Design of Veneer Cover Soils on Slopes using Geogrids

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ABSTRACT

This paper presents a method of analysis based on the Limit Equilibrium method to evaluate the stability of veneer cover soils on slopes. It is important to assess the stability of the slopes in order to eliminate potential sliding failures of the cover soils over the lined systems .The analysis is based on a uniform thickness of a cover soil over a finite length of slope and a given slope angle to arrive at a Factor of Safety (FOS) that is acceptable. Included in the analysis are the driving forces of equipment loads, surcharge and gravitational forces, which when applied to the lined system can create instability and generate a lower FOS. Numerous researchers have adopted different methods of improving stability of cover soils on slopes such as tapered cover soils, toe berms and geogrid reinforcement. This paper looks at increasing the FOS by incorporating a geogrid. The geogrid is anchored at the top of the slope and placed directly on the Geomembrane (GM), Geosynthetic Clay Liner (GCL) or Compacted Clay Liner (CCL). As the backfill is placed the geogrid becomes tensioned. The tensioning of the geogrid, depending on the allowable tensile strength resists the gravitational forces of the cover soils. The calculations presented in the paper show the difference between FOS with geogrid and FOS without a geogrid. The method is further illustrated by examples of landfills where geogrids have been designed as veneer reinforcement.

1. INTRODUCTION

The main concern covered in this paper is that no slippages should occur between the veneer cover soil and the underlying geosynthetic. Instability of a slope can be caused by gravitational forces (weight of the cover soil), construction equipment, seepage forces within the cover soil, and seismic forces in applicable areas. Stability of a slope is established using the limit equilibrium method, or a finite element analysis for more complex structures. In this paper, we investigate a systematic approach of using a limit equilibrium method of design which will allow the designer to arrive at a satisfactory FOS. The design will include a cover soil between 0.3 to 1.0m thick as has been seen to be common practice in South Africa. For the design process, a detailed account of equipment such as bulldozers must be accounted for in both directions of movement, that is, usually along the up-slope and the down-slope. A simplified table illustrated in the paper will assist when designing such veneer cover soils. The method table will include four scenarios: Case A) FOS for a standard example, Case B) FOS for equipment moving up-slope, Case C) FOS for equipment moving down-slope, Case D) FOS using geogrid reinforcement. Exploring these design situations will enable a conclusion to be drawn as to whether the use of geosynthetic reinforcement (geogrid) does amplify the FOS. The conclusion of the paper will depict: the use of geogrid reinforcement for veneer stability; comparable strengths of geogrids and the effect they have on the FOS.

2. METHOD OF ANALYSIS

2.1 Limit Equilibrium Method

Included in the analysis, are the factors that cause instability, namely, the weight of the cover soil, and the effect of tracked equipment on the slope. The method will identify the mechanism of failure and thereafter arrive at a FOS. If the FOS is unacceptable then it is further demonstrated that the inclusion of a geogrid can increase the FOS. The analysis that follows is from Koerner and Soong (1998). However, there are many similar publications: Koerner and Hwu (1991), Giroud and Beech (1989), and McKelvey and Deutsch (1991). All this published literature is aimed at increasing the awareness of the need for the analysis and design of veneer cover soils.

2.2. Design Example Framework

Figure1. below indicates the forces required within the active and passive wedge. These forces convey the balancing equation used to bring the system into equilibrium. The framework provides assistance in the layout of the final design. Research has shown that many design examples set the length of slope as infinite. Realistically, a specific length of slope along the liner must beset with a uniformly thick cover soil and placed over liner at a specific slope angle. This includes a passive wedge at the toe and tension crack at the crest (Figure 1). These forces convey the balancing equation used to bring the system into equilibrium. The placement of the cover soil on a slope should always be from the toe upward to the crest. The gravitational forces of the cover soil together with live load created by the construction equipment can cause instability and this is shown below The interface shear strength of the cover soil over the geosynthetic must be tested as it is critical to the design. Material testing must be site-specific, i.e. perform soil sampling on the material to be used as a cover soil along with candidate geosynthetics to be used for the final cover. These materials should undergo the necessary testing required to obtain the values for interface friction. Figure 2. (a & b) depict the scenarios where track equipment as previously explained , move either up or down-slope. The figure includes the necessary forces required to complete the quadratic equation. These figures in all four cases serve as an initial check to alert the designer of the forces that are generated to attain the limit equilibrium state. Although this paper does not examines the seepage forces created in the cover soil, it is important to assess this as a possible mode of failure. To avoid the possibility of seepage forces, adequate drainage must be provided for in the cover soil over the GM barrier.

