stock systems have led to larger forces and vibrations in railway super and substructures. Parallel to development in utilizing the modern railway systems the optimizing of design methods were taken in to the consideration. One of the challenges in development of railway networks in problematic soil areas is construction of high embankment on very soft to soft clayey subgrades.

This problem is unavoidable in many cases due to railway route design requirements as well as economical points of view. Reviewing the technical literature in this regards the conventional stabilization methods for railway embankment could be summarized as follows:

- Rehabilitation of embankment drainage system with ditches, deep drains and interceptor drains.
- Provision of berms at the foot of the slope, this method is used in order to stabilize slopes, but is not recommended when the slip circle is shallow or too high or when the embankment is set on an inclined terrain.
- Reduction of load at the top of a cutting slope, achieved either by earth removal or re-profiling.
- Mechanical action, by retaining base of the slope like retaining wall, sheet piling, traditional piles, flexible wall, micro-piles which most of them also have the effect of loading the toe of the slope.
- Surface treatment with, planting vegetation, stones, protective cover of non-cohesive soil, geo-grids and geo-composites.
- For embankments less than 6m high, excavation under the track and complete replacement by a material of better bearing capacity, excavation under the track and partial replacement by a low density material of better bearing capacity, excavation to the side of the track and replacement by a material of better bearing capacity and stabilization by berms.
- For embankments more than 6 m high, stabilization by berms, piles placed beside the tracks and piles placed under the track (which are either capped or spanned with slabs of concrete or other materials)

One of the efficient methods in embankment stabilization on the soft to very soft clayey subgrades is utilizing of geotextile sheets. In recent years many researchers deal with assessment of actual performance of geotextile from design and construction as well as performance points of view. The major of these research activities can be classified in three categories as development of analytical Eq. for evaluation of geotextile internal force, laboratory tests and full scale monitoring of geotxtile behavior. Among the developed numerical models to study the tensile behavior of geotextile the work of Hoeg *et al.* 1969 [2], DApplonia *et al.*1971 [3] could be pointed out. Many full scale tests for evaluation of geotextile performance under embankment on soft clay have been undertaken by Tavenas and Leroueil 1980 [4], Parry and Worth 1981 [5], Ortigao *et al.*1983 [6] and R.Kerry Rowe, Sean D Hinchberger; 2003[9] and R.Kerry Rowe and Brian L.J.Mylleville [8]. Among the various activities for determination of improved design methods validity, the work of e.g See Leroueil and Rowe 2000 [7] is noticeable. In the field of improvement of limit equilibrium techniques for assessing the undrained stability of reinforced embankment the research work of Jewell, 1982 [10] Milligan and La Rochelle, 1984 [11] Rowe and Soderman, 1985 [12] can be mentioned.

For practical design purposes generally two different geotechnical codes are vastly used by consultant engineers. The approach of first code distributed by FHWA [13] for geotextile design is based on the control of geotextile tensile failure which can produce by active forces in embankment cylindrical sliding mechanism. The second popular method which is vastly used in UK was suggested by Jewell [10]. This method also is based on tensile force control resulted from active forces, subgrade cohesion and the cylindrical sliding mechanism.

In the recent years application of numerical methods in complicated geotechnical calculations due to utilizing powerful computers have made considerable progress. In current research utilizing SLIDE program for limit equilibrium method slope stability analysis and calculations and PLAXIS code for nonlinear FEM calculations, the problem of railway embankment slope stability were run and geotextile tensile force was compared for both of limit equilibrium and numerical FE methods. This comparison was made for soft to very soft clayey subgarde with usual railway embankment specifications. The comparison results for two categories of calculations for geotextile tensile force showed considerable difference especially for soft to very soft clayey subgrade under usual 25 tone operational railway axle load.

LIMIT Equilibrium Methods Description and Comparison

In this section two wieldy used limit equilibrium methods in US and UK for geotextile analysis and design will be described and compared in their bases. The first one is the method which was accepted by FHWA and the second is the Jewell [10] work which is well known method in UK.

Jewell Method

Preliminary design

In this method the applied active force on embedded geotextile due to embankment fill calculate in the first stage using Eq. 1. In continue due to embedded length of geotextile and maximum mobilized inward shears stress on the soft clay the second part of tensile force applied on geotextile can be evaluated by Eq. 2 as follows:

$$P_{RL} = \frac{K_a \gamma H^2}{2} \tag{1}$$

$$P_{RE} = \frac{\left(L_e + {}^{L_C}/_{2}\right) \times F_{bc} \times S_{UO}}{f_U} \tag{2}$$

WhereK_a, is Rankin's active earth pressure coefficient of γ is unit weight and H is height of the embankment. S_{UO} is the undrained shear strength at the clay surface, L_e is length of embankment side slope, L_C is the width of the embankment crest, f_U is a factor of safety which can be selected between 1 and 1.5. In the case of wide crests embankments, $L_e > L_C$ the expression in the bracket may be replaced by $1.5L_e$.

In above equation $F_{bc}$is interaction coefficient between top of the soft clay layer and underside of the geotextile reinforcement which can be extracted from:

$$F_{bc} = \frac{\tau}{S_{UO}} \tag{3}$$

Where, τ is, shear strength developed between soft clay surface and geotextile. F_{bc}Will be negative if embankment is unreinforced. This factor could be select between 0 and 1 for vertical loading and fully reinforced embankment cases respectively. Finally the total tensile force in embedded geotextile can be calculated through summation of two previously defined forces as follows:

$$P_{RT} = P_{RL} + P_{PE} \qquad (4)$$

Detailed design

As a general in conventional approach for analysis and design of reinforced embankments on soft soils, usually uses limit equilibrium approach in the form of embankment circular slip analysis. The general procedure as presented by Jewell [10] is as follows; First a conventional slip circle analysis is performed to find the maximum active moment, minimum resistant moment and minimum overall factor of safety, then the additional resistant moment required (ΔM_R) is calculated.

$$M_D = W \times X \qquad (5)$$

$$\Delta M_R = P_{RT} \times Y \qquad (6)$$

$$P_{RT} \times Y = f_U \times M_D - M_R \qquad (7)$$

$$P_{RT} = \frac{f_U \times M_D - M_R}{\mathrm{Y}} \qquad (8)$$

Where Y is vertical distance between center of the most critical slip circle and the plane of the geotextile reinforcement. X is horizontal distance between central gravity of the slip surface and slip circle center. Knowing active moment M_D and safety factor $F.S$, the amount of restoring moment (M_R) can be found from the equation:

$$F.S = \frac{\mathrm{M_R}}{M_D} \qquad (9)$$

In the present study through back analysis procedure, the tensile force in geotextile layer spread beneath the railway embankment was calculated. For this purpose calculating the minimum F.S=1 as well as weight moment M_D for critical cylindrical sliding surface, the resistant moment $\mathrm{M_R}$ was calculated by Geo-Slope limit equilibrium based software. In continue by means of $\mathrm{M_R}$ value and using Eq. 8, the mobilized tensile force in geotextile were calculated.

FHWA Method

Base on analysis method which has established by FHWA [13] evaluation of geotextile adequacy could be check in two steps. In first step through satisfaction of defined factor of safety with rotational sliding of embankment, M_D and M_R values can be calculated and in final the tensile force in geotextile extracted. In second step due to possibility of embankment lateral spreading the geotextile axial force could be calculated. The detailed formulation in each step is presented in following.

Checking *rotational* shear stability

In this part a rotational slip surface analysis is performed on un-reinforced embankments and foundations to determine the critical failure surface and the factor of safety against general shear instability. If the calculated factor of safety is greater than the minimum required, then reinforcement is not needed, else the amount of tensile strength in the geotextile reinforcement is calculated from the following equation:

$$T_g = \frac{F.S \times M_D - \mathrm{M_R}}{\mathrm{R} \times \cos(\theta - \beta)} \qquad (10)$$

$$M_D = W \times X + q \times d \qquad (11)$$

Where F.S is commonly 1.3 and θ is angle from horizontal to tangent of slip circle at the geotextile reinforcement, and the measure of β is:

For brittle, strain-sensitive foundations soils (leached marine clays) or where a crust layer is considered in the analysis for increased support, equal to zero.