Figure 1: Limit Equilibrium forces involved in a finite length slope analysis, showing the use of allowable tensile strength for a geogrid reinforcement case (After Koerner and Soong, 1998).

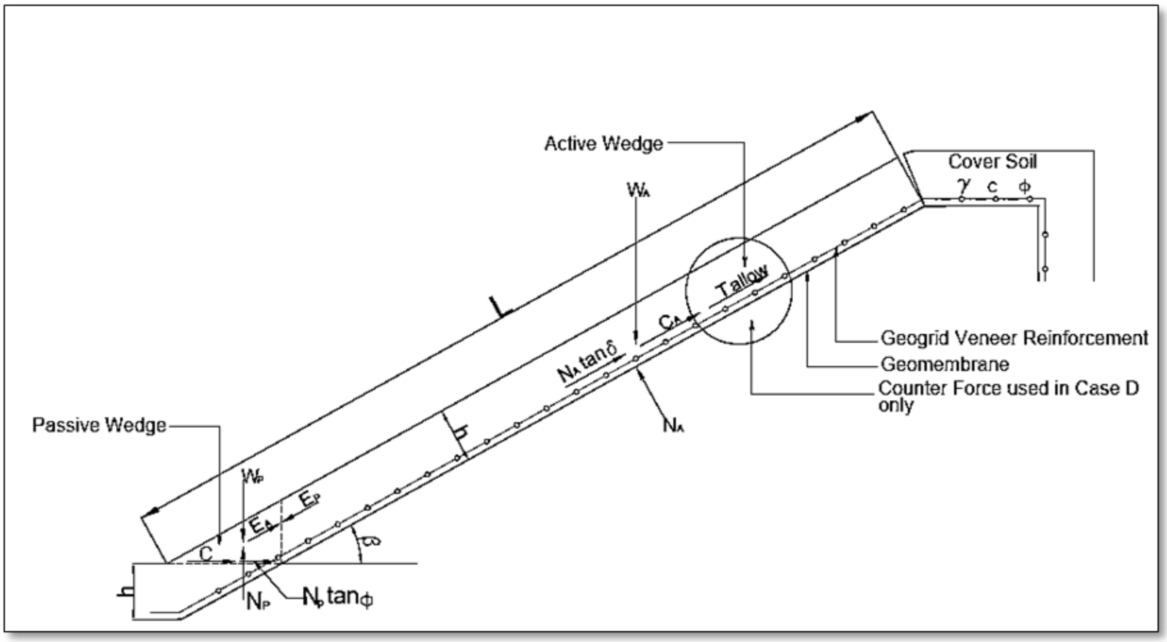
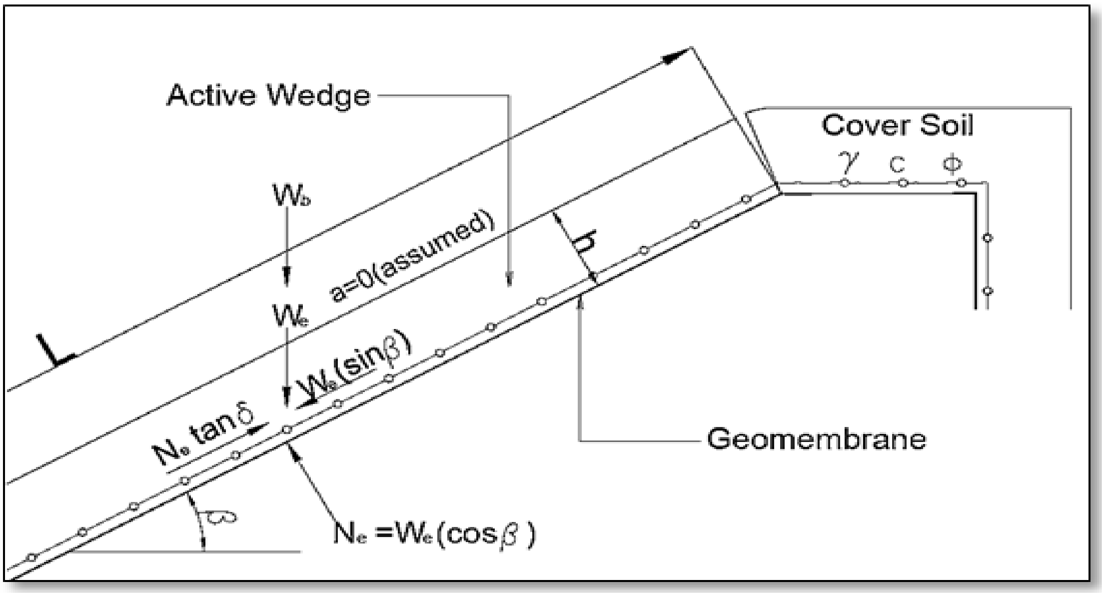
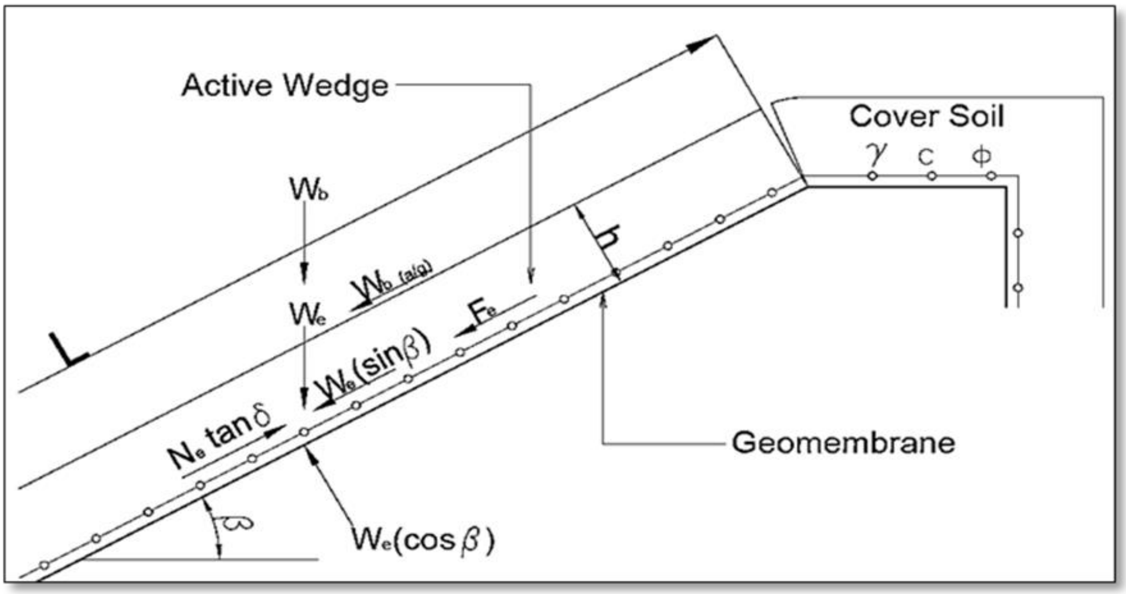