- For $\mathrm{D}/\mathrm{B} < 0.4$ (D is the depth of soft soil from the original ground line and B is the width of embankment) and moderate to highly compressible soils, equal to $\theta/2$.
- For $\mathrm{D}/\mathrm{B} < 0.4$ highly compressible soils and reinforcement with high elongation potential ($\varepsilon \geq 10\%$) and large tolerable deformations, equal to θ, when in any doubt, equal to zero.

In Eq. 11, q is a uniform surcharge and d is an arm of the force. The other parameters are similar to Eqs. 5 and 6.

Checking lateral sliding stability

If the calculated factor of safety is greater than the minimum required, then reinforcement is not needed, else the tensile force in geotextile reinforcement ($\mathrm{T_{ls}}$) against sliding is calculated from Eq. 12. Where, B is toe of the embankment and C_a assumed to be equal to zero for extremely soft soils.

$$(B \times C_a + \mathrm{T_{ls}}) = FS \times RF \times \frac{\mathrm{K_a}\,\gamma \mathrm{H}^2}{2} \qquad (12)$$

GEOTEXTILE TENSILE FORCE ASSESMENT

In recent decades application of numerical methods had a considerable development in all of engineering branches. In this way, geotechnical engineers have had great tendency to utilize powerful geomechanical software in various geotechnical fields. Among the various geomechanical codes, the PLAXIS code as a well known nonlinear FEM software could earn its real situation between geotechnical engineers. In the current study base on valuable PLAXIS abilities especially in geotextile modeling, the results of exact nonlinear FEM modeling were compared with two previously mentioned limit equilibrium methods. The process of geotextile tensile force assessment due to embankment weight and railway traffic using limit equilibrium and FE methods will be described in following section.

3.1. Railway Embankment Slope Stability Analysis

Finite element method has enough capacity to solve variety range of geotechnical engineering problems. As a special case performance of geotextile layer under the railway embankment can be evaluated for very soft to soft clayey subgrades. In this condition geotextile work as a reinforcing layer to control the settlement progress as well as bearing capacity. Regarding to mention abilities in this study the limit equilibrium methods result precision were compared with FEM solution. In first stage for calculation of critical sliding wedge in railway embankment was assessed using GEOSLOPE computer code and as results the weight and moment of sliding wedge was calculated. In continue knowing the existing factor of safety and extraction of weight sliding moment the resistant moment against sliding could be calculated. Based on the calculated weight and resistant moment's values the geotextile tensile force can be evaluated by utilizing closed form equations for two previously mentioned limit equilibrium methods. In this regard through consideration of required safety factor for embankment slope stability the geotextile tensile force were extracted using both FHWA [13] and Jewell[10] limit equilibrium methods. In this approach if the amount of reached safety factor by GEOSLPOE software was greater than 1 in Eq. 7 and 1.3 in Eq. 10, fraction would be negative and the answer was deleted from result collections. In second part, the PLAXIS software has been used to determined tensile force in geotextile reinforcement. In continue the geomechanical specification of the embankment and subgrade materials as well as geometrical properties and the implemented railway load will be described for three different categories of the solutions.

Geometric parameters

Specifications of railway embankment are defined in Table 1. In this regard the embankment slope was considered 1H: 1.5V and ballast thickness supposed to be 50 centimeters.

Geomechanical Parameters

In order to evaluate the effect of material properties on the tensile force of the geotextile, different material properties for embankment and subgrade materials were considered which summarized in Table 2.

Table1: Geometric parameters of Embankment

B(m)	H(m)	Crust with
3	2	Equal to 6m for one lane track
6	4	
9	6	
12	8	
15	10	
19	12	
21	14	

Table 2: Material properties used in the analyses

	Poisson's ratio	Young's modulus (kN/m^2)	unit weight (kN/m^3)	Friction angle	Cohesion (kN/m^2)
Ballast	0.35	3×10^5	19	45°	0
Embankment	0.3	$C_{Embk} \times 1000$	20	25°	5-50
Subgrade	0.4	$500 \times C_{Subg}$	17	0	5-50

Since the maximum force in the geotextile is a criterion for comparisons, a rigid geotextile material with axial stiffness equal to 10^5 kN/m was considered in calculations.

Loading

As a regular railway axle load a 25 ton concentrated load was considered for slope stability calculations. From railway operational point of view it was assumed that one half of the load is sustained by the loaded sleeper and the remainder by adjacent sleepers. The length of each sleeper is considered to be 2.6 m and the axial load is uniformly distributed on the subgrade by a value of 48 kN/m.

NUMERICAL RESULTS AND DISCUSSION

Considering all of the various geometry and geomechanical parameters of embankment and subgrade in the problem totally 168 different analyses were conducted using limit equilibrium and finite element methods. As a result the tensile forces generated in the geotextile are compared in Figures 1. It should be noted that only the unit weight and the shear strength are used in the limit equilibrium analyses while all the properties presented in Table 2 are used during finite element analyses. As it shown in the Table 2 the subgrade Young's modulus is selected regarding to proposed empirical equation of Skempton for normal and over-consolidated clays.