Figure 2: Limit Equilibrium forces involved in a finite length slope analysis for track equipment moving up-slope (a) and down-slope (b) (After Koerner and Soong, 1998)



a) Equipment moving up-slope



b) Equipment moving down-slope

2.3 Calculation Methodology

The following sections summarise the calculation methodologies for 4 scenarios. The required inputs for each scenario will be constructed in tabular format. After acquiring the required inputs the final outcome of the calculations will be the FOS for each scenario. To make the calculations clearly visible to the designer one should separate the calculation of the wedge forces and thereafter continue to complete the quadratic expression to find the suitable FOS. The tables that follow will be marked in numerical steps for the designer to complete the required calculations. This will be followed by a checklist to ensure that all steps were carried out.

2.3.1 Input Parameters Dependant on Case Selected **(Step 01)**

Table 1. Veneer Cover Soil Stability Check (Input Parameters)

	Case A	Case B	Case C	Case D
Required Inputs	Check stability of cover soil alone	Check stability of cover soil with bulldozer moving up slope	Check stability of cover soil with bulldozer moving down slope	Check Stability of cover soil using geogrid
Unit Weight of cover soil *(kN/m³)*	γ	γ	γ	γ
Thickness of cover soil *(m)*	h	h	h	h
Length of slope measured along geomembrane *(m)*	L	L	L	L
Soil slope angle beneath the geomembrane *(degrees)*	β	β	β	β
Friction angle of the cover soil *(degrees)*	Φ	Φ	Φ	Φ
Interface Friction angle between cover soil and geomembrane *(degrees)*	δ	δ	δ	δ
Cohesion of the cover soil *(kN/m²)*	c	c	c	c
Adhesive force between cover soil of the active wedge and geosynthetic *(kN/m)*	C_a	C_a	C_a	C_a
Adhesion between cover soil of the active wedge and the geomembrane *(kN/m²)*	c_a	c_a	c_a	c_a
Actual weight of equipment to place cover soil *(kN)*		W_b	W_b	
Length of equipment track *(m)*		W	W	
Width of equipment track *(m)*		B	B	
Influence factor at the geomembrane interface (Poulos and Davis (1974))		I	I	
Equivalent equipment force per unit width at the geomembrane interface *(kN/m)*		We=qwl …where q =Wb/(2wb)	We=qwl …where q =Wb/(2wb)	
Dynamic force per unit width parallel to the slope at the geomembrane interface*(kN/m)*		Fe=0	$\mathrm{Fe} = \mathrm{We}(\frac{a}{g})$	
Acceleration of the equipment		Assume a =0	a	

(m/s^2)				
Acceleration due to gravity (m/s^2)			g	
Allowable long term strength of the geosynthetic reinforcement *(kN/m)*				T_{allow}

2.3.2 Wedge Force Summation Process **(Step 02)**

Table 2: Sum of Forces Calculation

Required Calculation	Case A	Case B	Case C	Case D
Total weight of the active wedge *(kN/m)*	W_A	W_A	W_A	W_A
Effective force normal to the failure plane of the active wedge *(kN/m)*	N_A	N_A	N_A	N_A
Adhesive force between cover soil of the active wedge and membrane *(kN/m)*	C_a	C_a	C_a	C_a
Total weight of the passive wedge *(kN/m)*	W_P	W_P	W_P	W_P
Effective equipment force normal to the failure plane of the active wedge *(kN/m)*		N_e	N_e	

Where:

$$W_A = \gamma h^2 \left(\frac{L}{h} - \frac{1}{\sin\beta} - \frac{\tan\beta}{2}\right) \quad [1]$$

$$N_A = W_A \cos\beta \quad [2]$$

$$Ca = c_a \left(L - \frac{h}{\sin\beta}\right) \quad [3]$$

$$N_e = W_e \cos\beta \quad [4]$$

$$W_P = \frac{\gamma h^2}{\sin 2\beta} \quad [5]$$

2.3.4 Final Terms to perform Quadratic Function Calculations **(Step 03)**

Table 3: Final Quadratic Function Calculations

Gravitational Forces Only (Case A)		
Term 'a'	$(W_A - N_A \cos\beta)\cos\beta$	
Term 'b'	$-[(W_A - N_A\cos\beta)\sin\beta\tan\Phi + (N_A\tan\delta + Ca)\sin\beta\cos\beta + \sin\beta(C + W_p\tan\Phi)]$	
Term 'c '	$(N_A\tan\delta + Ca)\sin^2\beta\tan\Phi$	[6]
Up-slope /Down-slope Equipment (Case B and C)		
Term 'a'	$[(W_A + W_E)\sin\beta + Fe]\cos\beta$	
Term 'b'	$-\{[(N_E + N_A)\tan\delta + Ca]\cos\beta + [(W_A + W_e)\sin\beta\ Fe]\sin\beta\tan\Phi) + (C + W_p\tan\Phi)\}$	
Term 'c'	$[(N_E + N_A)\tan\delta + Ca]\sin\beta\tan\Phi$	[7]

Increasing FOS with Geogrid (Case D)		
Term 'a'	$(W_A - N_A \cos\beta - T\sin\beta)\cos\beta$	
Term 'b '	$-[(W_A - N_A\cos\beta - T\sin\beta)\sin\beta\tan\Phi + (N_A \tan\delta + Ca)\sin\beta\cos\beta + \sin\beta(C + W_p \tan\Phi)$	
Term 'c'	$(N_A \tan\delta + Ca)\sin^2\beta \tan\Phi$	[8]

2.3.5 Final Quadratic Expression

The design calculations should be completed in the following sequence;
***Step 01*:** Input of general parameters (Table 1)
Step 02: Calculation of forces required for limit equilibrium (Table 2)
Step 03: Final term calculations to obtain FOS (Table 3)
Step 04: Obtain the FOS is to substitute values obtained in Table 3. These values will be substituted into;

$$FOS = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \quad [9]$$

The solution to the quadratic will result in a factor of safety for the designer. These values of FOS can be compared to a guideline set by Koerner and Soong (2005). The designer must show extreme judgement in his deliberation of the factor of safety. Research of the following table shows that it should be used as a guide only. There are certain aspects which may recommend a FOS that is higher or in other cases lower, depending on the severity of the project. It is always advisable to check with local regulatory bodies on the FOS that is most suited to the application.