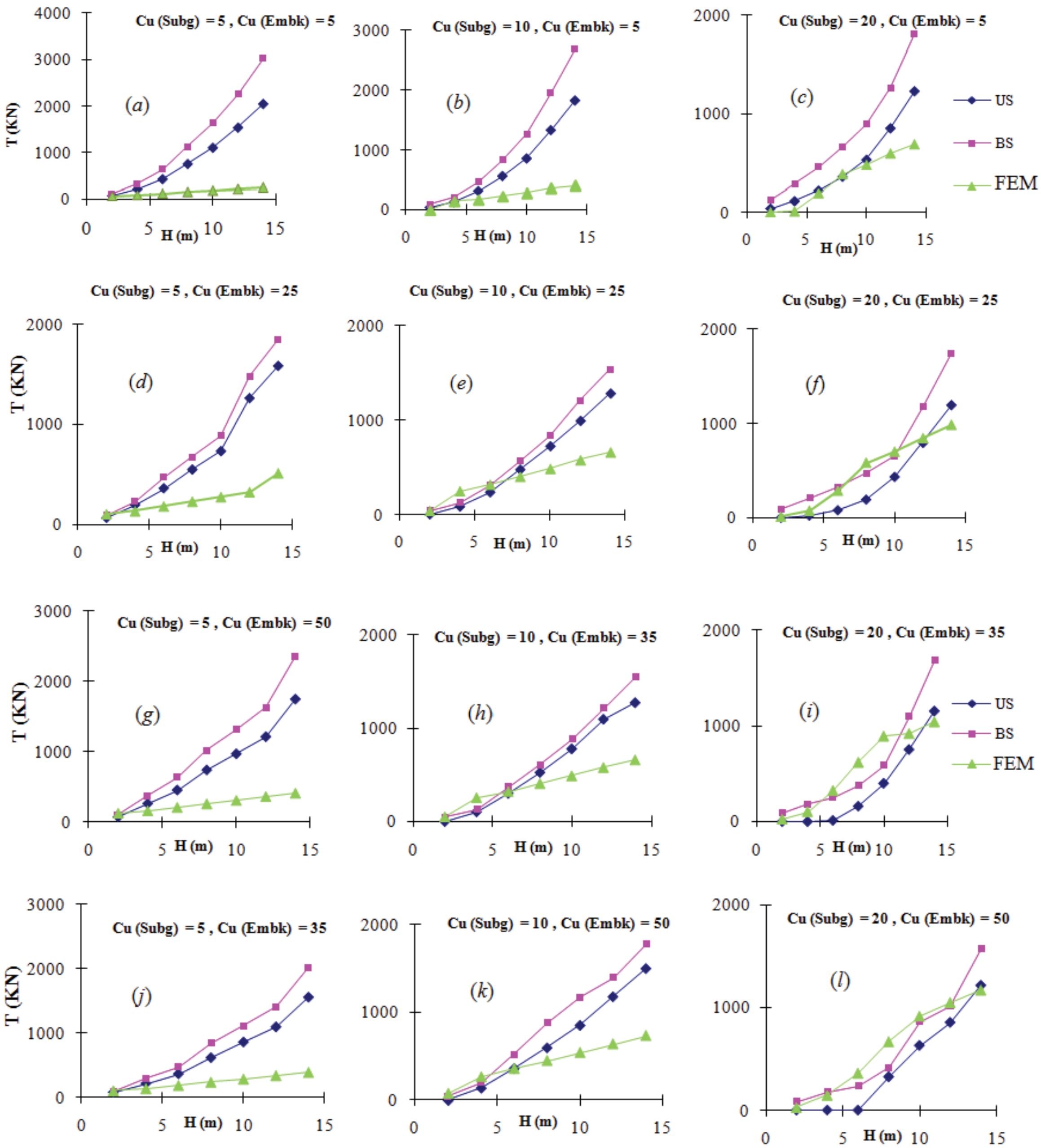

Figure 1: Relationship between height of embankment & geotextile tensile force (*a*) to (*l*)

Reviewing the extracted numerical results it could be seen that for subgrades by cohesions of 5, 10, and 25 kPa, by increasing in the cohesion of the embankment from 5 to 50 kPa, the two previously mentioned code results lead to approximately the same graphs for common subgrade cohesion. This fact is due to rotation type of failure for railway embankment over the loose subgrades which are confirmed by two codes calculation formulas. This means that for predomination of rotation in comparison to sliding mode of failure the cohesion of the embankment must be great enough. On the other hand in subgrades by cohesions value between

10 to 20 kPa, by changing embankment cohesion the FEM analysis results make distant from the codes results, which is due to the occurrence of the embankment failure in sliding mode .This means that the failure of the embankment took happen before end of construction. In limit equilibrium method, even though the safety factor obtained by the GEOSLOPE software is less than 1, the force in the geotextile would be excessive since the overturning moment is great because the great failure circle creation is impossible in practice. Therefore, it can be stated that the underestimated results of limit equilibrium method are fairly great in loose to very loose subgrades.

In subgrades with cohesions of 30, 40, and 50 kPa, Jewell's method results separates from FHWA[13] proposed results by increasing the embankment cohesion from 5 to 50 kPa. This could be related to predomination of sliding mode of failure for embankment in the case of high cohesive subgrades. Since sliding is resulted from sum of two components PRL and PRE in the Jewell's [10] method, and that PRL component is extremely reduced by increasing in subgrade cohesion while PRE remains ineligible and constant. Whereas, the FHWA [13] sliding formula is obtained by multiplying 3.25 and active pressure of the soil ($FS \times RF$); thus, the Jewell's [10] solutions would be greater in value.

In highly cohesive subgrades, by changing the subgrade cohesion and constant embankment cohesion, the FHWA [13] trend is constant. This is due to the constant active pressure of soil and sliding mode predomination of sliding modes for embankment.

In slightly cohesive subgrades, the obtained results from finite element solution are zero while FHWA [13] and Jewell's [10] codes result are substantial different. In this state, the horizontal sliding mode control the geotextile design; while the slip circle is tangent to the subgrade in the limit equilibrium method thus the obtained force from the rotational stability analysis would become zero. Therefore, in these cases the solutions resulted from the finite element analysis are close to those of the limit equilibrium approach.

In subgrades with cohesions of 30, 40, and 50 kPa, in constant subgrade cohesion and the increase of the embankment cohesion from 5 to 50 kPa; the geotextile force is reduced. This is because the sliding controls the design when the cohesion of the subgrade is increased, and the sliding is reduced by increasing the cohesion of the embankment; therefore, the geotextile force will be decreased. However the increasing procedure of the solutions obtained by FEM can be justified by assuming that FEM considers the subgrade cohesion effect as an addition factor in geotextile force similar to the Jewell's approach.

CONCLUSION AND REMARKS

In this study the geotextile tensile force was evaluated and analyzed by means of two limit equilibrium approaches recommended by Jewell [10] and FHWA [13] for the embankments supported on very soft to soft clayey subgrades. These results were compared with precise results of FEM method implemented in PLAXIS code. Through comparison of the geotextile internal forces for various embankments height and material properties underlying on the various clayey subgrades the below general results were observed:

1. In subgrades with cohesions of 5, 10, and 25 kPa and increasing in cohesion of embankment from 5 to 50 kPa, the two limit equilibrium methods lead to approximately the same results for common subgrade cohesion.

2. In subgrades with cohesions of 10 and 20 kPa, by variation of embankment cohesion the resulted of FE analysis differ from limit equilibrium methods. The mentioned difference has noticeable value in the case of loose subgrades.

3. In subgrades with cohesions of 30, 40, and 50 kPa, because of sliding mode of failure for embankment, Jewell's results has difference with FHWA[13] results. With increasing the embankment cohesion from 5 to 50 kPa, and shows greater solutions.

4. In highly cohesive subgrades, by changing the subgrade cohesion with constant embankment cohesion, The FHWA [13] results trends to constant. This is due to the constant active pressure of soil and that sliding governs the design.

5. In slightly cohesive subgrades, FE analysis results are close to the limit equilibrium approach results.

6. In subgrades with cohesions of 30, 40, and 50 kPa and constant subgrade cohesion with increase in embankment cohesion from 5 to 50 kPa, the geotextile force will be decreased.

REFRENCES

1. UIC 719-R (1994) "Earthworks and Track-Bed Layers for Railway Lines, International Union of Railways."
2. Hoeg *et al.* (1969) "Undrained Behaviour of Quick Clay Under Load Tests at Astrum. " Geotechnique, 19:101-115
3. D'Applonia *et al.* (1971) "Evaluation of Pore Pressures Beneath an Embankment." Journal of Soil Mechanics and Foundation Engineering , ASCE, 97:881-897.
4. Tavenas and Leroueil (1980) "The Behaviour of Embankments on Clay Foundations." Canadian Geotechnical Journal,;17:236-260.
5. Arry and Worth (1981) "Shear Stress-Strain Properties of Soft Clay. In Clay Engineering." Elsevier Scientific Publishing Company, 311-362.
6. Ortigao *et al.* (1983) "Embankment Failure on Clay Near Rio De Janeiro." ASCE Journal of The Geotechnical Engineering division,;109:1460-1479.
7. Leroueil e.g and Rowe (2000) "Embankments over Soft Soil and Peat. In Geotechnical and Geoenvironmental Engineering Hand Book" 463-499.
8. Rowe K.R. and Mylleville L.J. "Ageogrid Reinforced Embankment on Peat over Organic Silt: A Case History." Canadian Geotechnical Journal, 33:106-122.

9. Kerry Rowe R. and Sean Hinchberger D. Geosynthetic (2003) "Reinforced Embankments on Soft Clay Foundations: Predicting Reinforcement Strains at Failure. " Geotextiles and geomembranes;21:151-175.

10. Jewell R.A. A Limit (1982) "Equilibrium Design Method for Reinforced Embankments on Soft Foundations." Proceedings of Second International Conference on Geotextiles,; 2:671-274.

11. Milligan and La Rochelle (1984) "Design Methods for Embankments over Weak Soils." Symposium on Polymer Grid Reinforcement in Civil Engineering: Institute of Civil Engineers,; 34:95-102.

12. Rowe and Soderman (1985) "An Approximate Method for Estimating The Stability of Geotextile Reinforced Embankments." Canadian Geotechnical Journal,; 22:392-398.

13. U.S. Department of Transportation, (1998) "Federal Highway Administration." Geosynthetic Design and Construction Guidelines Participant Notebook.