Table 4: Recommended global factor-of safety values for static conditions in performing stability analysis of final cover systems, after Koerner and Soong (2005).

Type of Waste → Ranking ↓	Hazardous waste	Non-Hazardous waste	Abandoned Dumps	Waste piles and leach pads
Low	1.4	1.3	1.4	1.2
Moderate	1.5	1.4	1.5	1.3
High	1.6	1.5	1.6	1.4

2.3.4.1 Geogrid Selection Process

To evaluate a geogrid for the design, consideration must be given to short term tensile strength and long term tensile strength. The short term tensile strength of geogrids is available from manufacturers and suppliers. This value is generated from using either of the following standard wide-width tensile test methods.

1. SANS 1525-13 :Wide Width Tensile Test
2. ASTM D4595-11 :Wide Width Tensile Properties of geotextiles
3. EN ISO 10319-08 :Wide Width Tensile Test

The short term tensile strength or the maximum strength resulting from the test is referred to as T_{ult}. The tensile strength used in the design is referred to as T_{allow}. This is calculated by the introduction of reduction factors and shown in the equation below. Typically the reduction factors are for creep, installation/mechanical damage and chemical/biological damage. Other reduction factors can be included and this should be assessed on a site specific basis or geosynthetic product specific basis.

$$Tallow = \frac{\text{Tult}}{\text{RCR x RID x RCBD}} \quad [10]$$

Where:

- R_{CR} = creep reduction factor
- R_{ID} = installation damage reduction factor
- R_{CBD} = chemical and biological degradation reduction factor
- R_{SM} = other reduction factors to account for seams, holes, material etc

a. Creep

Creep is defined as permanent deformation under constant load. Typical values are shown below for the different t types of geogridAccelerated tests methods for creep are the Stepped Isothermal Method (SIMS) and Time-Temperature Superposition (TTS). Results below are taken from (Thornton et al 2000) which can be used in the selection of the reduction factor that's accounts for creep.

Table 5.Creep reduction factors for 114yrs ($10h^6$) for example? geogrids

Polymer (Typical UTS)	Strain Limit	%	Rupture Limit
PVA (50kN/m)	1.63	5	1.57
Aramid (75kN/m)	1.49	2.3	1.49
PA (25kN/m)	2.26	10	1.98
PET (40kN/m)	1.62	10	1.61
PP (35kN/m)	4.63	10	3.27
HDPE(70kN/m)	3.04	10	2.69

b. Installation/Mechanical damage

In most applications the geogrids are exposed to the highest mechanical stresses during the installation process. Damage to the geogrid during installation can reduce the tensile strength of the geogrid and sometimes this can exceed the design strength needed. In addition to the type of material composition of the geogrid, the level of damage will depend on a number of other factors: the type of construction equipment; the compaction effort applied; the graduation, angularity and condition of the fill. The following two tables provide factors that can be used to account for installation damage due to the particle size of the backfill.

Table 5.SANS 207:2006

Type of Fill	Typical Particle size (mm)	Partial Factor (fm_{21})
Crushed Rock	60-125	1.4
Gravels	2-60	1.3
Sands or finer	<2	1.1

Table 6. FHWA Installation Damage Reduction Factors

Geosynthetic	Type 1 backfill Maximum size 100mm D_{50} about 30mm	Type 2 backfill Maximum size 20mm D_{50} about 0.7mm
HDPE uniaxial geogrid	1.20 - 1.45	1.10 - 1.20
PP biaxial geogrid	1.20 - 1.45	1.10 - 1.20
PVC coated PET geogrid	1.30 - 1.85	1.10 - 1.30
Acrylic coated PET geogrid	1.30 - 2.05	1.20 - 1.40
Woven geotextiles (PP & PET)	1.40 - 2.20	1.10 - 1.40
Nonwoven geotextiles (PP & PET)	1.40 - 2.50	1.10 - 1.40

Slit film woven PP geotextiles	1.60 - 3.00	1.10 - 2.00

c. Chemical /Biological degradation

This is sometimes called the durability reduction factor, RFD, is dependent on the susceptibility of the geogrid to attack by microorganisms, chemicals, thermal oxidation, hydrolysis, stress cracking, and UV degradation. This is a very site- specific and product -specific assessment. *Typically, polyester products (PET) are susceptible to aging strength reductions due to hydrolysis (water availability) and high temperatures. Polyolefin products (PP and HDPE) are susceptible to aging strength losses due to oxidation (contact with oxygen) and or high temperatures. (FHWA)*

3. NUMERICAL STUDY

Landfill A is classified as a GLB^- site and Landfill B is classified as a GLB^+ site. The input parameters for the analysis are indicated in the table below. The Factors of Safety are calculated for each of the cases explained above in Table 1 to 3 for the different lining types of the landfills.

CASE A

	Landfill A		Landfill B	
Required Inputs	Lining Type 1	Lining Type 2	Lining Type 1	Lining Type 2
Unit Weight of cover soil	18	18	20	20
Thickness of cover soil	0.3	0.3	0.3	0.3
Length of slope	30	60	30	30
Soil slope angle beneath the geomembrane	18.4	18.4	18.4	26.7
Friction angle of the cover soil	30	30	34	34
Interface Friction angle between cover soil and geomembrane	22	22	22	22
Cohesion of the cover soil	0	0	0	0
Adhesive force between cover soil of the active wedge and geosynthetic	0	0	0	0
a	14.8	30.1	16.4	31.7
b	-21.0	-43.0	-24	-37.0
c	3.5	7.0	4.5	8.6
FOS	**1.25**	**1.23**	**1.26**	**0.84**

CASE B + C

	Landfill A		Landfill B	
Required Inputs	Lining Type 1	Lining Type 2	Lining Type 1	Lining Type 2
weight of equipment	30	30	30	30
Length of equipment track	3	3	3	3
Width of equipment track	0.6	0.6	0.6	0.6
Influence	0.97	0.97	0.97	0.97
Acceleration of the equipment	0	0	0	0
a	73.1	121.6	78.3	105.5
b	-104.1	-173.0	-115.0	-122.0
c	17.1	28.4	21.3	28.8
FOS	**1.24**	**1.23**	**1.25**	**0.83**

CASE D

	Landfill A		Landfill B	
Required Inputs	Lining Type 1	Lining Type 2	Lining Type 1	Lining Type 2
Tult	100	100	120	120
Reductions Factors	$R_{CR} = 1.6$ $R_{ID} = 2.0$ $R_{CBD} = 1.1$ $R_{SM} = 1.0$	$R_{CR} = 1.6$ $R_{ID} = 2.0$ $R_{CBD} = 1.1$ $R_{SM} = 1.0$	$R_{CR} = 2.0$ $R_{ID} = 2.0$ $R_{CBD} = 1.1$ $R_{SM} = 1.0$	$R_{CR} = 2.0$ $R_{ID} = 2.0$ $R_{CBD} = 1.1$ $R_{SM} = 1.0$
Tallow	28.4	28.4	27.3	27.3
a	6.3	21.6	8.3	20.7
b	-20.4	-41.0	-22.0	-33.0
c	3.5	7.0	4.5	8.6
FOS	**2.94**	**1.72**	**2.05**	**1.27**

4. CONCLUSION

The authors are able to propose an analysis of veneer cover soils on slopes based on the past research done by using the limit equilibrium analysis. The designer should follow the steps involved in calculating the final FOS as depicted in the steps shown.

The FOS calculated in the study based on gravitational forces only (Case A) ranges from 0.83 to 1.25, this is still considered low and methods to increase stability must be implemented. It is necessary to specify the construction equipment to place the soil; however the FOS for Case B and C shows a relatively small decrease in FOS. In comparing the results obtained from the calculations for the landfill A and B, it shows that when a geogrid is introduced into the system, the resulting FOS is increased.. The FOS was then compared against Table 4 to prove that the results found were within range to be deemed as a stable cover soil.

As with all geosynthetic designs, the construction and monitoring of these structures are critical. It must be stressed that the specific sequence of construction operations are explicitly followed as per the design engineers' details and that the geogrid utilised is as specified in the design.

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